



# Climate Data Analysis of Existing Weather Stations in and around the Central Alaska Network (CAKN)

*Update through 2010*

Natural Resource Technical Report NPS/CAKN/NRTR—2013/662



**ON THE COVER**

Denali National Park

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# **Climate Data Analysis of Existing Weather Stations in around the Central Alaska Network (CAKN)**

*Update through 2010*

Natural Resource Technical Report NPS/CAKN/NRTR—2013/662

Richard A. Keen

34296 Gap Road  
Golden, CO 80403

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## Abstract

The Central Alaska Network is part of the National Park Service Inventory and Monitoring Program. It is composed of three national park units: Wrangell-St. Elias National Park and Preserve, Denali National Park and Preserve, and Yukon-Charley Rivers National Preserve. The Inventory and Monitoring Program is the result of the National Parks Omnibus Management Act, which was passed by Congress in 1998. This act directs the National Park Service “to establish baseline [resource] information and to provide information on the long-term trends in the condition of National Park System resources.” The primary goal of the Central Alaska Network is to build a holistic picture of change across the ecosystems of the network — specifically, to detect change in their ecological components and in the relationships among those components. Knowing the condition of natural resources in national parks is fundamental to the Service’s ability to manage park resources “unimpaired for the enjoyment of future generations”.

The three park units of the Central Alaska Network together span an enormous area measuring approximately 650 km from north to south and 650 km from east to west. Elevations range from sea level to 6194 m (20,320’); latitudes reach to more than 65 degrees north. The climate in this vast, northern country is extremely variable, ranging from strongly maritime to strongly continental. Climate and climate change have been identified as one of the carefully selected elements or vital signs of the network that are deemed to be critical indicators of long-term, system-wide trends. A main objective for CAKN climate monitoring component is to monitor and record weather conditions at representative locations in order to quantify one of the drivers in Alaskan ecosystems, identify long and short-term trends, provide reliable climate data to other researchers, and to participate in larger scale climate monitoring and modeling efforts.

Several programs administered by various federal agencies and private entities deploy and/or manage weather stations throughout Interior Alaska. Most of the weather stations around the CAKN parks are located at airports, towns, and lodges. There are stations within each park and/or in the area adjacent to park lands that have been in operation for many decades. In order to provide a baseline of the past climate conditions in the regions surrounding the network this project involved the analysis and summary of any and all existing data within the scope of the network. The data series were analyzed to give a climatic description of the site including information on long-term averages and temporal variation. Comparisons of data from long-term stations such as McKinley Park, Eagle, and Gulkana with long-term climate data from Fairbanks and Anchorage were analyzed to see if the trends were similar. The methods used for data analysis and compilation are described in full so that in future years with the addition of new stations in the network the analysis could be replicated by NPS staff or other entities.

## Update through 2010

The initial study, completed in 2008, analyzed climate records through the end of 2005. Since then the short-term climate of Central Alaska has undergone variations. These changes are documented using climatological observations through the end of 2010 (and, in a few cases, through February 2011). The larger-scale causes, or at least apparent causes, and statistical attributions of these changes are assessed.

The initial study also examined the local variations of climate in the Denali section as recorded by a network of Remote Automated Weather Stations (RAWS). Seven new RAWS stations were installed in the Wrangell-St. Elias and Yukon-Charley sections in 2004-2005, and an examination of the local climate variations in these sections is included.

The format of this report is similar to that of the initial study, and rather than repeating material in the 2008 report, reference will be made to details of data sources, analysis techniques, and interpretations in that study. This report emphasizes new and/or changed data, sources, and assessments, and other revisions.

## Purpose of the Study

Climate data from approximately 99 climate stations, 61 snow monitoring stations, and 36 Remote Automated Weather Stations (RAWS) within and near the three units of the Central Alaska Network, (Wrangell-St. Elias National Park and Preserve, Denali National Park and Preserve, and Yukon-Charley Rivers National Preserve), have been documented, tabulated, summarized, and analyzed to provide a record of past climate changes and fluctuations over the period of record (beginning in 1899), to provide baseline normals and averages to help assess future climate variations, and to gain some insight into the possible causes of the climate variations.

Although a complete description of climate would include a large list of means, extremes, occurrence frequencies, etc., of an assortment of climate parameters, such as wind, solar radiation, cloudiness, synoptic weather patterns, and so on, this study is limited to analysis and interpretation of long-term records of the most basic climate parameter, namely, temperature, snow, and rain.

The goals of the initial study (2008 report) are to:

1. Document the available climate data, emphasizing records of temperature and precipitation (including snowfall). Documentation includes identification of stations, their periods of record, and sources from which the records can be accessed.
2. Provide a baseline climatology for stations located in and near CAKN units. A baseline climatology includes 1971-2000 standard normals of temperature and precipitation, means and extremes of temperature and precipitation, and period of record histories of the climate for selected stations.
3. Analyze climate variations over the period of record. This includes a statistical description of the trends and fluctuations of temperature and precipitation since 1899, and attempts to attribute a cause or statistical linkage to larger scale atmospheric, oceanic, and external factors.
4. Provide suggestions for monitoring of future long-term changes in the CAKN region.

This report updates the third goal listed above. The CAKN climate since 1899, and updated through 2010, is analyzed in greater detail to document the nature and possible causes of the changing climate. Significantly, there appears to have been a substantial change of the CAKN climate since 2005.



## **Types of Data and Documentation of the Stations**

The three basic types of weather and climate data reporting stations located in and near the three CAKN units are described below. These are described in detail in the original (2008) report.

- A. Climate (COOP) stations.
- B. Snow monitoring stations.
- C. Remote Automated Weather Stations (RAWS)

### **Sources of Data**

Climate data is available from a variety of sources, and can be found tabulated as hourly observations, daily summaries, monthly and annual summaries, and period of record summaries. Most data initially and historically published as hard copy (paper) has been digitized. The most extensive files of climate data are at the National Climate Data Center (NCDC), although data for some periods of record at some stations not on file at NCDC are available from other sources. Climate and Snow survey data is available from the Western Regional Climate Center (WRCC). Following is a list of sources of data used in this study, starting with the NCDC; details are listed in the 2008 report. In some cases new and/or changed data sources are given in the caption or description of the actual use of that data in this report.

- A. National Climate Data Center (NCDC)
- B. Environment Canada.
- C. Western Regional Climate Center (WRCC)
- D. NASA Goddard Institute for Space Studies (GISS)
- E. Alaska Climate Research Center (ACRC)
- F. Snow Surveys
- G. Environmental Sciences Research Laboratory (ESRL), formerly Climate Diagnostics Center (CDC)

The Physical Sciences Division (PSD) hosts a data site at: <http://www.esrl.noaa.gov/psd/data/>

A comprehensive list of climate indices is at:

<http://www.esrl.noaa.gov/psd/data/climateindices/list/>

NCAR/NCEP global reanalysis data is at:

<http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.derived.html>

- H. Remote Automated Weather Stations (RAWS)

Data for these stations are available from the National Interagency Fire Center (NIFC):

<http://www.fs.fed.us/raws/>

Real-time data may be accessed via the Real-Time Observation Monitor and Analysis Network (ROMAN): <http://raws.wrh.noaa.gov/roman/>

The best source for archived RAWs data is WRCC. Data for Alaskan stations is at:

<http://www.wrcc.dri.edu/wraws/akF.html> and for stations inside National Parks:

<http://www.wrcc.dri.edu/NPS.html>

## I. Alaska State Climate Center

The Alaska State Climate Center, operated by the Alaska State Climatologist at the University of Alaska Anchorage, has some data and useful background articles. <http://climate.uaa.alaska.edu/>

### **Alaska Climate Monitoring Stations – List and Maps**

#### A. Appendix 1, Alaska Station Data Inventory

Appendix 1, “Alaska Station Data Inventory”, lists the Coop, Snow course and SNOTEL, and RAWs stations in and adjacent to CAKN units for which data was located. This list has not changed since the 2008 report, and the reader is referred to that report for details. A map of the seven new CAKN RAWs stations is presented in the discussion section of this report.

### **Data Summaries – Normals, Means, Extremes**

A. Appendix 2, “Coop Station Normals”. See 2008 report.

B. Appendix 3, “Alaska Snow Course SWE Averages 1971-2000. See 2008 report

C. Appendix 4, CAKN area stations with published CLIM20 Summaries. See 2008 report.

The 1971-2000 normals for Coop and Snow Course stations will be updated and replaced with 1981-2010 normals in 2011. Also, CLIM20 Summaries may be updated in 2011. As of this writing, the 1971-2000 normals are still in effect and are not repeated in this updated report.

### **Long Time Series of Data**

Analysis of past climate change requires the construction of a time series of appropriate climate parameters (temperature and precipitation) over as long of a period of record as is possible. The earliest records in the CAKN region date from 1899 at Eagle, while eight other stations have records that begin between 1904 and 1922. Unfortunately, not all of the stations have operated continuously since the beginning of record. Therefore, it is often necessary to fill in gaps in the record with estimates based on nearby stations. In some cases, no single station operated for most of the period of record, but several stations with overlapping periods of record provide sufficiently complete data to allow the different records to be spliced together to generate one, nearly continuous, time series.

### **Temperature**

The 99 catalogued Coop stations have periods of record ranging from 1 to 111 years

- 40 stations in and near Denali
- 50 stations in and near Wrangell-St. Elias
- 9 stations in and near Yukon-Charley
- 62 stations have records > 15 years

- 9 stations have records > 80 years

The 36 RAWS stations have periods of record ranging from 1 to 22 years. However, without exception, the RAWS archived records are too short and too broken to be useful for climate studies. None of the stations satisfies the WMO standards for climatological normals. Although some stations have reasonably complete records for some summer months, most stations fail to operate during most winter months. As an example, Wein Lake, with a 17 year long period of record, has archived data for only 153 of the 204 months of record, and overall only 64 percent of the possible hours have data recorded.

The following Coop stations, or merged combination of stations, yielded 9 time series of temperature longer than 87 years (Anchorage is too distant from the regions of interest):

- Cordova
- Eagle/Dawson
- Fairbanks (University Experimental Station)
- Fort Yukon/Circle/Central
- McCarthy/Kennecott/Chitina
- McKinley
- Talkeetna
- Valdez
- Yakutat

All of the long term records had missing months of temperature data, although the records at Fairbanks/University, McKinley, Talkeetna, and Cordova had less than 5 percent missing data. The general methodology for filling in missing data is as follows:

- For each primary Coop station with a long term record, one or more nearby alternate stations with records overlapping the missing months/years was located.
- For the period of overlapping record (when both the primary station and the alternate station had data), temperature differences were calculated for each month. Then, for example, the mean difference for all the Januarys was calculated.
- Then, when the primary station had a missing temperature, the difference was applied to the alternate station's temperature and the adjusted temperature substituted for the missing data.
- If the closest (or most reliable) alternate station did not have data that month, the procedure was applied to the next alternate station.
- In a few rare cases where no alternate data was found, the long-term mean for the calendar month was used.

The following table lists, for each of the eight long-term stations, the name of the primary station, the total number of years of record, the number of years of missing data that had to be estimate from alternate stations, and the name(s) of the alternate stations.

Table 1. Stations (or combinations of stations) with long period of record.

| Primary Station          | Years record | Missing years | Alternate station(s)                                                                                                                           |
|--------------------------|--------------|---------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| McKinley                 | 88           | <1            |                                                                                                                                                |
| Fairbanks (Univ Exp Stn) | 107          | 1             | Fairbanks City, Eagle                                                                                                                          |
| Talkeetna                | 93           | 2             | Anchorage                                                                                                                                      |
| Yakutat                  | 94           | 2.5           | Cordova                                                                                                                                        |
| Cordova                  | 93           | 3             | Valdez                                                                                                                                         |
| Valdez                   | 102          | 5             | Cordova                                                                                                                                        |
| Eagle                    | 111          | 19            | Dawson                                                                                                                                         |
| Fort Yukon               | 94           | 29            | Eagle 3 years, Circle City 1 year, Circle Hot Springs 1 year, Central No.2 24 years (including 1997-present)                                   |
| McCarthy                 | 93           | ---           | Gulkana 1914-20, 1948-50<br>Kennebecott 1922-47<br>Chitina 1950-63<br>May Creek 1963-67<br>McCarthy 1 NE 1967-83<br>McCarthy 3 SW 1984-present |

The following figures show the locations, length of record, and annual mean temperature for these long term stations.

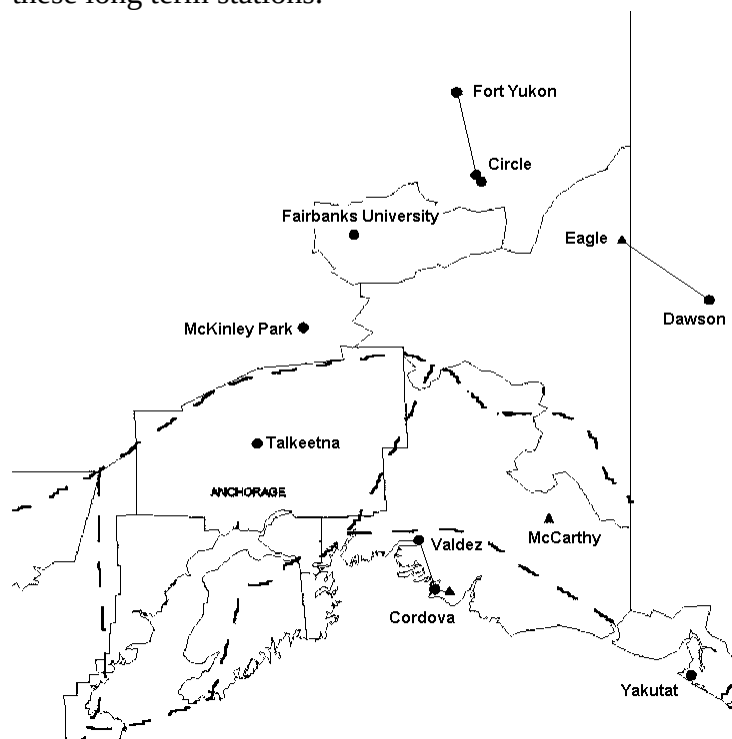


Figure 1. Cooperative stations with 87 or more years of record. The records from pairs of stations connected by lines were combined for producing continuous time series.

### CAKN region Long-term climate stations

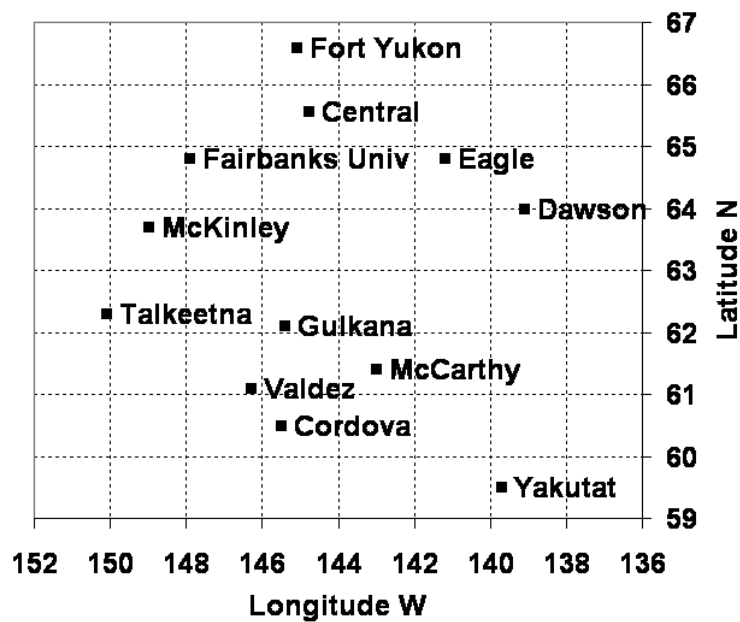


Figure 2. Location of 12 long-term climatological stations.

### CAKN region Long-term climate stations First year of nearly continuous records

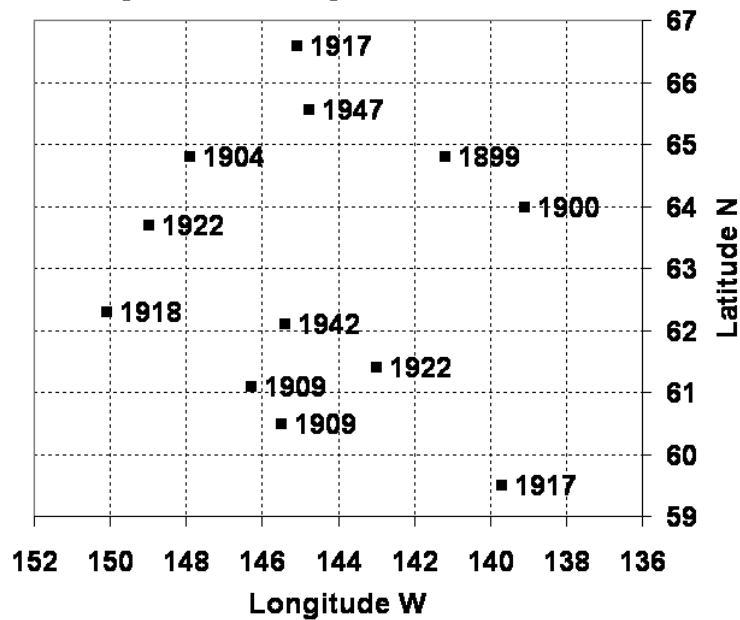


Figure 3. First year of continuous record for 12 stations.

**CAKN region Long-term climate stations  
1971-2000 average annual Temperature**

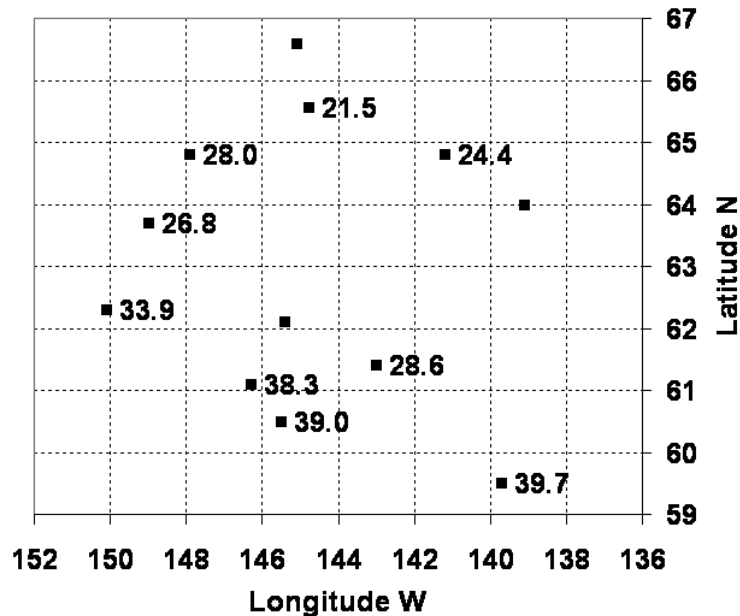


Figure 4. 1971-2000 climatological normal annual temperatures for 9 stations.

The following figures show examples of the long term temperature record. Annual average temperature is a commonly used indicator of climate change, as is the average for individual months or seasons (in this case, summer, defined as June-July-August). On many of the following graphs, the yearly values are plotted along with a 5-year moving average (the mean of the five years preceding and including the data point, so that the 1976-1980 mean is plotted at 1980). Moving averages, or “running means”, or “smoothing”, are applied to remove the often large year-to-year variability and to emphasize the longer term and more slowly varying changes of climate. Moving averages can be of any length that is less than the length of the entire record; five years is chosen because it emphasizes the decadal variability associated with changes in the regional and global atmospheric and oceanic circulations but maintains details of the timing and amplitude of decadal changes.

