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Examining Historical Climate with Respect to Future Permafrost and Engineering Design: An Analysis of Common Assumptions and Calculations

by

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Abstract

This paper examines changes in climate with respect to permafrost and engineering design in Arctic regions. Current understanding of climate changes, predictive modeling, and climate data were studied. Inconsistencies and differences were noted, discussed, and evaluated using comparisons of the resulting climate data and graphs. A graphical analysis was done to compare different methods of data analysis and different visual interpretations of historical climate trends.

The graphical analyses in this paper should be used as a guide for determining the accuracy of thermal design parameters applied to current project designs. The methodology used to evaluate raw data can greatly affect the output values used in design. It is important to understand the affect of different methods of evaluation. Review of this examination will provide designers and planners a better understanding of the complexity of climate data, data trends, and factors considered when applying climate variables to arctic design.

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List of Symbols, Nomenclature, and Abbreviations

AEC - Air Convection Embankment

AFI - Air Freezing Index: See FI below. Strictly applied to air temperatures.

ALCAN - Alaskan-Canadian Highway: Alaska Highway 2, Yukon Highway 1, BC Highway 97

ALT - Active Layer Thickness: thickness of the top layer of soil that freezes and thaws with the seasonal climate variation

AMEC - AMEC Earth and Environmental

AR4 - Intergovernmental Panel on Climate Change Fourth Assessment Report

CALM - Circumpolar Active Layer Monitoring

CAPS - Circumpolar Active-Layer Permafrost System

CIFAR - Cooperative Institute for Alaska Research

CO_2 - Carbon Dioxide

CRREL - US Army Cold Regions Research Engineering Laboratory

ECMWF - European Centre for Medium-Range Weather Forecasts

ERA-40 - ECMWF Re-Analysis

FAR - Intergovernmental Panel on Climate Change First Assessment Report

FDD - Freezing Degree Days: sum of the mean average degrees that occurred below 0^oC in a given time period (days, months, season, year). Temperatures above 0^oC are subtracted from the FDD value for accuracy within seasons.

FI - Freezing Index: cumulative number of degree days below 0^oC (32^oF) for a given time period

FI_d - Design Freezing Index: traditionally the average of the 3 coldest FI in a 30 year period of time or the coldest FI in a ten year period of time.

GCM - Global Climate Model

HDD - Heating Degree Days: sum of the mean average degrees that occurred below a given temperature (in this reference 0^oC was used) during a given time period (days, months, season, year).

ICICLE – ISER Comprehensive Infrastructure Climate Lifecycle Estimator

IPCC - Intergovernmental Panel on Climate Change

ISER – Institute of Social and Economic Research

MAAT - Mean Annual Air Temperature

MADT - Mean Annual Depth Temperature: temperature reading taken at 2m depth

MAGT - Mean Annual Ground Temperature

MAST - Mean Annual Surface Temperature

NCDC - Climatic Data Center

NEST - Northern Ecosystem Soil Temperature

NOAA - National Oceanic Atmospheric Administration

NRC - National Research Council Canada

NWT - Northwest Territories, Canada

RAM - Random-access Memory or “virtual memory”

RMSE - Root-mean-square error

ROW - Right-of-Way

SAR - Intergovernmental Panel on Climate Change Second Assessment Report

SDE – Snow Depth Equivalent

SWE - Snow Water Equivalent

TAPS - Trans-Alaska Pipeline System

TAR - Intergovernmental Panel on Climate Change Third assessment Report

TDD - Thawing Degree Days: sum of the average daily degrees that are greater than $0^{o}C$ ($32^{o}F$) in a given time period

TI - Thawing Index: cumulative number of degree days above $0^{o}C$ ($32^{o}F$) for a given time period

TI_{d} - Design Thawing Index: Traditionally the average of the 3 warmest TI in a 30 year period of time or the warmest TI in a ten year period of time.

TSP – Thermal State of Permafrost

UHI - Urban Heat Island

US – United States

1. Introduction

1.1 Background

1.1.1 Permafrost

Permafrost, also called perennially frozen ground, is defined as any soil that has remained at or below 0°C (32°F) for at least two consecutive winters as well as the summer in between (Andersland and Ladanyi, 2004). Above the permafrost layer is a thermally active region of soil referred to as the seasonal layer. The seasonal layer, or active layer, will freeze and thaw along with the variations in seasonal air temperature and is commonly between 150mm (6in) to 3m (3.3yd) thick (Burdick et al. 1978). Within the construction industry, the term 'frozen ground' is used as a general term to indicate any soil below 0°C (Andersland and Ladanyi, 2004).

The Arctic and Subarctic, where permafrost traditionally exists, has had many definitions; being located anywhere north of latitude 60°N (subarctic), north of the Arctic Circle (latitude 66°33'N) (arctic), or all latitudes north of the tree line anywhere between 53°N and 72°N (Burdick et al. 1978). The definition of permafrost varies so much by region that an analysis of soil and/or air temperature is the most relied upon method for determining regions of permafrost for engineering. It is believed that the majority of permafrost lies north of the -1°C ambient air temperature isotherm, continuous permafrost north of the -9°C isotherm (Hammer et al. 2004). By defining global boundaries, engineers can begin to understand and classify design requirements and construction environments.

1.1.2 History in Engineering

Over the last half century, geotechnical engineers have sought an improved understanding of permafrost and its impacts on engineering applications in the northern hemisphere. In 1946 the Army Corps of Engineers completed the Alaskan-Canadian Highway (ALCAN), during construction the workers had to overcome obstacles presented by the muskeg terrain, ice inclusions, and snowy conditions (Ussery 2007). This was one of the first major engineering ventures in the marginal permafrost zones and was an introduction to the difficulties in northern engineering design (Brown 1960). Following the construction of the ALCAN and Alaska's induction into statehood, the US Army founded the Cold Regions Research Engineering Laboratory (CRREL) in 1961 (Wright 1986). CRREL was developed to help the US better understand construction in the northern climate (Wright 1986). Major construction projects, like the Trans Alaska Pipeline constructed in the 1970s, benefited from the research done by large organizations like CRREL and the National Research Council Canada (NRC) as well as University research departments focused on arctic design practices. Projects like the Trans Alaska Pipeline were once uncommon in northern climates and are credited with bringing permafrost engineering knowledge into northern design (Rozell, 2008). The requirement for innovation on a construction timeline helped force depth into a previously limited facet of engineering and helped expand the knowledge of permafrost.

1.1.3 Current Focus

A growing concern with climate variation over the last three decades has increased the demand to understand how the future impacts of climate may change the

engineering aspects of frozen ground. Climate models are frequently analyzed and manipulated to present a more accurate estimation of future climate fluctuations. Walsh (2008) applied multiple climate modeling techniques to northern regions to examine the accuracy of the models themselves. Specifically focused on the impact of climate changes on permafrost degradation, Walsh (2008) evaluated the uncertainty in applying a modeling system to forecast design.

Climate changes on a broad scale can indirectly affect the characteristics of permafrost as well as the infrastructure that is built within and on it. For many years, scientists like Osterkamp (1990) and Smith (1998) along with many others have studied and attempted to understand the impacts that air temperature fluctuation has on permafrost and the infrastructure built on the permafrost. In recent years there has been an increased interest in the long term impact of climate changes on frozen ground engineering.

To date, studies regarding climate change have focused on the effects of air temperature on seasonal thaw, foundations relying on frozen ground, and the impacts on regional permafrost regimes. There is an increasing demand to understand the potential impact that climate change would have on current frozen ground engineering designs as well as the assumptions used in those designs. Current and future frozen ground engineering designs rely on a comprehensive understanding of forecasted climate trends as they relate to engineering analyses.

1.2 Research Objectives

Climate averages and trends are frequently used in engineering analyses and design without thorough examination of the raw data. The goal of this study is to examine

the variability in raw climate data as compared to the prepared and averaged data reported and used in most engineering designs.

This examination will illustrate how raw data can be summarized with relation to average and central tendency, frequency, and calendar cycles. In addition, the data will be reviewed in correlation with their use in foundation design and lifespan expectations and will be compared with estimates that are made for use in current designs.

This analysis will be carried out using raw data obtained through the National Climatic Data Center (NCDC) with the world's largest archive of climatic information (NCDC 2011). The NCDC is operated under the National Oceanic Atmospheric Administration (NOAA), which is part of the US Department of Commerce (Shea 2006).

Data for six main locations in Canada and the US will be compared based on their comparable latitudes; these locations will include Barrow, Fairbanks, and Anchorage in Alaska and will be related to Inuvik, Norman Wells, and Hay River in the Northwest Territories. Temperature, precipitation and snow depth data will be tabulated, analyzed, and presented graphically with respect to the mean, median, and mode as a basic representation of potential variability. The data will be analyzed with respect to the freeze/thaw indices and the six locations will be compared with respect to climatic influence on engineering design.

1.3 Thesis Outline

This thesis is composed of five chapters. Chapter one provides a general overview of permafrost and the more recent concerns of climate changes affecting engineering in northern regions. The second chapter focuses on previously reported work with respect to permafrost as a changing medium in engineering design. Chapter three

describes the data compilation and analytical work required to formulate a working data set for engineering design. Chapter four will present knowledge on environmental changes with respect to cold regions engineering work and chapter five will outline the critical elements of this research and will present suggestions for further research.

2. Literature Review

2.1 Research

2.1.1 A Changing Climate

As global air temperatures change, the fear of dramatic warming in the northern hemisphere has enhanced the demand for predictive modeling of the arctic ecosystems. By evaluating the arctic as a whole, a better projection can be made for the future impact of climate change on infrastructure in northern environments. Before examining historical climate shifts, current climate change reports were reviewed with respect to the scope and accuracy of modeling changes in northern regions.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 to help countries around the world collaborate and examine climate changes with respect to sustainability and urgency (IPCC 2010). The IPCC evolved from reports on climate concerns and potential impacts (First Assessment Report, FAR), to technical and economic aspects of mitigation (Second Assessment Report, SAR), and to human impact and future projections (Third Assessment Report, TAR) (IPCC 2010). The most recent IPCC report (Fourth Assessment Report, AR4) evaluates the effects of previous reporting errors, climate forcing, climate breakdown by continent, and mitigation options and their associated costs (IPCC 2010). The evolution of these reports present the trend throughout the 1990s and early 21st century; realizing that the climate is changing, focusing on the negative impacts and potential threat, and finally trying to agree on a realistic action plan. These reports, while not definitive, attempt to analyze potential impacts by forecasting trends using the best available scientific data.

Presenting data as a guideline or benchmark opens discussion from both supporters and critics. Syun Akasofu is a self proclaimed critic of climate change, claiming "science without criticism could go astray," (Akasofu 2007). He points out that the warming trend began in the 1800s, and was not initiated by greenhouse gasses. This previous warming trend should be subtracted from the current warming trends to correctly estimate the greenhouse emission effects (Akasofu 2007). He also points out that much literature throughout the 1970s presented claims of a drastic cooling trend based on data from the 1940s to 1975, despite the drastic increase of carbon dioxide (CO_2) during this period (Akasofu 2007). Consistent temperature records do not span sufficient time to be used to project climate changes a century forward (Akasofu 2007); most records only span a century with limited accuracy at best. While extreme criticism may not be warranted, it is important to be cautious when modeling and forecasting data in general, not just when modeling climate. A model's projection can only be as good as the input provided.

John Walsh, a notable professor in atmospheric sciences, is the director of the Cooperative Institute for Alaska Research (CIFAR) at the University of Alaska Fairbanks (NOAA 2008). In a plenary paper written for the 9th International Conference on Permafrost, he addressed the climate models used in the IPCC's AR4 paper and commented on their respective accuracies (Walsh 2008). In this paper, fifteen climate models were examined and assessed for their ability to predict recent weather changes. By ensuring a model's accuracy for current events, the model's ability to predict future events with relative accuracy becomes more reliable (Walsh 2008). Walsh evaluated climate models used in the report with respect to the six emissions scenarios laid out by

the IPCC and compared them to the European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis, ERA-40 (Walsh 2008; IPCC 2010).

The ERA-40 reanalysis is considered a good representation for arctic weather systems by Walsh (2008) and provides good estimates (Clark et al. 2008), but Frauenfeld et al. (2007) viewed the ERA-40 approach as biased, having a statistically significant warming bias across the Northern Hemisphere. Despite Frauenfeld's calculations, the ERA-40 model prediction showed relative accuracy and was used as a control for the bias found in Walsh's climate model evaluation (Walsh 2008).

Walsh summed the root-mean-square error (RMSE) values over a twelve month period to rank the modeling scenarios (Walsh 2008). Walsh quickly discovered that of the fifteen climate models examined only two or three represented the changing arctic climate with any relative accuracy, and of those working models none managed to mimic weather trends accurately throughout all four seasons (Walsh 2008). The models with the most accuracy in permafrost regions (Alaska, Canada, Greenland, etc.) tend to be the ones that work best over large regions and show climate getting wetter and warmer over time (Walsh 2008). For Alaska, Walsh found the MPI-ECHAM5 and GFDL-CM2.1 models to be the most accurate, although temperature biases were reported during winter months (Walsh 2008).

Walsh (2008) assumed that by relying on graphical comparisons and estimations best estimates can be made for the future impact of climate on northern infrastructure. Akasofu (2007) warns against taking these best estimates as they are presented and encourages researchers to understand the limitations of each approach. It is best to evaluate the impact of climactic change by analyzing all predicted outcomes with respect

to individual scenarios rather than assume a broad application of a single theory or model output. Walsh (2008) recognized that while best fit models can be found, errors and unknowns limit the ability to make firm predictions using these models. With the general consensus leaning toward warmer and wetter climate future, the evaluations of previous scientific studies can be reviewed with respect to the accuracy of the climate model used and the assumptions made throughout the research stage.

2.1.2 Environmental Concerns

With climate change, the impact on the environment plays a large role in the development and degradation of the subsurface permafrost regime. Much of the cross-disciplinary research carried out with respect to environmental impacts on permafrost did not start until the 1990s, making the research itself relatively recent.

Jorgenson (2001) examined physical changes observed in transitioning vegetation systems. Jorgenson et al. (2001) observed vegetation patterns over the last half century and witnessed a 35% reduction of birch forest over the Tanana Flats region of Alaska. The reduction of birch forests was paired with a 29% increase in fens and bogs over the same region from 1949 to 1995 (Jorgenson 2001). Vegetative changes like this would lead to an increase of plant biomass and soil organics, which in turn acts as a negative feedback insulating the ground from further rapid thaw (Walker et al. 2003). The increase of ground water from the thawing permafrost under birch forests would counter any negative feedback provided by the increase in organic material (Walker et al. 2003), so the thermal outcome of the vegetative transition would be difficult to predict. Transitions in vegetation like this are important to understand in a changing climate as 23% of the land area in the northern hemisphere is affected by permafrost (Jorgenson 2001). Of the 23%, 17% is considered discontinuous permafrost (Jorgenson 2001) and

therefore within a few degrees of thawing. This statistic places a large portion of permafrost regions in jeopardy of undergoing similar vegetative evolution. The associated impacts of vegetation change on the underlying permafrost regime are important in understanding the impact of vegetation evolution.

In 2004, Hassol wrote a general report to introduce the public to the concerns of a changing environment. She inferred the effects of climate change by discussing vegetation migration northward under a warming climate (Hassol 2004). With greater vegetative coverage there is an expectation that more of the sun's energy would be absorbed by the earth's surface, amplifying "global warming", especially in the northern regions. Along with continued warming, the rates and extent of forest fires has increased causing an even greater impact on the earth's surface (Hassol 2004). Environmental changes have the potential to affect the permafrost regime beneath the ground's surface resulting in unforeseen terrain disturbances.

The vegetative cover over the ground's surface acts as a barrier between the soil beneath it and the air above it. This vegetative barrier influences the impact that the air temperature has on the seasonal fluctuation of active layer thickness (ALT) and in turn the permafrost layer (Brown and Hinkel 2000, Walker et al. 2003, Woo et al. 2007, Burn and Kokelj 2009, Blok et al. 2010, Jorgenson et al. 2010, Kokelj 2010, and Morse et al. 2010). Similarly, permafrost and ALT are affected by snowfall and snow accumulation in the same manner as the vegetative cover; snow acts as an insulator reducing thermal effects at depth during the winter months and slows the effects of thaw during the spring (Brown and Hinkel 2000, Stieglitz 2003, Zhang et al. 2008, Burn and Kokelj 2009, Jorgenson et al. 2010, and Kokelj 2010).

Snowfall and its accumulation is largely affected by the structure of the vegetation (Burn and Kokelj 2009); tree cover limits surface accumulation, large shrubs may cause snow drift accumulation and snow depth variability, and while tundra vegetation is one of the most favorable terrain type for the natural accumulation of snow, it is frequently associated with windy conditions with the potential for large snow drifts and uneven snow accumulation (Woo et al. 2007). It is generally thought that snow cover has a positive effect on the thermal regime due to its natural insulating properties (Brown and Hinkel 2000, Stieglitz 2003, Zhang et al. 2008, Burn and Kokelj 2009, Jorgenson et al. 2010, and Kokelj 2010). Depending on the snow condition and regional relationship it can create a negative impact on ground temperature (Vasiliev 2008), making it much more complex when analyzing the thermal barrier between air temperature and ground temperature.

The negative impact of snow cover on the ground's thermal regime can be due to increased snow density, the increased duration of snow cover at more northern latitudes, and the increased albedo caused by an increase in snow cover duration (Vasiliev 2008). In theory, an increase in overall air temperature would cause a decrease in snow depth (due to melt) which would reduce the insulating effect throughout the winter, allowing the soil to cool more directly (Zhang et al. 2008). Such theories are simplified and show that all scenarios must be accounted for when modeling the impact of atmospheric and environmental changes on the sub-surface thermal regime.

Monitoring the changing landscape along with changes in climate is important in understanding the interactions between climate and subsurface thermal impacts. While vegetative shifts occur over centuries, precipitation changes tend to cycle in decades referencing yearly, 10-year, and 100-year events. More recently the same cycle has been

witnessed and followed in air temperature and snowfall (Osterkamp et al. 1994). Osterkamp et al. (1994) examined an air temperature periodicity that was just longer than 10 years (10.1 years) and a 10 year snowfall cycle. These cycles have been compared to the 10 to 11 year sunspot cycle which has shown a 2 to 3 year lead in ground temperatures at depth of 30 m (Osterkamp et al. 1994). Recognizing climate cycles and their reoccurring trends may help predict expected changes to northern environments. Incorporating solar cycles into climate trends for the purpose of examining patterns in subsurface thaw exemplifies the importance of multidisciplinary research for the purpose of understanding causality in nature.

Each surface element has a cause and effect relationship to changes seen in climate. The physiography of the area determines the extent to which the air temperature can affect the permafrost regime throughout the region (Jorgenson and Osterkamp 2005, Jorgenson et al. 2010). Just as snow accumulation depends on the vegetative structure, the vegetation relies on the region's geologic characteristics (Burn and Kokelj 2009). Soil moisture (Brown and Hinkel 2000, Jorgenson et al. 2010), organics (Brown and Hinkel 2000, Walker et al. 2003, Jorgensen et al. 2010), soil pH (Walker et al. 2003), ground water (Burn and Kokelj 2009, Chapin et al. 2010, Jorgenson et al. 2010), and geomorphology (Jorgenson and Osterkamp 2005, Jorgenson et al. 2010, Morse et al. 2010) are all contributing factors to the thermal regime beneath the ground's surface. Jorgenson et al. (2010) examined the individual effects that various ground elements had on the surface and sub-surface thermal regime with the intent to quantify them.

Environmental influences on ground temperature have a wide range of variability at each specific location. The variability of each location makes the relationship between air temperature and ground temperature much more complex and more difficult to

predict. Unique surface characteristics have major influences on the air to ground temperature relationship which directly impact the permafrost regime (Chapin et al. 2010). Geographic surface characteristics will continue to play an integral role in the way permafrost is impacted by climate changes.

2.1.3 The Changing State of Permafrost

The general state of permafrost was examined more closely following some of the first major construction projects in the north. During the construction of the ALCAN in 1946 (Brown 1960, Ussery 2007) and Trans-Alaska Pipeline System (TAPS) in the 1970s (Rozell 2008) permafrost conditions impeded the rapid progression of the projects' development. Engineers had to quickly learn how to work with and around permafrost for the sake of the longevity of their construction projects.

In 1991, a volunteer program called Circumpolar Active Layer Monitoring (CALM) was created to help centralize and cultivate global active layer information (CALM 2007). CALM was not officially started until 1998, but collected and maintains data from 1990 to present (CALM 2007). While not part of the CALM system, older data from the 1940s can be found throughout Alaska with more regular data available from the 1970s when the TAPS was constructed (Brown et al. 2010). The goal for the CALM system was to develop a long term data base for the "collection and synthesis" of global data (Brown and Hinkel 2000) which would encourage and support multi-disciplinary research with respect to ground movement and subsurface temperature profiles.

The formation of CRREL in 1961 (Wright 1986), the IPCC reports in 1988 (IPCC 2010), and the CALM network in 1991 (CALM 2007) all led to today's global data network and data sharing approaches to understand climate change and its impacts

on permafrost. Data that would otherwise be lost or forgotten can now be stored, maintained and distributed to interested parties through programs like the Thermal State of Permafrost (TSP) borehole data and the Circumpolar Active-Layer Permafrost System (CAPS) (Parsons 2008). Information on borehole data, soil temperatures, climatology, maps, etc. can be found in these global data networks and can be used to broaden understanding of the state of permafrost on an international scale (Parsons 2008). Modern programs like these are helping researchers understand the variability and trends that might otherwise go unnoticed.

The CALM system, TSP borehole data, and CAPS have collectively allowed scientists to relate and share theories and findings through the use of a common data source. From resources like these, the thawing index (TI) can be examined and correlated to the changes seen in the ALT during yearly cycles (Walker et al. 2003, Osterkamp 2005, Blok et al. 2010). Smith et al. (1998) and Osterkamp (2005) agree that in most cases, the effects of winter conditions are what separate arctic soil conditions from their southern counterparts. The thawing degree day (TDD) data is similar between more northern and more southern regions in the north, while the freezing degree day (FDD) values in “arctic soil” were reportedly “double those of boreal and taiga soils” (Smith et al. 1998). Brown and Hinkle (2000) supported this finding, noting that ground temperatures have risen during the winter much more than the few tenths of a degree change observed during summer processes.

The few tenths of a degree change during the summer season is considered normal for climatic variability, while the changes in winter air temperatures are deemed to be abnormal (Brown and Hinkle 2000). The TI, occurring during the summer season, has commonly been associated with ALT changes over time; increased shrub growth and

expansion along with surface characteristic changes can cause negative temperature feedback, offsetting the effects of climate change (Blok et al. 2010). Surface vegetation, alone, can change the way permafrost is affected by air temperature, which means continued climate warming may not necessarily have an immediate effect on the permafrost condition at depth (Walker et al. 2003).

Prior to the development of data collection programs, like the CALM system, researchers like Misener et al. (1956) had to rely on their own data collection operations to examine permafrost at depth. Most of these data were therefore original and not always relatable over a broad scale due to the limitations of their sampling distribution. With the help of calculation Misener et al. (1956) extrapolated the data he managed to collect at depths up to 650ft (198m), finding that some of the most northern permafrost was close to 1,280ft (390m) deep at the time he carried out this research. At lower latitudes permafrost thicknesses decrease; the thickness of permafrost at Norman Wells, N.W.T. was at one point around 150ft (46m)thick and at Hay River, N.W.T. only 5ft (1.5m) thick (Brown 1960). Since the time of these records, permafrost thicknesses have varied and the focus of the changes seen in permafrost regions has turned toward measured climatic variables rather than physical measurement associated with permafrost temperatures.

Much of Osterkamp's research is focused on the climatic trends related to the effects seen in regional permafrost patterns (Osterkamp et al. 1987, Osterkamp and Lachenbruch 1990, Osterkamp et al. 1994, Osterkamp and Romanovsky 1999, Osterkamp 2003, Osterkamp 2005). In a report compiled for the Alaska Department of Transportation and Public Facilities, Osterkamp et al. (1987) discussed the warming of permafrost dating back to the mid-1800s. While not directly related, Osterkamp et al. (1987) places a growing concern on the increased air temperature trends observed from

1976-1982 because of the impact it would have on the already warm permafrost in the central Alaskan region. Since this 'warming' period, warm winters have become common (Osterkamp and Lachenbruch 1990). During these warm winters snowfall decreased, which may have dampened the effects of the warmer period on the permafrost layer by allowing more direct winter cooling (Osterkamp et al. 1994). Air temperature changes are continually compared to ground temperature changes, however the effect of the thermal offsets on the ground's surface can be difficult to predict. Permafrost degradation was witnessed at one research site strictly due to a significant accumulation of snowfall (Osterkamp and Romanovsky 1999). With endless variability and area specific occurrences, long term studies are needed to build a basic understanding of the thermal impacts on the underlying permafrost associated with a changing climate.

Due to the uncertainties of climate change and the need for continuous permafrost data for correlation, many test site monitoring systems were installed in the coldest areas of a specific region to ensure that permafrost was present for the initial readings (Osterkamp and Romanovsky 1999). This practice may have influenced the regional generalizations and induced error in the resulting data. That being said, the mean annual air temperature (MAAT) increased 1.5^{o}C over the 20-year period following 1976 compared to the 20-year period prior to 1976 (Osterkamp and Romanovsky 1999). Similar warming trends have been seen across the state of Alaska since 1977 (Osterkamp 2005). From 1977 to 2003 Osterkamp (2005) used a series of borehole data and daily logger data to analyze ground temperatures at depth. Using the resulting ground temperature data the bottom of the active layer could be estimated as well as the temperature at the top/surface of the permafrost layer (Osterkamp 2005). Using the resulting temperature data, both linear and power law curves were used (each curve had

an R^2 value of 0.99 or better) to display permafrost surface temperature variations. Exponential and linear results show that the permafrost's surface has warmed; 3-4^{o}C on the Arctic Coastal Plain, 1-2^{o}C around the Brooks Range, and 0.3-1^{o}C south of the Yukon River (Osterkamp 2005). While the temperature changes witnessed at these three locations seemingly mimic an increasing air temperature, the thermal offset between the air and the ground temperature changes the magnitude of its impact (Osterkamp 2005). Thermal offsets like vegetation, snow accumulation, and surface water all affect the longevity of the underlying permafrost regime and reduce the correlation between air temperatures and surface or ground temperatures.

With a heightened interest in the recent increase in climate variability, it is important to note that this is not the first time, historically, that degradation has been seen in permafrost regions (Chapin et al. 2010, Jorgenson et al. 2010). In past occurrences of climate change (Medieval Warm Period and Little Ice Age), permafrost has shown a natural resilience to permanent fluctuations with the help of natural processes (Chapin et al. 2010). During thawing periods, ice-rich permafrost shows a distinct lag in its response due to the latent heat of fusion (Stendel 2002). This 'lag time' can cause the discontinuous permafrost to remain for centuries or millennia, making it challenging to place a timeframe around permafrost degradation and loss (Stendel 2002, Osterkamp 2005).

Generally discontinuous permafrost is located where ground temperatures are higher than -2^{o}C and continuous permafrost can be found at ground temperatures as low as -15^{o}C (Smith et al. 2010). Remarkably, permafrost can withstand MAATs of as high as +2^{o}C and has been seen degrading at MAATs as low as -20^{o}C; this is all due to surface conditions (Jorgenson et al. 2010). In a modeling study carried out by Jorgenson et al.

(2010), surface water had the greatest impact on subsurface temperatures: where water accumulates, temperatures have been recorded ~10^{o}C above the MAAT; ground water ranges from 2-7^{o}C and can initiate thaw in permafrost areas; a reduction in snow depth by 50% can cause a reduction in mean annual depth temperature (MADT) of around 2^{o}C; and vegetation can insulate the soil beneath it causing a mean annual surface temperature (MAST) cooling up to 6^{o}C and MADT cooling up to 7^{o}C. A combination of surface characteristics would compound the resulting influence on temperature and is a good example of the complexities found in relating MAAT to underlying permafrost temperatures.

Despite the various effects of a thermal barrier, like snow or vegetation, the permafrost south of the Arctic Circle is predominantly within 3^{o}C of thawing and south of the Alaska Range it is within 1^{o}C of thaw (Esch and Osterkamp 1990). Although much of Alaska's permafrost is considered 'warm permafrost', this characterization is not new as the lateral boundary of all discontinuous permafrost is assumed to be at or around 0^{o}C (Osterkamp 2003). The thawing of permafrost is not a new occurrence, some of the earliest thermokarst formations date back to the 1840s-50s (Barber and Osterkamp 1998). There is evidence from the 1920s-30s that show the early development of thermokarst pit formations near Anchorage, Alaska, where there is no longer any near-surface permafrost (Barber and Osterkamp 1998). With a changing climate, basal thaw in permafrost fluctuates and stabilizes with the temperature variations at the surface of the permafrost layer (Osterkamp 2003). Although many other elements affect air temperature before its effect reaches the permafrost's surface, it is important to understand the dynamics of temperature fluctuation within the permafrost itself.

In an attempt to predict permafrost fluctuation and distribution, the FI and TI are calculated and compared in regions of concern (Frauenfeld et al. 2007). Frauenfeld et al. (2007) noted an increase in the TI in Western Canada and Alaska, but saw a more dramatic increase in Eastern Canada. The more pressing change to Canada and Alaska is the decreasing FI across both regions (Frauenfeld et al. 2007). The greatest warming rates are witnessed north of the treeline (Smith et al. 2010) where a thinner snow cover helps express the effects of the gradually warmer winter (Throop et al. 2010). Despite the warming trends seen in Western Canada and Alaska the MAGTs seen in Western Canada are lower than those in Eastern Canada (Smith et al. 2010). The ground temperatures can be easily affected by regional soil moisture and substrate and the ground temperatures beneath forested areas have shown less annual variability than those soils in tundra regions (Smith et al. 2010). With a greater knowledge of soil/air temperature interactions, scientists began modeling northern permafrost regions in hopes of better understanding this regional variability.

Smith and Burgess (1998) compiled geological data from across Canada to better categorize regions based on their mineral composition, vegetative structure, and physical geology. By classifying Canada's regions, a more accurate prediction can be made for the specific effect that temperatures in that region might have on the permafrost regime in the area (Smith and Burgess 1998).

With phases of climate cooling from the 1950s-1970s and climate warming from the late 1970s to today (Throop et al. 2010), climate models have been developed and used in hopes of predicting further changes in the environment. The most recent increases in air temperature have likely caused the near-surface warming observed in borehole data in Western Canada and Alaska (Burn 1998). The near-surface warming has caused a $2^{o}C$

to 4^{o}C change in surface temperatures which has moved the southern permafrost boundary northward (Burn 1998). Modeling these thermal shifts and changes has been the driving focus of climate change impact studies, but modeling the effect of air temperature changes with respect to ground temperature has become the focus of many engineering studies for design.

With thermal variability at the ground's surface, it is important to account for the effects of regional topography, vegetation, and climate conditions when attempting to model temperature variation at depth (Burn 1998). Although ground thermal models are appealing for design purposes, their limitations make them a challenging substitute for field investigations (Burn 1998). Zhang et al. (2008) focused on the creation of an accurate ground thermal model that could account for the thermal variation due to snowfall. In this model, Zhang et al. (2008) described the importance of understanding the snow dynamic and the use of long term snowfall data which has greater detail than most monthly data collections. For relative accuracy in snowfall modeling detailed historical data is required, unfortunately greater detail in snowfall records is not available for most northern locations; or at least not over a time span long enough to provide accurate input in most models.

The northern ecosystem soil temperature (NEST) model was more recently adapted with the snow depth or snow water equivalent (SWE) to create a more reliable modeling approach (Zhang et al. 2008). The NEST model with SWE shows correlation coefficient of 0.88 between the recorded and predicted snowfall in Canada (Zhang et al. 2008). While the correlation to the model is positive, it is not definitive and like other modeling approaches, should be used with caution. Due to the increased concern of the potential impacts of climate change on permafrost, geotechnical engineers must

familiarize themselves with Global Climate Models (GCMs) and the newest thermal modeling approaches (Springman 2008). The increased use of these thermal models in design, investigation, and site monitoring is risky without knowing and understanding the specific model's limitations (Springman 2008). A general understanding of the relation between air temperatures and soil temperatures has helped improve the scientific understanding of the effects of climate change on permafrost mapping, but permafrost models have a long way to go in the quest for greater accuracy required in engineering design.

2.1.4 Impact on Infrastructure

The impacts of vegetation migration and changes in surface albedo described by Hassol (2004) are in addition to the urban impacts created by humans (Hinkel et al. 2003). Hinkel et al. (2003) examined the community of Barrow, Alaska; although not large in population, the effects of the Urban Heat Island (UHI) were recordable. As humans build, they inadvertently change the environmental landscape causing indirect changes to the existing thermal regime (Hinkel et al. 2003). Buildings and roadways change the reflective properties of the ground's surface, cast shadows, impact the local winds, and can unintentionally create heat sinks within the urban settings (Hinkel et al. 2003). The construction of new buildings can cause inadvertent changes to snow drift patterns which might help insulate the ground in new areas, warming it at depth (Long and Yarmak Jr. 2008). Because of the many disturbances urbanization creates, it is important to take a more area-wide approach to design in the north (Long and Yarmak Jr. 2008). Due to urbanization, the MAAT within the community of Barrow is higher than most rural areas within the same region (Hinkel et al. 2003). In turn, the higher temperatures within the town cause the snow melt to be earlier compared to the

neighboring areas (Hinkel et al. 2003). The effect of rapid urbanization on the ground thermal regime was not directly discussed in Hinkel et al.'s (2003) report, but the importance of the effect was implied.

Urbanization alone cannot be blamed for warming trends in permafrost. Over the last few decades the arctic regions have warmed at twice the global rate, showing most temperature increases during the winter and spring (Hayley 2008, Instanes and Anisimov 2008). Although winter and spring temperatures are warming more noticeably (Instanes and Anisimov 2008), foundations are more affected by summer surface temperature changes (Long and Yarmak Jr. 2008). Thawing, or warming, permafrost could lead to failure of building foundations and with most of the northern permafrost, below the Arctic Circle, within a few degrees of thawing (Esch and Osterkamp 1990, Bush et al. 1998) this would lead to major negative impacts on infrastructure across Alaska and northern Canada. Researchers, like Instanes and Anisimov (2008), have produced "hazard maps" indicating the most vulnerable regions to future permafrost warming and thaw in hopes of directing restoration efforts and limiting unnecessary expenses that will come with permafrost degradation in urban areas.

In the northernmost permafrost regions a warming climate may only cause a limited decrease in bearing capacity, however, more southern permafrost regions will witness the greatest impacts of warming permafrost (Vyalov et al. 1993). Warming of permafrost at depth would cause a reduction in the adfreeze bond between piles and the adjoining permafrost, increased creep rates of piles, footings, and embankment foundations; an increased active layer thaw would lead to thaw settlements and increased frost heave during winter refreezing of the active layer; and talik formation would lead to progressive surface settlement, more landslide movement, and decrease in the effective

length of piles used in permafrost (Esch and Osterkamp 1990, Instanes 2006). Major concerns for foundations in a warming Arctic landscape would be the overall decrease in mechanical strength (Esch and Osterkamp 1990, Bush et al. 1998) and the increases in creep rates (Esch and Osterkamp 1990).

With the safety and longevity of northern foundations in question, researchers have attempted to model and predict changing climate and permafrost scenarios for decades. Vyalov et al. (1993) predicts that permafrost thaw of 30-50 m would take centuries, but that thaw to a depth of 5-10 m may only take 40 years. Using GCMs Hayley and Horne (2008) predicted the presence of permafrost to be ongoing 100 and 200 years from now. Predictions like Vyalov et al.'s (1993) and Hayley and Horne (2008) have been supported and refuted numerous times, but in most cases are cautioned against without the inclusion of the multitude of surficial variables that can often times have a greater influence to the ALT and overall permafrost thickness than climate changes alone (Seifert 1994).

Many times, GCMs are used to predict air temperature and permafrost changes, but due to their global focus, fail to take into account the more minute variable changes from region to region over a long term and therefore do not accurately predict current climate changes let alone future change regionally (Hayley and Horne 2008). GCMs can be helpful in isolating the impacts of specific weather variables, but cannot account for climatic surprises or the direct impact on ground temperature (Bush et al. 1998). Due to the inaccuracies in using GCMs for regional climate forecasts, the application of GCMs for the prediction of permafrost retreat in urban areas should be used with caution. As with GCM uncertainty, Hayley and Horne (2008) pointed out that the linear trend lines used in forecasting climate changes are not accurate beyond a 30 year timeline and are

strongly cautioned against for any duration longer than the historical record being used to create the trend line.

Hayley and Horne (2008) used various climate models (ECHAM4, HadCM3, and CGCM2) to estimate and evaluate the FI and TI from 1957 to 2000 in order to determine model accuracy in FI and TI calculations. In their research, Hayley and Horne (2008) focused on the Mackenzie Valley region in the Northwest Territories (NWT) due to its climatic extremes. In the examination of the relationship between common design parameters, used in foundation design, and climate change, Hayley and Horne (2008) determined that the use of thirty-year design parameters was no longer an accurate procedural assumption. In place of a foundation design parameter based on historic thirty-year climate normals, Hayley and Horne (2008) suggested the use of a set of parameters based on even longer climate trends to determine long term building foundation risk due to climate change. By evaluating "five consecutive 1-in-5 warm years followed by a 1-in-100 warm year; ten consecutive 1-in-5 warm years; and a linear warming trend over the life of the structure," a reasonable evaluation could be made for a foundation design (Hayley and Horne 2008). Despite the efforts made to predict and analyze past and future climate changes, foundation design for a changing climatic landscape in a permafrost region requires the assumption of the unknown.

The specific foundation design or application may also play a role in the correlations found between air temperature and ground temperature. Roadway foundations see a much closer correlation between air temperature and ground temperature in part because the effects of precipitation and evaporation are minimized (Esch and Osterkamp 1990). Due to the sensitivity of roadway foundation to temperature changes, foundation designs have evolved to help promote natural cooling to avoid the

further increase of the foundation temperature (Wei et al. 2009). Wei et al. (2009) examined the use of shading boards, crushed rocks, ventilation ducts, thermosyphons, and dry bridges in an attempt to control radiation, convection, and conduction in roadway foundations.

The greatest effects on foundations will be seen in those designs that assume a design life with no change in the soil state and that avoid taking proactive measures against changes in temperature (Vyalov et al. 1993). Basic ventilated foundation designs in the warmest regions would need to take a more proactive approach to maintaining the soil temperatures, using tools like thermosyphons or thermopiles to maintain the ground's thermal state (Vyalov et al. 1993). More active approaches to the maintenance of the soil's thermal regime include gravel pads and pile foundations; thermosyphons are one of the most active approaches used (Seifert 1994). Although foundation design choice may lead to future soil instability, other factors may increase the risk of failure in a foundation (Instanes 2006). Designing for incorrectly assumed site conditions, designing for inaccurate building loads, not accounting for ALT or permafrost temperatures in the design, straying from the design itself, lack of building maintenance, using a structure for an unintended purpose, or even the construction itself can affect the ground conditions and thermal properties of the foundation (Instanes 2006). There are many variables besides the climate that can have negative impacts on foundations in permafrost.

Smith and Riseborough (2010) pointed out that many buildings that fail to meet the active frozen ground foundation design standard were built prior to the 1990s. Most early foundations did not account for thermal variability in foundation design (Smith and Riseborough 2010) and did little to account for it. Early pipeline construction is a great example of the importance in accounting for thermal variability in foundation design

(Oswell et al. 2010). Excess pore water pressure, thaw settlement, upward heave, the variability of soil strengths between freeze/thaw interfaces, and pipeline installation methods all affected the design of early pipelines (Oswell et al. 2010). Most of the issues seen in early pipeline construction have since been corrected or minimized with advanced technology, but right of way (ROW) disturbance is an ongoing issue for Northern construction (Oswell et al. 2010, Smith and Riseborough 2010).

The removal of trees and shrubs alone in the ROW zone can induce a 2^{o}C ground temperature increase in the affected zone (Smith and Riseborough 2010). Smith and Riseborough (2010) witnessed a deeper thaw in coarser, less ice-rich soils; however, the thaw in the ROW zone outweighed disturbances due to climate change in the first 10-15 years of the project's lifespan. Smith and Riseborough's (2010) research stresses the importance of understanding the full effects of construction in arctic zones. Companies working on northern construction projects will frequently fund their own research in order to monitor and track changes associated with their projects (ex: Cavanagh and Tchekhovski 2010). Cavanagh and Tchekhovski (2010) used a finite element modeling software, called SIMTEMP, to predict and calculate changes that may affect a frozen core dam designed by AMEC Earth and Environmental (AMEC). This research had to account for climate variability due to its reliance on a frozen thermal state and focused on the importance of design, construction, and protocol for the use of the frozen core dam (Cavanagh and Tchekhovski 2010). As Springman and Arenson (2008) stressed, geotechnical engineering in a northern changing climate requires knowledge and understanding of thermal modeling for use in site investigation, project design, as well as future site monitoring.

New foundation and construction design processes rely on computer modeling software to predict global climate trends; there has been an increased focus on modeling the economic impact for various climate change scenarios. The Institute of Social and Economic Research (ISER) developed the ISER Comprehensive Infrastructure Climate Lifecycle Estimator (ICICLE) to model climate projections, organize a database of northern infrastructure and create a cost estimate based on the effective life cycles of the infrastructure with and without changes in climate (Larson et al. 2008). Models like ICICLE were developed due to the increased concern for the longevity of Alaska's infrastructure in a rapid climate change scenario (Larson et al. 2008).

Wang and Paudel (2010) studied the effects of freeze/thaw cycles on the consolidation properties of fine grained soils. Thirty two remolded soil samples were taken from 1 m depth from two separate landslide sites in the Mackenzie River Valley for the study (Wang and Paudel 2010). These samples were tested at different moisture contents over 0, 3, 5, and 10 year freeze/thaw cycles to determine the changes in the coefficient of consolidation and hydraulic conductivity over time (Wang and Paudel 2010). Over just a ten year freezing and thawing period in the Mackenzie Valley in northern Canada, the coefficient of consolidation was estimated to have increased one order of magnitude and the hydraulic conductivity is estimated to have increased anywhere from 1-2 orders of magnitude (Wang and Paudel 2010). Changes like these can directly impact soil properties, directly affect slope stability (Wang and Paudel 2010), and indirectly increase the maintenance costs for northern foundations (Khrustalel 1995). Warming of just a few tenths of a degree can initiate failure in a foundation relying on the frozen state of soil and that failure will directly impact the lifespan of the building (Khrustalel 1995).

Khrustalel's (1995) research suggested that climate change should be accounted for in the original foundation design when the potential future cost impact of failure supersedes the cost of implementing preemptive cooling measures from the beginning of the project. No matter what approach is taken in the design phase, climate change has the potential to increase the costs of northern construction (Khrustalel 1995, Instanes 2006, Auld et al. 2007, and Chinowsky et al. 2010).

Researchers in northern Canada and Alaska have similarly taken inventories of the infrastructure at risk and made worst case scenario and adaptive response cost estimates respectively (Hoeve et al. 2006, and Larson et al. 2008). In the NWT, Canada the cost estimation of a complete rebuild is estimated to be in the range of $420 million (CAD) by 2030 and was based on a qualitative approach rather than quantitative (Hoeve et al. 2006). The cost of building adaptation in the state of Alaska would be $3.6-6.1 billion (USD), 10-20% above regular wear and tear costs by the year 2030 (Larson et al. 2008). Due to the magnitude of the cost estimates, preventative measures and guideline implementation are critically important in current design in order to offset potential future costs (Auld et al. 2007). Auld et al. (2007) warns that as much as a 5% increase in annual costs could be seen solely due to increased storm repairs and strongly suggests the need to educate the public, consider multi-generational/post building lifespan impacts, more detailed vulnerability assessments, and the general avoidance of construction in high-risk zones.

Taking into account warnings like Auld et al.'s (2007), guidelines for evaluating and constructing buildings have been reworked to account for climate variability (Zhou and Zhang 2008, and Chinowsky et al. 2010). In the evaluation of an impacted building, Zhou and Zhang (2008) suggested a three way approach in determining the cost

effectiveness of building adaptation. If a building has reached maturity (50 years for residential and 65 years for business) or if a building requires fixing before it reaches maturity the building may be "retired" and the building's ownership would bear the incurred costs of premature building retirement (Zhou and Zhang 2008). In the case of a building that hasn't reached maturity, adaptations may be made to increase the building's lifespan if the adaptation is cost-effective and beneficial in the long term (Zhou and Zhang 2008).

Chinowsky et al. (2010) only looked at the various approaches to building adaptation. The three approaches used in Chinowsky et al.'s (2010) research were: rapid continuous adaptation, phased adaptation, and forced adaptation. Rapid continuous adaptation assumes the regular updating of building codes on an event-driven basis or when climate conditions require that changes be made, phased adaptation updates and adapts on a regular generational time frame, and forced adaptation occurs following significant damage (Chinowsky et al. 2010). Forced adaptation would incur the largest cost over time where as the regularly timed code updating method results in the lowest cost over time (Chinowsky et al. 2010). Cost impact analyses like these are gradually being evaluated in current design to help reduce the impact on future developments, but the qualitative approach to the assessments and uncertainty in the cost estimations make it less appealing for industry-wide change.

2.1.5 Evaluation and Calculations

In the evaluation of climate parameters and their effect on northern foundations through changes in permafrost, it is important not only to look at the methods used in estimating climate, but also the methods used to relate climate to ground temperatures. Originally the thermal offset between air temperature and ground temperature was noted,

but not well understood. Carlson (1952) discussed the broad relationship between air temperature and surface temperature due to the influences of surface characteristics, the quantitative relationship was referred to as the n-factor. N-factors were developed as a method of categorizing ground surface features. Jorgenson and Krieg (1988) began modeling the thermal relationships between air temperature, surface physiography and permafrost distribution putting a large emphasis on the use of n-factors. Since the development of the n-factor, it has been used as a guideline in engineering design.

By 1988 the U.S. Army and Air Force was already recommending the use of n-factors to represent the monthly and seasonal trends in air to ground surface temperature correlation (U.S. Army and Air Force 1988). An accurate n-factor is reliant on numerous full freezing and thawing cycles and will noticeably decrease with snow accumulation and increase with wind speeds (U.S. Army and Air Force 1988, Karunaratne and Burn 2003, and Hinkel et al. 2008). Jorgenson and Krieg (1988) used the n-factor in a model used to map out permafrost formation based on surface terrain. Throughout the study, Jorgenson and Krieg's (1988) computer model was able to predict areas of permafrost with a 92.7 % agreement with air photo permafrost assessments of the same region. The two methods were compared though visual interpretation, but field analysis was not conducted (Jorgenson and Krieg 1988). It was noted that the model was more sensitive to the changes made in the n-factors than the variations in soil moisture seen in the ground (Jorgenson and Krieg 1988). The sensitivity of the model to n-factors showed a much greater change when thawing n-factors were manipulated compared to the changes depicted when freezing n-factors were varied (Jorgenson and Krieg 1988). Only recently has climate change, and its impact on surface characteristics, become a component in the analysis of n-factors.

Despite the early accuracies seen with the use of a surface n-factor in modeling, many scientists caution against its use in practice (Klene et al. 2001, Karunaratne and Burn 2003, and Hinkel et al. 2008). The correlations between air temperature and ground temperature are dependent on a wide range of characteristics; from snow cover and vegetation to urbanization and topography (Klene et al. 2001, Karunaratne and Burn 2003, and Hinkel et al. 2008). The interannual variation is up to 30 % and +/- 20 % can be associated with variations in snow cover due to variations in vegetation of an area (Karunaratne and Burn 2003). Likewise, increased urbanization can have major effects on a region's n-factor (Hinkel et al. 2008). Topography like buildings and roadways, can create irregular snow buildup in areas that are windswept, the variation in snow cover directly affects the calculated n-factor of that site (Hinkel et al. 2008). Work done by Klene et al. (2001) reevaluated the acquisition of n-factor data. Prior n-factors were frequently estimated based on a single thermistor ("2m thermistor cable connected to a miniature single-channel data logger") placed in a given region; Klene et al. (2001) used an array of thermistors to increase the accuracy of the n-factor analysis. Likewise, Hanson et al. (2010) suggested the use of daily n-factors versus seasonal n-factors to account for variability seen in the spring and fall months where seasons change. By using a multi-point array of thermistors, the resultant n-factor values would be accurate enough to use in computer generated modeling systems throughout the Arctic (Klene et al. 2001).

Due to the inaccuracies of the single thermistor n-factor approach and the heightened requirements of the thermistor array (Klene et al. 2001), the design air freezing index (FI_d) and the design air thawing index (TI_d) have understandably been more frequently examined for use in foundation design today (Walter 1991). The FI_d and TI_d, unlike the FI and TI, were created for use in design by accounting for the previous

10-30 year period prior to the design of a new foundation, and not just for a specific year in question (Walter 1991, Frauenfeld et al. 2007, and Hanson et al. 2010). Throughout Walter's (1991) analysis, two approaches were analyzed: the traditional approach, using mean FI and TI values in calculation, and the return period approach, which analyzes the mean and standard deviations of FI and TI values throughout calculation to predict probability. The return period approach better analyzes the entirety of the FI and TI data available and allows the engineer to incorporate "acceptable risk" into the design and therefore is considered a better choice than the theoretical approach (Walker 1991).

As with the accuracy in the approach, it is also important to understand the data being analyzed. Traditionally the FI_d and TI_d are based on the air temperature extremes: the hottest summers and the coldest winters (Scher 2002). In the changing climate, warmer winters have proven to be more common and are of more concern in northern design (Scher 2002). Scher (2002) suggested the use of both a warm winter and warm summer approach to the calculation of FI_d and TI_d. Calculating the warm extremes would allow the engineer to account for reductions in shear strength and bearing capacity as well as increased creep rates (Scher 2002).

Scher's (2002) newly proposed FI_d/TI_d was tempered with the caution of using monthly mean temperatures in calculation versus daily, claiming the monthly averages cause major error in the calculated design indices. Although daily temperature averages are more accurate than monthly averages, they are also much less common and can lead to gaps in research and extensive missing data (Frauenfeld et al. 2007). A FI calculated using daily average air temperatures can be 2-38 % different from a FI calculated using monthly average air temperatures while a TI may only see 0-4 % variation (Hanson et al. 2010). Similar variations can be seen in FI_d and TI_d calculations; 30 year scenarios

resulted in a FI_d that was 12-49 % higher and TI_d that was 1-6 % higher than the respective single year calculations, a FI_d 2-18 % higher than the 10 year calculations for FI_d, and a TI_d within 3 % of the 10 year calculations for TI_d (Hanson et al. 2010). In all cases the effects of climate change on the FI were apparent as the FI consistently showed a greater variation compared to the TI (Hanson et al. 2010). Hanson et al.'s (2010) research showed the importance of regulating or specifying the method used during design and the uncertainty in various approaches that have been previously used and recommended for use.

Globally there are three approaches to the calculation of the FI or more specifically, the air freezing index (AFI): the U.S. method, Finnish method, and Norwegian method (Steurer and Crandell 1995, and Khalili et al. 2007). Although calculations may vary within methods, it is also important to understand how each method relates to one another when relating design parameters in a global context. The Finnish Method and Norwegian Method both calculate the AFI based on the heating degree days (HDD) while the US method uses the freezing degree days (FDD) approach (Steurer and Crandell 1995). By analyzing the HDD, the Finnish Method's use of monthly averages in calculation leads to the underestimation of the AFI and the Norwegian Method's use of daily averages can lead to an overestimation of the AFI (Steurer and Crandell 1995). In general the mean AFI for the Norwegian method is always greater than the U.S. or Finnish method and the U.S. method is greater than the Finnish method (Steurer and Crandell 1995), but the U.S. method is the most accurate under varying climates (Khalili et al. 2007). The overall trend for variability between these approaches is most notable in warmer climates (Steurer and Crandell 1995). As the climate continues to change and engineers attempt to adapt, it will be important to

understand the limitations and potential errors in these methods as well as the methods that should be used in future design.

2.2 Gaps in Research

Climate change has been analyzed through air temperature fluctuations that have been recorded around the globe. When analyzing the effects of climate change on frozen soils in permafrost regions, average air temperatures are frequently used to predict or determine the extent of change expected in foundations throughout their lifespan (Misener et al. 1956, Brown 1960, Osterkamp et al. 1987, U.S. Army and Air Force 1988, Esch and Osterkamp 1990, Osterkamp and Lachenbruch 1990, Walter 1991, Vyalov et al. 1993, Scher 2002).

Researchers proceed to compare and critique work done with respect to climate change without discerning what methods were used in the analysis prior to design. Although most analysis is based on a mean temperature, this mean might come from a monthly average or a daily average, and can then be used to compute FI and TI or FI_d and TI_d (Walter 1991, Scher 2002, and Hanson et al. 2010). The use of a monthly average compared to a daily average in calculation can bring about variability in reported values (Frauenfeld et al. 2007). Most North American regions north of ~45^{o}N latitude show a difference between monthly and daily FI and TI averages of less than 10%, however, it is important to note that the TI in the Rockies and coastal areas north of 60^{o}N latitude have a 5-10% difference between monthly and daily averages (Frauenfeld et al. 2007). The Canadian Rockies and both Alaskan and Canadian northern coasts are some of the areas of greater concern when designing for permafrost in engineering designs and a 5-10% difference in the calculated TI is a significant variability. Unless the averaging method is noted in the design report, the resulting values may be compared without regard to

consistency, which can lead to error in judgment and inaccurate assumptions throughout the design and comparison between designs.

The mean is the most commonly used averaging method for calculation in design (Walter 1991, Frauenfeld et al. 2007, Hanson et al. 2010). As a central tendency as well an averaging method, the mean is used more often than central tendencies in design. The evaluation of central tendencies, like median and mode, in air temperature data is not common, but could affect engineering design. The omission of these comparisons should be analyzed and accounted for before being excluded from use in research and design. Both the period chosen to be evaluated and the type of evaluation used may affect the overall assumptions relied on in northern design.

Northern design frequently takes air temperature change into account through the use of FI_d and TI_d (Frauenfeld et al. 2007, Hanson et al. 2010). The design indices rely on data collected 10 and 30 years prior to construction in a given area. Due to the limited population in northern regions and the more recent population shift to the north, air temperature data have not been recorded, in detail, for most northern areas (Frauenfeld et al. 2007). Continuous hourly air temperature records for larger northern communities go back to 1970, but less so for smaller towns or northern stations (NOAA 2010). Variable gaps in air temperature data make solid data comparison a challenge (Frauenfeld et al. 2007); in some cases more detailed thermal trends are interpreted based on available data. The assumption of data and comparison of assumed data to detailed reports adds to the inaccuracy of climate change theories and predictions.

The use of computer modeling to forecast climate trends has added new sources for potential error in these comparisons. One model may be based on historical monthly

air temperature averages while another was based on daily averages; whether a model accounts for snowfall, snow depth, precipitation, soil type, topography, proximity to urbanization, ground water, and vegetation can all have a dramatic effect on the model's output. Models can be one of the best approaches to forecast and predict climate changes, but they cannot easily be compared due to the variability between models. A model's output is heavily reliant on the accuracy of the input used; therefore, accurate comparisons should ensure that the inputs are the same for each model evaluated for comparison.

The origin of data can impact the raw data used in models and designs. Variables, like climate data, are assumed to be based on values used for meteorological record rather than for technical design. Traditionally 'yearly' trends are viewed in terms of the Gregorian or "Western" Calendar. The Gregorian calendar is used and understood universally and therefore is utilized to present data sets of all types. The Gregorian calendar spans from January 1st to December 31st and is historically linked to religious doctrine influenced by the solar cycle rather than scientific or earthly patterns (timeanddate.com 2011). With no two hemispheres alike, temperature data should not be classified using the Gregorian calendar format, but rather, classified with respect to the seasonal and regional differences of the particular area in question. As with any research it is important to know and understand the variability between approaches as well as potential impact of differing analytical approaches used to produce data summaries.

Engineers obtaining meteorological data most frequently receive it in a Gregorian organization, or "yearly" format, making it more difficult and time consuming to view temperatures with respect to full seasonal fluctuations. When applied to permafrost engineering, temperatures are frequently examined through the calculation of the FI and

TI. With respect to the Gregorian calendar format the ‘freezing’ degree days are split between two different Gregorian calendar years within the northwestern hemisphere. In Alaska and Canada winter temperatures dip below freezing from October of one year and extend well into the April of the following year. The fear is that the result of splitting the winter freezing degree days between two separate seasonal cycles will reduce the statistical influence of a particularly cold or particularly warm winter season.

Once a comparison of the freeze thaw indices can be made between the Gregorian formatted calculation and a seasonal-based calculation then a proper analysis of this effect can be acknowledged. By applying the FI calculated, using both methods, to geotechnical engineering design a more precise analysis can be made. Existing practice does not require a specific analysis method or specified time frame be used to calculate freeze thaw indices, however, by comparing the two methods a degree of error, if any, can be approximated and any revisions to current assumptions can then be made.

2.2.1 Contribution

Independent central tendencies have been calculated for this paper so that all methods of analysis and source data could be checked for accuracies and variations. All climate data acquired is of the same format and has been converted in the same manner to reduce potential variability. A mean, median, and mode have been calculated for daily, weekly, monthly, as well as annual air temperature values and all have been compared over an equivalent timeline. Inconsistencies and differences can be more easily evaluated using direct comparisons of the resulting information presented graphically.

Air temperature data has been compared to snow depth and precipitation records to evaluate trends that may appear on a yearly or decadal schedule. By overlapping snow

depth and precipitation with temperature trends a better estimation of their influences can be made for future analysis using modeling software. Data will be analyzed using both, the Gregorian calendar format and a seasonal calendar format, in order to present the weaknesses seen using a split winter analysis (Gregorian calendar format). The two calendar cycles will help show the differing effects of winter temperature analysis over time as well as the importance of observing seasonal temperature changes as a whole rather than divided by year.

For designers and planners in arctic environments, the analysis will stress the importance of identifying the methodology used in future infrastructure design. This examination of climate change with respect to permafrost and engineering design stresses the importance of the input parameters chosen for use in climate models and illustrates the value of comparative historical analysis of raw data. The graphical analysis in this paper should be used as a guide for determining the accuracy of the thermal design parameters chosen in current projects and should help define predicative analysis for thermal variations. A review of this examination will provide designers and planners an understanding of the complexity of climate change and hopefully an understanding of the factors that must be considered in future arctic design.

3. Climate Data

3.1 Data Analysis

To properly analyze the techniques used in traditional research methods, raw, hourly, temperature data was needed. Central tendencies were calculated from the raw, hourly data to obtain the mean, median, and mode for daily, weekly, monthly, and annual units of time. By acquiring all raw data needed from a single source, the three basic techniques of central tendency calculation were compared without discrepancies due to source disparities.

3.1.1 Acquiring Data

There are many free sources of climate data, but generally they are only available for a single country and/or select locations. Environment Canada offers detailed daily climate data for free, but only allows the data to be viewed one month at a time which makes it difficult to download large periods of record for a full analysis (Environment Canada 2012). At an educational institution in the US, NOAA will provide free access to much of their data bases, but to access the data for free a .gov, .edu, .mil, .k12, or a .us domain needs to be used (NOAA 2010). The analysis for this report was conducted at a Canadian institution and therefore did not meet the requirements for free access. The US Historical Climatology Network holds much of the same climate data as NOAA and provides it free of cost and downloadable from countries outside of the US, however only daily and monthly data were made available for select US cities (USHCN 2011). While difficult to track down, NOAA's National Climatic Data Center (NCDC) 3505 FTP Subscription was chosen and purchased for the analysis done throughout this report. The NCDC 3505 FTP Subscription data provide hourly climate data from around the globe formatted for consistency and checked for accuracy (NOAA 2010). With the data, an

analysis was made, eliminating much of the source error and variability that might have occurred through the use of mixed sources.

For the analysis of the raw data, 6 primary locations throughout Canada and Alaska were chosen for this study: Inuvik, Norman Wells, and Hay River in the Northwest Territories were compared to Barrow, Fairbanks, and Anchorage in Alaska. The locations were chosen for their relative latitudes and respective permafrost zone locations and are more or less representative of the continuous, discontinuous and sporadic regions of permafrost respectively. While the locations are relative, they are not precisely similar.

Alaska	**Latitude (Deg. North)**	**Terrain Type**	**Permafrost Zone**
Barrow	71.29	Tundra	Continuous
Anaktuvuk Pass	68.14	Tundra/Mountain	Continuous/Mountain
Fairbanks	64.84	Taiga/Boreal	Discontinuous
Anchorage	61.22	Marine/Boreal	Sporadic/Permafrost Free

Canada	**Latitude (Deg. North)**	**Terrain Type**	**Permafrost Zone**
Inuvik	68.35	Tundra/Taiga	Continuous/Discontinuous
Norman Wells	65.28	Taiga/Plains	Discontinuous
Hay River	60.85	Taiga/Plains	Sporadic

Table 1: Study Locations and their Respective Latitude, Ecology, and Permafrost Conditions: Based on Information from Figure 1 and Figure 2

As shown in Table 1, Anchorage and Hay River share similar latitudes, but have different terrain types and permafrost zones; Fairbanks and Norman Wells have similar terrain types, latitudes, and permafrost zones; while Barrow and Inuvik show some disparity in all fields. Anaktuvuk Pass, in Alaska would be closer to the same latitude, but varies more greatly than Barrow and Inuvik in terrain type. While the comparisons are

meant to be used as a general guide across Alaska and Northwestern Canada, it is important to acknowledge the differences in these regions as well.

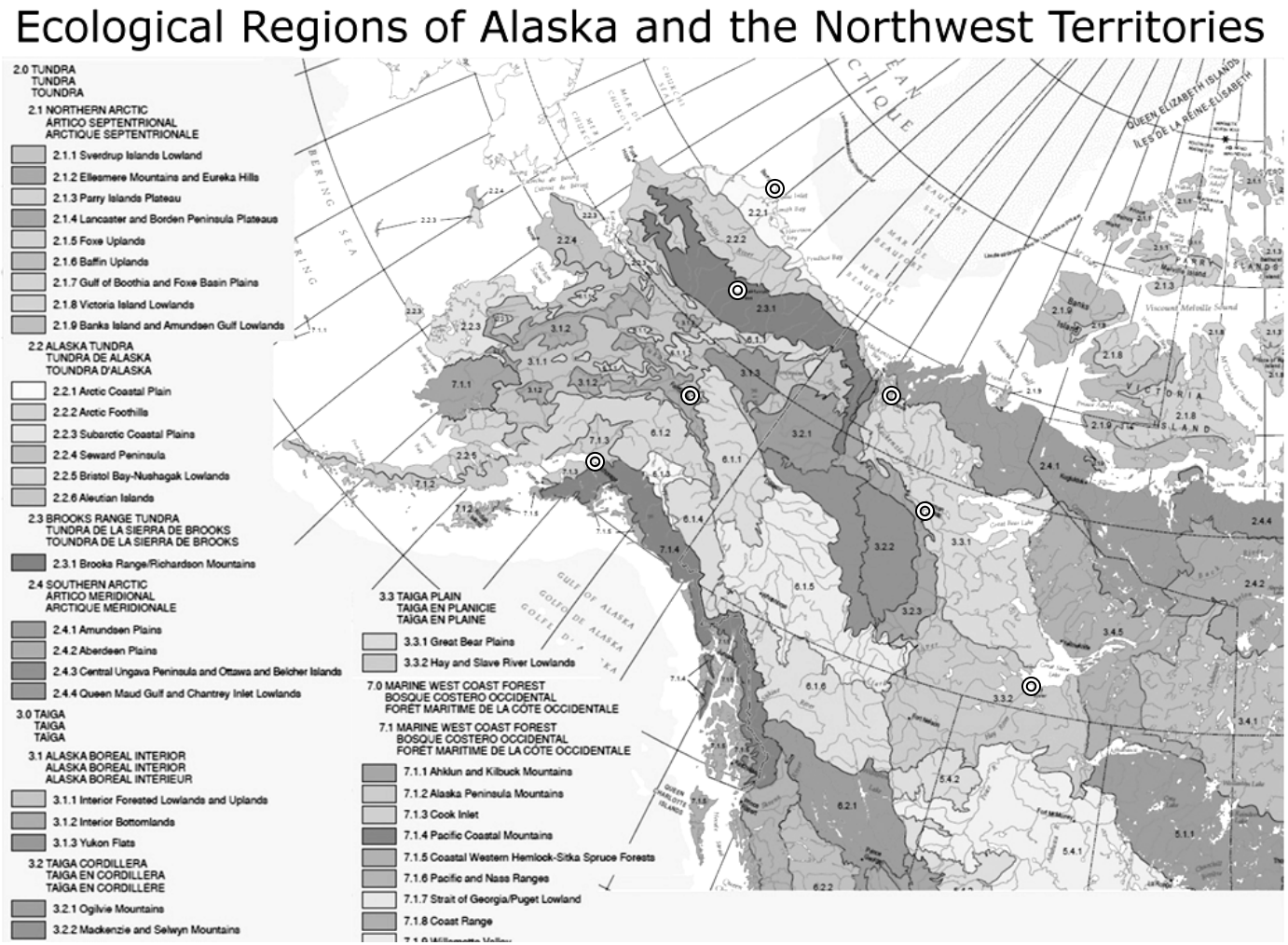

Figure 1: Ecology of the Locations Examined in this Study: Graphic Adapted from "Ecological Regions of North America" 2006.

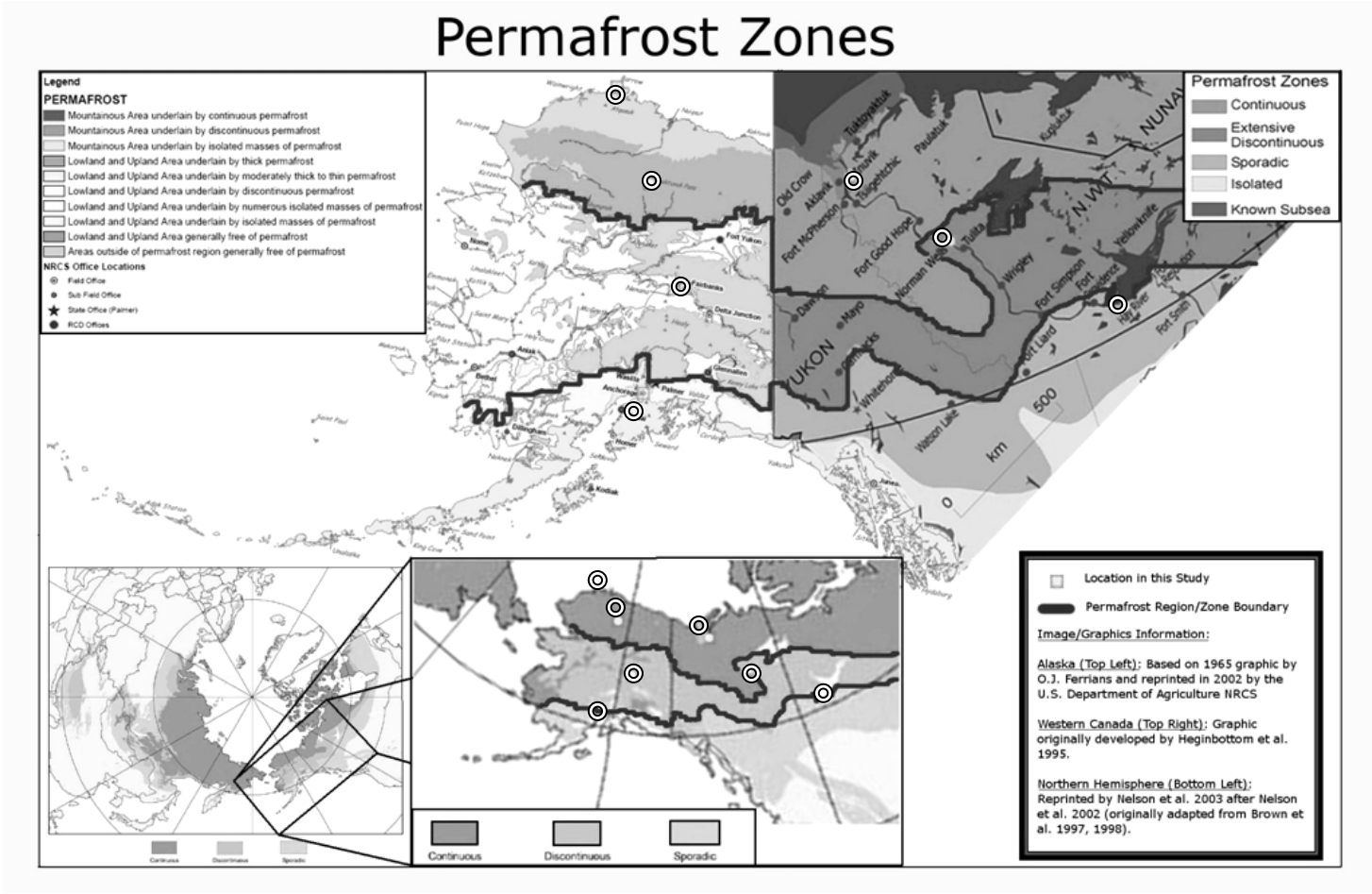

Figure 2: Continuous, Discontinuous, and Sporadic Permafrost Zones Depicted Graphically by O.J. Ferrians (1965), Heginbottom et al. (1995), and Brown et al. (1997).

One of the primary factors in selecting Barrow, Fairbanks, Anchorage, Inuvik, Norman Wells, and Hay River, was the relative length of data collection available at each site. Many northern sites do not have a public weather station, have not been collecting data for more than 10 years continuously, or do not have hourly records available. For this reason, Anaktuvuk Pass was omitted from most comparisons as the data available for the Anaktuvuk Pass weather station had numerous gaps and irregularities. The remaining 6 locations had relatively thorough data records for the last ~40 years; the records for each location were, however, missing numerous years of data prior to the 1970s. To omit any error due to missing data, the following analysis focused on the available and relatively continuous data from 1975-2010.

3. 2 Programming

The hourly climate data acquired through the NCDC FTP Subscription was originally formatted as a GNU zip or gzip (.gz) file type. The raw files were unzipped into a text file, using WinZip (a free online file archiving and compressor for Microsoft Windows and Mac OS X), before being imported into excel for general viewing. While Excel is commonly used in engineering, it posed various problems when used to view and format vast amounts of climate data.

3.2.1 Excel

A Microsoft Excel 2007 worksheet can handle 16,384 columns and 1,048,576 rows; earlier versions of excel can only handle 256 columns and 65,536 rows. The issue with the 2007 Excel grid allowance is that most computers have difficulty even opening a file with a data set greater than the pre 2007 limits. As a reference, a five year time span of climate data for a single location covers roughly 326 columns and approximately 50,600 rows, therefore it cannot be saved into a pre 2007 excel format (due to the number

of columns). Despite being far less than the maximum quantity of columns and rows, the data file for the five year span still takes roughly a minute to open in excel with a standard operating system. Due to the vast size of data acquired, advanced computer programming was needed to run basic formatting and central tendency calculations; running each operation by hand would not be a feasible option for the quantity of data being processed in this study.

3.2.2 Excel Macros

The first method of programming attempted for the analysis of the climate data obtained was using Excel Macros. Excel Macros is a user friendly interface created and specifically designed to help apply a similar set of functions and formats to a variety of Excel sheets using a single command. Because each data file obtained through the NCDC 3505 FTP Subscription was organized in the same manner, an Excel Macro could theoretically be used to format and organize the data without requiring significant manual work.

Using Excel Macros the data was reorganized to avoid excessive abbreviations and to clarify the data present. The NCDC 3505 FTP Subscription data were originally in English units/Fahrenheit rather than metric/Celsius and Excel Macros were used to convert the data uniformly. By using Excel Macros to make all conversions, the risk of manual errors was significantly reduced. With data conversion there is a greater risk of rounding errors in the resulting values; however, due to the large quantity of data being examined in this study, these errors were not expected to affect the results of this study.

3.2.3 Visual Basic for Applications

Once the data had been uniformly formatted, a user interface was programmed to run various central tendency scenarios (Green and Adamczak 2011). The Excel Macros program used to format the data sets is run using a basic Visual Basic for Applications (VBA) programming language. Using more advanced VBA coding, the three central tendency techniques in this study (mean, median, and mode) were applied to daily, weekly, and monthly central tendencies of the climate data obtained for the six weather stations in this study. Once the code was completed for use in Excel, the interface test run had difficulties running through the entire Excel file before "crashing" or "stalling" due to memory overload. While the VBA code was feasible and excel was capable of handling the written code, it became apparent that an average workstation would not be able to run the written program as the quantity of data being process would frequently overwhelm the computer's Random-access Memory or "virtual memory" (RAM).

3.2.4 C# (C Sharp) Programming Language

Both the Microsoft Visual Studio and the Microsoft SQL Server were downloaded so that programming code could be written to determine the central tendencies of the NCDC 3505 FTP Subscription data. Once it was established that the VBA code could not sift through and calculate central tendencies for the vast amount of climate data acquired, without need of a specialized computer, the C# programming language was used to complete the process. Green and Adamczak (2011) were able to construct a user interface as well as a method for basic analysis of the climate data acquired for this study. The use of C# allowed the data to be analyzed and sorted more systematically using less RAM and the resulting interface was therefore more compatible for use with an average work station.

The Excel data can be formatted using the Excel Macros formats in Appendix 10 and the formatted Excel file can be uploaded to Microsoft Visual Studio through the Microsoft SQL Server software. Due to the uniform nature of the data being uploaded the produced interface can be applied to any weather station data downloaded from the NCDC 3505 FTP Subscription. Once the C# interface has been run, the results are saved in a text format and can be imported back into excel where graphical analysis can occur.

3.3 Equations

3.3.1 Determining Central Tendency

For the purpose of this study a mean, median, and mode were analyzed based on the hourly weather station data obtained. To calculate the mean of the temperature data, the arithmetic mean equation was used;

$$\overline{\boldsymbol{x}} = \frac{\mathbf{1}}{\boldsymbol{n}} \cdot \sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} \boldsymbol{x_i}$$

where $\bar{x}$ is the mean and n is the number of data points recorded for the time frame being averaged. The problem with using an arithmetic mean is that any extreme outlier can skew the resulting mean, for this reason the mean was compared to central tendencies like the median and mode.

To calculate the median and mode the equations are much less arithmetic. The median was evaluated as the value(s) that fell in the exact middle of the data set;

$$\boldsymbol{median} = \left\{\frac{(\boldsymbol{n}+\mathbf{1})}{\mathbf{2}}\right\}$$

***Determines the numeric position of the "middle" value, not the value of the median.**

where n is the number of data points recorded for the time frame being examined. In the median equation, if n is an even value, then the mean (see above) is taken of the two values in the middle of the data set. The median value will ignore extreme values or outliers and merely represents the middle value, by position, in a set of data. Because the median is merely a positional determination, it is better used as a reference point than a predictive element in a temperature series.

The mode was the third method used for central tendency comparison in this study. Like the median the mode generally ignores extreme values and outliers, but instead notes the frequency of the values in a given data set. The most frequent value becomes the mode, if there are two or more values that are equally as frequent, the data set is considered multimodal and a mean of those values is used to determine the "mode" for this study.

The mode is helpful for more reasonable long term predictions due to the exclusion of outliers and less frequent extremes, but completely ignoring the extreme values and focusing absolutely on the most common piece of data may reduce one's understanding of the overall climate conditions or potential for future variability. Seasonal temperatures are normally distributed with some natural variability and skewness. Figure 3 shows the relationship between each method of central tendency determination with respect to different "skewness" conditions (Johnson and Christensen 2007**)** and exemplifies the importance of knowing what type of data is being analyzed as well as the shortcomings of the chosen method of analysis. Viewing all three methods of calculating central tendency comparably will help give credence to the method chosen in final calculations and if nothing else will help emphasize the importance in understanding the source and variability of the data used in the analysis.

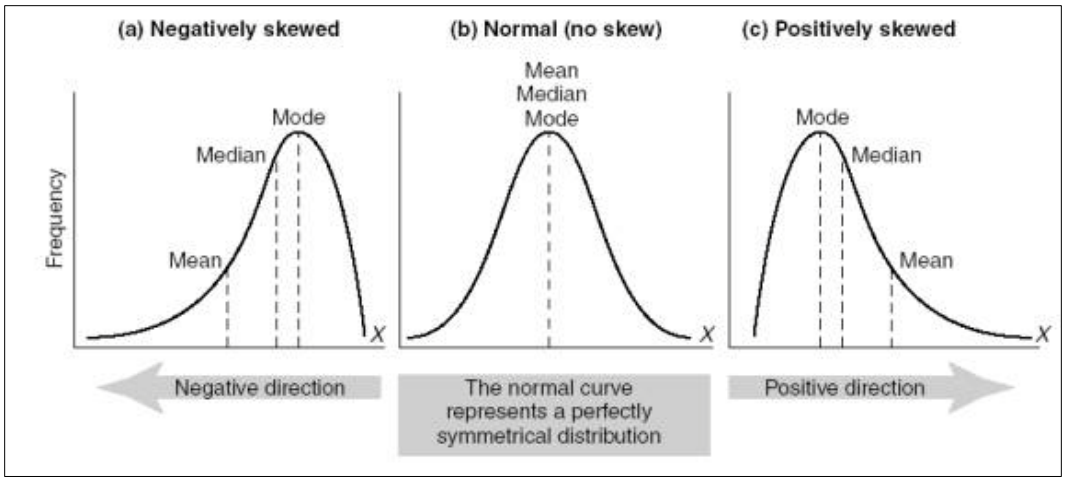

Figure 3: Comparison of the Mean, Median, and Mode Methods of Determining Central Tendency Using Three Log-Normal Distributions with Different Skewness (σ) (Johnson and Christensen 2007).

3.3.2 Unit Conversions

The NCDC 3505 FTP Subscription data is an accumulation of data from weather stations around the globe. As a US based group, all data were converted into English Units for uniformity. For the purpose of a more widespread comprehension and uniformity of the data analyzed and compared in this study, the climate data was converted into Metric Units. Half of the stations in this study were originally recorded in English Units and the other half Metric so the potential for conversion error is equivalent regardless of the unit of measure chosen. Due to the vast quantity of data analyzed and the relatively minute potential for variable error, any possible conversion discrepancies will not affect the outcome of the results in this study.

3.3.3 Miscellaneous Adjustments

The recorded precipitation and snow depth levels for the NCDC 3505 FTP Subscription data were recorded numerically based on depth of the medium, however, when depths were too small to associate with a depth measurement the weather stations generally record the amount as “trace”. Any “trace” measurements recorded in the

NOAA 3505 FTP Subscription data would appear as the letter “T” or “0.00T” throughout the data set. Since a letter value cannot be evaluated using numerical methods the “T” and “0.00T”values were converted to numerical values based on work done by Mekis (2005). Trace measurements of rainfall range between 0.0 mm and 0.2 mm so using 0.1 mm for all trace amounts is suggested (Mekis 2005). For trace measurements of snowfall the recommended substitutions are more varied; Mekis (2005) suggests using 0.07 mm, but Metcalfe et al. (1994) highlighted the clear progression of trace measurements from 0.07 mm in the southern regions of Canada to 0.03 mm in the high Arctic. Because the research in this paper took place north of the 60th parallel north, 0.04 mm was chosen to represent the average trace snowfall measurement in the data examined in this study. This numeric adaptation will allow “trace” values to be accounted for rather than ignored and will present the best representation of true values for this study. Significant snow depths can accumulate in northern regions based on numerous “trace” snowfall events and should therefore be included.

4. Discussion

4.1 Graphical Results

Once the raw climate data were formatted, graphical comparisons were used to identify the impacts of various methods of evaluation. The initial examination focused on the central tendencies, followed by the frequency of the evaluation. Because temperature data are normally distributed naturally, it was important to take into account the effects of skewness on the central tendency being presented. Figure 3 displays the variability conditions between central tendency calculations based on normal distribution skewness. Using the central tendency data, both linear and moving trends were reviewed and analyzed. Snow depth and precipitation averages are displayed in relation to temperatures to give a more comprehensive overview of recent climate shifts.

4.1.1 Central Tendencies

The first comparative analysis was focused on central tendency calculations and the impact they have on basic graphical representation of temperature changes over the last 40± years. Figures 4, 5, and 6 (below) display the air temperatures (^{o}C) calculated by determining the central tendency of the air temperature for each day, week, month, and year. Daily, weekly, monthly, and annual temperatures have all been used in past design work, climate models, and/or studies and have therefore been included in each graph for visual comparison.

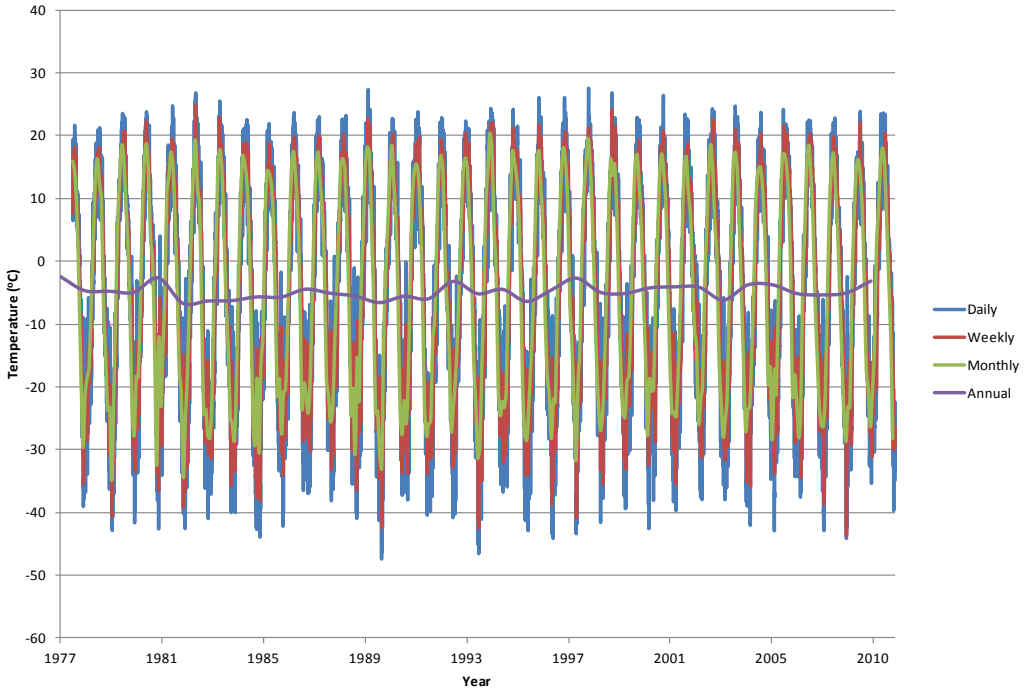

Figure 4: Norman Wells, Northwest Territories Daily, Weekly, Monthly and Annual Mean Temperatures (^{o}C) Compared.

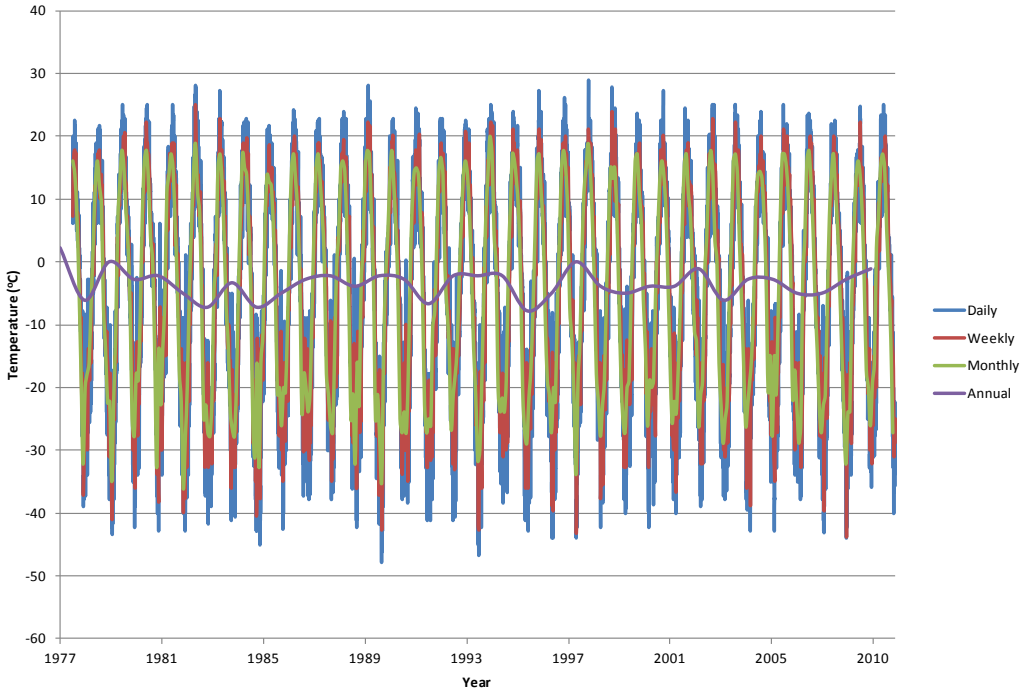

Figure 5: Norman Wells, Northwest Territories Daily, Weekly, Monthly and Annual Median Temperatures (^{o}C) Compared.

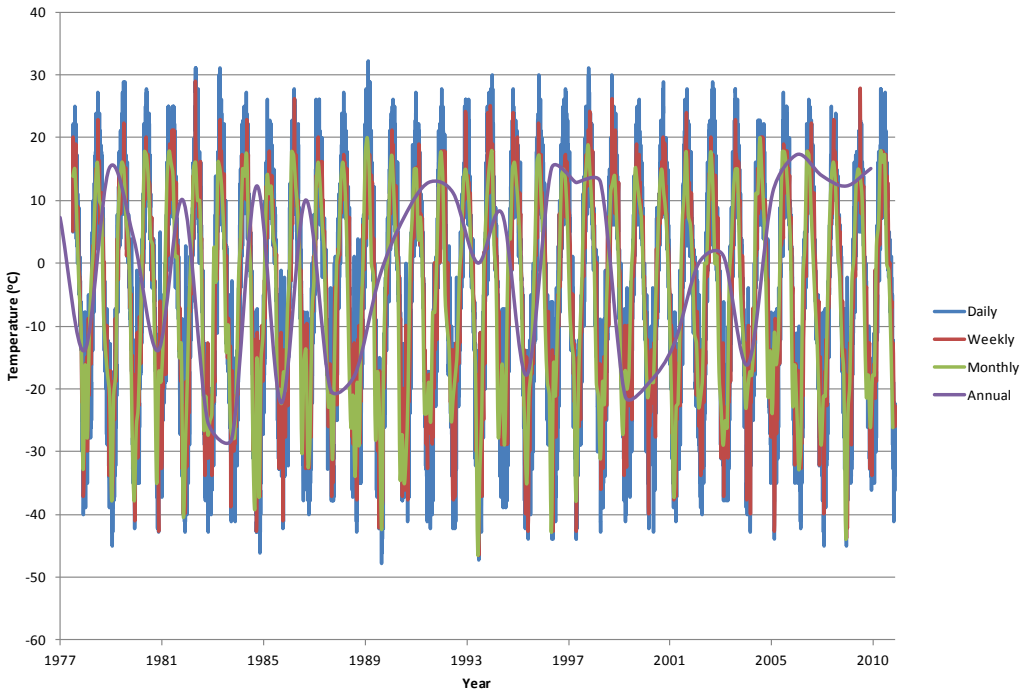

Figure 6: Norman Wells, Northwest Territories Daily, Weekly, Monthly and Annual Mode Temperatures (^{o}C) Compared.

It is important to note that the amplitude of each graph increases as examined from Figure 4 to Figure 5 and then again from Figure 5 to Figure 6. This amplitude magnification is most prominently seen in the more linear annual central tendencies. The increasing amplitude from the mean to median to the mode central tendency is apparent for each examined location; graphical representation of other locations can be seen in the appendices at the end of this report. Table 2 shows the resulting maximum and minimum historical temperatures for each graphing method used in this study. In each case, the absolute values of the maximum and minimum temperatures increases just slightly which agrees with the visual interpretations in Figure 4, 5, and 6.

Barrow		Minimum	Maximum
Daily	Mean	-45.06	16.27
	Median	-45	16.11
	Mode	-46.11	21.67
Weekly	Mean	-43.48	12.04
	Median	-43.89	11.67
	Mode	-44.44	11.11
Monthly	Mean	-36.06	8.15
	Median	-36.11	7.78
	Mode	-41.11	8.33
Annual	Mean	-14.44	-7.36
	Median	-15	-2.22
	Mode	-1.11	6.11

Inuvik		Minimum	Maximum
Daily	Mean	-46.81	27.13
	Median	-47.22	27.22
	Mode	-47.78	30
Weekly	Mean	-42.42	21.3
	Median	-42.78	22.22
	Mode	-46.11	26.11
Monthly	Mean	-34.75	18.64
	Median	-36.11	17.78
	Mode	-46.11	18.89
Annual	Mean	-10.34	-3.58
	Median	-12.22	0
	Mode	-25	10

Anaktuvuk		Minimum	Maximum
Daily	Mean	-48.29	22.64
	Median	-48.89	23.89
	Mode	-49.44	25.56
Weekly	Mean	-41.9	17.03
	Median	-41.67	17.78
	Mode	-42.78	22.22
Monthly	Mean	-30.53	15.56
	Median	-32.78	15.56
	Mode	-39.44	15.56
Annual	Mean	-23.28	2.19
	Median	-23.33	5
	Mode	-27.78	11.11

Fairbanks		Minimum	Maximum
Daily	Mean	-49.1	27.87
	Median	-49.17	28.33
	Mode	-50.56	31.67
Weekly	Mean	-47.27	23.91
	Median	-48.33	23.89
	Mode	-48.89	29.44
Monthly	Mean	-35.77	20.54
	Median	-39.44	20.56
	Mode	-48.33	20
Annual	Mean	-5.76	0.31
	Median	-4.44	1.67
	Mode	-17.78	15.56

Norman Wells		Minimum	Maximum
Daily	Mean	-47.43	27.62
	Median	-47.78	28.89
	Mode	-47.78	32.22
Weekly	Mean	-43.72	24.81
	Median	-43.89	25
	Mode	-46.11	28.89
Monthly	Mean	-34.91	20.36
	Median	-36.11	20
	Mode	-46.11	20
Annual	Mean	-6.65	-2.41
	Median	-7.78	2.22
	Mode	-27.78	17.22

Anchorage		Minimum	Maximum
Daily	Mean	-30.09	21.77
	Median	-30.56	22.22
	Mode	-31.11	25
Weekly	Mean	-24.49	18.46
	Median	-24.44	18.33
	Mode	-26.11	20.56
Monthly	Mean	-17.16	17
	Median	-17.78	16.67
	Mode	-18.33	20.56
Annual	Mean	0.65	4.36
	Median	0.56	5.56
	Mode	-3.89	14.44

Hay River		Minimum	Maximum
Daily	Mean	-41.89	27.08
	Median	-42.22	28.89
	Mode	-42.22	32.78
Weekly	Mean	-38.23	22.41
	Median	-38.06	22.78
	Mode	-41.11	27.22
Monthly	Mean	-33.72	18.28
	Median	-33.89	17.78
	Mode	-37.22	17.78
Annual	Mean	-4.86	0.18
	Median	-3.89	6.11
	Mode	-2.22	15

Table 2: Maximum and Minimum Temperatures (^{o}C) from Graphical Analysis of Various Central Tendencies.

The use of temperature averages in engineering design generally implies that a mean average has been calculated. Despite the more prominent use of a mean average, it is important to understand how various calculation techniques can affect the resulting data. For the purpose of this examination the mean, median, and mode were compared and contrasted. In Figures 4, 5, and 6 each graph shows the same temperatures and years with respect to daily, weekly, monthly, and annual units of time; but the central tendency used for calculation is different in each. The change made only to the central tendency causes different aspects of the information to be highlighted.

The mean central tendency gives equal weight to all temperatures recorded throughout the evaluated unit of time; because of this, the graph will be influenced by extreme or outlying conditions, incorporating all recorded temperatures into the graphical representation. The mode central tendency, unlike the mean, gives emphasis to the most common temperature occurrences during a specified time interval. Weighting the most common temperature occurrences leads to a more erratic graphical interpretation of the data, but can be informative in the examination of subsurface thermal impacts. While noting that the temperature dropped to -15 ^{o}C might be important, it may be a much greater impact if the temperature remained at -15 ^{o}C for the large part of a day. As with most insulated facilities, soil will not change temperature instantly. There is a delayed response in soil temperature due to the low thermal conductivity (high thermal resistance) of soils. Permafrost below the active layer would be even less susceptible to sporadic air temperature changes due to its specific latent heat effects associated with liquid water.

The erratic nature of the modal central tendency does not make it less accurate, but rather harder to predict and less easy to understand. The mode emphasizes the lack of predictability in temperature fluctuation by emphasizing the most common temperature

recorded. The median central tendency, unlike the mean and mode, is merely presented as an alternative method of analysis. While the mean and mode central tendencies are more directly applicable to thermal changes seen in soils, the median eliminates extreme temperatures focusing on the temperature in the middle of the data set. Although it may not be as directly applicable, the median is a good way to gauge the interpretation of the mean and mode by comparing the skewness of each (as seen in Figure 3).

In many cases the mean, median, and mode values for a particular unit of time are the same or similar. This occurrence can be seen in Figures 7, 8, 9, and 10 which depict the mean, median, and mode overlain for each time unit examined. It is important to note that while the central tendencies are similar when the unit of time is daily (Figure 7), the similarities weaken for data evaluated by the year (Figure 10). The impact of the central tendency calculation used on the resulting climate data is much less noticeable than the impact produced by different units of time evaluated. With annual central tendencies, resulting data is based on the omission of variables; the more frequent the data (e.g., daily calculations) the more applicable the central tendency is to the true climate condition.

4.1.2 Frequency of Data Analysis

The second graphical comparison examined was the effect that the unit of time would have on the data calculations. In many rural, northern areas data collection is intermittent and therefore the frequency of climate data in those regions can be sporadic at best. For this reason it is important to understand the effect that a chosen frequency has on the graphical interpretation of that specific region. Figures 7, 8, 9, and 10 display air temperatures (^{o}C) for Norman Wells over the last 40 years with respect to daily, weekly,

monthly, and annual temperatures. Each graph depicts central tendencies calculated using mean, median, and mode for a more thorough analysis.

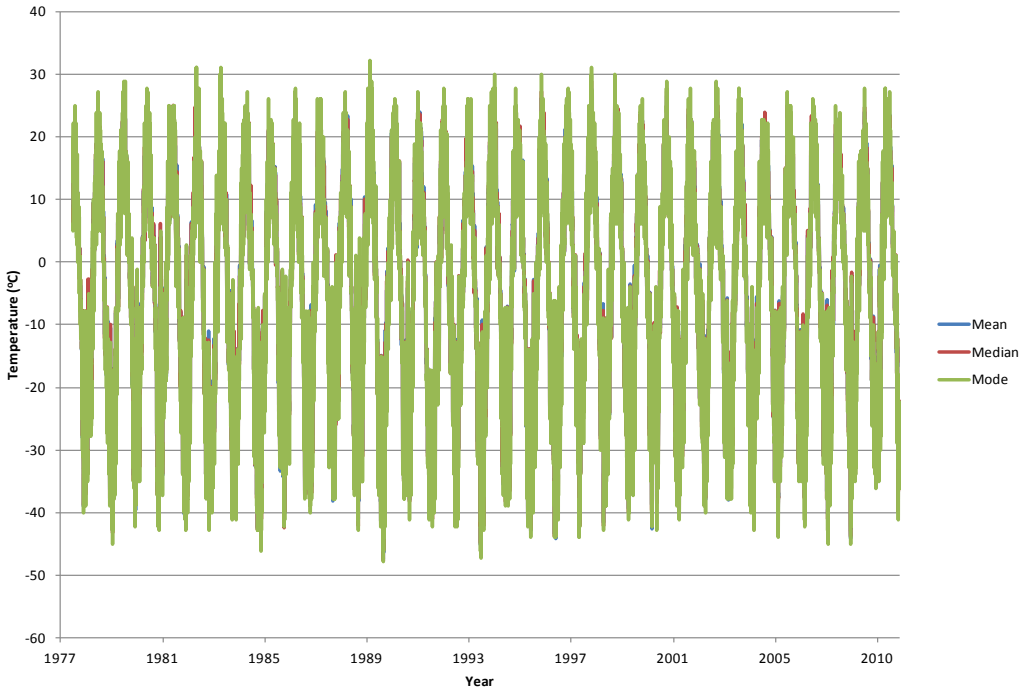

Figure 7: Norman Wells, Northwest Territories Mean, Median, and Mode Daily Temperatures (^{o}C) Compared.

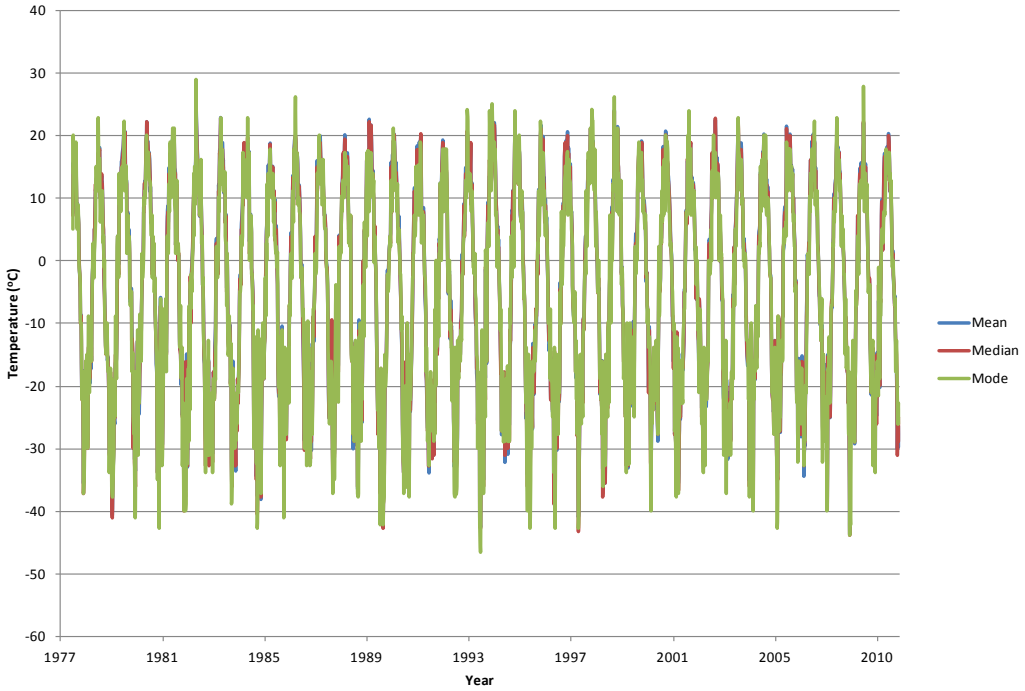

Figure 8: Norman Wells, Northwest Territories Mean, Median, and Mode Weekly Temperatures (^{o}C) Compared.

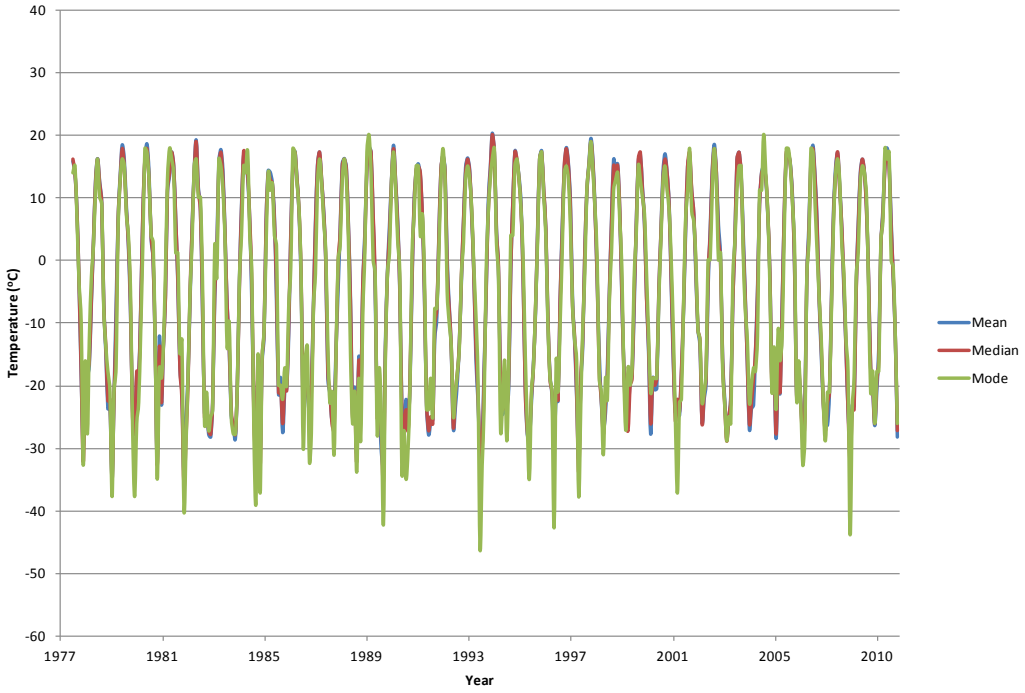

Figure 9: Norman Wells, Northwest Territories Mean, Median, and Mode Monthly Temperatures (^{o}C) Compared.

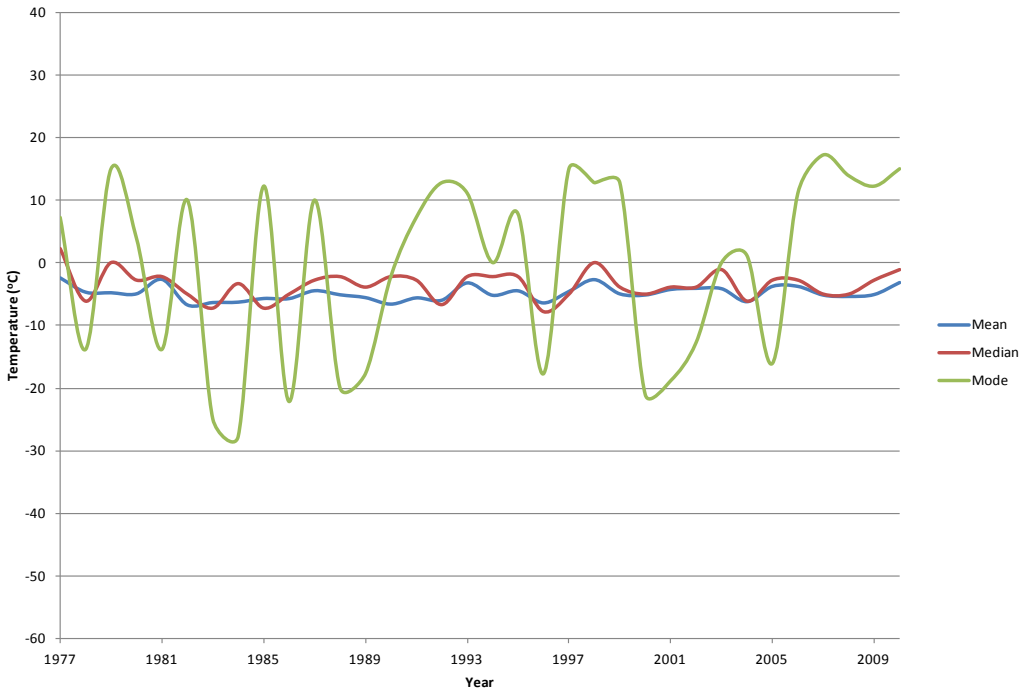

Figure 10: Norman Wells, Northwest Territories Mean, Median, and Mode Annual Temperatures (°C) Compared.

As with Figures 4, 5, and 6, there is a noticeable change in amplitude shown in Figures 7 through 10. As with Figures 4, 5, and 6, the maximum and minimum absolute values for Figures 7 through 10 can be compared in Table 2. In this case the amplitude diminishes from Figure 7 to Figure 10 and the change is much more obvious than the previous case (evaluation of central tendency). Loss of detail in the seasonal trends is more prevalent as data frequency diminishes. Further examples of this trend can be seen in the graphical analyses presented for each location in this study (located in Appendix 1 through Appendix 7).

4.1.3 Trend Line Representations

Due to the increasing interest in climate forecasts a basic review of linear trends was carried out using the methods previously discussed in this paper. The difficulty with forecasts in general is the omission of unknown factors. With linear trends, the trend is

only based on the known information; in this case the linear forecast is solely based on the previous 40 years of data. The limited number of years used for this linear projection will influence its behavior drastically. If an even smaller set of years were used for the projection, say for instance 1970-1975, the linear projections may have had a negative slope rather than a positive one due to those years showing annual cooling. In many forecasted trends scientists generally do not make forecasting estimates further than ~50 years beyond what is currently known (e.g., Walsh 2008, Smith and Risebourough 2010). Because only the past 40 years have been used in this examination, that general limit might be reduced due to potential error in forecasting further into the future than what is known in the past.

Despite its relatively common use for general estimation, linear trends are a poor forecasting model for sinusoidal-like temperature trends. The ease of application of linear trend lines makes them readily accessible for climate estimation in practice, but they should be used with caution. In this examination it was important to present a graphical interpretation of these trends in order to begin to understand the resulting issues.

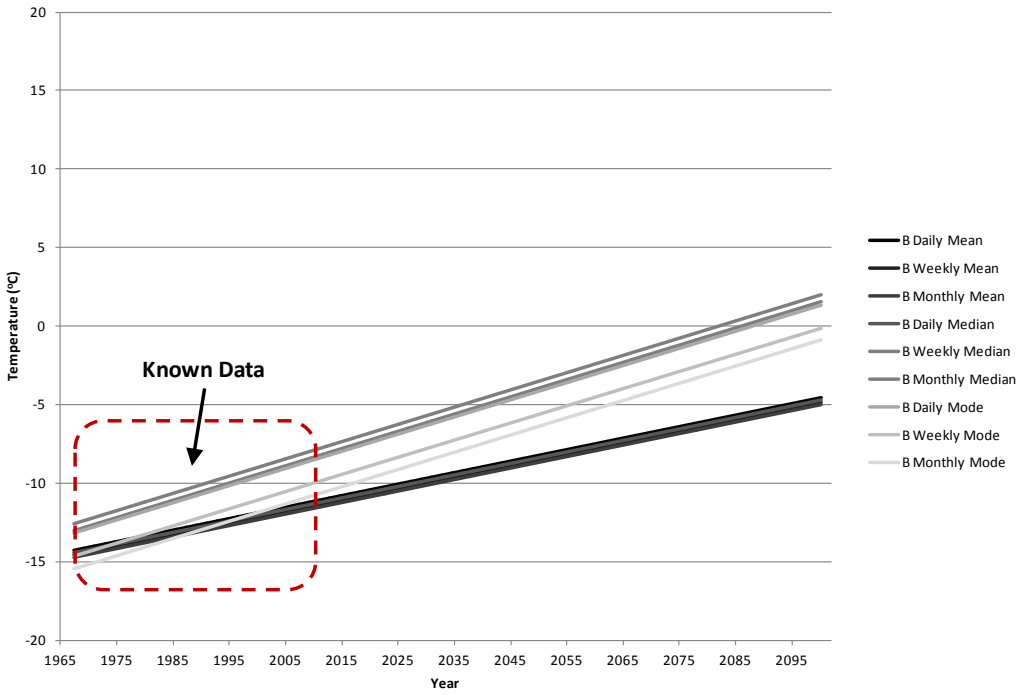

Figure 11: A Projected Linear Trend for Barrow, Alaska (B) Based on Historical Data.

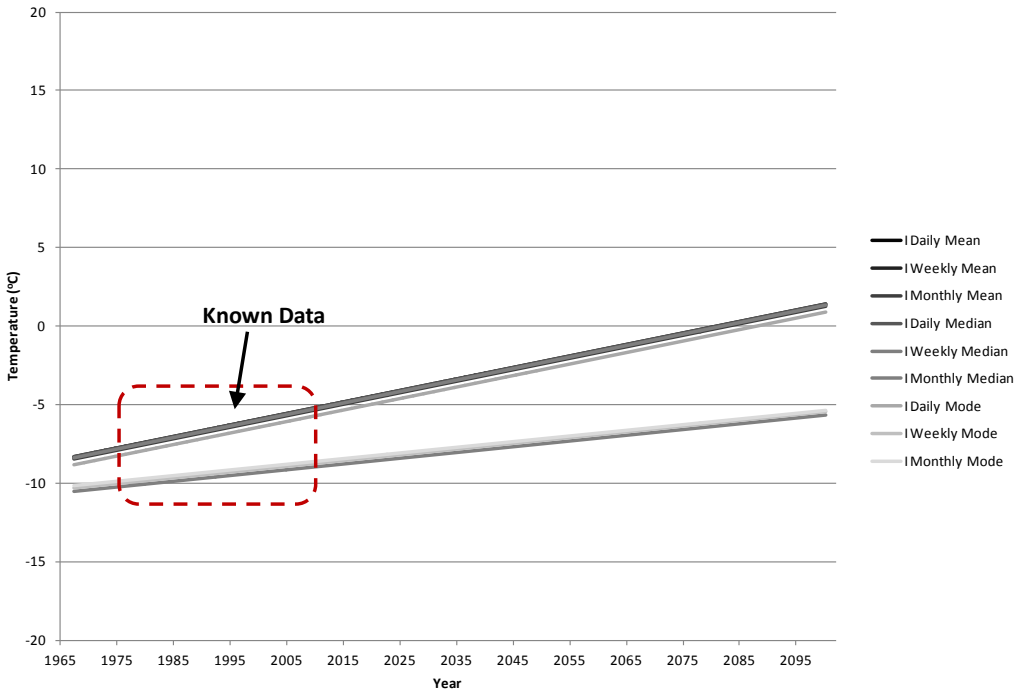

Figure 12: A Projected Linear Trend for Inuvik, Northwest Territories (I) Based on Historical Data.

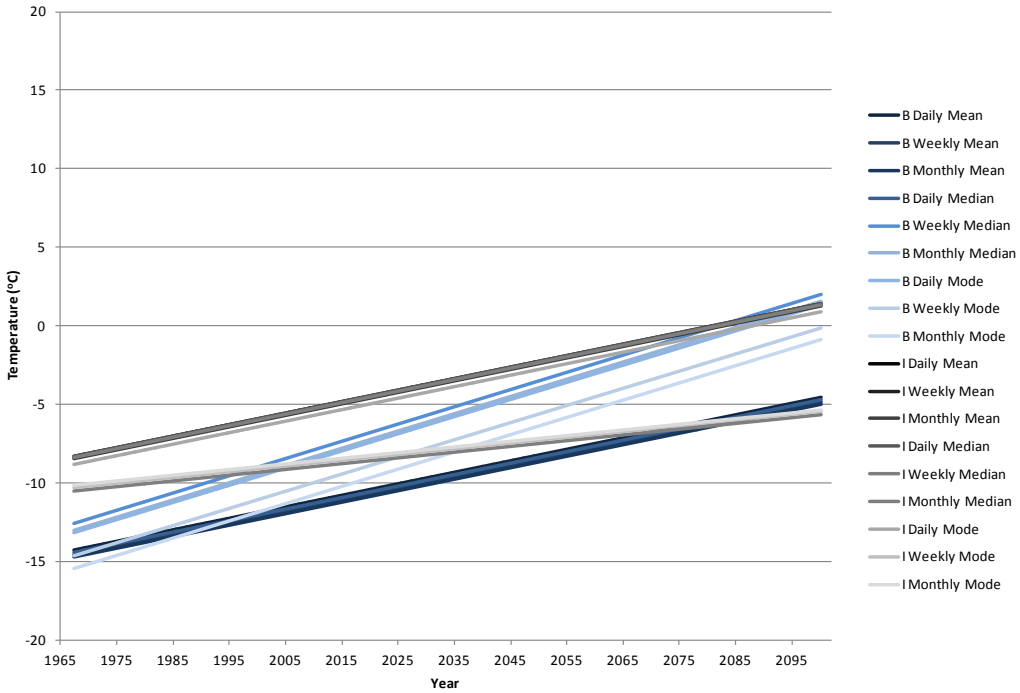

Figure 13: A Comparison of Projected Linear Trends for Barrow, Alaska (B) and Inuvik, Northwest Territories (I) Based on Historical Data.

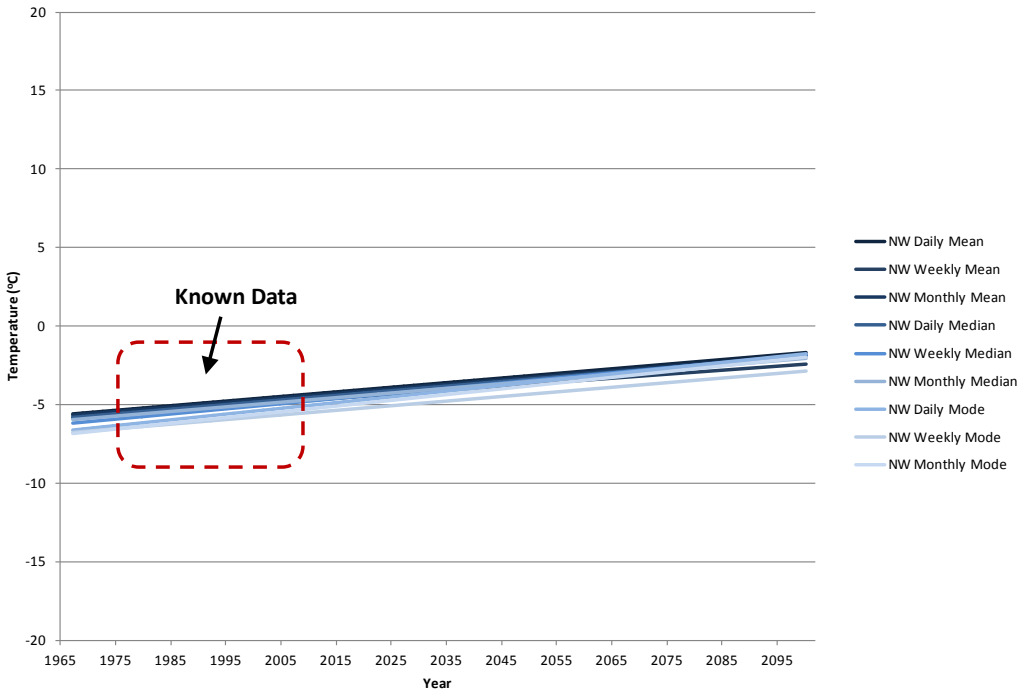

Figure 14: A Projected Linear Trend for Norman Wells, Northwest Territories (NW) Based on Historical Data.

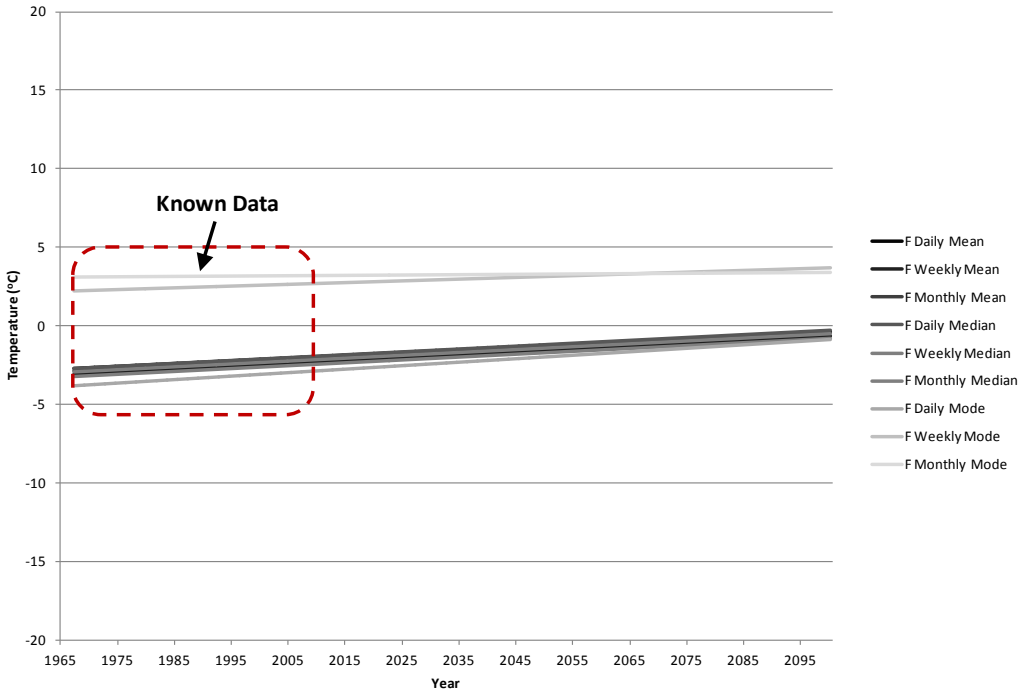

Figure 15: A Projected Linear Trend for Fairbanks, Alaska (F) Based on Historical Data.

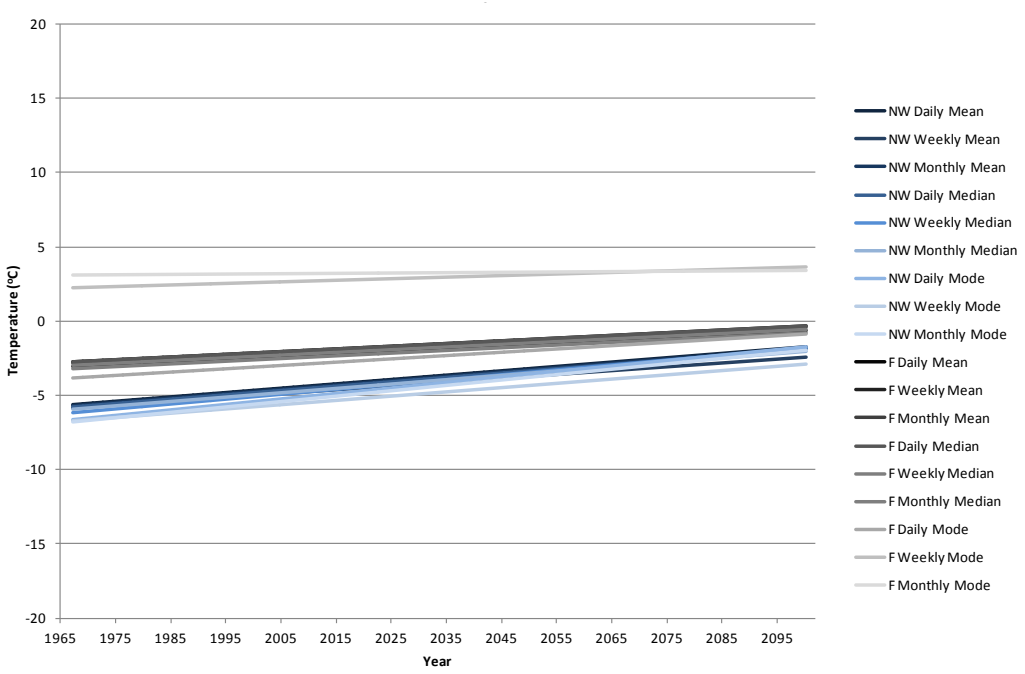

Figure 16: A Comparison of Projected Linear Trends for Fairbanks, Alaska (F) and Norman Wells, Northwest Territories (NW) Based on Historical Data.

Figure 17: A Projected Linear Trend for Anchorage, Alaska (A) Based on Historical Data.

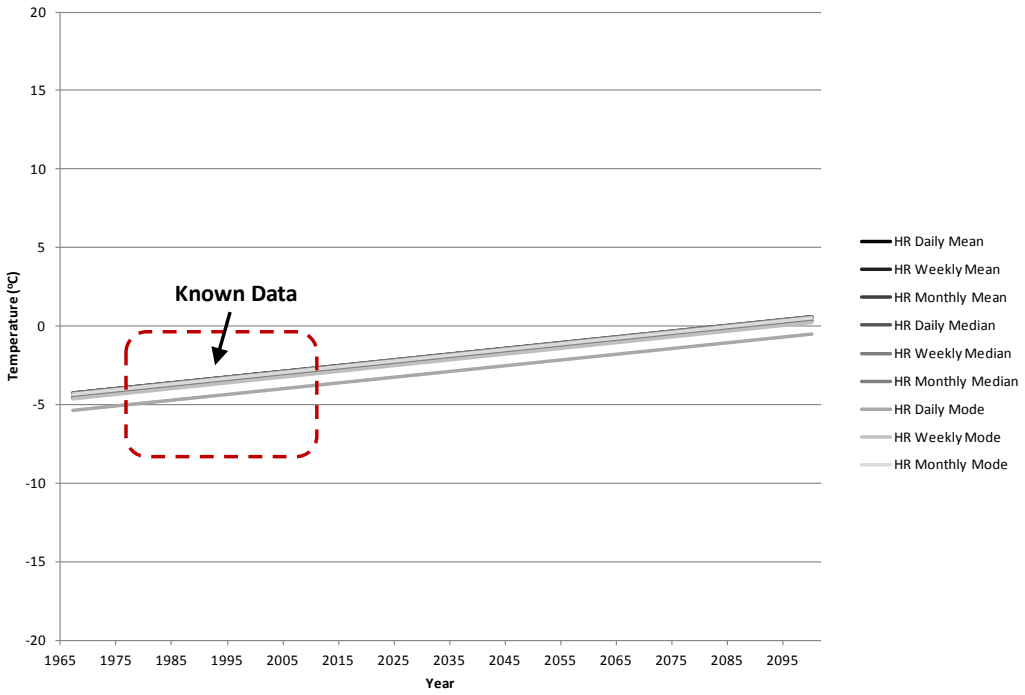

Figure 18: A Projected Linear Trend for Hay River, Northwest Territories (HR) on Historical Data.

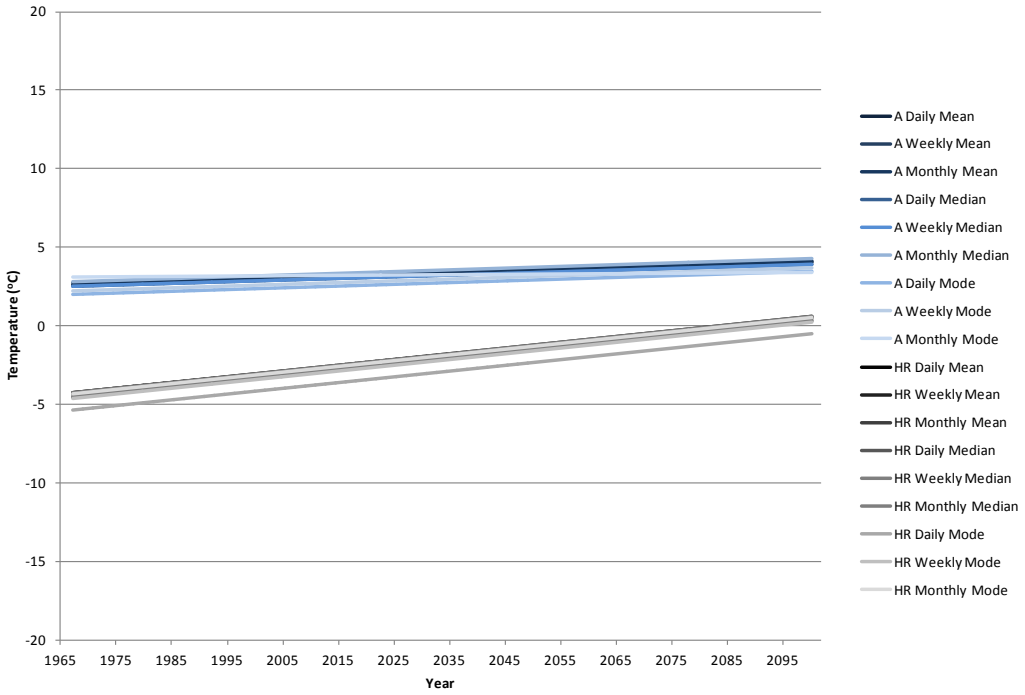

Figure 19: A Comparison of Projected Linear Trends for Anchorage, Alaska (A) and Hay River, Northwest Territories (HR) Based on Historical Data.

In Figures 11through 19, a linear trend line based on the data and graphs shown in Figures 7, 8, 9, 10 are displayed for each of the communities. To get a better idea of the resulting trends and future impacts Table 2 shows the projected future impacts for each location.

Temperature Changes											
1968-2010				2010-2050				2010-2100			
Anaktuvuk	Daily	Weekly	Monthly	Anaktuvuk	Daily	Weekly	Monthly	Anaktuvuk	Daily	Weekly	Monthly
Mean	3.14	3.14	1.57	Mean	2.92	2.92	1.46	Mean	6.57	6.57	3.29
Median	3.14	3.14	1.57	Median	2.92	2.92	1.46	Median	6.57	6.57	3.29
Mode	4.71	3.14	0.16	Mode	4.38	2.92	0.15	Mode	9.85	6.57	0.33
Anchorage	Daily	Weekly	Monthly	Anchorage	Daily	Weekly	Monthly	Anchorage	Daily	Weekly	Monthly
Mean	0.47	0.47	0.47	Mean	0.44	0.44	0.44	Mean	0.99	0.99	0.99
Median	0.47	0.47	0.47	Median	0.44	0.44	0.44	Median	0.99	0.99	0.99
Mode	0.47	0.47	0.11	Mode	0.44	0.44	0.10	Mode	0.99	0.99	0.23
Barrow	Daily	Weekly	Monthly	Barrow	Daily	Weekly	Monthly	Barrow	Daily	Weekly	Monthly
Mean	3.14	3.14	3.14	Mean	2.92	2.92	2.92	Mean	6.57	6.57	6.57
Median	3.14	4.71	4.70	Median	2.92	4.38	4.38	Median	6.57	9.85	9.86
Mode	4.71	4.71	4.70	Mode	4.38	4.38	4.38	Mode	9.85	9.85	9.86
Fairbanks	Daily	Weekly	Monthly	Fairbanks	Daily	Weekly	Monthly	Fairbanks	Daily	Weekly	Monthly
Mean	0.79	0.78	0.78	Mean	0.73	0.73	0.73	Mean	1.64	1.64	1.64
Median	0.79	0.78	0.78	Median	0.73	0.73	0.73	Median	1.64	1.64	1.64
Mode	0.94	0.09	1.57	Mode	0.88	0.09	1.46	Mode	1.97	0.20	3.29
Hay River	Daily	Weekly	Monthly	Hay River	Daily	Weekly	Monthly	Hay River	Daily	Weekly	Monthly
Mean	1.57	1.57	1.57	Mean	1.46	1.46	1.46	Mean	3.28	3.28	3.29
Median	1.57	1.57	1.57	Median	1.46	1.46	1.46	Median	3.28	3.28	3.29
Mode	1.57	1.57	1.57	Mode	1.46	1.46	1.46	Mode	3.28	3.28	3.29
Inuvik	Daily	Weekly	Monthly	Inuvik	Daily	Weekly	Monthly	Inuvik	Daily	Weekly	Monthly
Mean	3.14	3.14	3.14	Mean	2.92	2.92	2.92	Mean	6.57	6.57	6.57
Median	3.14	1.57	3.14	Median	2.92	1.46	2.92	Median	6.57	3.28	6.57
Mode	3.14	1.57	1.57	Mode	2.92	1.46	3.03	Mode	6.57	3.28	4.85
Norman We	Daily	Weekly	Monthly	Norman We	Daily	Weekly	Monthly	Norman We	Daily	Weekly	Monthly
Mean	1.26	1.10	1.25	Mean	1.17	1.02	1.17	Mean	2.63	2.30	2.63
Median	1.26	1.41	1.25	Median	1.17	1.31	1.17	Median	2.63	2.96	2.63
Mode	1.57	1.26	1.57	Mode	1.46	1.17	1.46	Mode	3.28	2.63	3.29

Table 3: Magnitude of Temperature Change Based on Measured Data and Linear Projections in Degrees Celsius for the Mean, Median, and Mode of Daily, Weekly, and Monthly Central Tendencies.

The numbers in Table 3 are extreme and while the linear trend is accurate it is not necessarily a true depiction of the future temperatures. An examination of Table 3 shows

that the monthly mode produces the most irregular and unpredictable temperature changes. By comparing future trends and their impacts, the limitations of each method used can be evaluated. While linear predictions are easy to apply they may not accurately depict future conditions.

In Excel, a value called the R^2 value is used for trend lines to scale a line's accuracy by gauging how well it fits the data. An R^2 value of 1 indicates that the trend line is an exact fit with the data and that all data points lie directly on the trend line; the larger the number of data points off the trend line and the further from the trend line the data points are, the lower the R^2 values get. Because temperature data are sinusoidal-like, the R^2 value will never be 1 or even close to 1, that does not necessarily mean that the linear trend is not accurate, but likewise it does not enhance the argument for the use of the linear trend for forecasting purposes.

The most important argument, based on Figures 11 through 19, against the use of a linear trend line for future temperature prediction is that the linear approach assumes that the future is an extrapolation of the past. The different combinations of the mean, median, and mode and the daily, weekly, and monthly calculations produce a wide variation for the majority of the cases evaluated. Anchorage and Hay River have the most favorable linear trends; the trends for all combinations of calculations examined match each other or are parallel signifying a strong agreement between the data. From a latitude perspective, the more northern the data set, the weaker the relationship between the linear trends. Barrow and Inuvik, the most northern comparables in this study, have the most erratic relationship as displayed by Figures 11, 12, and 13.

From this graphical examination, it is important to note that forecasting long term temperatures tends to be more difficult or erratic for the high latitude arctic regions. For permafrost engineering design applications and practices, this suggests the need for applied caution and thorough review when designing for future conditions or potential thermal impacts on a proposed engineering structure.

4.1.4 Seasonal Temperature Comparisons and Trends

In an attempt to understand trends and changes in temperature over time, a comparison graph was produced to show the seasonal effects and intricacies of a changing climate. The graphical comparison produced for this work was influenced by a comparison presented by Osterkamp (2007) in which the trend for 20 years prior to a known change in permafrost conditions was shown over the top of the following 20 years, after the permafrost change (Figure 20). Osterkamp's (2007) graph examined two 20 year periods as two, averaged, smoothed lines over the time span of a single year (January to December). By plotting the two lines, Osterkamp (2007) was able to compare the temperature changes by season and could then note which months underwent the largest changes over the period being examined. One concern with this approach is that by plotting the graph for a single year, the winter months were split, making a thorough analysis of the changes during the winter months more difficult to present.

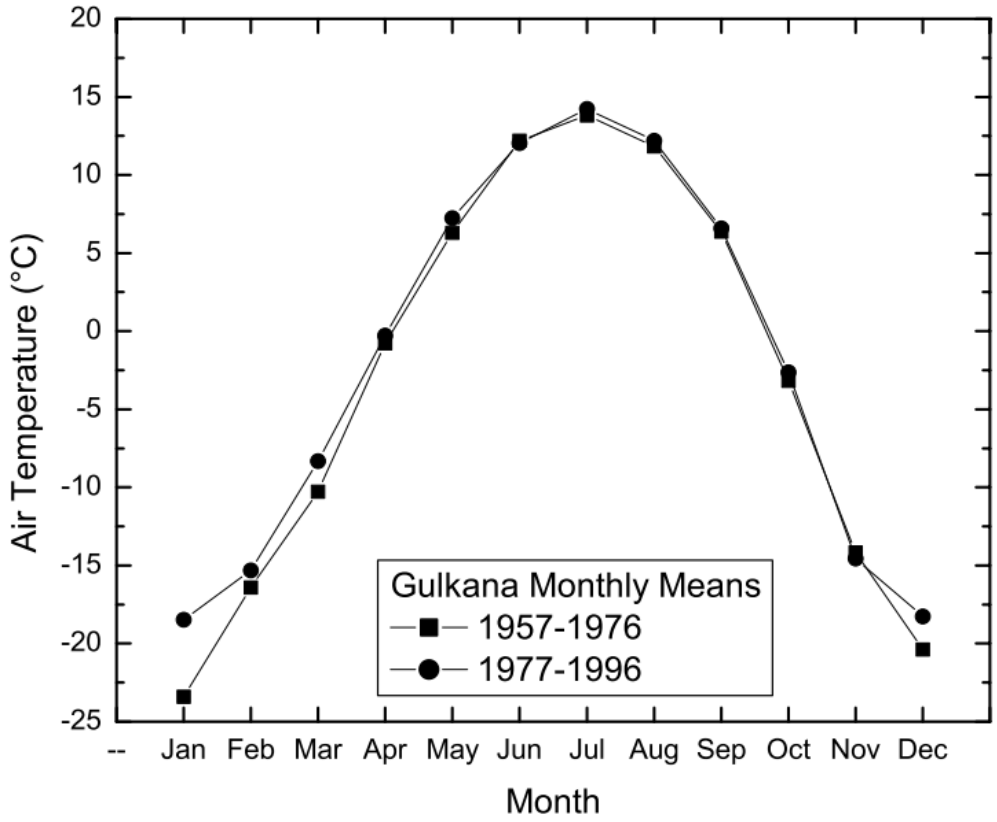

Figure 20: T.E. Osterkamp's (2007) Graphical Examination of Seasonal Changes in Temperature (^{o}C) Witnessed in Gulkana, Alaska Comparing 1957-1976 to 1977-1996.

In this study, a similar method was used, but instead of combining many years of data into a single smooth line for comparison, individual daily and monthly averages from multiple years were compared and plotted over a 1.5 year time span. Using both daily and monthly averages a more detailed visual interpretation of the temperature changes witnessed over time for a particular area. Figure 21 shows multiple years from the beginning of the Norman Wells data set compared to the most recent years examined. This comparison is presented using varying shades as well as symbols; darker lines with triangles are displayed for the earliest years in the study and lighter lines with squares are used to display the most recent years, the lightest lines in the background represent daily variation for each monthly trend line shown. While Figure 21 provides a unique interpretation of the temperature changes seen over time, it does not provide a clear

comparison of seasonal data. By presenting multiple years of data over one another, a particularly cold year might be compared with a particularly warm year and the comparison has the potential to be flawed, representing the exception and potentially not the true trend.

To properly gauge the seasonal changes over time, a span of 1.5 years was selected and compared to every fifth year throughout the continuous available data. By graphing 1.5 years of data instead of only a single year, the temperature changes during winter months can also be evaluated and compared unlike Osterkamp's (2007) graphical analysis, which displayed a split winter. By overlaying a more regular interval and limiting the period of time compared, a more reliable graphical interpretation is established. Figures 22, 23, and 24 show the seasonal temperature shifts over time, in a method similar to that used by Osterkamp (2007). Unlike Osterkamp's graphical analysis, Figures 22, 23, and 24 include daily temperature data which shows more detailed depictions of the variations in temperature. With both monthly and daily data presented together on a single graph, changes can be analyzed in greater detail.

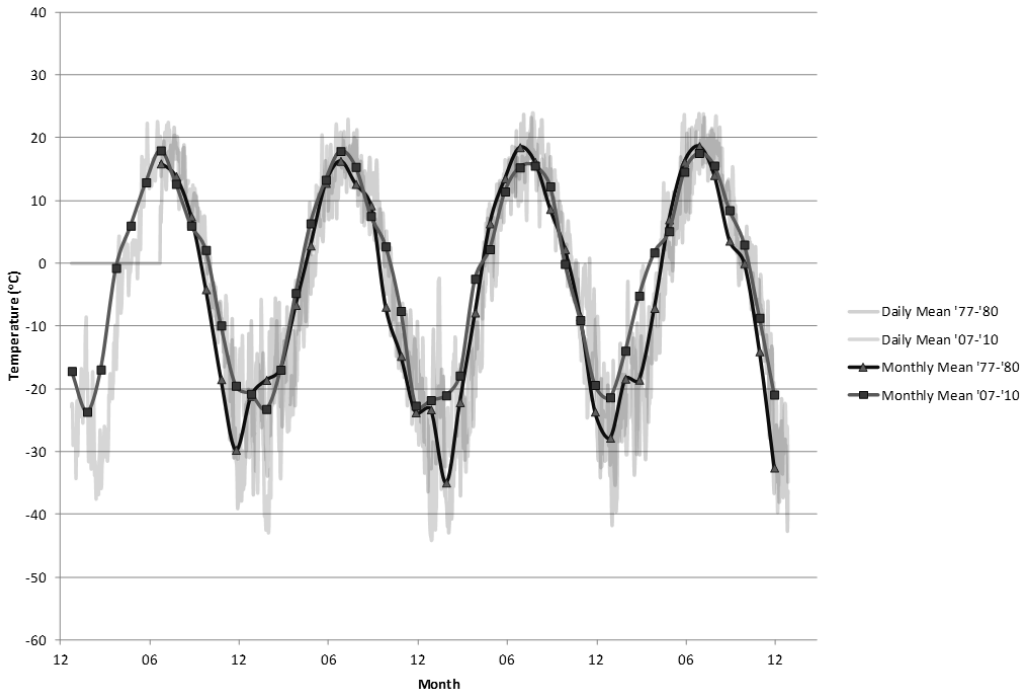

Figure 21: A Multi-Year Seasonal Comparison of Mean Temperatures (°C) from Norman Wells, Northwest Territories in 1977-1980 Compared to 2007-2010.

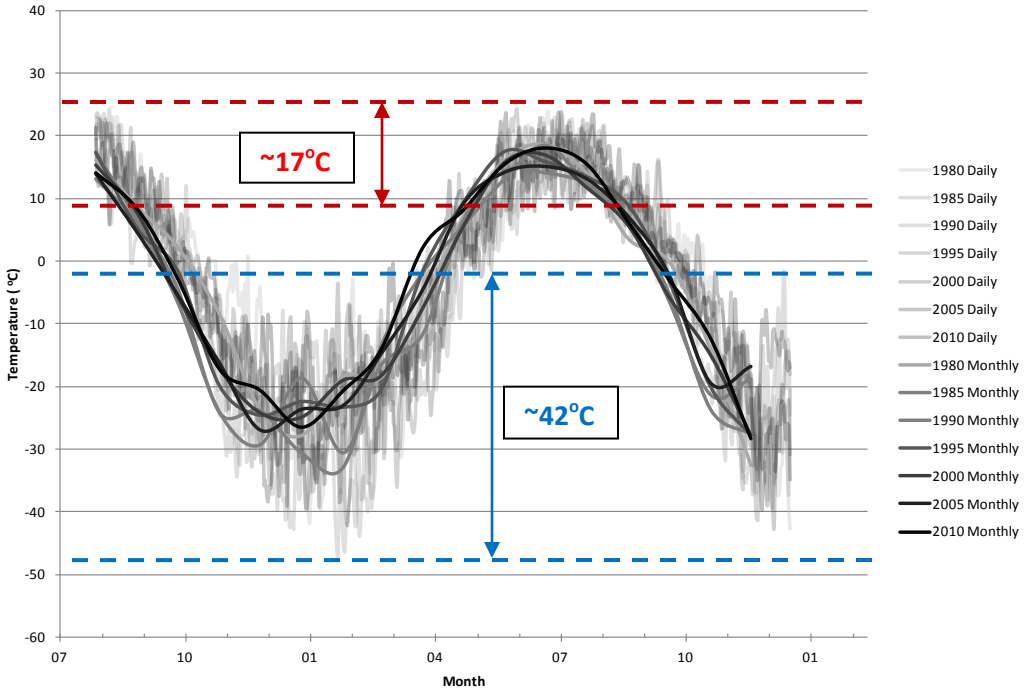

Figure 22: A Comparison of Daily and Monthly Mean Air Temperatures (°C) for Norman Wells, Northwest Territories: Every 5th Year Between 1980 and 2010 are Graphed in 1.5yr Increments for Seasonal Comparison. Dashed Lines Indicate Maximum and Minimum Temperatures for each Season (Degree Differences are Labeled).

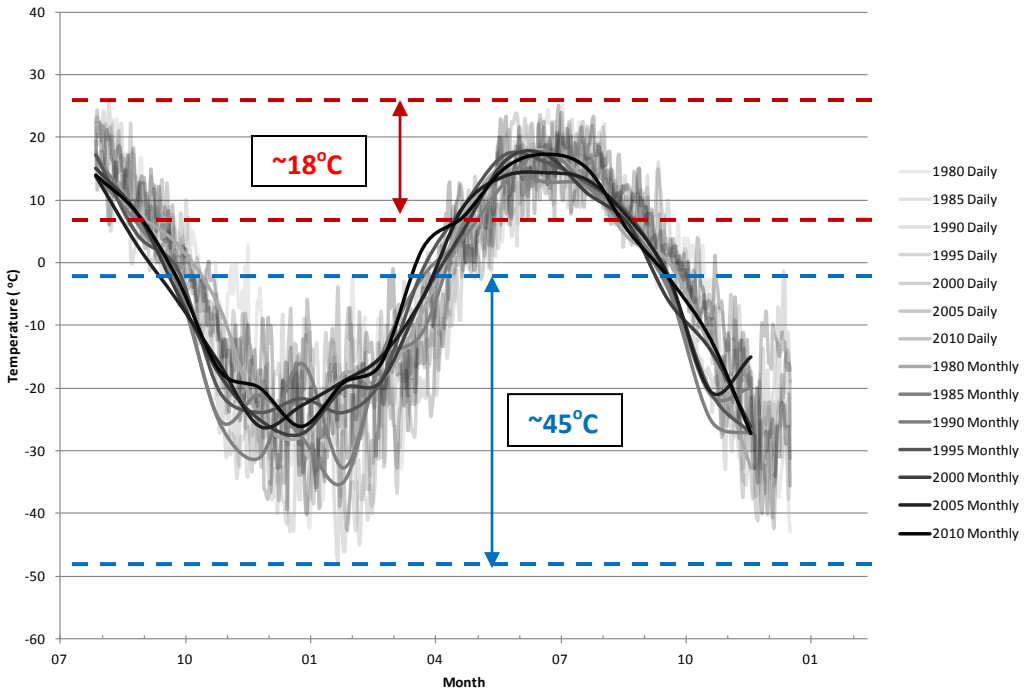

Figure 23: A Comparison of Daily and Monthly Median Air Temperatures (°C) for Norman Wells, Northwest Territories: Every 5th Year Between 1980 and 2010 are Graphed in 1.5yr Increments for Seasonal Comparison. Dashed Lines Indicate Maximum and Minimum Temperatures for each Season (Degree Differences are Labeled).

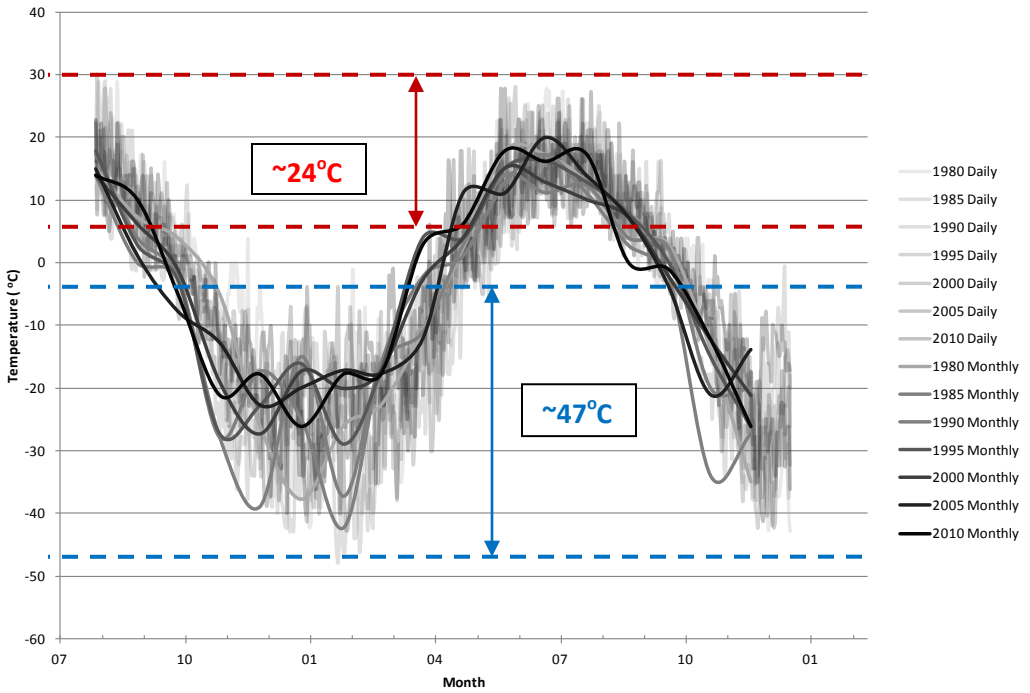

Figure 24: A Comparison of Daily and Monthly Mode Air Temperatures (°C) for Norman Wells, Northwest Territories: Every 5th Year Between 1980 and 2010 are Graphed in 1.5yr Increments for Seasonal Comparison. Dashed Lines Indicate Maximum and Minimum Temperatures for each Season (Degree Differences are Labeled).

Based on Figure 21, mean monthly summer temperatures show minimal change over time while the mean monthly winter temperatures have dramatically increased. Figure 21 only depicts data for Norman Wells, however, Appendix 1 through 7 display graphical comparisons for each location in this study. Although the Norman Wells data displays a striking set of trends, trends for the other locations in this study were not always as obvious. Due to the small selection of the years of record compared in Figure 21 and the variety of outcomes seen throughout the other six locations, Figures 22, 23, and 24 were developed for further examination of seasonal trends and range of seasonal temperature variation.

Review of Figures 22, 23, and 24, reveals a notable variability between the temperature amplitudes observed during the winter months. The temperature variability in the summer months does not display the same temperature variation. To emphasize

and compare the range of variability of the summer season temperatures with the winter season temperatures, dashed lines have been used for visual interpretation of the seasonal temperature variations in Figures 22, 23, and 24. The numbers centered between dashed lines represent the range of seasonal temperature variation in degrees Celsius observed during the summer and winter months. The magnitude of temperature variability seen in each figure is accurate only for the years displayed. Temperature magnitudes for all comparisons show dramatic variability of temperatures during the winter when compared to those variations observed during the summer months. It is important to note that the temperature variability during the winter months diminishes over time causing the monthly temperatures for the most recent years to become smoother and less variable during the winter. The reduced air temperature variability over time is important when relating historical air temperatures to forecasted climate changes.

4.1.5 Freezing and Thawing Indices

In engineering design FI and TI are generally used in place of air temperatures for infrastructure design life projections. Although Figures 25, 26, and 27 are not forecasts, they compare common methods used to calculate FI and TI.

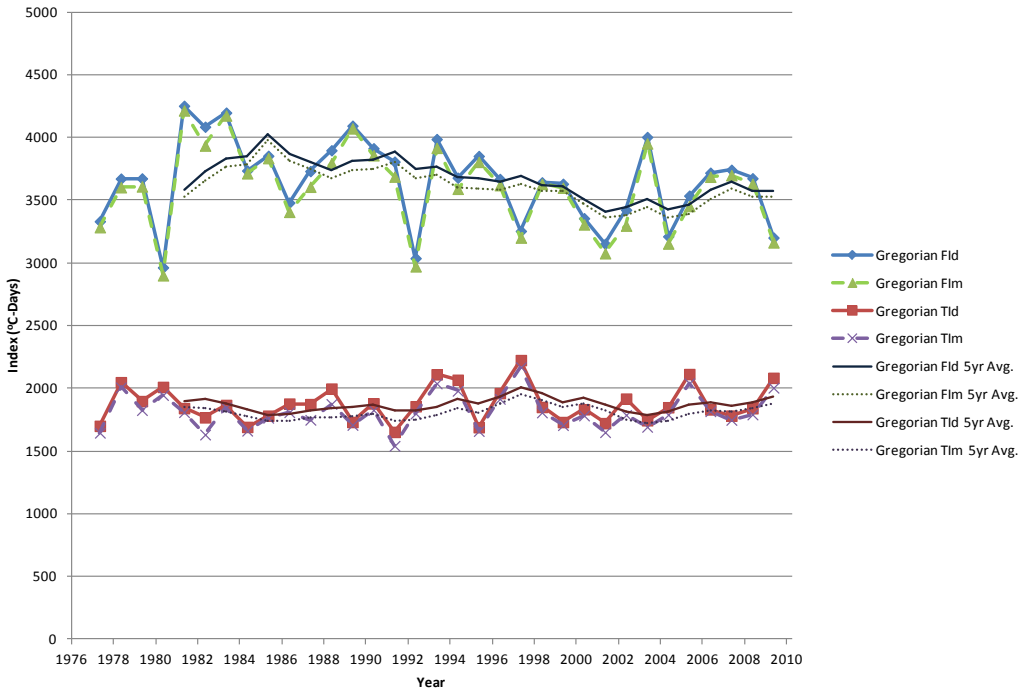

Figure 25: Freezing and Thawing Indices (^{o}C-Day) for Norman Wells, Northwest Territories Calculated based on a Gregorian Calendar (January-December) using both Daily (FI_d/TI_d) and Monthly (FI_m/TI_m) Mean Averages.

Figure 25 compares FI and TI calculated using both daily and monthly mean averaging techniques. By plotting the 5yr moving trend for both the daily and monthly FI and TI averaging techniques, the difference between the use of daily and monthly averages is illustrated. The gap seen between the average daily FI and TI and the average monthly FI and TI follows the results found in Fraunfeld et al.'s (2007) study that showed less than a 10% difference between daily and monthly averages used to calculate FI and TI in regions north of ~45^{o}N latitude.

The FI and TI time spans analyzed in Figure 25 were based on the traditional, Gregorian calendar, format where a year spans from the first day of January to the last day of December. This yearly format splits the FI from one winter into two separate years and misrepresents the FI of a given season. In Figure 26 a seasonal time span was analyzed where a given year began on the first day of September and ended on the last

day of August. Although there may still be a few lost FI and/or TI days to either side of that annual division, it produces a much more accurate interpretation of the FI and TI for one full year of seasonal change.