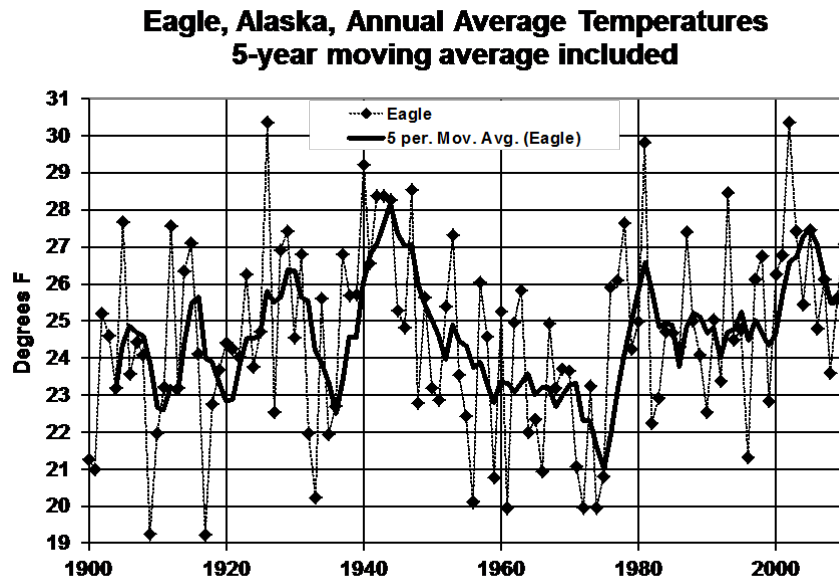


Figure 5. 111 year record of Eagle annual temperatures.

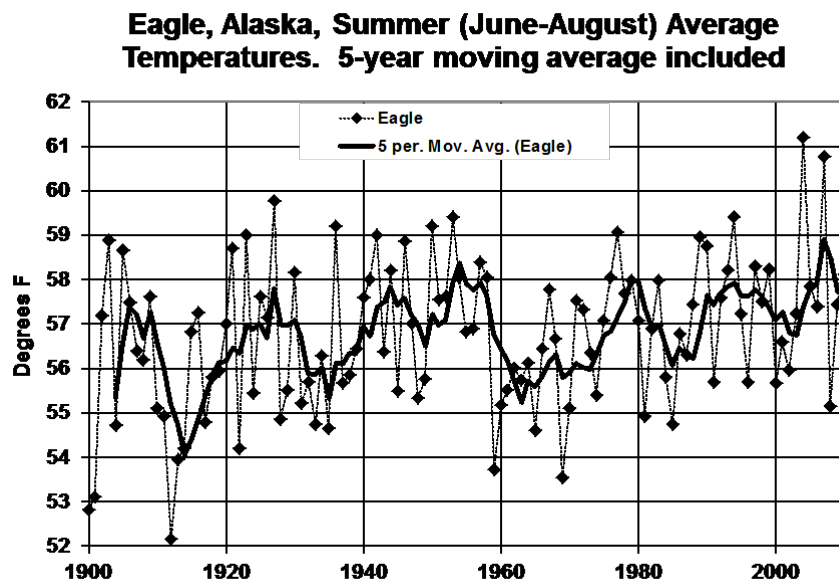


Figure 6. 111 year record of Eagle summer temperatures.

Other indicators of climate change are extremes, such as the highest temperature recorded each year at a station, or the lowest temperature recorded over the winter. The third order polynomial fit emphasizes the temperature changes over the course of several decades.

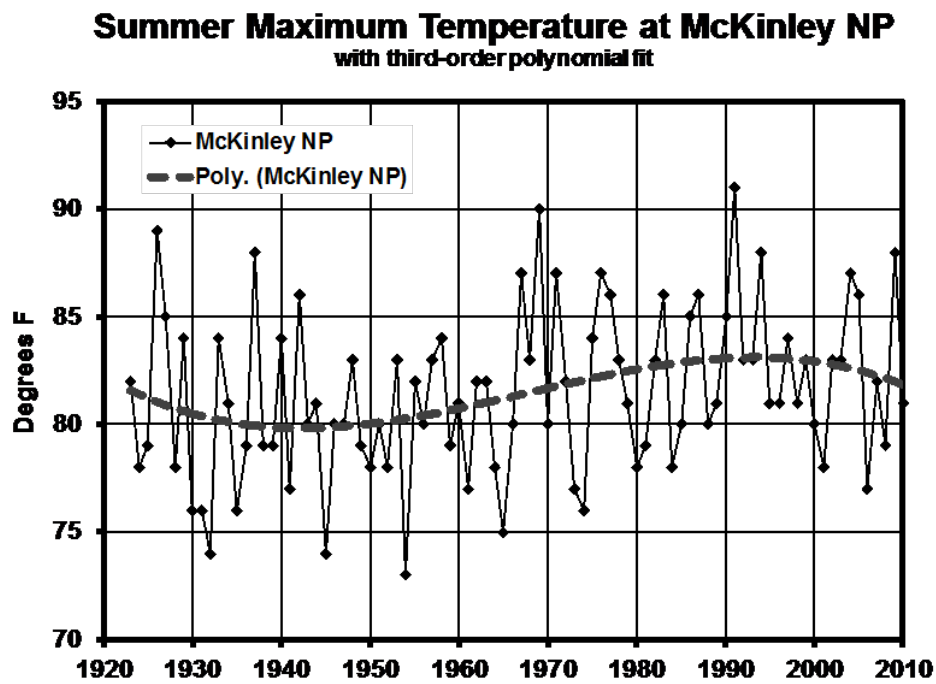


Figure 7. 88 years of summer maximum temperatures at McKinley.

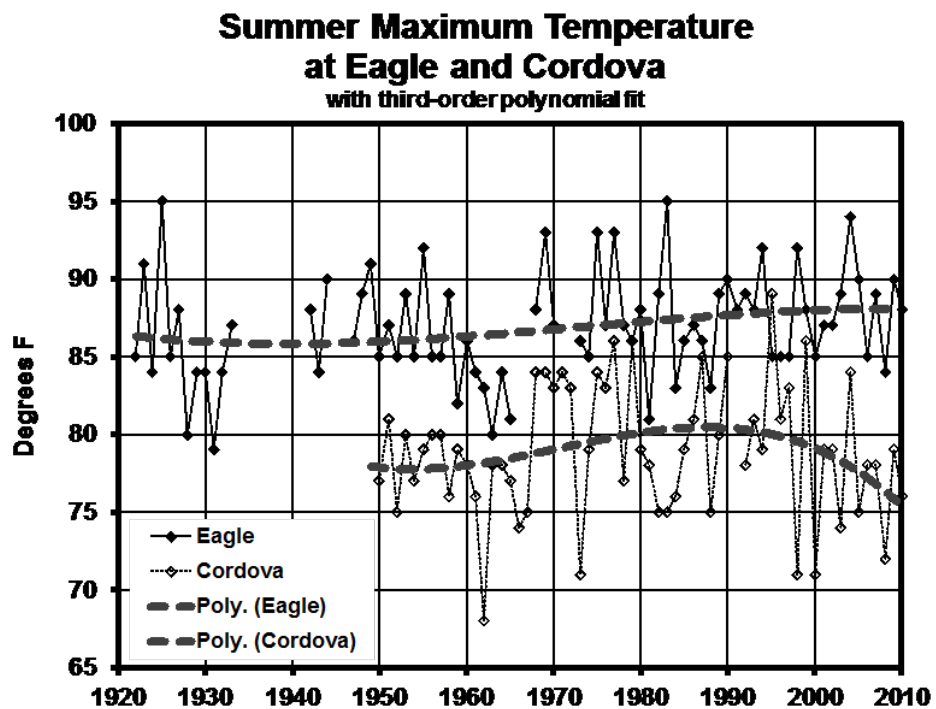


Figure 8. 70+ years of summer maximum temperatures at Eagle and Cordova.

Apparent in both graphs above is a tendency for warmer summer extremes in the late 20<sup>th</sup> century than earlier in the century, with an indication of cooling in the early 21<sup>st</sup> century.

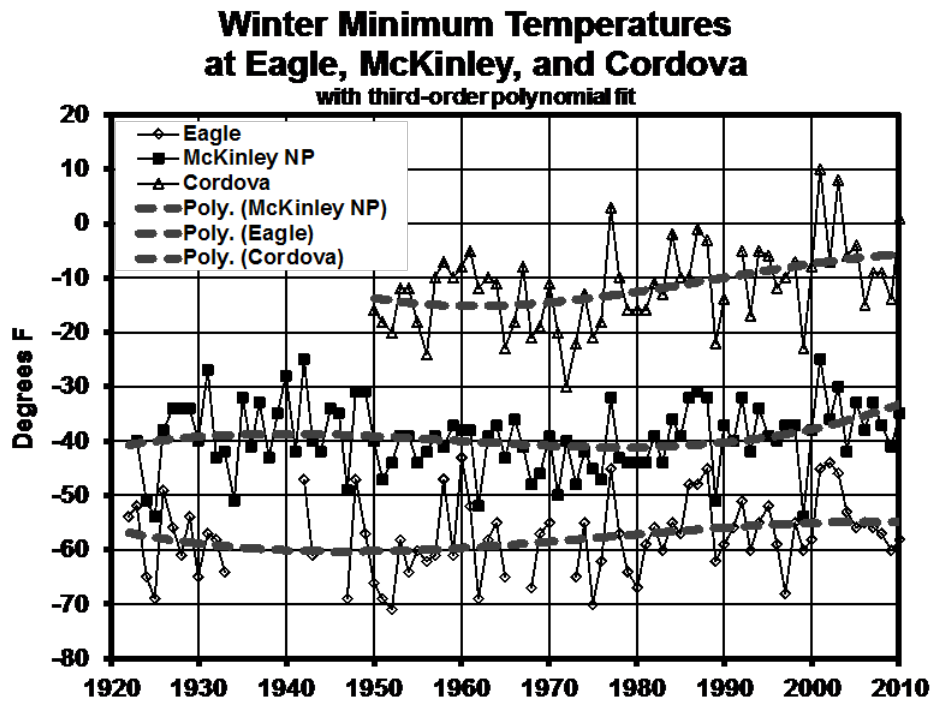


Figure 9. Winter minimum temperatures at Eagle, McKinley, and Cordova.

Yet another indicator is the frequency of occurrence of specific events, such as the number of days with a daily minimum temperature of Zero F or lower:

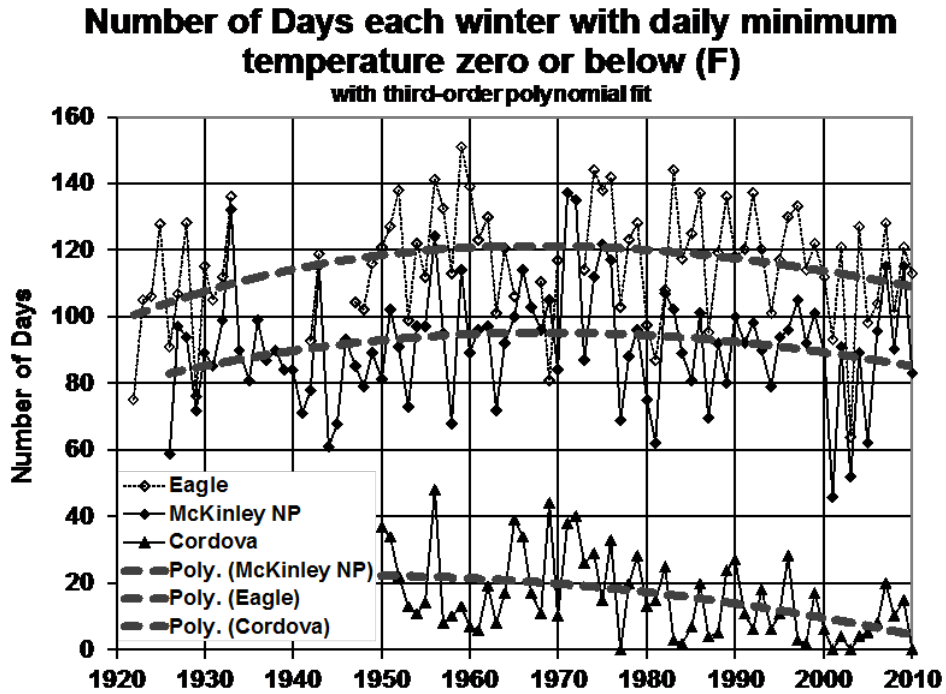


Figure 10. Yearly occurrence of zero degree temperatures at Eagle, McKinley, and Cordova.

Winter conditions were generally colder during the mid-20<sup>th</sup> century as compared to the decades before and after.

The following sequence of maps shows the spatial distribution of temperature anomalies (departures from the 1971-2000 normals, degrees F) for the long-term stations in the CAKN region during a selection of extreme years.

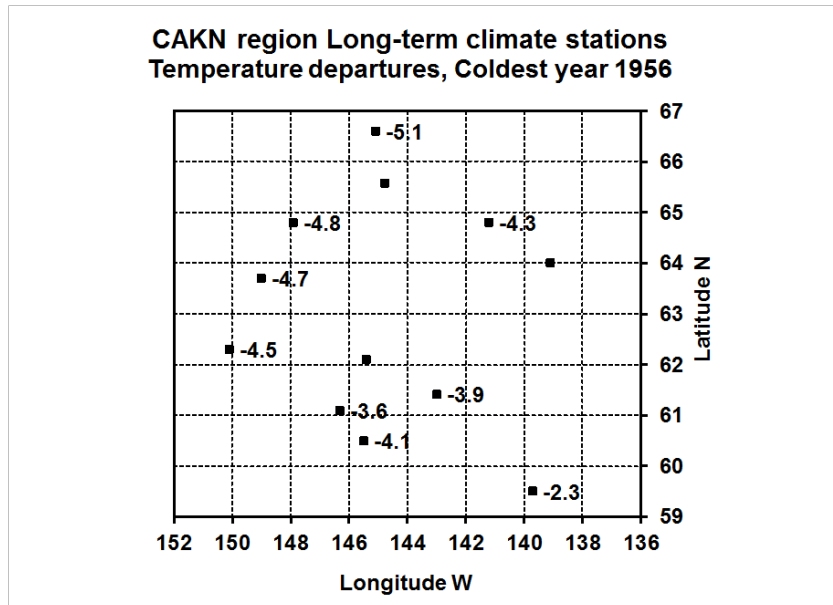


Figure 11. CAKN Temperature departures, Coldest year 1956.

**CAKN region Long-term climate stations**  
**Temperature departures, Coldest recent year 2008**

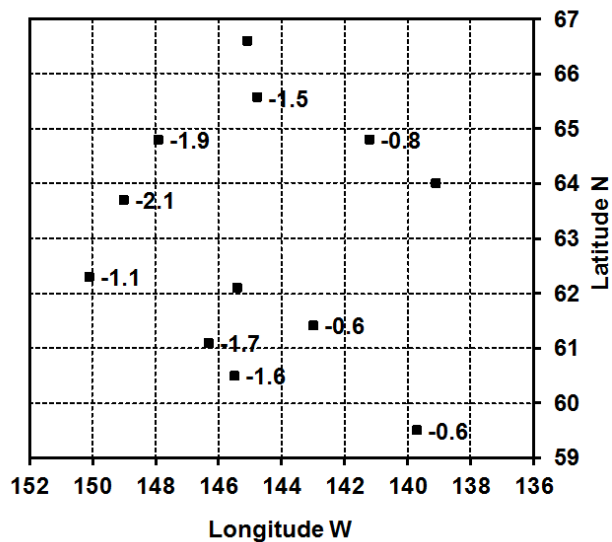


Figure 12. CAKN Temperature departures, Cold year 2008.

**CAKN region Long-term climate stations**  
**Temperature departures, Coldest winter 1965**

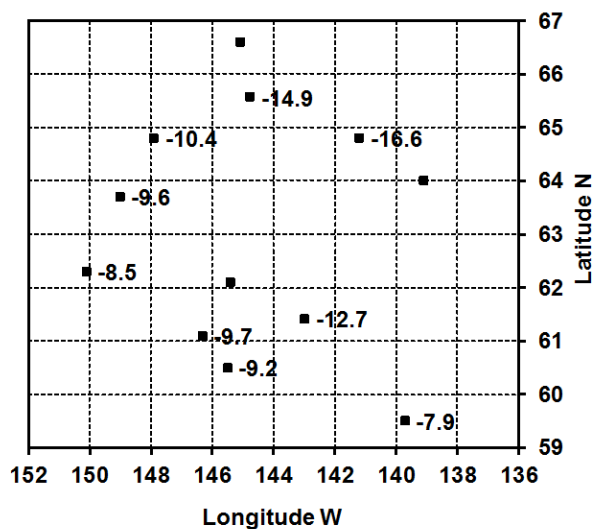


Figure 13. CAKN Temperature departures, Coldest winter 1965.

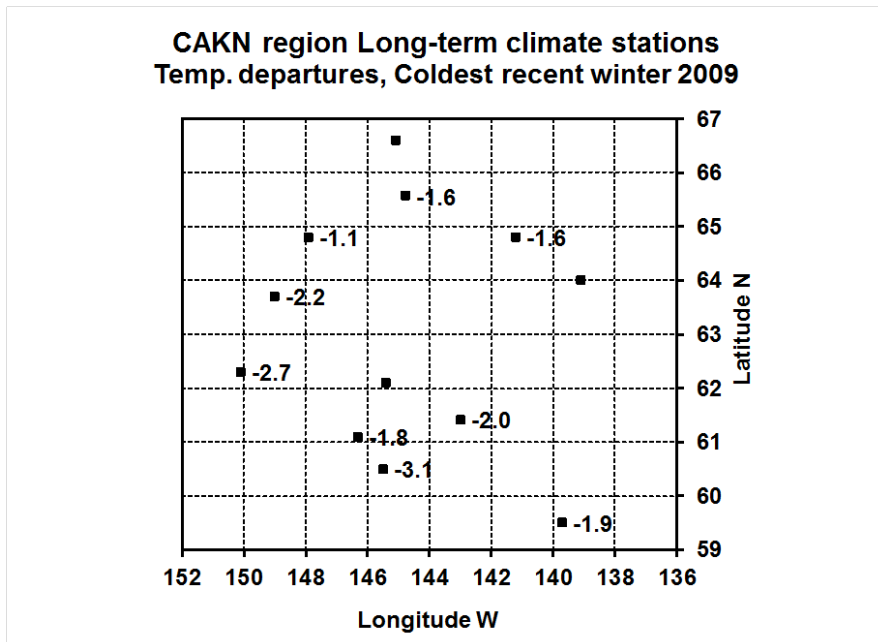


Figure 14. CAKN Temperature departures, Cold winter 2009.

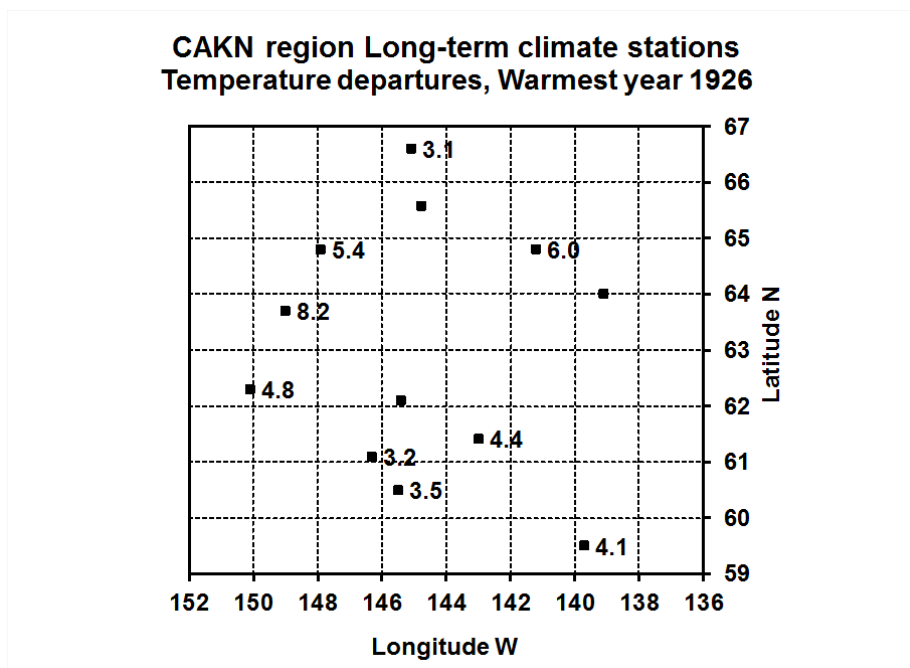


Figure 15. CAKN Temperature departures, Warmest year 1926.

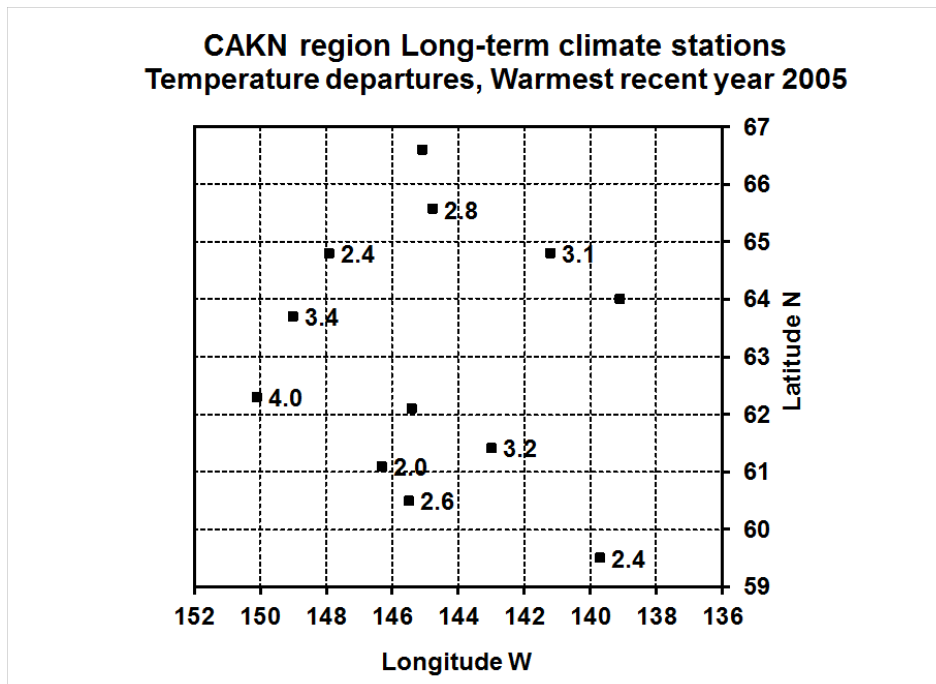


Figure 16. CAKN Temperature departures, Warm year 2005.

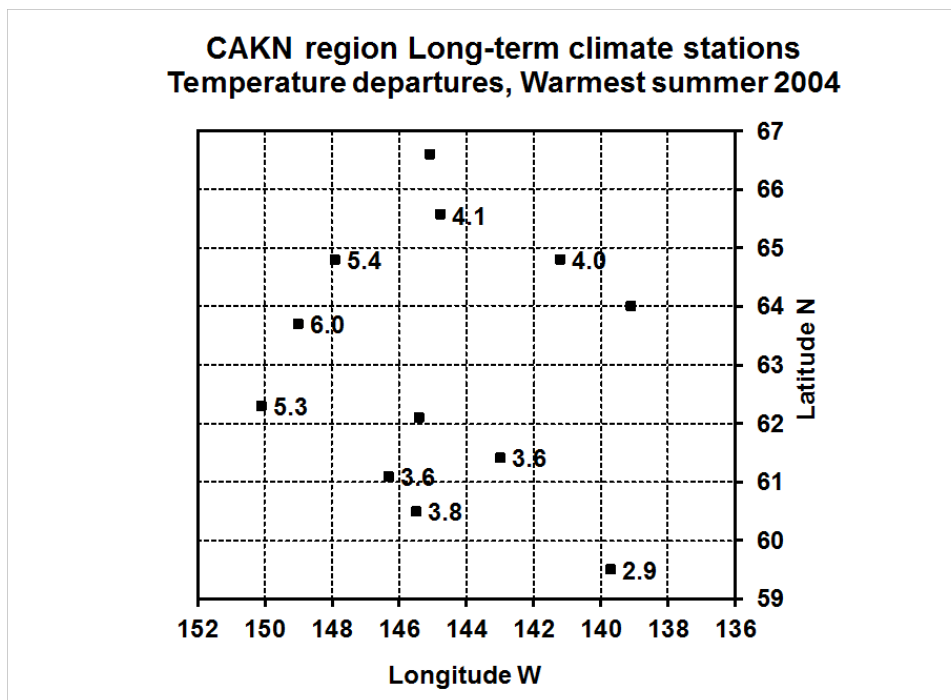


Figure 17. CAKN Temperature departures, Warmest summer 2004.

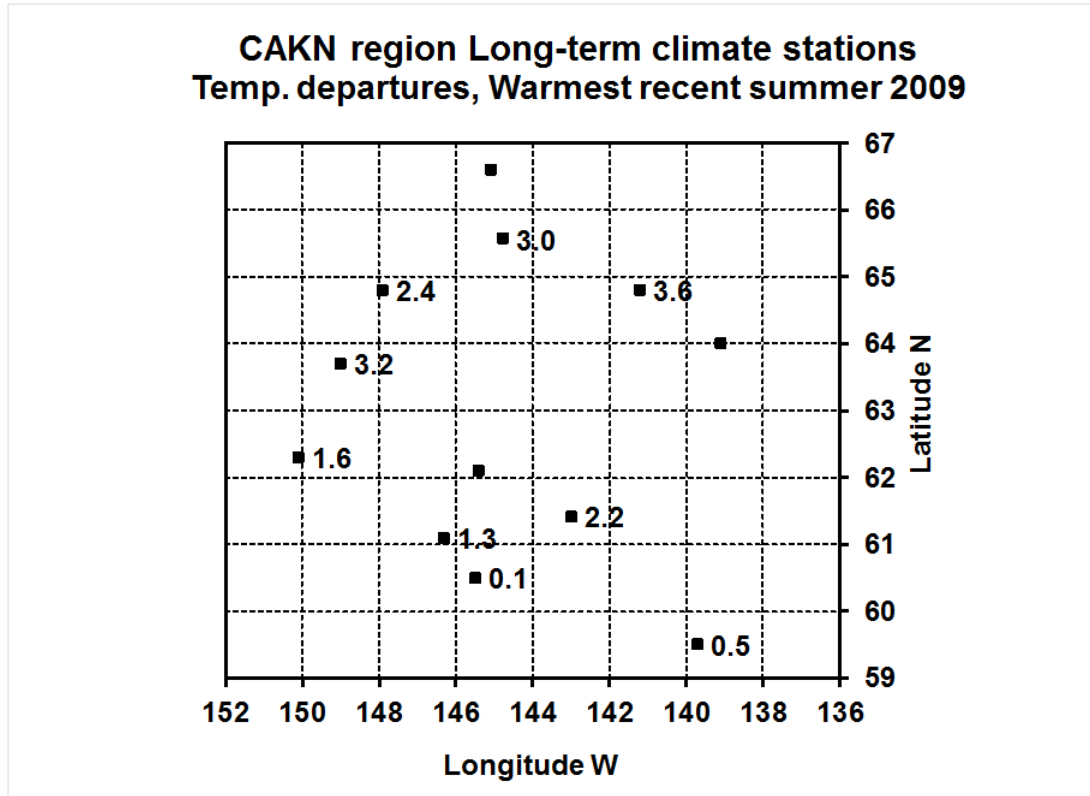


Figure 18. CAKN Temperature departures, Warmest recent summer 2009.

A glance at the preceding maps of temperature anomalies reveals that temperature departures tend to be fairly consistent across the region. Therefore, one might presume that analysis of the CAKN region's climate variations can be simplified by examining the average temperature across the region, rather than examining each time series individually. This approach is justified by the rather large spatial coherence of the temperature across the region. For summer (June-August) temperatures over the period of record, the correlations between the individual long term stations and the average of all nine range from 0.67 to 0.90. For winter (December-February) temperatures, the correlations are even better, ranging from 0.85 to 0.96. Correlations for annual mean temperatures range from 0.78 to 0.93. Fairbanks University and McKinley HQ, the two stations with the longest continuous records at one location and with the fewest months of missing data, i.e., the two most diligently maintained sites, have the best correlations ( $R = 0.93$  for annual means). Thus, if one needs a quick update for CAKN regional temperatures, one or both of these stations would be a good choice. Both stations are climatological treasures.

To avoid weighting the nine-station mean towards those stations (like Eagle or Fort Yukon) that have a greater range of temperatures, the nine-station means used in this study are of normalized annual (or seasonal) temperature departures. The normalized departure for each year (or season) at each station is given by:

*Normalized Departure = (Annual temperature – 1971-2000 normal)/Standard Deviation of annual temps*

The next three figures show the nine-station average of normalized annual, summer, and winter temperatures. Five-year moving averages are added to all three time series. These time series are updated from 2005. Normalized departures prior to 2005 have change slightly since the previous report because the standard deviations have been updated and changed.

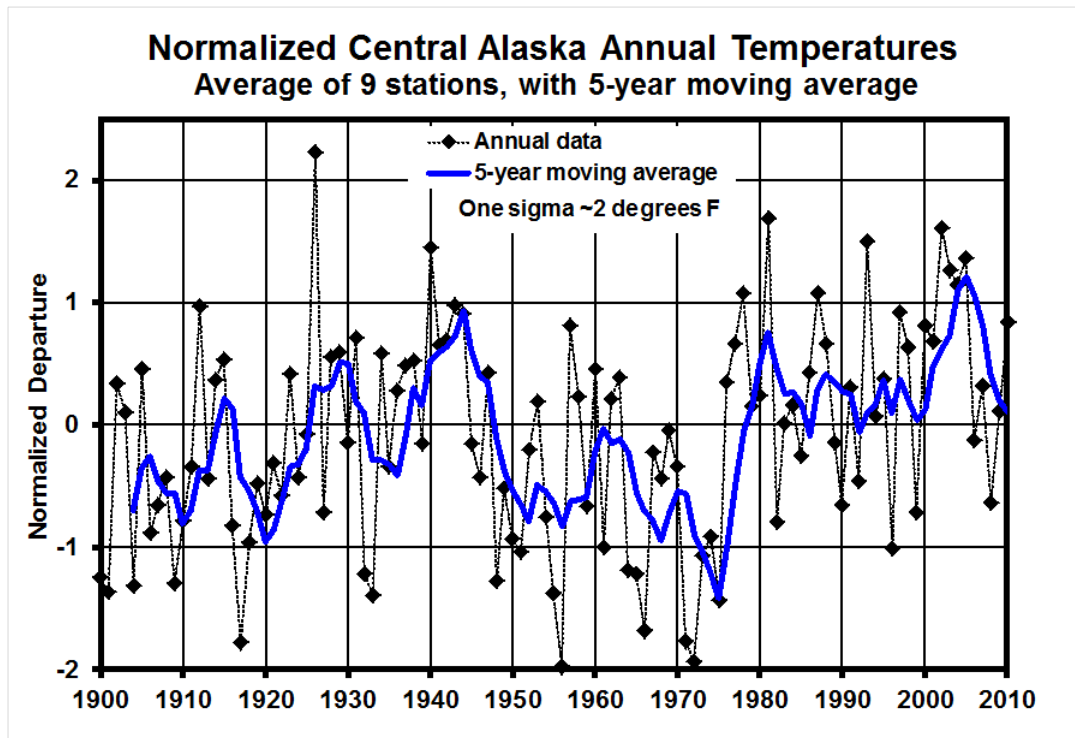


Figure 19. 111 year record of regional Annual Average Temperature.

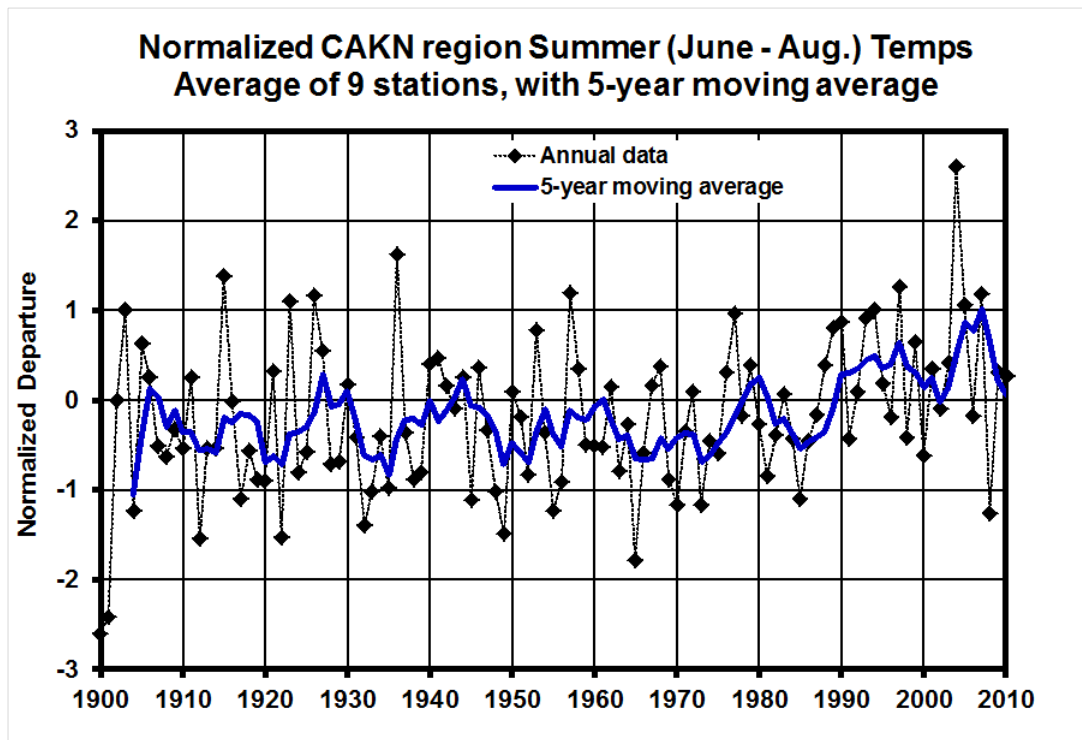


Figure 20. 111 year record of regional Summer Average Temperature.

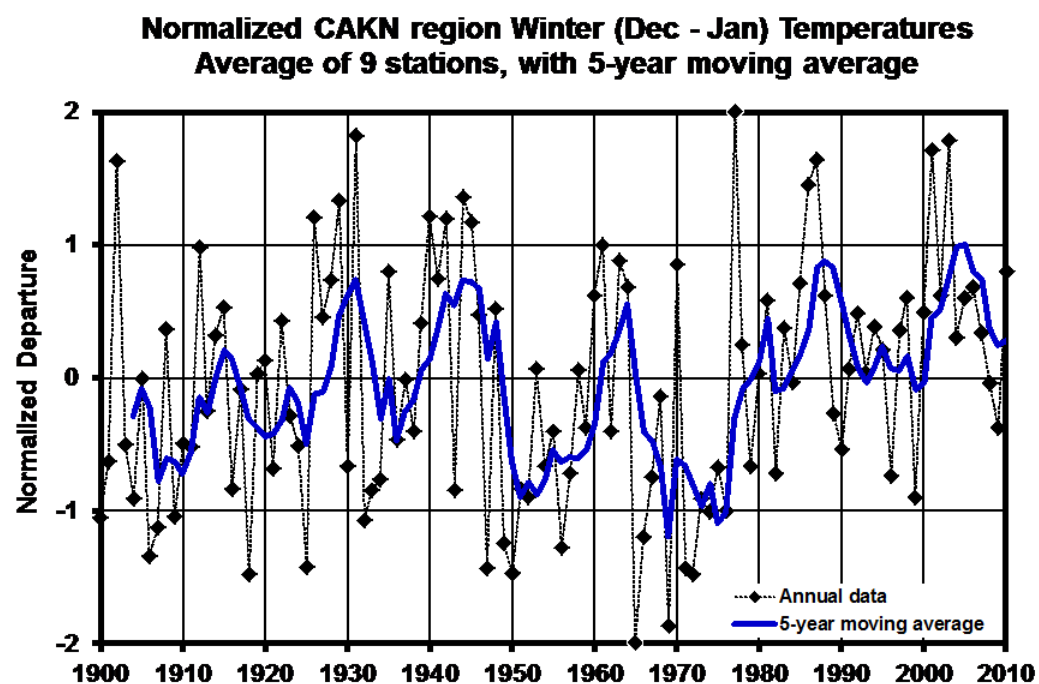


Figure 21. 111 year record of regional Winter Average Temperature.

Denali summit temperatures can be estimated from upper air temperature and pressure data produced by the NCEP/NCAR Reanalysis project, archived at the NOAA Earth System Research Laboratory (ESRL). In essence Denali summit temperatures are estimated from Anchorage and

Fairbanks radiosonde soundings. Reanalysis data include temperatures and pressure heights at 2.5-degree grid intervals of latitude and longitude. Denali summit temperatures are estimated from data for 62.5 degrees North, 210 degrees East (or 150 degrees West), close to the actual summit coordinates of 63.1 North, 151.0 West. Given the monthly temperatures (degrees C) at the 400 millibar and 500 millibar pressure levels, and the height (in meters) of those pressure levels, temperatures at the 6194 meter summit of Denali can be interpolated. Interpolated annual, summer, and winter temperatures are shown in the next figure. The ESRL data site is: <http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.derived.pressure.html>

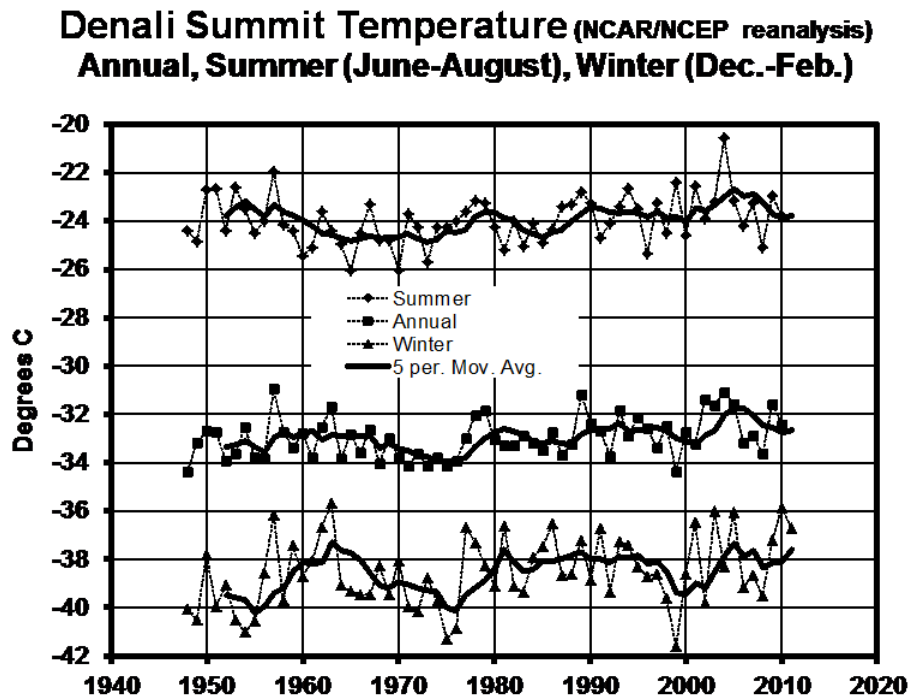


Figure 22. Denali summit temperatures, from NCAR/NCEP re-analysis.