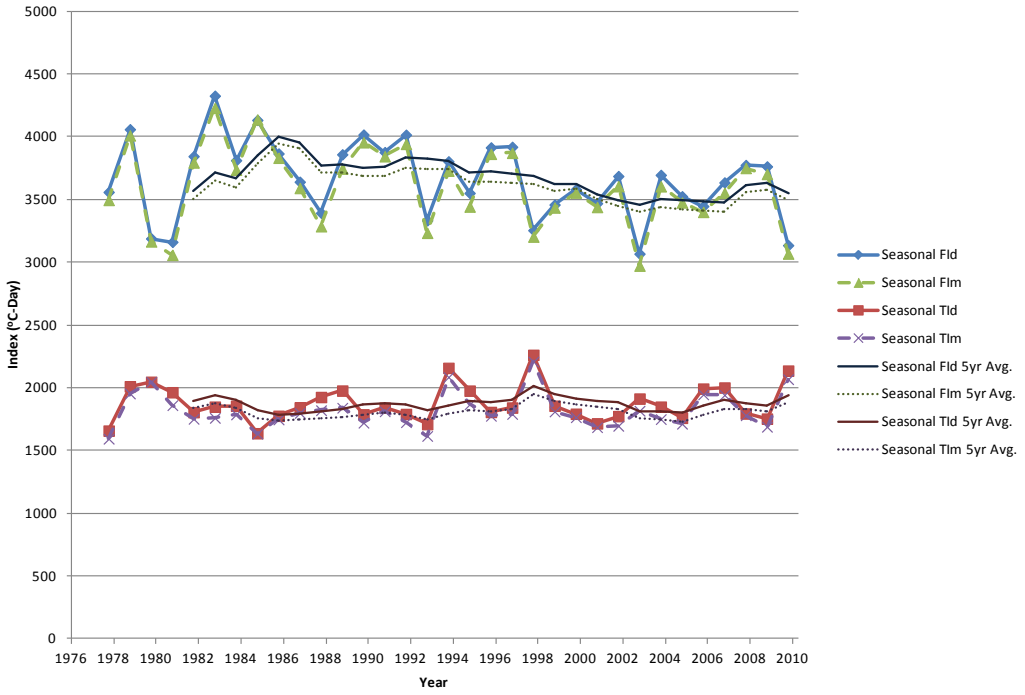

Figure 26: Freezing and Thawing Indices (°C-Day) for Norman Wells, Northwest Territories Calculated based on a Seasonal Calendar (September-August) using both Daily (FI_d/TI_d) and Monthly (FI_m/TI_m) Mean Averages.

As in Figure 25, the difference between the 5yr moving averages for daily verses monthly calculations shows the same relative separation in Figure 26. Figure 25 and 26 illustrate the differences between the use of daily and monthly averages in the calculation of FI and TI, in Figure 27 the use of a Gregorian calendar format is compared to a more seasonal calendar format. Unlike Figures 25 and 26, Figure 27 only displays FI and TI calculations based on daily averages to clarify the comparison between Gregorian and seasonal approaches. Like Figures 25 and 26 above, Figure 27 uses a moving 5yr average to compare the two approaches used in calculation. The difference between Gregorian and seasonal annual formats were not uniform, like the daily/monthly comparison, but

display greater congruency between TI and only a rough similarity between the calculated FI trends over time.

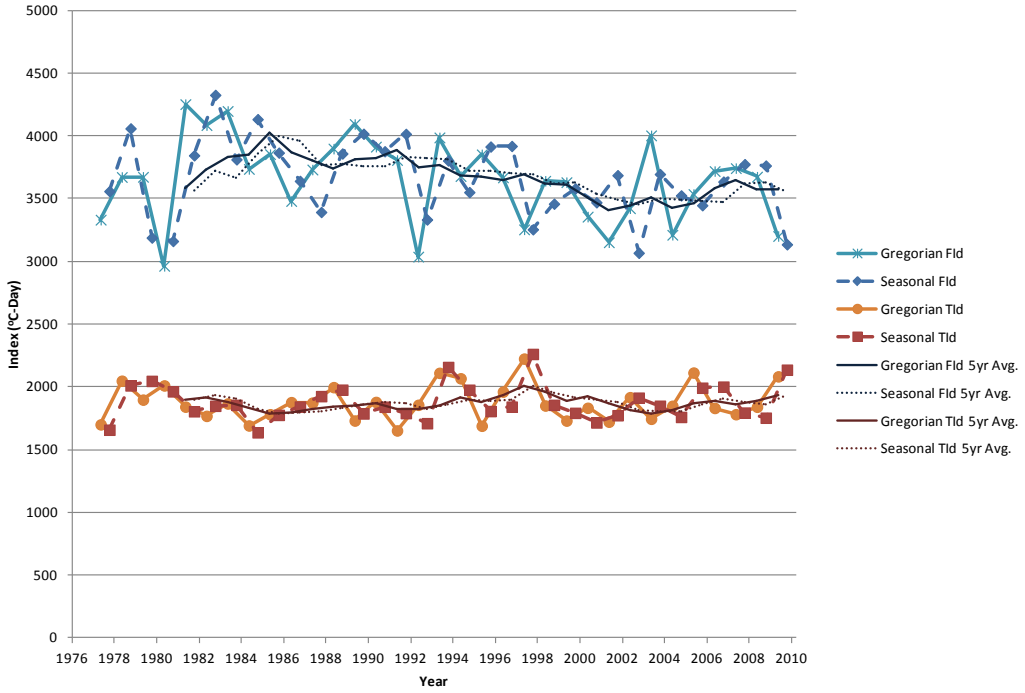

Figure 27: Gregorian (January-December) and Seasonal Calendar (September-August) Freezing and Thawing Indices (°C-Day) for Norman Wells, Northwest Territories; Calculations for Daily (FI_d/TI_d) Mean Averages.

4.1.6 Precipitation and Snow Depth

For this study, precipitation and snow depth records were examined with respect to changes seen in the climate temperature record. Since previous figures summarized information analyzed based on the hourly recorded data for a given location, the available hourly precipitation record data was also used. Due to a lack of hourly precipitation data for Norman Wells, the graph for Hay River is displayed below (Figure 28).

In relating the data for this study with previous studies, many of the same trends are apparent. Zhang and Osterkamp (1993) noted the relationship between air

temperature and snowfall, stating that snowfall is greatest during the colder periods on record and decreases during the warmest periods. The correlation between snowfall and temperatures is also apparent in the data examined in this study, although snow depth has been graphed for Figure 28 in place of snowfall. The same correlation is not as obvious when relating the precipitation to air temperature records, however, a trend of increasing precipitation during cooler periods of record is observable in some locations suggesting some similarities to the air temperature snowfall relation.

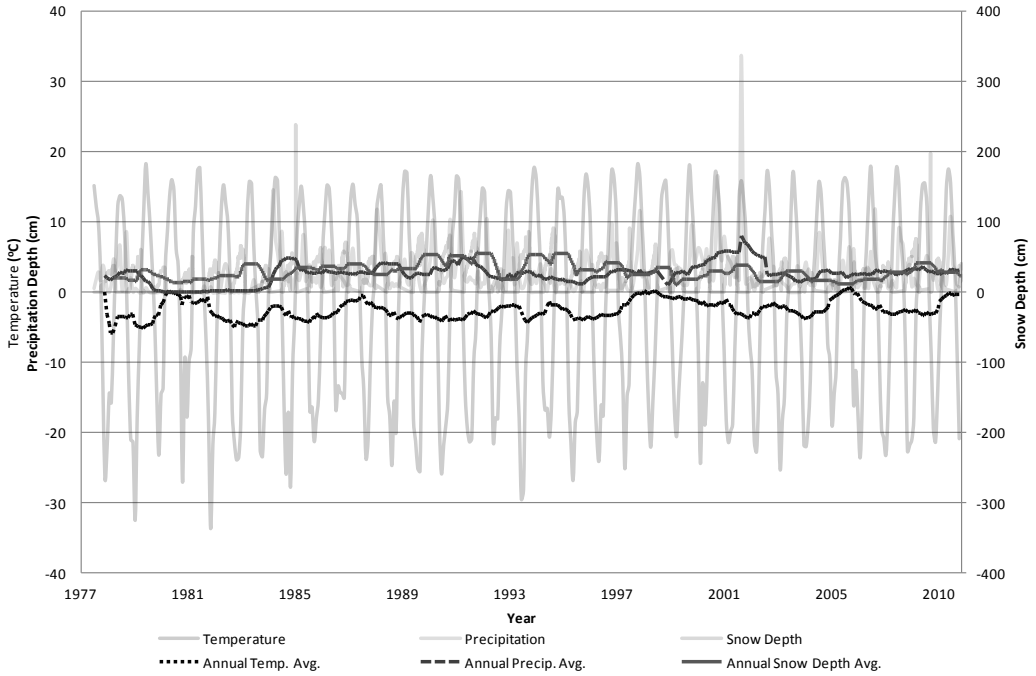

Figure 28: Hay River, Northwest Territories Snow Depth (cm) and Precipitation (cm) Records Plotted with Mean Annual Air Temperature (^{o}C) Averages over Time.

A concern with Zhang and Osterkamp's (1993) relation between snowfall and temperature is that, while it is commonly applicable, it is not always accurate. The snow depth, precipitation and air temperature records for Barrow (Figure 29) show that there is a noticeable increase in temperature around 1998, however, the snow depth and precipitation do not decrease with the same emphasis. The limited change of snow depth during periods with dramatic fluctuations in temperature proves that the correlation

between the two, while dependent, may not be direct. The trend does support the hypothesis that higher temperatures correlate to minimal snow depth despite the lag time that is apparent between the two. Morse (2010) pointed out that changes in snow cover are the primary influence on how air temperature affects the ground thermal regime; with warmer winters producing lower snow depths, the decreased insulating capability of the snow is offset by the more direct effect of the winter air temperatures. Considering both Zhang and Osterkamp's (1993) study and Morse's (2010) conclusion, the fluctuation in temperature and snow depth would appear to balance itself. Milder winter temperatures occur when the insulating influence of snow is reduced.

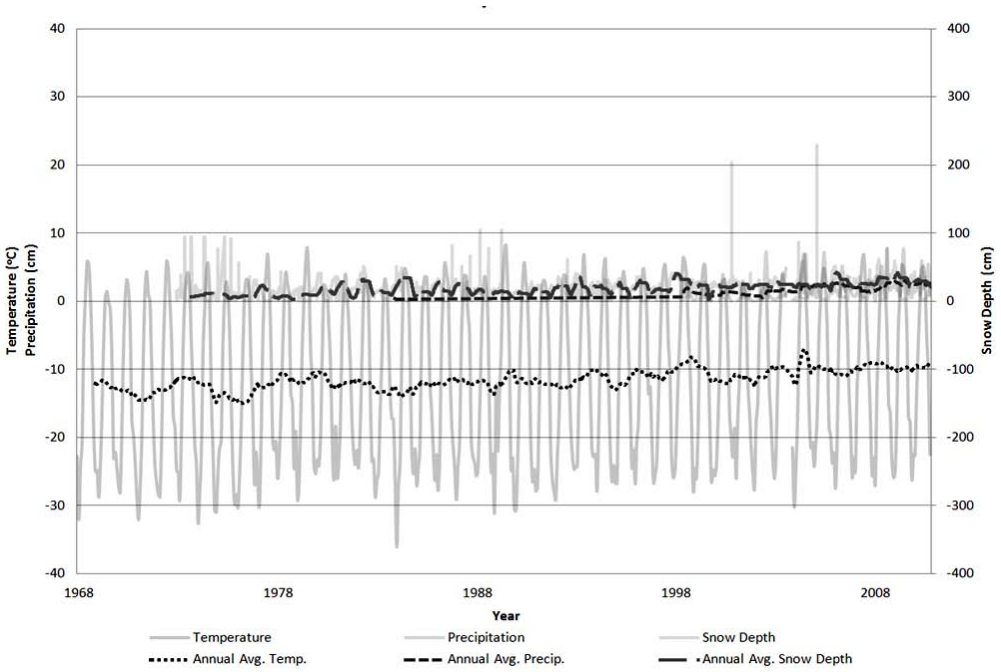

Figure 29: Barrow, Alaska Snow Depth (cm) and Precipitation (cm) Records Plotted with Mean Annual Air Temperature (^{o}C) Averages over Time.

In Figure 29, the lack of data for precipitation as well as snow depth measurements is apparent prior to the 1980s. The lack of data is primarily due to the use of hourly records in place of daily records. In future work, the use of daily precipitation

and snow depth recordings would be a more useful measure; hourly records are frequently incomplete and sporadic and thus less useful.

4.2 Comparisons of Locations

Due to the similarities between Northwestern Canada and Alaska, 6 primary locations, 3 in Canada and 3 in Alaska (Table 1), were chosen based on their relative latitudes in an effort to compare and examine the variability seen regionally.

4.2.1 Barrow and Inuvik (and Anaktuvuk)

Climatic data for Barrow, Alaska and Inuvik, Northwest Territories were compared for this study. While Barrow and Inuvik are both northern communities in their respective state/territory, they do not actually share similar latitudes. Due to the difference in latitude between Barrow and Inuvik, Anaktuvuk, Alaska was also reviewed as its latitude is more comparable to Inuvik's.

In Figures 30, 31, and 32 the range of seasonal temperature variation can be compared as well as annual temperature fluctuations. In a closer examination of the range of summer temperature variation compared with the range of variation in winter temperatures, Barrow's summer temperature range is 39% of its winter temperature range while Inuvik's summer temperature range is 51% of its winter temperature range, and Anaktuvuk's summer temperature range is 55% of its winter temperature range. Using this method of comparison, Inuvik would be more comparable to Anaktuvuk. In an examination of the overall annual amplitude, Barrow shows a 60 degree (Celsius) range in temperature while Inuvik shows a 73 degree (Celsius) range and Anaktuvuk a 62

degree (Celsius) range in temperature variation. In the comparison of annual amplitudes, Barrow and Anaktuvuk data are more similar to one another than Inuvik.

The summer and winter temperature variability is different between locations and there does not appear to be any direct correlation between seasonal amplitude and the latitude of a particular location. Although a direct correlation is not apparent, the data itself can be a useful input parameter for forecasting models. The summer and winter temperature variability can provide insight to the maximum and minimum temperatures expected historically for each season. The annual temperature variability should be monitored for greater changes in climate patterns. Since seasonal and annual temperature variability diminishes with time, the historical maximum and minimum temperatures could be used as an extreme boundary to validate future temperature projections used in design.

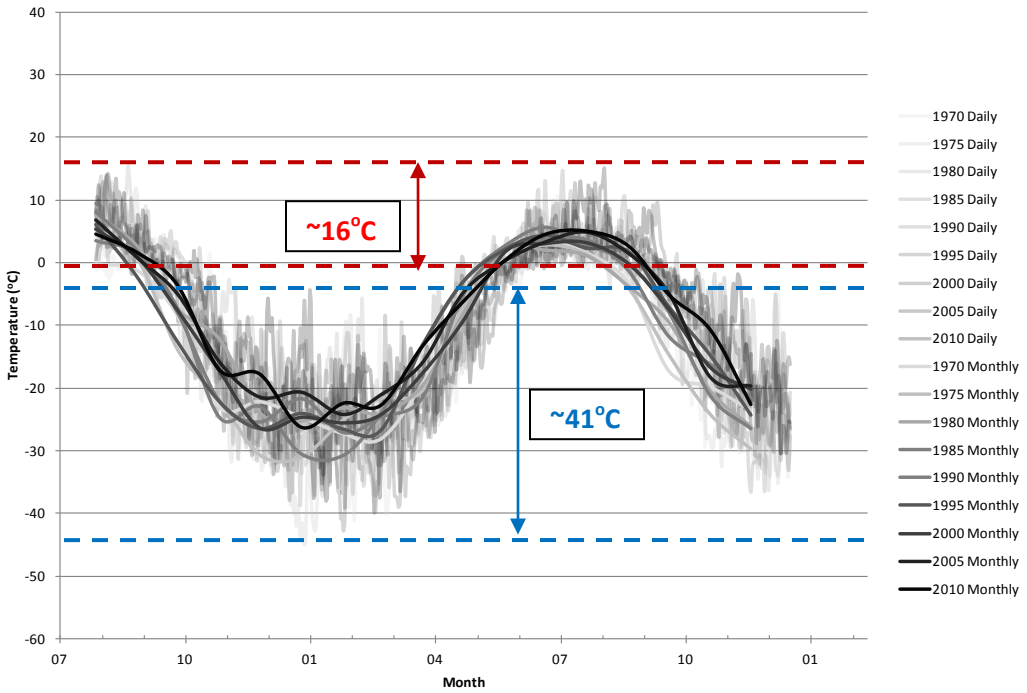

Figure 30: A Comparison of Daily and Monthly Mean Air Temperatures (°C) for Barrow, Alaska: Every 5th Year Between 1970 and 2010 are Graphed in 1.5yr Increments for Seasonal Comparison. Dashed Lines Indicate Maximum and Minimum Temperatures for each Season (Degree Differences are Labeled).

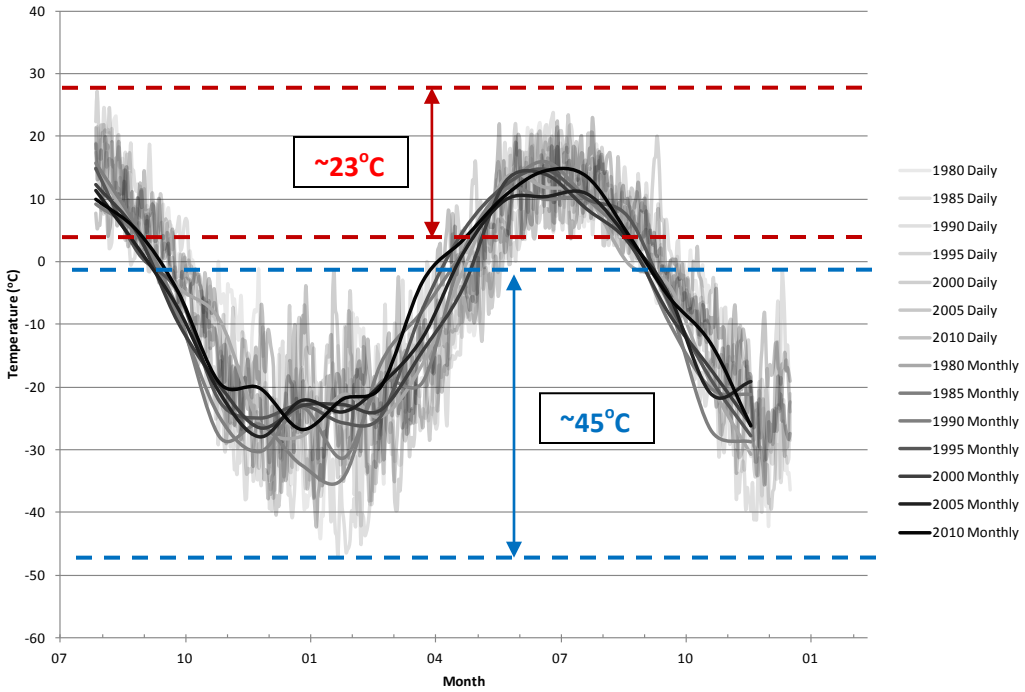

Figure 31: A Comparison of Daily and Monthly Mean Air Temperatures (°C) for Inuvik, Northwest Territories: Every 5th Year Between 1980 and 2010 are Graphed in 1.5yr Increments for Seasonal Comparison. Dashed Lines Indicate Maximum and Minimum Temperatures for each Season (Degree Differences are Labeled).

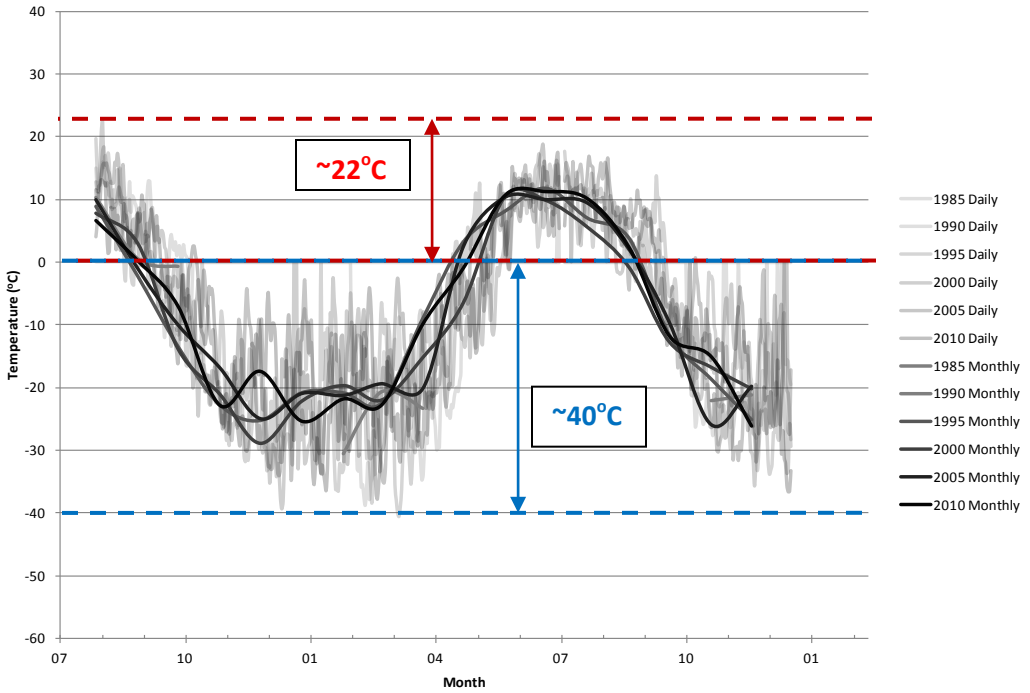

Figure 32: A Comparison of Daily and Monthly Mean Air Temperatures (°C) for Anaktuvuk, Alaska: Every 5th Year Between 1985 and 2010 are Graphed in 1.5yr Increments for Seasonal Comparison. Dashed Lines Indicate Maximum and Minimum Temperatures for each Season (Degree Differences are Labeled).

It is important to note that in each case (Figure 30, 31 and 32) the range of winter temperature variability decreases with time. The diminishing variability of winter temperatures over time is most noticeable in the monthly trends where trend lines are more distinct and can be more easily compared to one another. The winter temperatures for each location studied, trend warmer, resulting in less variable extreme freezing temperatures throughout the winter season.

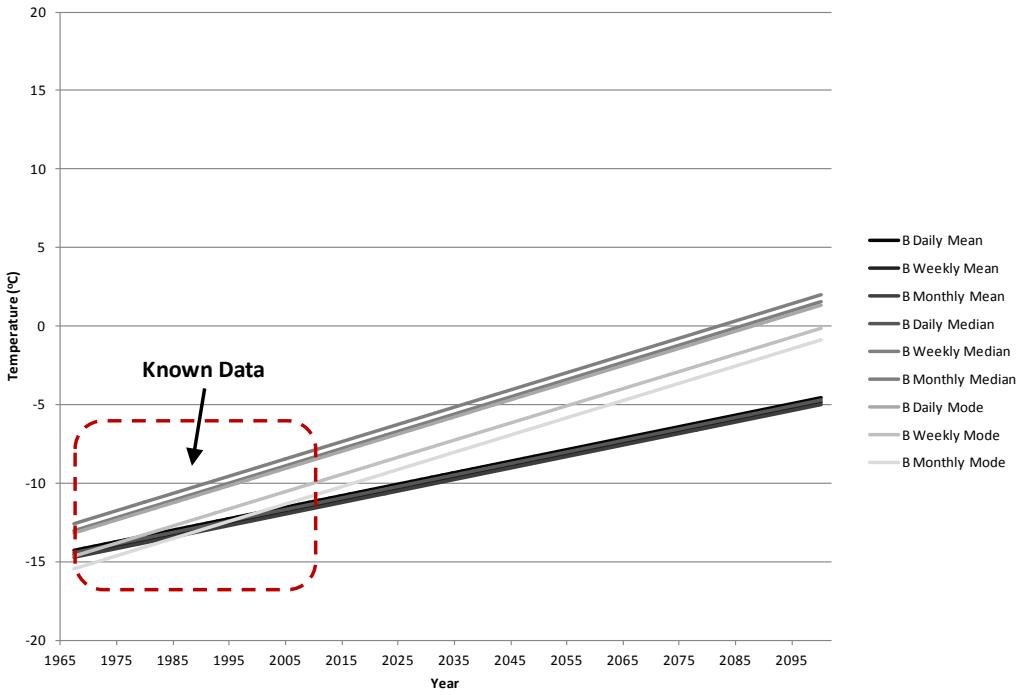

Figure 33: A Projected Linear Trend for Barrow, Alaska (B) Based on Historical Data.

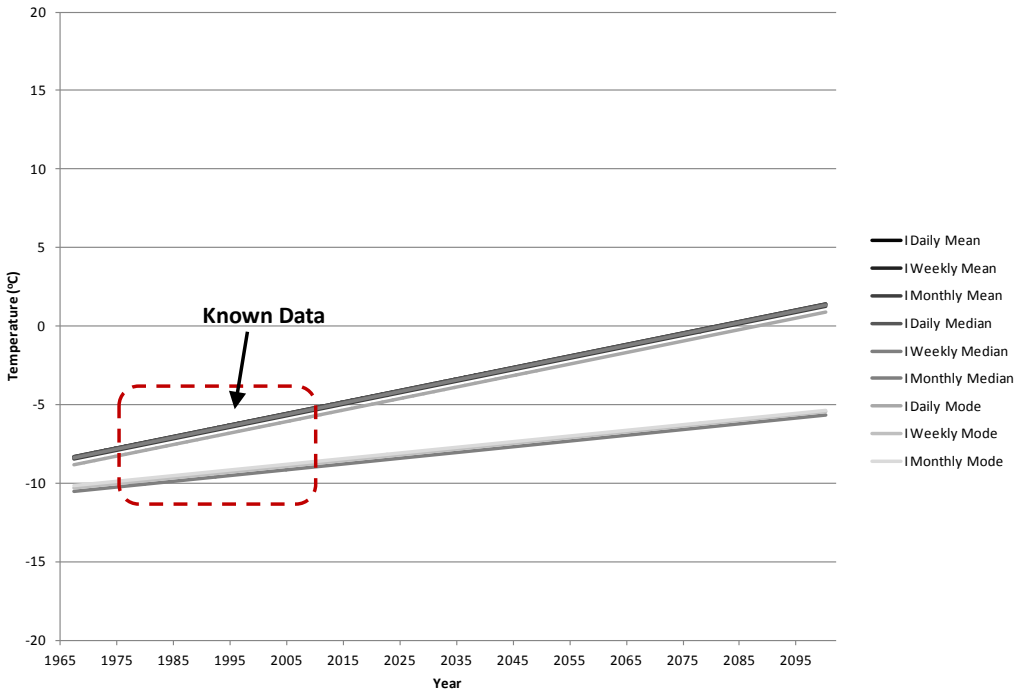

Figure 34: A Projected Linear Trend for Inuvik, Northwest Territories (I) Based on Historical Data.

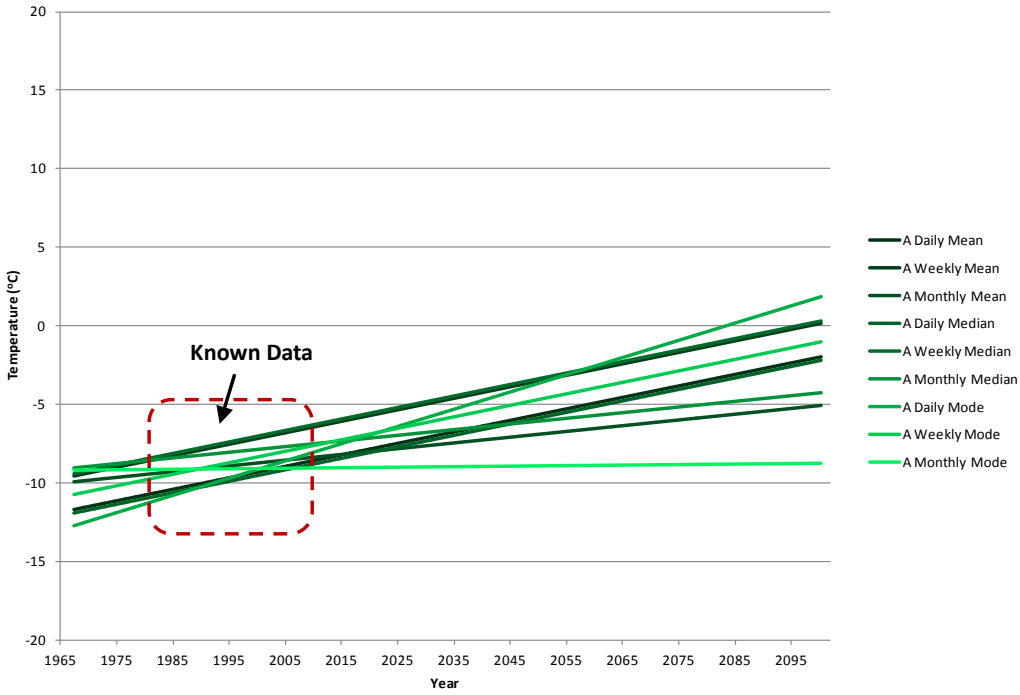

Figure 35: A Projected Linear Trend for Anaktuvuk, Alaska (A) Based on Historical Data.

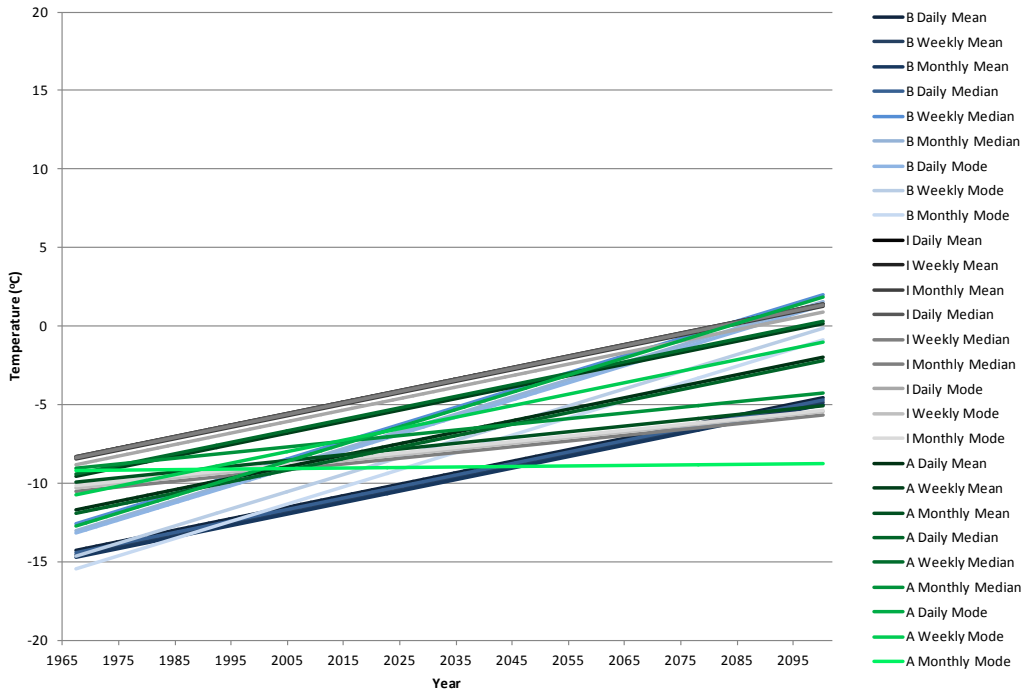

Figure 36: A Comparison of Projected Linear Trends for Barrow, Alaska (B); Inuvik, Northwest Territories (I); and Anaktuvuk, Alaska (A) Based on Historical Data.

In Figures 33 through 36, linear trend line projections of historical air temperature data are compared for Barrow, Inuvik, and Anaktuvuk data sets. As with the comparisons in air temperature variations (in Figures 30, 31, and 32), there is a consistent range in which the resulting trends occur. Despite this common range, the linear trends themselves show little to no correlation with one another. The slopes appear to be similar for some scenarios, but there are no consistent similarities.

4.2.2 Norman Wells and Fairbanks

Norman Wells, Northwest Territories and Fairbanks, Alaska climate data sets were also compared in this study. Barrow and Inuvik were used to represent more northern, continuous, permafrost zones while Norman Wells and Fairbanks act as a mid-point for the discontinuous permafrost zone in this study. Of the six primary locations

reviewed in this examination, Norman Wells and Fairbanks have the most comparable latitudes and regional characteristics.

In Figures 37 and 38, seasonal temperature variability is compared and annual temperature fluctuation is examined. The range of temperature variability in the summer months for Norman Wells is 41% of the winter range of temperature variability while the summer temperature range of variability for Fairbanks is only 35% of its winter temperature range. The difference between the summer and the winter temperature ranges of variability for Norman Wells and Fairbanks are not the same, but are within 6% of one another.

Examining the annual range in temperatures, Norman Wells and Fairbanks display the same annual range of 72 degrees (Celsius). The similarity of the annual range in temperature supports comparison between Norman Wells and Fairbanks. The same analysis done for Barrow, Inuvik, and Anaktuvuk did not produce similarly comparable numbers. Although a definitive trend is not obvious, it is important to note the similarities in climate patterns between Norman Wells and Fairbanks. More work is needed in other regions to assess the confidence in the trends produced for this examination.

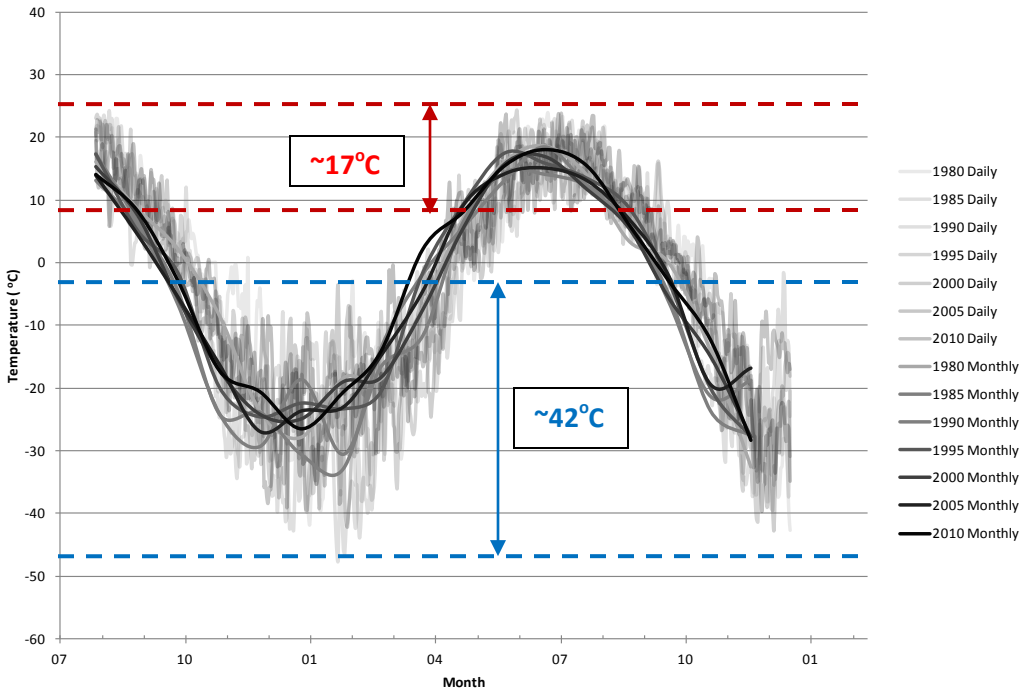

Figure 37: A Comparison of Daily and Monthly Mean Air Temperatures (^{o}C) for Norman Wells, Northwest Territories: Every 5th Year Between 1980 and 2010 are Graphed in 1.5yr Increments for Seasonal Comparison. Dashed Lines Indicate Maximum and Minimum Temperatures for each Season (Degree Differences are Labeled).

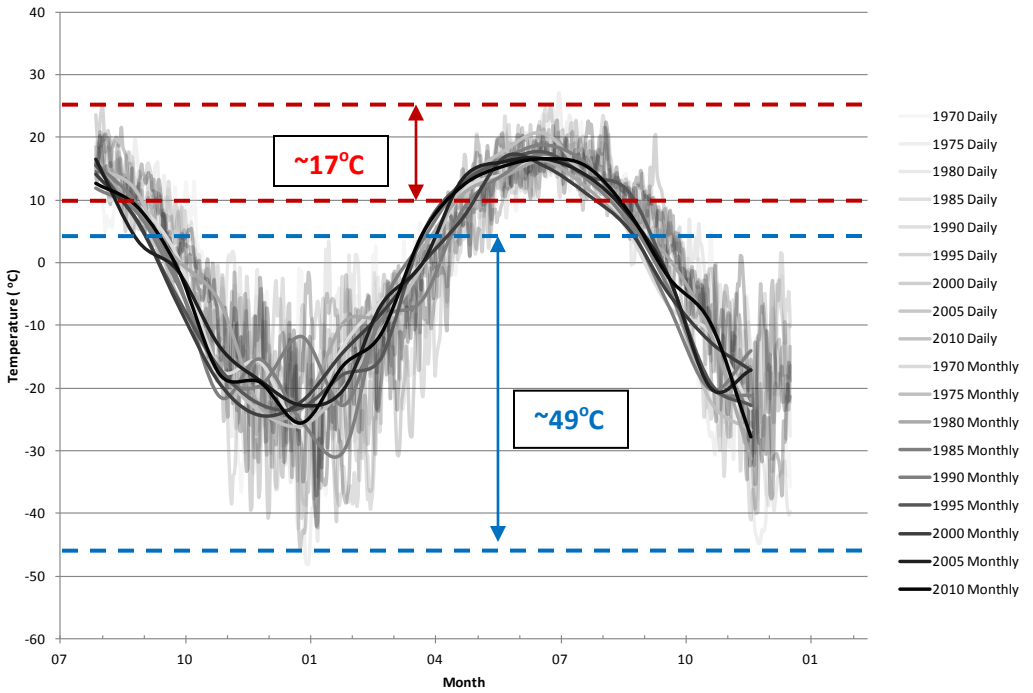

Figure 38: A Comparison of Daily and Monthly Mean Air Temperatures (°C) for Fairbanks, Alaska: Every 5th Year Between 1970 and 2010 are Graphed in 1.5yr Increments for Seasonal Comparison. Dashed Lines Indicate Maximum and Minimum Temperatures for each Season (Degree Differences are Labeled).

Figure 37 and 38 (as with Figures 30, 31, and 32) display a noticeable difference in the range of seasonal temperature variations. The range of winter temperature variability diminishes with time as they did with the previous locations studied. The diminishing variability of temperatures over time is most noticeable in the winter monthly trend lines. The diminishing amplitude of air temperatures recorded during the winter months in Norman Wells and Fairbanks is comparable to the previous locations (Barrow, Inuvik, and Anaktuvuk). The "smoothing out" of temperatures over time is a consistent trend throughout each location studied.

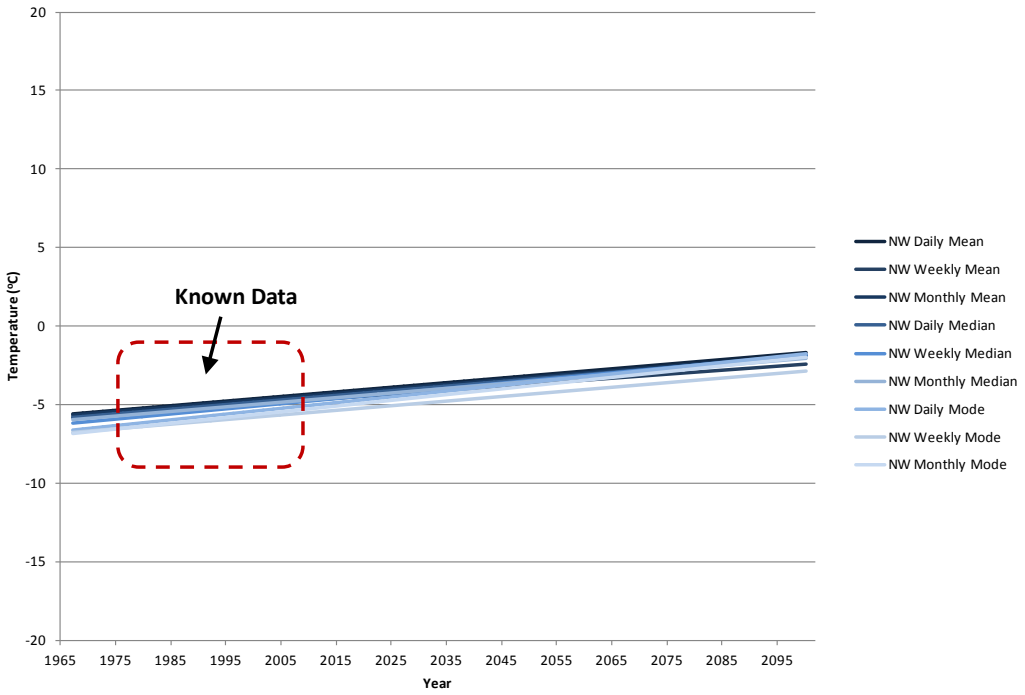

Figure 39: A Projected Linear Trend for Norman Wells, Northwest Territories (NW) Based on Historical Data.

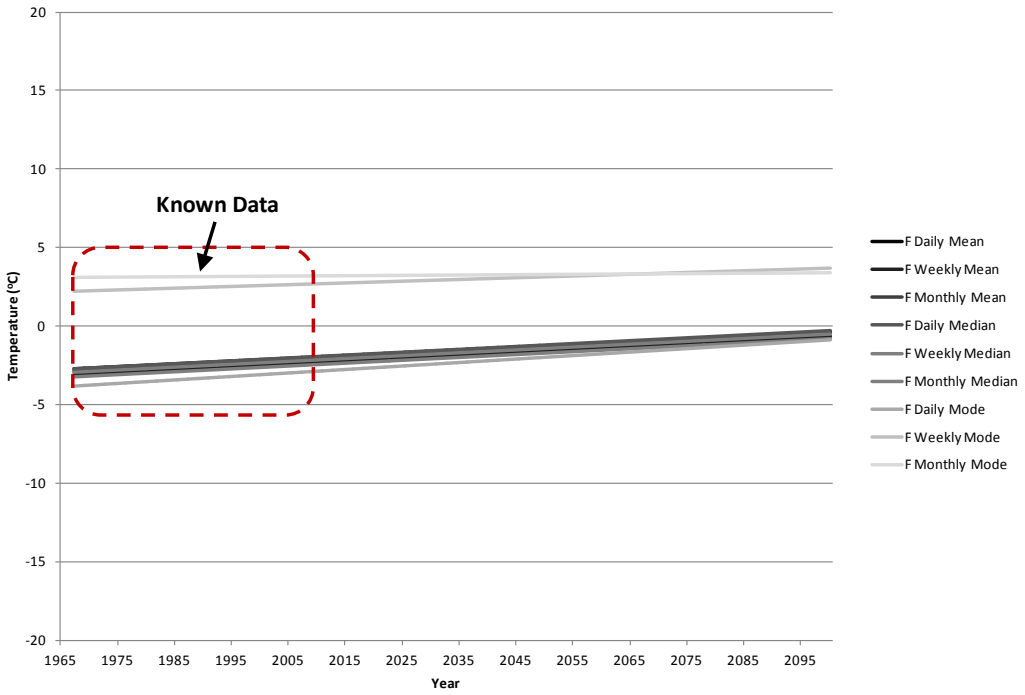

Figure 40: A Projected Linear Trend for Fairbanks, Alaska (F) Based on Historical Data.

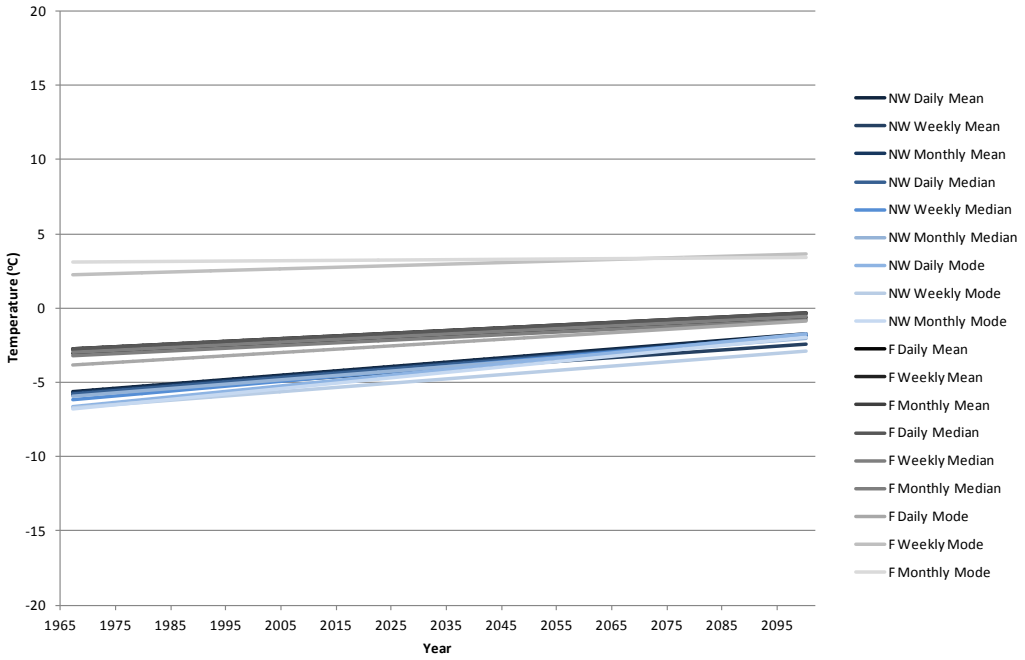

Figure 41: A Comparison of Projected Linear Trends for Norman Wells, Northwest Territories (NW) and Fairbanks, Alaska (F) Based on Historical Data.

Figure 39 through 41 display the projected linear trend lines for Norman Wells and Fairbanks. Unlike Barrow, Inuvik, and Anaktuvuk, Norman Wells and Fairbanks

show a more congruent trend. The slopes for the linear trends of each location are more similar to one another and more consistent. Despite the inaccuracies of forecasting through linear trends, it is important to note the consistencies in the data for these locations.

4.2.3 Anchorage and Hay River

Anchorage, Alaska and Hay River, Northwest Territories were the third set of compared locations and both represent a more sporadic permafrost influence. Like Barrow, Anchorage is also located near the coast of Alaska. Coastal weather patterns have similarities to the lake-effect weather patterns that would be prevalent in Hay River, NWT. Coastal weather patterns share similarities to lake-effect weather patterns, but have a more extreme effect on surrounding regions. The influence of coastal weather patterns in Anchorage, Alaska makes the comparison to landlocked Hay River, NWT more difficult. By way of landscape differences alone, Anchorage and Hay River are the least similar of the geographically compared locations in this study.

Figures 42 and 43 (below) display the seasonal temperature variability and annual temperature ranges for Anchorage and Hay River respectively. Comparing the summer to the winter temperature range of variability; Anchorage's summer temperatures are 31% of the winter temperatures and Hay River's summer temperatures are 35% of the winter temperatures. The summer to winter seasonal temperature comparison is strikingly similar between the two locations, despite their regional and geographical differences.

The similarities between Anchorage and Hay River's seasonal temperature ranges are interesting considering the differences of the geography surrounding the two locations. Anchorage lies at the inland end of Turnagain Arm (an ocean inlet) and is

therefore more protected from the direct effects of the Gulf of Alaska weather stream; Hay River, on the other hand, lies on the edge of Great Slave Lake and may therefore be more exposed to lake-effect weather patterns making the temperatures more similar to the generally more extreme coastal conditions. The unique landscape features offsets the differences between both locations and improves the quality of the comparison between Anchorage and Hay River's air temperature trends; however, it does not make the weather patterns the same.

Again using Figures 42 and 43 for reference, a comparison of annual temperature amplitudes were compared. Anchorage witnesses a 50 degree (Celsius) temperature variation while Hay River witnesses a 66 degree (Celsius) annual temperature variation. Unlike the summer to winter seasonal temperature comparison, Anchorage and Hay River do not have comparable annual thermal amplitudes. This difference is most likely due to the dissimilarities between the surrounding landscapes of the two locations.

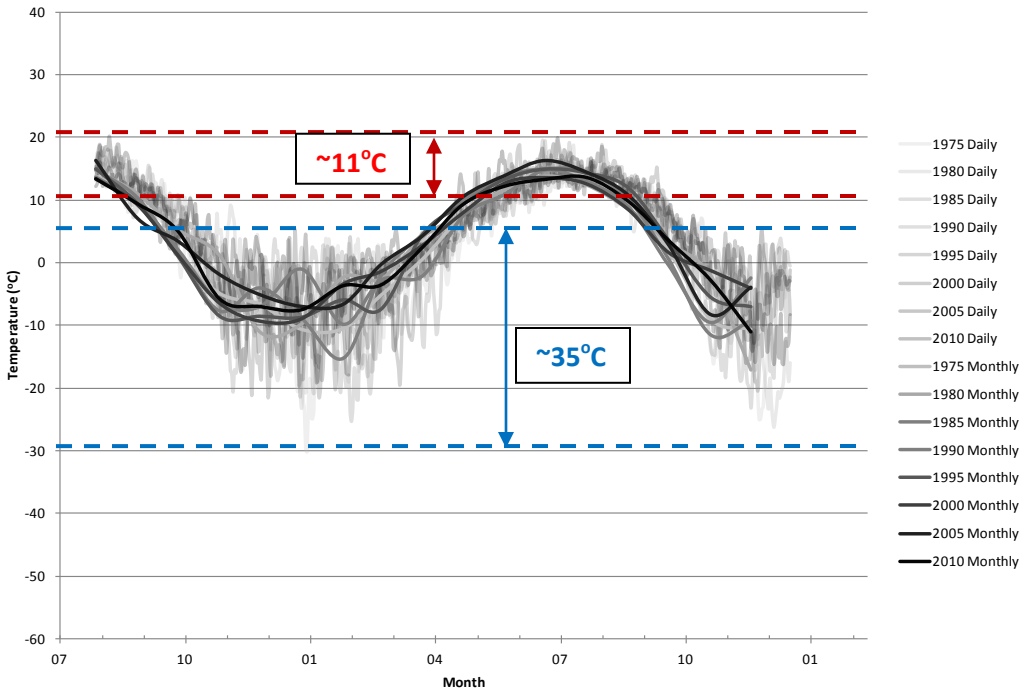

Figure 42: A Comparison of Daily and Monthly Mean Air Temperatures (°C) for Anchorage, Alaska: Every 5th Year Between 1975 and 2010 are Graphed in 1.5yr Increments for Seasonal Comparison. Dashed Lines Indicate Maximum and Minimum Temperatures for each Season (Degree Differences are Labeled).

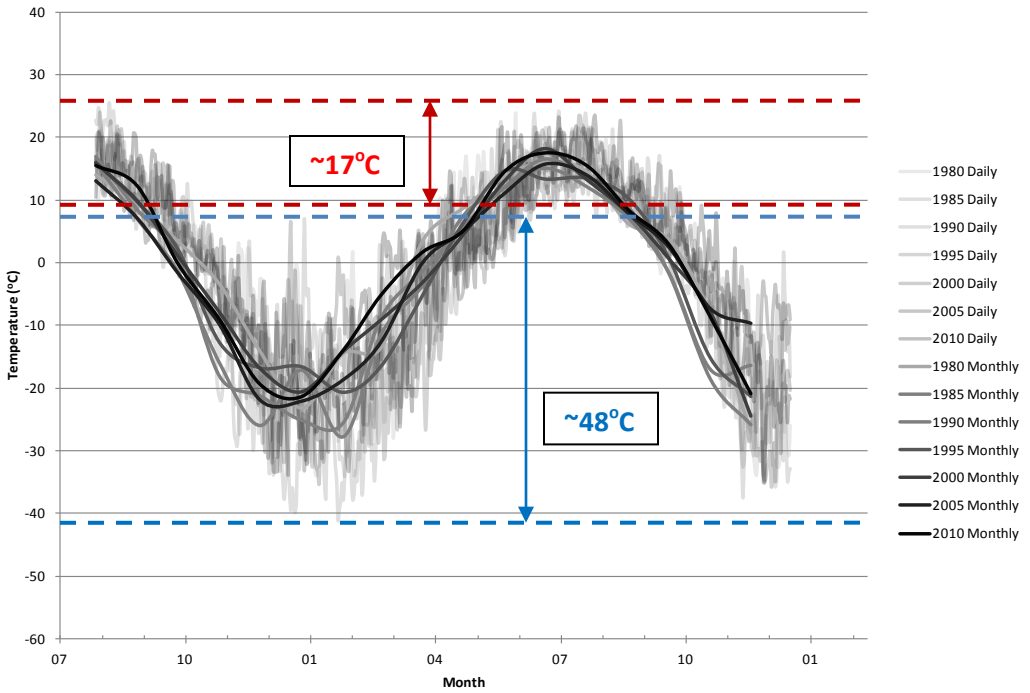

Figure 43: A Comparison of Daily and Monthly Mean Air Temperatures (°C) for Hay River, Northwest Territories: Every 5th Year Between 1980 and 2010 are Graphed in 1.5yr Increments for Seasonal Comparison. Dashed Lines Indicate Maximum and Minimum Temperatures for each Season (Degree Differences are Labeled).

Again seasonal temperatures presented in Figures 42 and 43 display a trend toward reduced temperature variability within a given season and less extreme temperature fluctuation. This visual trend is the same throughout all seven locations analyzed throughout this study. Although this trend can be observed throughout all locations, this study alone is not sufficient evidence to declare a widespread phenomenon.

A study presented by Balling et al. (1998) displayed the same trend of a warming winter in colder regions as seen in this examination. In a global analysis, Balling et al. (1998) found that in mid to high latitudes winters were warming more quickly than the summers. Michaels et al. (1998) discusses the same trend of a warming winter by discussing the reduction in temperature variability over the last 50-100yrs. The global trend is toward more “stabilized” temperatures that are more “summer-like” than “winter-like.” It is important to recognize the potential effects of these trends and the witnessed

reduction in temperature variability, occurring primarily during the winter season should be applied to other northern locations to aid in further verification of forecasted temperatures used in design.

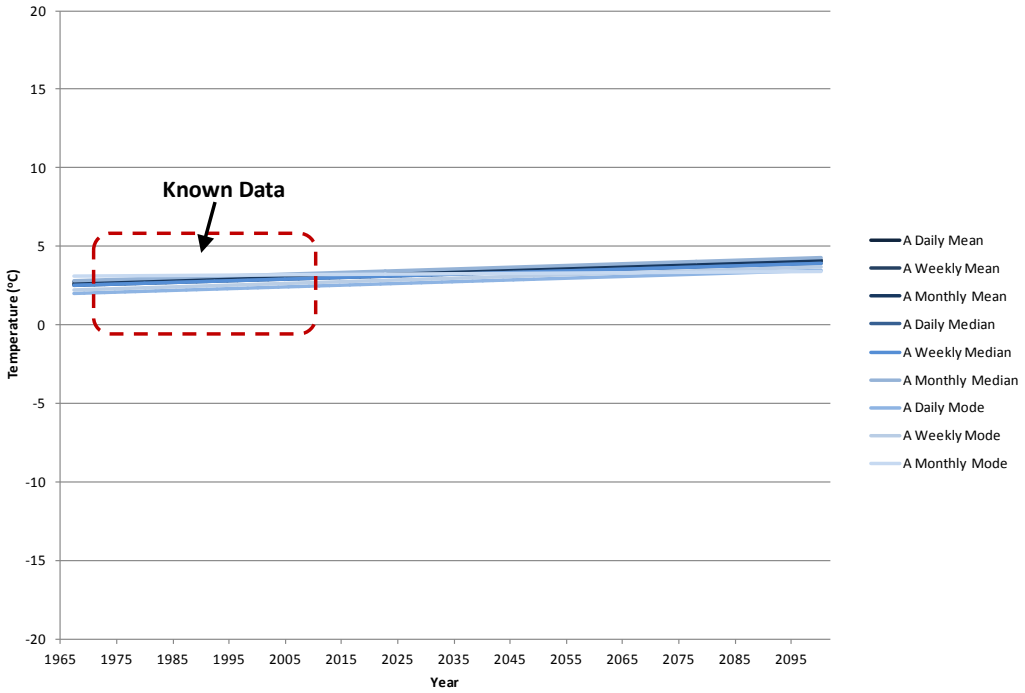

Figure 44: A Projected Linear Trend for Anchorage, Alaska (A) Based on Historical Data.

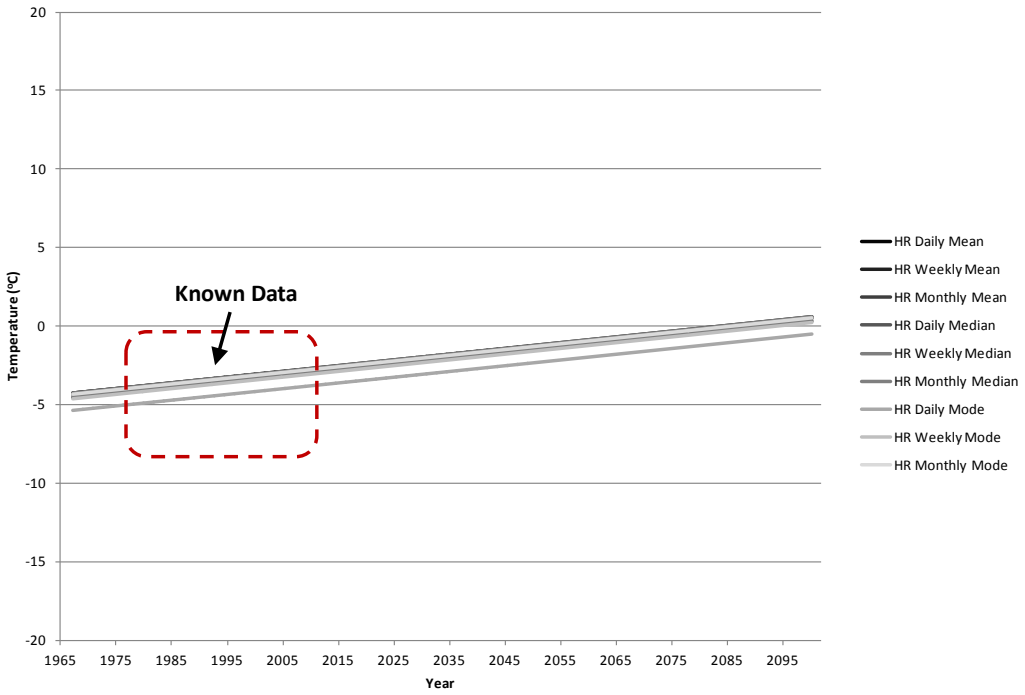

Figure 45: A Projected Linear Trend for Hay River, Northwest Territories (HR) Based on Historical Data.

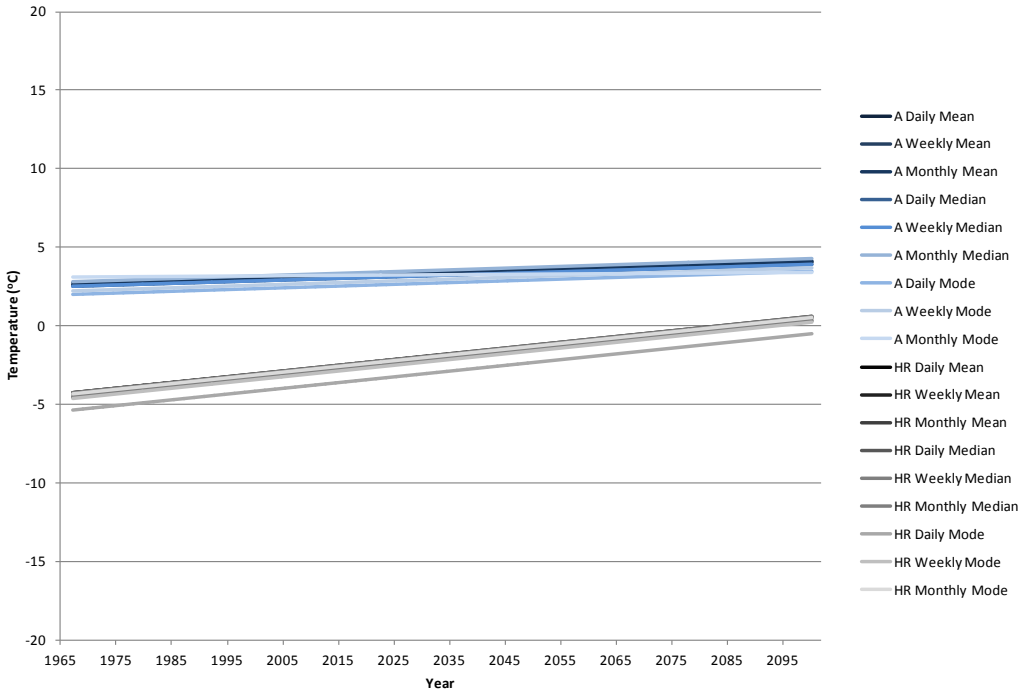

Figure 46: A Comparison of Projected Linear Trends for Anchorage, Alaska (A) and Hay River, Northwest Territories (HR) Based on Historical Data.

The linear trend forecast for Anchorage and Hay River seen in Figures 44, 45, and 46, have the greatest congruency, individually, of any of the five prior locations examined. Although the comparison between the linear trend lines for Anchorage and those of Hay River do not display similar slopes or even similar y-axis intercepts, the individual sets of lines show strong agreement among each location separately. The strong agreement among the linear trends of various calculation techniques does not signify accuracy in the forecasted line, but rather the interchangeable use of the calculations in these locations.

4.3 Other Work

Due to the obvious disparity in the summer temperature ranges and the winter temperature ranges in every location in this study, an alternative method of presenting the data was used to portray the trends of seasonal temperatures. Figure 47, below, was created using Microsoft Excel's Bubble Chart. Bubble Charts are generally used for Scatter Charts in which each point has 3 associated values (an x, y, and z, or bubble dimension value). The data points in this examination have only two associated values (a temperature and a time); the presentation of data in this manner, using a constant for the bubble size, gives the temperature data a new dimension. For this graphical interpretation, the bubble sizes were chosen to span five years in width allowing for sufficient overlap, yet maintaining some of the distinct separation in temperature fluctuation.

The summer season temperature maximums are clearly visible and noticeably distinct from the winter season temperature minimums. By giving each datum point an area and slight transparency, temperature trends of a higher frequency become darker

with each overlapping datum point. The summer season and winter season temperature extremes are clearly distinguishable in Figure 47. Unexpectedly, two distinct temperature ranges appear between the summer season and winter season in the Norman Wells data. The two temperature frequencies situated between the summer and winter regions are each a mixture of spring and fall freeze/thaw temperatures. In most cases only the summer and winter seasons are clearly defined and there are no distinguishable interim temperature trends (graphs for each studied location are available in Appendix 1-7). This method of analysis in this examination is only used to distinguish the winter and summer temperature trends. The use of the Bubble Chart graphing technique helps display the warming winter trend more visually than in previous interpretations conducted in this study.

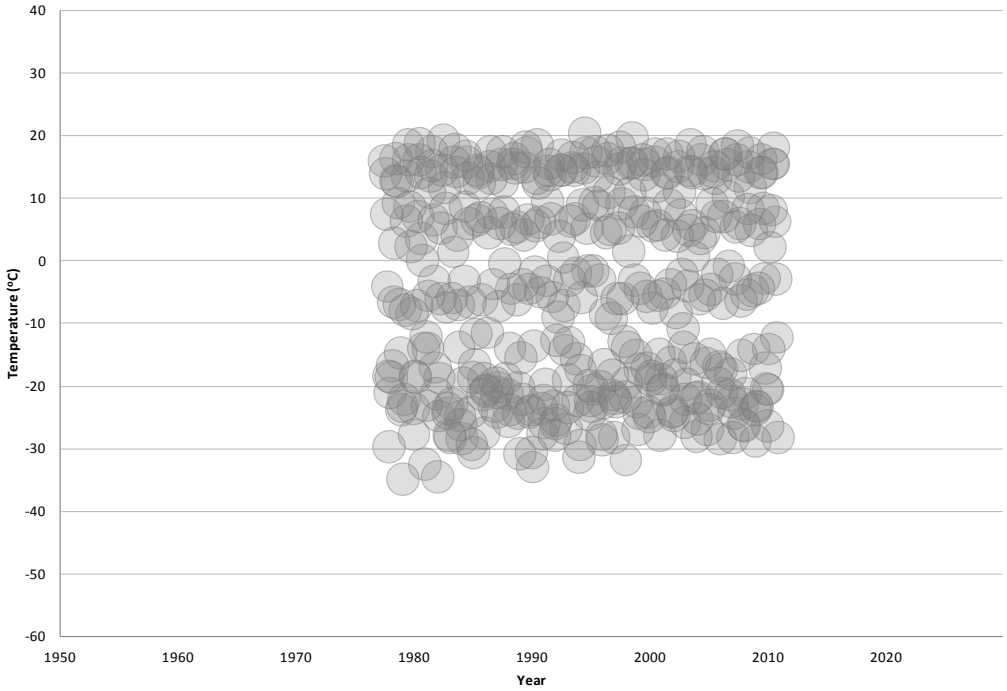

Figure 47: Monthly Mean Temperatures (^{o}C) for Norman Wells, Northwest Territories: Points Plotted with a 5yr Diameter to Reduce Noise and Emphasize Summer Season and Winter Temperature Trends.

4.4 Application of Knowledge

Although a detailed analysis of climate interpretation may not be viewed as a necessity in engineering applications, it is important to remember that the data used are often just as important as the equation relied upon during the analysis of a design. For this reason it is crucial for engineers not only to know, but also to understand which data are being used, where they are coming from, and how they have been analyzed prior to their use during design.

4.4.1 Freezing and Thawing Indices

Freezing and thawing indices are frequently referred to, in engineering design, as a method of interpreting and incorporating changes in temperature. In a recent study presented by Hanson et al. (2010), it was noted that many engineering designs do not

specify the unit of time (monthly or daily) used in calculating the FI and TI even though the selected unit of time results in differing indices for a given location. The impact of a selected unit of time was analyzed in this study and is displayed in Figures 7, 8, 9, and 10 for air temperature analysis and in Figures 25, 26, and 27 for FI and TI analysis. It is clear that the unit of time used affects the graphical amplitudes for air temperature and the overall magnitude of the FI and TI and should therefore be clarified in design relying on these variables.

The comparison graphs (as in Figure 22) in this study provide an interesting look into the cycle of freezing and thawing over the last 40 years for the seven locations examined. In the comparison graphs the summer and winter seasons can be examined in full due to the time period of a year and a half used for the graphs. Many graphs limit the seasonal timeline to one single year and are frequently formatted for the Gregorian calendar format, as seen in Figure 20 developed by Osterkamp (2007). By lengthening the graphical time span, both seasons can be seen in their entirety allowing for full seasonal analyses to be conducted. In Figure 27 the effect of the Gregorian calendar on FI and TI is shown and compared to a seasonal calendar (September 1st-August 31st) approach.

In 2008 Brewer and Jin noted that the surficial thawing of permafrost was primarily determined by the summer TI. It is important to note that the comparison graphs in this study show significantly less variation in summer temperature fluctuation than in the winter. In 2010, Hanson et al. determined that the air and surface FI varied more so than the TI. Hanson's (2010) work validates the appearance of the comparison graphs, with greater temperature variability in the winter. Brewer and Jin's (2008) study focused on the impact of changing TI and Hanson et al.'s (2010) recognition of greater

variability in FI as opposed to TI in nature; it stands to reason that with limited regular variability in summer season temperatures, changes in the TI would have a greater impact on permafrost thaw than changes in the FI. There should be concern for the future impact of reduced winter temperature variability; a more "summer-like" winter with "stabilized" temperatures (Michaels et al. 1998) may cause the sensitivity of the FI in engineering design to increase over time. The potential increase in the sensitivity of the FI would affect a large portion of cold regions engineering design.

Brewer and Jin's (2008) analysis of permafrost warming concluded that while warming of permafrost has been seen over the last half century, the thawing of permafrost has not occurred. Unlike the work done by Brewer and Jin, this study only examines the last 40 years, but it is clear that the temperature shifts over that time have been primarily isolated to the winter season. Without noticeable summer season temperature shifts, Brewer and Jin (2008) and Hanson et al. (2010) would agree that the air temperature impact on permafrost during this time would remain minimal since their assertion is that summer season temperatures have the greatest impact on permafrost thaw.

Although previous FI have had a limited impact on the permafrost warming and thawing conditions, the warming trend of winter temperatures may eventually manifest itself through greater thaw. Throop et al. (2010) credits the increasing ground temperature to increasing winter temperatures directly. Where snow cover was minimal, winter temperatures were more influential (Throop et al. 2010). Surface characteristics, like snow cover, are not incorporated into FI, but are critical in evaluating other thermal design parameters, such as the n-factors. Surface characteristics may therefore become more critical in design as winter temperatures warm.

4.4.2 N-Factors

N-factors are frequently referenced in engineering design and planning. While FI and TI are primarily affected by air temperature changes, the n-factor was created to interpret a variety of surface factors influencing the direct correlation of air temperature to ground surface temperatures. N-factors are used as a method of connection between air temperature changes and ground temperature changes, but the sensitivity of a given model using n-factors relies heavily on the thawing n-factor parameters as compared to the freezing n-factor parameters. The n-factor's sensitivity to thawing parameters is concurrent with the heightened impact of a variable TI.

With n-factors, air temperature is not the only element that can impact the calculated value. Natural elements such as snowfall, vegetation, and rainfall will directly impact the n-factor while manmade components like buildings and roadways will influence the impact that natural elements will have on a specific area. In engineering design it is important not only to account for preexisting conditions at a site, but also to account for the effect that the design itself will have on future conditions.

4.5 Effect on Engineering Design

Changes in climate can affect design variables dependent on air temperature (FI, TI, n-factor), but changes in climate conditions can effect a design directly and would require design life analysis to be reevaluated. Frequently models are used to forecast and predict design issues and concerns; each model relies on the accuracy of the input parameters, like FI and TI and n-factors.

This study emphasizes the temperature variability during the winter season as compared to the consistency in temperatures throughout the summer season. Variability in summer temperatures would therefore be more unusual and would cause greater disturbances in the known ground thermal regimes. Long and Yarmak Jr. (2008) pointed out that changes in summer temperatures affect foundation temperatures more so than similar changes in winter temperature. Long and Yarmak Jr.'s (2008) findings emphasize the natural differences in seasonal temperature variability.

Temperature forecasts and engineering design models are often hard to calibrate due to the variability in seasonal extreme temperatures. Although computer generated models are relatively quick and easy to produce, computer modeling cannot be substituted for field investigations (Burn 1998). The accuracy of any model is dependent on the quality of the data used in its development (Storch and Zwiers 1999); because climate data are only relatively predictable, it is fair to say that a model developed using climate data would only be relatively accurate at best. In a study presented by Walsh (2008) comparing multiple climate models and climate scenarios, both models and climate scenario agreement outcomes began to noticeably diverge around 2070. This divergence is greater across predictive scenarios than it is across the climate modeling in the study (Walsh 2008), however, the rapid divergence in data shows uncertainty in long term climate simulation.

Since design models rely on the accuracy of the climate data provided, engineers cannot yet use modeling practices as the sole source of information used in design. It is important to continue looking at predictive analysis in design as a second opinion, but site investigation and historical analysis must still be carried out to understand local climate characteristics. Widespread trends in decreasing winter temperature amplitude

compared to summer temperature amplitude should be examined, with respect to engineering design, in order to understand and scale the affects this trend will have on construction and design life.

4.5.1 Foundation Concerns

Air Convection Embankments (ACEs)

Many cold regions engineering designs take current MAAT into account during the design phase, but changes in air temperature characteristics over time could change the expected effect of the design's properties and lifespan. ACEs rely on the cooler winter temperatures to settle into the embankment via convection to cool the foundation (Goering 1998). With a reduction of cold temperature variability and the trend toward warmer, more "summer-like," winter climate conditions (Michaels et al. 1998) the natural convective cooling of ACEs may become less effective in a warmer winter climate.

Slope Stability

The trend toward "summer-like" conditions may lead toward increased advective thaw in bedrock slopes (Gruber and Haeberli 2007). The flow of melt water during spring thaw and inter-season thaw cycles will increase thaw rates at the permafrost's surface (Gruber and Haeberli 2007) and will increase the porewater pressures within permafrost at any depth after soil thaw (Harris et al. 1995). In bedrock slopes, higher temperatures can cause rapid failures (Gruber and Haeberli 2007); in soil slopes solifluction occurs over time during periods of heightened porewater pressures, generally a few days following soil thaw (Harris et al. 1995).

Pile Foundations (Adfreeze Bond Strength)

In building foundations built on grade, conduction is the main form of heat transfer between the building and the subsurface permafrost regime. With pile foundations conductive heat transfer is minimalized, but foundation soil strength is more critical to the supporting piles. The reduced temperature variability during the winter season and trending higher temperatures will warm ground conditions at depth (Harris et al. 1995) increasing the unfrozen water content of the permafrost (Biggar and Sego 1992, Hivon and Sego 1995). Increases in air temperature and saline content of soils both cause increasing unfrozen water contents which in turn causes a decrease in the overall strength of the soil (Hivon and Sego 1995). Pile deformations occur in direct relation to temperature and salinity increases; increases in either will weaken the adfreeze bond strength of a pile in permafrost (Biggar and Sego 1992, Biggar and Sego 1993). In designs that rely on adfreeze bonds, a more "summer-like" climate condition will destabilize the design at a more rapid rate than may have been assumed during implementation.

In northern regions affected by permafrost, further research needs to be conducted to assess the implications of a more "summer-like" climate on the design life expectations of cold regions infrastructure. Foundations and landscapes will be affected by a shifting climate, but the degree of change expected is still unknown.

5. Conclusions

5.1 Summary

5.1.1 Central Tendencies

From this study it is clear that methods and procedures used in data analysis can have a significant effect on the results produced. Although it is assumed that most climate data are analyzed using the same methods and procedures, it is not often specified within a given publication. Climate data and trends used in engineering design are usually general summaries, and therefore may not accurately reflect the climate at a specific design location. By examining climate variables through the variety of analytical methods available, a range of accurate values and trends can be determined for comparison. Despite the popularity and frequency of use, the mean was compared against the median and mode for examination purposes. Likewise, the unit of time was examined and daily, weekly, monthly, and annual central tendencies were compared. Once the methods of calculation were compared, linear trends and annual time periods were compared to review consistency within the data approaches used.

The difference between central tendencies calculated using the mean, median, and mode show only slight variation. Of the three methods used in this study, the mode produces a central tendency with the greatest variation between the maximum temperatures and minimum temperatures. The median and mean are much more similar graphically than the mode. Although each method produced similar results, it is important to note the data emphasized were different when using each method. The mean takes into consideration all outliers, but does not place emphasis on the frequency of temperatures

occurring in the records. The median ignores outlying temperature data and focuses solely on the middle number in the set of data which may not properly value all temperatures seen throughout a given time frame. The mode places emphasis on datum frequency, for temperatures this would mean ignoring outliers and giving emphasis to the most common temperature during a given time frame. For the purpose of engineering design it would be most helpful to analyze the mean and mode, which in this case are also the most different.

5.1.2 Unit of Time Analyzed

Analyzing data through a variety of time units produced more variable results than the calculation of different central tendencies. The amplitude of the resulting temperatures is reduced as the unit of time evaluated gets longer (i.e. daily calculations have a greater amplitude over time than annual calculations). Annual analysis produces the least accuracy in data investigation as seasonal temperature details are not accounted for. Daily data for analysis tend to be difficult to obtain and may therefore be harder to rely on for comparisons. Because weekly analyses are less common, a monthly analysis is recommended for use in evaluating long term trends in engineering analysis and daily analysis is only suggested for comparison of accuracy within the dataset.

5.1.3 Linear Temperature Trends

Linear trends were examined to compare the similarity between calculation methods for each location. Linear trend lines do not account for the seasonal fluctuation in temperatures and therefore provide a highly simplistic analysis of the potential temperature changes. As such, linear trends should not be used for definitive prediction and, like most models, cannot be relied on more than 50 years into the future at best.

Despite the general trust in models forecasting for a half century, it is recommended that no model forecast be used and trusted for a longer period into the future than the time period of historical data that the model is based on. In this study, linear trends were used primarily to distinguish sites that showed high consistency between different central tendencies over the time intervals used in the analysis and not for forecasting purposes. From the linear trend lines, it appears as though the central tendency calculation and unit of time considered are less important at lower latitudes than at higher latitude regions. This essentially means that in areas that are most affected by permafrost, models will be less likely to accurately forecast climate changes; it is more critical in these permafrost locations to understand and note the calculation approaches used in design and the impact of the temperature changes.

5.1.4 Comparison Graphs (1.5 yr Graphical Comparison)

To examine seasonal temperature trends more closely, regular intervals of temperature records were overlain for critical comparison of seasonal temperature trends. By comparing a year and a half during each time interval, a full perspective of both the winter and summer season could be viewed and compared. There are considerable differences in the summer temperature amplitudes and the winter temperature amplitudes. Winter temperatures for all locations in this study are 30-50% more variable than those in the summer season which correlates to results presented by Balling et al. (1998) and Michaels et al. (1998).

Other research has shown that variability in summer temperatures affects ground temperatures much more than a change in winter temperatures (Brewer and Jin 2008). The impact of the natural variability of winter air temperature variability depends on

snowfall as it acts as a natural insulating cover for the ground beneath. The noticeable reduction in winter temperature variability is important to recognize and account for in future cold regions engineering design.

5.1.5 Freezing and Thawing Indices

To better illustrate the changes in winter temperatures as compared to summer temperatures, FI and TI were graphed. As with the comparison graphs, there is a much greater annual fluctuation in the winter or FI than can be seen in the summer or TI graphs. The FI, like the winter air temperature analysis, shows a steady decline over time or warming trend. The FI and TI graphs were also used to compare daily and monthly averages used in calculation as well as the annual format used for calculation (Gregorian versus seasonal years).

FI and TI based on daily averages were consistently larger than those based on monthly averages which reinforce the results found in a study by Frauenfeld et al. (2007). In Frauenfeld et al.'s (2007) study it was found that the difference between FI and TI based on daily and monthly averages were less than 10% different for locations north of latitude ~45^{o}N, which applies to Norman Wells, Northwest Territories. As for the annual approach used, more work should be done to quantify the results. FI and TI calculated based on the Gregorian calendar split the winter FI for one seasonal winter into two parts where as a seasonal calendar ideally accounts for both the full winter and summer seasons for one year. Graphically the FI and TI for both annual approaches follow the same long term trend. The TI for each approach is nearly identical, but the FI shows greater variation between individual years examined. If a design relies heavily on a FI for a particular year then a seasonal annual approach would be critical.

5.1.6 Precipitation and Snow Depth

Most data records for precipitation and snow depth (or snowfall) are sporadic at best prior to the 1980s; because of this, data for the locations in this study were incomplete. The data presented showed agreement with Zhang and Osterkamp's (1993) generalization that snowfall was greater during colder months during the winter season. Despite the intermittent periods of record, basic trends can still be observed when comparing the snow depth records to the temperature trends. Precipitation records do not display the same distinct trend that snow depth records show in this examination. For this study hourly precipitation records were reviewed, however, hourly records were even more sporadic than daily precipitation records. To make use of the daily precipitation records further analyses would be required.

5.1.7 Impacts on Engineering Design

Although air temperatures do not dictate engineering design, they have an indirect influence on ground temperature changes and can therefore affect engineering design in permafrost regions. The warming winter trend has the potential to reduce the effectiveness of ACEs, cause future slope instability, increase the unfrozen water contents in permafrost at depth, and reduce the adfreeze bond in pile foundations. These infrastructure concerns are just a few of the difficulties that may face arctic design due to a more "summer-like" climate shift.

5.1.8 Concluding Points

- Methods used to calculate engineering design temperatures and other climate variables used in design should be specified and/or clarified within the design so that the work can be reassessed in the future if needed.
- The mean should continue to be used as the primary method for calculating the central tendency of temperature and climate based work as it is the most common method used and provides an adequate representation of thermal changes.
- The mode should be considered in climate change studies focused on ground temperature changes as the most frequent air temperature value will impact ground temperature more so than a temporary single spike or dip in the air temperature.
- Daily temperatures should be used whenever possible; the use of monthly temperatures reduces the accuracy of the resulting data, but would be acceptable whenever daily data is not available (e.g., in long term data studies where daily records are infrequent and full of data gaps).
- Linear trend lines are not an acceptable format for climate forecasting, but can be used to determine the similarity among methods of calculation and locations being studied.
- Comparison graphs should be used more frequently in arctic engineering design to relate the effects of seasonal climate disparities over time to changes seen in engineering projects.
- As shown by the comparison graphs, winter temperatures are 30-50% more variable than summer temperatures.

- Analysis of the comparison graphs show that most climate change has occurred throughout the winter months. Winter air temperature variability has decreased over time and winters have become warmer on average.
- Changes in MAAT seem to be primarily influenced by warming winter temperatures. Annual analysis omits seasonal influences which can have a greater impact on engineering design than an annual trend.
- Graphical analysis of FI and TI show warming FI while the TI is remaining steady.
- FI and TI based on daily averages are consistently larger than those based on monthly averages.
- FI and TI calculated using a Gregorian versus a seasonal calendar format show that the TI results remain the same; the FI, while showing similar trending over time, has a much different variability between individual years.
- Work needs to be done to further examine the effects of a warming winter on engineering design.
- Snowfall and precipitation data trends show some correlation to temperature trends over time, but further research is needed to correlate the changes to permafrost engineering design.

5.2 Recommendations

This study points out some of the arithmetic differences that occur through different analytical approaches of climatic variables. Based on the range of outcomes produced for this examination, it clear that any analysis done using climate data should specify the methods used throughout the data analysis. Although engineering design does not currently require the specification of approaches used to determine temperature

variables in design, it may be critical for future reference when and if a site requires restoration.

Based on the success of the comparison graphs in this study it may be useful to examine the summer temperature variability as compared to the historical winter temperature variability as a tool for analysis in rural cold climate regions. The amplitude seen for both the summer and winter temperatures in this examination weakened over time for all 7 locations in this study. Weakening thermal amplitude within the winter season suggests that the maximum and minimum temperatures seen historically would likely remain the high and low extremes for future climate trends. The warming winter temperature variability will undoubtedly affect the successes of air convection embankments, may influence the occurrence of slope stability issues in cold regions, and will affect the reliability of adfreeze bonding in pile foundations. The comparison would provide a visual interpretation of the air temperature trends in a given design region and could be used to determine the expected annual air temperature fluctuation that will affect a given design. Comparison graphs should be used in place of linear trends (given the uncertainty of linear forecasting methods) and can provide information on seasonal air temperature trends.

Although the graphical trends for snow depth and precipitation are not as thorough in this examination, research suggests the importance of those records in determining a building's design life. Fluctuation in snow depth or precipitation alone can strongly influence the ground's thermal regime and should be considered and examined whenever a climactic forecast is required.

5.2.1 Future Work

Time constraints and limited resources restricted the scope of this examination. In future work a separation of summer and winter data points for air temperatures would allow for individual graphical analysis of each season. With the noticeable difference in summer and winter temperature fluctuation, the separation of the two seasons would allow forecasts to be made seasonally. Seasonal Temperature shifts can be seen in the FI and TI graphs, but a closer look at air temperature changes would be helpful for climate model analysis. Currently the reduction in winter temperature variation relates to a 'warming' winter trend that also affects the annual temperature trend of a specific location. If summer temperature trends show little or no change, then the winter temperature trends are the driving force behind increasing MAAT.

As with the separate seasonal temperature examination, a closer look at snow depth and precipitation with relation to temperature used in engineering design may be warranted. If separate seasonal trends can be plotted, it would be interesting to view precipitation trends with relation to summer temperatures and winter temperature trends with relation to snow depth records. This separate comparison will eliminate the opposing season and allow both precipitation and snow depth to be reviewed separately. Additionally it would be interesting to see both the precipitation and snow depth examined using the comparison graphing method so that changes over time can be viewed in terms of seasonal trends and the intensity of the changes with temperature can be evaluated.

The examination of climate resources and variables can be both educational as well as critical to future work done in any field. Despite the common occurrence in the

engineering field to place minimal emphasis on temperature unknowns, climate change has become a real concern. Changes in climate will affect design in colder climates much more rapidly than in most global locations. Some laboratory and field testing would be helpful to determine how decreasing winter air temperature variability will affect current and future engineering designs. Examining creep rates and shear strength changes with respect to changing air temperatures would be helpful when trying to relate the seasonal temperature changes with the effect they have on infrastructure. For infrastructure that relies on pile foundations, further testing to determine how air temperatures influence adfreeze strengths and unfrozen moisture contents would be both informative and helpful in future design. Engineering structures, like ACEs, may witness the more direct effect of seasonal temperature change, but long term slope stability parameters and adfreeze bonding in a warming "summer-like" climate shift will affect a wide range of engineering structures. Field analyses should be conducted to determine the immediate and long term future impacts on northern engineering designs. For regions like Canada and Alaska, research on the impacts of climactic variables is critical for future engineering design.

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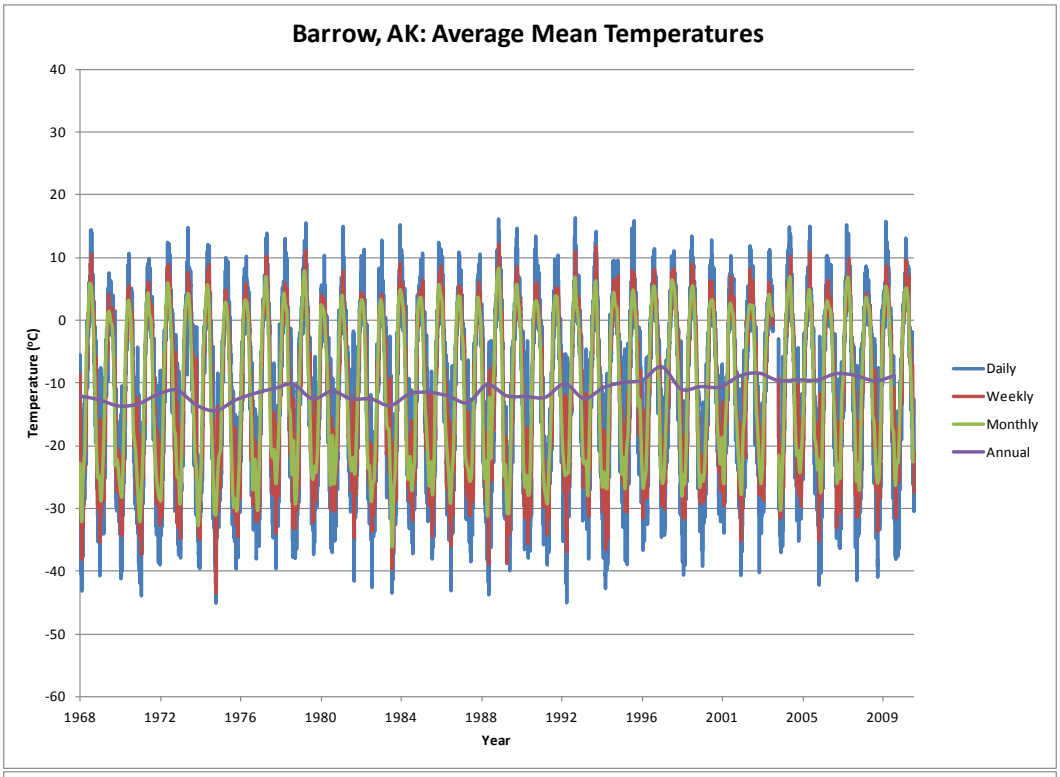
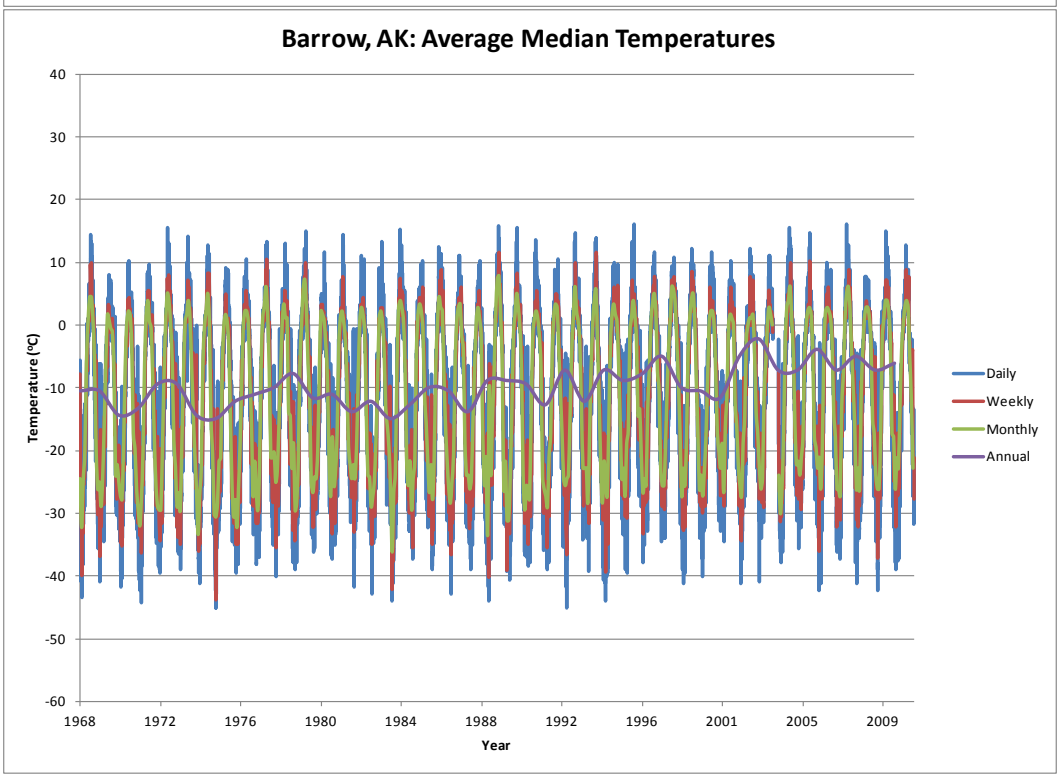
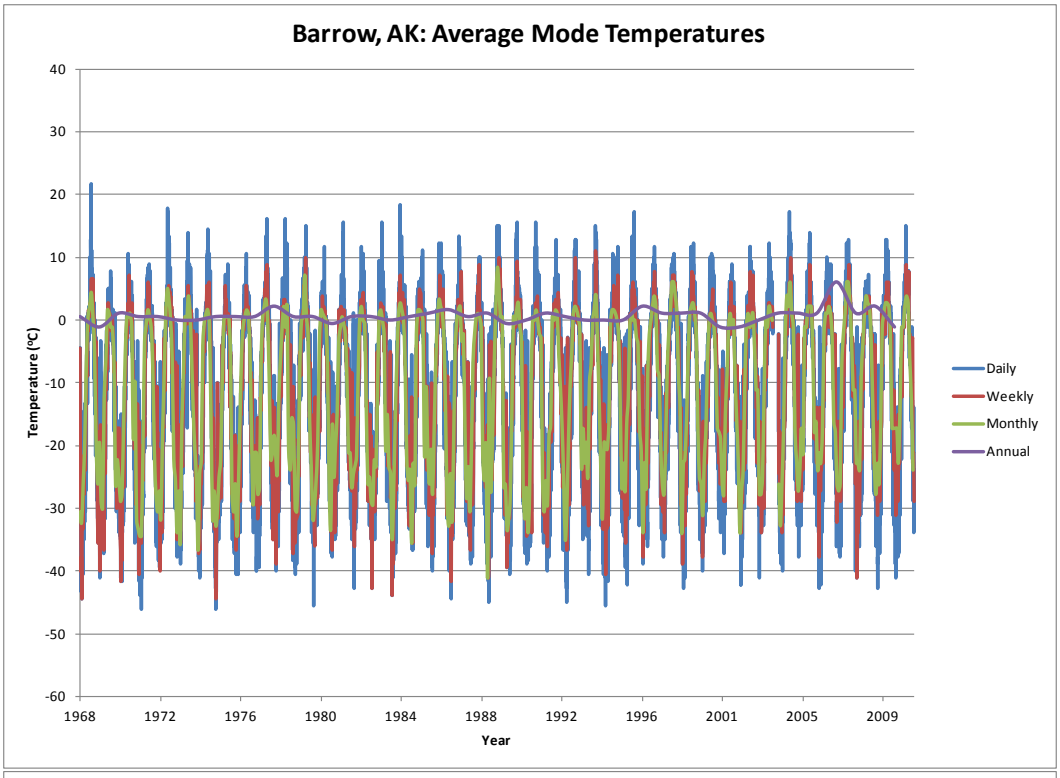
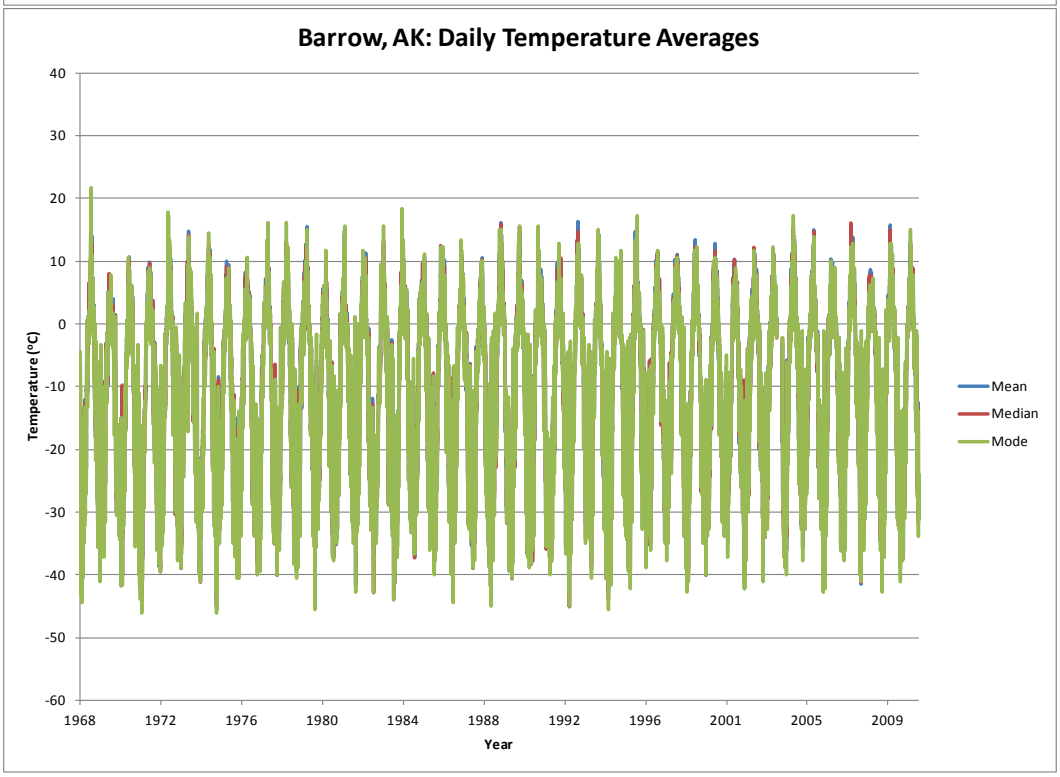
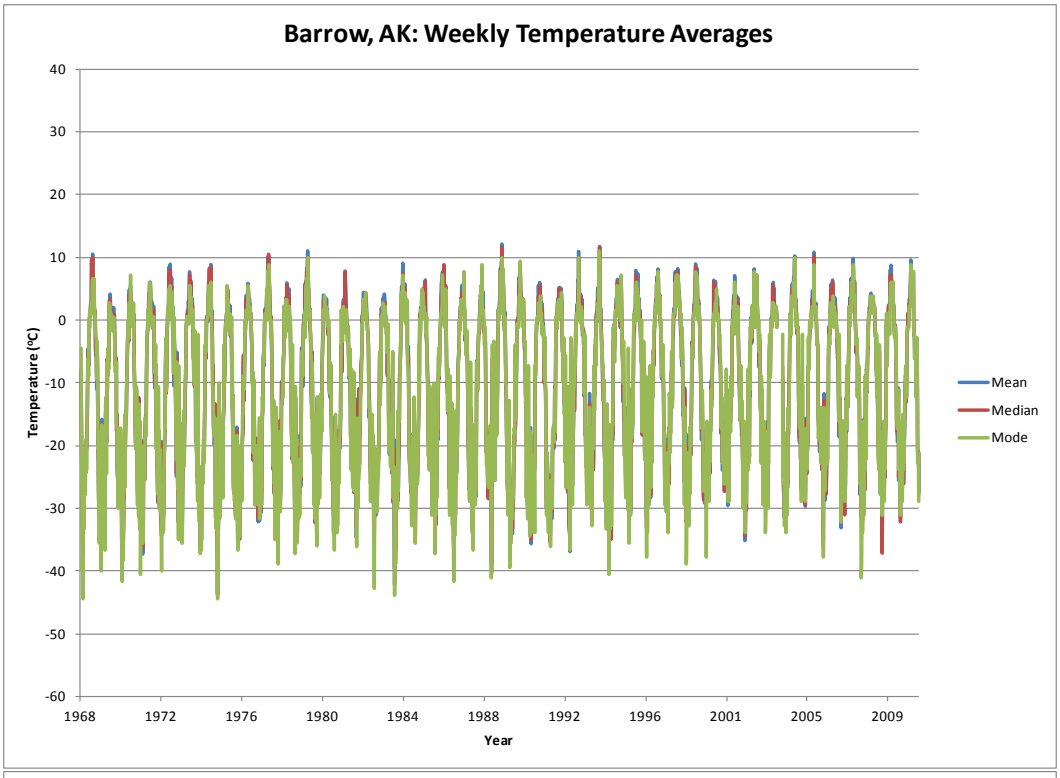
Appendix 1: Barrow, Alaska

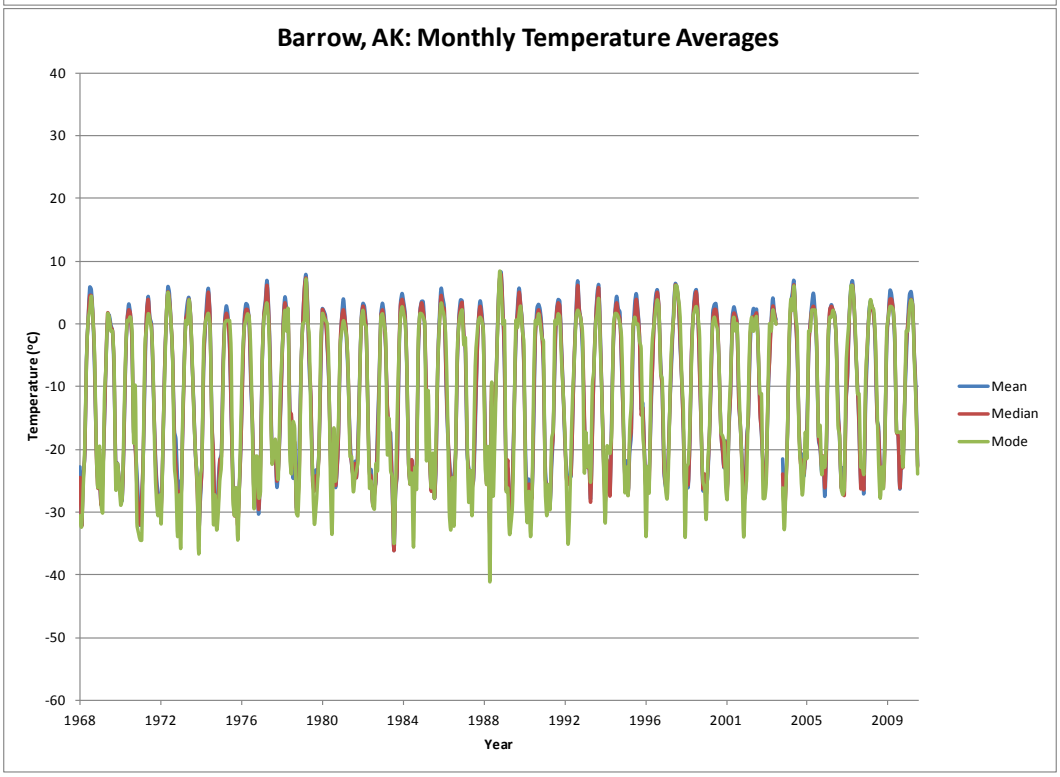


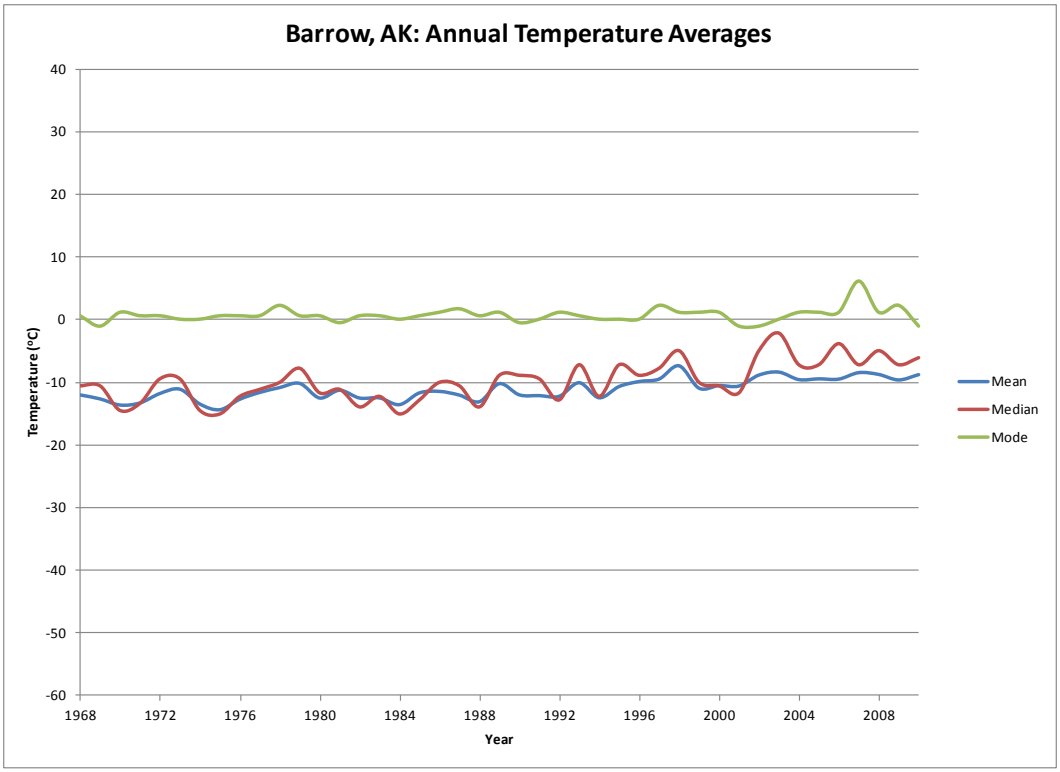



Barrow, AK: Average Mode Temperatures
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1968
1972
1976
1980
1984
1988
1992
1996
2001
2005
2009
Year
Daily
Weekly
Monthly
Annual


Barrow, AK: Daily Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1968
1972
1976
1980
1984
1988
1992
1996
2001
2005
2009
Year
Mean
Median
Mode


Barrow, AK: Weekly Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1968
1972
1976
1980
1984
1988
1992
1996
2001
2005
2009
Year
Mean
Median
Mode


Barrow, AK: Monthly Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1968
1972
1976
1980
1984
1988
1992
1996
2001
2005
2009
Year
Mean
Median
Mode


Barrow, AK: Annual Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1968
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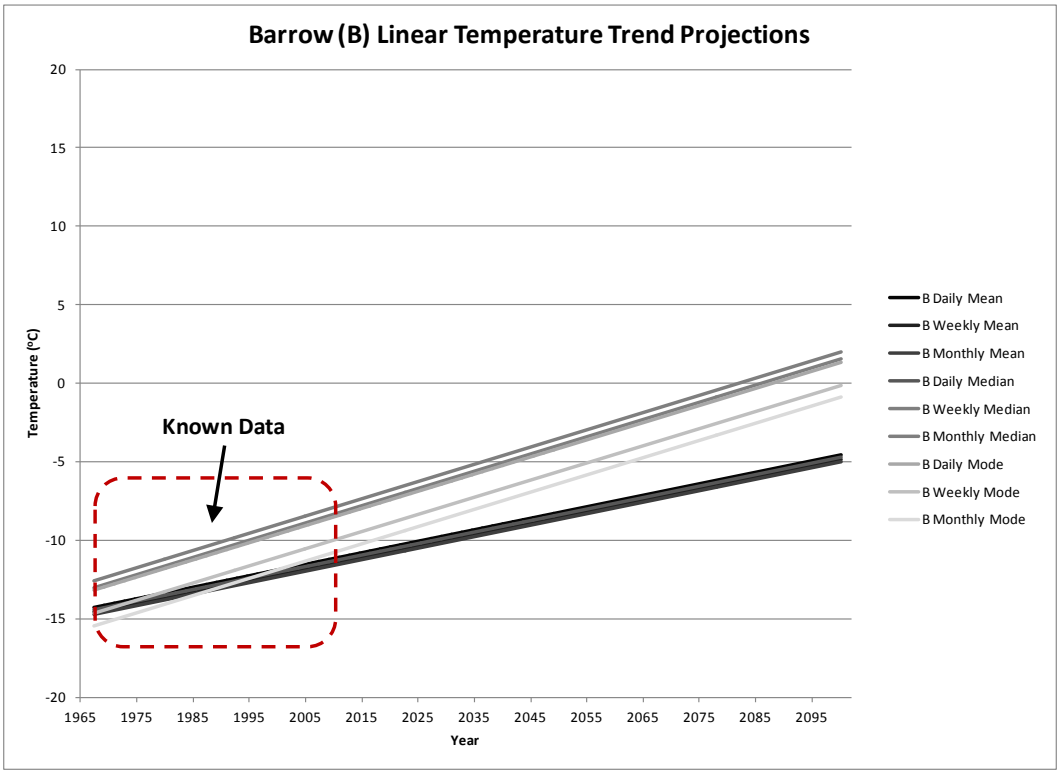
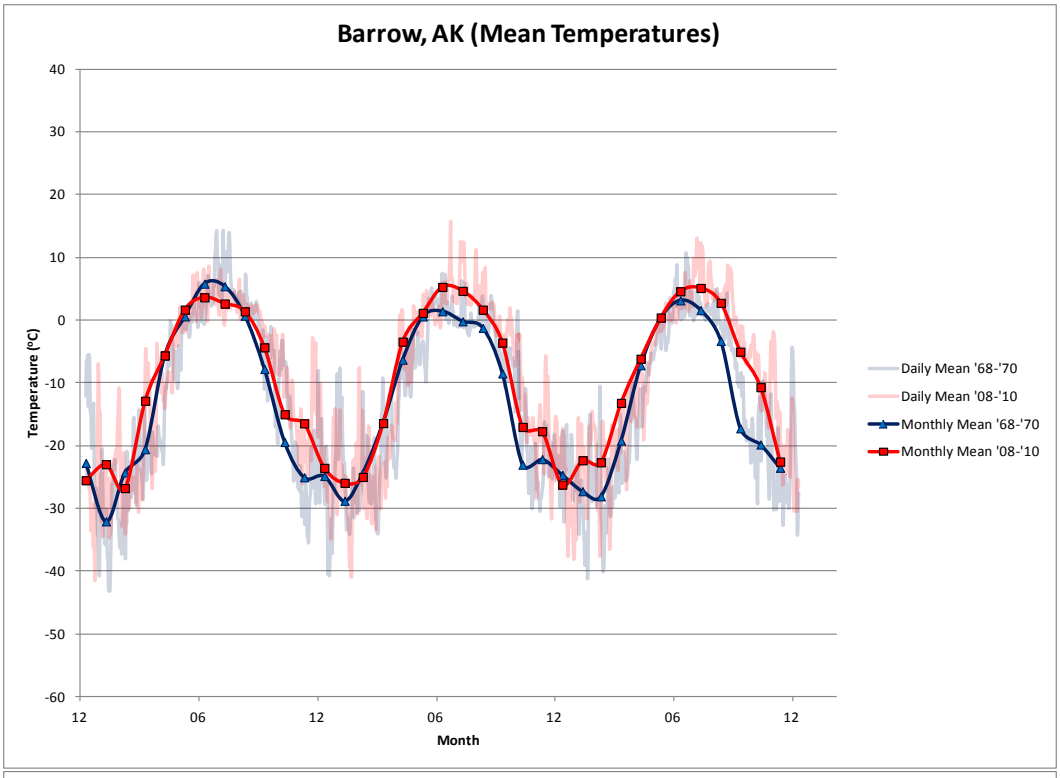
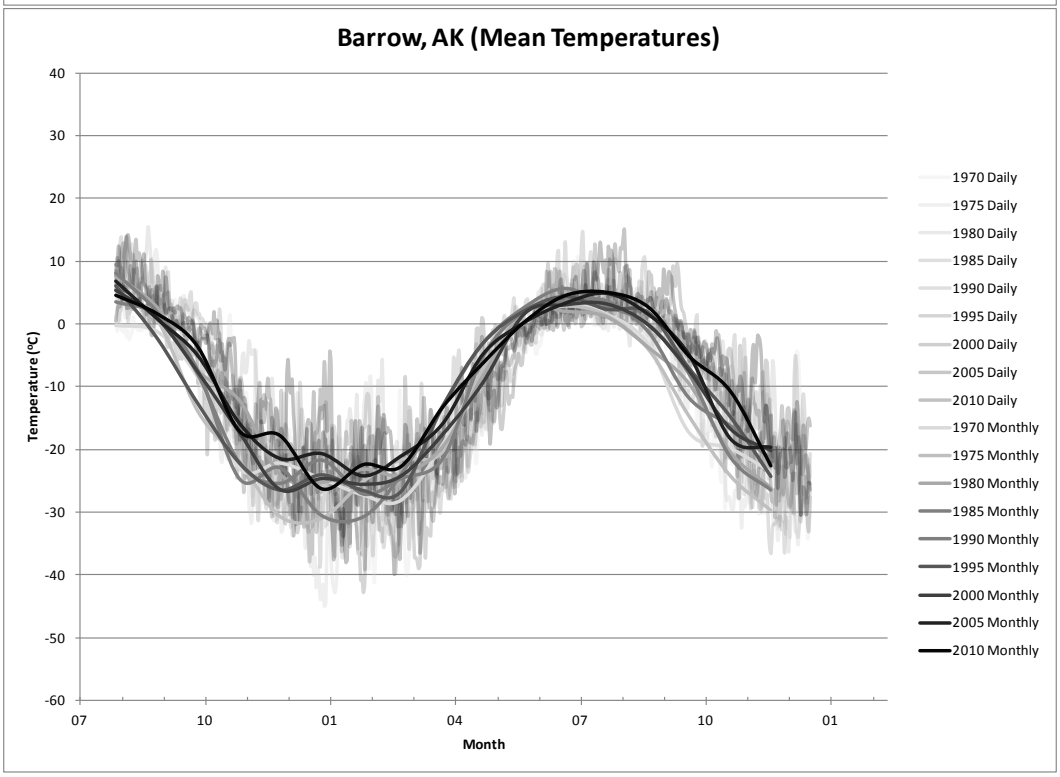
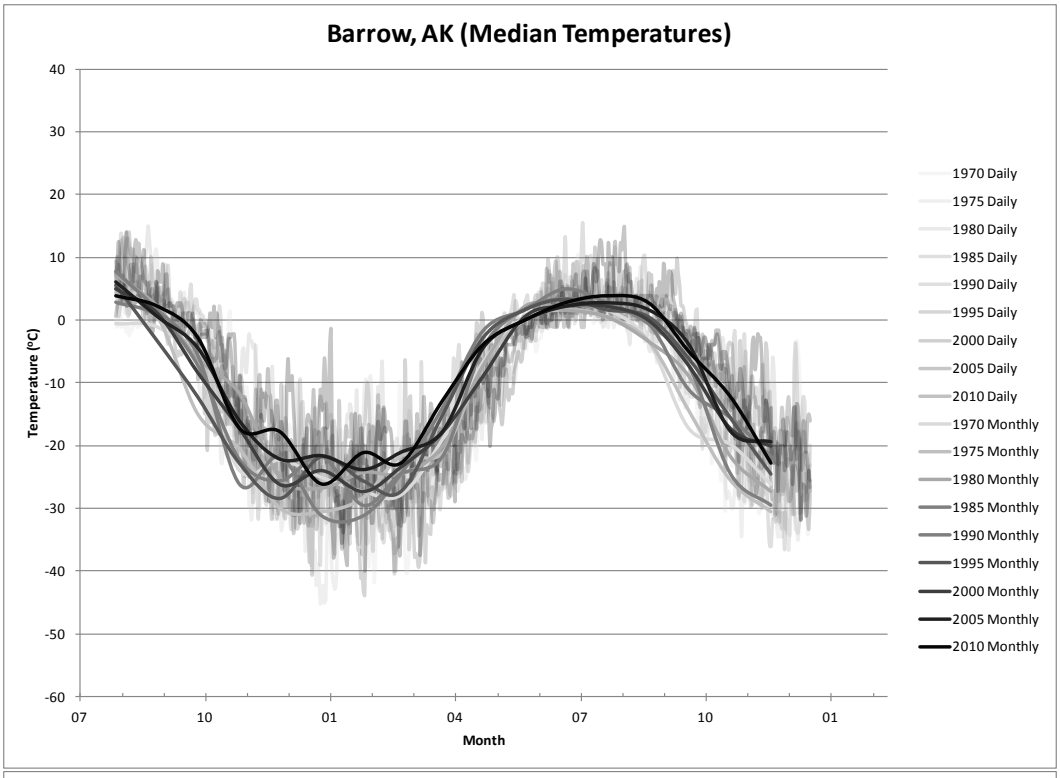
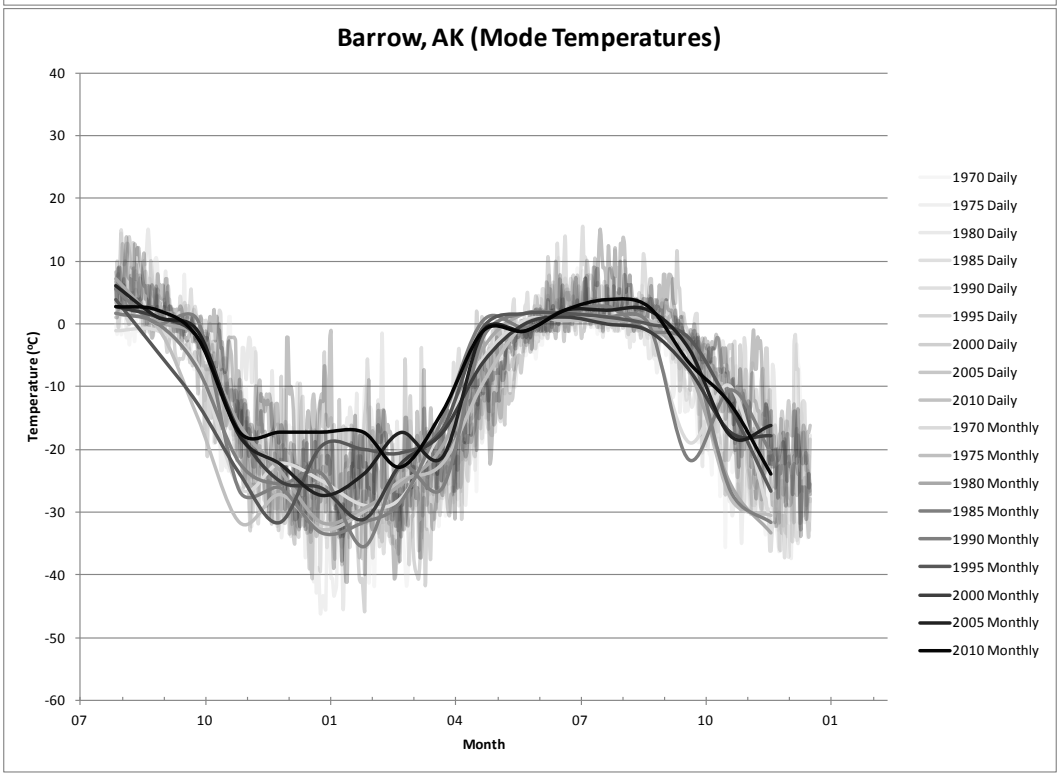
2004
2008
Year
Mean
Median
Mode

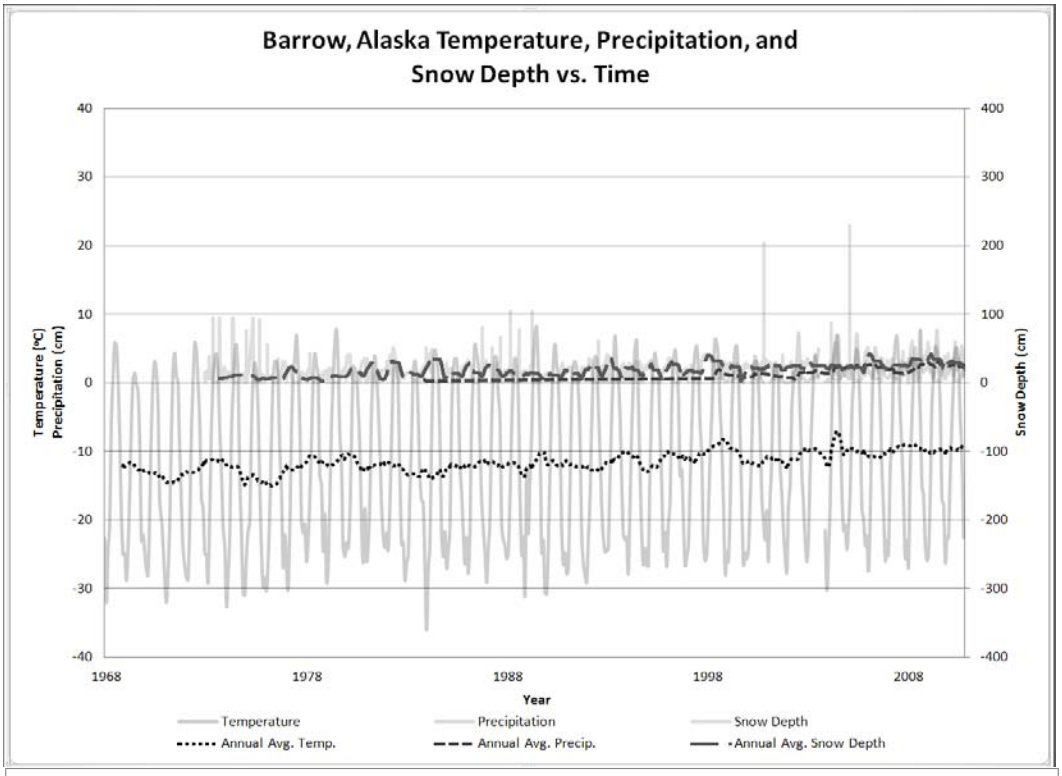

Barrow (B) Linear Temperature Trend Projections
Temperature (°C)
20
15
10
5
0
-5
-10
-15
-20
1965
1975
1985
1995
2005
2015
2025
2035
2045
2055
2065
2075
2085
2095
Year
Known Data
B Daily Mean
B Weekly Mean
B Monthly Mean
B Daily Median
B Weekly Median
B Monthly Median
B Daily Mode
B Weekly Mode
B Monthly Mode

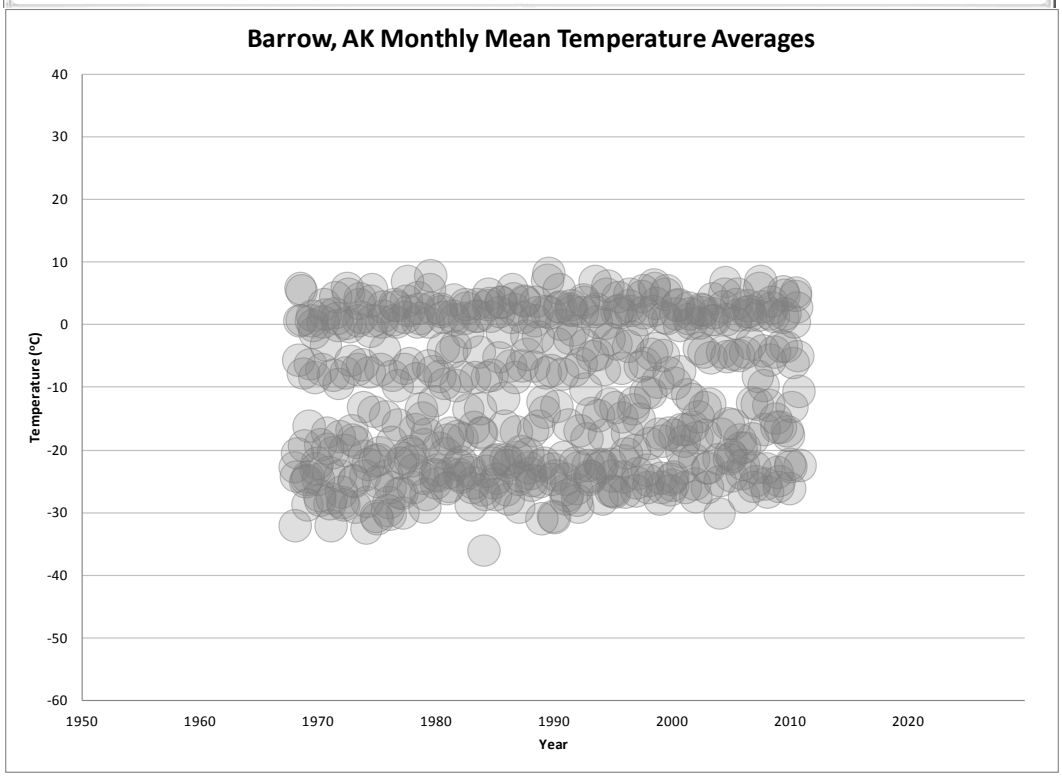

Barrow, AK (Mean Temperatures)
Temperature (ºC)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
12
06
12
06
12
06
12
Month
Daily Mean '68-'70
Daily Mean '08-'10
Monthly Mean '68-'70
Monthly Mean '08-'10


Barrow, AK (Mean Temperatures)
Temperature (ºC)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1970 Daily
1975 Daily
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1970 Monthly
1975 Monthly
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

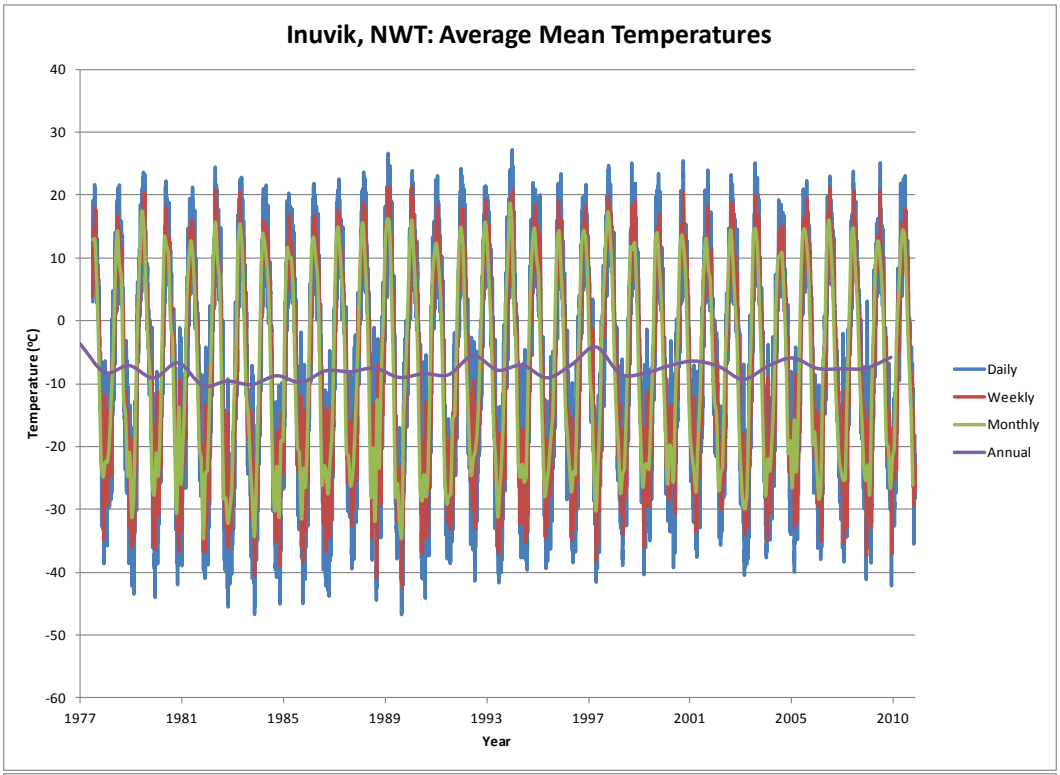

Barrow, AK (Median Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1970 Daily
1975 Daily
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1970 Monthly
1975 Monthly
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

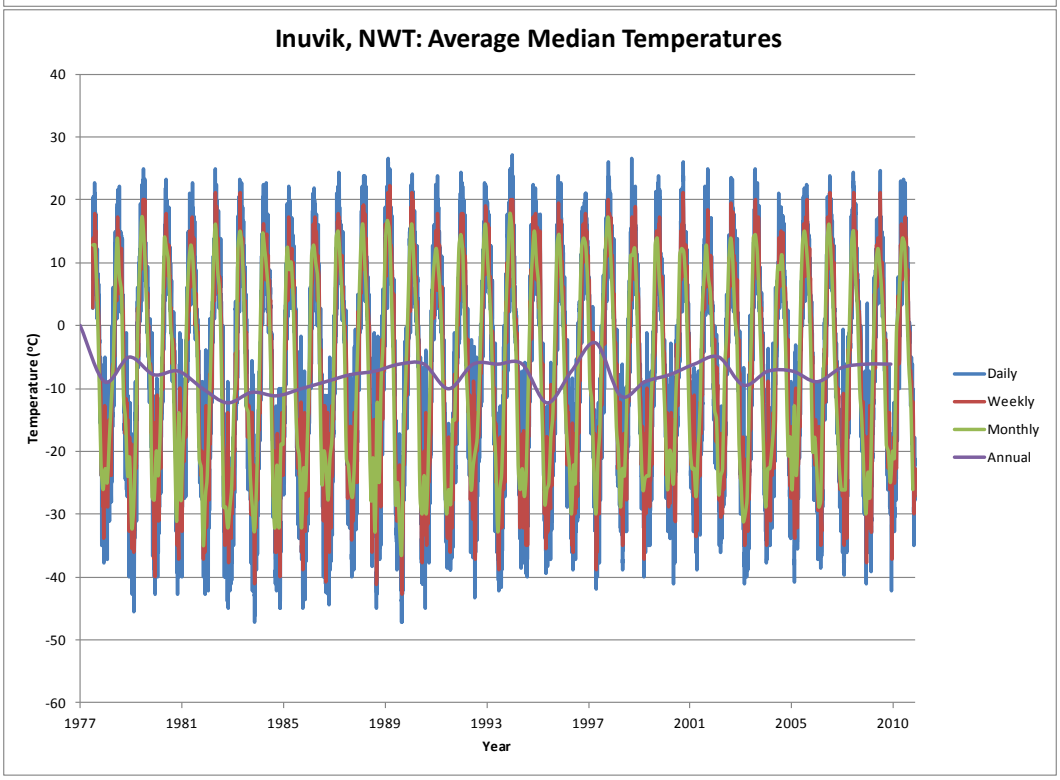

Barrow, AK (Mode Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1970 Daily
1975 Daily
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1970 Monthly
1975 Monthly
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

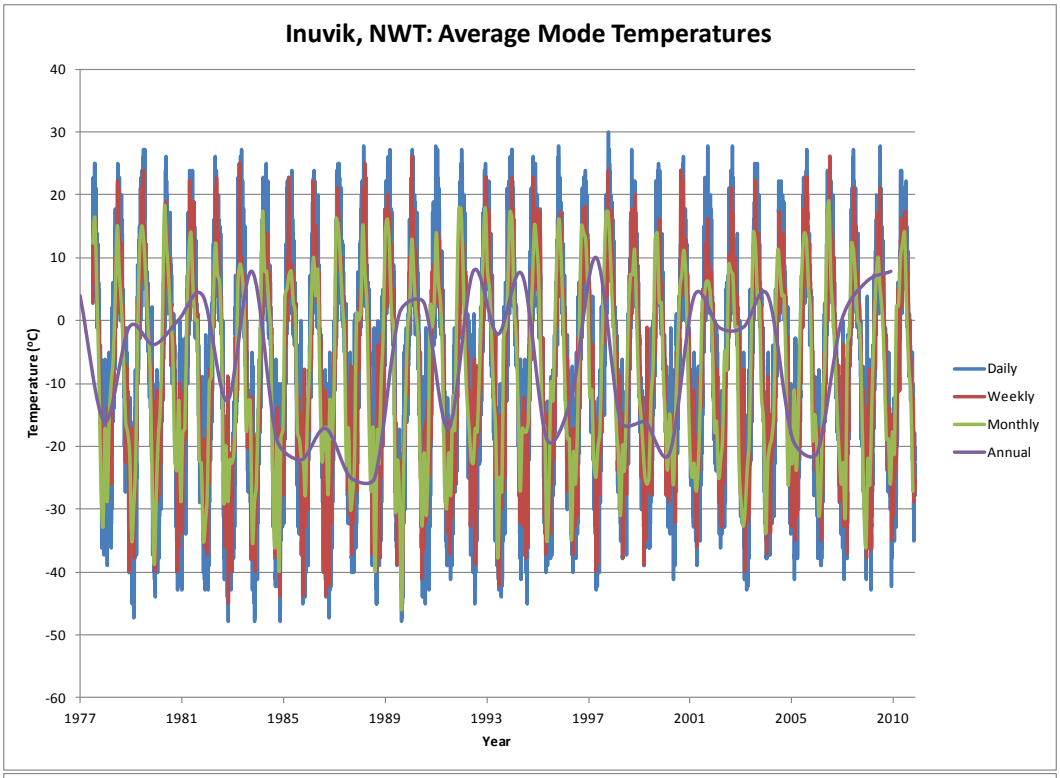

Barrow, Alaska Temperature, Precipitation, and Snow Depth vs. Time
Temperature (°C) Precipitation (cm)
Snow Depth (cm)
40
30
20
10
0
-10
-20
-30
-40
400
300
200
100
0
-100
-200
-300
-400
1968
1978
1988
1998
2008
Year
Temperature
Precipitation
Snow Depth
Annual Avg. Temp.
Annual Avg. Precip.
Annual Avg. Snow Depth

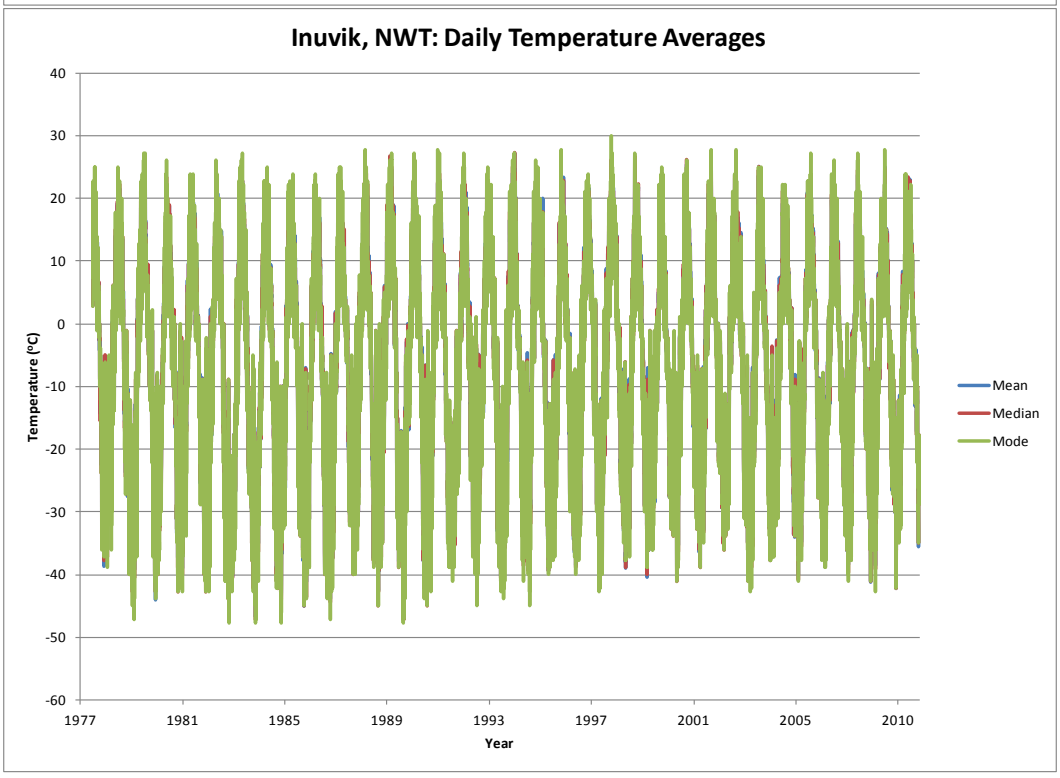

Barrow, AK Monthly Mean Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1950
1960
1970
1980
1990
2000
2010
2020
Year

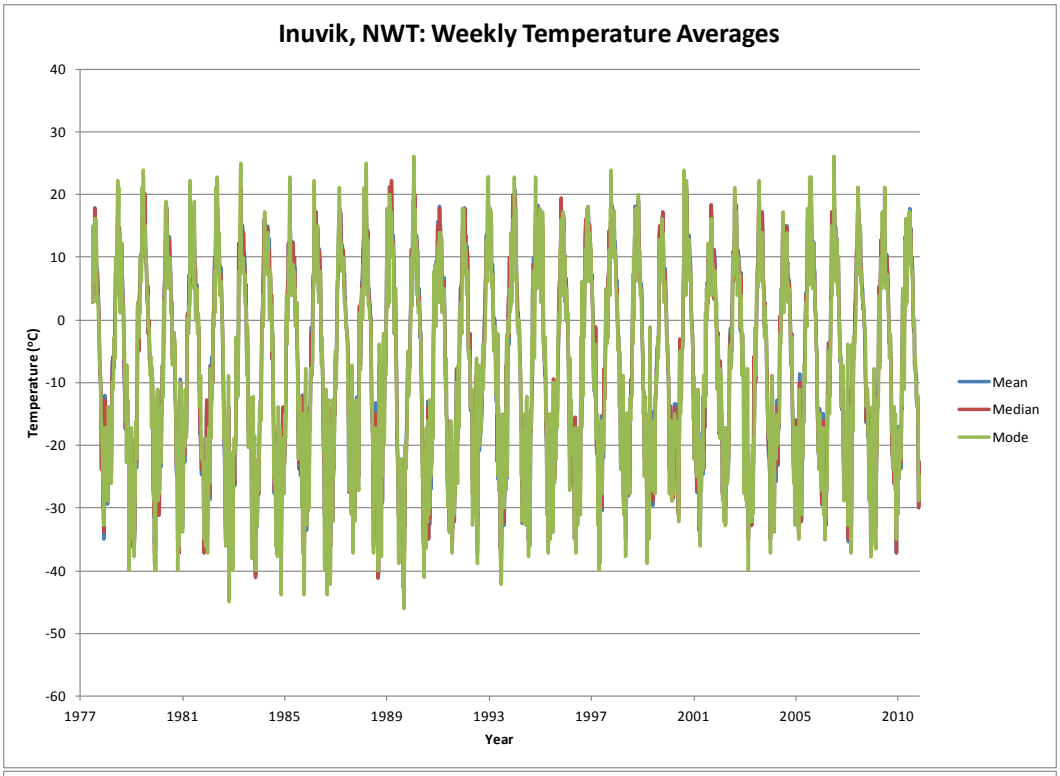
Appendix 2: Inuvik, Northwest Territories

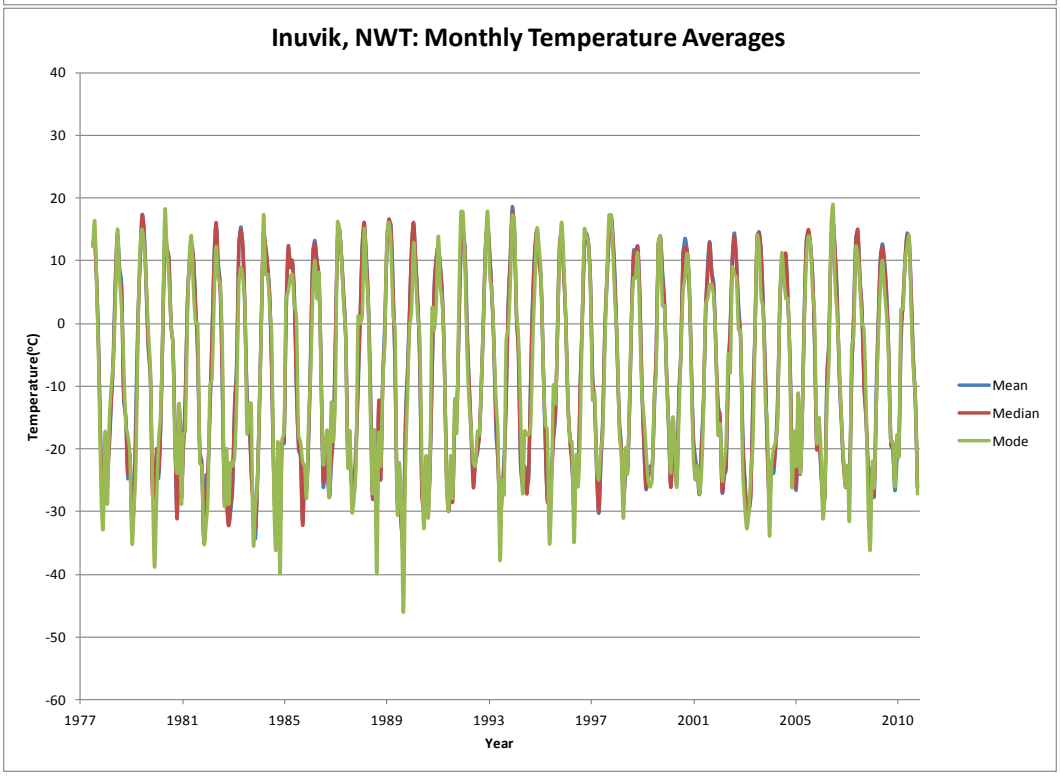


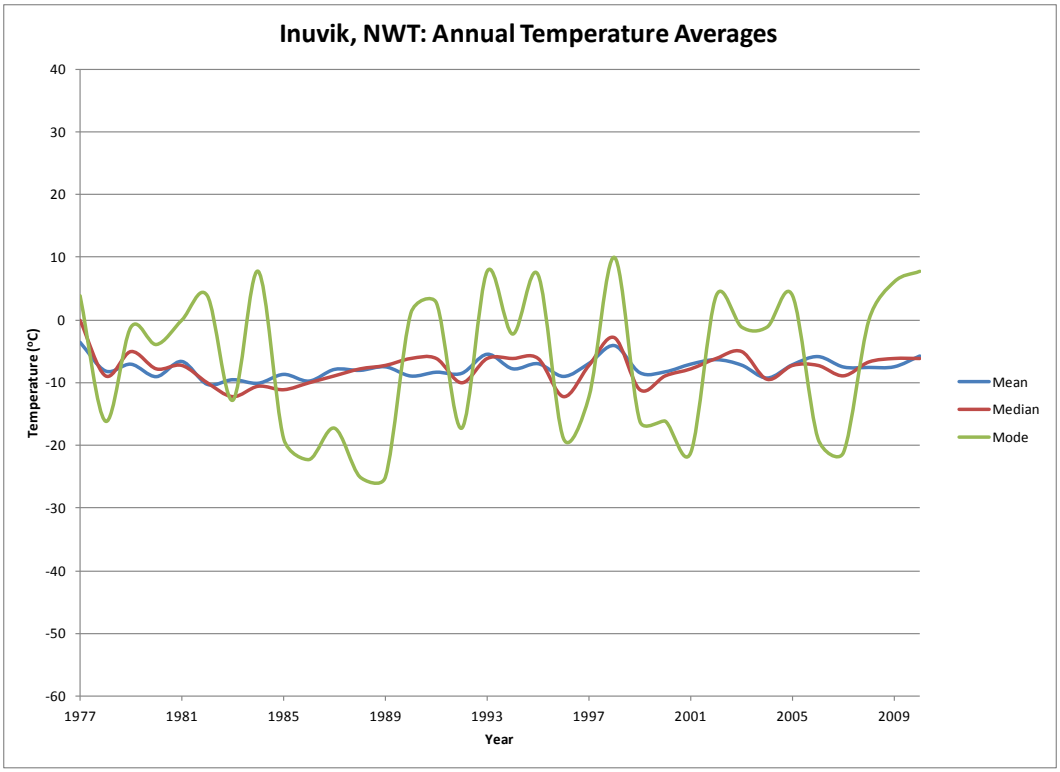


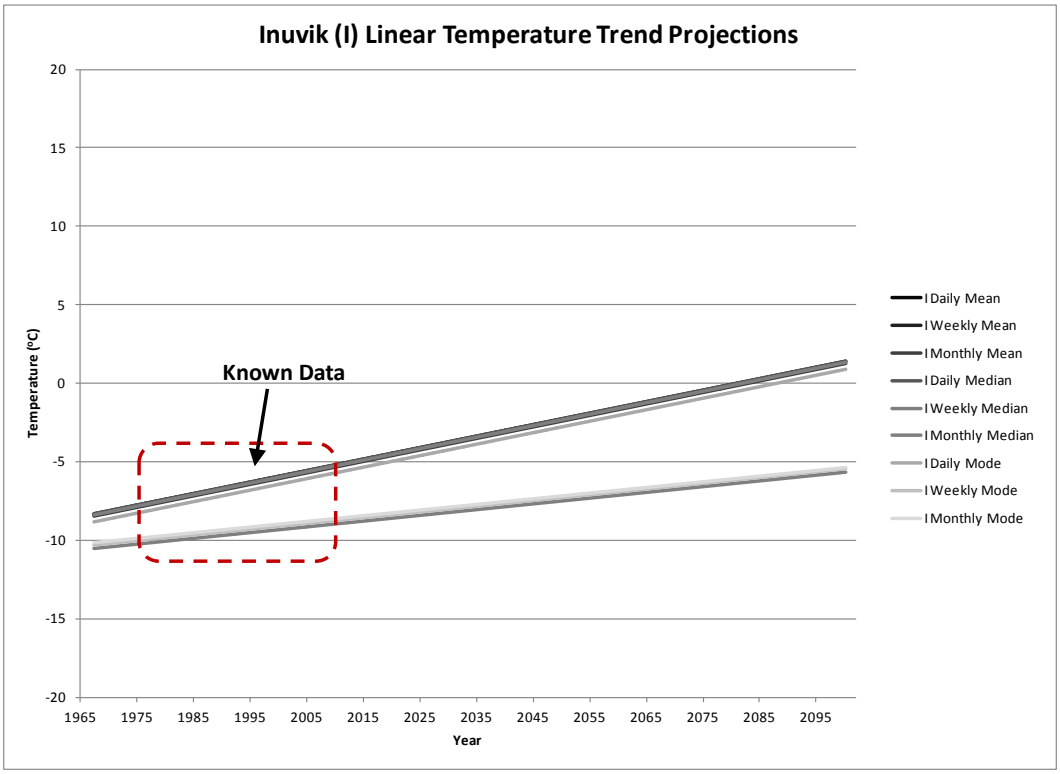

Inuvik, NWT: Average Mode Temperatures
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2010
Year
Daily
Weekly
Monthly
Annual

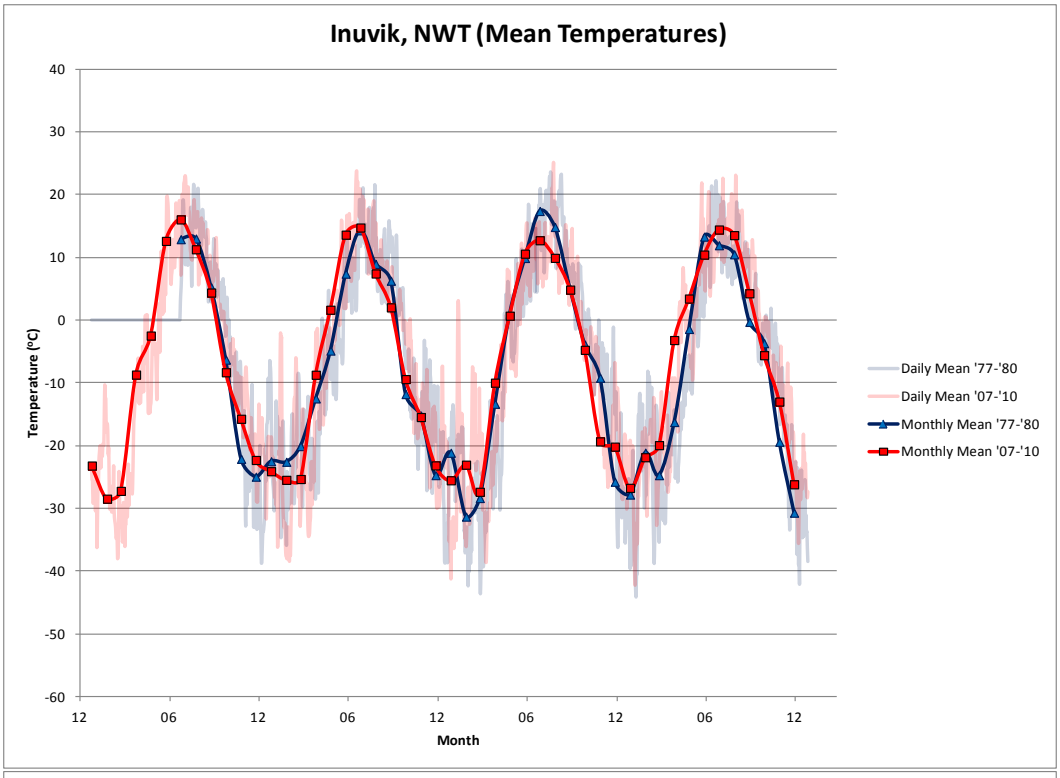

Inuvik, NWT: Daily Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2010
Year
Mean
Median
Mode

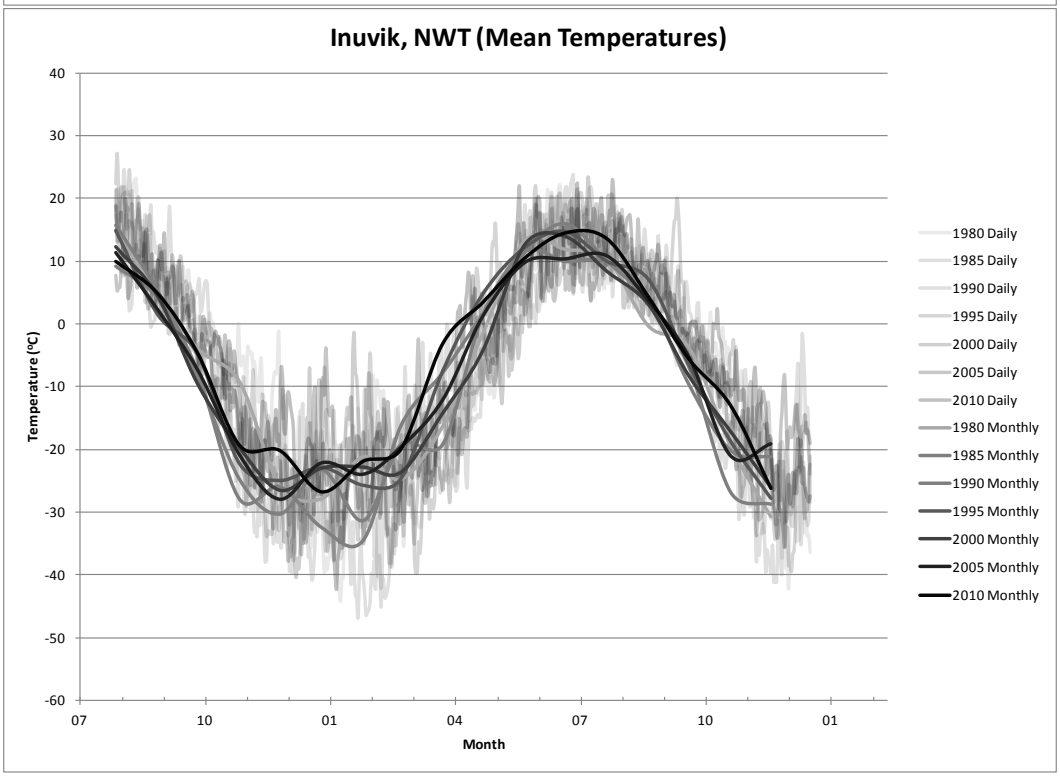

Inuvik, NWT: Weekly Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2010
Year
Mean
Median
Mode

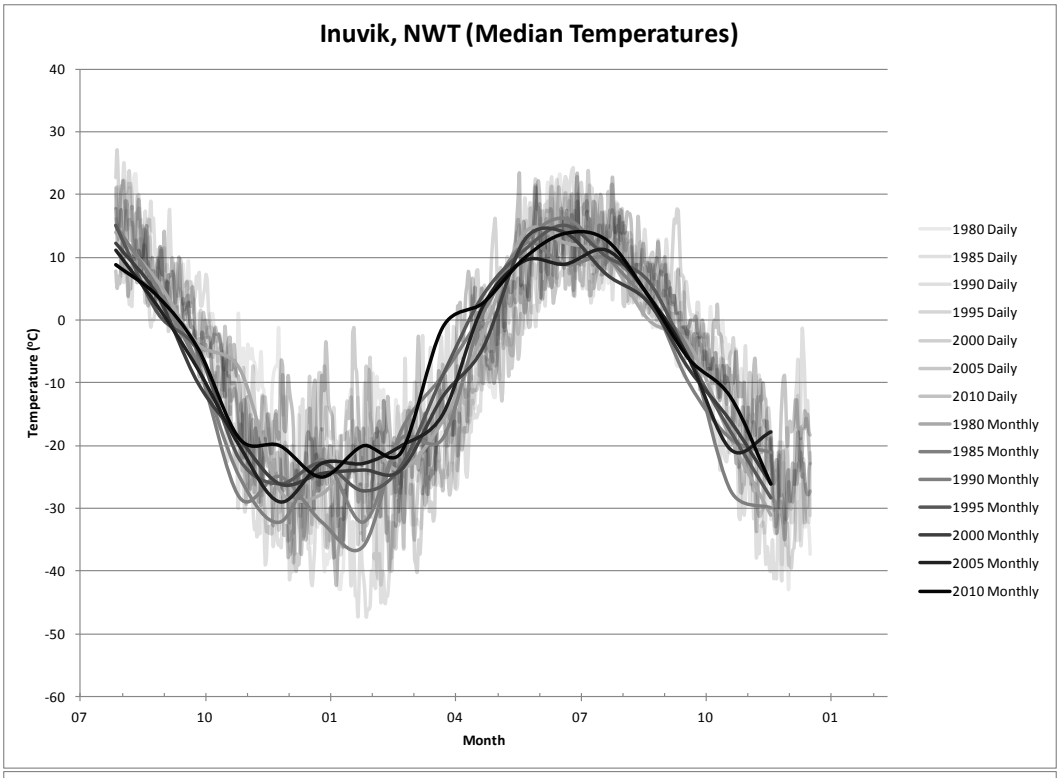

Inuvik, NWT: Monthly Temperature Averages
Temperature(°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2010
Year
Mean
Median
Mode