### Snow and Snow Water Equivalent

The 61 catalogued Snow Survey stations have periods of record ranging from 1 to 45 years

- 23 stations in and near Denali
- 21 stations in and near Wrangell-St. Elias
- 17 stations in and near Yukon-Charley
- 40 stations have records > 10 years
- 18 stations have records > 30 years
- 32 stations have sufficiently complete records to allow 30-year normals to be calculated.

As was the case with temperature, analysis of climate variations can be simplified by averaging the snow survey records, and in particular the Snow Water Equivalent (SWE), across all the sites in a park unit. The analysis is further simplified by using the maximum value of the SWE during each winter as an indicator of the total precipitation that fell as snow. Following the methodology used by the NWCC in their monthly snowpack basin summaries, the individual site SWE is expressed as a percent of the 1971-2000 average for that site and month. In this study,

the winter maximum SWE is expressed as a percentage of the highest monthly value of the 1971-2000 monthly means. The NWCC averages the SWE percentages for all the operating sites in the hydrological unit; in this study, the individual percentages will be averaged over all the sites in the park unit.

The next three figures show the annual values of the maximum percentage SWE for each park unit. Also shown on each figure are the percentage SWE for each individual site, although no attempt is made to indicate which site is which line on the graph.

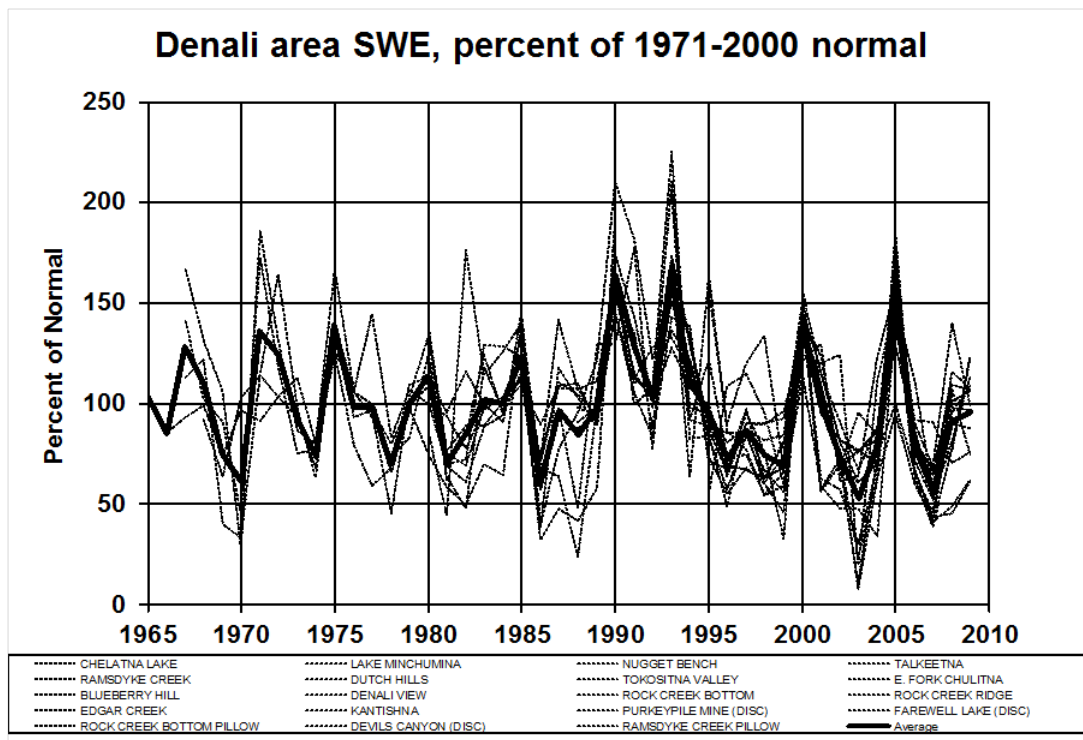


Figure 23. Denali area Snow Water Equivalent (SWE), from records at 19 snow survey sites.

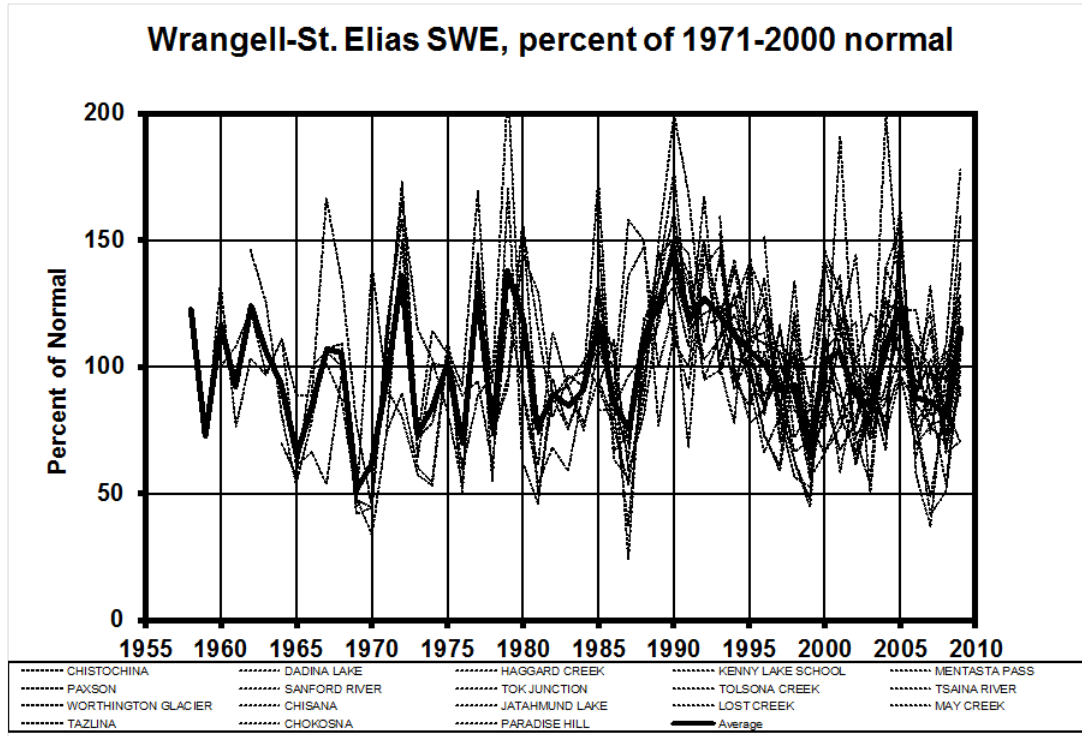


Figure 24. Wrangell-St. Elias area Snow Water Equivalent (SWE), from records at 18 snow survey sites.

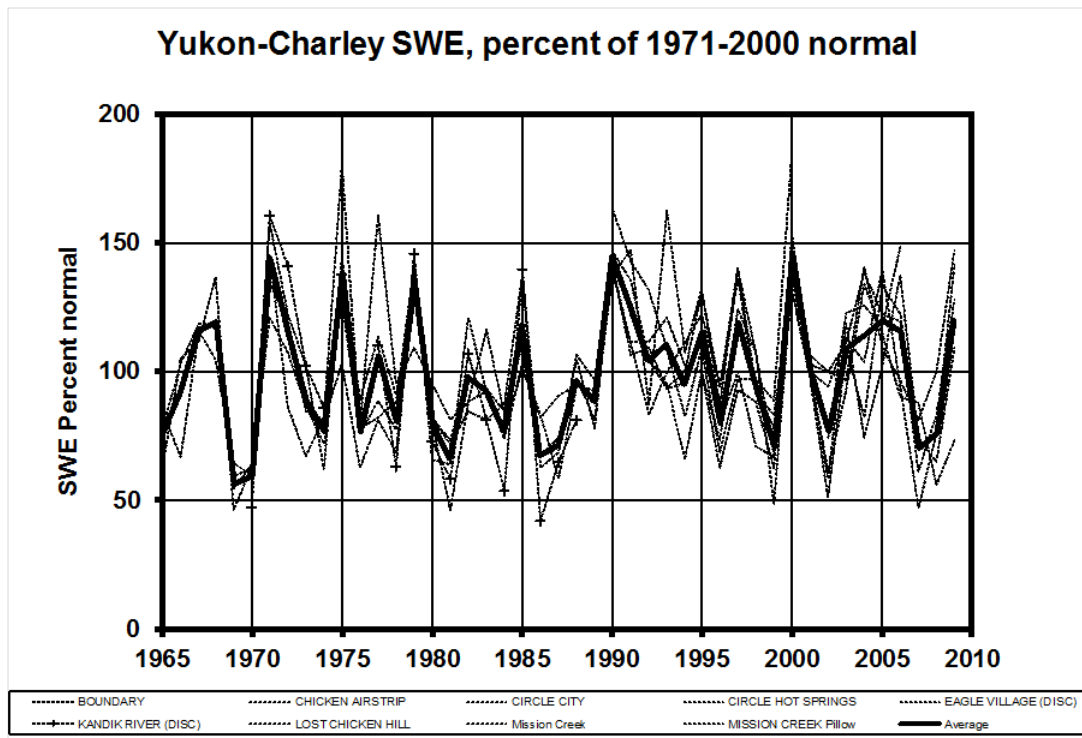


Figure 25. Yukon-Charley area Snow Water Equivalent (SWE), from records at 9 snow survey sites.

There is a good spatial coherence among the individual sites within each unit. The correlations between the 19 sites within the Denali unit and the Denali average range from 0.53 to 0.98, and

the average of the 19 correlation coefficients is 0.84. For Wrangell-St. Elias, the 18 site correlation coefficients range from 0.38 to 0.83, averaging 0.66; within Yukon-Charley the 9 site correlations range from 0.77 to 0.95, and average 0.85.

Furthermore, there is an equally respectable spatial coherence among the average SWE for the three units. Between Denali and Wrangell-St. Elias, the correlation is 0.60; between Denali and Yukon-Charley, 0.68; and between Wrangell-St. Elias and Yukon-Charley, 0.68. The respective correlations between Denali, Yukon-Charley, and Wrangell-St. Elias and the three-unit average are 0.89, 0.86, and 0.89. Because the variations of SWE in the three units are so well correlated, the “grand average” SWE (next figure) can be used for analyzing the possible causes of the variations.

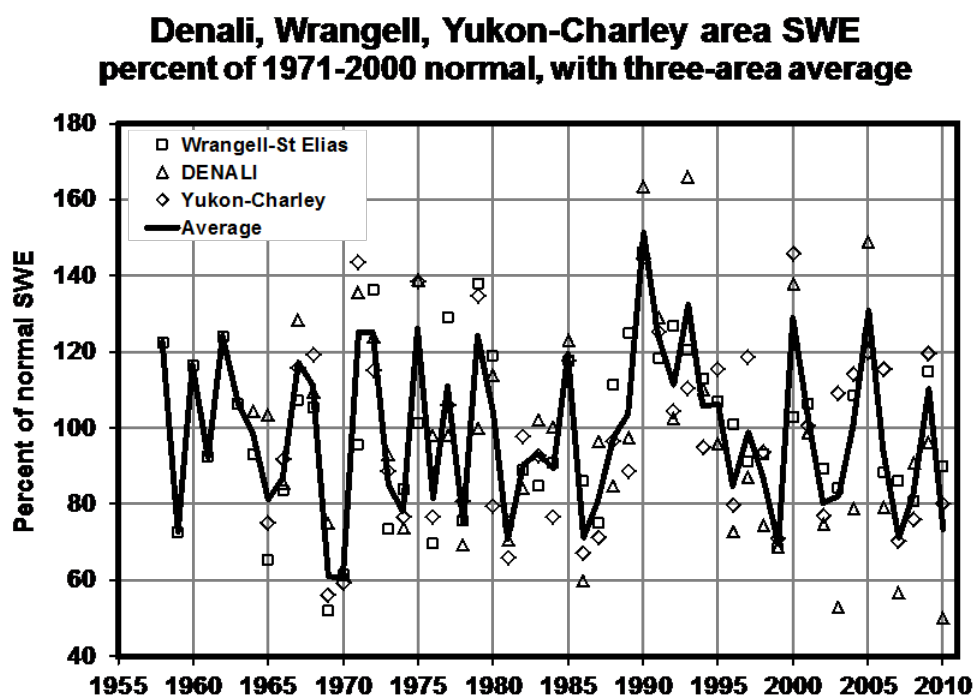


Figure 26. CAKN regional Snow Water Equivalent (SWE), average of Denali, Wrangell-St. Elias, and Yukon-Charley SWE.

### **Precipitation**

Compared to temperature, precipitation is generally more difficult to compile, analyze, and interpret. There are several reasons for this: precipitation is usually less spatially coherent than temperature, and estimating from nearby stations is less effective; measurement of precipitation is more difficult, especially during snow, due to problems with wind, gauge design, evaporation, etc.; and station changes – even small location changes and gauge changes – can introduce substantial inconsistencies in the record. The stations in the CAKN region are no exception to this generality, and with one exception, there are no Coop precipitation records that are suitable for long term climate analysis. The published records all, with again one exception, have a large number of missing months and a suspiciously large number of months with zero precipitation. The one exception is the McKinley Park cooperative station.

The next three graphs show the Annual Precipitation, which is rain and melted snow; Seasonal Snowfall (measured from July to June, but mostly falling October to April); and Annual Rainfall (measured April to October, but falling mostly June to September). Monthly precipitation and snowfall are published in Climatological Data and elsewhere, but rainfall is not specifically tabulated. For this study, rainfall for April to October was calculated by subtracting the precipitation estimated to have fallen as snow from the total precipitation for each month, with the water equivalent of the snow set equal to the monthly snowfall divided by ten. If the result was less than zero, rainfall was set equal to zero.

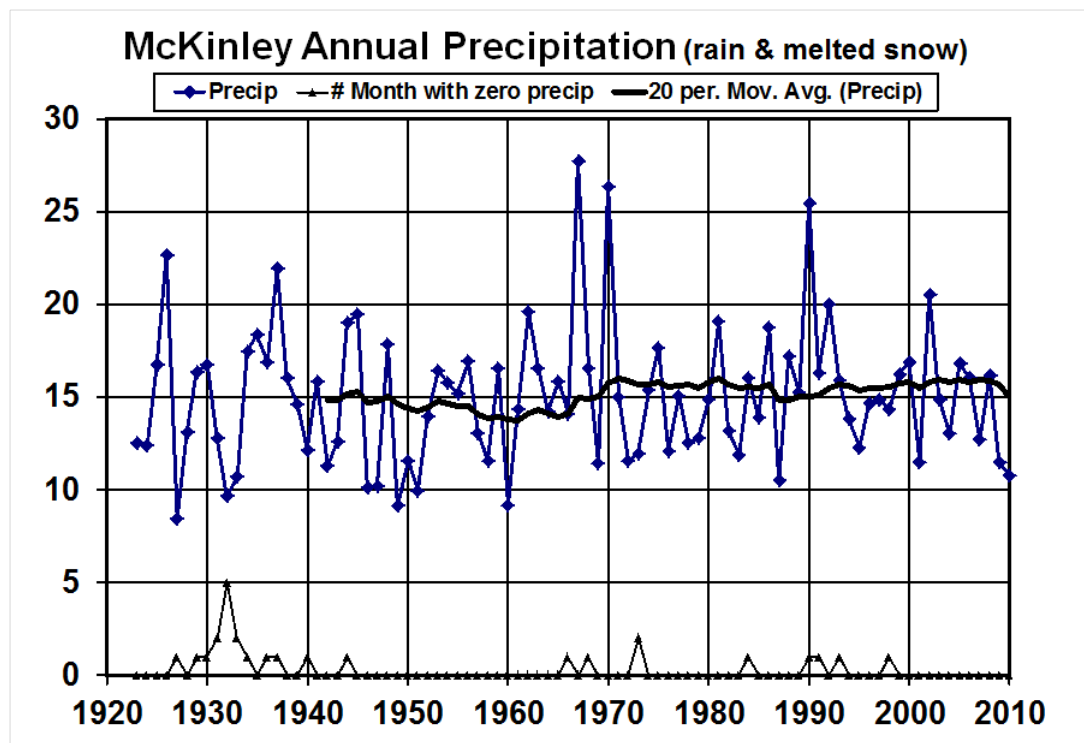


Figure 27. Annual Precipitation (rain and melted snow) at the McKinley Park coop station. The heavy solid line is a 20-year running mean. The small triangles along the bottom axis note the number of months (from 1 to 5) each year with zero precipitation, and indicate the likely amount of missing data each year.

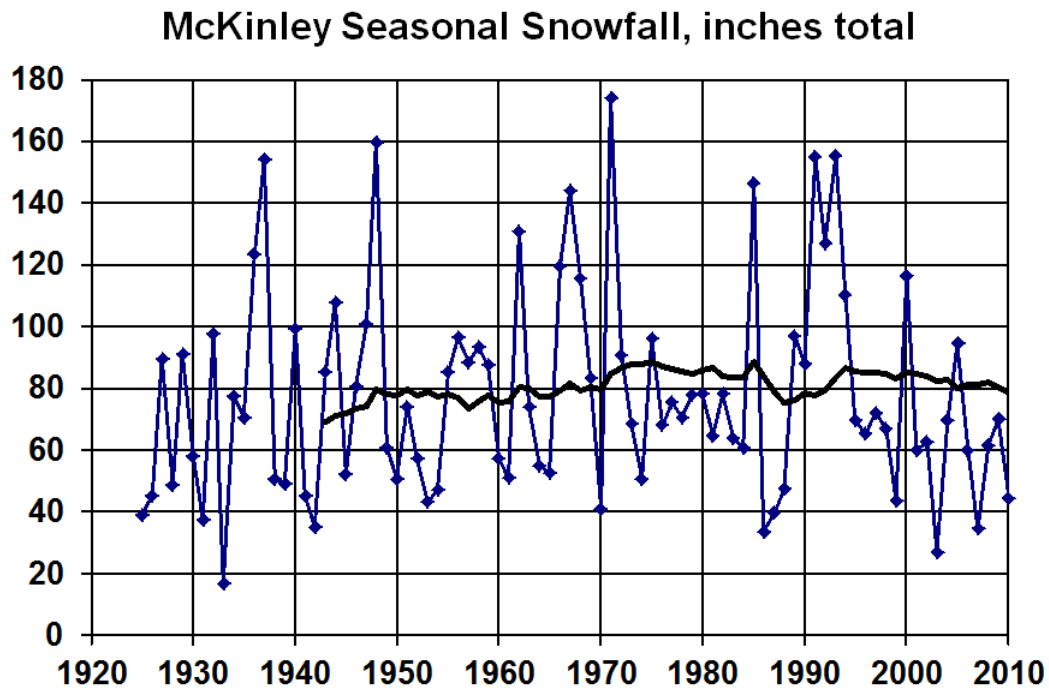


Figure 28. Seasonal (July to June) snowfall at the McKinley Park coop station. The heavy solid line is a 20-year running mean.

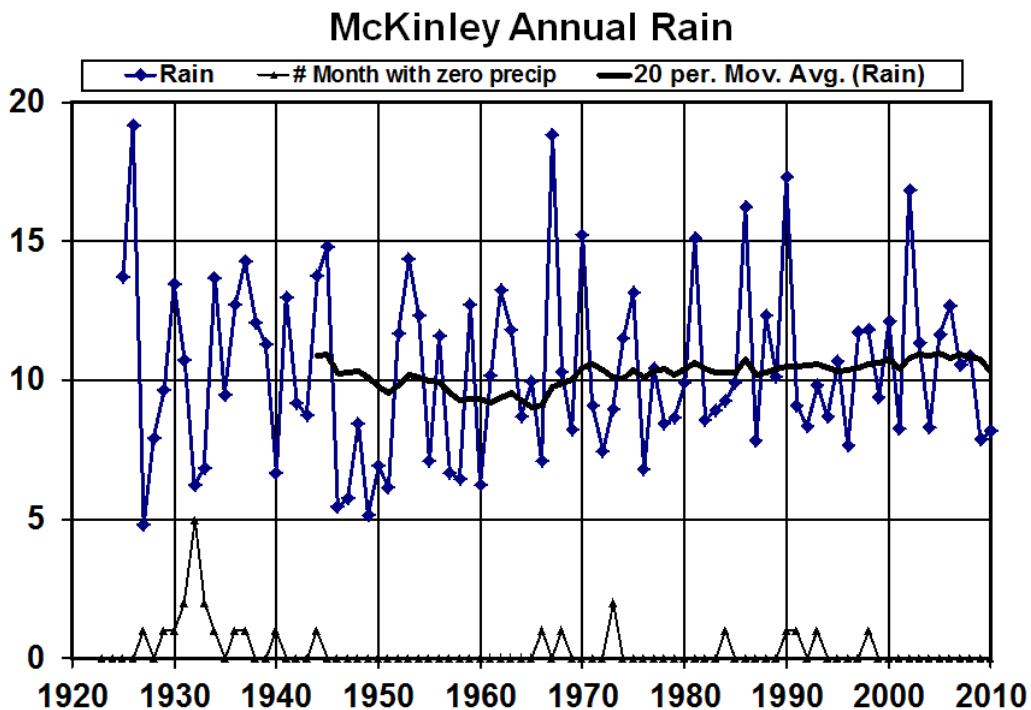


Figure 29. Annual Rainfall at the McKinley Park coop station. The heavy solid line is a 20-year running mean. The small triangles along the bottom axis note seasons (May to September) having a month with zero precipitation, and indicate the likely amount of missing data.

No pronounced climate signal is apparent in the annual precipitation and rainfall statistics. Precipitation has a statistically insignificant trend of +0.08 inches per decade, or roughly 0.5 percent per decade. Likewise, rainfall displays an increasing trend of +0.03 inches per decade, or about 0.3 percent per decade. Snowfall has experienced an increasing trend of +0.4 inches per decade, also about 0.5 percent per decade. McKinley seasonal snowfall is well correlated with the Denali region average SWE over the period of mutual record, with  $r = 0.72$ . Thus, the conclusions of the climate analysis of SWE in the next section will also apply to the measured snowfall for a longer period of time.

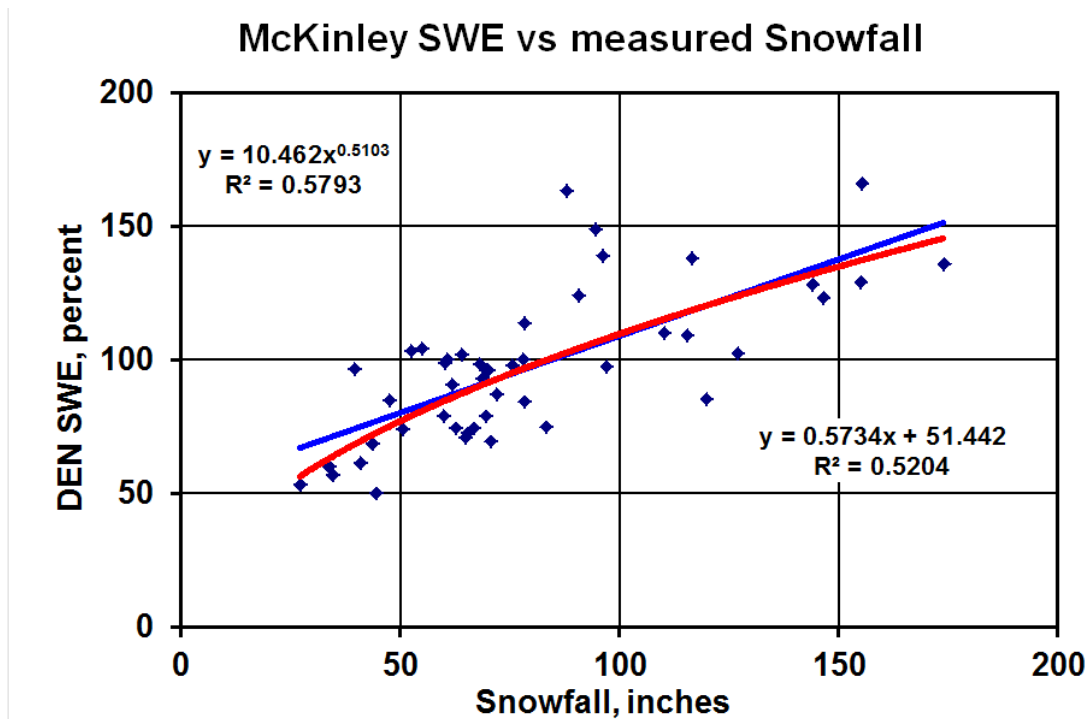


Figure 30. Correlation of McKinley regional means SWE vs. total seasonal snowfall measured at the McKinley NP coop station. Linear and power-law regression lines both correlate better than  $r=0.7$ .



# Analysis of Climate Change over the Past Century

## Indicators of Climate Change

The search for ultimate causes of climate change and variability can be frustrating, and perhaps the best we can hope for is to link local and regional variability, such as occurs in the CAKN region, with larger scale (and perhaps even global scale) changes in the atmospheric and oceanic circulations, and perhaps even with so-called “external forcings”, such as volcanoes, changes in greenhouse gases in the atmosphere, and variability of the Sun. The first step is to compile time series of climate parameter, as described in the previous section of this study, and to compile time series of the climate “forcings”. Since the atmosphere (and ocean) are infinitely complex, the best descriptors are one-dimensional indices that describe some of the important modes of the observed variability of the atmospheric and oceanic circulations. There is a growing number of these as researchers probe ever deeper into the working of the ocean-atmosphere system, and a comprehensive list of indices, including descriptions and tabulations, is at the CDC web site:

<http://www.esrl.noaa.gov/psd/data/climateindices/list/>  
and  
<http://www.cgd.ucar.edu/cas/jhurrell/indices.info.html>

In addition, another index is included in this study, namely, the annual average surface temperature of the Arctic (65 N to 90 N). This index is added on the presumption that the annual temperature of the polar cap north of the CAKN region can influence the atmospheric circulation at the edge of the polar cap (i.e., around the latitude of the CAKN region), and that the presence or absence of polar air masses in the polar cap will have an effect on the CAKN region’s climate.

Many of the atmospheric indices are highly correlated with other indices, meaning that the indices are not always independent of each other and, in many cases, are descriptors of essentially the same atmospheric pattern. For example, there are several “el Niño” related indices which, not surprisingly, are highly correlated with each other. In and around Alaska, the NP (North Pacific), PDO (Pacific Decadal Oscillation), and PNA (Pacific North America) indices are highly correlated. The CDC web site allows the user to generate correlations between climate indices and NCEP/NCAR reanalysis data, and this is a useful tool to screen indices to determine which ones have the potential to explain some of the variance of the CAKN regional climate.

After screening the indices for independent and significant correlations, the following indices (plus the “external forcings”, Solar variability and Carbon Dioxide) have been found to be relevant to the climate of central Alaska. The descriptions of the indices are followed by a series of charts presented yearly and 5-year moving averages of annual values of these indices. The 5-year averages display the longer-term and more slowly varying oscillations and trends that are important for climate change.

- Total Solar Irradiance (TSI) – total energy flux from the Sun, in Watts per square meter, converted to a radiative equilibrium temperature in Kelvins. Data from Hoyt and Schatten (1997). Updates since 1998 are estimated from sunspot numbers and measured solar fluxes.

- Carbon Dioxide (CO<sub>2</sub>) –concentration of Carbon Dioxide in the Earth’s atmosphere, in parts per million. Data from NASA/GISS, <http://www.giss.nasa.gov/data/simodel/ghgases/GCM.html>
- Arctic Mean Annual Temperature – the annual average surface temperature of the Arctic (65 N to 90 N) compiled by Alan Cheetham, found at: <http://www.appinsys.com/GlobalWarming/> The station data is from the NOAA GHCN database, and the 29 stations selected are nun-urban sites in the region with continuous records extending at least from 1930 to 2000.

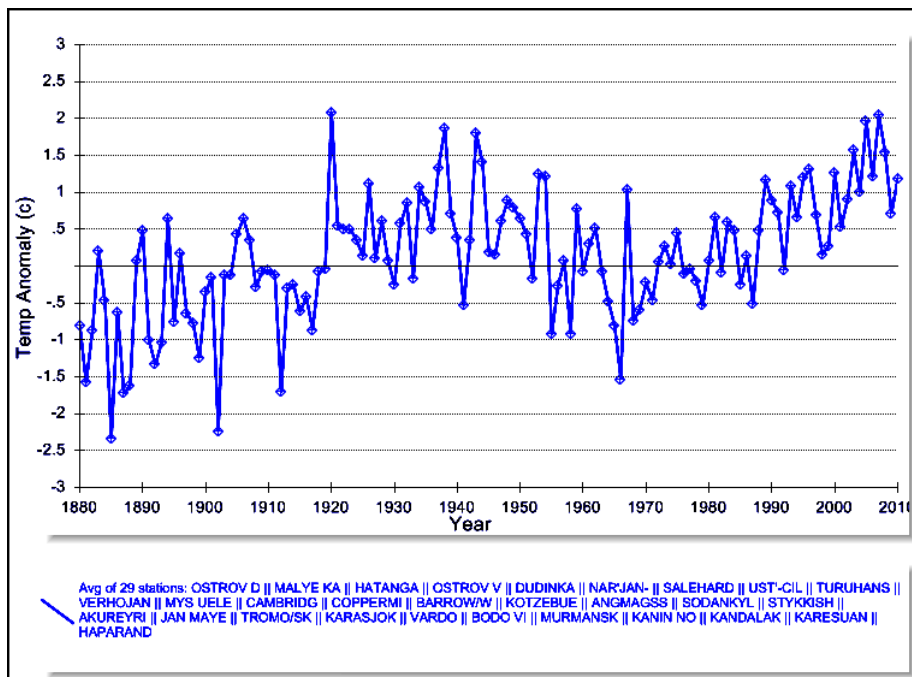


Figure 31. Arctic mean annual temperatures, 1880 to 2010.

- Northern Annular Mode (NAM) or Arctic Oscillation (AO) – a hemispheric surface pressure pattern, with positive index values indicating lower than normal pressures and temperatures in the Arctic (north of 65 N), higher pressures and temperatures at middle latitudes, particularly over the north Pacific and north Atlantic Oceans. This leads to stronger than normal zonal westerly winds at the surface and a stronger jet stream which is displaced poleward (in other words, a strengthening and contraction of the polar vortex), which in turn leads to a northward displacement of the normal cyclone tracks in the north Pacific and north Atlantic Oceans. Indices are normalized December-March averages from Jim Hurrell at NCAR: <http://www.cgd.ucar.edu/cas/jhurrell/indices.data.html#nam>

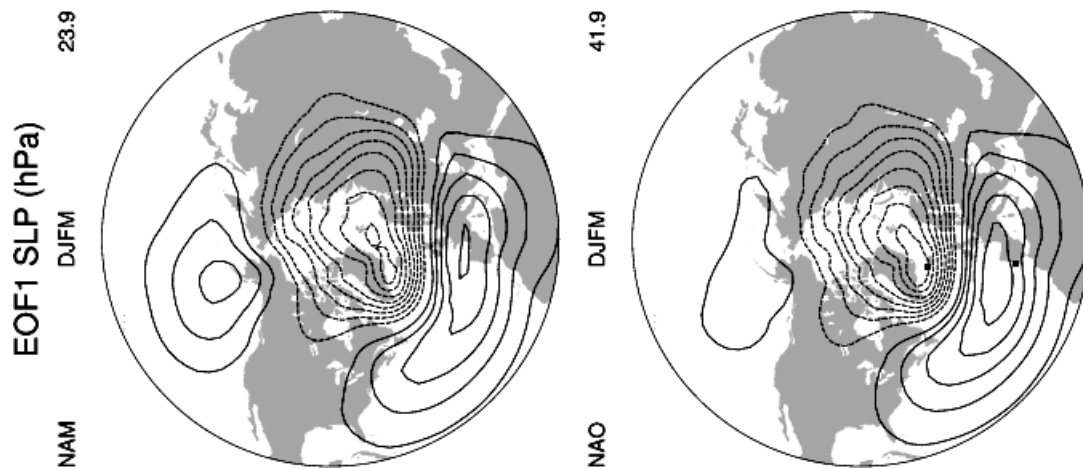


Figure 32. Northern Hemisphere surface pressure patterns associated with the NAM/AO (left) and NAO (right). Solid contours show positive pressure changes associated with positive index values; dashed lines are negative pressure changes. The image is rotated for comparison with other images. From <http://www.cgd.ucar.edu/cas/jhurrell/indices.info.html>

- North Atlantic Oscillation (NAO) – a measure of the strength of the weather pattern over the North Atlantic, measured as the normalized pressure difference between the Azores High and the Icelandic Low. Positive values of the index indicate stronger-than-average westerlies over the middle latitudes. Data and information from NCAR and NOAA: <http://www.cgd.ucar.edu/cas/jhurrell/indices.info.html>  
<http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao.shtml>
- North Pacific (NP) – area-weighted sea level pressure over the region 30N-65N, 160E-140W, as an indicator of the strength of the Aleutian/Gulf of Alaska Low. Units are November to March average departures from the long-term mean; negative numbers indicate a stronger Aleutian Low with lower pressures. Data and background from Jim Hurrell at NCAR: <http://www.cgd.ucar.edu/cas/jhurrell/npindex.html> or <http://www.cgd.ucar.edu/cas/jhurrell/indices.info.html#np>

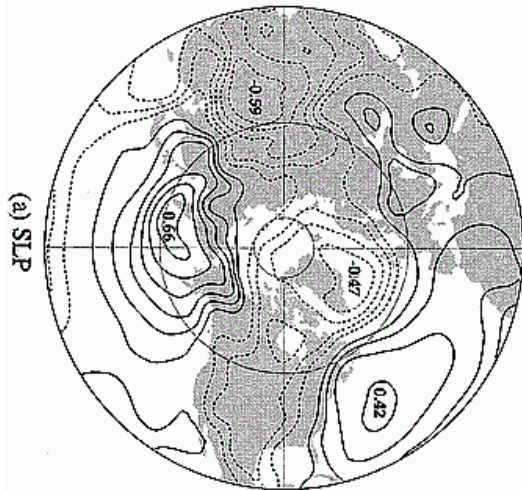


Figure 33. Northern Hemisphere surface pressure patterns associated with the North Pacific oscillation. Solid contours show positive pressure changes associated with positive index values; dashed lines are negative pressure changes. From Overland et al., 1999.

There is a striking similarity between the maps of the AO, NAO, and NP patterns. Simply put, the AO is a measure of the westerlies all the way around the Arctic, while the NAO and NP measure the Atlantic and Pacific components of the AO vortex.

- Pacific Decadal Oscillation (PDO) – the leading Principal Component of monthly Sea Surface Temperature (SST) anomalies in the North Pacific Ocean. This component is characterized by positive (warm) SST anomalies along the entire west coast of North American, including Alaska, and negative anomalies extending from north of Hawaii to Japan. Units are normalized departures from the long-term mean of winter (December to February) averages, and positive values define a general SST pattern across the north Pacific of warm east and cold west. The PDO is highly correlated with the NP ( $r = -0.56$ ), which means that a positive PDO SST pattern is conducive to maintaining a strong Aleutian Low (NP index). Physically, the PDO is the oceanic component of an air-sea feedback process that is responsible for the NP variations that so profoundly affect the climate of Alaska. In this report the process will be often referred to as the NP/PDO in recognition of its combined nature. Data is from John M. Wallace at the University of Washington's Joint Institute for the Study of the Atmosphere Oceans, [ftp://ftp.atmos.washington.edu/mantua/pnw\\_impacts/INDICES/PDO.latest](ftp://ftp.atmos.washington.edu/mantua/pnw_impacts/INDICES/PDO.latest). The importance of the PDO to the changing climate of Alaska is discussed in previous studies, such as Hartmann and Wendler, 2005, and Wendler and Shulski, 2009.
- East Pacific Oscillation (EP) – a pattern with low pressures in the central North Pacific (north of Hawaii) and eastern Canada and a ridge of high pressure in between, along the west coast of North America into Alaska. In extreme cases this is an “Omega” blocking pattern in western Canada and Alaska. Details and data at: <http://www.cpc.ncep.noaa.gov/data/teledoc/ep.shtml>
- Atlantic Multidecadal Oscillation (AMO) – the area weighted average sea surface temperature over the entire North Atlantic, from the equator to 70N, departure from

average. As suggested by the name, this varies slowly over years and decades, and influences hurricane activity, the strength and location of the Bermuda High, heat waves in North America, and jet streams and storm tracks over the North Atlantic. Details at: <http://www.esrl.noaa.gov/psd/data/timeseries/AMO/>

- Multidecadal ENSO Index (MEI) – an index of el Niño – Southern Oscillation (ENSO) variations that combines sea and air temperatures, surface pressures and winds, and cloudiness, all of which are affected by the processes that cause el Niño. Details and data are at: <http://www.esrl.noaa.gov/psd/enso/mei/mei.html>

As previously mentioned, some indices are highly correlated with others. NOAA provides a table of monthly cross-correlations that shows, for example, a correlation of  $R = 0.65$  between the NAO and AO. However, monthly values of the NP and PDO indices are only slightly correlated with  $R = -0.15$  (the negative correlation results from the index definitions, where a negative NP should physically correlate with a positive PDO, and vice-versa. At longer time scales, though, the NP - PDO correlations increase to -0.62 for annual values and -0.77 for 5-year averages.