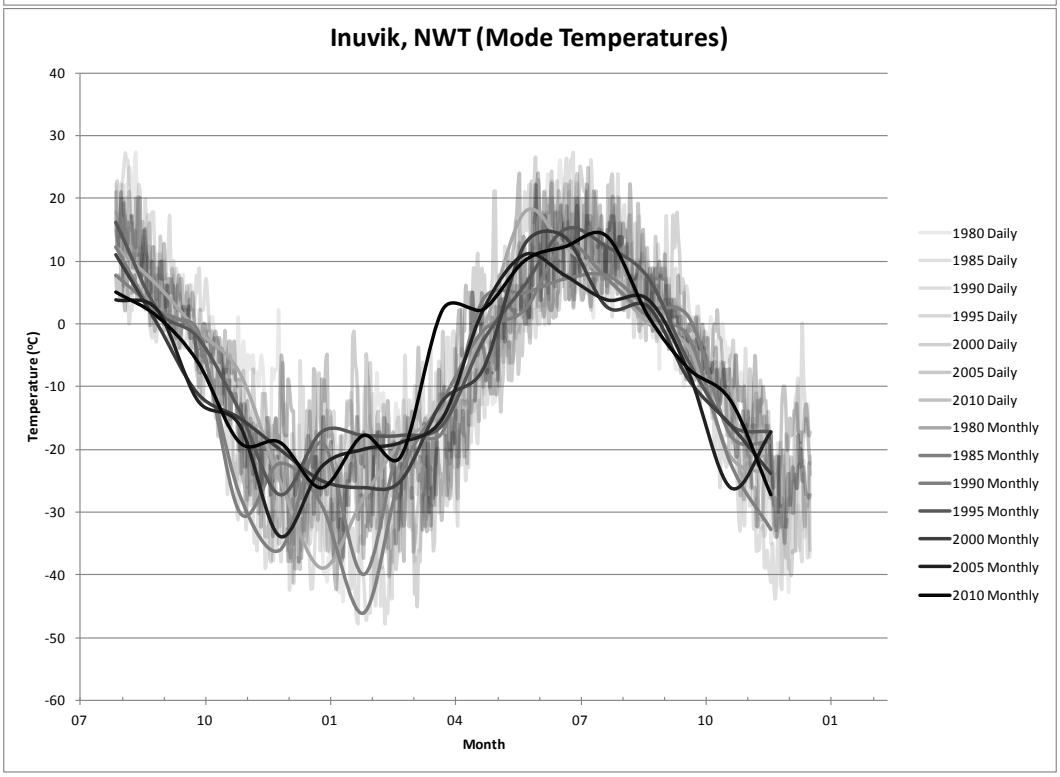

Inuvik, NWT: Annual Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2009
Year
Mean
Median
Mode

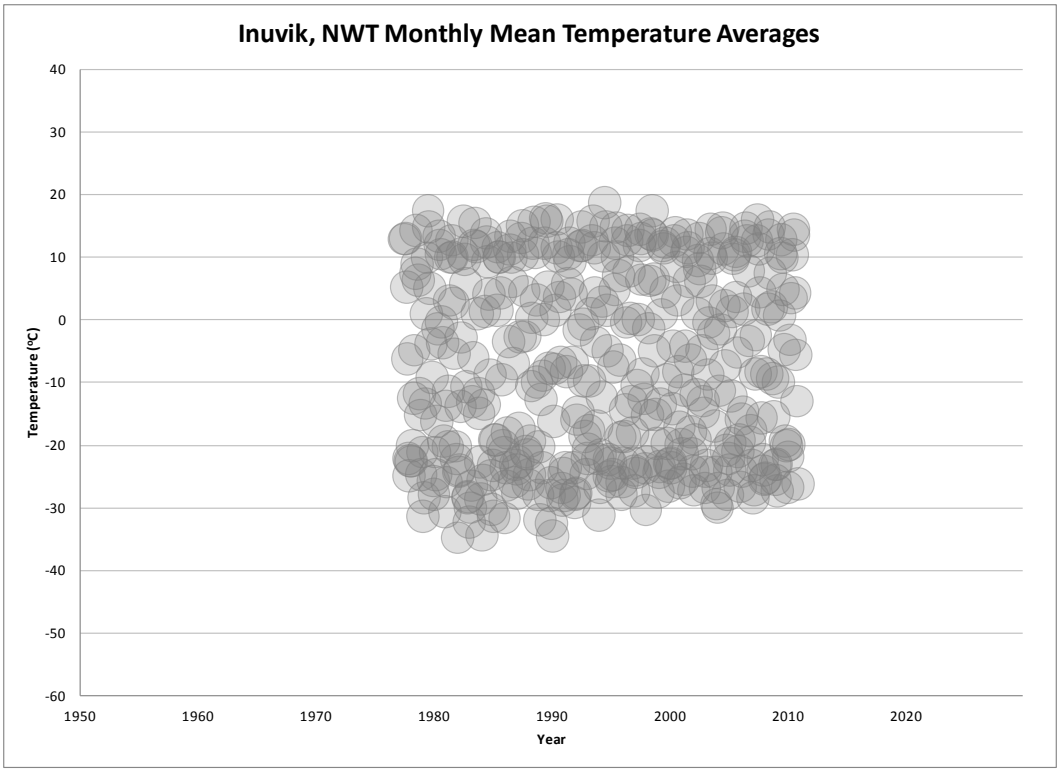

Inuvik (I) Linear Temperature Trend Projections
Temperature (°C)
20
15
10
5
0
-5
-10
-15
-20
1965
1975
1985
1995
2005
2015
2025
2035
2045
2055
2065
2075
2085
2095
Year
Known Data
I Daily Mean
I Weekly Mean
I Monthly Mean
I Daily Median
I Weekly Median
I Monthly Median
I Daily Mode
I Weekly Mode
I Monthly Mode


Inuvik, NWT (Mean Temperatures)
Temperature (ºC)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
12
06
12
06
12
06
12
06
12
Month
Daily Mean '77-'80
Daily Mean '07-'10
Monthly Mean '77-'80
Monthly Mean '07-'10

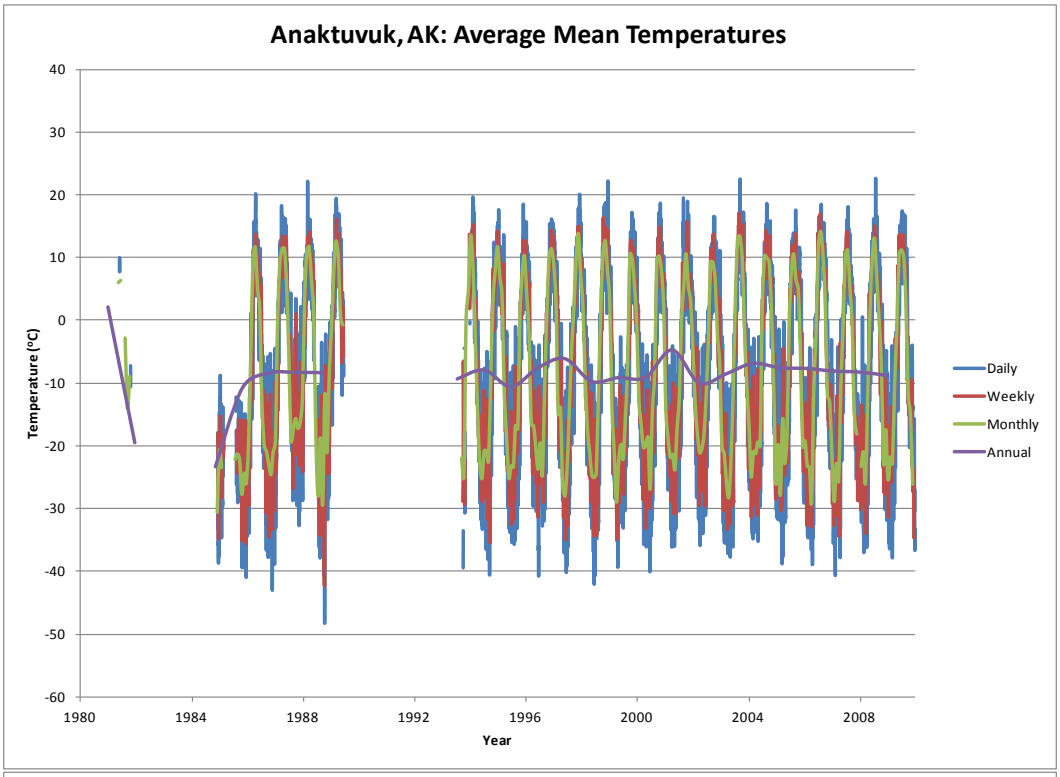

Inuvik, NWT (Mean Temperatures)
Temperature (ºC)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

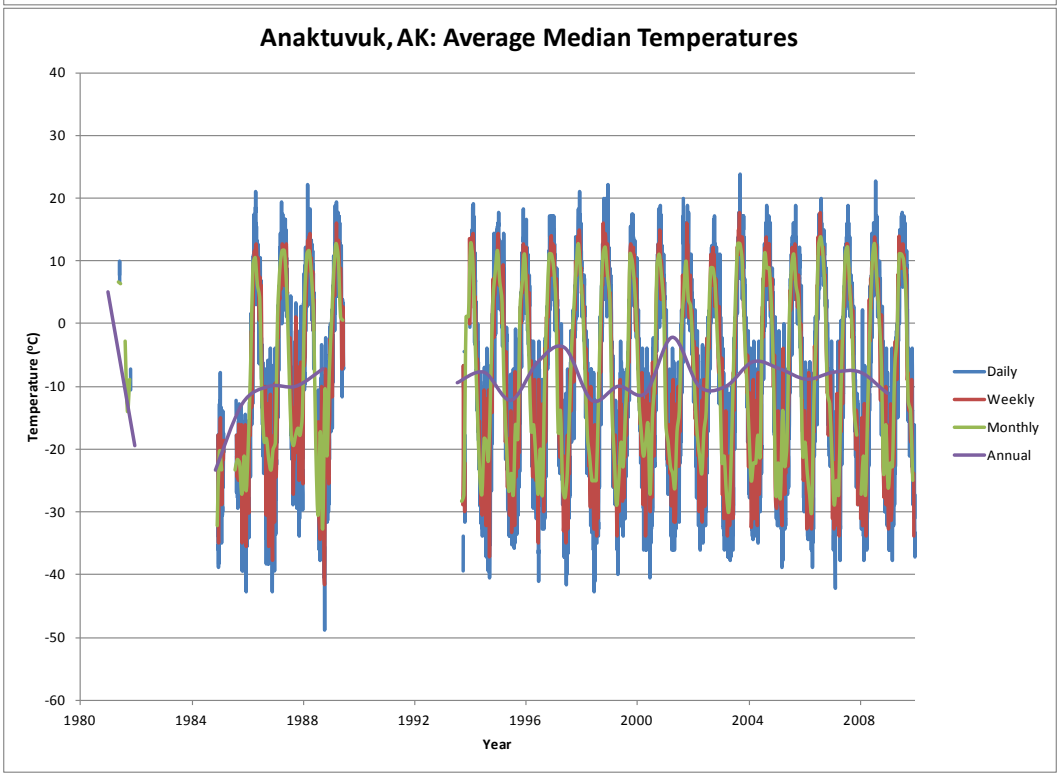

Inuvik, NWT (Median Temperatures)
Temperature (ºC)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

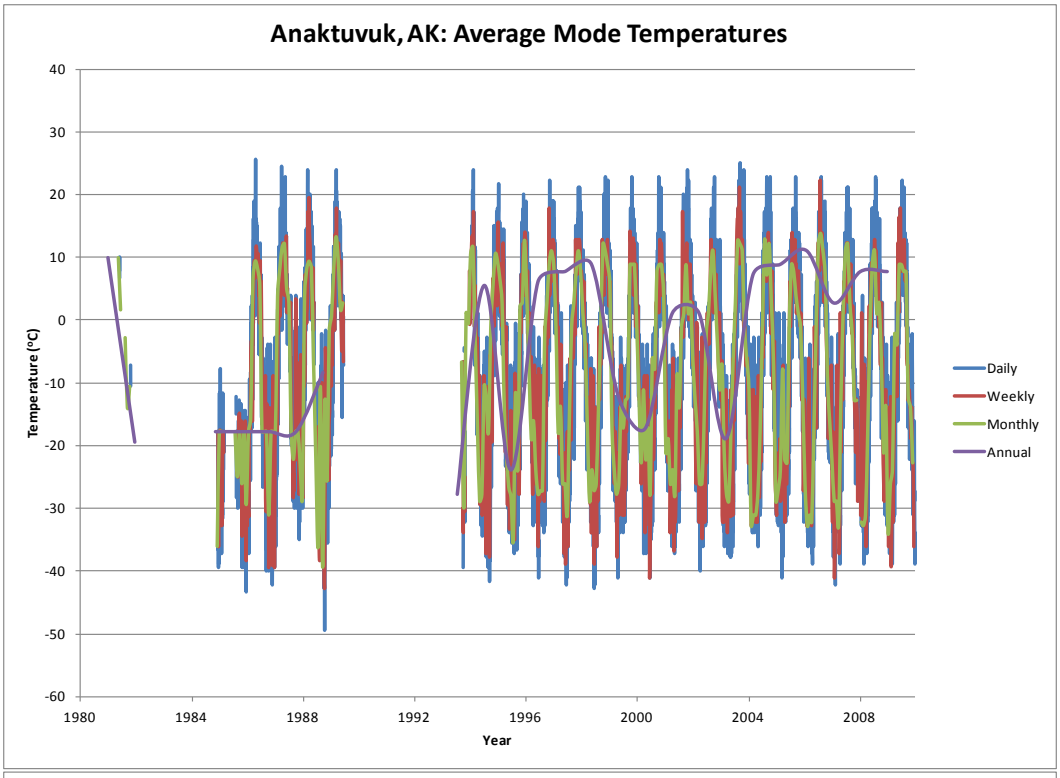

Inuvik, NWT (Mode Temperatures)
Temperature (ºC)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

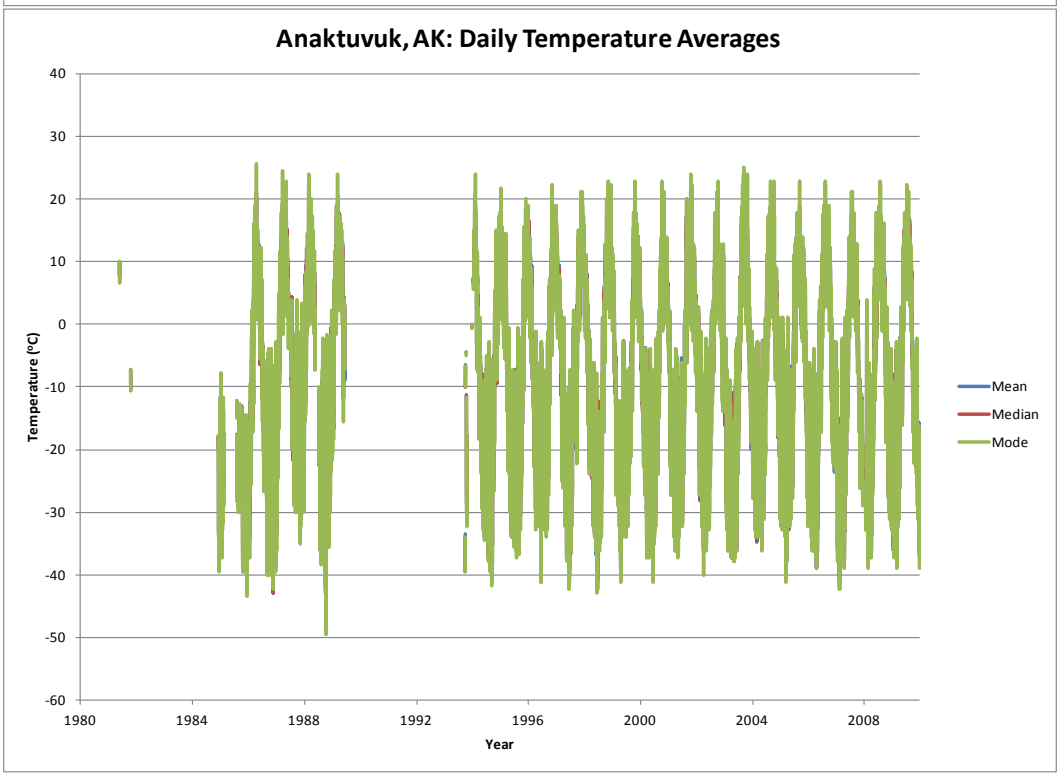

Inuvik, NWT Monthly Mean Temperature Averages
40
30
20
10
0
-10
-20
-30
-40
-50
-60
Temperature (°C)
1950
1960
1970
1980
1990
2000
2010
2020
Year

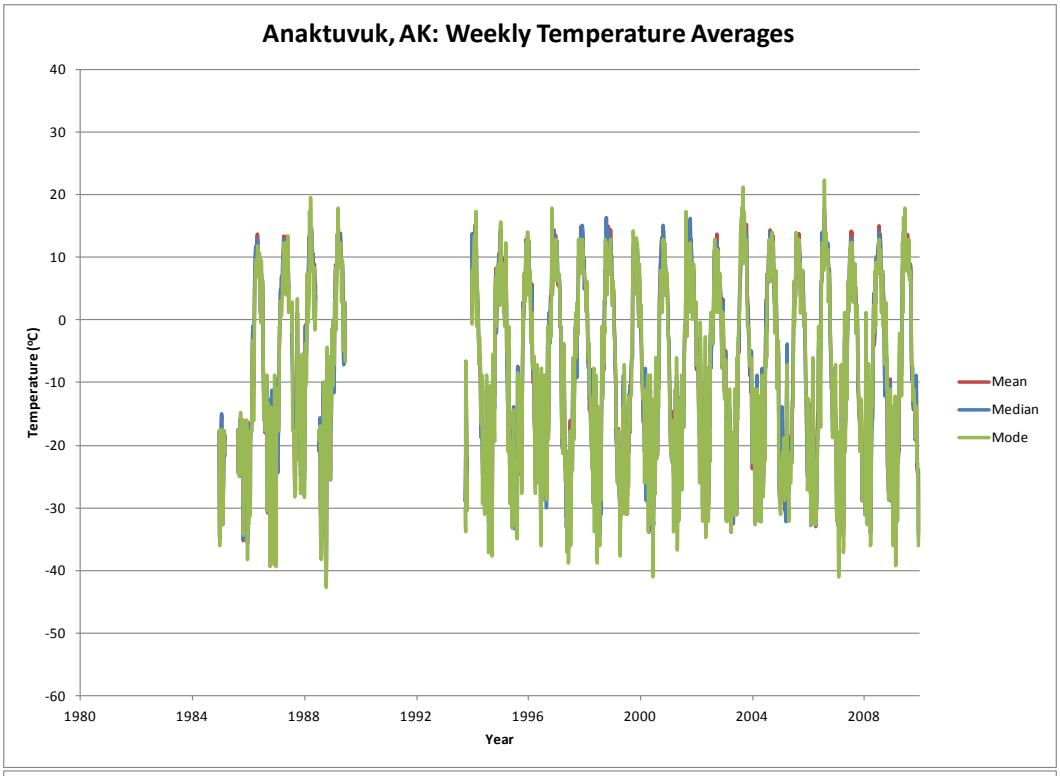
Appendix 3: Anaktuvuk Pass, Alaska

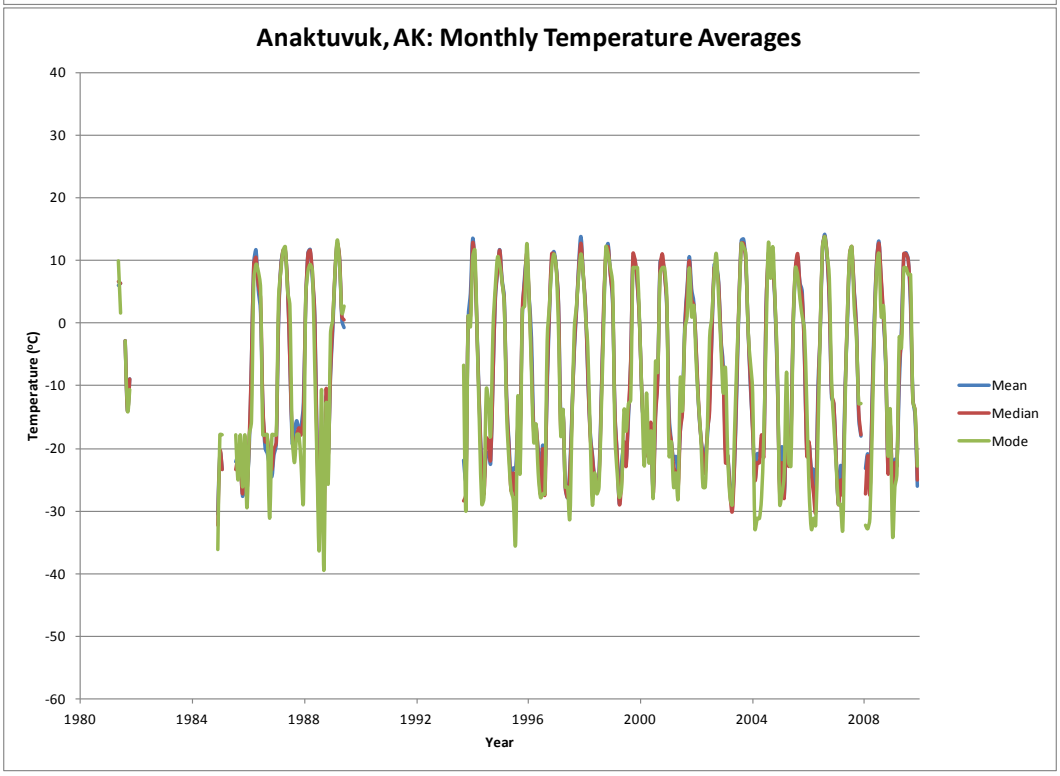


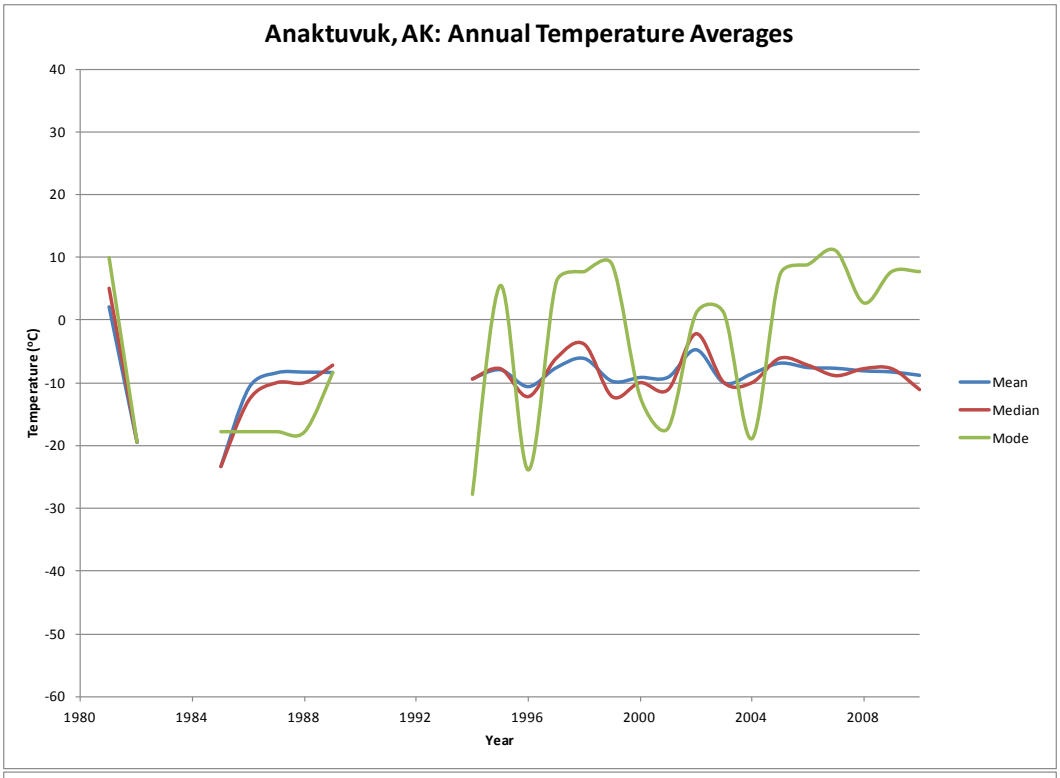


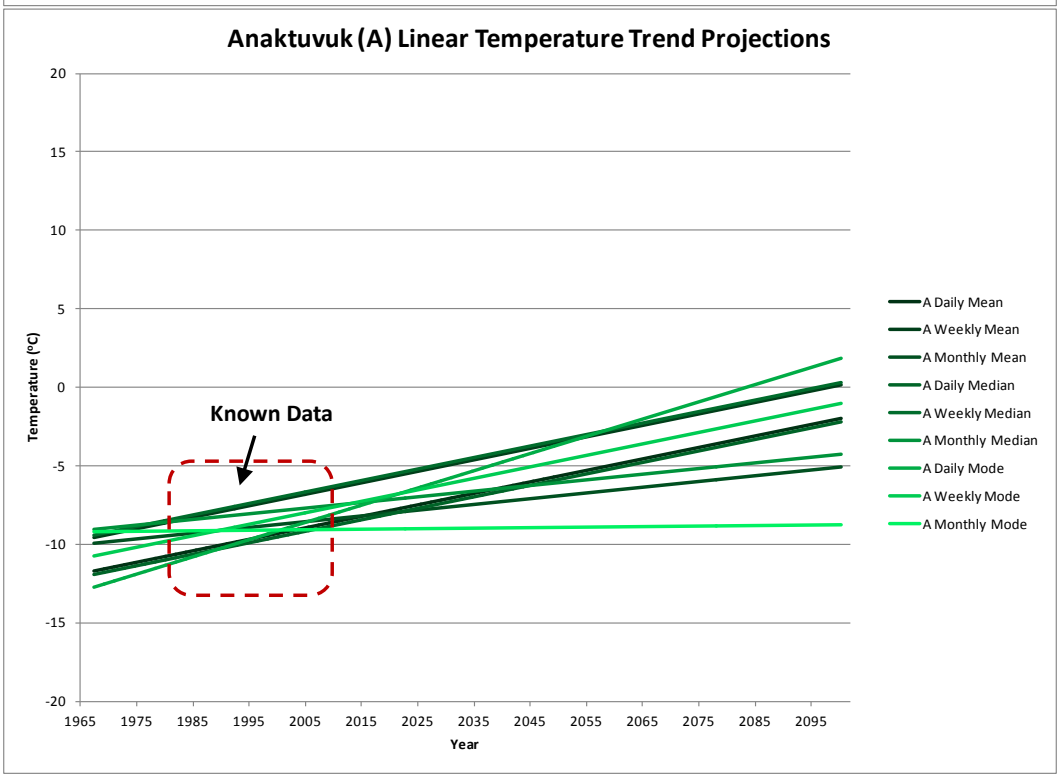

Anaktuvuk, AK: Average Mode Temperatures
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1980
1984
1988
1992
1996
2000
2004
2008
Year
Daily
Weekly
Monthly
Annual

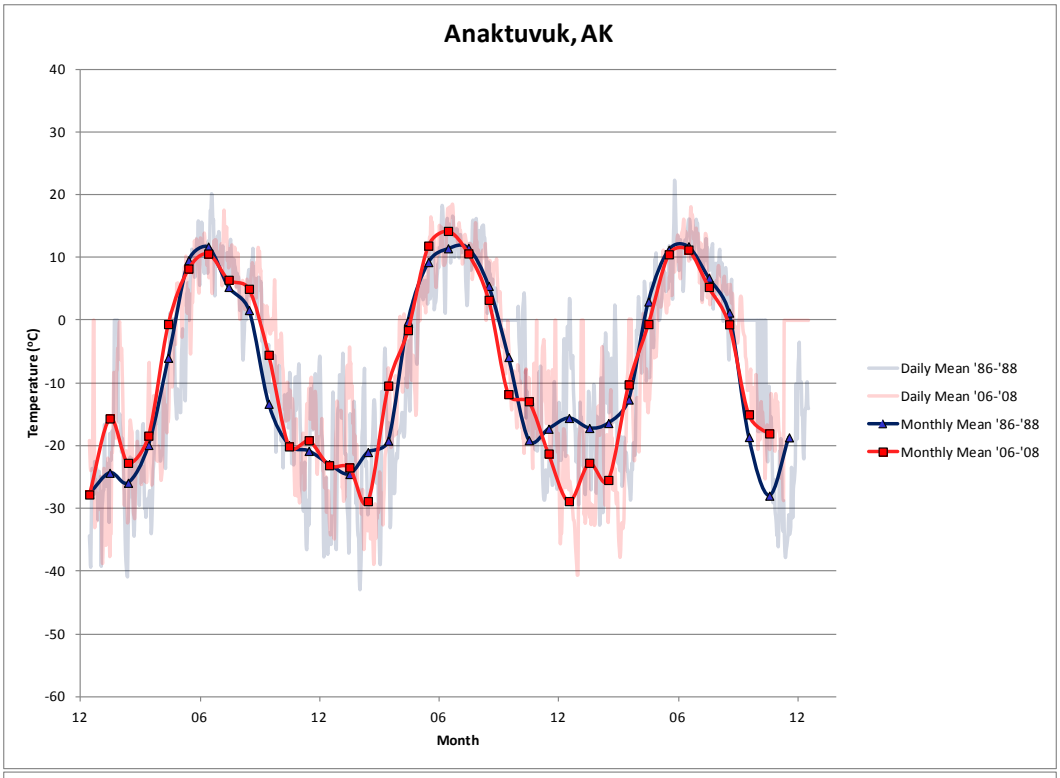

Anaktuvuk, AK: Daily Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1980
1984
1988
1992
1996
2000
2004
2008
Year
Mean
Median
Mode

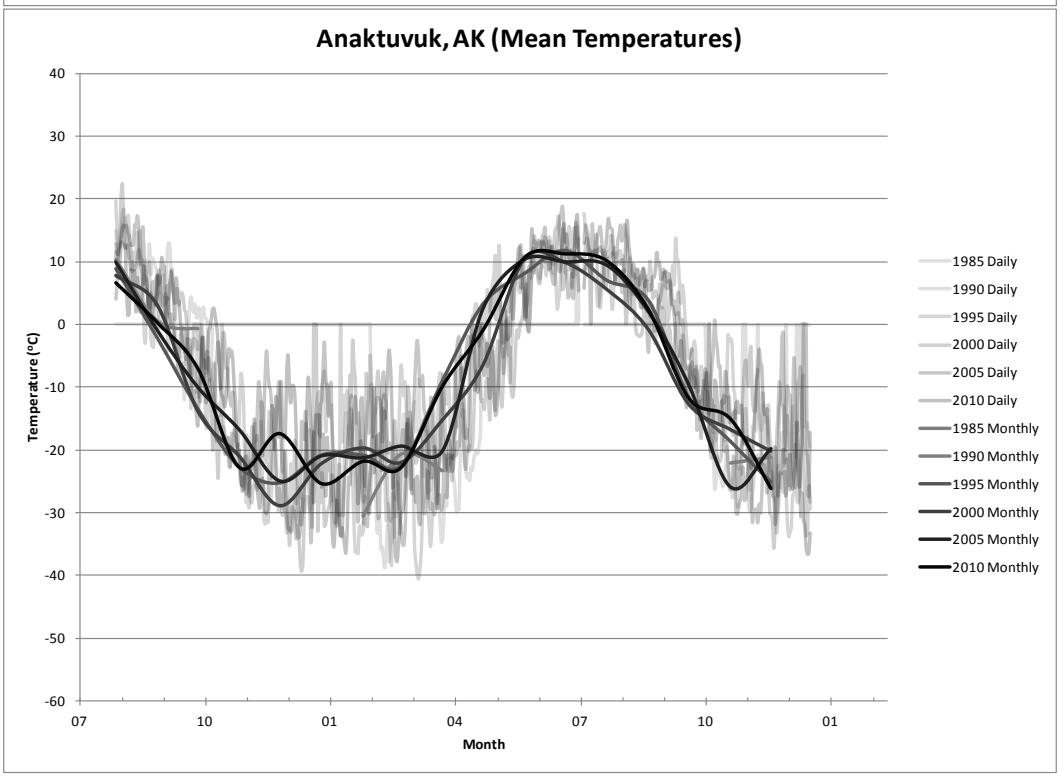

Anaktuvuk, AK: Weekly Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1980
1984
1988
1992
1996
2000
2004
2008
Year
Mean
Median
Mode

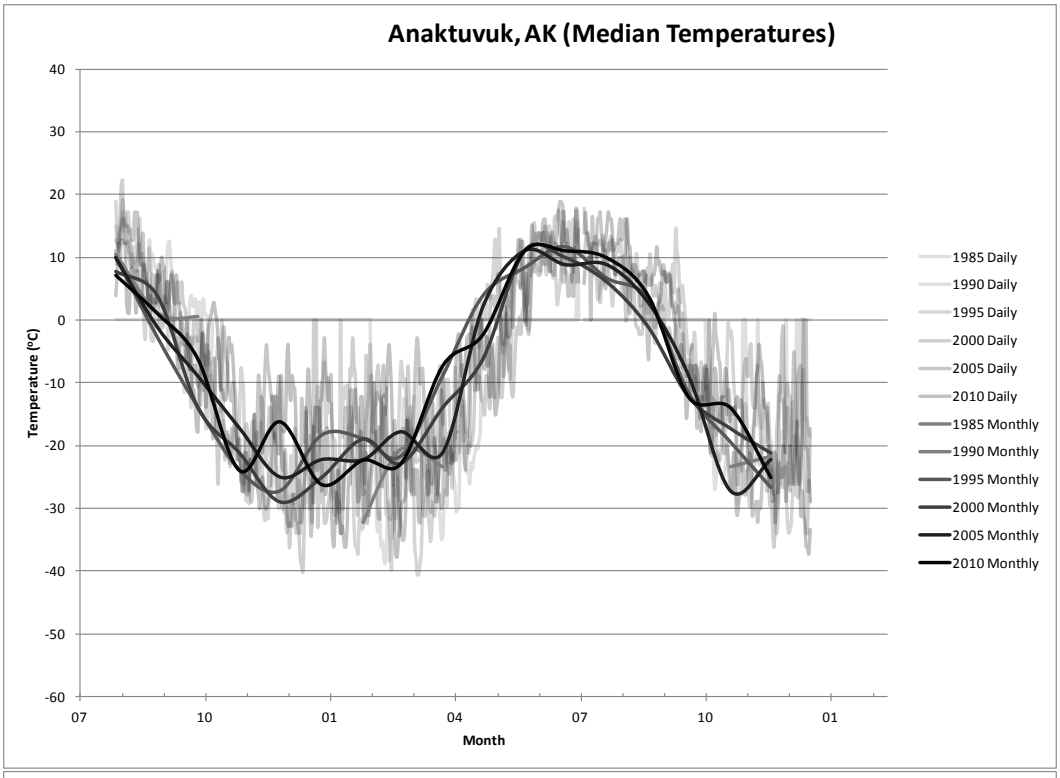

Anaktuvuk, AK: Monthly Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1980
1984
1988
1992
1996
2000
2004
2008
Year
Mean
Median
Mode

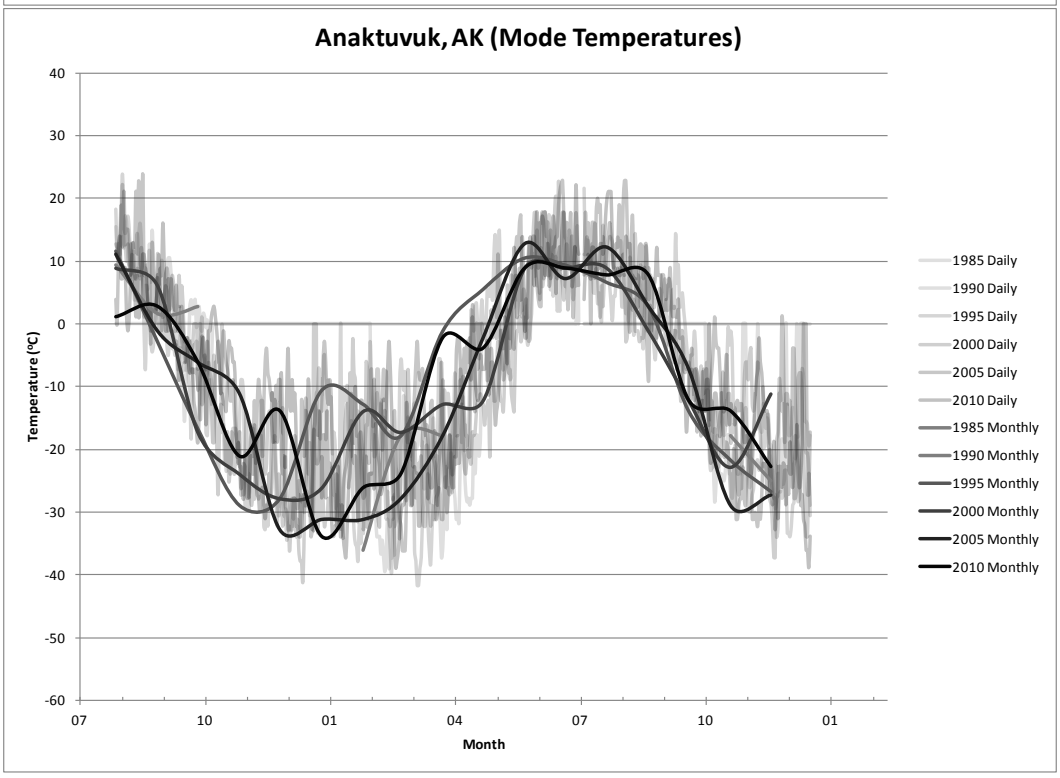

Anaktuvuk, AK: Annual Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1980
1984
1988
1992
1996
2000
2004
2008
Year
Mean
Median
Mode

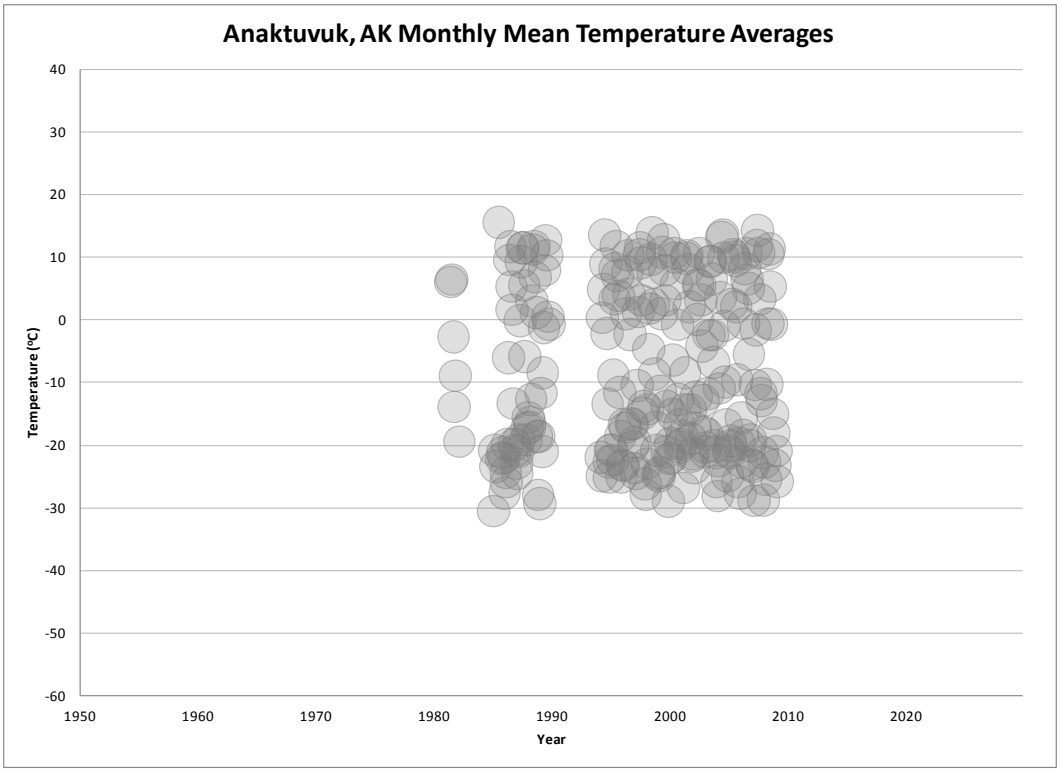

Anaktuvuk (A) Linear Temperature Trend Projections
Temperature (°C)
20
15
10
5
0
-5
-10
-15
-20
1965
1975
1985
1995
2005
2015
2025
2035
2045
2055
2065
2075
2085
2095
Year
Known Data
A Daily Mean
A Weekly Mean
A Monthly Mean
A Daily Median
A Weekly Median
A Monthly Median
A Daily Mode
A Weekly Mode
A Monthly Mode


Anaktuvuk, AK
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
12
06
12
06
12
06
12
Month
Daily Mean '86-'88
Daily Mean '06-'08
Monthly Mean '86-'88
Monthly Mean '06-'08

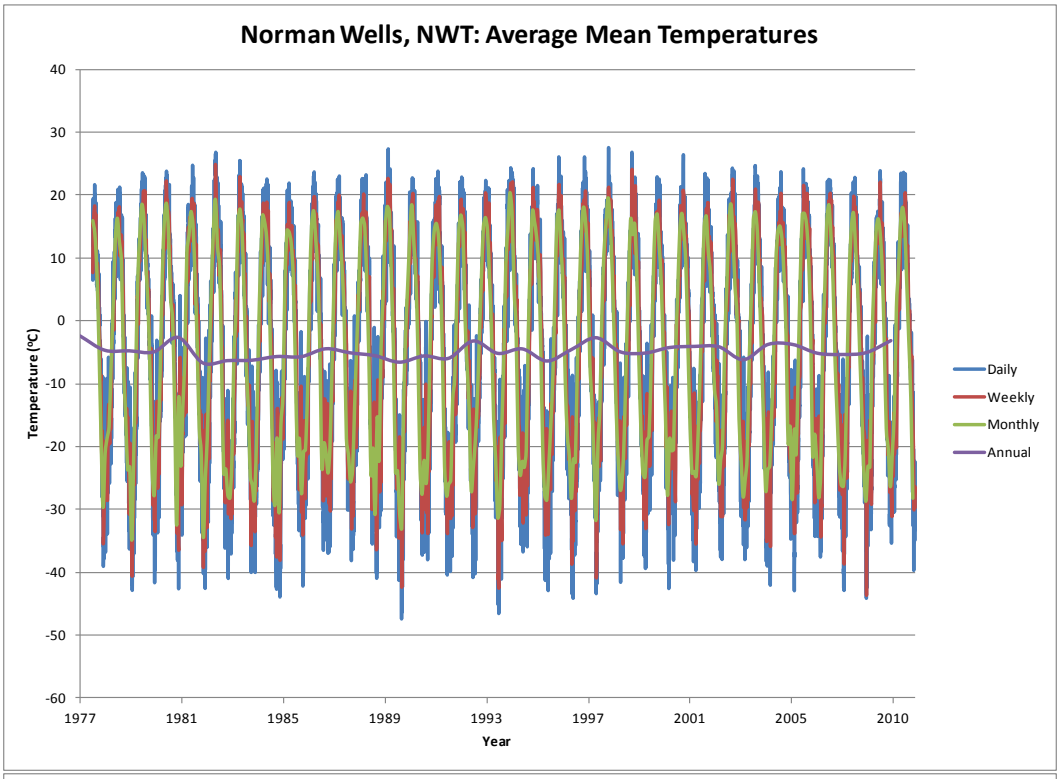

Anaktuvuk, AK (Mean Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

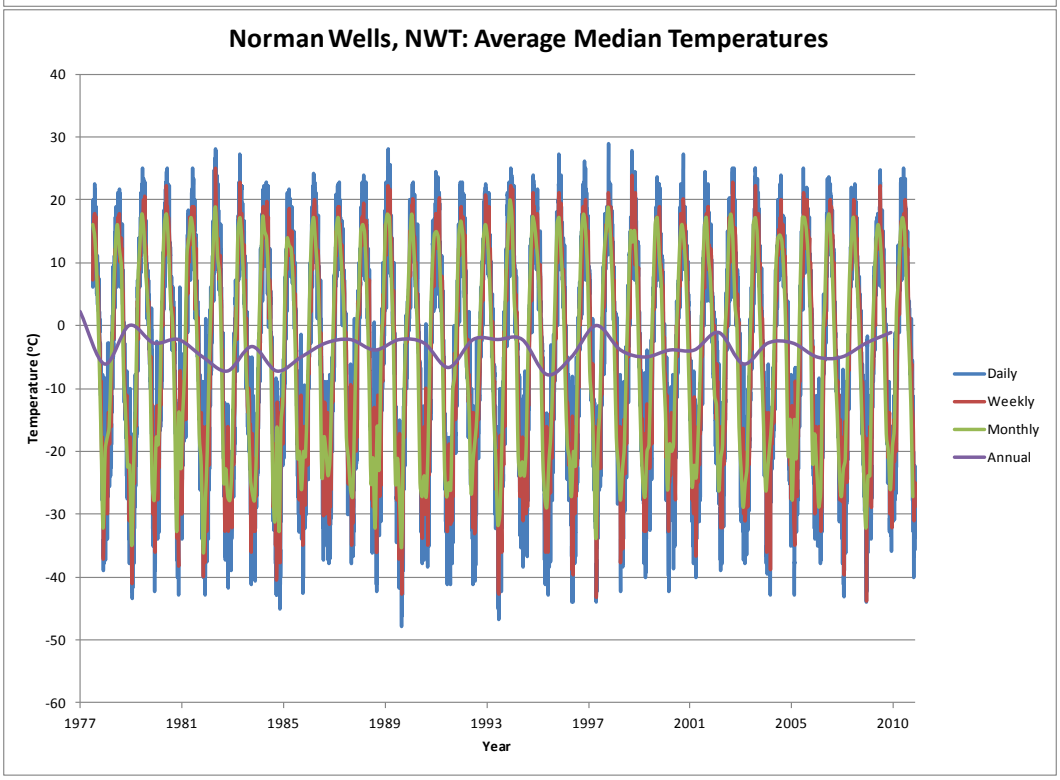

Anaktuvuk, AK (Median Temperatures)
Temperature (ºC)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

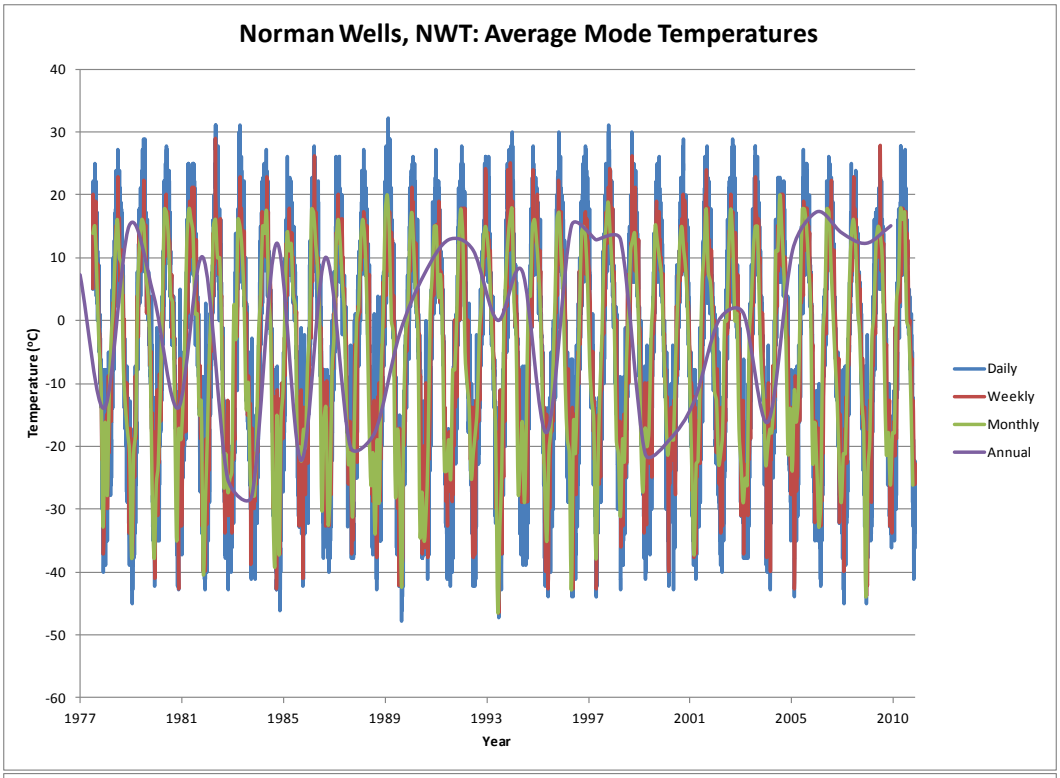

Anaktuvuk, AK (Mode Temperatures)
Temperature (ºC)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

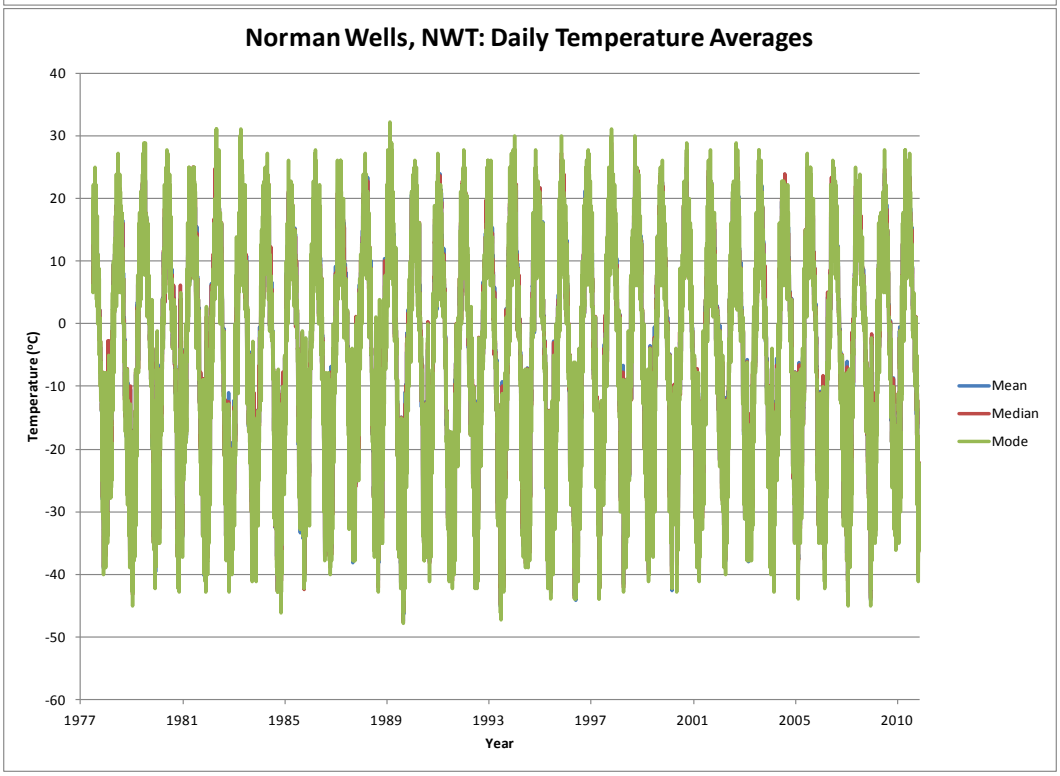

Anaktuvuk, AK Monthly Mean Temperature Averages
40
30
20
10
0
-10
-20
-30
-40
-50
-60
Temperature (°C)
1950
1960
1970
1980
1990
2000
2010
2020
Year

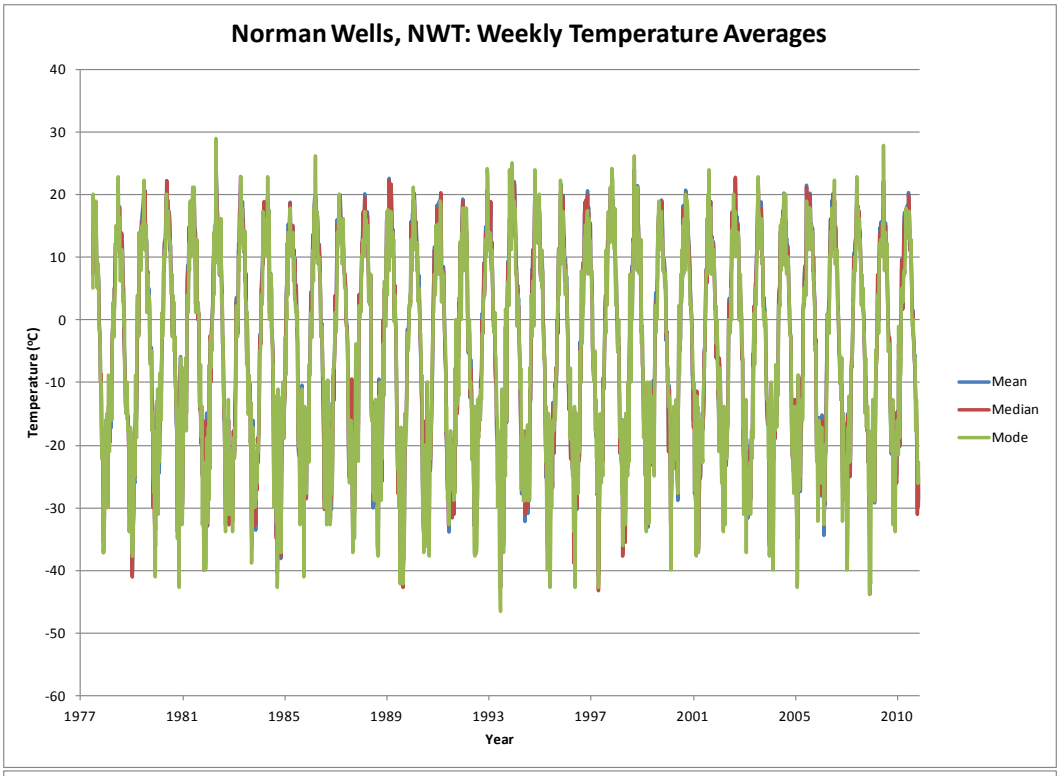
Appendix 4: Norman Wells, Northwest Territories

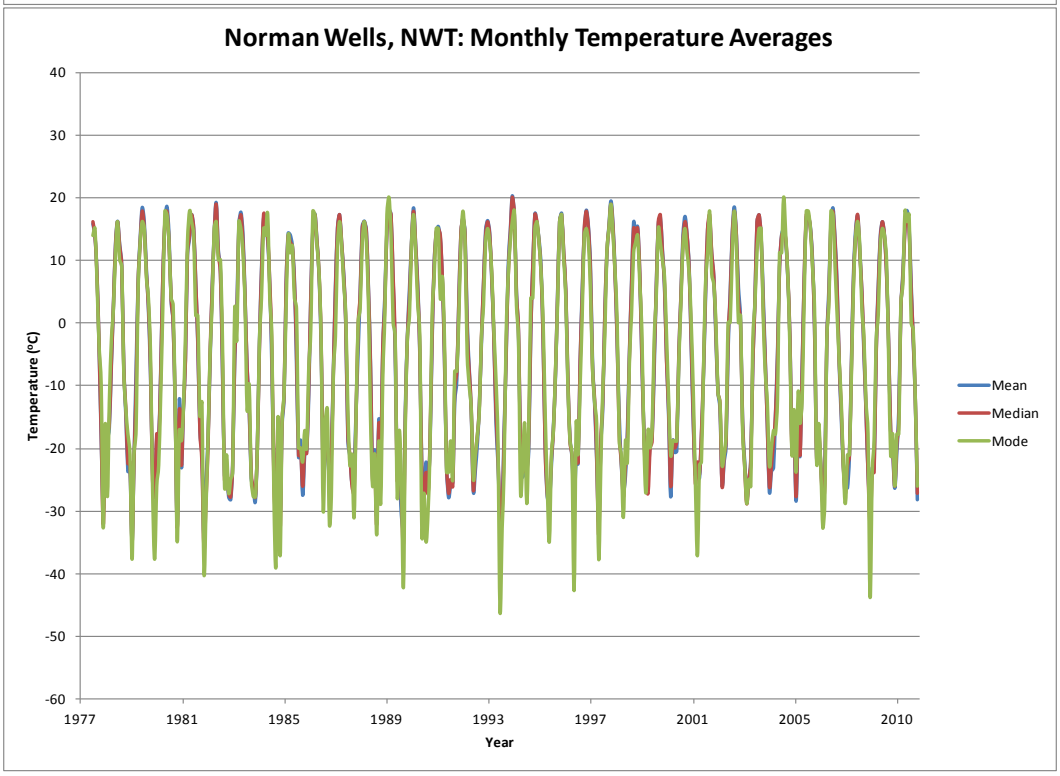


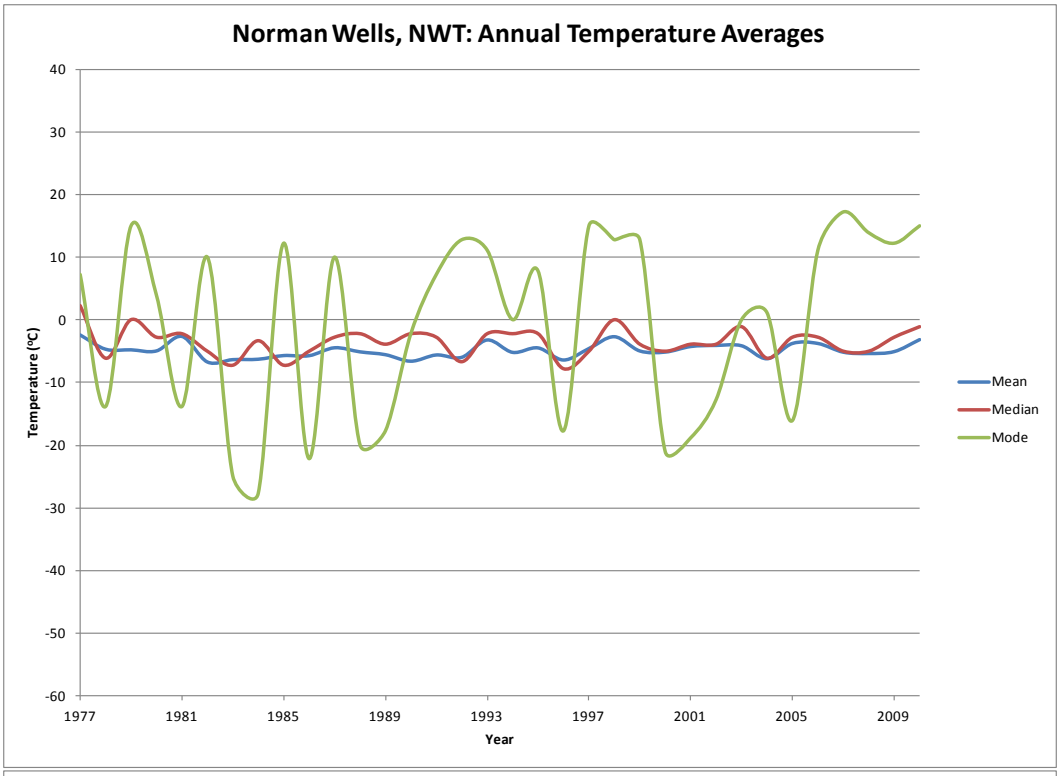


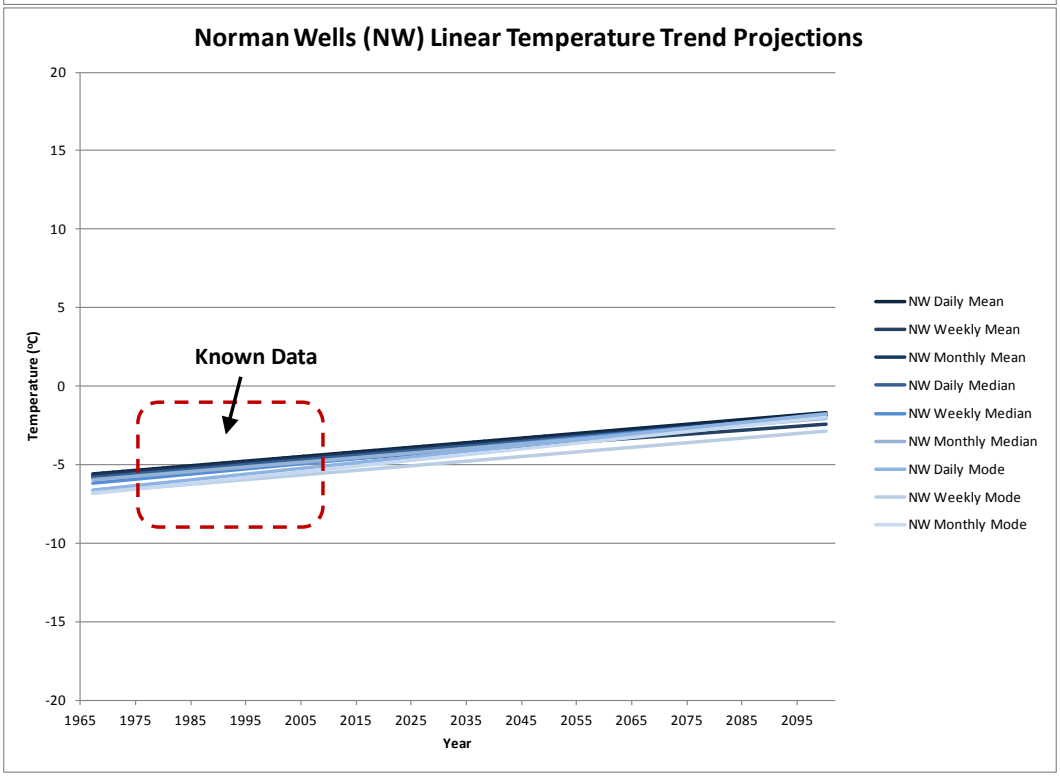

Norman Wells, NWT: Average Mode Temperatures
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2010
Year
Daily
Weekly
Monthly
Annual

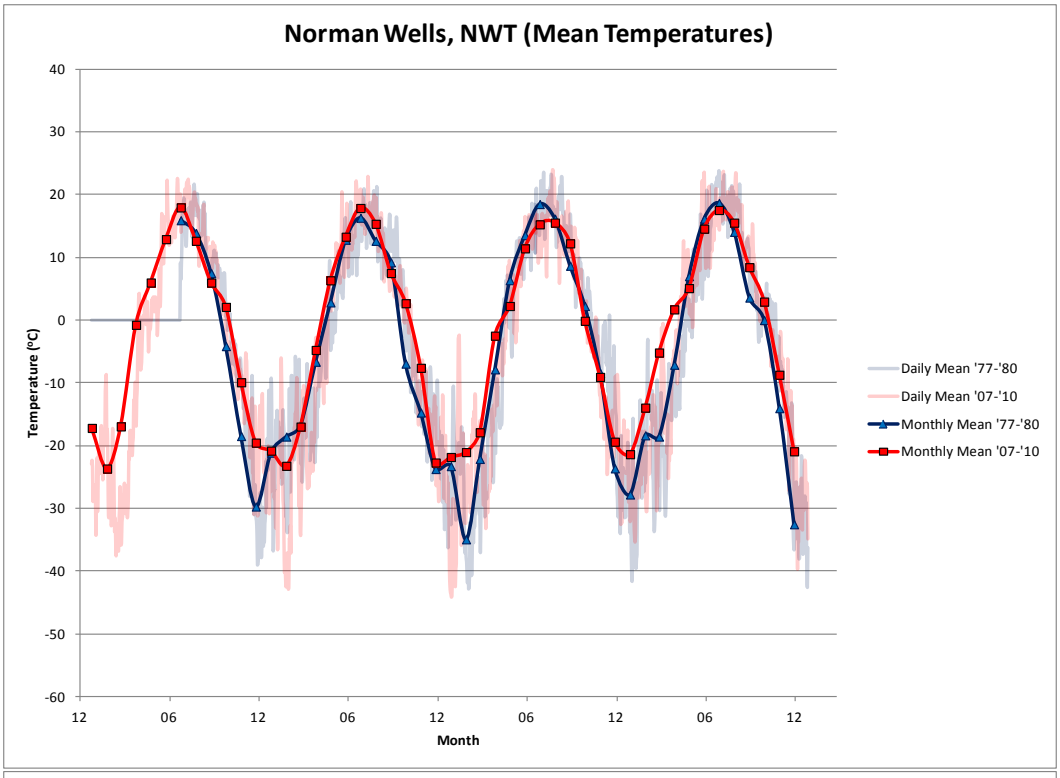

Norman Wells, NWT: Daily Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2010
Year
Mean
Median
Mode

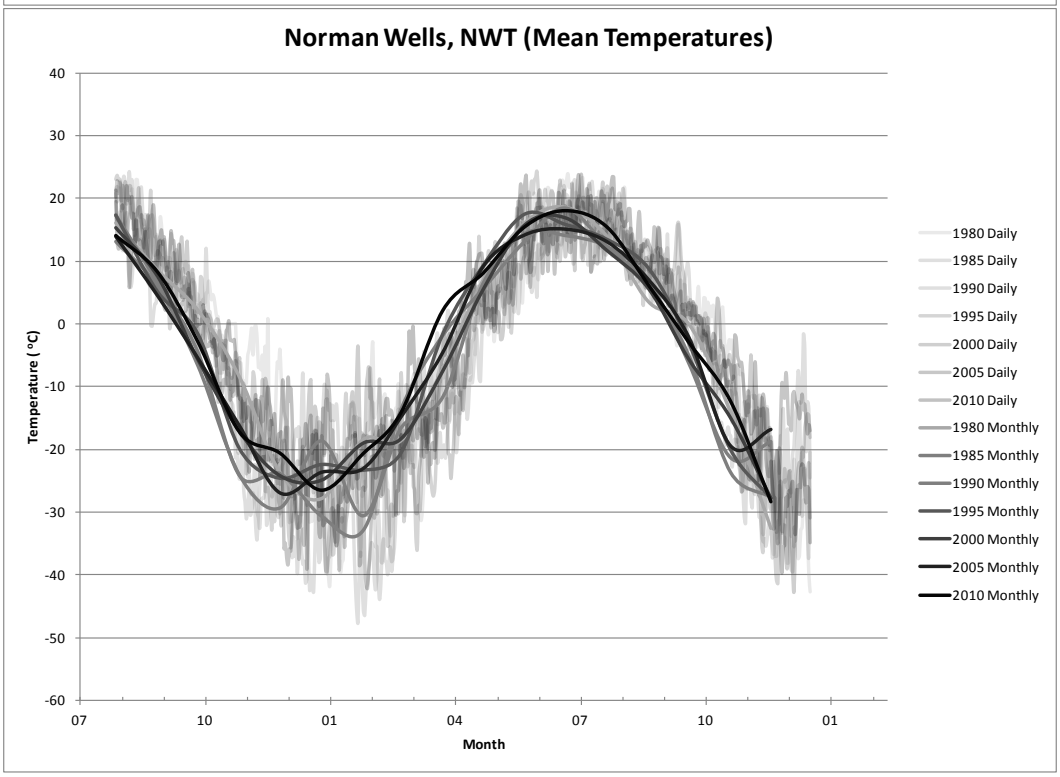

Norman Wells, NWT: Weekly Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2010
Year
Mean
Median
Mode

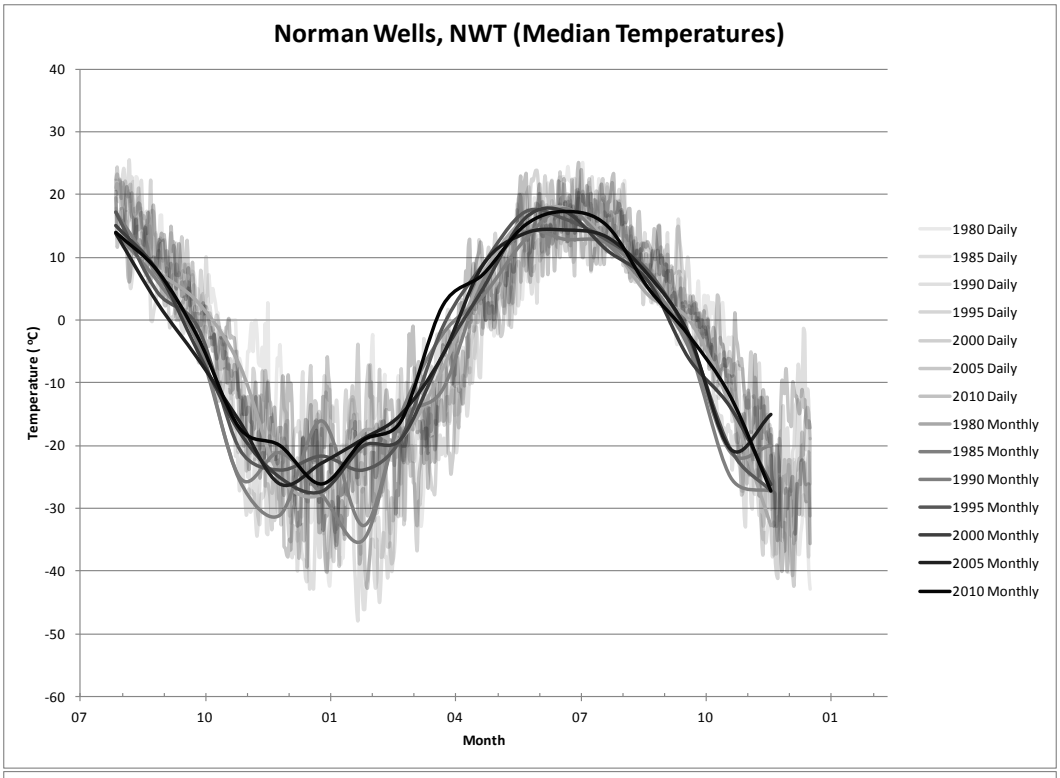

Norman Wells, NWT: Monthly Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2010
Year
Mean
Median
Mode

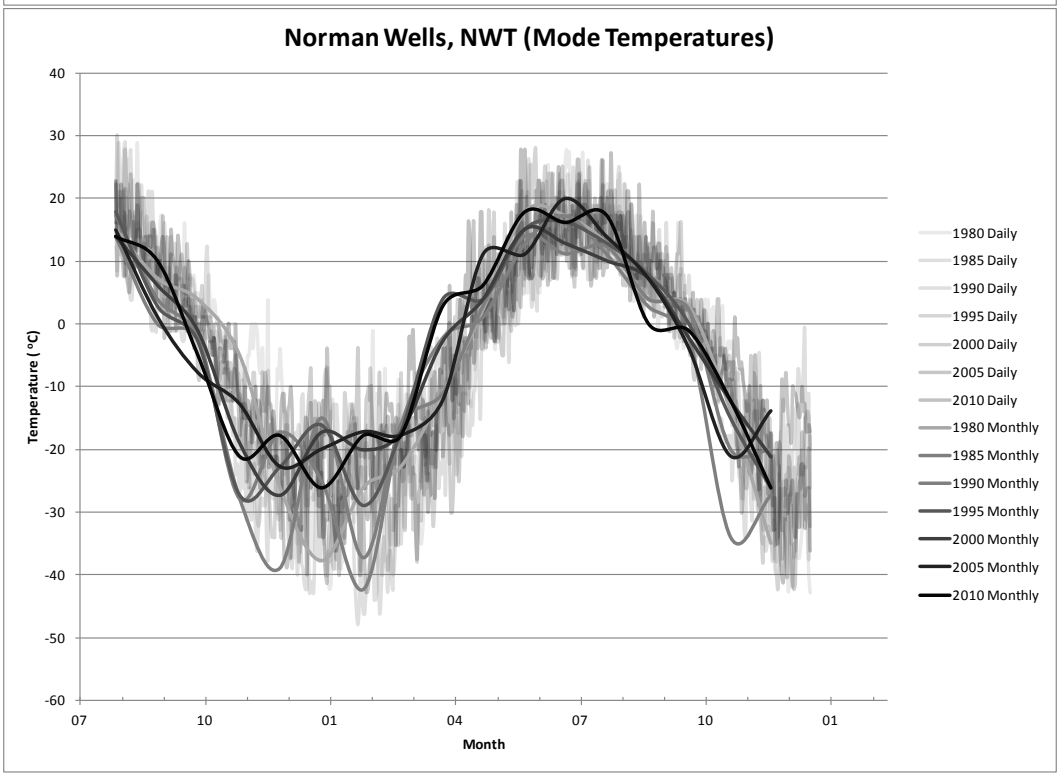

Norman Wells, NWT: Annual Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2009
Year
Mean
Median
Mode

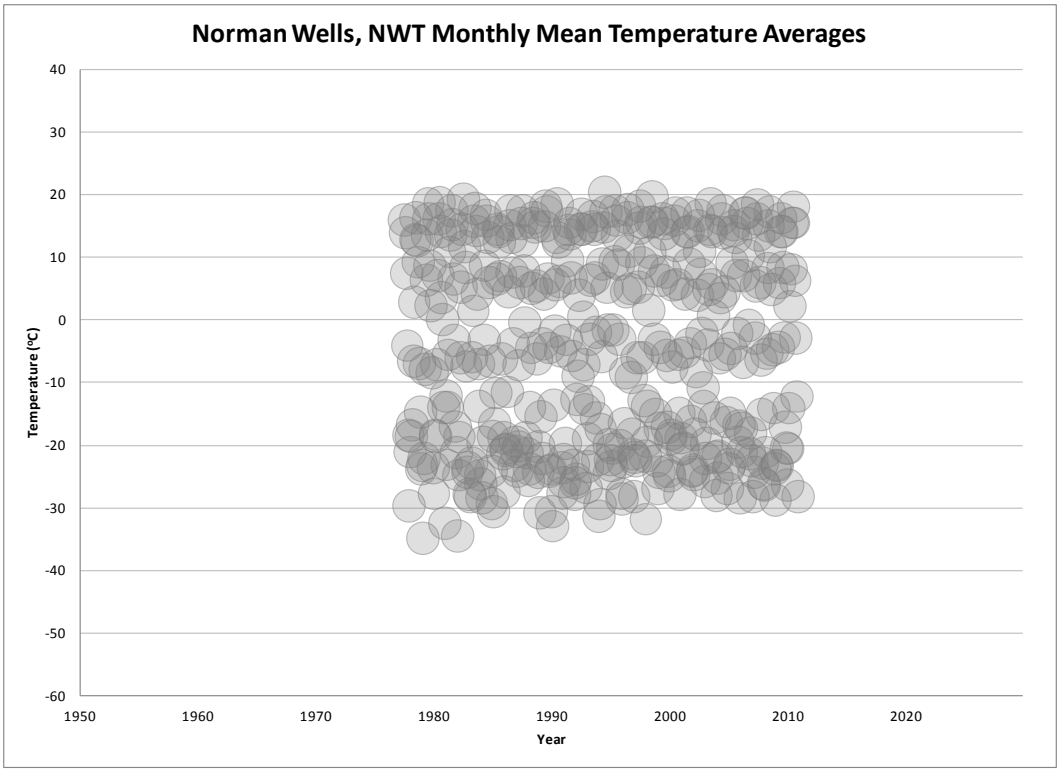

Norman Wells (NW) Linear Temperature Trend Projections
Temperature (°C)
20
15
10
5
0
-5
-10
-15
-20
Known Data
1965
1975
1985
1995
2005
2015
2025
2035
2045
2055
2065
2075
2085
2095
Year
NW Daily Mean
NW Weekly Mean
NW Monthly Mean
NW Daily Median
NW Weekly Median
NW Monthly Median
NW Daily Mode
NW Weekly Mode
NW Monthly Mode