Table 2. Cross-correlations of Climate indices.

| Cross-correlations of Climate Indices                                                                                   |       |       |       |       |       |       |       |       |       |
|-------------------------------------------------------------------------------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| <a href="http://www.esrl.noaa.gov/psd/data/correlation/table/">http://www.esrl.noaa.gov/psd/data/correlation/table/</a> |       |       |       |       |       |       |       |       |       |
|                                                                                                                         | nao   | pdo   | np    | ao    | trend | solar | mei   | epo   | amo   |
| nao                                                                                                                     | 1.00  | -0.03 | 0.00  | 0.65  | 0.10  | 0.02  | -0.04 | 0.14  | -0.07 |
| pdo                                                                                                                     | -0.03 | 1.00  | -0.15 | -0.15 | 0.41  | -0.05 | 0.57  | 0.03  | -0.28 |
| np                                                                                                                      | 0.00  | -0.15 | 1.00  | 0.17  | -0.06 | -0.05 | -0.11 | -0.04 | 0.01  |
| ao                                                                                                                      | 0.65  | -0.15 | 0.17  | 1.00  | 0.18  | 0.05  | -0.07 | 0.03  | -0.12 |
| trend                                                                                                                   | 0.10  | 0.41  | -0.06 | 0.18  | 1.00  | -0.01 | 0.28  | 0.03  | -0.74 |
| solar                                                                                                                   | 0.02  | -0.05 | -0.05 | 0.05  | -0.01 | 1.00  | 0.09  | -0.03 | 0.10  |
| mei                                                                                                                     | -0.04 | 0.57  | -0.11 | -0.07 | 0.28  | 0.09  | 1.00  | -0.17 | -0.12 |
| epo                                                                                                                     | 0.14  | 0.03  | -0.04 | 0.03  | 0.03  | -0.03 | -0.17 | 1.00  | -0.14 |
| amo                                                                                                                     | -0.07 | -0.28 | 0.01  | -0.12 | -0.74 | 0.10  | -0.12 | -0.14 | 1.00  |

### Total Solar Irradiance and CO<sub>2</sub> concentrations

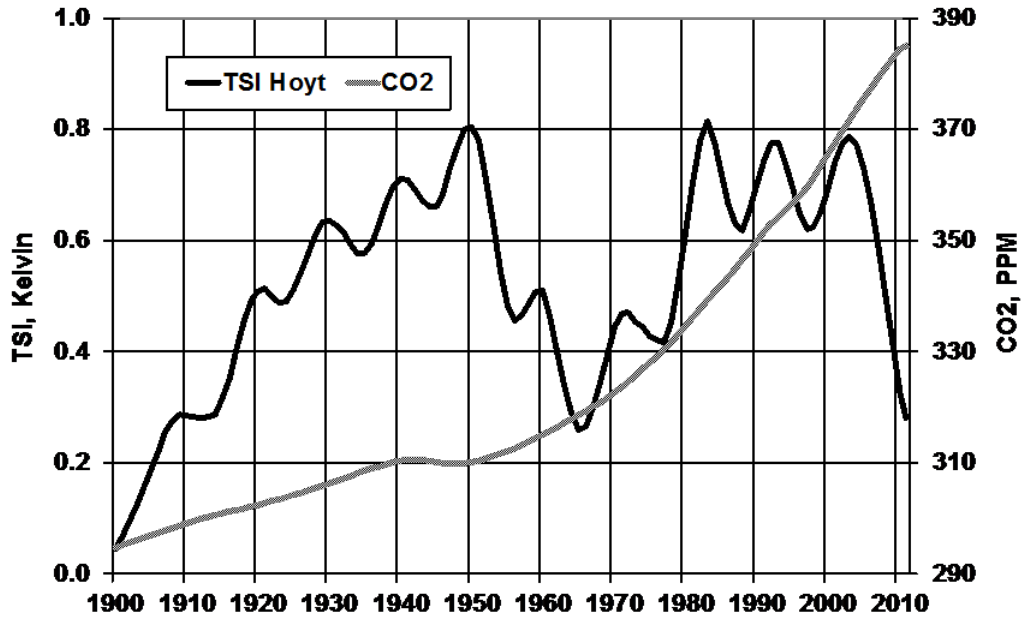


Figure 34. Five-year smoothed values of Total Solar Irradiance (from Hoyt, updated by Keen) and atmospheric Carbon Dioxide concentration (from NASA/GISS).

### Winter (DJFM) Northern Annular Mode (AO) Index: yearly and 5-year means

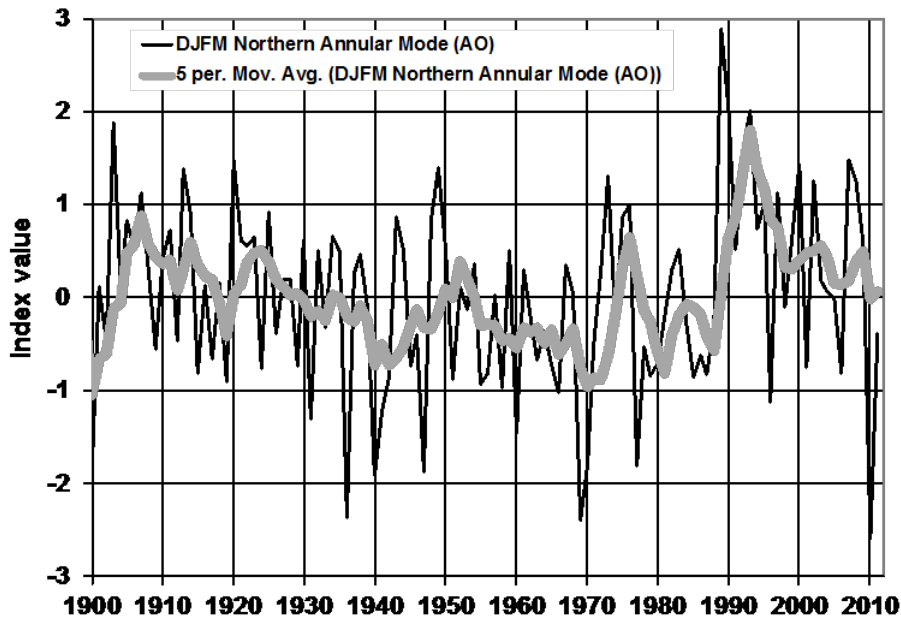


Figure 35. Yearly and Five-year smoothed values of winter and annual Northern Annular Mode, or Arctic Oscillation (AO), indices.

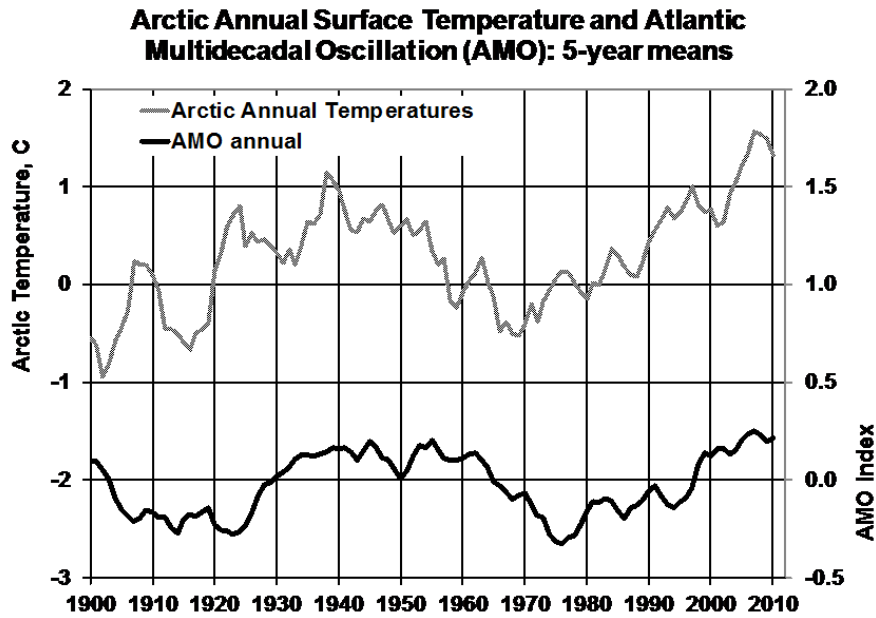


Figure 36. Five-year smoothed values of the Atlantic Multidecadal Oscillation (AMO) Index and of Arctic Annual mean surface temperatures. The Atlantic Ocean and the Arctic have varied similarly over the past century, with the Atlantic following the Arctic by about a decade.

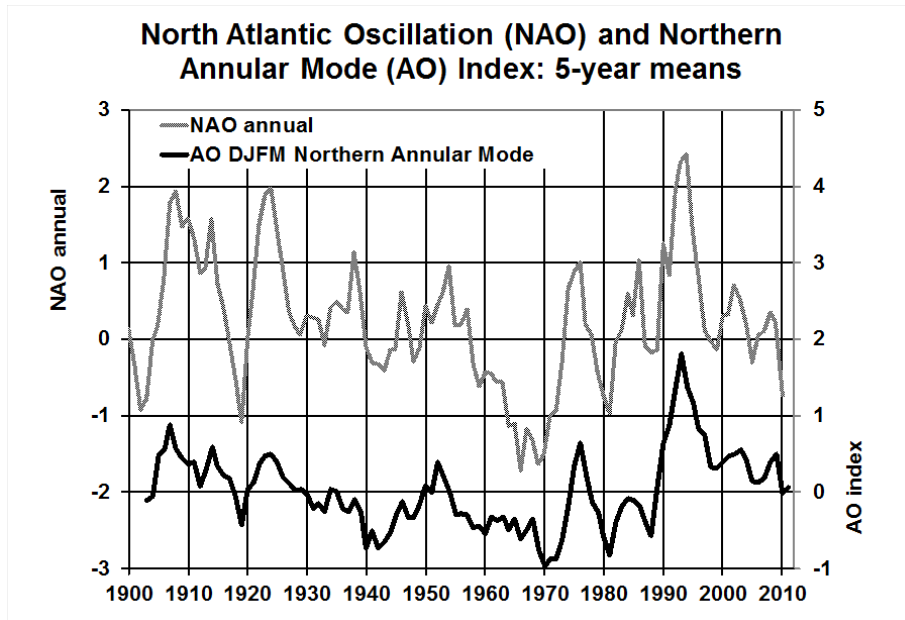


Figure 37. Five-year smoothed values of Northern Atlantic Oscillation (AMO) index, and of the. Northern Annular Mode, or Arctic Oscillation (AO) index. Since the NAO measures the largest component of variability of the AO, the two indices are highly correlated.

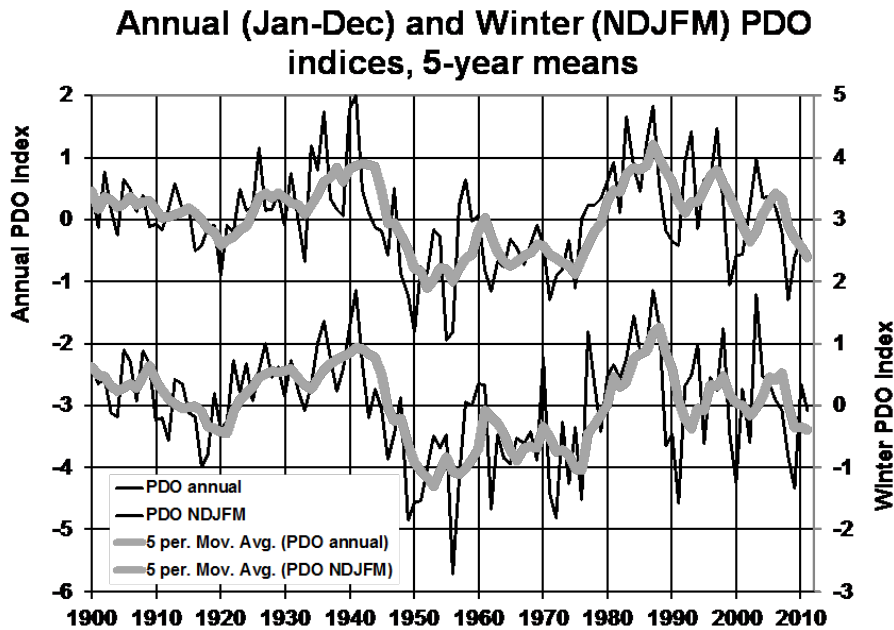


Figure 38. Yearly and Five-year smoothed values of the winter and annual Pacific Decadal Oscillation (PDO) indices. The PDO is an oceanic index, and exhibits smaller short-term variations than do the atmospheric indices.

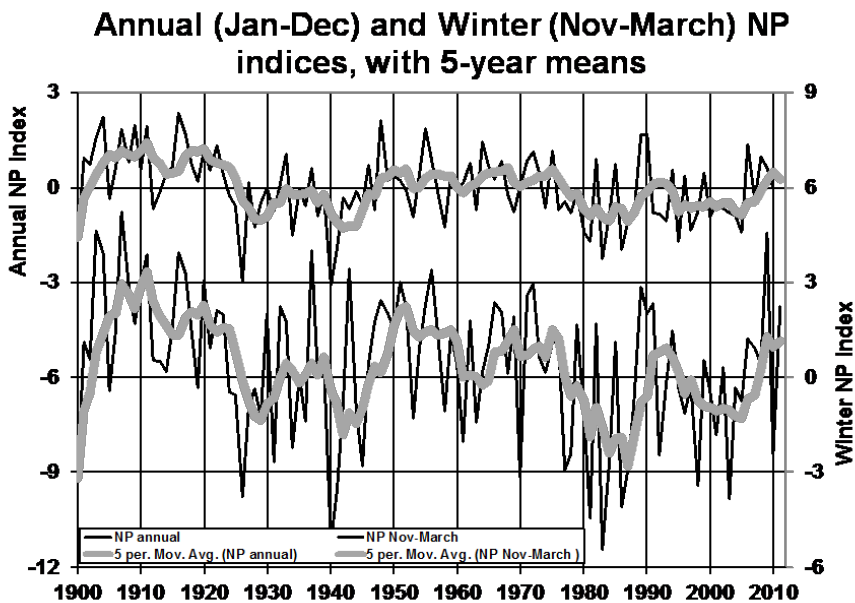


Figure 39. Yearly and Five-year smoothed values of the winter and annual North Pacific (NP) indices. The annual values follow the winter values quite closely but with reduced amplitude, since the annual indices are dominated by the stronger winter values.

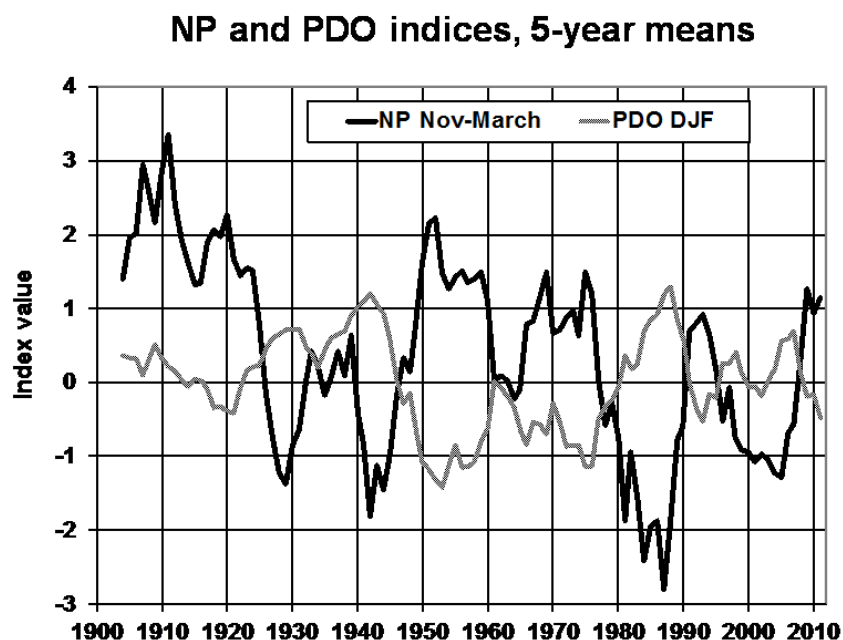


Figure 40. Comparison of Five-year smoothed values of North Pacific and Pacific Decadal Oscillation indices. On this time scale, the two indices are highly (but negatively, due to their definitions) correlated.

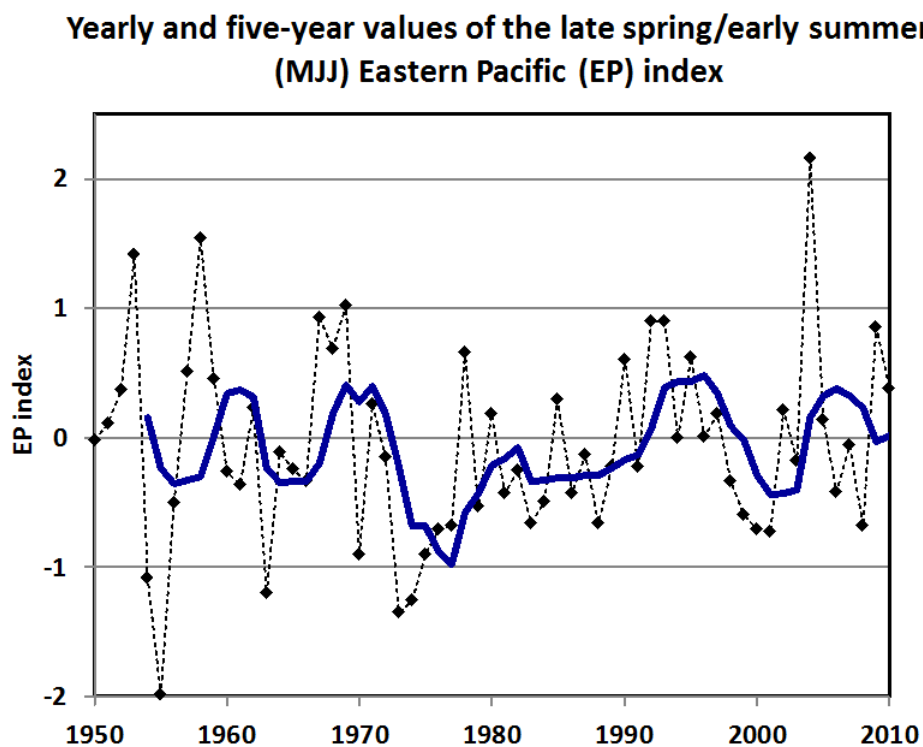


Figure 41. Yearly and Five-year smoothed values of the late spring/early summer Eastern Pacific (EP) index. This index has an occasional connection with unusually hot or cold summers.

## Correlations between CAKN Climate and Climate Indices

The following table lists correlations between CAKN area temperatures (the average of the nine long-term stations) and eleven climate indices. Note that the indices are either annual or winter values, while the temperatures are annual, winter, and summer values. For example, winter temperature is correlated with the contemporaneous NP index, while summer temperature is correlated with the NP index for the preceding winter. Most annual values are dominated by the winter values, when the atmospheric circulation is strongest. Regressions were done between annual values of temperature and indices, as well as with 5-year moving averages of temperatures and indices.

Table 3. Correlations between CAKN temperatures and Climate indices.

| 1-year   | Arctic Temp | NP NDJFM | NP ann  | PDO DJF | PDO NDJFM | PDO ann | AO DJFM | NAO ann | AMO ann | TSI   | CO2   |
|----------|-------------|----------|---------|---------|-----------|---------|---------|---------|---------|-------|-------|
| Ann Temp | 0.31*       | -0.50**  | -0.68** | 0.38**  | 0.40**    | 0.60**  | -0.05   | -0.12   | 0.29*   | 0.34* | 0.31* |
| DJF Temp | 0.10        | -0.59**  | -0.37** | 0.61**  | 0.55**    | 0.39**  | -0.17   | -0.21   | 0.26    | 0.17  | 0.25  |
| JJA Temp | 0.24        | -0.09    | -0.20   | 0.15    | 0.13      | 0.30*   | 0.13    | 0.04    | 0.14    | 0.23  | 0.33* |
|          |             |          |         |         |           |         |         |         |         |       |       |
| 5-year   | Arctic Temp | NP NDJFM | NP ann  | PDO DJF | PDO NDJFM | PDO ann | AO DJFM | NAO ann | AMO ann | TSI   | CO2   |
| Ann Temp | 0.54*       | -0.73**  | -0.77** | 0.66**  | 0.65**    | 0.67**  | 0.07    | 0.00    | 0.43    | 0.56* | 0.48* |
| DJF Temp | 0.42        | -0.71**  | -0.63** | 0.67**  | 0.63**    | 0.59**  | 0.04    | -0.06   | 0.37    | 0.42  | 0.43  |
| JJA Temp | 0.56*       | -0.34    | -0.43   | 0.26    | 0.26      | 0.36    | 0.39    | 0.13    | 0.31    | 0.34  | 0.65* |

Significance levels of the correlations are indicated as follows:

\* significant at the .05 level

\*\* significant at the .01 level

Note that while many  $r$  coefficients get larger with longer moving averages, the significance level does not necessarily also increase. This is because the number of independent samples,  $N$ , decreases. Due to a small lag autocorrelation ( $r = 0.28$ ) between successive years of temperature, the full 105 years of data contains about 60 independent samples. There are about 16 independent 5-year averages, eight 10-year averages, and only four 20-year averages. The resulting significance levels are in the following table.