Norman Wells, NWT (Mean Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
12
06
12
06
12
06
12
06
12
Month
Daily Mean '77-'80
Daily Mean '07-'10
Monthly Mean '77-'80
Monthly Mean '07-'10

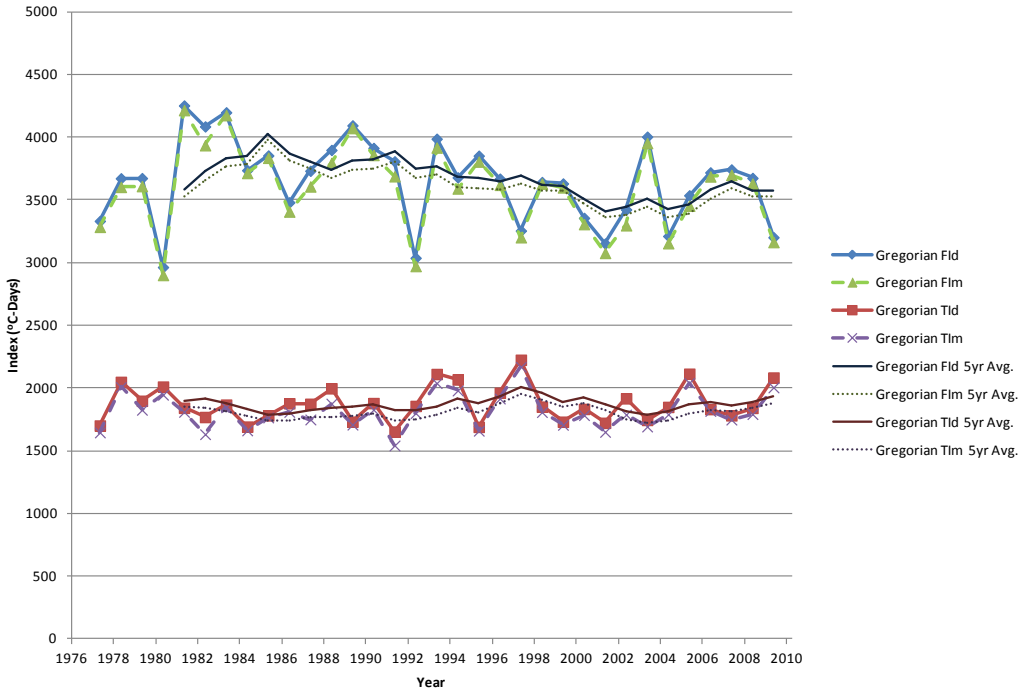

Norman Wells, NWT (Mean Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly


Norman Wells, NWT (Median Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

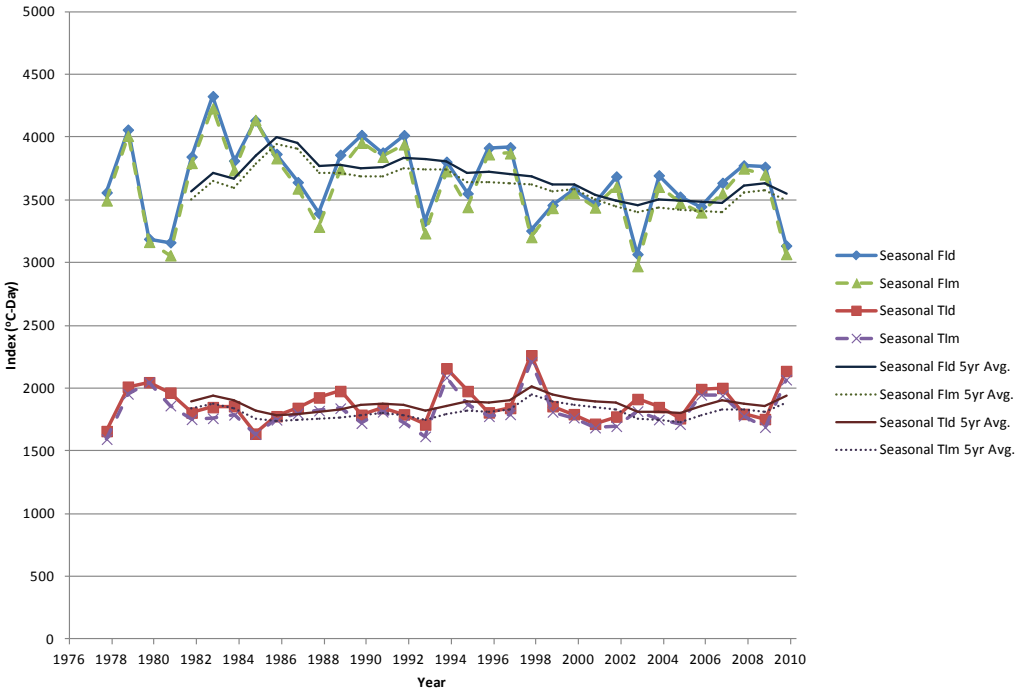

Norman Wells, NWT (Mode Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly



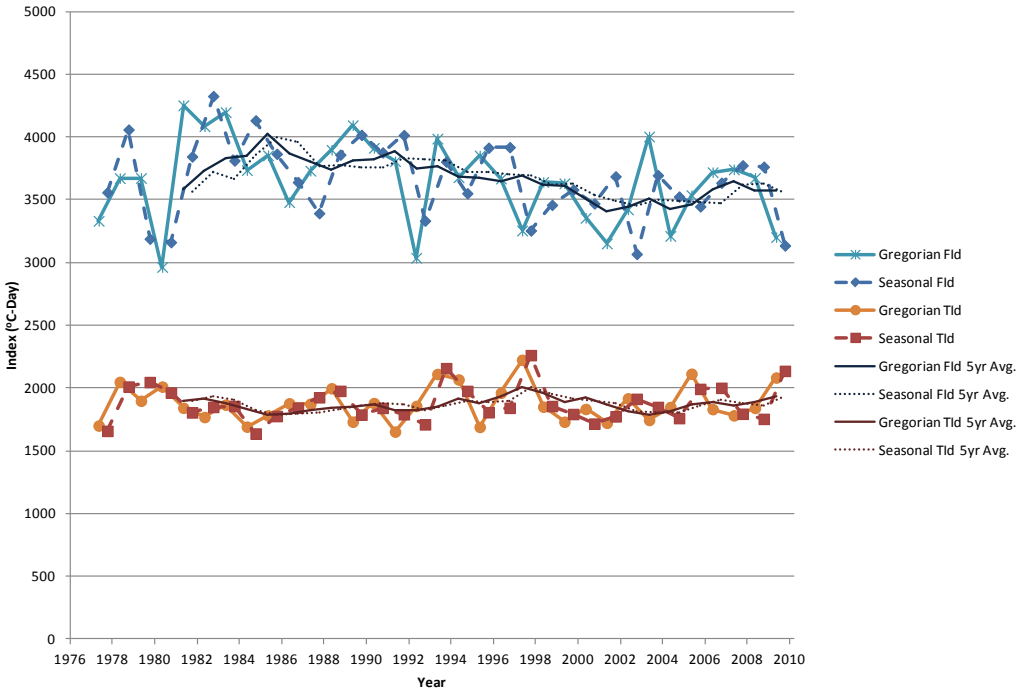
Norman Wells Daily and Monthly FI and TI with respect to a Gregorian calendar cycle



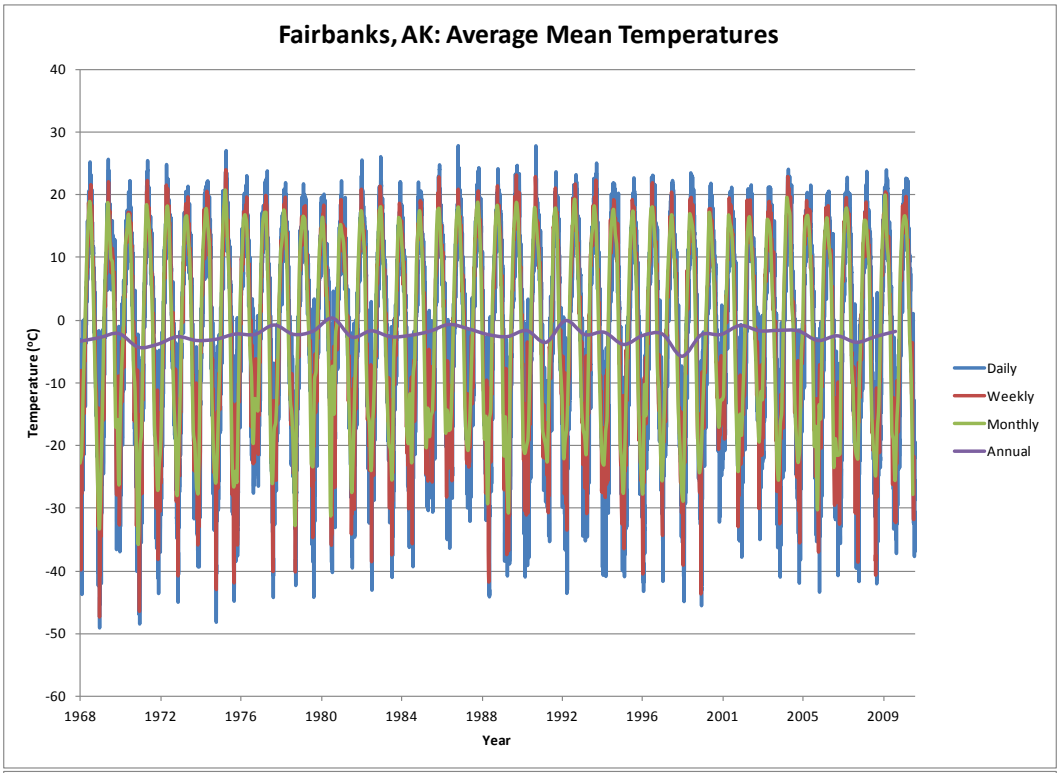
Norman Wells Daily and Monthly FI and TI with respect to a Seasonal calendar cycle

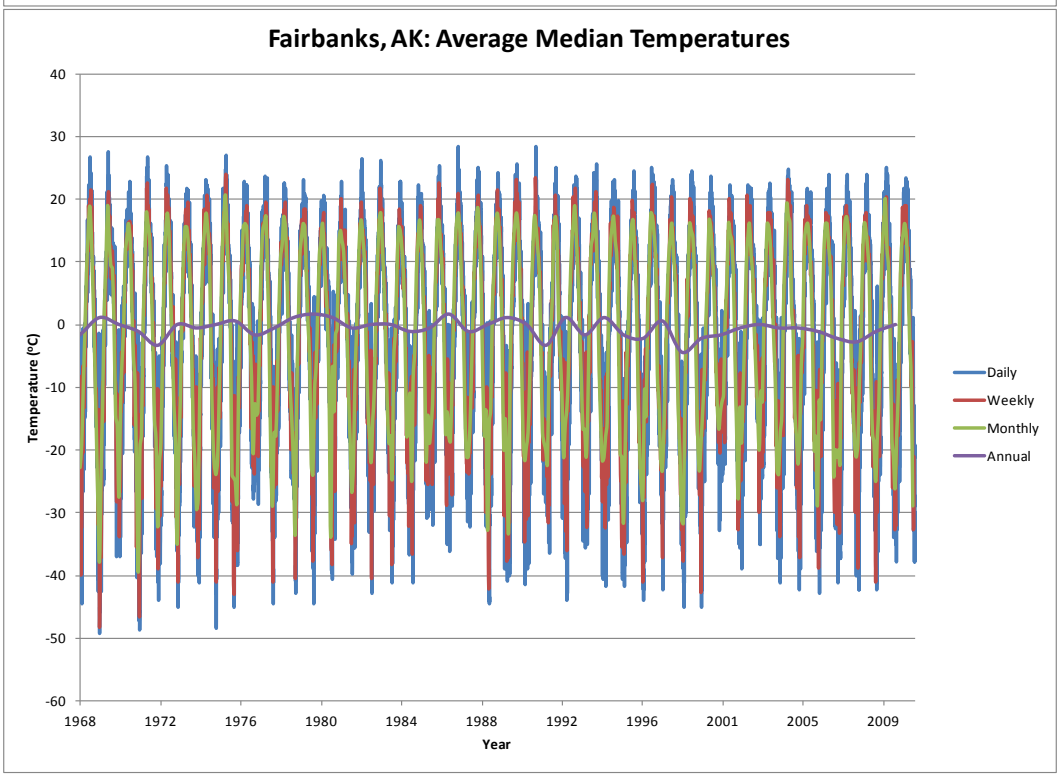


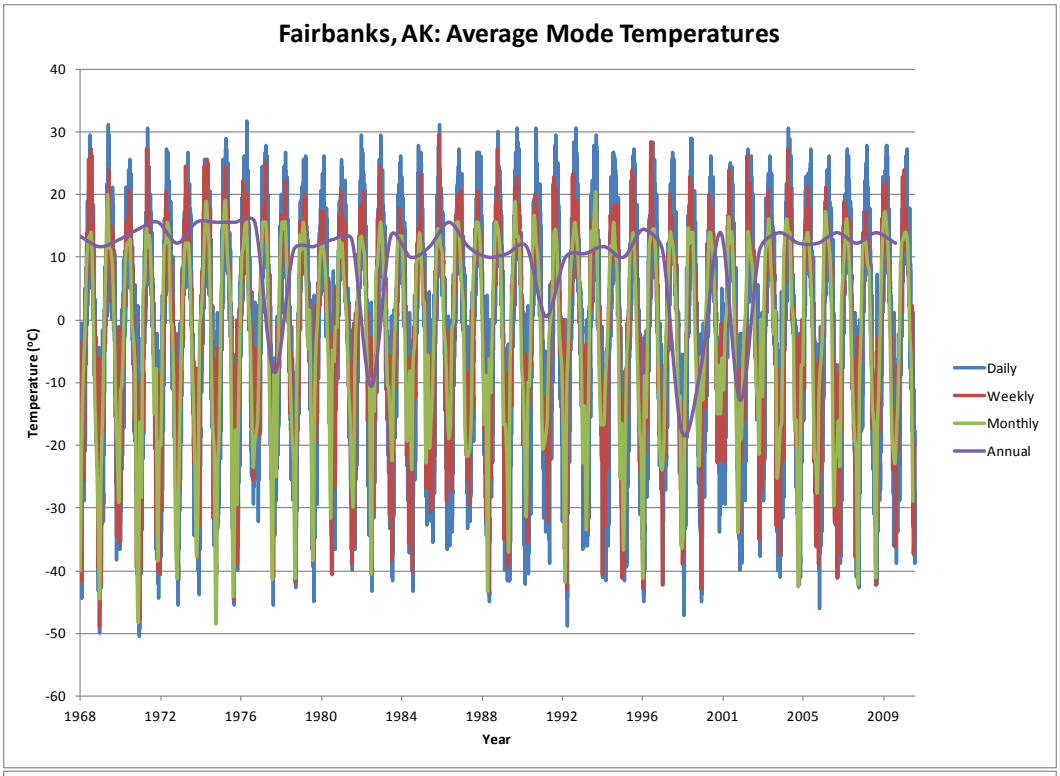
Norman Wells Daily FI and TI with respect to both Gregorian and Seasonal calendar cycles

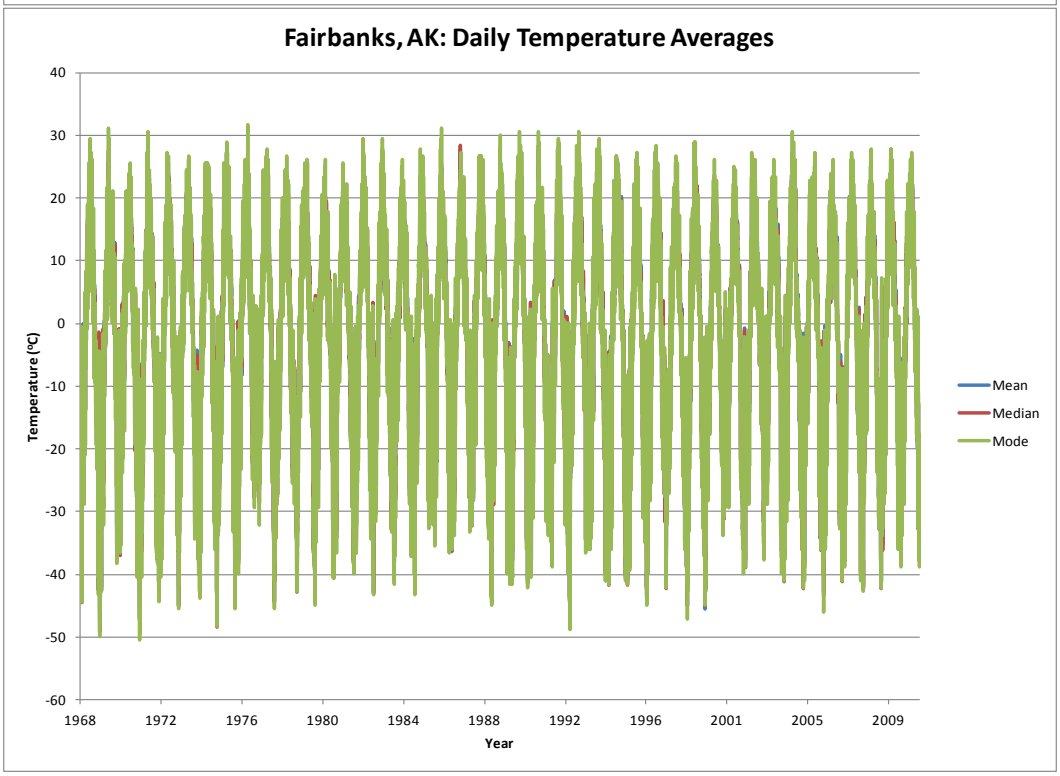


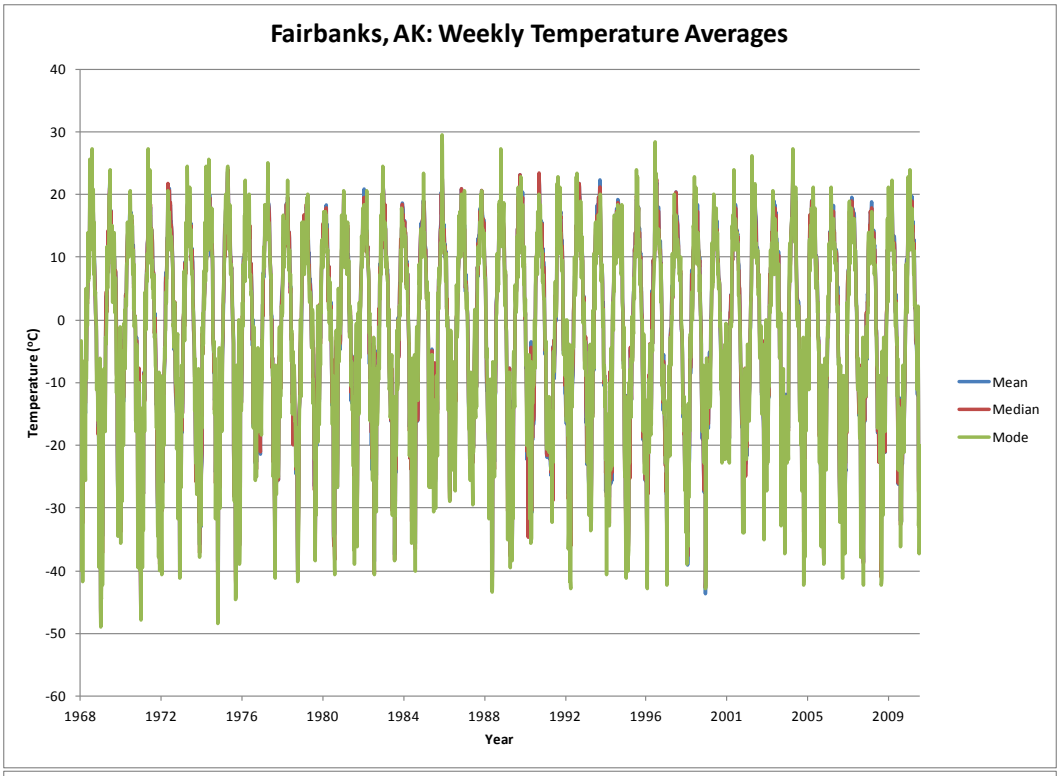
Appendix 5: Fairbanks, Alaska

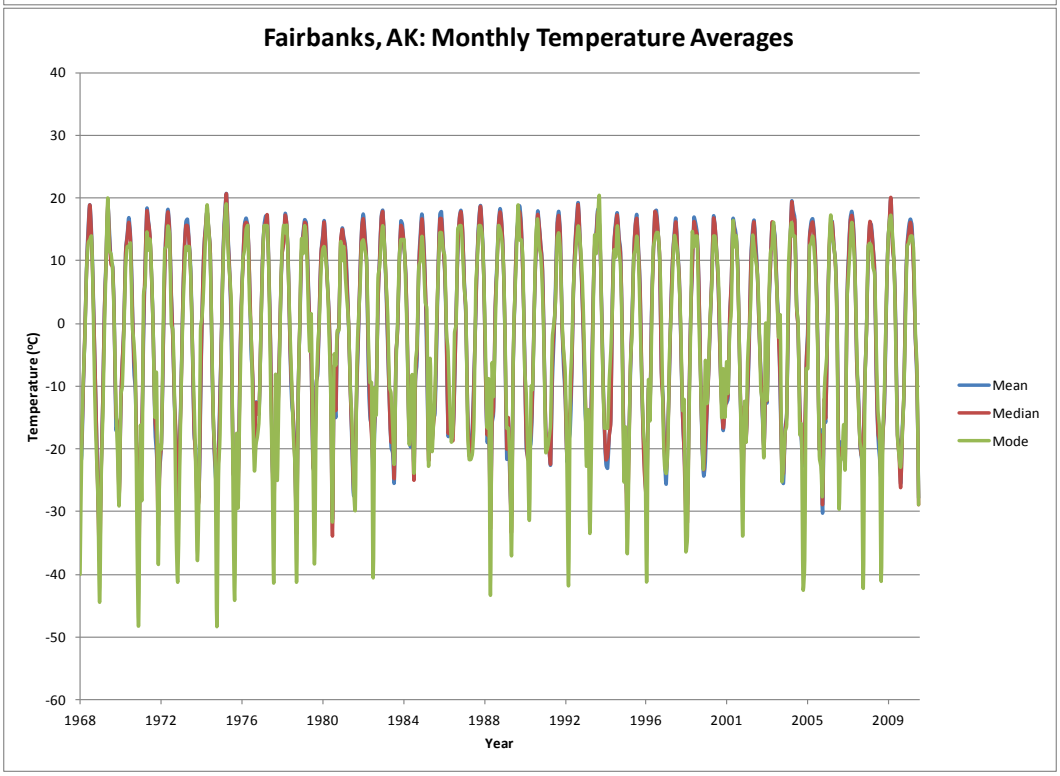


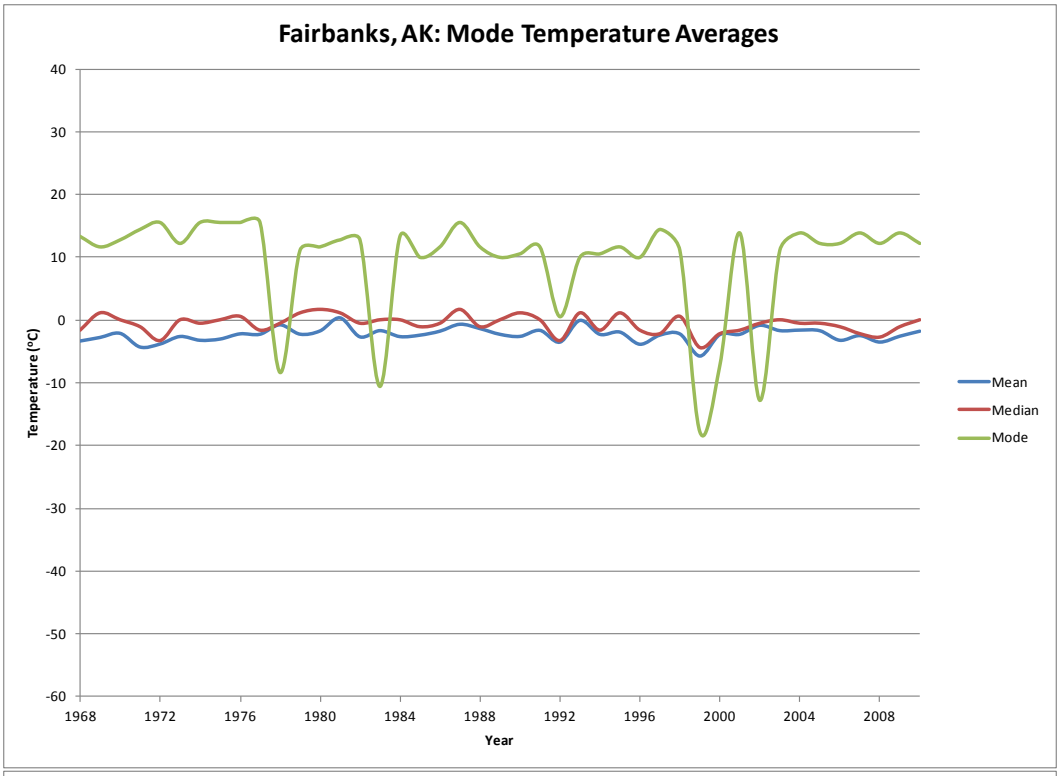


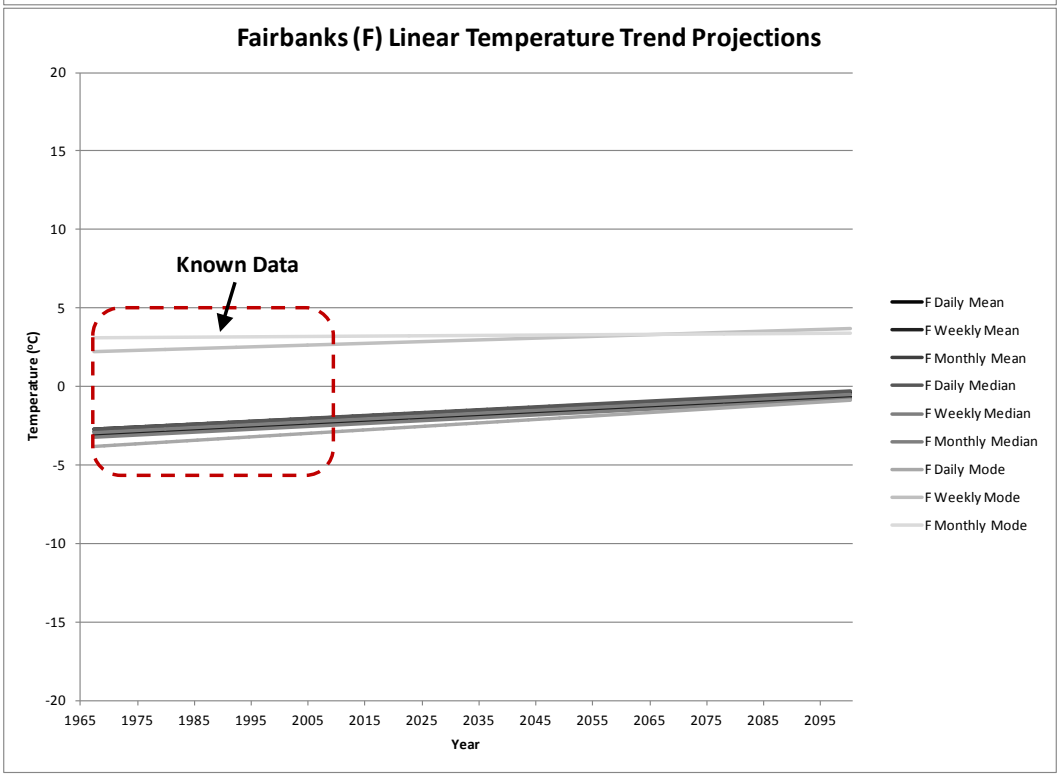

Fairbanks, AK: Average Mode Temperatures
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1968
1972
1976
1980
1984
1988
1992
1996
2001
2005
2009
Year
Daily
Weekly
Monthly
Annual

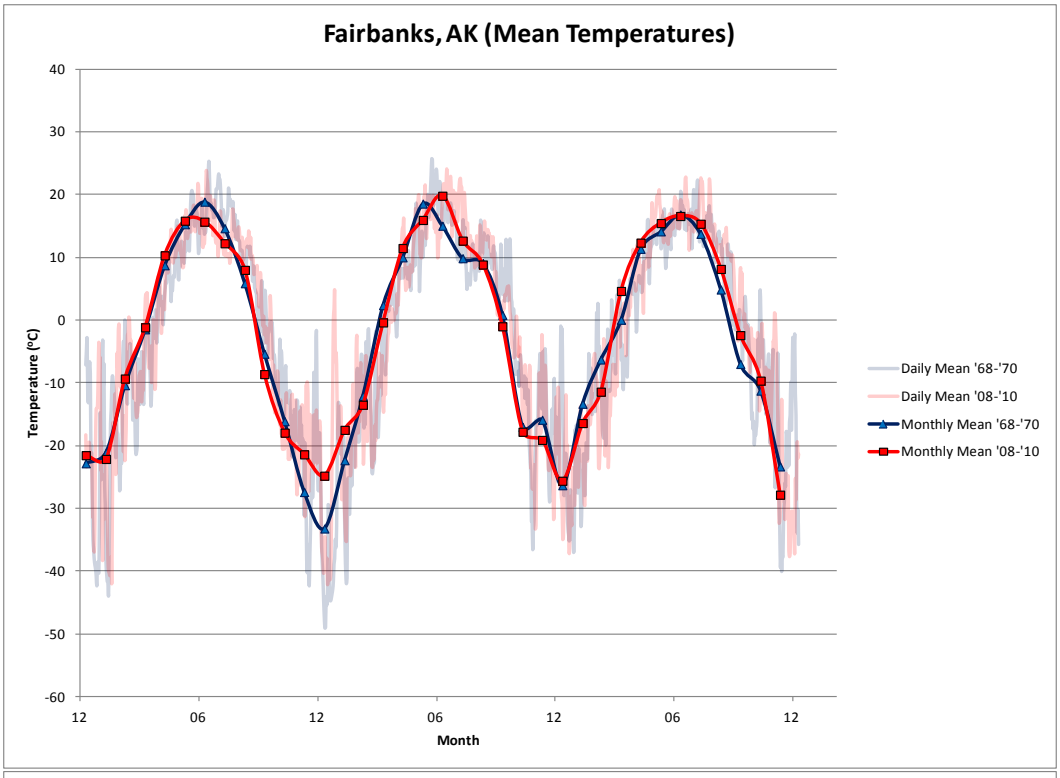

Fairbanks, AK: Daily Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1968
1972
1976
1980
1984
1988
1992
1996
2001
2005
2009
Year
Mean
Median
Mode

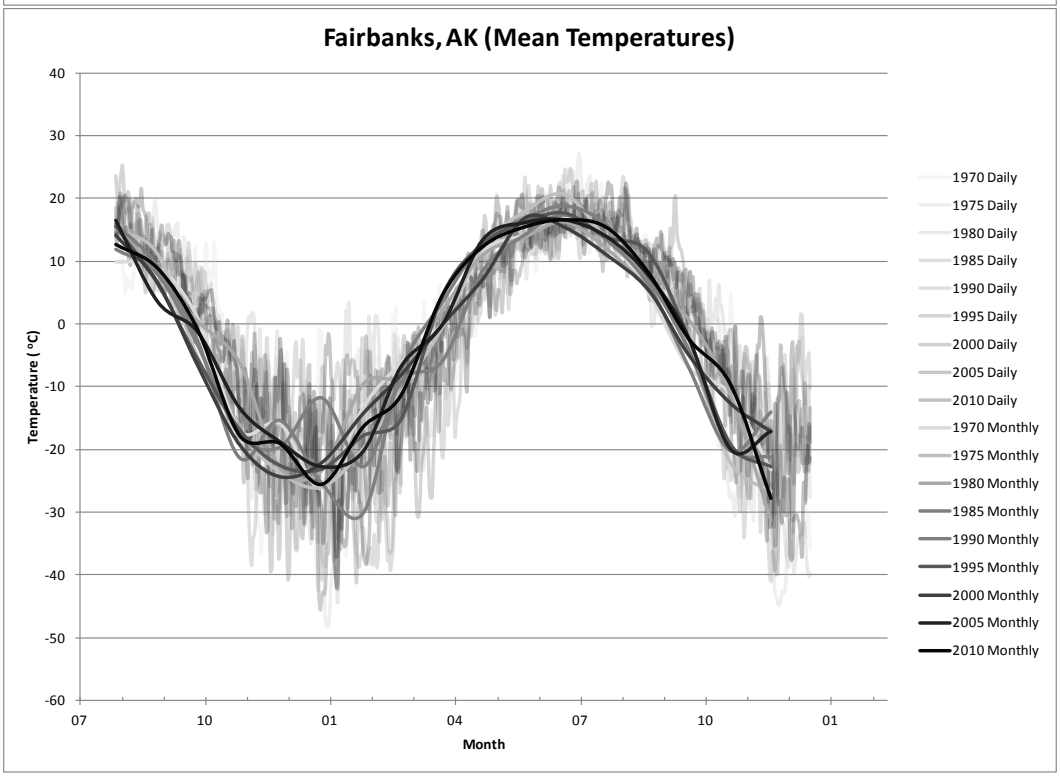

Fairbanks, AK: Weekly Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1968
1972
1976
1980
1984
1988
1992
1996
2001
2005
2009
Year
Mean
Median
Mode

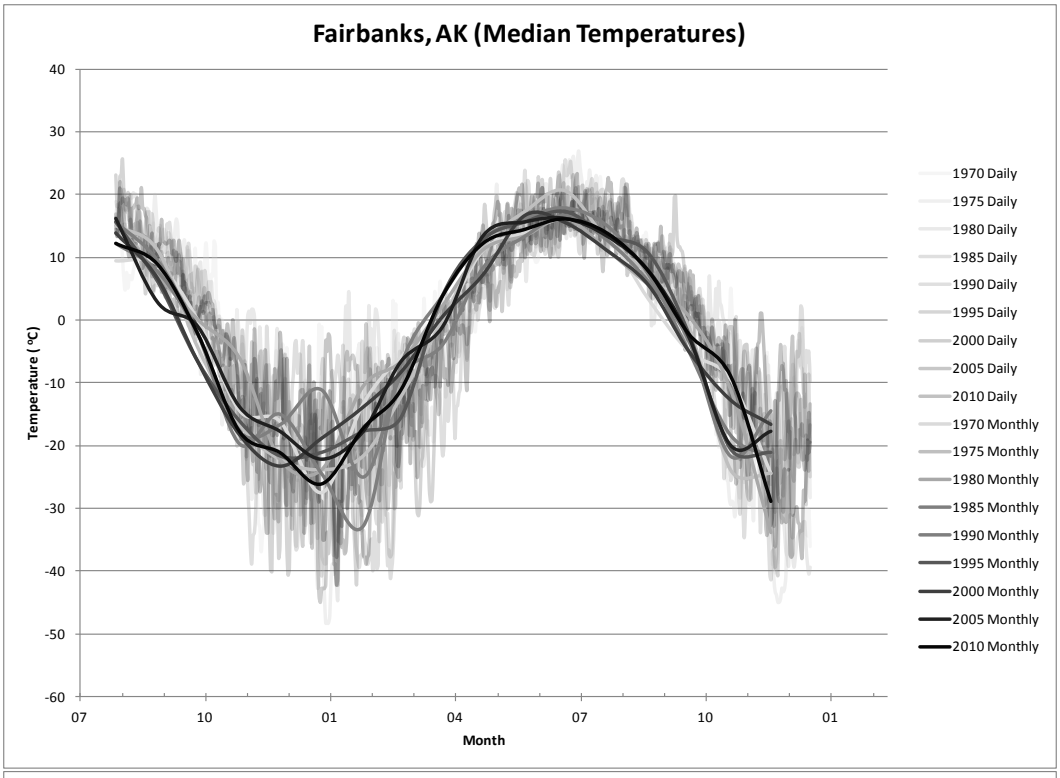

Fairbanks, AK: Monthly Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1968
1972
1976
1980
1984
1988
1992
1996
2001
2005
2009
Year
Mean
Median
Mode

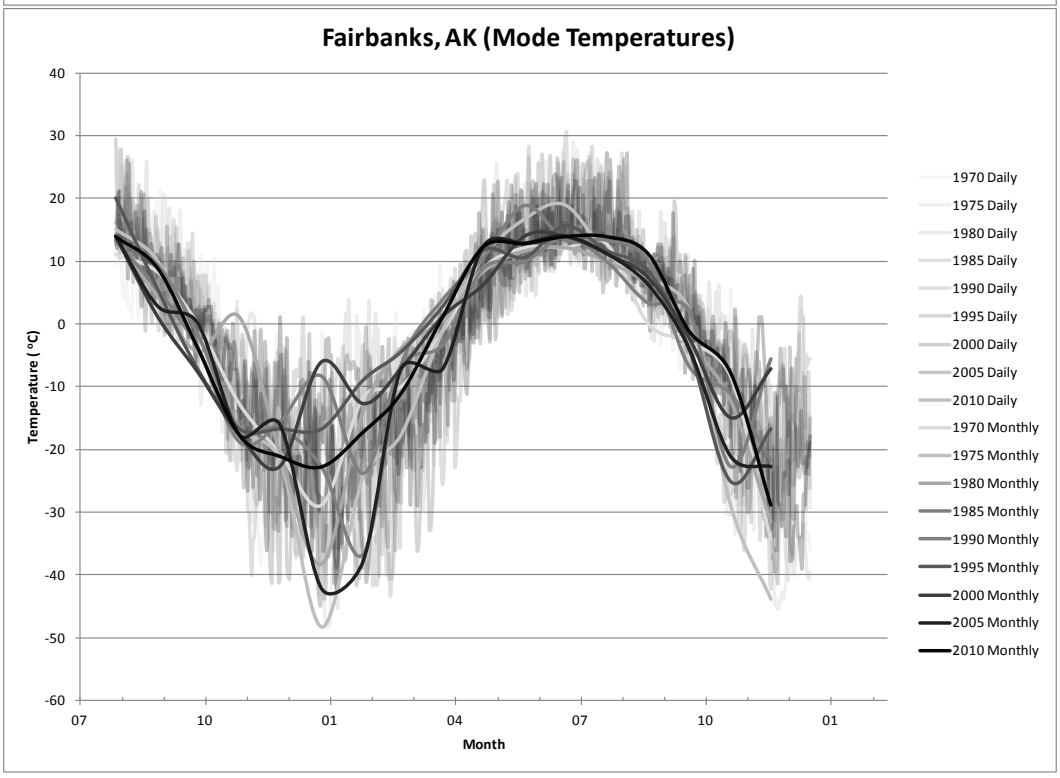

Fairbanks, AK: Mode Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
2008
Year
Mean
Median
Mode

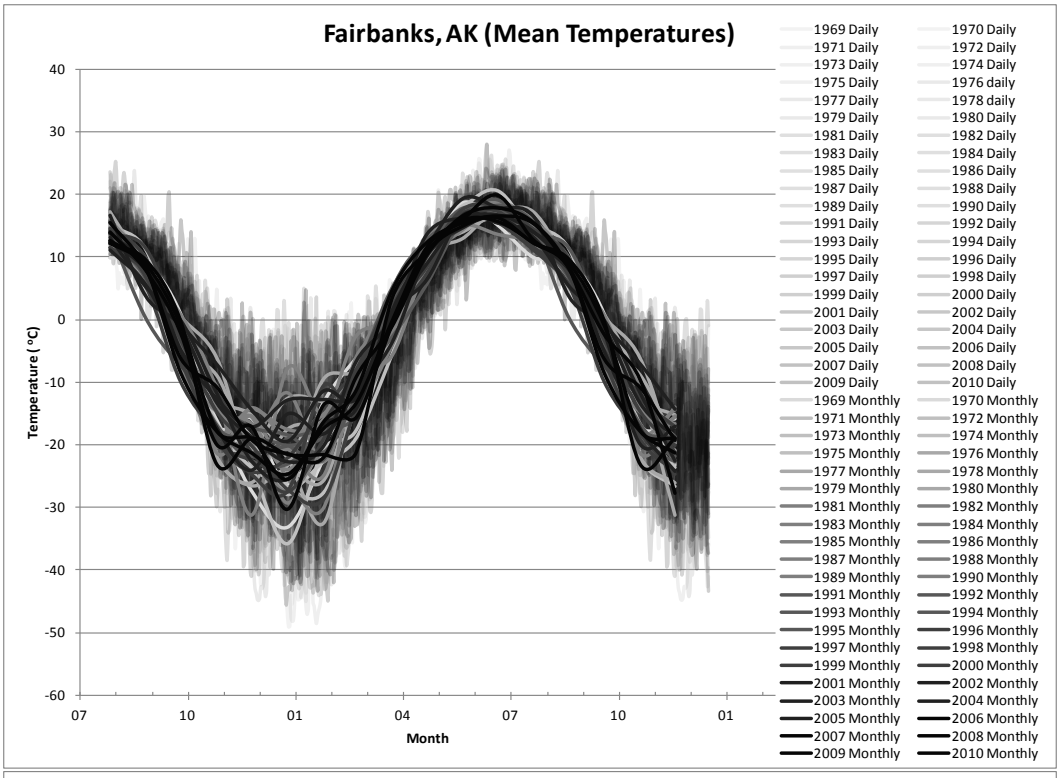

Fairbanks (F) Linear Temperature Trend Projections
Temperature (°C)
20
15
10
5
0
-5
-10
-15
-20
1965
1975
1985
1995
2005
2015
2025
2035
2045
2055
2065
2075
2085
2095
Year
Known Data
F Daily Mean
F Weekly Mean
F Monthly Mean
F Daily Median
F Weekly Median
F Monthly Median
F Daily Mode
F Weekly Mode
F Monthly Mode

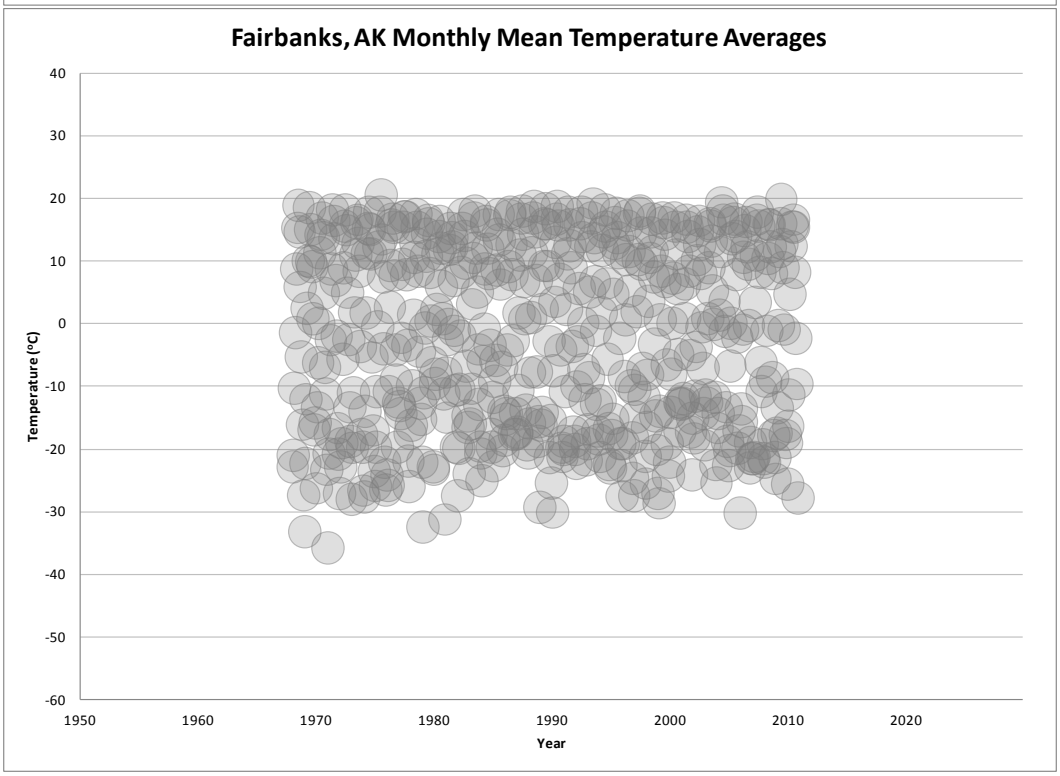

Fairbanks, AK (Mean Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
12
06
12
06
12
06
12
Month
Daily Mean '68-'70
Daily Mean '08-'10
Monthly Mean '68-'70
Monthly Mean '08-'10


Fairbanks, AK (Mean Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1970 Daily
1975 Daily
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1970 Monthly
1975 Monthly
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

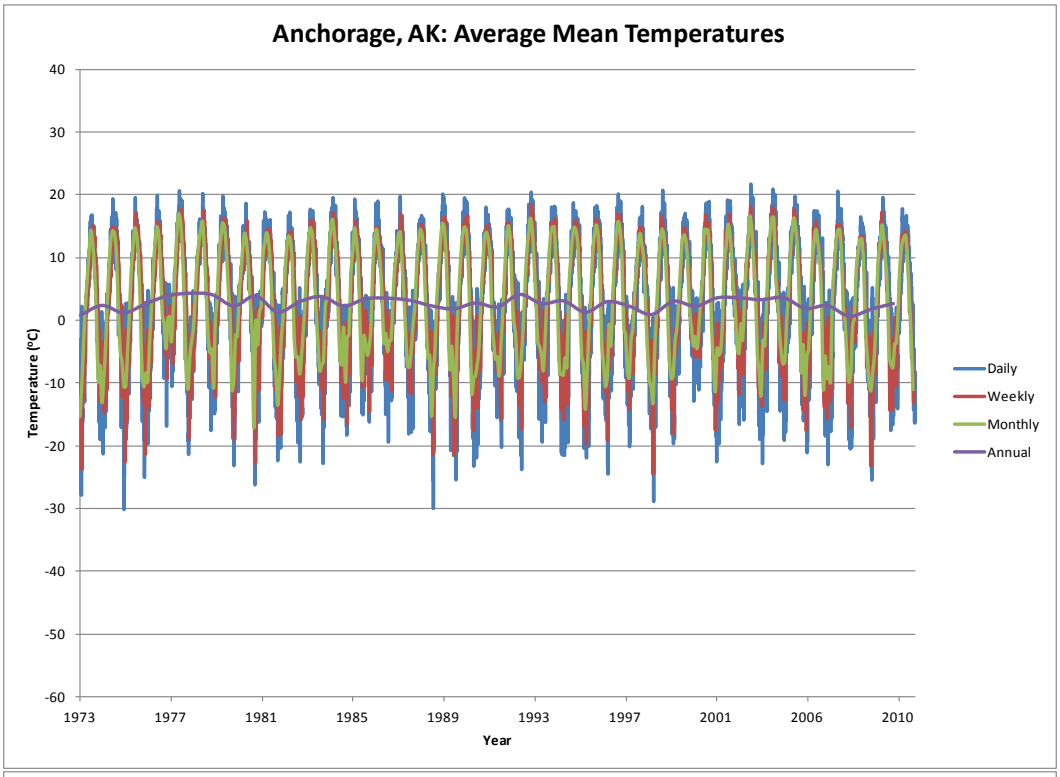

Fairbanks, AK (Median Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1970 Daily
1975 Daily
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1970 Monthly
1975 Monthly
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

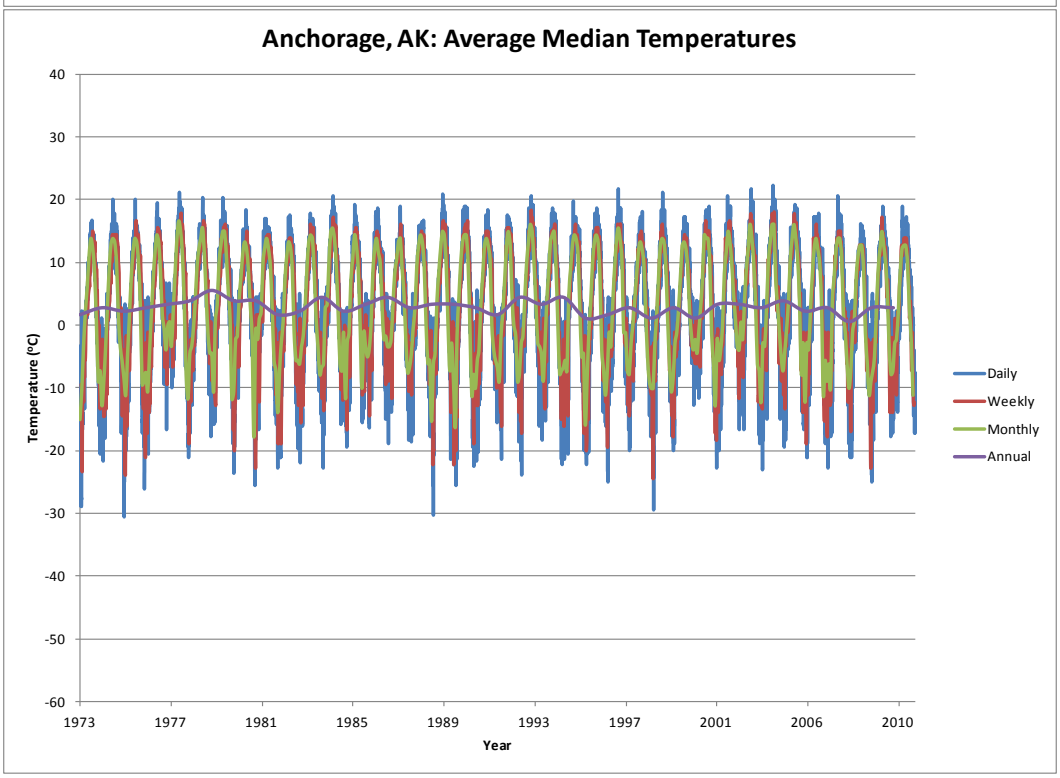

Fairbanks, AK (Mode Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1970 Daily
1975 Daily
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1970 Monthly
1975 Monthly
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

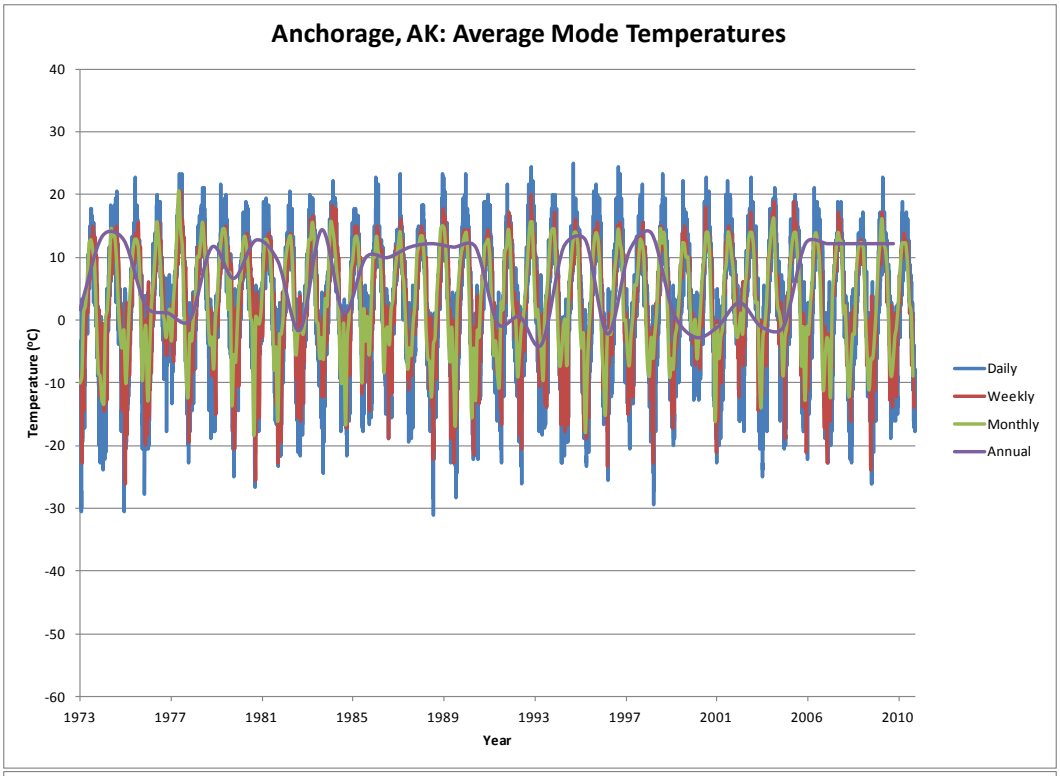

Fairbanks, AK (Mean Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1969 Daily
1970 Daily
1971 Daily
1972 Daily
1973 Daily
1974 Daily
1975 Daily
1976 daily
1977 Daily
1978 daily
1979 Daily
1980 Daily
1981 Daily
1982 Daily
1983 Daily
1984 Daily
1985 Daily
1986 Daily
1987 Daily
1988 Daily
1989 Daily
1990 Daily
1991 Daily
1992 Daily
1993 Daily
1994 Daily
1995 Daily
1996 Daily
1997 Daily
1998 Daily
1999 Daily
2000 Daily
2001 Daily
2002 Daily
2003 Daily
2004 Daily
2005 Daily
2006 Daily
2007 Daily
2008 Daily
2009 Daily
2010 Daily
1969 Monthly
1970 Monthly
1971 Monthly
1972 Monthly
1973 Monthly
1974 Monthly
1975 Monthly
1976 Monthly
1977 Monthly
1978 Monthly
1979 Monthly
1980 Monthly
1981 Monthly
1982 Monthly
1983 Monthly
1984 Monthly
1985 Monthly
1986 Monthly
1987 Monthly
1988 Monthly
1989 Monthly
1990 Monthly
1991 Monthly
1992 Monthly
1993 Monthly
1994 Monthly
1995 Monthly
1996 Monthly
1997 Monthly
1998 Monthly
1999 Monthly
2000 Monthly
2001 Monthly
2002 Monthly
2003 Monthly
2004 Monthly
2005 Monthly
2006 Monthly
2007 Monthly
2008 Monthly
2009 Monthly
2010 Monthly

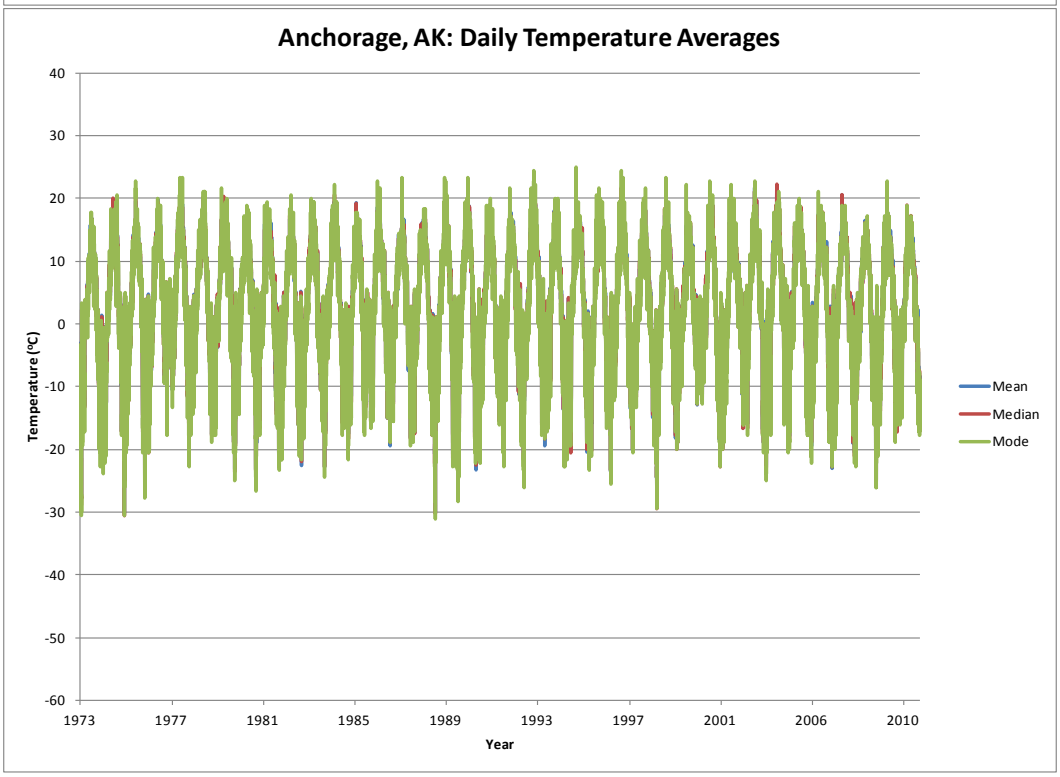

Fairbanks, AK Monthly Mean Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1950
1960
1970
1980
1990
2000
2010
2020
Year

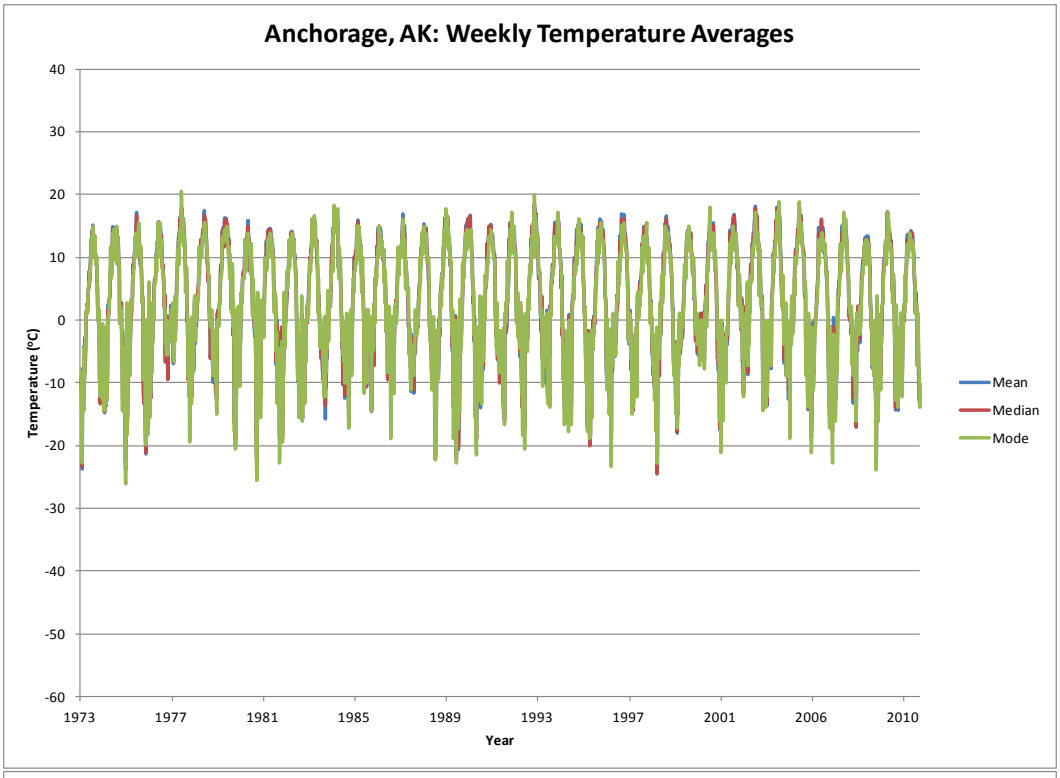
Appendix 6: Anchorage, Alaska

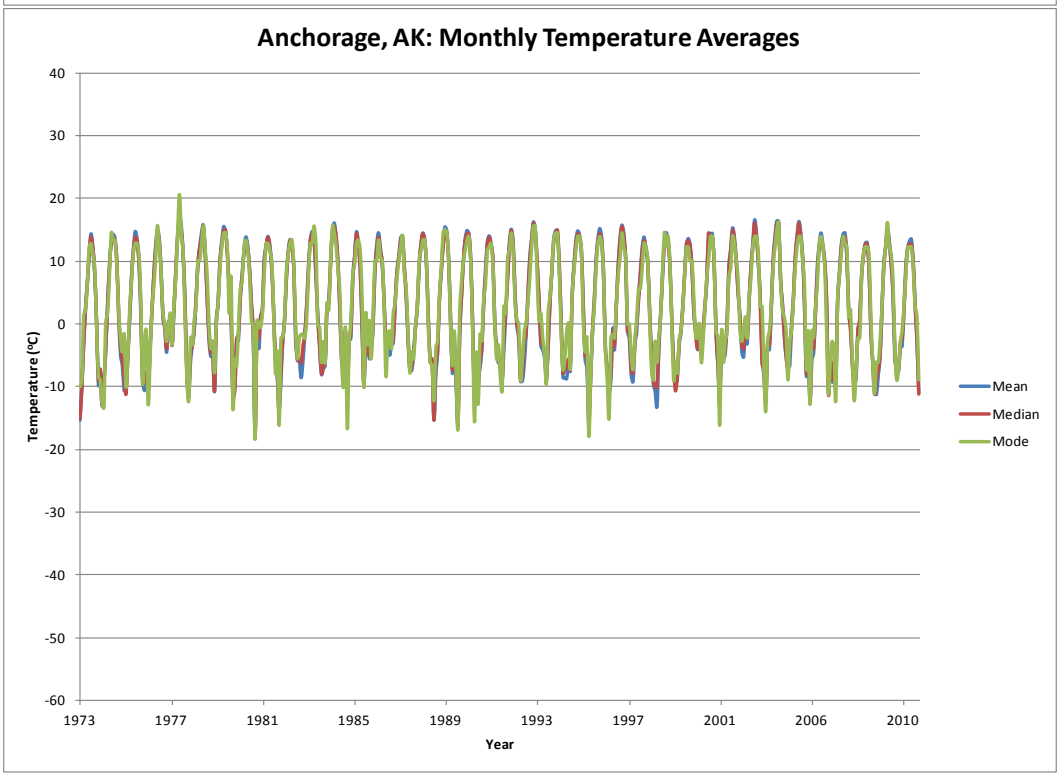


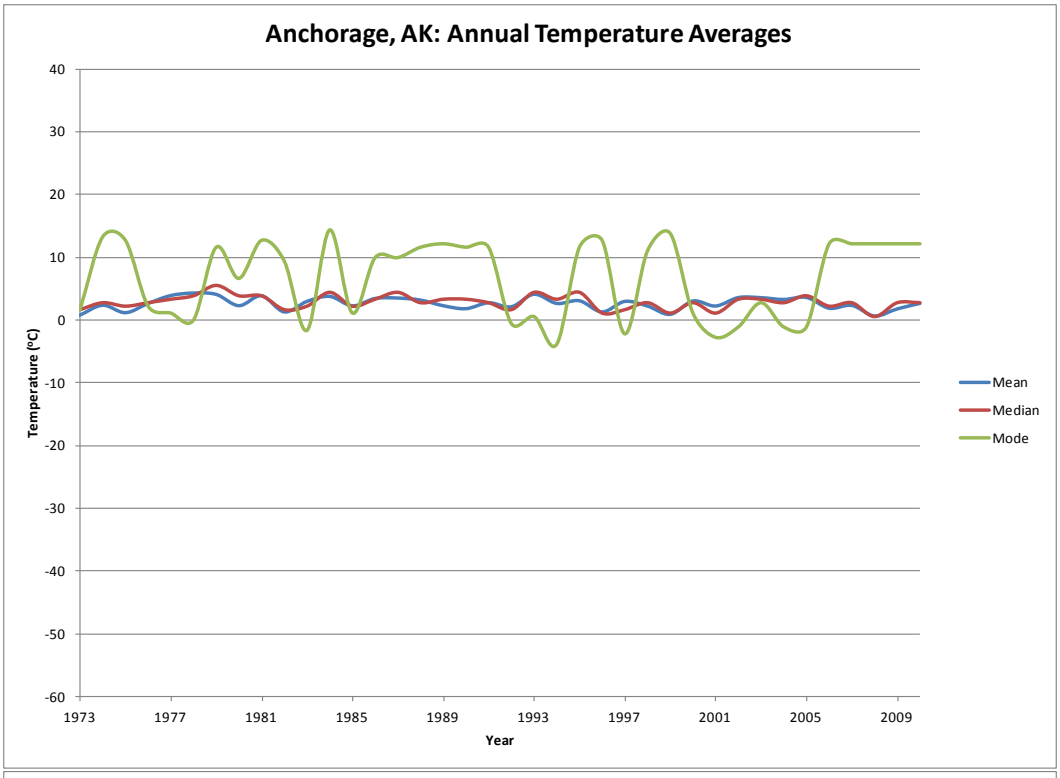


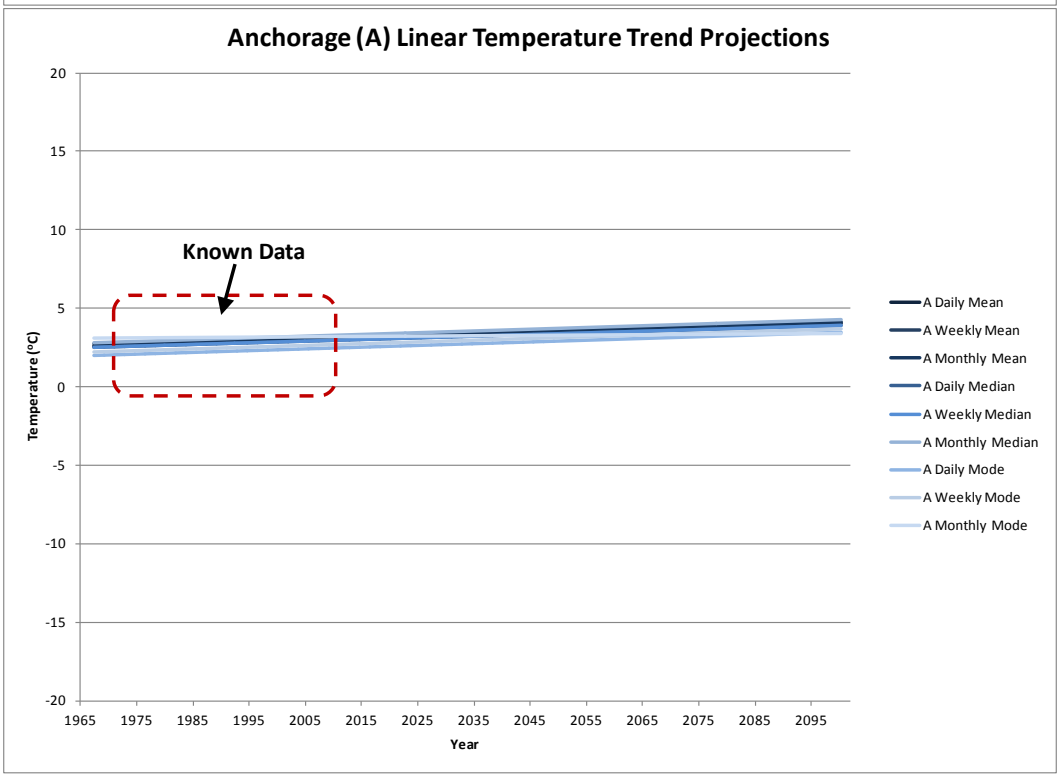

Anchorage, AK: Average Mode Temperatures
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1973
1977
1981
1985
1989
1993
1997
2001
2006
2010
Year
Daily
Weekly
Monthly
Annual

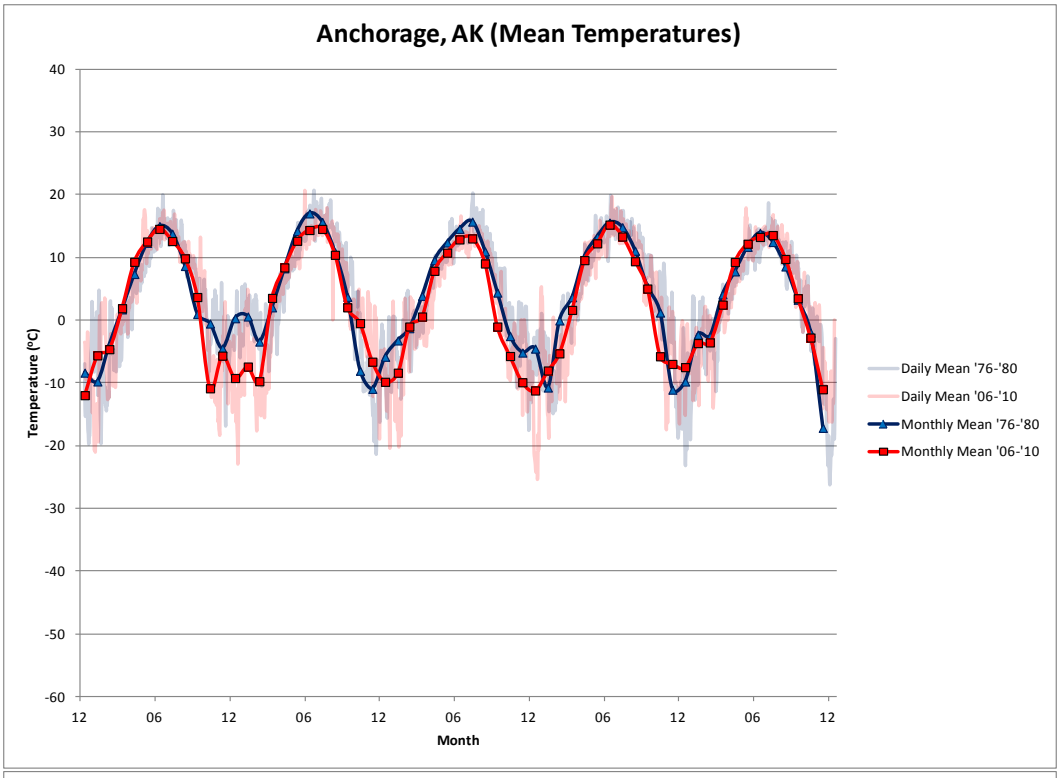

Anchorage, AK: Daily Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1973
1977
1981
1985
1989
1993
1997
2001
2006
2010
Year
Mean
Median
Mode

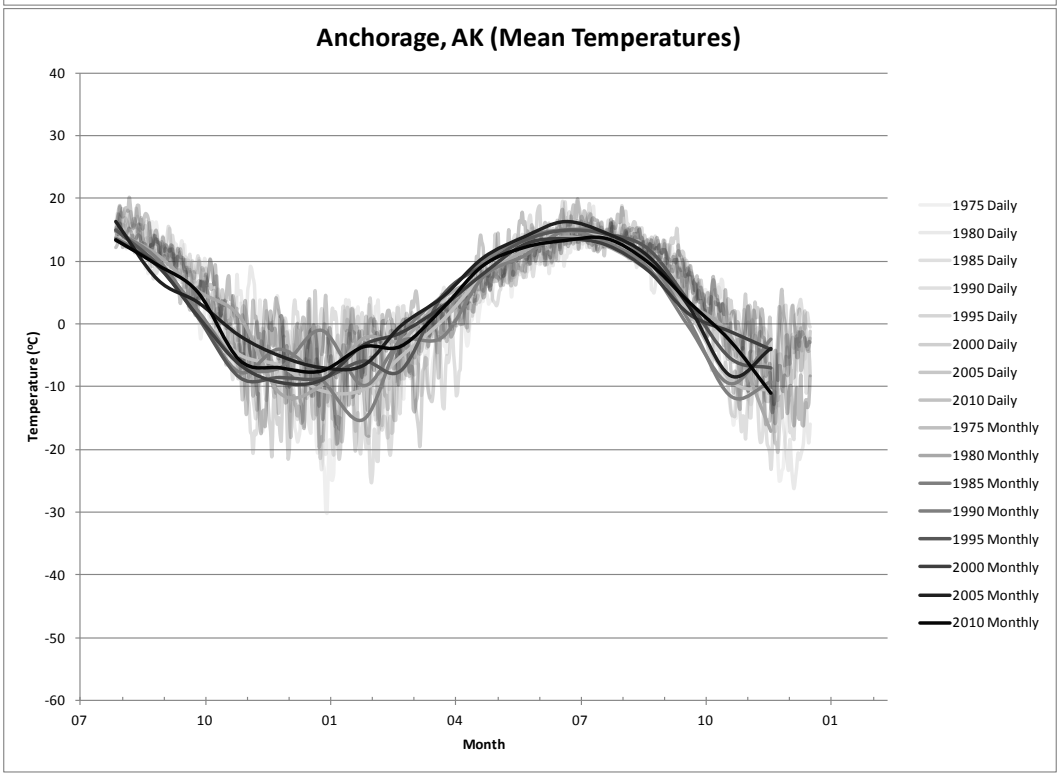

Anchorage, AK: Weekly Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1973
1977
1981
1985
1989
1993
1997
2001
2006
2010
Year
Mean
Median
Mode

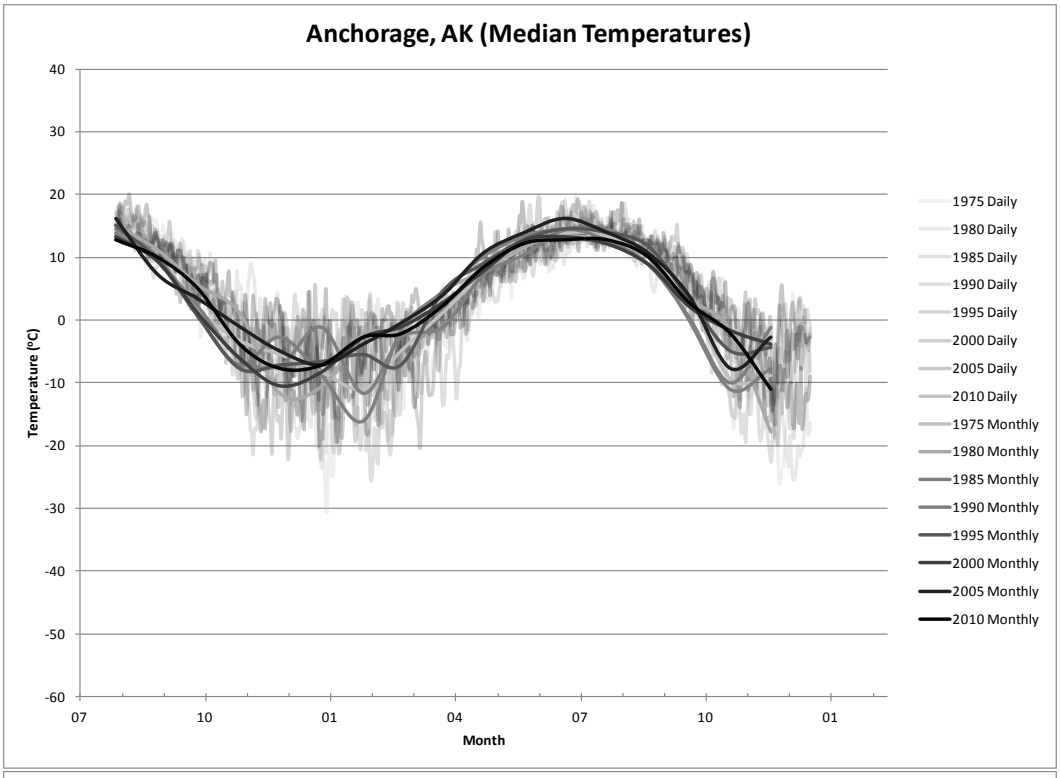

Anchorage, AK: Monthly Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1973
1977
1981
1985
1989
1993
1997
2001
2006
2010
Year
Mean
Median
Mode

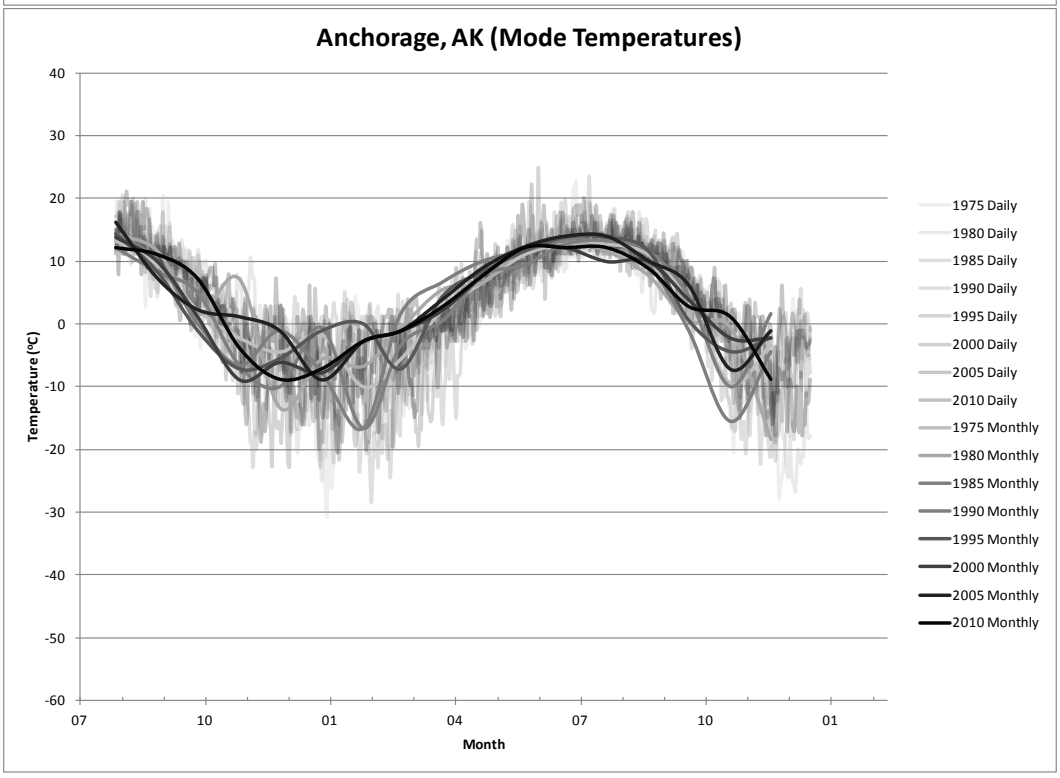

Anchorage, AK: Annual Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1973
1977
1981
1985
1989
1993
1997
2001
2005
2009
Year
Mean
Median
Mode

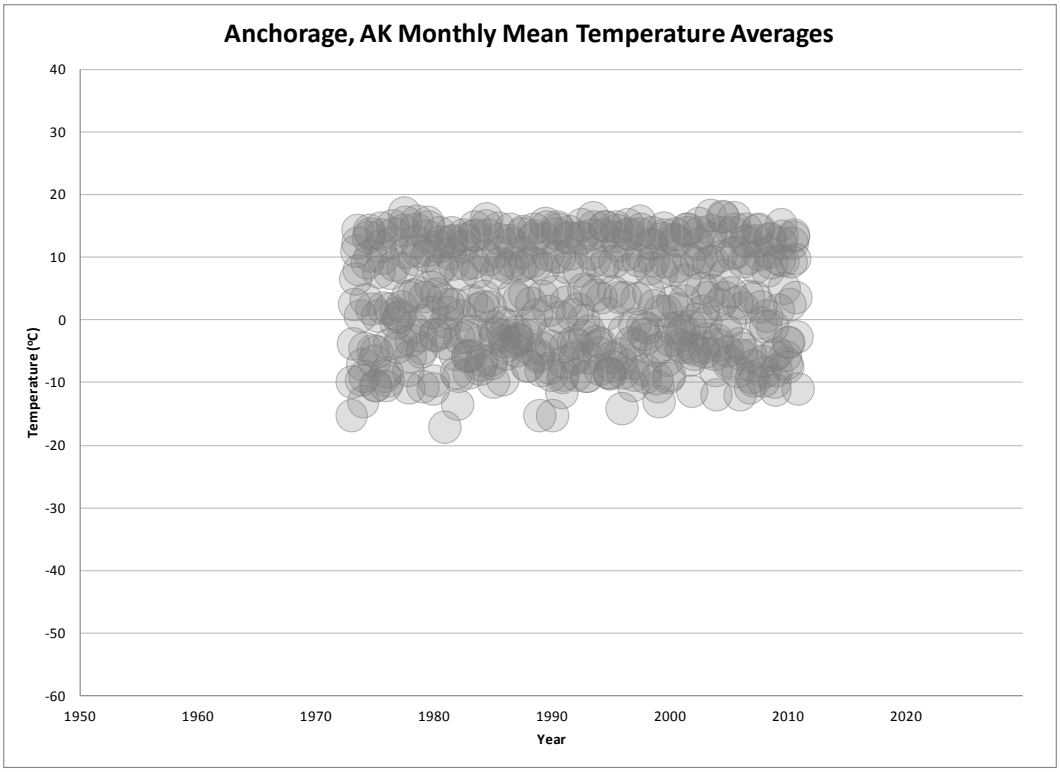

Anchorage (A) Linear Temperature Trend Projections
Temperature (°C)
20
15
10
5
0
-5
-10
-15
-20
1965
1975
1985
1995
2005
2015
2025
2035
2045
2055
2065
2075
2085
2095
Year
Known Data
A Daily Mean
A Weekly Mean
A Monthly Mean
A Daily Median
A Weekly Median
A Monthly Median
A Daily Mode
A Weekly Mode
A Monthly Mode


Anchorage, AK (Mean Temperatures)
Temperature (ºC)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
12
06
12
06
12
06
12
06
12
06
12
Month
Daily Mean '76-'80
Daily Mean '06-'10
Monthly Mean '76-'80
Monthly Mean '06-'10

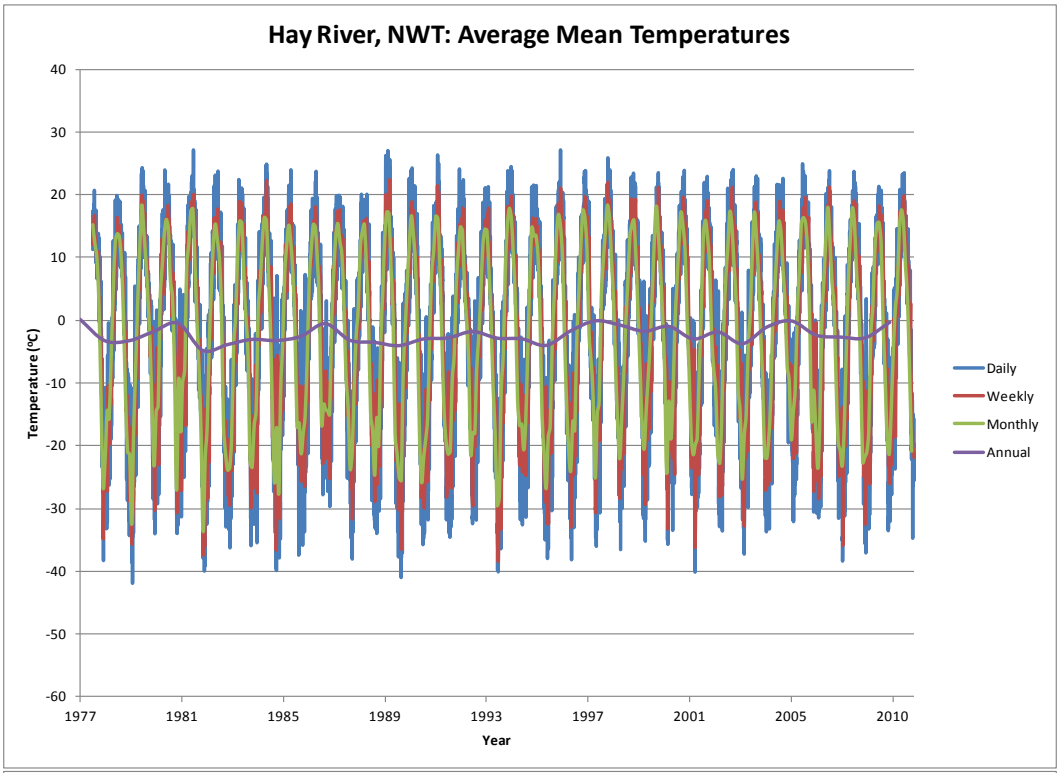

Anchorage, AK (Mean Temperatures)
Temperature (ºC)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1975 Daily
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1975 Monthly
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

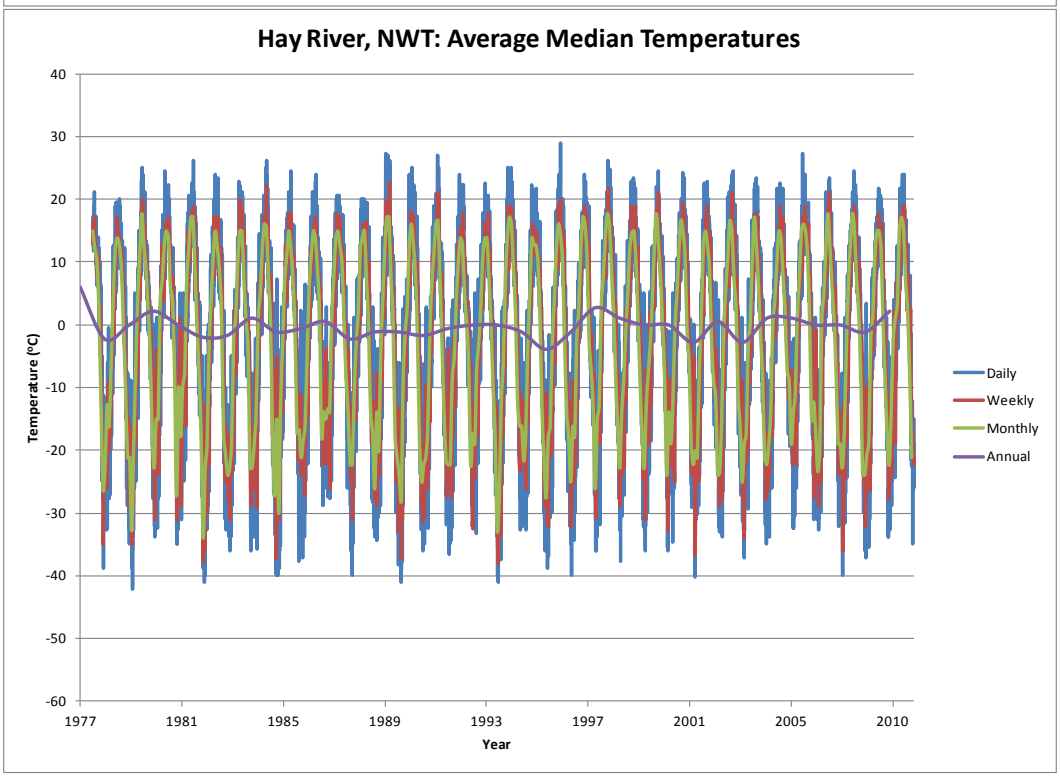

Anchorage, AK (Median Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1975 Daily
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1975 Monthly
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

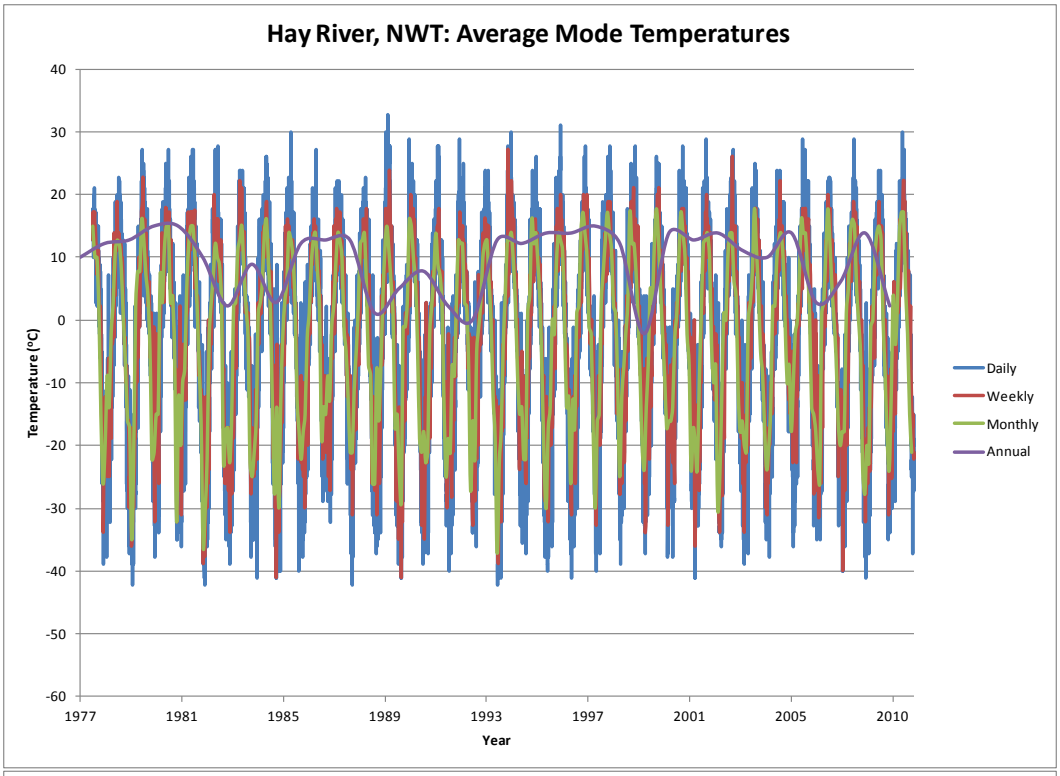

Anchorage, AK (Mode Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1975 Daily
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1975 Monthly
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

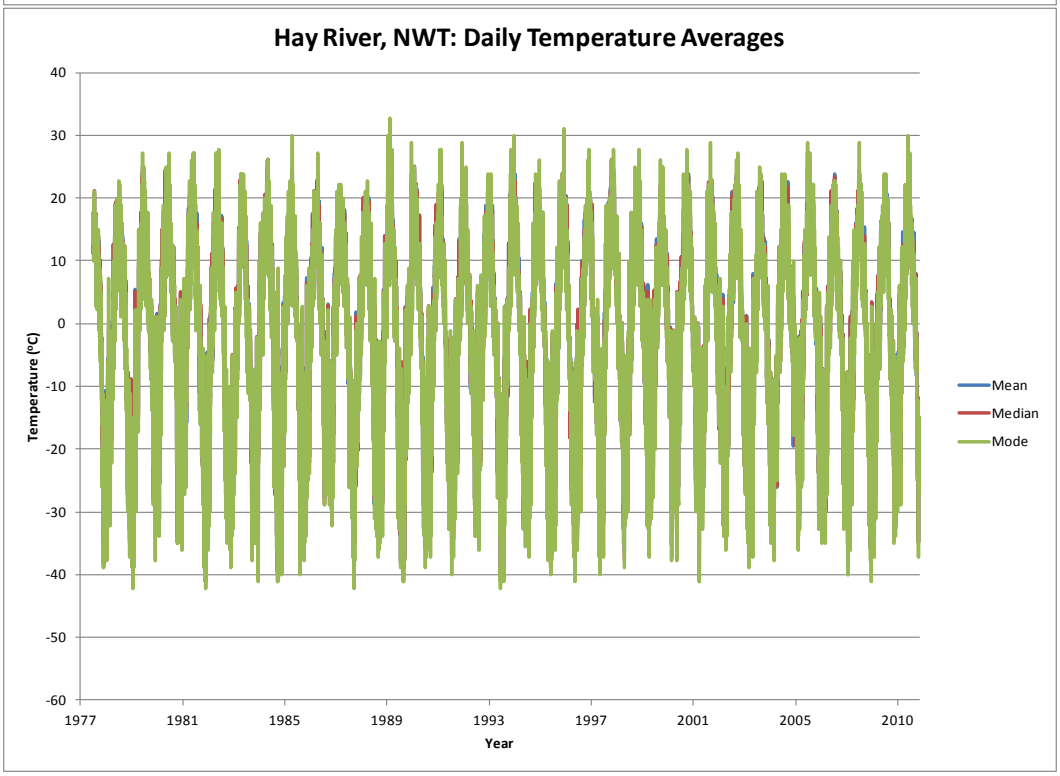

Anchorage, AK Monthly Mean Temperature Averages
40
30
20
10
0
-10
-20
-30
-40
-50
-60
Temperature (°C)
1950
1960
1970
1980
1990
2000
2010
2020
Year

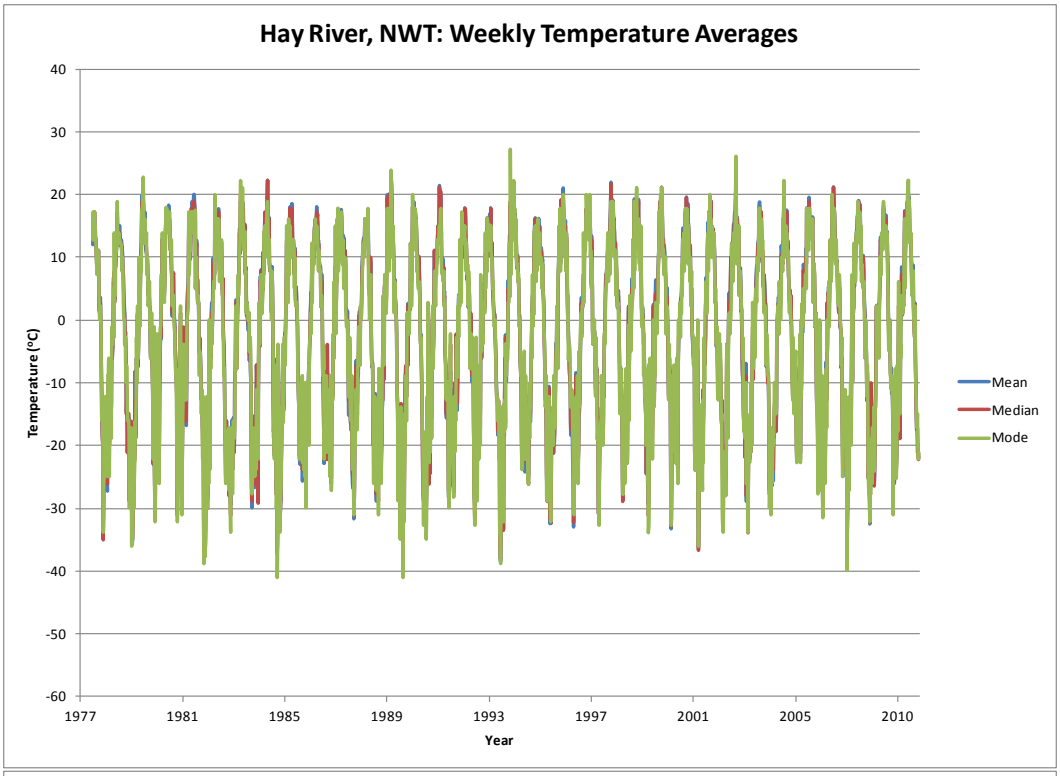
Appendix 7: Hay River, Northwest Territories

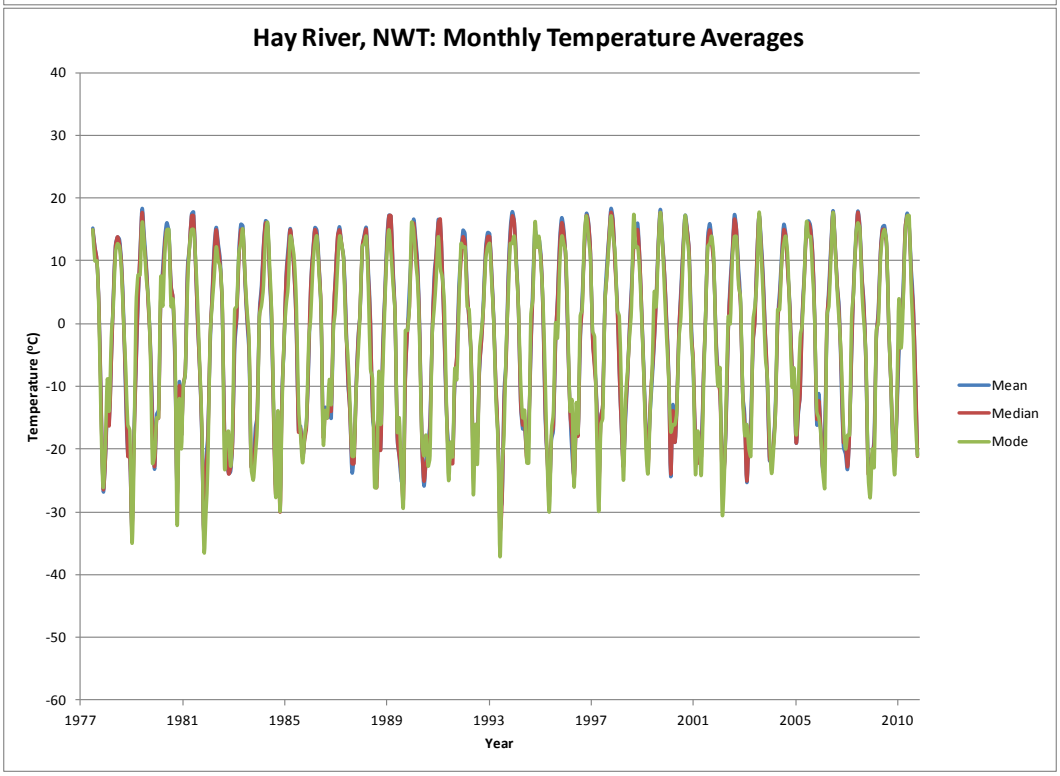


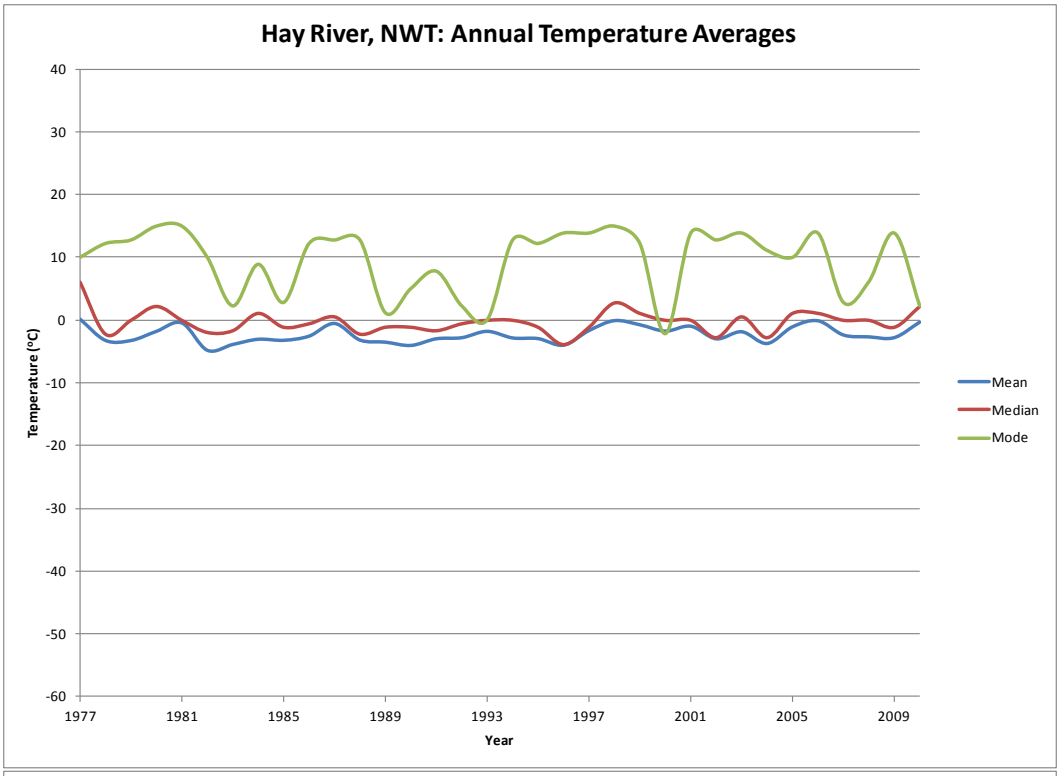


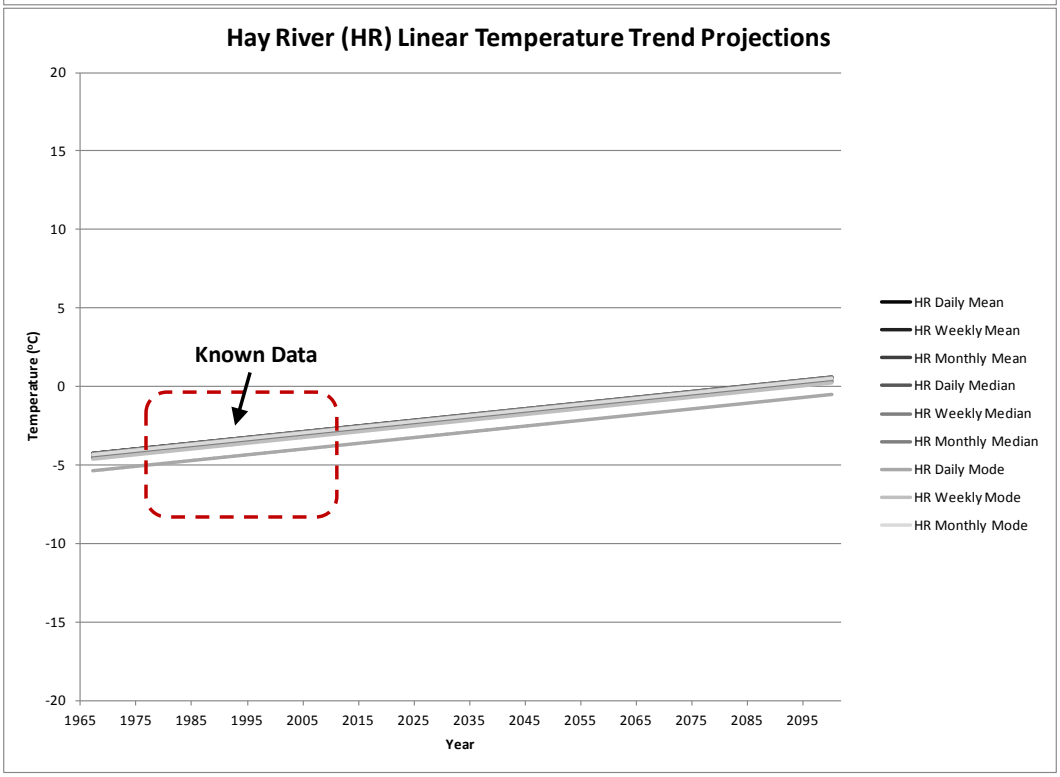

Hay River, NWT: Average Mode Temperatures
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2010
Year
Daily
Weekly
Monthly
Annual

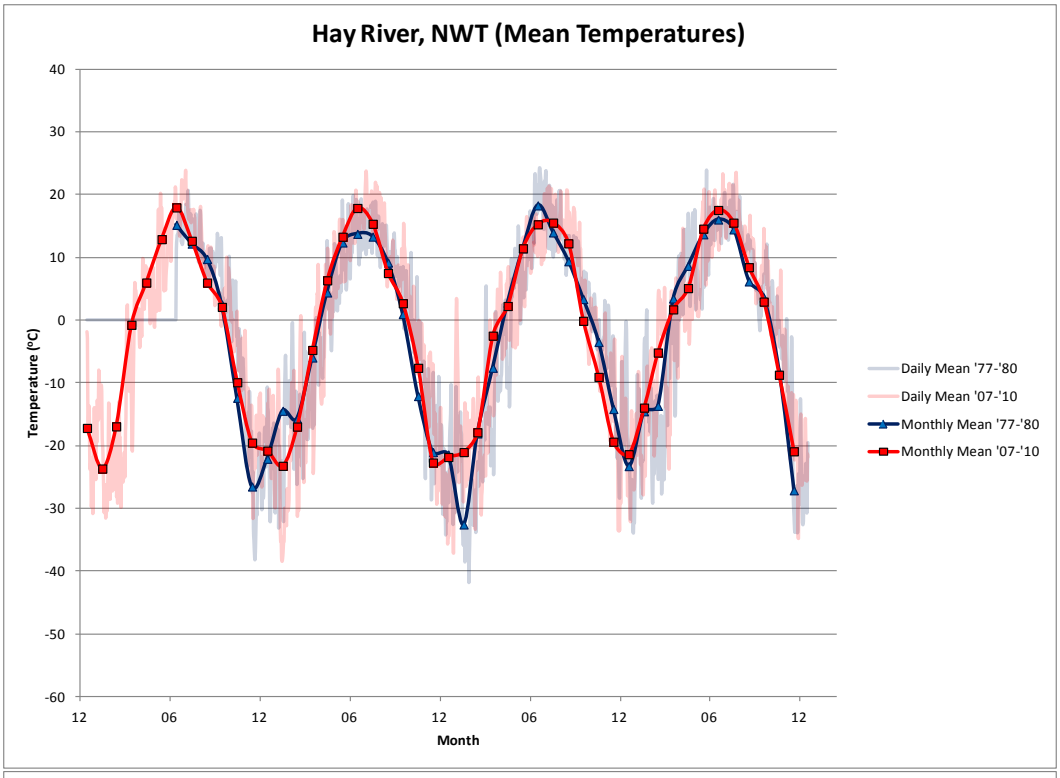

Hay River, NWT: Daily Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2010
Year
Mean
Median
Mode

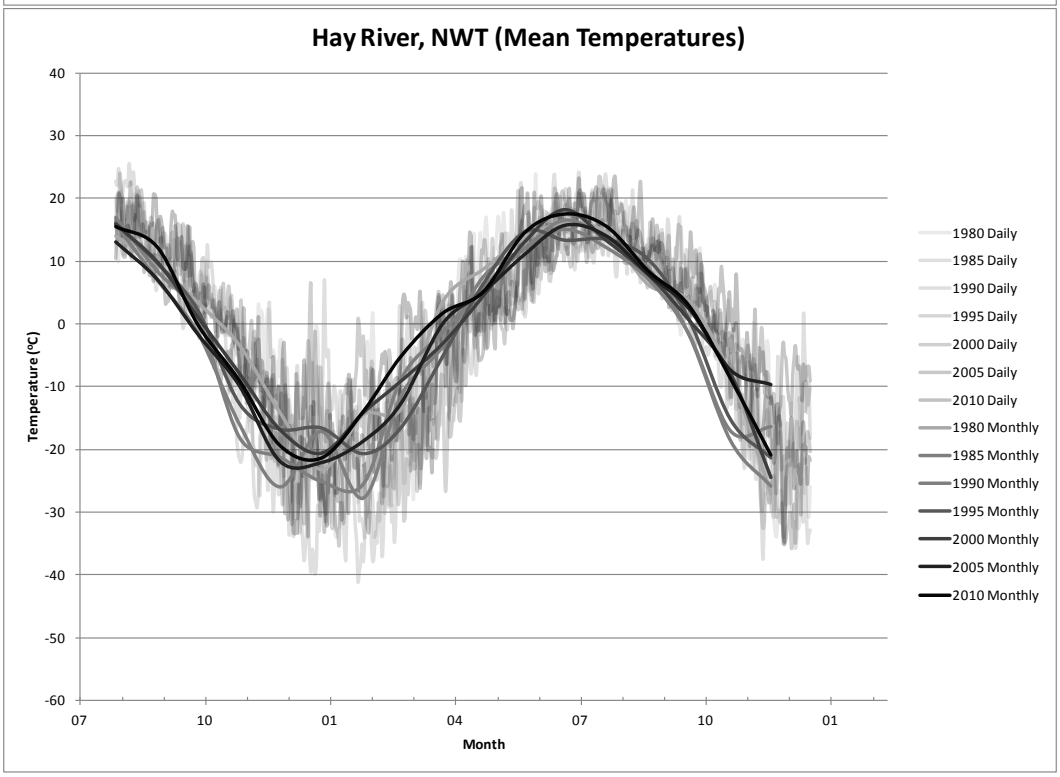

Hay River, NWT: Weekly Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2010
Year
Mean
Median
Mode

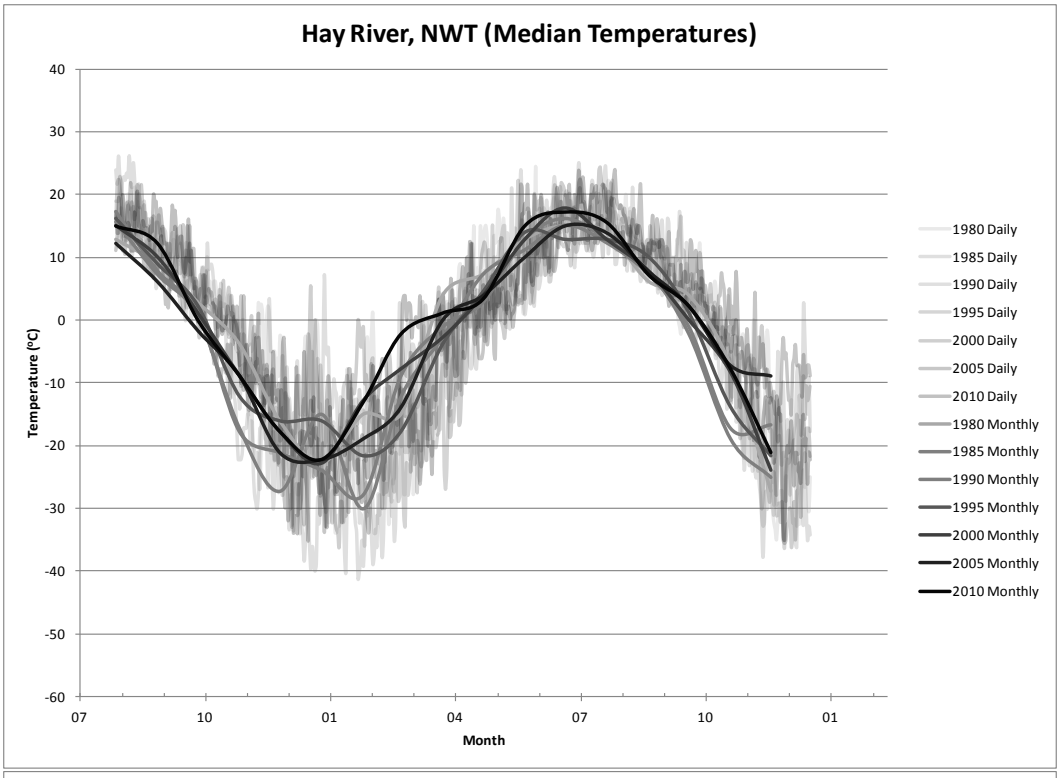

Hay River, NWT: Monthly Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2010
Year
Mean
Median
Mode

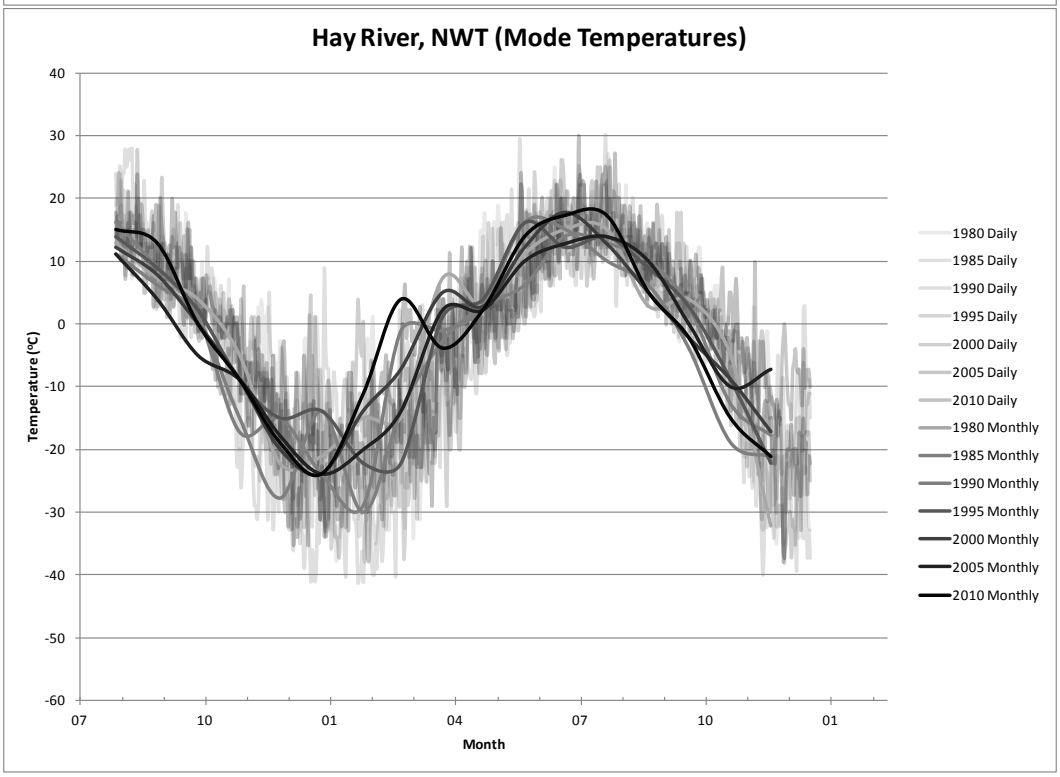

Hay River, NWT: Annual Temperature Averages
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
1977
1981
1985
1989
1993
1997
2001
2005
2009
Year
Mean
Median
Mode

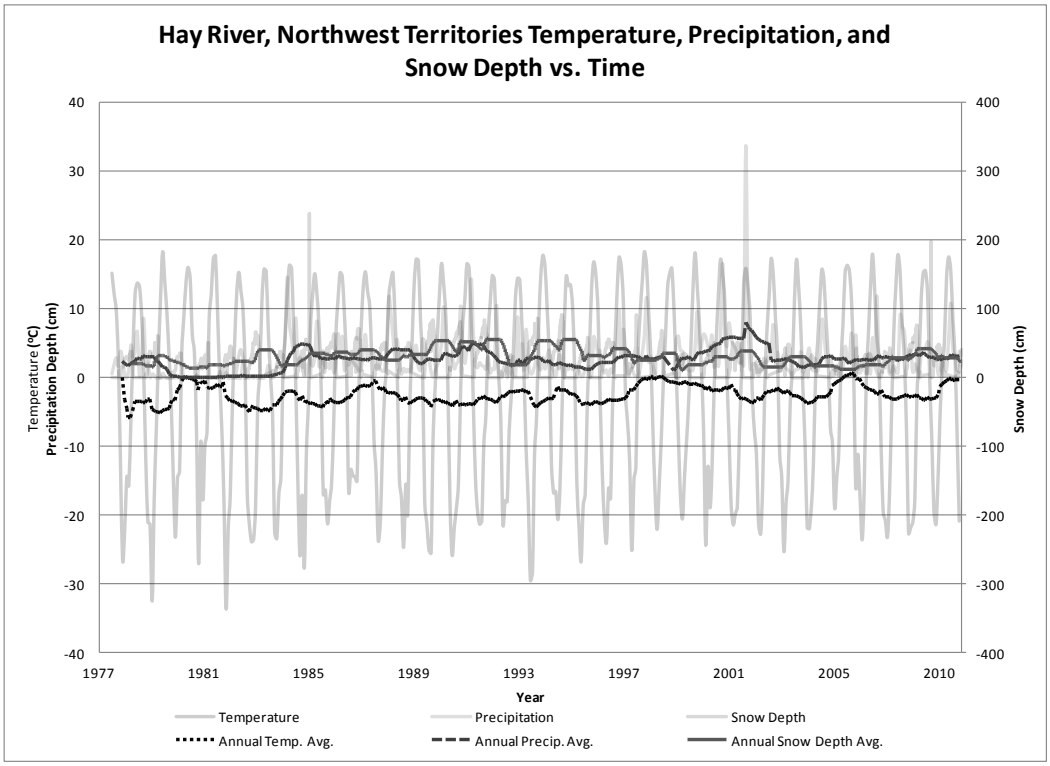

Hay River (HR) Linear Temperature Trend Projections
Temperature (°C)
20
15
10
5
0
-5
-10
-15
-20
Known Data
1965
1975
1985
1995
2005
2015
2025
2035
2045
2055
2065
2075
2085
2095
Year
HR Daily Mean
HR Weekly Mean
HR Monthly Mean
HR Daily Median
HR Weekly Median
HR Monthly Median
HR Daily Mode
HR Weekly Mode
HR Monthly Mode

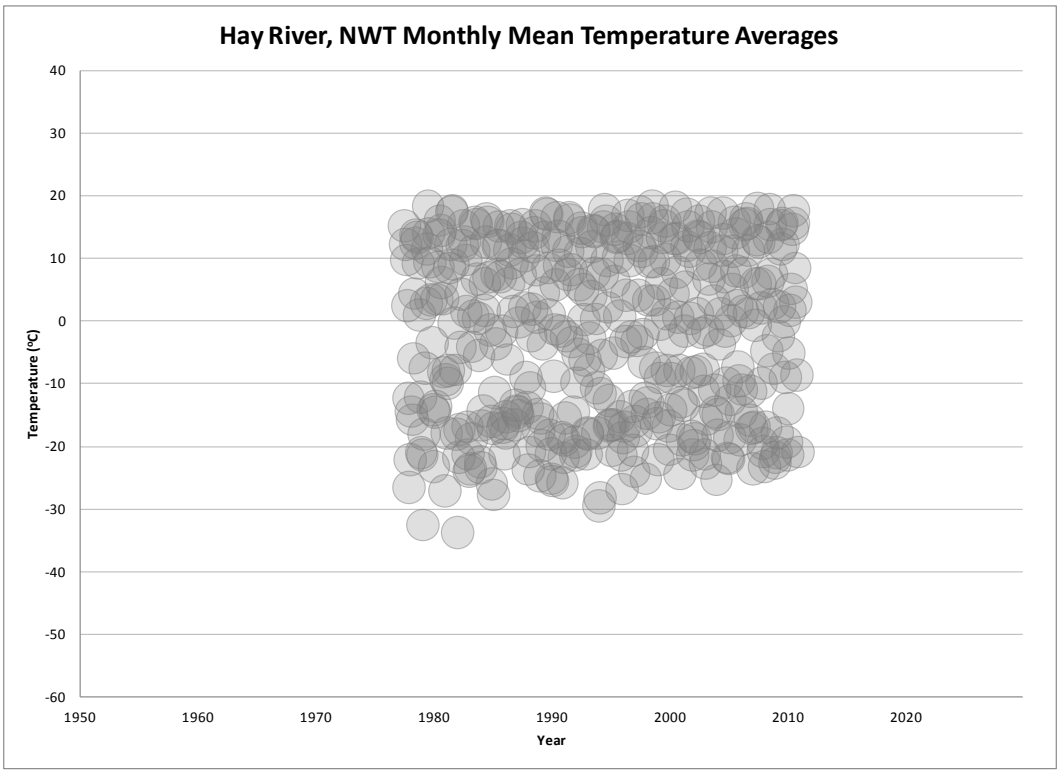

Hay River, NWT (Mean Temperatures)
Temperature (ºC)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
12
06
12
06
12
06
12
06
12
Month
Daily Mean '77-'80
Daily Mean '07-'10
Monthly Mean '77-'80
Monthly Mean '07-'10


Hay River, NWT (Mean Temperatures)
Temperature (ºC)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

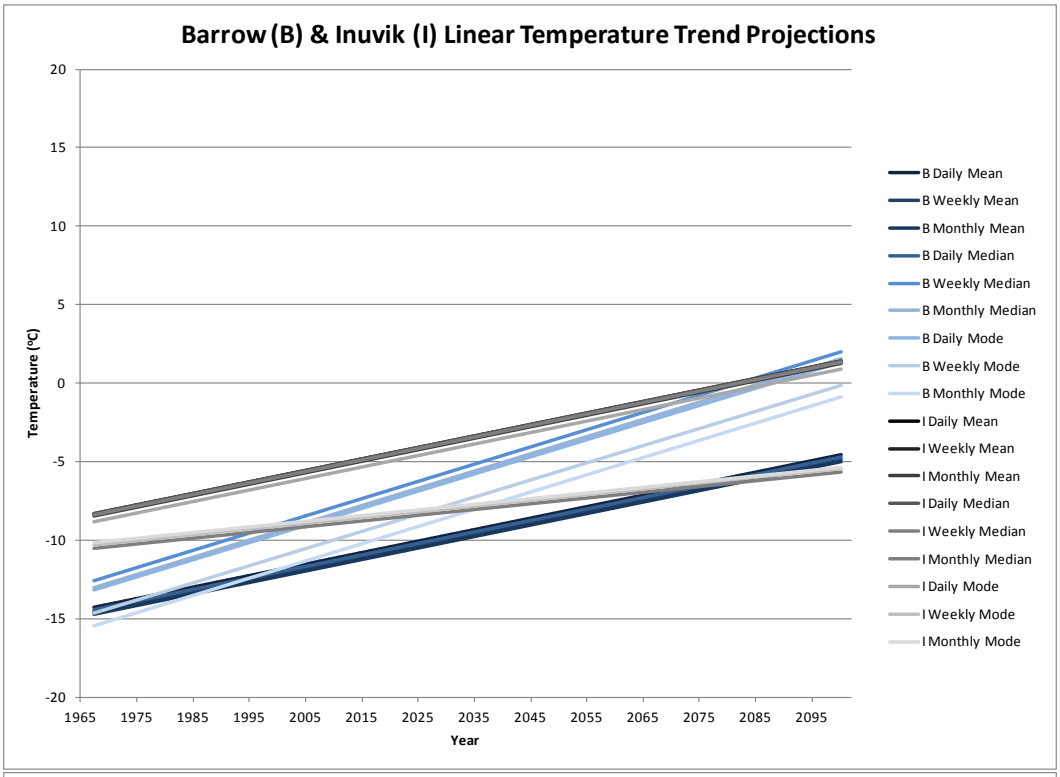

Hay River, NWT (Median Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

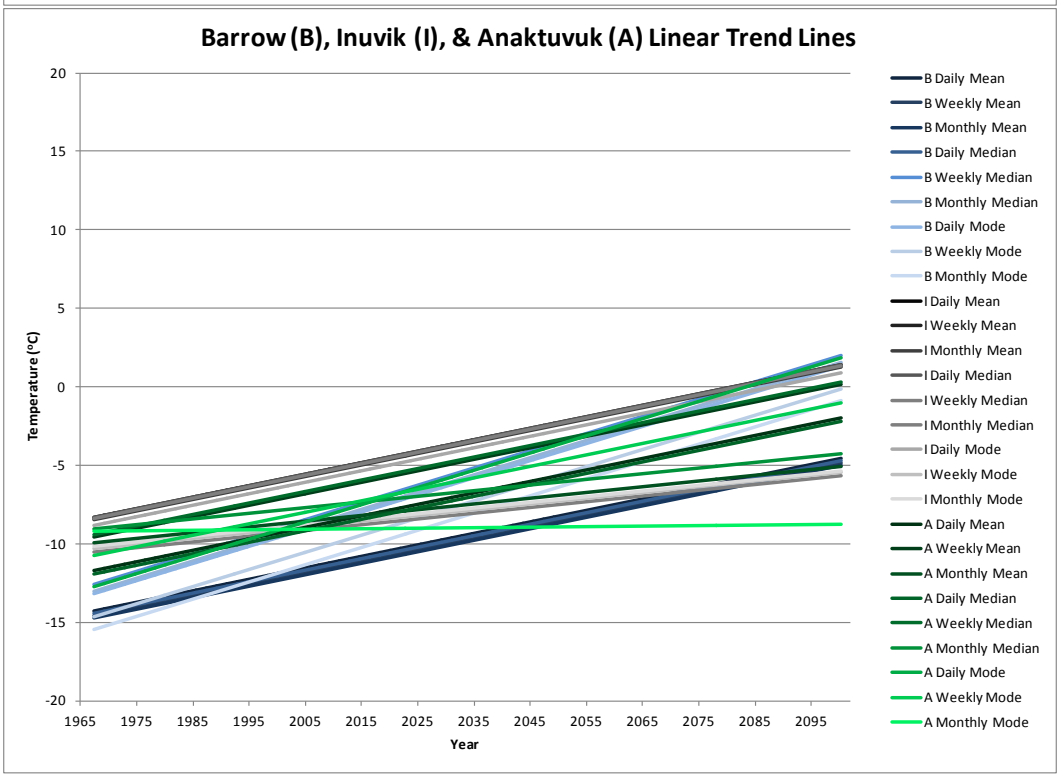

Hay River, NWT (Mode Temperatures)
Temperature (°C)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
07
10
01
04
07
10
01
Month
1980 Daily
1985 Daily
1990 Daily
1995 Daily
2000 Daily
2005 Daily
2010 Daily
1980 Monthly
1985 Monthly
1990 Monthly
1995 Monthly
2000 Monthly
2005 Monthly
2010 Monthly

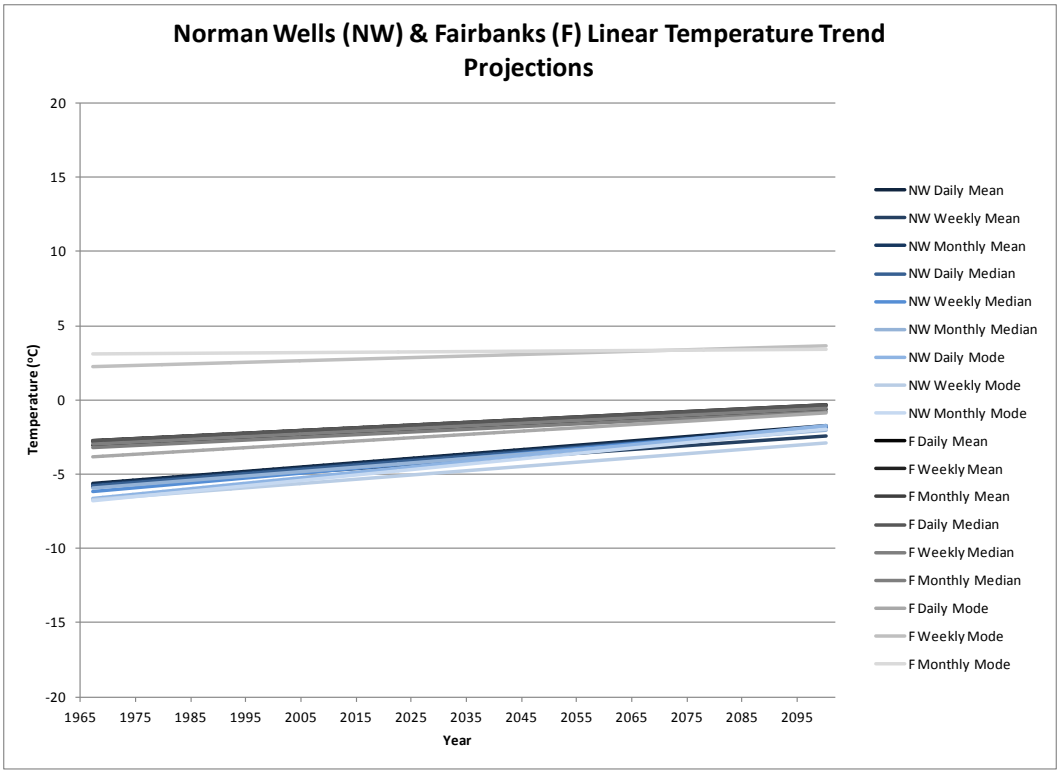

Hay River, Northwest Territories Temperature, Precipitation, and Snow Depth vs. Time
Temperature (°C)
Precipitation Depth (cm)
Snow Depth (cm)
Year
Temperature
Precipitation
Snow Depth
Annual Temp. Avg.
Annual Precip. Avg.
Annual Snow Depth Avg.

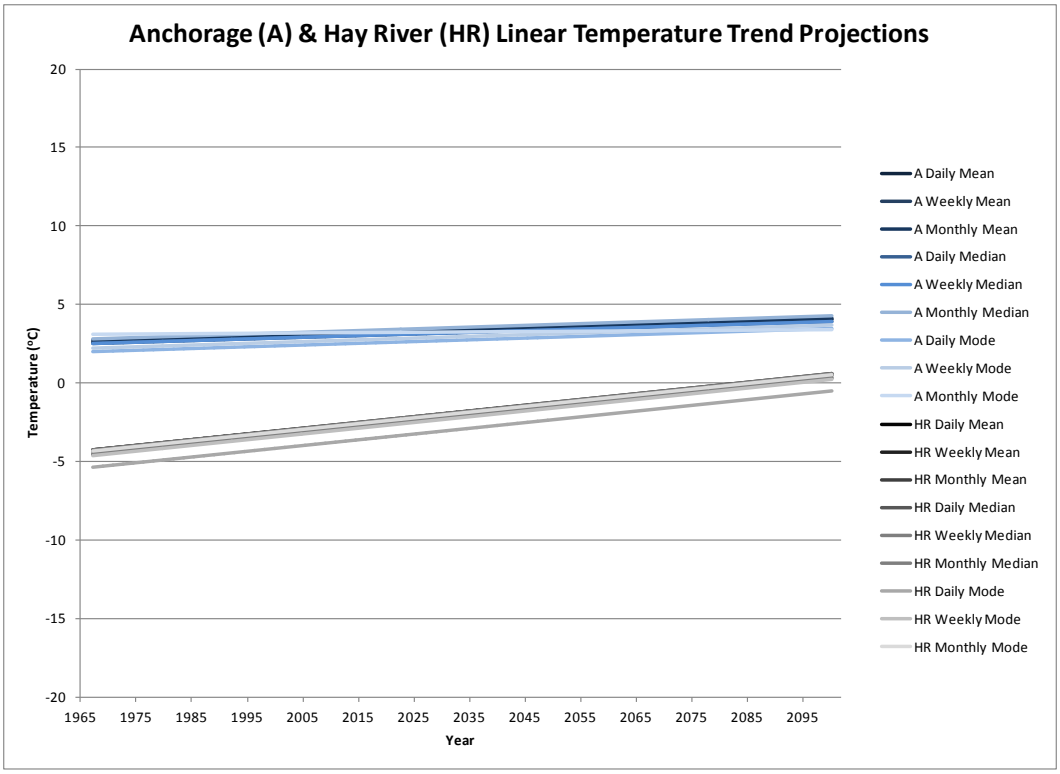

Hay River, NWT Monthly Mean Temperature Averages
Temperature (°C)
Year

Appendix 8: Location Comparison Graphs






Norman Wells (NW) & Fairbanks (F) Linear Temperature Trend Projections
Temperature (°C)
Year
NW Daily Mean
NW Weekly Mean
NW Monthly Mean
NW Daily Median
NW Weekly Median
NW Monthly Median
NW Daily Mode
NW Weekly Mode
NW Monthly Mode
F Daily Mean
F Weekly Mean
F Monthly Mean
F Daily Median
F Weekly Median
F Monthly Median
F Daily Mode
F Weekly Mode
F Monthly Mode


Anchorage (A) & Hay River (HR) Linear Temperature Trend Projections
Temperature (°C)
Year
A Daily Mean
A Weekly Mean
A Monthly Mean
A Daily Median
A Weekly Median
A Monthly Median
A Daily Mode
A Weekly Mode
A Monthly Mode
HR Daily Mean
HR Weekly Mean
HR Monthly Mean
HR Daily Median
HR Weekly Median
HR Monthly Median
HR Daily Mode
HR Weekly Mode
HR Monthly Mode

Appendix 9: Images and Tables

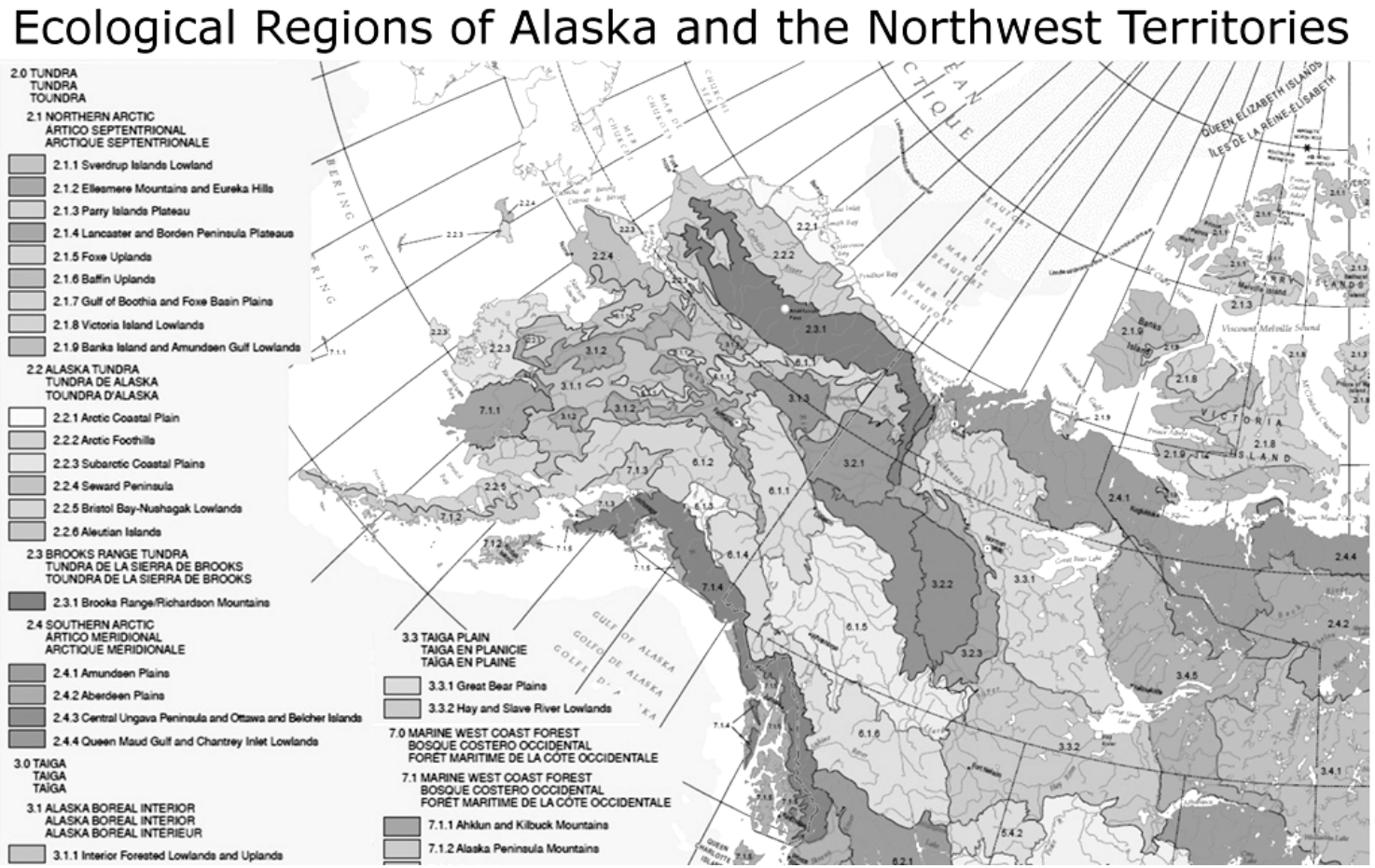


Figure 48: Ecology of the Locations Examined in this Study: Graphic Adapted from "Ecological Regions of North America" 2006.

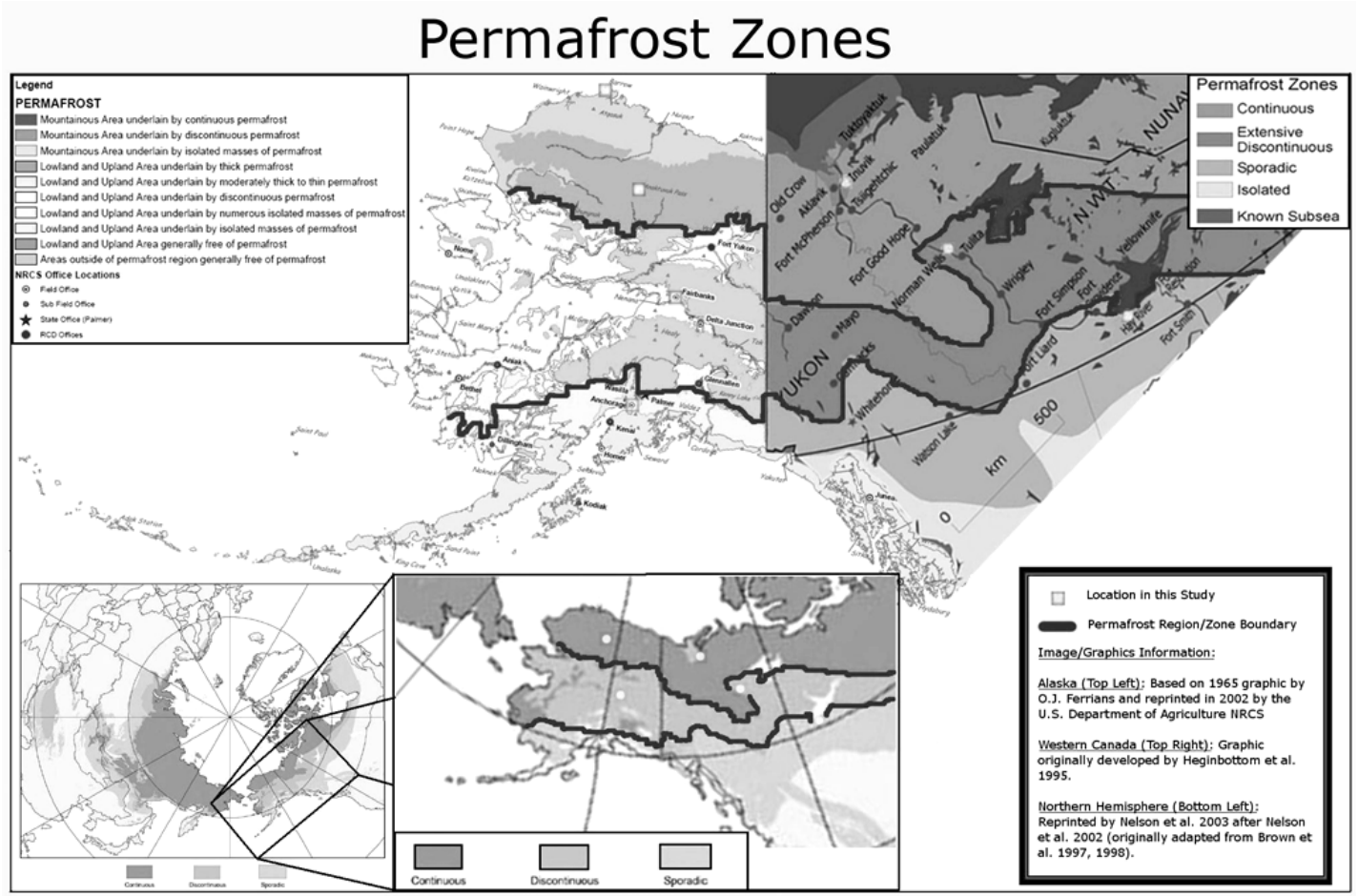


Figure 49: Continuous, Discontinuous, and Sporadic Permafrost Zones Depicted Graphically by O.J. Ferrians (1965), Heginbottom et al. (1995), and Brown et al. (1997).

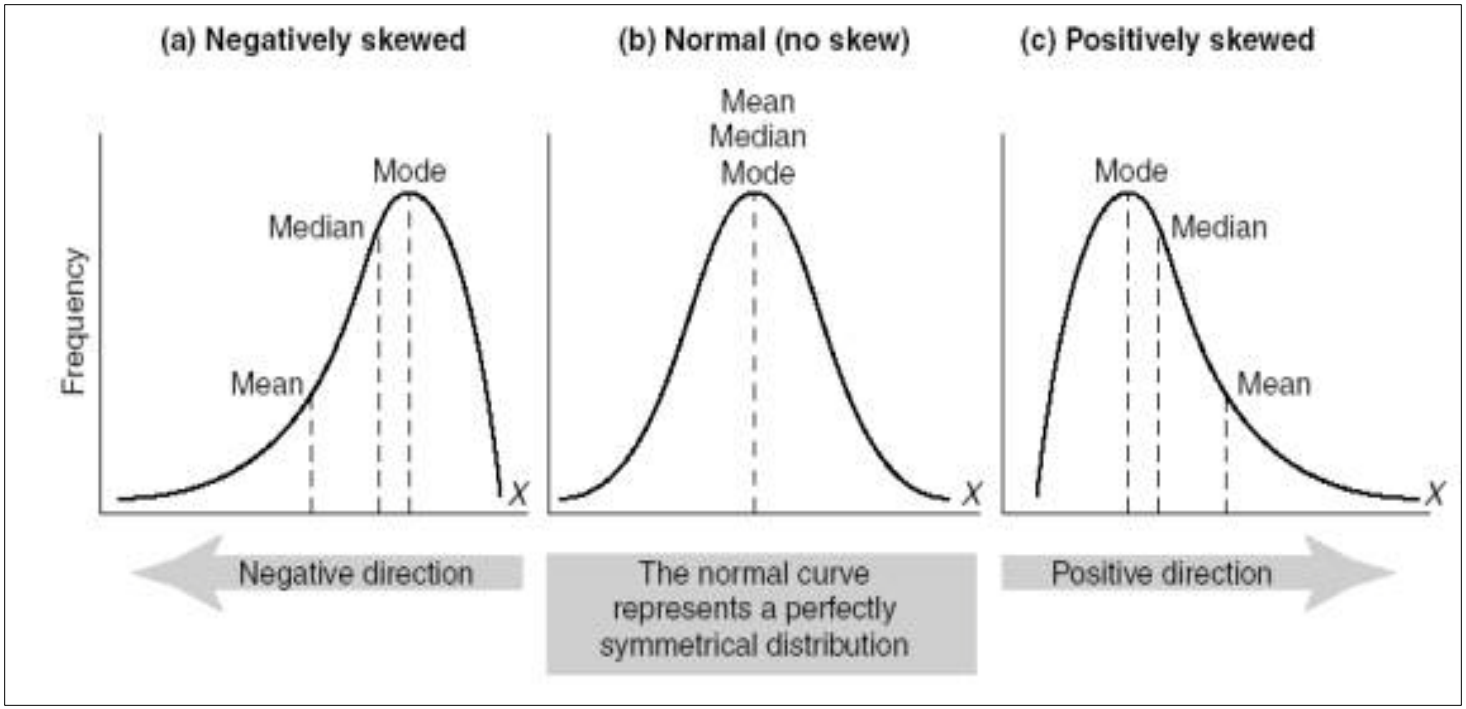


Figure 50: Comparison of the Mean, Median, and Mode Methods of Central Tendency Using Three Log-Normal Distributions with Different Skewness (σ) (Johnson and Christensen 2007).

Alaska	Latitude (Deg. North)	Terrain Type	Permafrost Zone
Barrow	71.29	Tundra	Continuous
Anaktuvuk Pass	68.14	Tundra/Mountain	Continuous/Mountain
Fairbanks	64.84	Taiga/Boreal	Discontinuous
Anchorage	61.22	Marine/Boreal	Sporadic/Permafrost Free

Canada	Latitude (Deg. North)	Terrain Type	Permafrost Zone
Inuvik	68.35	Tundra/Taiga	Continuous/Discontinuous
Norman Wells	65.28	Taiga/Plains	Discontinuous
Hay River	60.85	Taiga/Plains	Sporadic

Table 4: Study Locations and their Respective Latitude, Ecology, and Permafrost Conditions: Based on Information from Figure 1 and Figure 2

Barrow		Minimum	Maximum
Daily	Mean	-45.06	16.27
	Median	-45	16.11
	Mode	-46.11	21.67
Weekly	Mean	-43.48	12.04
	Median	-43.89	11.67
	Mode	-44.44	11.11
Monthly	Mean	-36.06	8.15
	Median	-36.11	7.78
	Mode	-41.11	8.33
Annual	Mean	-14.44	-7.36
	Median	-15	-2.22
	Mode	-1.11	6.11

Inuvik		Minimum	Maximum
Daily	Mean	-46.81	27.13
	Median	-47.22	27.22
	Mode	-47.78	30
Weekly	Mean	-42.42	21.3
	Median	-42.78	22.22
	Mode	-46.11	26.11
Monthly	Mean	-34.75	18.64
	Median	-36.11	17.78
	Mode	-46.11	18.89
Annual	Mean	-10.34	-3.58
	Median	-12.22	0
	Mode	-25	10

Anaktuvuk		Minimum	Maximum
Daily	Mean	-48.29	22.64
	Median	-48.89	23.89
	Mode	-49.44	25.56
Weekly	Mean	-41.9	17.03
	Median	-41.67	17.78
	Mode	-42.78	22.22
Monthly	Mean	-30.53	15.56
	Median	-32.78	15.56
	Mode	-39.44	15.56
Annual	Mean	-23.28	2.19
	Median	-23.33	5
	Mode	-27.78	11.11

Fairbanks		Minimum	Maximum
Daily	Mean	-49.1	27.87
	Median	-49.17	28.33
	Mode	-50.56	31.67
Weekly	Mean	-47.27	23.91
	Median	-48.33	23.89
	Mode	-48.89	29.44
Monthly	Mean	-35.77	20.54
	Median	-39.44	20.56
	Mode	-48.33	20
Annual	Mean	-5.76	0.31
	Median	-4.44	1.67
	Mode	-17.78	15.56

Norman Wells		Minimum	Maximum
Daily	Mean	-47.43	27.62
	Median	-47.78	28.89
	Mode	-47.78	32.22
Weekly	Mean	-43.72	24.81
	Median	-43.89	25
	Mode	-46.11	28.89
Monthly	Mean	-34.91	20.36
	Median	-36.11	20
	Mode	-46.11	20
Annual	Mean	-6.65	-2.41
	Median	-7.78	2.22
	Mode	-27.78	17.22

Anchorage		Minimum	Maximum
Daily	Mean	-30.09	21.77
	Median	-30.56	22.22
	Mode	-31.11	25
Weekly	Mean	-24.49	18.46
	Median	-24.44	18.33
	Mode	-26.11	20.56
Monthly	Mean	-17.16	17
	Median	-17.78	16.67
	Mode	-18.33	20.56
Annual	Mean	0.65	4.36
	Median	0.56	5.56
	Mode	-3.89	14.44

Hay River		Minimum	Maximum
Daily	Mean	-41.89	27.08
	Median	-42.22	28.89
	Mode	-42.22	32.78
Weekly	Mean	-38.23	22.41
	Median	-38.06	22.78
	Mode	-41.11	27.22
Monthly	Mean	-33.72	18.28
	Median	-33.89	17.78
	Mode	-37.22	17.78
Annual	Mean	-4.86	0.18
	Median	-3.89	6.11
	Mode	-2.22	15

Table 5: Maximum and Minimum Temperatures (^{o}C) from Graphical Analysis of Various Central Tendencies

Temperature Changes												
1968-2010				2010-2050				2010-2100			
Anaktuvuk	Daily	Weekly	Monthly	Anaktuvuk	Daily	Weekly	Monthly	Anaktuvuk	Daily	Weekly	Monthly
Mean	3.141	3.1396	1.5675	Mean	2.922	2.917	1.461	Mean	6.5684	6.5694	3.2872
Median	3.141	3.1396	1.5675	Median	2.922	2.917	1.461	Median	6.5684	6.5694	3.2872
Mode	4.7115	3.1396	0.15675	Mode	4.383	2.917	0.1461	Mode	9.8526	6.5694	0.32872
Anchorage	Daily	Weekly	Monthly	Anchorage	Daily	Weekly	Monthly	Anchorage	Daily	Weekly	Monthly
Mean	0.47115	0.47094	0.47025	Mean	0.4383	0.43755	0.4383	Mean	0.98526	0.98541	0.98616
Median	0.47115	0.47094	0.47025	Median	0.4383	0.43755	0.4383	Median	0.98526	0.98541	0.98616
Mode	0.47115	0.47094	0.109725	Mode	0.4383	0.43755	0.10227	Mode	0.98526	0.98541	0.230104
Barrow	Daily	Weekly	Monthly	Barrow	Daily	Weekly	Monthly	Barrow	Daily	Weekly	Monthly
Mean	3.141	3.1396	3.135	Mean	2.922	2.917	2.922	Mean	6.5684	6.5694	6.5744
Median	3.141	4.7094	4.7025	Median	2.922	4.3755	4.383	Median	6.5684	9.8541	9.8616
Mode	4.7115	4.7094	4.7025	Mode	4.383	4.3755	4.383	Mode	9.8526	9.8541	9.8616
Fairbanks	Daily	Weekly	Monthly	Fairbanks	Daily	Weekly	Monthly	Fairbanks	Daily	Weekly	Monthly
Mean	0.78525	0.7849	0.78375	Mean	0.7305	0.72925	0.7305	Mean	1.6421	1.64235	1.6436
Median	0.78525	0.7849	0.78375	Median	0.7305	0.72925	0.7305	Median	1.6421	1.64235	1.6436
Mode	0.9423	0.094188	1.5675	Mode	0.8766	0.08751	1.461	Mode	1.97052	0.197082	3.2872
Hay River	Daily	Weekly	Monthly	Hay River	Daily	Weekly	Monthly	Hay River	Daily	Weekly	Monthly
Mean	1.5705	1.5698	1.5675	Mean	1.461	1.4585	1.461	Mean	3.2842	3.2847	3.2872
Median	1.5705	1.5698	1.5675	Median	1.461	1.4585	1.461	Median	3.2842	3.2847	3.2872
Mode	1.5705	1.5698	1.5675	Mode	1.461	1.4585	1.461	Mode	3.2842	3.2847	3.2872
Inuvik	Daily	Weekly	Monthly	Inuvik	Daily	Weekly	Monthly	Inuvik	Daily	Weekly	Monthly
Mean	3.141	3.1396	3.135	Mean	2.922	2.917	2.922	Mean	6.5684	6.5694	6.5744
Median	3.141	1.5698	3.135	Median	2.922	1.4585	2.922	Median	6.5684	3.2847	6.5744
Mode	3.141	1.5698	1.5675	Mode	2.922	1.4585	3.0285	Mode	6.5684	3.2847	4.8547
Norman Wells	Daily	Weekly	Monthly	Norman Wells	Daily	Weekly	Monthly	Norman Wells	Daily	Weekly	Monthly
Mean	1.2564	1.09886	1.254	Mean	1.1688	1.02095	1.1688	Mean	2.62736	2.29929	2.62976
Median	1.2564	1.41282	1.254	Median	1.1688	1.31265	1.1688	Median	2.62736	2.95623	2.62976
Mode	1.5705	1.25584	1.5675	Mode	1.461	1.1668	1.461	Mode	3.2842	2.62776	3.2872

Table 6: Linear Temperature Change Forecasts in Degrees Celsius for the Mean, Median, and Mode of Daily, Weekly, and Monthly Central Tendencies.