Table 4. Significance levels of smoothed data

| Moving average | Number of independent samples | r-value with .05 significance | r-value with .01 significance |
|----------------|-------------------------------|-------------------------------|-------------------------------|
| 1-year         | 60                            | 0.25                          | 0.33                          |
| 5-year         | 16                            | 0.47                          | 0.59                          |

While no index explains as much as half of the variance ( $r$ -squared) of annual temperature, several indices explain more than half of the variance of the 5-year moving averages. This is because the smoothing removes the large interannual variability which is not related to the indices, leaving the slower climate changes which apparently are more closely related to the slower changing indices. The NP and PDO indices have the highest correlations, and as concluded in the earlier report, this ocean-atmosphere process is by far the largest factor affecting the changing climate of central Alaska.

## Multiple Regression Correlations between CAKN Climate and Climate Indices

With the NP and PDO responsible for much of Alaska's climate change, we now look at which factors also contribute. The basic procedure here is to quantify the effect of the NP, subtract it from the observed climate record, and look for the signal of other factors.

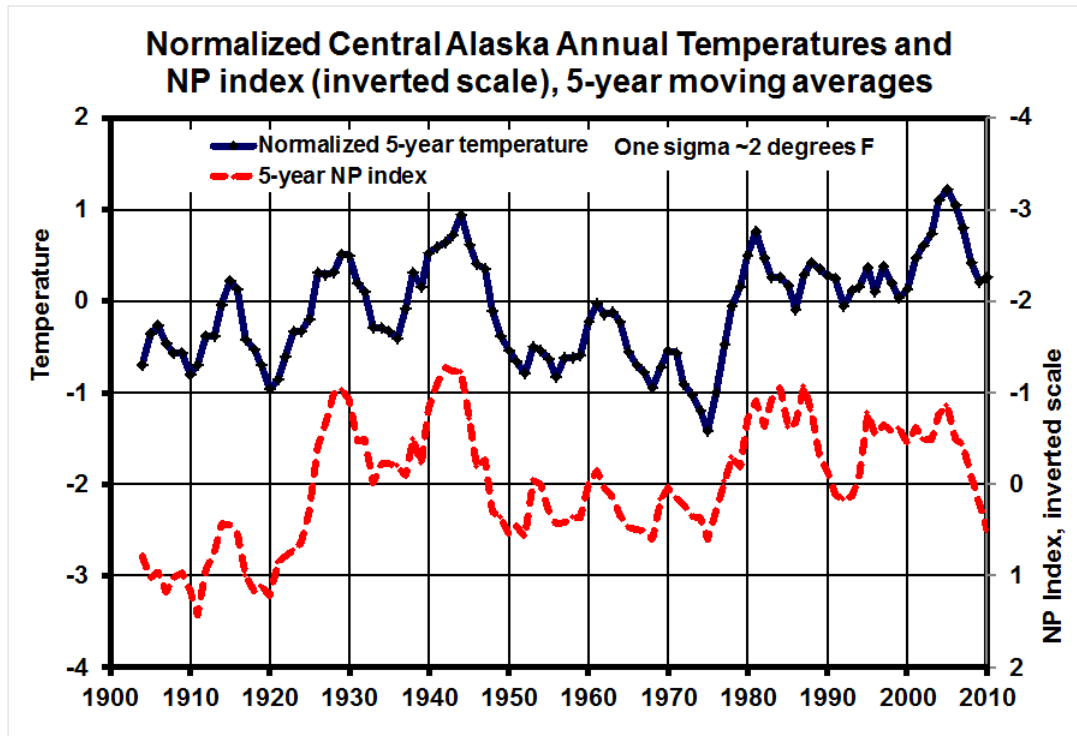


Figure 42. Five-year smoothed values of the annual North Pacific (NP) index compared to five-year values of the CAKN annual temperature.

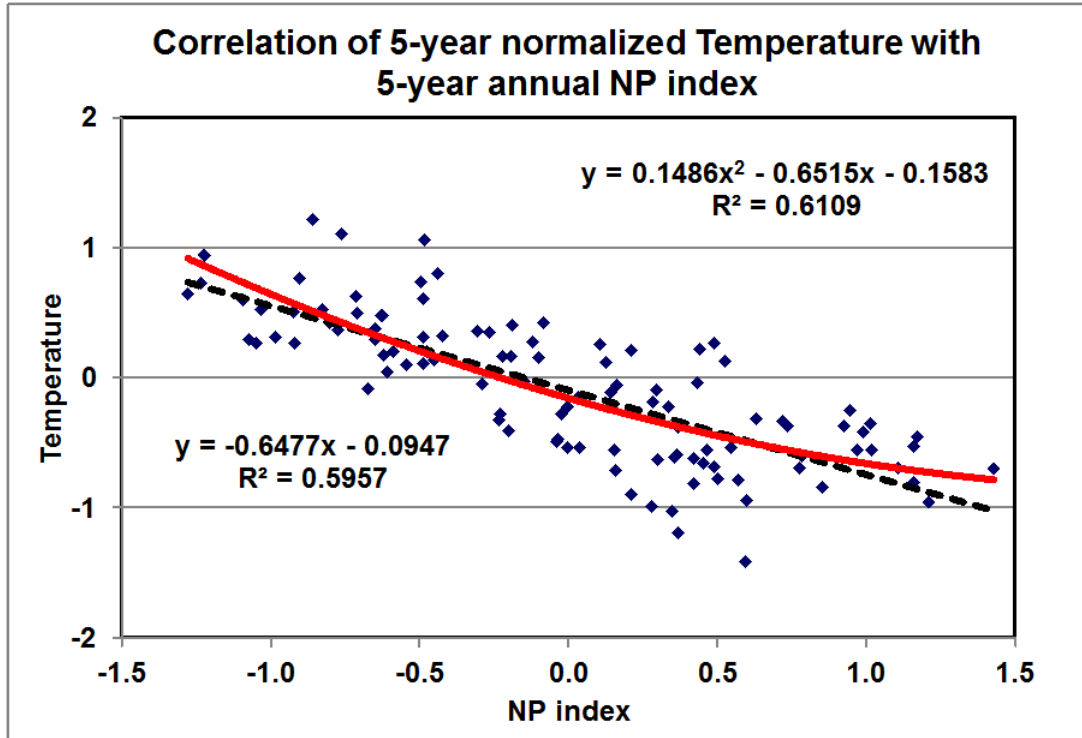


Figure 43. Scatter plot of five-year smoothed values annual NP indices and annual CAKN temperatures. A quadratic fit explains a little more of the variance, and is used to calculate the magnitude of the NP-related climate signal. The NP explains 61 percent of the variance of the five-year temperatures, leaving 39 percent to be explained by other factors.

The quadratic equation on the above graph is used to calculate the component of temperature (y) linked to the NP index (x). Subtracting this NP component from the actual five-year temperatures yields a residual, which is then correlated with other climate indices. The winter AO index has the largest correlation ( $R = 0.37$ ) with this residual, and it explains 14 percent of the residual variance (or 5 percent of the original variance). The regression equation for the temperature contribution of the AO is:

$$\text{Delta Temperature (AO)} = 0.2507 \cdot \text{AO}$$

Adding in the AO component gives another residual. The two residuals are shown in the next graph, and it is clear that the NP is the dominant factor, while the AO component is much smaller.

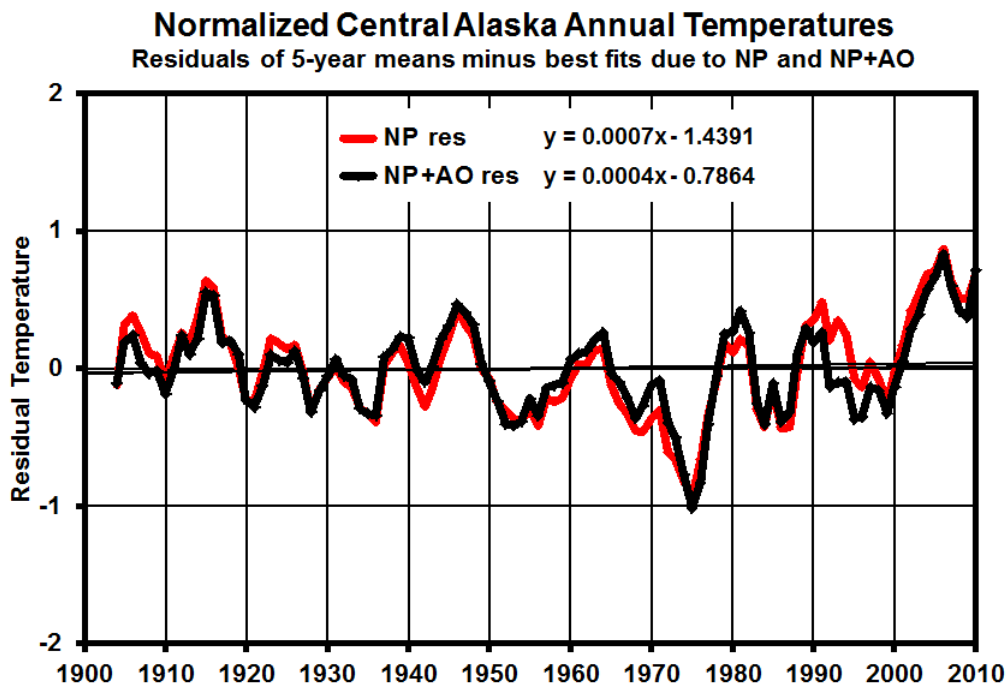


Figure 44. Residual temperature of five-year CAKN temperatures minus the NP component, and minus the NP + AO components.

Together, the NP and AO explain 66 percent of the total variance of five-year CAKN temperatures. They also explain nearly all of the observed trend over the past 110 years. The residual trend lines are on the above graph, and are quite small: less than 0.1 degree per century after removing the NP alone. After the NP and AO are removed, no other index explains more than 4 percent of the residual, or about 1 percent of the total variance. The correlation of Carbon Dioxide with the NP+AO residual is shown below, and shows that CO<sub>2</sub> explains 4.28 percent of the residual variance, or 1.4 percent of the total variance. The standard deviation of the five-year means is 0.56\*sigma (sigma is the standard deviation of annual normalized means, which is by definition 1.0). Sigma is also about 2.1 degrees F, so the standard deviation of five year means is about 1.2 degrees F.

R-squared is the percent of variance explained, and the variance is the standard deviation (StDev) squared. Thus, variance explained by any variable is R-squared times StDev squared. The square root of the explained variances, i.e. R times StDev, is the amplitude (standard deviation) of the signal explained by NP, CO<sub>2</sub>, or other independent variable. In this case, the CO<sub>2</sub> signal is SQRT(0.014) times 1.2F, or 0.17F.

Attempts were made to force a solution by using other indices, such as TSI, CO<sub>2</sub>, and AO as the initial variable. In all cases a large residual was so highly correlated with the NP that the NP ended up explaining most of the variance.

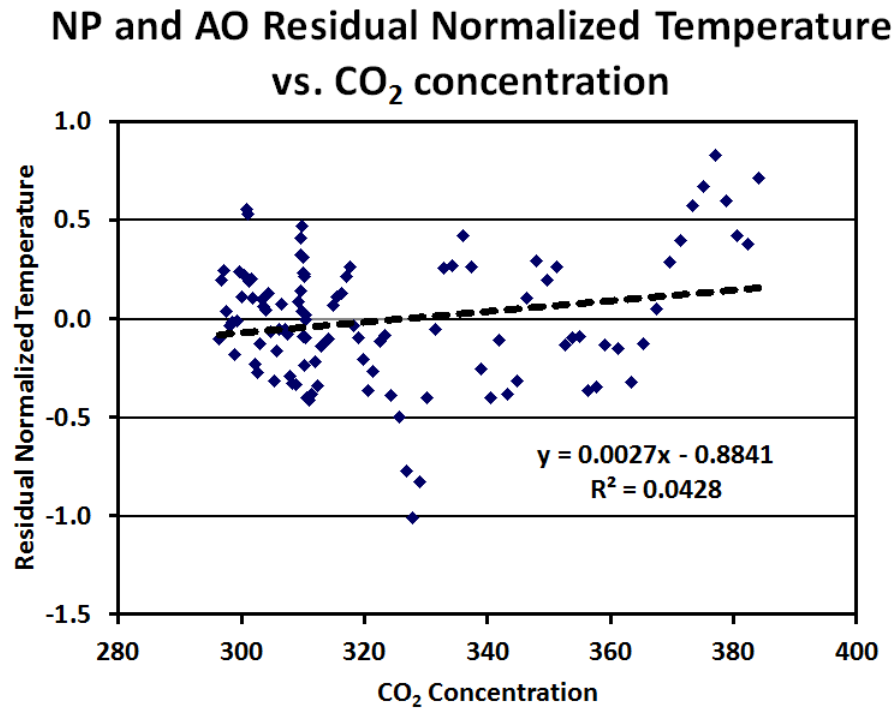


Figure 45. Correlation of CO<sub>2</sub> contributions with Residual temperature of five-year CAKN temperatures minus the NP + AO components.

The following eight maps show the individual station correlations, residuals, and residual correlations and variances using the same methodology that was used above for the CAKN regional mean. Overall the maps show that the strong correlations (NP) are fairly uniform across the region, while the weaker correlations are more randomly scattered (as for TSI and CO<sub>2</sub>) .

### CAKN region Long-term climate stations

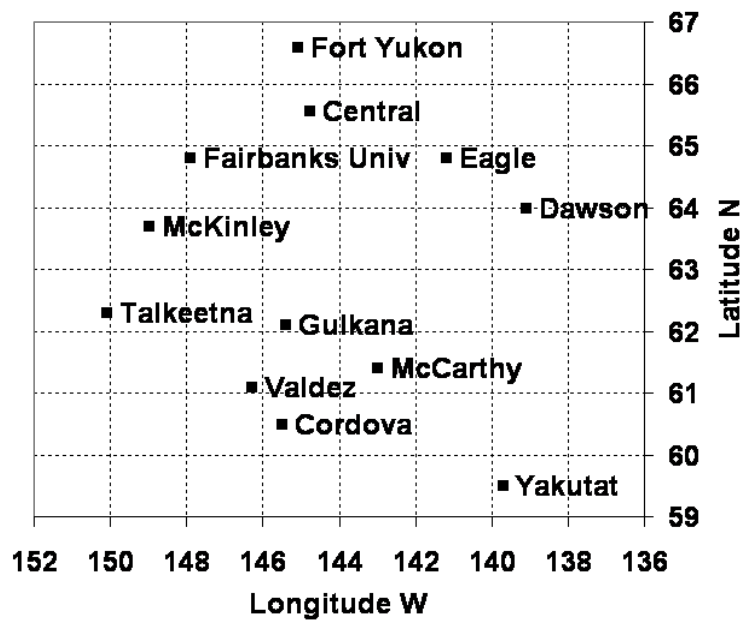


Figure 46. The map of the locations of the stations is repeated here.

### CAKN region Long-term climate stations Standard Deviation of 5-year mean Temperatures

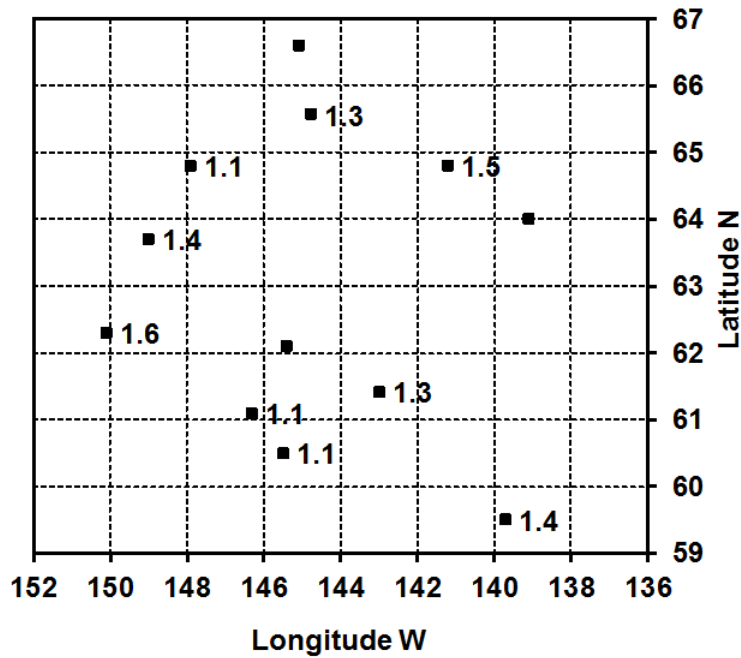


Figure 47. Standard deviation of five-year averages of Annual mean station temperatures.

**CAKN region Long-term climate stations**  
**Correlation of 5-year mean Temperatures with NP index**

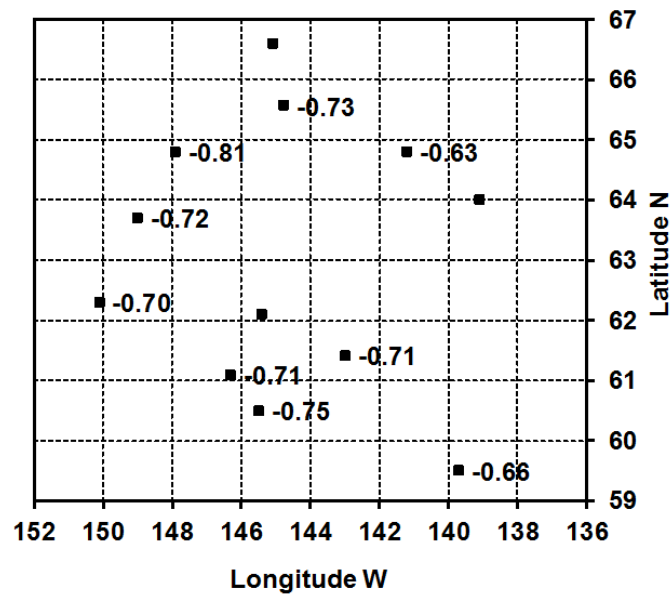


Figure 48. Correlation: Five-year average station temperatures vs. five-year mean North Pacific indices.

**CAKN region Long-term climate stations**  
**Variation of 5-year mean Temps correlated with NP**

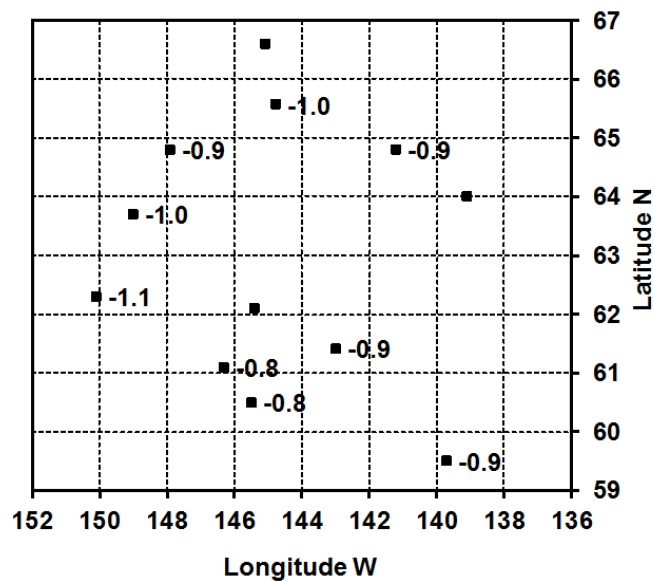


Figure 49. Variation of five-year mean station temperatures correlated with North Pacific index. Variation equals Correlation R times Standard Deviation.