Station	USAF	Years Available	Used	Lat. (°N)	Lon. (°N)	Elev. (.1 M)
Barrow/W. Post W.R.	700260-27502	1920-2011	1968-2010	+71287	-156763	+00040
Inuvik Climate	719570-99999	1958-1967, 1977-2011	1977-2010	+68317	-133517	+01030
Anaktuvuk Pass	701625-26542	2009-2011	2009-2010	+68134	-151743	+06410
Anaktuvuk Pass	701625-99999	1980-1982, 1985-1989, 1994-2008	All	+68133	-151733	+06410
Norman Wells Arpt.	710430-99999	1945-1947, 1955-1963, 1977-2011	1977-2010	+65283	-126800	+00730
Fairbanks Intl. Arpt.	702610-26411	1923-1927, 1929-2011	1968-2010	+64817	-147855	+01384
Anchorage Intl. Arpt.	702730-26451	1973-2011	1973-2010	+61175	-149993	+00402
Hay River	719350-99999	1934-1948, 1955-1963, 1977-2011	1977-2010	+60833	-115767	+01640
Anchorage Elm.	702720-26401	2008-2011	None	+61253	-149794	+00649
Anchorage Elm.	702720-99999	1941-1970, 1973-2008	None	+61250	-149800	+00590

Table 4: Summary of Study Locations and Available Data

Appendix 10: Programming

Excel Macro Formatting by Adamczak, K.M.:

' Get Data Macro

```
With ActiveSheet.QueryTables.Add(Connection:= _
    "TEXT;[Insert file location without brackets]" _
    , Destination:=Range("$A$4"))
    .Name = "700260-27502-1996"
    .FieldNames = True
    .RowNumbers = False
    .FillAdjacentFormulas = False
    .PreserveFormatting = True
    .RefreshOnFileOpen = False
    .RefreshStyle = xlInsertDeleteCells
    .SavePassword = False
    .SaveData = True
    .AdjustColumnWidth = True
    .RefreshPeriod = 0
    .TextFilePromptOnRefresh = False
    .TextFilePlatform = 437
    .TextFileStartRow = 1
    .TextFileParseType = xlFixedWidth
    .TextFileTextQualifier = xlTextQualifierDoubleQuote
    .TextFileConsecutiveDelimiter = False
```

```
        .TextFileTabDelimiter = True
        .TextFileSemicolonDelimiter = False
        .TextFileCommaDelimiter = False
        .TextFileSpaceDelimiter = False
        .TextFileColumnDataTypes = Array(1, 1, 5, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, _
        1, 1, 1, 1, 1, 1, 1)
        .TextFileFixedColumnWidths = Array(7, 6, 13, 4, 4, 4, 4, 4, 2, 2, 2, 5, 3, 3, 3, 2, 5, 5, 7, 6 _
        , 7, 4, 4, 6, 6, 6, 6)
        .TextFileTrailingMinusNumbers = True
        .Refresh BackgroundQuery:=False
    End With
' Format Macro
    Columns("D:D").Select
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
    Columns("C:C").Select
    Selection.NumberFormat = "0"
    Range("D5").FormulaR1C1 = "=--TEXT(RC[-1],""0000\-00\-00\ 00\:00"")"
    LastRow = Range("A65536").End(xlUp).Row
    Range("D5").AutoFill Destination:=Range("D5:D" & LastRow)
    Columns("D:D").Select
    Selection.NumberFormat = "[$-409]m/d/yy h:mm AM/PM;@"
    Range("D4").Select
    ActiveCell.FormulaR1C1 = "Date & Time"
    Rows("5:5").Select
    Selection.Insert Shift:=xlDown, CopyOrigin:=xlFormatFromLeftOrAbove
```

```
Range("D5").Select
ActiveCell.FormulaR1C1 = "MM/DD/YY HH:MM"
Range("E4").Select
ActiveCell.FormulaR1C1 = "DIRECTION"
Range("F4").Select
ActiveCell.FormulaR1C1 = "SPEED"
Range("G4").Select
ActiveCell.FormulaR1C1 = "GUST"
Range("H4").Select
ActiveCell.FormulaR1C1 = "CEILING"
Range("I4").Select
ActiveCell.FormulaR1C1 = "SKY COVER"
Range("J4").Select
ActiveCell.FormulaR1C1 = "LOW CLOUD TYPE"
Range("K4").Select
ActiveCell.FormulaR1C1 = "MIDDLE CLOUD TYPE"
Range("L4").Select
ActiveCell.FormulaR1C1 = "HIGH CLOUD TYPE"
Range("M4").Select
ActiveCell.FormulaR1C1 = "VISIBILITY"
Range("N4").Select
ActiveCell.FormulaR1C1 = "PRESENT WEATHER"
Range("Q4").Select
ActiveCell.FormulaR1C1 = "PAST WEATHER"
Range("R4").Select
ActiveCell.FormulaR1C1 = "TEMPERATURE"
```

```
Range("S4").Select
ActiveCell.FormulaR1C1 = "DEW POINT"
Range("T4").Select
ActiveCell.FormulaR1C1 = "SEA LEVEL PRESSURE"
Range("U4").Select
ActiveCell.FormulaR1C1 = "ALTIMETER"
Range("V4").Select
ActiveCell.FormulaR1C1 = "STATION PRESSURE"
Range("W4").Select
ActiveCell.FormulaR1C1 = "MAX TEMPERATURE"
Range("X4").Select
ActiveCell.FormulaR1C1 = "MIN TEMPERATURE"
Range("Y4").Select
ActiveCell.FormulaR1C1 = "1-HR LIQUUID PRECIPITATION"
Range("Z4").Select
ActiveCell.FormulaR1C1 = "6-HR LIQUID PRECIPITATION"
Range("AA4").Select
ActiveCell.FormulaR1C1 = "24-HR LIQUID PRECIPITATION"
Range("AC4").Select
ActiveCell.FormulaR1C1 = "SNOW DEPTH"
Range("E5").Select
ActiveCell.FormulaR1C1 = "Compass Deg."
Range("F5").Select
ActiveCell.FormulaR1C1 = "mph"
Range("G5").Select
ActiveCell.FormulaR1C1 = "mph"
```

```
Range("H5").Select
ActiveCell.FormulaR1C1 = "Hundreds of Feet"
Range("M5").Select
ActiveCell.FormulaR1C1 = "Miles"
Range("R5").Select
ActiveCell.FormulaR1C1 = "Temp (oF)"
Range("S5").Select
ActiveCell.FormulaR1C1 = "Temp (oF)"
Range("T5").Select
ActiveCell.FormulaR1C1 = "Millibars"
Range("U5").Select
ActiveCell.FormulaR1C1 = "Inches"
Range("V5").Select
ActiveCell.FormulaR1C1 = "Millibars"
Range("W5").Select
ActiveCell.FormulaR1C1 = "Temp (oF)"
Range("X5").Select
ActiveCell.FormulaR1C1 = "Deg. F"
Range("Y5").Select
ActiveCell.FormulaR1C1 = "Inches"
Range("Z5").Select
ActiveCell.FormulaR1C1 = "Inches"
Range("AA5").Select
ActiveCell.FormulaR1C1 = "Inches"
Range("AC5").Select
ActiveCell.FormulaR1C1 = "Inches"
```

'**Delete Filler**

```
LastRow = Cells.Find("*", SearchOrder:=xlByRows, SearchDirection:=xlPrevious).Row

Dim startStr As String

Dim endStr As String

startStr = "A1"

endStr = "AM" & LastRow

Range(startStr, endStr).Select

Selection.Replace What:="~*", Replacement:="", LookAt:=xlPart, _

SearchOrder:=xlByRows, MatchCase:=False, SearchFormat:=False, _

ReplaceFormat:=False
```

' Converting Units Macro

```
LastRow = Cells(Rows.Count, 1).End(xlUp).Row

    Columns("G:G").Select

    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove

    Range("G6").FormulaR1C1 = "=IF(ISBLANK(RC[-1]),"" "",(IF((RC[-
1]=""T""),""0"",(IF((RC[-1]=""0.00T""),""0"",RC[-1]*1.6)))))"

    Range("G6").AutoFill Destination:=Range("G6:G" & LastRow)

    Range("G5").Select

    ActiveCell.FormulaR1C1 = "kph"

    Range("G4").Select

    ActiveCell.FormulaR1C1 = "SPEED"

    Columns("I:I").Select

    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove

    Range("I6").FormulaR1C1 = "=IF(ISBLANK(RC[-1]),"" "",(IF((RC[-
1]=""T""),""0"",(IF((RC[-1]=""0.00T""),""0"",RC[-1]*1.6)))))"

    Range("I6").AutoFill Destination:=Range("I6:I" & LastRow)

    Range("I5").Select
```

```
ActiveCell.FormulaR1C1 = "kph"
Range("I4").Select
ActiveCell.FormulaR1C1 = "GUST"
Columns("K:K").Select
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Range("K6").FormulaR1C1 = "=IF(ISBLANK(RC[-1]),"" "",RC[-1]*0.3048)"
Range("K6").AutoFill Destination:=Range("K6:K" & LastRow)
Range("K5").Select
ActiveCell.FormulaR1C1 = "km"
Range("K4").Select
ActiveCell.FormulaR1C1 = "CEILING"
Columns("K:K").Select
Selection.NumberFormat = "0.00"
Columns("Q:Q").Select
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Range("Q6").FormulaR1C1 = "=IF(ISBLANK(RC[-1]),"" "",RC[-1]*1.6)"
Range("Q6").AutoFill Destination:=Range("Q6:Q" & LastRow)
Range("Q5").Select
ActiveCell.FormulaR1C1 = "km"
Range("Q4").Select
ActiveCell.FormulaR1C1 = "VISIBILITY"
Columns("W:W").Select
Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
Range("W6").FormulaR1C1 = "=IF(ISBLANK(RC[-1]),"" "",(RC[-1]-32)*(5/9)) "
Range("W6").AutoFill Destination:=Range("W6:W" & LastRow)
Range("W5").Select
```

```
    ActiveCell.FormulaR1C1 = " Temp (oC)"
    Range("W4").Select
    ActiveCell.FormulaR1C1 = "TEMPERATURE"
    Columns("W:W").Select
    Selection.NumberFormat = "0.00"
    Columns("Y:Y").Select
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
    Range("Y6").FormulaR1C1 = "=IF(ISBLANK(RC[-1]),"" "",(RC[-1]-32)*(5/9)) "
    Range("Y6").AutoFill Destination:=Range("Y6:Y" & LastRow)
    Range("Y5").Select
    ActiveCell.FormulaR1C1 = " Temp (oC)"
    Range("Y4").Select
    ActiveCell.FormulaR1C1 = "DEW POINT"
    Columns("AF:AF").Select
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
    Range("AF6").FormulaR1C1 = "=IF(ISBLANK(RC[-1]),"" "",(IF((RC[-
1]=""T""),""0.01"",(IF((RC[-1]=""0.00T""),""0.001"",RC[-1]*2.54)))) "
    Range("AF6").AutoFill Destination:=Range("AF6:AF" & LastRow)
    Range("AF5").Select
    ActiveCell.FormulaR1C1 = "cm"
    Range("AF4").Select
    ActiveCell.FormulaR1C1 = "1-Hr PRECIP"
    Columns("AF:AF").Select
    Selection.AutoFilter
    ActiveSheet.Range("AF6:AF" & LastRow).AutoFilter Field:=1, Criteria1:="="
    Selection.SpecialCells(xlCellTypeFormulas, 23).Select
```

```
    Selection.ClearContents
    Selection.AutoFilter
    Columns("AH:AH").Select
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
    Range("AH6").FormulaR1C1 = "=IF(ISBLANK(RC[-1]),"" "",(IF((RC[-
1]=""T""),""0.01"",(IF((RC[-1]=""0.00T""),""0.001"",RC[-1]*2.54)))))"
    Range("AH6").AutoFill Destination:=Range("AH6:AH" & LastRow)
    Range("AH5").Select
    ActiveCell.FormulaR1C1 = "cm"
    Range("AH4").Select
    ActiveCell.FormulaR1C1 = "6-Hr PRECIP"
    Columns("AH:AH").Select
    Selection.AutoFilter
    ActiveSheet.Range("AH6:AH" & LastRow).AutoFilter Field:=1, Criteria1:="="
    Selection.SpecialCells(xlCellTypeFormulas, 23).Select
    Selection.ClearContents
    Selection.AutoFilter
    Columns("AJ:AJ").Select
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
    Range("AJ6").FormulaR1C1 = "=IF(ISBLANK(RC[-1]),"" "",(IF((RC[-
1]=""T""),""0.01"",(IF((RC[-1]=""0.00T""),""0.001"",RC[-1]*2.54)))))"
    Range("AJ6").AutoFill Destination:=Range("AJ6:AJ" & LastRow)
    Range("AJ5").Select
    ActiveCell.FormulaR1C1 = "cm"
    Range("AJ4").Select
    ActiveCell.FormulaR1C1 = "24-Hr PRECIP"
    Columns("AJ:AJ").Select
```

```
    Selection.AutoFilter
    ActiveSheet.Range("AJ6:AJ" & LastRow).AutoFilter Field:=1, Criteria1:="="
    Selection.SpecialCells(xlCellTypeFormulas, 23).Select
    Selection.ClearContents
    Selection.AutoFilter
    Columns("AM:AM").Select
    Selection.Insert Shift:=xlToRight, CopyOrigin:=xlFormatFromLeftOrAbove
    Range("AM6").FormulaR1C1 = "=IF(ISBLANK(RC[-1]),"" "",(IF((RC[-
1]=""T""),""0.004"",(IF((RC[-1]=""0.00T""),""0.0004"",RC[-1]*2.54)))))"
    Range("AM6").AutoFill Destination:=Range("AM6:AM" & LastRow)
    Range("AM5").Select
    ActiveCell.FormulaR1C1 = "cm"
    Range("AM4").Select
    ActiveCell.FormulaR1C1 = "SNOW DEPTH"
    Columns("AM:AM").Select
    Selection.AutoFilter
    ActiveSheet.Range("AM6:AM" & LastRow).AutoFilter Field:=1, Criteria1:="="
    Selection.SpecialCells(xlCellTypeFormulas, 23).Select
    Selection.ClearContents
    Selection.AutoFilter
' Hide Columns
Range("C:C,F:F,H:H,J:J,L:L,M:M,N:N,O:O,P:P,R:R,S:S,T:T,U:U,V:V,X:X,Y:Y,Z:Z,A
A:AA,AB:AB,AC:AC,AD:AD,AE:AE,AG:AG,AI:AI,AK:AK,AL:AL").Select
    Range("AL1").Activate
' Resize Columns
    Selection.EntireColumn.Hidden = True
```

```
Columns("A:A").EntireColumn.AutoFit
Columns("B:B").EntireColumn.AutoFit
Columns("D:D").EntireColumn.AutoFit
Columns("E:E").EntireColumn.AutoFit
Columns("G:G").EntireColumn.AutoFit
Columns("I:I").EntireColumn.AutoFit
Columns("K:K").EntireColumn.AutoFit
Columns("Q:Q").EntireColumn.AutoFit
Columns("W:W").EntireColumn.AutoFit
Columns("AF:AF").EntireColumn.AutoFit
Columns("AH:AH").EntireColumn.AutoFit
Columns("AJ:AJ").EntireColumn.AutoFit
Columns("AM:AM").EntireColumn.AutoFit
```

C# (C Sharp) Programming Code by Green, J.M. and Adamczak, K.M.:

App.config

```
<?xml version="1.0" encoding="utf-8" ?>
<configuration>
    <configSections>
    </configSections>
    <connectionStrings>
        <add
name="Katie_Version_2.Properties.Settings.mainConnectionString"
            connectionString="Data
Source=.\SQLEXPRESS;AttachDbFilename=|DataDirectory|\main.mdf;Integrated
Security=True;Connect Timeout=30;User Instance=True"
            providerName="System.Data.SqlClient" />
    </connectionStrings>
</configuration>
```

config.properties

```
connectionString#Data Source=JEFF-HP;Initial Catalog=Test;Integrated
Security=SSPI;
fileLocation#C:\Testing\
```

DailyTempIndexCalculator.cs

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Data;
using System.Data.SqlClient;
using System.Drawing;
using System.Globalization;
using System.IO;
using System.Threading;
using System.Windows.Forms;


namespace Katie_Version_2
{
    public class DailyTempIndexCalculator : TempIndexCalculator
    {


        public DailyTempIndexCalculator(IndexType indexType, YearRangeType
yearRangeType)
            : base(indexType, yearRangeType)
        {

        }
```

```
        public override List<DateValuePair> Calculate()
        {
            foreach (DataRow row in AvailDates.Rows)
            {
                String timeString = (String)row[0];
                DateTime time;
                try
                {
                    time = DateTime.ParseExact(timeString, "dd/MM/yyyy",
CultureInfo.CurrentCulture);
                }
                catch (FormatException)
                {
                    //log(timeString);
                    continue;
                }

                String whereClause = "CONVERT(VARCHAR, " + DateColumnName +
", 103) = '" + timeString + "'";
                string sqlClause;

                sqlClause = String.Format(meanSql, whereClause, TableName,
DataColumnName);
                double? temp = QueryAndOutput(sqlClause);
                if (temp != null)
                {
                    switch(_indexType) {
                        case IndexType.Freezing:
                            if (temp < 0)
                            {
                                //Add absolute value of temp to value
stored for its year
                                RecordValue(time, Math.Abs((double)temp));
                            }
                            break;
                        case IndexType.Thawing:
                            if (temp > 0)
                            {
                                RecordValue(time, (double)temp);
                            }
                            break;
                    }
                }

                ProgressBar.Invoke(new MethodInvoker(delegate {
ProgressBar.Increment(1); }));
            }

            List<DateValuePair> values = PrepareResults();
            values.Sort(new YearSorter());

            return values;
        }
    }
}
```

DateValuePair.cs

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;

namespace Katie_Version_2
{
    public class DateValuePair
    {
        private String date;
        private String value;
        private String displayValue;

        public DateValuePair(string date, string value)
        {
            this.date = date;
            this.value = value;
            this.displayValue = date;
        }

        public DateValuePair(string date, string value, string
displayValue)
        {
            this.date = date;
            this.value = value;
            this.displayValue = displayValue;
        }

        public String Date
        {
            get { return date; }
            set { date = value; }
        }

        public string Value
        {
            get { return value; }
            set { this.value = value; }
        }

        public string DisplayValue
        {
            get { return displayValue; }
            set { displayValue = value; }
        }
    }
}
```

C# (C Sharp) Programming User Interface Code by Green, J.M. and Adamczak, K.M.:

Form1.designer.cs

```
namespace Katie_Version_2
{
	partial class Form1
	{
		/// <summary>
		/// Required designer variable.
		/// </summary>
		private System.ComponentModel.IContainer components = null;

		/// <summary>
		/// Clean up any resources being used.
		/// </summary>
		/// <param name="disposing">true if managed resources should
be disposed; otherwise, false.</param>
		protected override void Dispose(bool disposing)
		{
			if (disposing && (components != null))
			{
				components.Dispose();
			}
			base.Dispose(disposing);
		}

		#region Windows Form Designer generated code

		/// <summary>
		/// Required method for Designer support - do not modify
		/// the contents of this method with the code editor.
		/// </summary>
		private void InitializeComponent()
		{
		this.startDatePicker = new
System.Windows.Forms.DateTimePicker();
		this.label1 = new System.Windows.Forms.Label();
		this.endDatePicker = new System.Windows.Forms.DateTimePicker();
		this.label2 = new System.Windows.Forms.Label();
		this.executeButton = new System.Windows.Forms.Button();
		this.tableNameTextBox = new System.Windows.Forms.TextBox();
		this.label3 = new System.Windows.Forms.Label();
		this.label4 = new System.Windows.Forms.Label();
		this.dateColumnTextBox = new System.Windows.Forms.TextBox();
		this.label5 = new System.Windows.Forms.Label();
		this.tempTextBox = new System.Windows.Forms.TextBox();
		this.progressBar = new System.Windows.Forms.ProgressBar();
		this.label6 = new System.Windows.Forms.Label();
		this.processingType = new System.Windows.Forms.Label();
		this.Standard = new System.Windows.Forms.TabControl();
		this.tabPage1 = new System.Windows.Forms.TabPage();
		this.sumCheck = new System.Windows.Forms.CheckBox();
		this.annualCheck = new System.Windows.Forms.CheckBox();
		this.modeCheck = new System.Windows.Forms.CheckBox();
		this.medianCheck = new System.Windows.Forms.CheckBox();
		this.meanCheck = new System.Windows.Forms.CheckBox();
		this.monthlyCheck = new System.Windows.Forms.CheckBox();
```

```
            this.weeklyCheck = new System.Windows.Forms.CheckBox();
            this.dailyCheck = new System.Windows.Forms.CheckBox();
            this.tabPage2 = new System.Windows.Forms.TabPage();
            this.SeasFlm = new System.Windows.Forms.CheckBox();
            this.SeasTlm = new System.Windows.Forms.CheckBox();
            this.SeasTld = new System.Windows.Forms.CheckBox();
            this.SeasFld = new System.Windows.Forms.CheckBox();
            this.GregTlm = new System.Windows.Forms.CheckBox();
            this.GregFlm = new System.Windows.Forms.CheckBox();
            this.GregTld = new System.Windows.Forms.CheckBox();
            this.GregFld = new System.Windows.Forms.CheckBox();
            this.label8 = new System.Windows.Forms.Label();
            this.label7 = new System.Windows.Forms.Label();
            this.Standard.SuspendLayout();
            this.tabPage1.SuspendLayout();
            this.tabPage2.SuspendLayout();
            this.SuspendLayout();
            //
            // startDatePicker
            //
            this.startDatePicker.Location = new System.Drawing.Point(164,
23);
            this.startDatePicker.Name = "startDatePicker";
            this.startDatePicker.Size = new System.Drawing.Size(200, 20);
            this.startDatePicker.TabIndex = 0;
            this.startDatePicker.Value = new System.DateTime(1909, 12, 25,
0, 0, 0, 0);
            //
            // label1
            //
            this.label1.AutoSize = true;
            this.label1.Location = new System.Drawing.Point(44, 29);
            this.label1.Name = "label1";
            this.label1.Size = new System.Drawing.Size(55, 13);
            this.label1.TabIndex = 1;
            this.label1.Text = "Start Date";
            //
            // endDatePicker
            //
            this.endDatePicker.Location = new System.Drawing.Point(164,
70);
            this.endDatePicker.Name = "endDatePicker";
            this.endDatePicker.Size = new System.Drawing.Size(200, 20);
            this.endDatePicker.TabIndex = 2;
            //
            // label2
            //
            this.label2.AutoSize = true;
            this.label2.Location = new System.Drawing.Point(44, 77);
            this.label2.Name = "label2";
            this.label2.Size = new System.Drawing.Size(52, 13);
            this.label2.TabIndex = 3;
            this.label2.Text = "End Date";
            //
            // executeButton
            //
```

```
            this.executeButton.Location = new System.Drawing.Point(148,
438);
            this.executeButton.Name = "executeButton";
            this.executeButton.Size = new System.Drawing.Size(75, 23);
            this.executeButton.TabIndex = 10;
            this.executeButton.Text = "Execute";
            this.executeButton.UseVisualStyleBackColor = true;
            this.executeButton.Click += new
System.EventHandler(this.executeButton_Click);
            //
            // tableNameTextBox
            //
            this.tableNameTextBox.Location = new System.Drawing.Point(164,
109);
            this.tableNameTextBox.Name = "tableNameTextBox";
            this.tableNameTextBox.Size = new System.Drawing.Size(200, 20);
            this.tableNameTextBox.TabIndex = 11;
            this.tableNameTextBox.Text = "Anaktuvuk";
            //
            // label3
            //
            this.label3.AutoSize = true;
            this.label3.Location = new System.Drawing.Point(44, 116);
            this.label3.Name = "label3";
            this.label3.Size = new System.Drawing.Size(65, 13);
            this.label3.TabIndex = 12;
            this.label3.Text = "Table Name";
            //
            // label4
            //
            this.label4.AutoSize = true;
            this.label4.Location = new System.Drawing.Point(44, 149);
            this.label4.Name = "label4";
            this.label4.Size = new System.Drawing.Size(99, 13);
            this.label4.TabIndex = 13;
            this.label4.Text = "Date Column Name";
            //
            // dateColumnTextBox
            //
            this.dateColumnTextBox.Location = new System.Drawing.Point(164,
142);
            this.dateColumnTextBox.Name = "dateColumnTextBox";
            this.dateColumnTextBox.Size = new System.Drawing.Size(200, 20);
            this.dateColumnTextBox.TabIndex = 14;
            this.dateColumnTextBox.Text = "[Date & Time]";
            //
            // label5
            //
            this.label5.AutoSize = true;
            this.label5.Location = new System.Drawing.Point(44, 184);
            this.label5.Name = "label5";
            this.label5.Size = new System.Drawing.Size(103, 13);
            this.label5.TabIndex = 15;
            this.label5.Text = "Temp Column Name";
            //
            // tempTextBox
```

```
            //
            this.tempTextBox.Location = new System.Drawing.Point(164, 176);
            this.tempTextBox.Name = "tempTextBox";
            this.tempTextBox.Size = new System.Drawing.Size(200, 20);
            this.tempTextBox.TabIndex = 16;
            this.tempTextBox.Text = "TEMPERATURE";
            //
            // progressBar
            //
            this.progressBar.Location = new System.Drawing.Point(47, 400);
            this.progressBar.Name = "progressBar";
            this.progressBar.Size = new System.Drawing.Size(284, 23);
            this.progressBar.TabIndex = 17;
            //
            // label6
            //
            this.label6.AutoSize = true;
            this.label6.Location = new System.Drawing.Point(47, 369);
            this.label6.Name = "label6";
            this.label6.Size = new System.Drawing.Size(62, 13);
            this.label6.TabIndex = 18;
            this.label6.Text = "Processing:";
            //
            // processingType
            //
            this.processingType.AutoSize = true;
            this.processingType.Location = new System.Drawing.Point(115,
369);
            this.processingType.Name = "processingType";
            this.processingType.Size = new System.Drawing.Size(0, 13);
            this.processingType.TabIndex = 19;
            //
            // Standard
            //
            this.Standard.Controls.Add(this.tabPage1);
            this.Standard.Controls.Add(this.tabPage2);
            this.Standard.Location = new System.Drawing.Point(50, 200);
            this.Standard.Name = "Standard";
            this.Standard.SelectedIndex = 0;
            this.Standard.Size = new System.Drawing.Size(280, 169);
            this.Standard.TabIndex = 20;
            //
            // tabPage1
            //
            this.tabPage1.Controls.Add(this.sumCheck);
            this.tabPage1.Controls.Add(this.annualCheck);
            this.tabPage1.Controls.Add(this.modeCheck);
            this.tabPage1.Controls.Add(this.medianCheck);
            this.tabPage1.Controls.Add(this.meanCheck);
            this.tabPage1.Controls.Add(this.monthlyCheck);
            this.tabPage1.Controls.Add(this.weeklyCheck);
            this.tabPage1.Controls.Add(this.dailyCheck);
            this.tabPage1.Location = new System.Drawing.Point(4, 22);
            this.tabPage1.Name = "tabPage1";
            this.tabPage1.Padding = new System.Windows.Forms.Padding(3);
            this.tabPage1.Size = new System.Drawing.Size(272, 143);
```

```
this.tabPage1.TabIndex = 0;
this.tabPage1.Text = "tabPage1";
this.tabPage1.UseVisualStyleBackColor = true;
//
// sumCheck
//
this.sumCheck.AutoSize = true;
this.sumCheck.Location = new System.Drawing.Point(190, 116);
this.sumCheck.Name = "sumCheck";
this.sumCheck.Size = new System.Drawing.Size(47, 17);
this.sumCheck.TabIndex = 29;
this.sumCheck.Text = "Sum";
this.sumCheck.UseVisualStyleBackColor = true;
//
// annualCheck
//
this.annualCheck.AutoSize = true;
this.annualCheck.Location = new System.Drawing.Point(21, 116);
this.annualCheck.Name = "annualCheck";
this.annualCheck.Size = new System.Drawing.Size(59, 17);
this.annualCheck.TabIndex = 28;
this.annualCheck.Text = "Annual";
this.annualCheck.UseVisualStyleBackColor = true;
//
// modeCheck
//
this.modeCheck.AutoSize = true;
this.modeCheck.Location = new System.Drawing.Point(190, 83);
this.modeCheck.Name = "modeCheck";
this.modeCheck.Size = new System.Drawing.Size(53, 17);
this.modeCheck.TabIndex = 27;
this.modeCheck.Text = "Mode";
this.modeCheck.UseVisualStyleBackColor = true;
//
// medianCheck
//
this.medianCheck.AutoSize = true;
this.medianCheck.Location = new System.Drawing.Point(190, 46);
this.medianCheck.Name = "medianCheck";
this.medianCheck.Size = new System.Drawing.Size(61, 17);
this.medianCheck.TabIndex = 26;
this.medianCheck.Text = "Median";
this.medianCheck.UseVisualStyleBackColor = true;
//
// meanCheck
//
this.meanCheck.AutoSize = true;
this.meanCheck.Location = new System.Drawing.Point(190, 10);
this.meanCheck.Name = "meanCheck";
this.meanCheck.Size = new System.Drawing.Size(53, 17);
this.meanCheck.TabIndex = 25;
this.meanCheck.Text = "Mean";
this.meanCheck.UseVisualStyleBackColor = true;
//
// monthlyCheck
//
```

```
this.monthlyCheck.AutoSize = true;
this.monthlyCheck.Location = new System.Drawing.Point(21, 83);
this.monthlyCheck.Name = "monthlyCheck";
this.monthlyCheck.Size = new System.Drawing.Size(63, 17);
this.monthlyCheck.TabIndex = 24;
this.monthlyCheck.Text = "Monthly";
this.monthlyCheck.UseVisualStyleBackColor = true;
//
// weeklyCheck
//
this.weeklyCheck.AutoSize = true;
this.weeklyCheck.Location = new System.Drawing.Point(21, 46);
this.weeklyCheck.Name = "weeklyCheck";
this.weeklyCheck.Size = new System.Drawing.Size(62, 17);
this.weeklyCheck.TabIndex = 23;
this.weeklyCheck.Text = "Weekly";
this.weeklyCheck.UseVisualStyleBackColor = true;
//
// dailyCheck
//
this.dailyCheck.AutoSize = true;
this.dailyCheck.Location = new System.Drawing.Point(21, 10);
this.dailyCheck.Name = "dailyCheck";
this.dailyCheck.Size = new System.Drawing.Size(49, 17);
this.dailyCheck.TabIndex = 22;
this.dailyCheck.Text = "Daily";
this.dailyCheck.UseVisualStyleBackColor = true;
//
// tabPage2
//
this.tabPage2.Controls.Add(this.SeasFlm);
this.tabPage2.Controls.Add(this.SeasTlm);
this.tabPage2.Controls.Add(this.SeasTld);
this.tabPage2.Controls.Add(this.SeasFld);
this.tabPage2.Controls.Add(this.GregTlm);
this.tabPage2.Controls.Add(this.GregFlm);
this.tabPage2.Controls.Add(this.GregTld);
this.tabPage2.Controls.Add(this.GregFld);
this.tabPage2.Controls.Add(this.label8);
this.tabPage2.Controls.Add(this.label7);
this.tabPage2.Location = new System.Drawing.Point(4, 22);
this.tabPage2.Name = "tabPage2";
this.tabPage2.Padding = new System.Windows.Forms.Padding(3);
this.tabPage2.Size = new System.Drawing.Size(272, 143);
this.tabPage2.TabIndex = 1;
this.tabPage2.Text = "tabPage2";
this.tabPage2.UseVisualStyleBackColor = true;
//
// SeasFlm
//
this.SeasFlm.AutoSize = true;
this.SeasFlm.Location = new System.Drawing.Point(141, 87);
this.SeasFlm.Name = "SeasFlm";
this.SeasFlm.Size = new System.Drawing.Size(42, 17);
this.SeasFlm.TabIndex = 9;
this.SeasFlm.Text = "Flm";
```

```
this.SeasFlm.UseVisualStyleBackColor = true;
//
// SeasTlm
//
this.SeasTlm.AutoSize = true;
this.SeasTlm.Location = new System.Drawing.Point(141, 109);
this.SeasTlm.Name = "SeasTlm";
this.SeasTlm.Size = new System.Drawing.Size(43, 17);
this.SeasTlm.TabIndex = 8;
this.SeasTlm.Text = "Tlm";
this.SeasTlm.UseVisualStyleBackColor = true;
//
// SeasTld
//
this.SeasTld.AutoSize = true;
this.SeasTld.Location = new System.Drawing.Point(141, 64);
this.SeasTld.Name = "SeasTld";
this.SeasTld.Size = new System.Drawing.Size(41, 17);
this.SeasTld.TabIndex = 7;
this.SeasTld.Text = "Tld";
this.SeasTld.UseVisualStyleBackColor = true;
//
// SeasFld
//
this.SeasFld.AutoSize = true;
this.SeasFld.Location = new System.Drawing.Point(141, 40);
this.SeasFld.Name = "SeasFld";
this.SeasFld.Size = new System.Drawing.Size(40, 17);
this.SeasFld.TabIndex = 6;
this.SeasFld.Text = "Fld";
this.SeasFld.UseVisualStyleBackColor = true;
//
// GregTlm
//
this.GregTlm.AutoSize = true;
this.GregTlm.Location = new System.Drawing.Point(16, 109);
this.GregTlm.Name = "GregTlm";
this.GregTlm.Size = new System.Drawing.Size(43, 17);
this.GregTlm.TabIndex = 5;
this.GregTlm.Text = "Tlm";
this.GregTlm.UseVisualStyleBackColor = true;
//
// GregFlm
//
this.GregFlm.AutoSize = true;
this.GregFlm.Location = new System.Drawing.Point(16, 86);
this.GregFlm.Name = "GregFlm";
this.GregFlm.Size = new System.Drawing.Size(42, 17);
this.GregFlm.TabIndex = 4;
this.GregFlm.Text = "Flm";
this.GregFlm.UseVisualStyleBackColor = true;
//
// GregTld
//
this.GregTld.AutoSize = true;
this.GregTld.Location = new System.Drawing.Point(16, 63);
```

```
this.GregTld.Name = "GregTld";
this.GregTld.Size = new System.Drawing.Size(41, 17);
this.GregTld.TabIndex = 3;
this.GregTld.Text = "Tld";
this.GregTld.UseVisualStyleBackColor = true;
//
// GregFld
//
this.GregFld.AutoSize = true;
this.GregFld.Location = new System.Drawing.Point(16, 40);
this.GregFld.Name = "GregFld";
this.GregFld.Size = new System.Drawing.Size(40, 17);
this.GregFld.TabIndex = 2;
this.GregFld.Text = "Fld";
this.GregFld.UseVisualStyleBackColor = true;
//
// label8
//
this.label8.AutoSize = true;
this.label8.Location = new System.Drawing.Point(138, 12);
this.label8.Name = "label8";
this.label8.Size = new System.Drawing.Size(51, 13);
this.label8.TabIndex = 1;
this.label8.Text = "Seasonal";
//
// label7
//
this.label7.AutoSize = true;
this.label7.Location = new System.Drawing.Point(9, 12);
this.label7.Name = "label7";
this.label7.Size = new System.Drawing.Size(53, 13);
this.label7.TabIndex = 0;
this.label7.Text = "Gregorian";
//
// Form1
//
this.AutoScaleDimensions = new System.Drawing.SizeF(6F, 13F);
this.AutoScaleMode = System.Windows.Forms.AutoScaleMode.Font;
this.ClientSize = new System.Drawing.Size(376, 473);
this.Controls.Add(this.Standard);
this.Controls.Add(this.processingType);
this.Controls.Add(this.label6);
this.Controls.Add(this.progressBar);
this.Controls.Add(this.tempTextBox);
this.Controls.Add(this.label5);
this.Controls.Add(this.dateColumnTextBox);
this.Controls.Add(this.label4);
this.Controls.Add(this.label3);
this.Controls.Add(this.tableNameTextBox);
this.Controls.Add(this.executeButton);
this.Controls.Add(this.label2);
this.Controls.Add(this.endDatePicker);
this.Controls.Add(this.label1);
this.Controls.Add(this.startDatePicker);
this.Name = "Form1";
this.Text = "Stats Calculator";
```

```
            this.Standard.ResumeLayout(false);
            this.tabPage1.ResumeLayout(false);
            this.tabPage1.PerformLayout();
            this.tabPage2.ResumeLayout(false);
            this.tabPage2.PerformLayout();
            this.ResumeLayout(false);
            this.PerformLayout();

              }

              #endregion

              private System.Windows.Forms.DateTimePicker startDatePicker;
              private System.Windows.Forms.Label label1;
              private System.Windows.Forms.DateTimePicker endDatePicker;
        private System.Windows.Forms.Label label2;
              private System.Windows.Forms.Button executeButton;
              private System.Windows.Forms.TextBox tableNameTextBox;
              private System.Windows.Forms.Label label3;
              private System.Windows.Forms.Label label4;
              private System.Windows.Forms.TextBox dateColumnTextBox;
              private System.Windows.Forms.Label label5;
              private System.Windows.Forms.TextBox tempTextBox;
              private System.Windows.Forms.ProgressBar progressBar;
              private System.Windows.Forms.Label label6;
        private System.Windows.Forms.Label processingType;
        private System.Windows.Forms.TabControl Standard;
        private System.Windows.Forms.TabPage tabPage1;
        private System.Windows.Forms.CheckBox sumCheck;
        private System.Windows.Forms.CheckBox annualCheck;
        private System.Windows.Forms.CheckBox modeCheck;
        private System.Windows.Forms.CheckBox medianCheck;
        private System.Windows.Forms.CheckBox meanCheck;
        private System.Windows.Forms.CheckBox monthlyCheck;
        private System.Windows.Forms.CheckBox weeklyCheck;
        private System.Windows.Forms.CheckBox dailyCheck;
        private System.Windows.Forms.TabPage tabPage2;
        private System.Windows.Forms.Label label7;
        private System.Windows.Forms.CheckBox GregFld;
        private System.Windows.Forms.Label label8;
        private System.Windows.Forms.CheckBox SeasFlm;
        private System.Windows.Forms.CheckBox SeasTlm;
        private System.Windows.Forms.CheckBox SeasTld;
        private System.Windows.Forms.CheckBox SeasFld;
        private System.Windows.Forms.CheckBox GregTlm;
        private System.Windows.Forms.CheckBox GregFlm;
        private System.Windows.Forms.CheckBox GregTld;
      }
}
```

MonthlyTempIndexCalculator.cs

```
using System;
using System.Collections.Generic;
using System.Linq;
```

```
using System.Text;
using System.Data;
using System.Globalization;
using System.Windows.Forms;

namespace Katie_Version_2
{
    public class MonthlyTempIndexCalculator : TempIndexCalculator
    {
        public MonthlyTempIndexCalculator(IndexType indexType,
YearRangeType yearRangeType)
            : base(indexType, yearRangeType)
        {

        }

        public override List<DateValuePair> Calculate()
        {
            List<string> processedMonths = new List<string>();
            foreach (DataRow row in AvailDates.Rows)
            {
                String timeString = (String)row[0];
                DateTime time;
                try
                {
                    time = DateTime.ParseExact(timeString, "dd/MM/yyyy",
CultureInfo.CurrentCulture);
                }
                catch (FormatException)
                {
                    //log(timeString);
                    continue;
                }

                int month = time.Month;
                            int year = time.Year;

                if(processedMonths.Contains(month + "/" + year)) {
                    continue;
                }

                String whereClause = " DATEPART(mm, " + DateColumnName + ")
= " + month + " AND DATEPART(yyyy, " + DateColumnName + ") = " + year;
                string sqlClause;

                sqlClause = String.Format(meanSql, whereClause, TableName,
DataColumnName);
                double? temp = QueryAndOutput(sqlClause);
                if (temp != null)
                {
                    switch (_indexType)
                    {
                        case IndexType.Freezing:
                            if (temp < 0)
                            {
```

```
                                //Add absolute value of temp to value
stored for its year
                                RecordValue(time, Math.Abs((double)temp) *
DateTime.DaysInMonth(year, month));
                            }
                            break;
                        case IndexType.Thawing:
                            if (temp > 0)
                            {
                                RecordValue(time, (double)temp *
DateTime.DaysInMonth(year, month));
                            }
                            break;
                    }

                    processedMonths.Add(month + "/" + year);
                }

                ProgressBar.Invoke(new MethodInvoker(delegate {
ProgressBar.Increment(1); }));
            }

            List<DateValuePair> values = PrepareResults();
            values.Sort(new YearSorter());

            return values;
        }
    }
}
```

Program.cs

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Windows.Forms;

namespace Katie_Version_2
{
       static class Program
       {
              /// <summary>
              /// The main entry point for the application.
              /// </summary>
              [STAThread]
              static void Main()
              {
                     Application.EnableVisualStyles();
                     Application.SetCompatibleTextRenderingDefault(false);
                     Application.Run(new Form1());
              }
       }
}
```

TempIndexCalculator.cs

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;

namespace Katie_Version_2
{
    public abstract class TempIndexCalculator : ValueCalculator
    {
        protected IndexType _indexType;
        protected YearRangeType _yearRangeType;

        protected Dictionary<int, double> _yearlyTempSums = new
Dictionary<int, double>();
        protected Dictionary<int, double> _seasonalTempSums = new
Dictionary<int, double>();

        public TempIndexCalculator(IndexType indexType, YearRangeType
yearRangeType)
        {
            _indexType = indexType;
            _yearRangeType = yearRangeType;
        }

        protected void RecordValue(DateTime day, double temperature)
        {
            switch (_yearRangeType)
            {
                case YearRangeType.Gregorian:
                    //Initialize
                    if (!_yearlyTempSums.ContainsKey(day.Year))
                    {
                        _yearlyTempSums[day.Year] = temperature;
                    }
                    else
                    {
                        _yearlyTempSums[day.Year] += temperature;
                    }
                    break;
                case YearRangeType.Seasonal:
                    //Note: We will use the Sept 1 year (X) to track
temperatures for Sept 1, X - Aug 21, X+1
                    int yearToUse;
                    if (day.Month < 9)
                    {
                        yearToUse = day.Year - 1;
                    }
                    else
                    {
                        yearToUse = day.Year;
                    }

                    if (!_seasonalTempSums.ContainsKey(yearToUse))
                    {
                        _seasonalTempSums[yearToUse] = temperature;
                    }
```

```
                    else
                    {
                        _seasonalTempSums[yearToUse] += temperature;
                    }
                    break;
            }
        }

        protected List<DateValuePair> PrepareResults()
        {
            List<DateValuePair> valuePairs = new List<DateValuePair>();
            Dictionary<int, double> dictToUse = null;

            switch (_yearRangeType)
            {
                case YearRangeType.Gregorian:
                    dictToUse = _yearlyTempSums;
                    break;
                case YearRangeType.Seasonal:
                    dictToUse = _seasonalTempSums;
                    break;
            }

            foreach(KeyValuePair<int, double> kvp in dictToUse)
            {
                valuePairs.Add(new DateValuePair(kvp.Key.ToString(),
kvp.Value.ToString()));
            }

            return valuePairs;
        }

        protected class YearSorter : IComparer<DateValuePair>
        {
            public int Compare(DateValuePair x, DateValuePair y)
            {
                return
Int32.Parse(x.DisplayValue).CompareTo(Int32.Parse(y.DisplayValue));
            }
        }

        public enum IndexType
        {
            Freezing,
            Thawing
        }

        public enum YearRangeType
        {
            Gregorian,
            Seasonal
        }
    }
}
```

ValueCalculator.cs

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Data;
using System.Data.SqlClient;
using System.Globalization;
using System.Windows.Forms;

namespace Katie_Version_2
{
    public abstract class ValueCalculator
    {

        protected string meanSql = "SELECT AVG({2}) " +
                                   "FROM {1} " +
                                   "WHERE {0}";

        public string ConnectionString { get; set; }
        public DataTable AvailDates { get; set; }
        public string DateColumnName { get; set; }
        public string DataColumnName { get; set; }
        public string TableName { get; set; }
        public ProgressBar ProgressBar { get; set; }

        public abstract List<DateValuePair> Calculate();

        protected DataTable Query(String query)
        {
            SqlConnection cn = new SqlConnection(ConnectionString);
            DataTable table = new DataTable();
            try
            {
                //log("Before Open");
                cn.Open();
                //log("After Open");

                SqlDataAdapter da = new SqlDataAdapter(query, cn);
                da.Fill(table);
            }
            catch (Exception ex)
            {
                //log("Table Open/Query Failed." + ex);
            }
            finally
            {
                if (cn.State != ConnectionState.Closed)
                {
                    cn.Close();
                }
            }

            return table;
        }

        protected double? QueryAndOutput(string query)
```

```
        {
            DataTable table = Query(query);

            if (table.Rows.Count == 0)
            {
                return null;
            }
            else if (table.Rows[0][0] == DBNull.Value)
            {
                return null;
            }

            return table.Rows[0][0] as double?;
        }

        protected class DateSorter : IComparer<DateValuePair>
        {
            public int Compare(DateValuePair x, DateValuePair y)
            {
                DateTime xDate = DateTime.ParseExact(x.DisplayValue,
"dd/MM/yyyy", CultureInfo.CurrentCulture);
                DateTime yDate = DateTime.ParseExact(y.DisplayValue,
"dd/MM/yyyy", CultureInfo.CurrentCulture);
                return xDate.CompareTo(yDate);
            }
        }
    }
}
```

Form1.cs

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Data.SqlClient;
using System.Drawing;
using System.Globalization;
using System.IO;
using System.Linq;
using System.Text;
using System.Threading;
using System.Windows.Forms;

namespace Katie_Version_2
{
       public partial class Form1 : Form
       {
              public static string meanSql = "SELECT AVG({2}) " +
                                                          "FROM {1} " +
                                                          "WHERE {0}";

              private string medianSql = "SELECT (( " +
                                                          "SELECT TOP 1
{2} " +
```

```
                                                                    "FROM
( " +
       "SELECT TOP 50 PERCENT {2} " +
       "FROM {1} " +
              "WHERE {2} IS NOT NULL AND {0}" +
              "ORDER BY {2} " +
                                                                    ") AS
A " +
                                                                "ORDER BY {2}
DESC) +" +
                                                                "( " +
                                                                "SELECT TOP 1
{2} " +
                                                                    "FROM
( " +
       "SELECT TOP 50 PERCENT {2} " +
       "FROM {1} " +
       "WHERE {2} IS NOT NULL AND {0}" +
       "ORDER BY {2} DESC " +
                                                                    ") AS
A " +
                                                                "ORDER BY {2}
ASC)) / 2";
              private string modeSql = "SELECT TOP 1 WITH ties {2} " +
                                                                "FROM {1} " +
                                                                "WHERE {2} IS
Not NULL AND {0}" +
                                                                "GROUP BY {2}
" +
                                                                "ORDER BY
COUNT(*) DESC";


        private string sumSql = "SELECT SUM({2}) " +
                                "FROM {1} " +
                                "WHERE {0}";

              private readonly string _connectionString;
              private readonly string _fileLocation;
              private const string LogLocation = "log.error";

              public Form1()
              {
                     InitializeComponent();
                     StreamReader reader = new
StreamReader("config.properties");
                     String line;
```

```
                while ((line = reader.ReadLine()) != null)
                {
                        string[] lineSplit = line.Split('#');
                        switch (lineSplit[0])
                        {
                                case "connectionString":
                                        _connectionString = @lineSplit[1];
                                        break;
                                case "fileLocation":
                                        _fileLocation = @lineSplit[1];
                                        break;
                        }
                }
        }


        private void executeButton_Click(object sender, EventArgs e)
        {
                Thread thread = new Thread(new ThreadStart(execute));
                thread.Start();
        }

        private void execute()
        {
                SetScreen(false);

                File.Delete(_fileLocation + LogLocation);

                List<DateValuePair> dailyMean = new
List<DateValuePair>();
                List<DateValuePair> dailyMedian = new
List<DateValuePair>();
                List<DateValuePair> dailyMode = new
List<DateValuePair>();
            List<DateValuePair> dailySum = new List<DateValuePair>();

                List<DateValuePair> weeklyMean = new
List<DateValuePair>();
                List<DateValuePair> weeklyMedian = new
List<DateValuePair>();
                List<DateValuePair> weeklyMode = new
List<DateValuePair>();
            List<DateValuePair> weeklySum = new List<DateValuePair>();

                List<DateValuePair> monthlyMean = new
List<DateValuePair>();
                List<DateValuePair> monthlyMedian = new
List<DateValuePair>();
                List<DateValuePair> monthlyMode = new
List<DateValuePair>();
            List<DateValuePair> monthlySum = new List<DateValuePair>();

            List<DateValuePair> annualMean = new List<DateValuePair>();
            List<DateValuePair> annualMedian = new List<DateValuePair>();
            List<DateValuePair> annualMode = new List<DateValuePair>();
            List<DateValuePair> annualSum = new List<DateValuePair>();
```

```
                    String queryDates =
                                "SELECT DISTINCT CONVERT(VARCHAR, " +
dateColumnTextBox.Text + ", 103) FROM {2} WHERE " + dateColumnTextBox.Text
+ " > '{0}' AND " + dateColumnTextBox.Text + " < '{1}'";
                    DateTime startDateTime = startDatePicker.Value;
                    string startDate = startDateTime.Month + "/" +
startDateTime.Day + "/" + startDateTime.Year;

                    DateTime endDateTime = endDatePicker.Value;
                    string endDate = endDateTime.Month + "/" +
endDateTime.Day + "/" + endDateTime.Year;

                    String dateQuery = String.Format(queryDates, startDate,
endDate, tableNameTextBox.Text);
                    log("Initial Query Before");
                    DataTable table = Query(dateQuery);
                    log("Initial Query After " + table.Rows.Count);

                    progressBar.Minimum = 0;
            if (progressBar.InvokeRequired)
            {
                progressBar.Invoke(new MethodInvoker(delegate {
progressBar.Maximum = table.Rows.Count; }));
            } else {
                progressBar.Maximum = table.Rows.Count;
            }

                    List<DateValuePair> dailyMeanFilled = new
List<DateValuePair>();
                    List<DateValuePair> dailyMedianFilled = new
List<DateValuePair>();
                    List<DateValuePair> dailyModeFilled = new
List<DateValuePair>();
            List<DateValuePair> dailySumFilled = new List<DateValuePair>();

                    if (dailyCheck.Checked)
                    {
                            processingType.Invoke(new MethodInvoker(delegate
{ processingType.Text = "Dailies"; }));
                progressBar.Invoke(new MethodInvoker(delegate {
progressBar.Value = 0; }));
                            log("Pre Dailies Loop");

                            foreach(DataRow row in table.Rows)
                            {
                                    String timeString = (String)row[0];
                                    DateTime time;
                                    try
                                    {
                                            time =
DateTime.ParseExact(timeString, "dd/MM/yyyy", CultureInfo.CurrentCulture);
                                    }
                                    catch (FormatException)
                                    {
                                            log(timeString);
```

```
                                        continue;
                                }

                                String whereClause = "CONVERT(VARCHAR, "+
dateColumnTextBox.Text +", 103) = '" + timeString + "'";
                                string sqlClause;
                                if(meanCheck.Checked)
                                {
                                        sqlClause = String.Format(meanSql,
whereClause, tableNameTextBox.Text, tempTextBox.Text);
                                        double? temp =
QueryAndOutput(sqlClause);
                                        if(temp != null)
                                        {
                                                dailyMean.Add(new
DateValuePair(timeString, temp.ToString()));
                                        }
                                }

                                if(medianCheck.Checked)
                                {
                                        sqlClause =
String.Format(medianSql, whereClause, tableNameTextBox.Text,
tempTextBox.Text);
                                        double? temp =
QueryAndOutput(sqlClause);
                                        if(temp != null)
                                        {
                                                dailyMedian.Add(new
DateValuePair(timeString, temp.ToString()));
                                        }
                                }

                                if(modeCheck.Checked)
                                {
                                        sqlClause = String.Format(modeSql,
whereClause, tableNameTextBox.Text, tempTextBox.Text);
                                        double? temp =
QueryAndOutput(sqlClause);
                                        if(temp != null)
                                        {
                                                dailyMode.Add(new
DateValuePair(timeString, temp.ToString()));
                                        }
                                }

                    if (sumCheck.Checked)
                    {
                        sqlClause = String.Format(sumSql, whereClause,
tableNameTextBox.Text, tempTextBox.Text);
                        double? temp = QueryAndOutput(sqlClause);
                        if (temp != null)
                        {
                            dailySum.Add(new DateValuePair(timeString,
temp.ToString()));
                        }
```

```
                    }

                    progressBar.Invoke(new MethodInvoker(delegate {
progressBar.Increment(1); }));
                            }

                processingType.Invoke(new MethodInvoker(delegate {
processingType.Text = "Dailies: Sorting"; }));
                            dailyMean.Sort(new DateSorter());
                            dailyMedian.Sort(new DateSorter());
                            dailyMode.Sort(new DateSorter());
                dailySum.Sort(new DateSorter());


                processingType.Invoke(new MethodInvoker(delegate {
processingType.Text = "Dailies: Filling in the blanks"; }));
                            DateTime loopDate = startDatePicker.Value;

                            while(loopDate < endDateTime)
                            {
                    string currentDate = loopDate.ToString("dd/MM/yyyy");//
Day + "/" + loopDate.Month + "/" + loopDate.Year;
                                    DateValuePair pair =
dailyMean.Get(currentDate);
                                    if(pair == null)
                                    {
                                            dailyMeanFilled.Add(new
DateValuePair(currentDate, ""));
                                    } else
                                    {
                                            dailyMeanFilled.Add(pair);
                                    }

                                    pair = dailyMedian.Get(currentDate);
                                    if(pair == null)
                                    {
                                            dailyMedianFilled.Add(new
DateValuePair(currentDate, ""));
                                    } else
                                    {
                                            dailyMedianFilled.Add(pair);
                                    }

                                    pair = dailyMode.Get(currentDate);
                                    if(pair == null)
                                    {
                                            dailyModeFilled.Add(new
DateValuePair(currentDate, ""));
                                    } else
                                    {
                                            dailyModeFilled.Add(pair);
                                    }

                    pair = dailySum.Get(currentDate);
                    if (pair == null)
                    {
```

```
                        dailySumFilled.Add(new DateValuePair(currentDate,
"", 0));
                    }
                    else
                    {
                        dailySumFilled.Add(pair);
                    }

                                loopDate = loopDate.AddDays(1);
                            }
                    }

                    OutputToDisk(dailyMeanFilled, "dailyMean.txt");
                    OutputToDisk(dailyMedianFilled, "dailyMedian.txt");
                    OutputToDisk(dailyModeFilled, "dailyMode.txt");
            OutputToDisk(dailySumFilled, "dailySum.txt");
                    log("Post Dailies Loop");

                    List<DateValuePair> weeklyMeanFilled = new
List<DateValuePair>();
                    List<DateValuePair> weeklyMedianFilled = new
List<DateValuePair>();
                    List<DateValuePair> weeklyModeFilled = new
List<DateValuePair>();


                    if (weeklyCheck.Checked)
                    {
                            DateTimeFormatInfo dfi =
DateTimeFormatInfo.CurrentInfo;
                            Calendar cal = dfi.Calendar;
                processingType.Invoke(new MethodInvoker(delegate {
processingType.Text = "Weeklies"; }));
                            progressBar.Invoke(new MethodInvoker(delegate
{progressBar.Value = 0;}));
                            log("Pre Weeklies Loop");
                            foreach (DataRow row in table.Rows)
                            {
                                    String timeString = (String)row[0];
                                    DateTime time;
                                    try
                                    {
                                            time =
DateTime.ParseExact(timeString, "dd/MM/yyyy", CultureInfo.CurrentCulture);
                                    }
                                    catch (FormatException)
                                    {
                                            log(timeString);
                                            continue;
                                    }
                                    int weekOfYear = cal.GetWeekOfYear(time,
dfi.CalendarWeekRule, dfi.FirstDayOfWeek);
                                    int year = time.Year;

                                    if (weeklyMean.Exists(pair => pair.Date
== weekOfYear + "/" + year) ||
```

```
                                        weeklyMedian.Exists(pair => pair.Date
== weekOfYear + "/" + year) ||
                                        weeklyMode.Exists(pair => pair.Date
== weekOfYear + "/" + year) ||
                        weeklySum.Exists(pair => pair.Date == weekOfYear +
"/" + year))
                                    {
                                        progressBar.Invoke(new
MethodInvoker(delegate {progressBar.Increment(1);}));
                                        continue;
                                    }

                                    String whereClause = " DATEPART(ww, " +
dateColumnTextBox.Text + ") = " + weekOfYear + "AND DATEPART(yyyy, " +
dateColumnTextBox.Text + ") = " + year;
                                    String sqlClause;
                                    if (meanCheck.Checked)
                                    {
                                        sqlClause = String.Format(meanSql,
whereClause, tableNameTextBox.Text, tempTextBox.Text);
                                        double? temp =
QueryAndOutput(sqlClause);
                                        if(temp != null)
                                        {
                                            weeklyMean.Add(new
DateValuePair(weekOfYear + "/" + year, temp.ToString(), time.Month + "/" +
time.Day + "/" + year));
                                        }
                                    }

                                    if (medianCheck.Checked)
                                    {
                                        sqlClause =
String.Format(medianSql, whereClause, tableNameTextBox.Text,
tempTextBox.Text);
                                        double? temp =
QueryAndOutput(sqlClause);
                                        if(temp != null)
                                        {
                                            weeklyMedian.Add(new
DateValuePair(weekOfYear + "/" + year, temp.ToString(), time.Month + "/" +
time.Day + "/" + year));
                                        }
                                    }

                                    if (modeCheck.Checked)
                                    {
                                        sqlClause = String.Format(modeSql,
whereClause, tableNameTextBox.Text, tempTextBox.Text);
                                        double? temp =
QueryAndOutput(sqlClause);
                                        if(temp != null)
                                        {
                                            weeklyMode.Add(new
DateValuePair(weekOfYear + "/" + year, temp.ToString(), time.Month + "/" +
time.Day + "/" + year));
```

```
                                    }
                                }

                    if (sumCheck.Checked)
                    {
                        sqlClause = String.Format(sumSql, whereClause,
tableNameTextBox.Text, tempTextBox.Text);
                        double? temp = QueryAndOutput(sqlClause);
                        if (temp != null)
                        {
                            weeklySum.Add(new DateValuePair(weekOfYear +
"/" + year, temp.ToString(), time.Month + "/" + time.Day + "/" + year));
                        }
                    }

                                    progressBar.Invoke(new
MethodInvoker(delegate {progressBar.Increment(1);}));
                                }
                    }

                    OutputToDisk(weeklyMean, "weeklyMean.txt");
                    OutputToDisk(weeklyMedian, "weeklyMedian.txt");
                    OutputToDisk(weeklyMode, "weeklyMode.txt");
            OutputToDisk(weeklySum, "weeklySum.txt");
                    log("Post Weeklies Loop");

                    if (monthlyCheck.Checked)
                    {
                                processingType.Invoke(new MethodInvoker(delegate
{processingType.Text = "Monthlies";}));
                                progressBar.Invoke(new MethodInvoker(delegate
{progressBar.Value = 0;}));
                                log("Pre Monthlies Loop");
                                foreach (DataRow row in table.Rows)
                                {
                                        String timeString = (String)row[0];
                                        DateTime time;
                                        try
                                        {
                                                time =
DateTime.ParseExact(timeString, "dd/MM/yyyy", CultureInfo.CurrentCulture);
                                        } catch(FormatException)
                                        {
                                                log(timeString);
                                                continue;
                                        }

                                        int month = time.Month;
                                        int year = time.Year;

                                        if (monthlyMean.Exists(pair => pair.Date
== month + "/" + year) ||
                                            monthlyMedian.Exists(pair =>
pair.Date == month + "/" + year) ||
                                            monthlyMode.Exists(pair => pair.Date
== month + "/" + year) ||
```

```
                        monthlySum.Exists(pair => pair.Date == month + "/"
+ year))
                                    {
                                          progressBar.Invoke(new
MethodInvoker(delegate {progressBar.Increment(1);}));
                                          continue;
                                    }

                                    String whereClause = " DATEPART(mm, " +
dateColumnTextBox.Text + ") = " + month + " AND DATEPART(yyyy, " +
dateColumnTextBox.Text + ") = " + year;
                                    String sqlClause;
                                    if(meanCheck.Checked)
                                    {
                                          sqlClause = String.Format(meanSql,
whereClause, tableNameTextBox.Text, tempTextBox.Text);
                                          double? temp =
QueryAndOutput(sqlClause);
                                          if(temp != null)
                                          {
                                                monthlyMean.Add(new
DateValuePair(month + "/" + year, temp.ToString()));
                                          }
                                    }

                                    if(medianCheck.Checked)
                                    {
                                          sqlClause =
String.Format(medianSql, whereClause, tableNameTextBox.Text,
tempTextBox.Text);
                                          double? temp =
QueryAndOutput(sqlClause);
                                          if(temp != null)
                                          {
                                                monthlyMedian.Add(new
DateValuePair(month + "/" + year, temp.ToString()));
                                          }
                                    }

                                    if(modeCheck.Checked)
                                    {
                                          sqlClause = String.Format(modeSql,
whereClause, tableNameTextBox.Text, tempTextBox.Text);
                                          double? temp =
QueryAndOutput(sqlClause);
                                          if(temp != null)
                                          {
                                                monthlyMode.Add(new
DateValuePair(month + "/" + year, temp.ToString()));
                                          }
                                    }

                        if (sumCheck.Checked)
                        {
                            sqlClause = String.Format(sumSql, whereClause,
tableNameTextBox.Text, tempTextBox.Text);
```

```
                        double? temp = QueryAndOutput(sqlClause);
                        if (temp != null)
                        {
                            monthlySum.Add(new DateValuePair(month + "/" +
year, temp.ToString()));
                        }
                    }

                                    progressBar.Invoke(new
MethodInvoker(delegate {progressBar.Increment(1);}));
                                }
                    }

                    OutputToDisk(monthlyMean, "monthlyMean.txt");
                    OutputToDisk(monthlyMedian, "monthlyMedian.txt");
                    OutputToDisk(monthlyMode, "monthlyMode.txt");
            OutputToDisk(monthlySum, "monthlySum.txt");
                    log("Post Monthlies Loop");

            if (annualCheck.Checked)
            {
                processingType.Invoke(new MethodInvoker(delegate {
processingType.Text = "Annuals"; }));
                progressBar.Invoke(new MethodInvoker(delegate {
progressBar.Value = 0; }));
                log("Pre Annuals Loop");
                foreach (DataRow row in table.Rows)
                {
                    String timeString = (String)row[0];
                    DateTime time;
                    try
                    {
                        time = DateTime.ParseExact(timeString,
"dd/MM/yyyy", CultureInfo.CurrentCulture);
                    }
                    catch (FormatException)
                    {
                        log(timeString);
                        continue;
                    }

                    int year = time.Year;

                    if (annualMean.Exists(pair => pair.Date == "" + year)
||
                        annualMedian.Exists(pair => pair.Date == "" + year)
||
                        annualMode.Exists(pair => pair.Date == "" + year)
||
                        annualSum.Exists(pair => pair.Date == "" + year))
                    {
                        progressBar.Invoke(new MethodInvoker(delegate {
progressBar.Increment(1); }));
                        continue;
                    }
```

```
                    String whereClause = " DATEPART(yyyy, " +
dateColumnTextBox.Text + ") = " + year;
                    String sqlClause;
                    if (meanCheck.Checked)
                    {
                        sqlClause = String.Format(meanSql, whereClause,
tableNameTextBox.Text, tempTextBox.Text);
                        double? temp = QueryAndOutput(sqlClause);
                        if (temp != null)
                        {
                            annualMean.Add(new DateValuePair("" + year,
temp.ToString()));
                        }
                    }

                    if (medianCheck.Checked)
                    {
                        sqlClause = String.Format(medianSql, whereClause,
tableNameTextBox.Text, tempTextBox.Text);
                        double? temp = QueryAndOutput(sqlClause);
                        if (temp != null)
                        {
                            annualMedian.Add(new DateValuePair("" + year,
temp.ToString()));
                        }
                    }

                    if (modeCheck.Checked)
                    {
                        sqlClause = String.Format(modeSql, whereClause,
tableNameTextBox.Text, tempTextBox.Text);
                        double? temp = QueryAndOutput(sqlClause);
                        if (temp != null)
                        {
                            annualMode.Add(new DateValuePair("" + year,
temp.ToString()));
                        }
                    }

                    if (sumCheck.Checked)
                    {
                        sqlClause = String.Format(sumSql, whereClause,
tableNameTextBox.Text, tempTextBox.Text);
                        double? temp = QueryAndOutput(sqlClause);
                        if (temp != null)
                        {
                            annualSum.Add(new DateValuePair("" + year,
temp.ToString()));
                        }
                    }

                    progressBar.Invoke(new MethodInvoker(delegate {
progressBar.Increment(1); }));
                }
            }
```

```
            OutputToDisk(annualMean, "annualMean.txt");
            OutputToDisk(annualMedian, "annualMedian.txt");
            OutputToDisk(annualMode, "annualMode.txt");
            OutputToDisk(annualSum, "annualSum.txt");
            log("Post Annuals Loop");

            processingType.Invoke(new MethodInvoker(delegate {
processingType.Text = "Gregorian FId"; }));
            progressBar.Invoke(new MethodInvoker(delegate {
progressBar.Value = 0; }));

            if (GregFld.Checked)
            {
                DailyTempIndexCalculator calc = new
DailyTempIndexCalculator(TempIndexCalculator.IndexType.Freezing,
TempIndexCalculator.YearRangeType.Gregorian);
                calc.AvailDates = table;
                calc.ConnectionString = _connectionString;
                calc.DataColumnName = tempTextBox.Text;
                calc.DateColumnName = dateColumnTextBox.Text;
                calc.TableName = tableNameTextBox.Text;
                calc.ProgressBar = progressBar;

                OutputToDisk(calc.Calculate(), "gregorianFld.txt");
            }

            processingType.Invoke(new MethodInvoker(delegate {
processingType.Text = "Gregorian TId"; }));
            progressBar.Invoke(new MethodInvoker(delegate {
progressBar.Value = 0; }));
            if (GregTld.Checked)
            {
                DailyTempIndexCalculator calc = new
DailyTempIndexCalculator(TempIndexCalculator.IndexType.Thawing,
TempIndexCalculator.YearRangeType.Gregorian);
                calc.AvailDates = table;
                calc.ConnectionString = _connectionString;
                calc.DataColumnName = tempTextBox.Text;
                calc.DateColumnName = dateColumnTextBox.Text;
                calc.TableName = tableNameTextBox.Text;
                calc.ProgressBar = progressBar;

                OutputToDisk(calc.Calculate(), "gregorianTld.txt");
            }

            processingType.Invoke(new MethodInvoker(delegate {
processingType.Text = "Gregorian FIm"; }));
            progressBar.Invoke(new MethodInvoker(delegate {
progressBar.Value = 0; }));
            if (GregFlm.Checked)
            {
                MonthlyTempIndexCalculator calc = new
MonthlyTempIndexCalculator(TempIndexCalculator.IndexType.Freezing,
TempIndexCalculator.YearRangeType.Gregorian);
                calc.AvailDates = table;
                calc.ConnectionString = _connectionString;
```

```
                calc.DataColumnName = tempTextBox.Text;
                calc.DateColumnName = dateColumnTextBox.Text;
                calc.TableName = tableNameTextBox.Text;
                calc.ProgressBar = progressBar;

                OutputToDisk(calc.Calculate(), "gregorianFlm.txt");
            }

            processingType.Invoke(new MethodInvoker(delegate {
processingType.Text = "Gregorian TIm"; }));
            progressBar.Invoke(new MethodInvoker(delegate {
progressBar.Value = 0; }));
            if (GregTlm.Checked)
            {
                MonthlyTempIndexCalculator calc = new
MonthlyTempIndexCalculator(TempIndexCalculator.IndexType.Thawing,
TempIndexCalculator.YearRangeType.Gregorian);
                calc.AvailDates = table;
                calc.ConnectionString = _connectionString;
                calc.DataColumnName = tempTextBox.Text;
                calc.DateColumnName = dateColumnTextBox.Text;
                calc.TableName = tableNameTextBox.Text;
                calc.ProgressBar = progressBar;

                OutputToDisk(calc.Calculate(), "gregorianTlm.txt");
            }

            processingType.Invoke(new MethodInvoker(delegate {
processingType.Text = "Seasonal FId"; }));
            progressBar.Invoke(new MethodInvoker(delegate {
progressBar.Value = 0; }));
            if (SeasFld.Checked)
            {
                DailyTempIndexCalculator calc = new
DailyTempIndexCalculator(TempIndexCalculator.IndexType.Freezing,
TempIndexCalculator.YearRangeType.Seasonal);
                calc.AvailDates = table;
                calc.ConnectionString = _connectionString;
                calc.DataColumnName = tempTextBox.Text;
                calc.DateColumnName = dateColumnTextBox.Text;
                calc.TableName = tableNameTextBox.Text;
                calc.ProgressBar = progressBar;

                OutputToDisk(calc.Calculate(), "seasonalFld.txt");
            }

            processingType.Invoke(new MethodInvoker(delegate {
processingType.Text = "Seasonal TId"; }));
            progressBar.Invoke(new MethodInvoker(delegate {
progressBar.Value = 0; }));
            if (SeasTld.Checked)
            {
                DailyTempIndexCalculator calc = new
DailyTempIndexCalculator(TempIndexCalculator.IndexType.Thawing,
TempIndexCalculator.YearRangeType.Seasonal);
                calc.AvailDates = table;
```

```
                calc.ConnectionString = _connectionString;
                calc.DataColumnName = tempTextBox.Text;
                calc.DateColumnName = dateColumnTextBox.Text;
                calc.TableName = tableNameTextBox.Text;
                calc.ProgressBar = progressBar;

                OutputToDisk(calc.Calculate(), "seasonalTld.txt");
            }

            processingType.Invoke(new MethodInvoker(delegate {
processingType.Text = "Seasonal FIm"; }));
            progressBar.Invoke(new MethodInvoker(delegate {
progressBar.Value = 0; }));
            if (SeasFlm.Checked)
            {
                MonthlyTempIndexCalculator calc = new
MonthlyTempIndexCalculator(TempIndexCalculator.IndexType.Freezing,
TempIndexCalculator.YearRangeType.Seasonal);
                calc.AvailDates = table;
                calc.ConnectionString = _connectionString;
                calc.DataColumnName = tempTextBox.Text;
                calc.DateColumnName = dateColumnTextBox.Text;
                calc.TableName = tableNameTextBox.Text;
                calc.ProgressBar = progressBar;

                OutputToDisk(calc.Calculate(), "seasonalFlm.txt");
            }

            processingType.Invoke(new MethodInvoker(delegate {
processingType.Text = "Seasonal TIm"; }));
            progressBar.Invoke(new MethodInvoker(delegate {
progressBar.Value = 0; }));
            if (SeasTlm.Checked)
            {
                MonthlyTempIndexCalculator calc = new
MonthlyTempIndexCalculator(TempIndexCalculator.IndexType.Thawing,
TempIndexCalculator.YearRangeType.Seasonal);
                calc.AvailDates = table;
                calc.ConnectionString = _connectionString;
                calc.DataColumnName = tempTextBox.Text;
                calc.DateColumnName = dateColumnTextBox.Text;
                calc.TableName = tableNameTextBox.Text;
                calc.ProgressBar = progressBar;

                OutputToDisk(calc.Calculate(), "seasonalTlm.txt");
            }

                    SetScreen(true);
          }

          private class DateSorter : IComparer<DateValuePair>
          {
                    public int Compare(DateValuePair x, DateValuePair y)
                    {
```

```
                        DateTime xDate =
DateTime.ParseExact(x.DisplayValue, "dd/MM/yyyy",
CultureInfo.CurrentCulture);
                        DateTime yDate =
DateTime.ParseExact(y.DisplayValue, "dd/MM/yyyy",
CultureInfo.CurrentCulture);
                        return xDate.CompareTo(yDate);
                    }
                }

                private void SetScreen(bool b)
                {
            startDatePicker.Invoke(new MethodInvoker(delegate {
startDatePicker.Enabled = b; }));
            endDatePicker.Invoke(new MethodInvoker(delegate {
endDatePicker.Enabled = b; }));
            tableNameTextBox.Invoke(new MethodInvoker(delegate {
tableNameTextBox.Enabled = b; }));
            dateColumnTextBox.Invoke(new MethodInvoker(delegate {
dateColumnTextBox.Enabled = b; }));
            tempTextBox.Invoke(new MethodInvoker(delegate {
tempTextBox.Enabled = b; }));
            dailyCheck.Invoke(new MethodInvoker(delegate {
dailyCheck.Enabled = b; }));
            weeklyCheck.Invoke(new MethodInvoker(delegate {
weeklyCheck.Enabled = b; }));
            monthlyCheck.Invoke(new MethodInvoker(delegate {
monthlyCheck.Enabled = b; }));
            annualCheck.Invoke(new MethodInvoker(delegate {
annualCheck.Enabled = b; }));
            meanCheck.Invoke(new MethodInvoker(delegate { meanCheck.Enabled
= b; }));
            medianCheck.Invoke(new MethodInvoker(delegate {
medianCheck.Enabled = b; }));
            modeCheck.Invoke(new MethodInvoker(delegate { modeCheck.Enabled
= b; }));
            executeButton.Invoke(new MethodInvoker(delegate {
executeButton.Enabled = b; }));
                }

                private void OutputToDisk(List<DateValuePair> list, String
fileName)
                {
                    using (StreamWriter writer =
                        new StreamWriter(_fileLocation + fileName))
                    {

                        foreach (DateValuePair pair in list)
                        {
                            writer.WriteLine(pair.DisplayValue + ", "
+ pair.Value);
                        }
                    }
                }

                private void log(String logString)
```

```
            {
                  using(StreamWriter writer = new
StreamWriter(_fileLocation + LogLocation, true))
                  {
                        writer.WriteLine(logString);
                  }
            }

            private DataTable Query(String query)
            {
                  SqlConnection cn = new
SqlConnection(_connectionString);
                  DataTable table = new DataTable();
                  try
                  {
                        log("Before Open");
                        cn.Open();
                        log("After Open");

                        SqlDataAdapter da = new SqlDataAdapter(query,
cn);
                        da.Fill(table);
                  }
                  catch (Exception ex)
                  {
                        log("Table Open/Query Failed." + ex);
                  }
                  finally
                  {
                        if (cn.State != ConnectionState.Closed)
                        {
                              cn.Close();
                        }
                  }

                  return table;
            }

        private double? QueryAndOutput(string query)
        {
            DataTable table = Query(query);

            if (table.Rows.Count == 0)
            {
                return null;
            }
            else if (table.Rows[0][0] == DBNull.Value)
            {
                return null;
            }

            return table.Rows[0][0] as double?;
        }

      }
```

```
	public static class ListDateValueHelper
	{
		public static bool Contains(this List<DateValuePair> list,
string dateString)
		{
			return list.Any(dvp =>
dvp.DisplayValue.Equals(dateString));
		}

		public static DateValuePair Get(this List<DateValuePair> list,
string dateString)
		{
			return list.FirstOrDefault(dvp =>
dvp.DisplayValue.Equals(dateString));
		}
	}
}
```