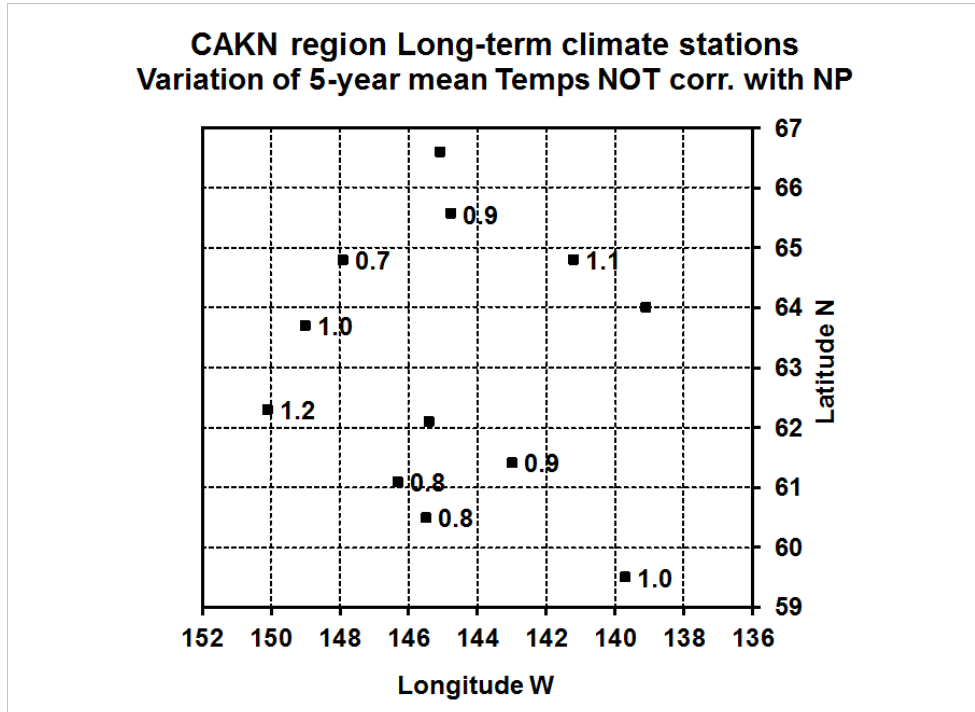


Figure 50.Amount of Variation of five-year mean station temperatures NOT correlated with North Pacific index.

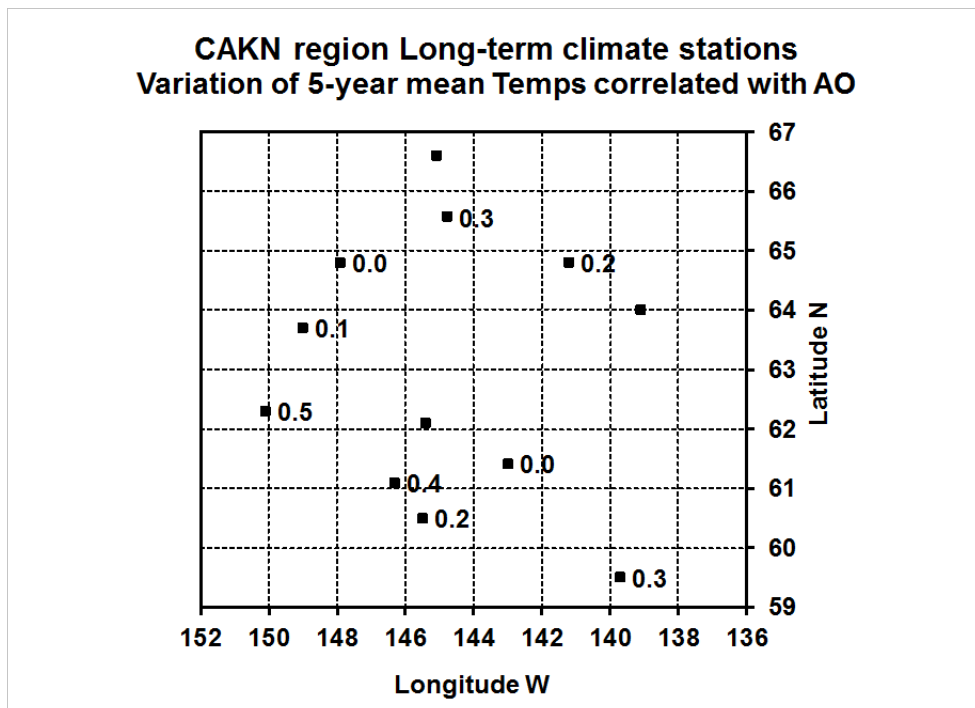


Figure 51. Amount of Variation of five-year mean station temperatures NOT correlated with North Pacific index that IS correlated with the Arctic Oscillation (AO) index.

**CAKN region Long-term climate stations**  
**Variation of 5-year mean Temps correlated with NAO**

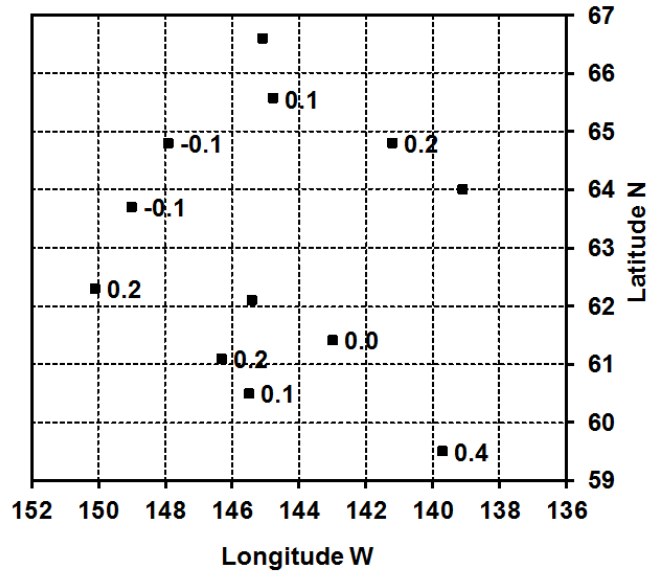


Figure 52. Amount of Variation of five-year mean station temperatures NOT correlated with North Pacific index that IS correlated with the North Atlantic Oscillation (NAO) index.

**CAKN region Long-term climate stations**  
**Variation of 5-year mean Temps correlated with AMO**

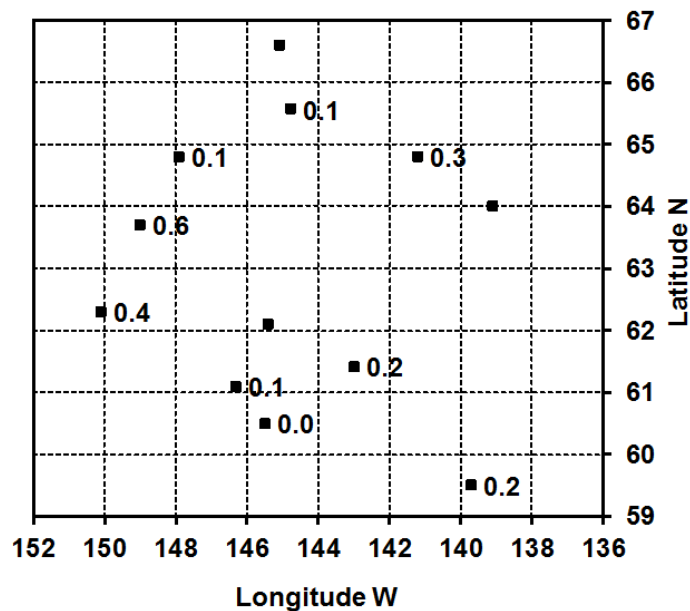


Figure 53. Amount of Variation of five-year mean station temperatures NOT correlated with North Pacific index that IS correlated with the Atlantic Multidecadal Oscillation (AMO) index.

**CAKN region Long-term climate stations**  
**Variation of 5-year mean Temps correlated with TSI**

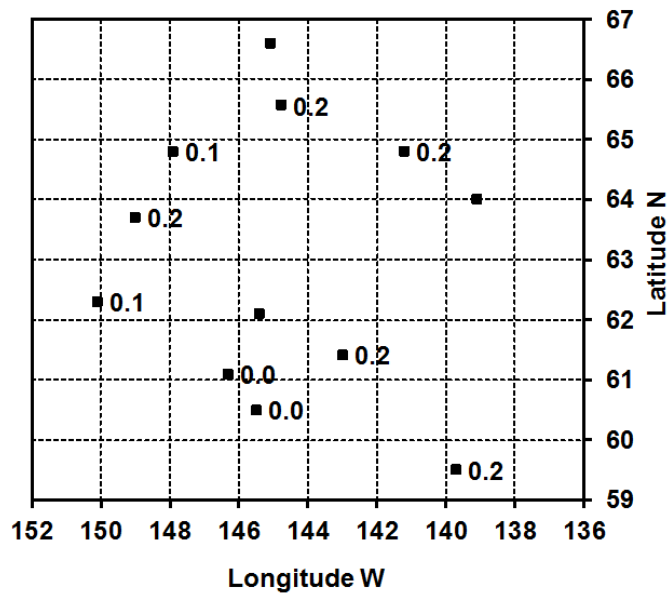


Figure 54. Amount of Variation of five-year mean station temperatures NOT correlated with North Pacific index that IS correlated with the Total Solar Irradiance (TSI). The average of the nine stations is 0.1F.

**CAKN region Long-term climate stations**  
**Variation of 5-year mean Temps correlated with CO<sub>2</sub>**

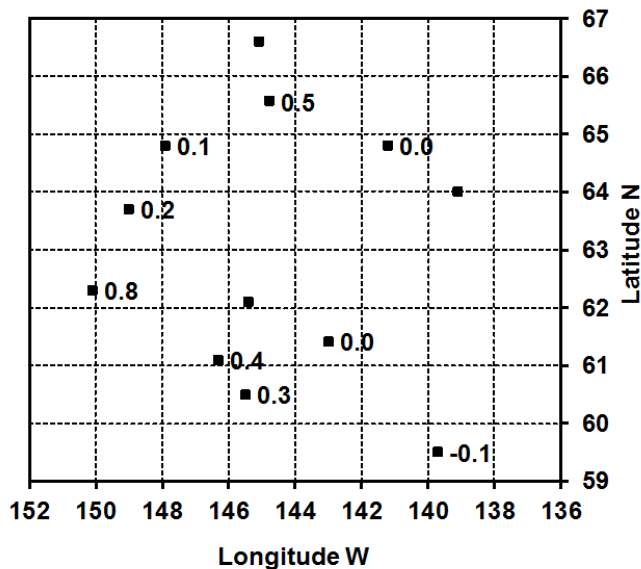


Figure 55. Amount of Variation of five-year mean station temperatures NOT correlated with North Pacific index that IS correlated with Carbon Dioxide (CO<sub>2</sub>). The average of the nine stations is +0.2F.

In general, the correlations of Annual temperature with the PDO and NP are dominated by the winter correlations, and these correlations tend to be greater in the southern part of the region – i.e., for those stations closer to the Pacific Ocean. Conversely, the correlation of the annual temperature with Total Solar Irradiance is somewhat greater for the inland stations. The correlation of annual station temperature with Arctic average annual temperature is fairly uniform across the region.

### CAKN Temperatures and the North Pacific Mode and Pacific Decadal Oscillation

The map below summarizes the effect of the NP on the climate of central Alaska.

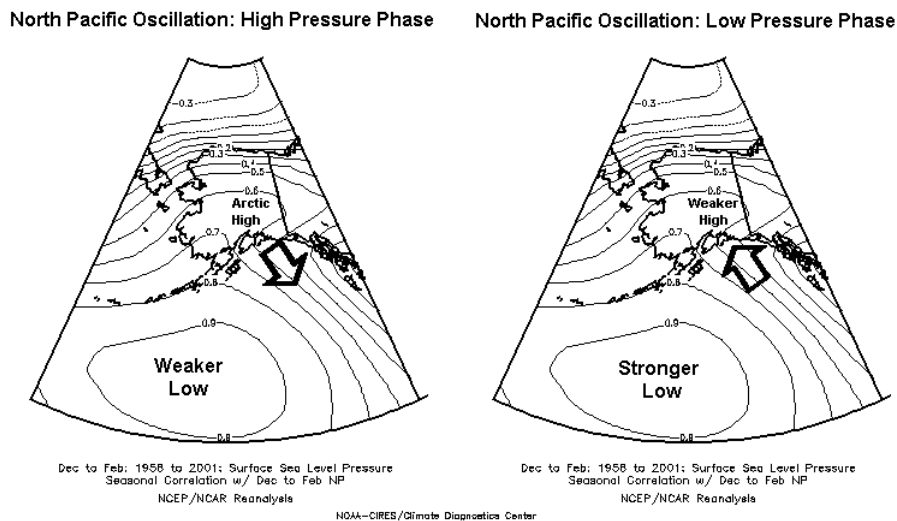


Figure 56. Surface pressure pattern characteristic of positive and negative values of the North Pacific index, showing offshore flow from the Arctic High over interior Alaska during the positive phase (left) and onshore flow from the Gulf of Alaska Low during the negative phase.

The time series of NP and PDO indices reveal that shifts from predominately positive to predominately negative modes (or vice-versa) occurred around 1923, 1946, and 1977. After each shift the indices persisted in the new mode for two or three decades before undergoing another shift; this multidecadal time scale led to the inclusion of “Decadal” in the name of the Pacific Decadal Oscillation. For example, see: Decadal Variability of the Aleutian Low and Its Relation to High-Latitude Circulation (James E. Overland, Jennifer Miletta Adams and Nicholas A. Bond), 1999.

The shifts of the NP/PDO regimes can be treated as step function changes, as in the next three figures of nine-station average temperatures. Superimposed on the annual (or winter and summer) values are the averages for high NP/low PDO index (weak Aleutian Low) years 1900-1922 and 1947-1976, and the low NP/high PDO index (strong Aleutian Low) years 1923-1946 and 1977-2004.

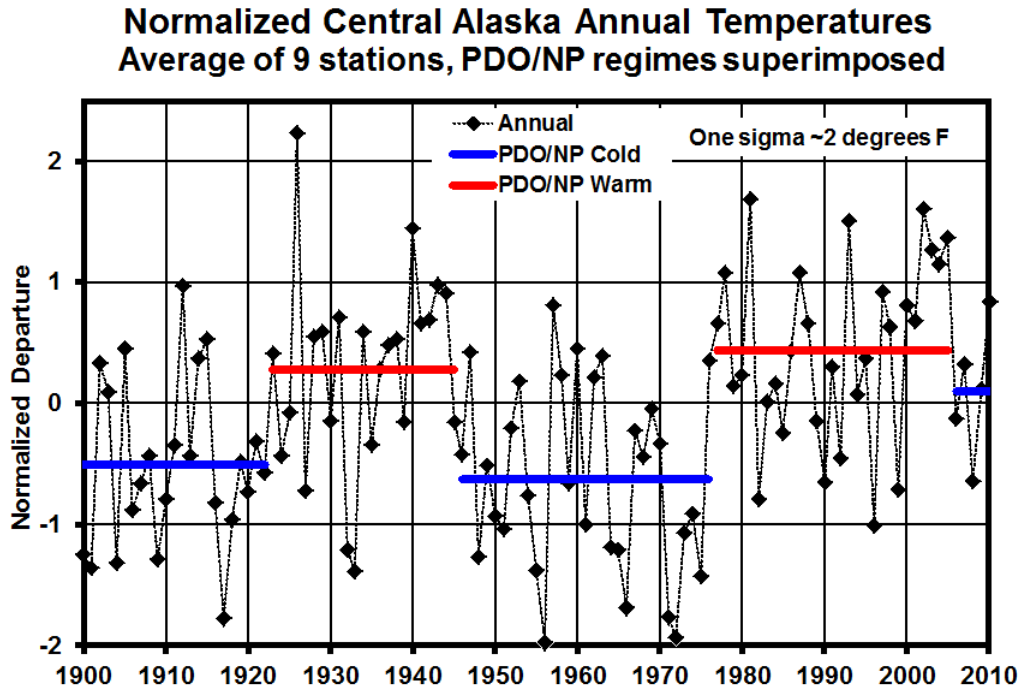


Figure 57. 105 year record of regional Annual Average Temperature with PDO regimes superimposed.

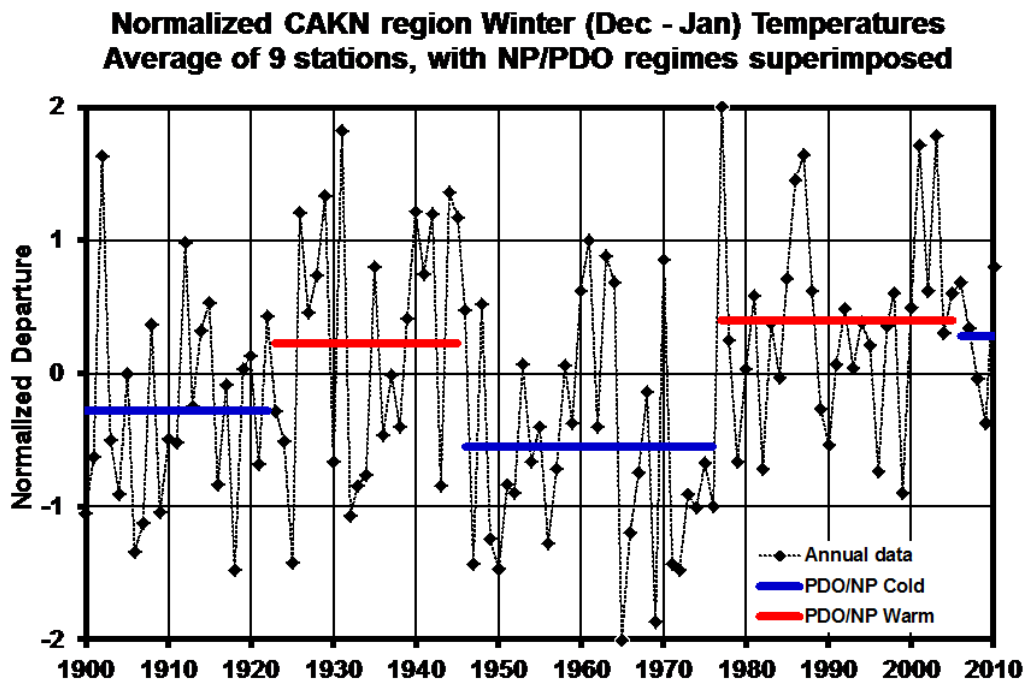


Figure 58. 105 year record of regional Winter Average Temperature with PDO regimes superimposed.

Average annual and winter temperature shift about 1 standard deviation (about 2 degrees F) between opposing NP/PDO regimes, which means the baseline climate of the opposing regimes is significantly different. However, this does not preclude a “cold” regime year or winter from

being warmer than a “warm” regime year or winter. Summer temperatures are virtually unaffected by the NP/PDO.

The next three maps show the spatial distribution of the changes in mean annual temperatures associated with changes in NP/PDO regimes that occurred around 1946 and 1977. The third of these maps is the average magnitude of the change resulting from the 1946 “cooling” and the 1923 and 1977 “warmings”.

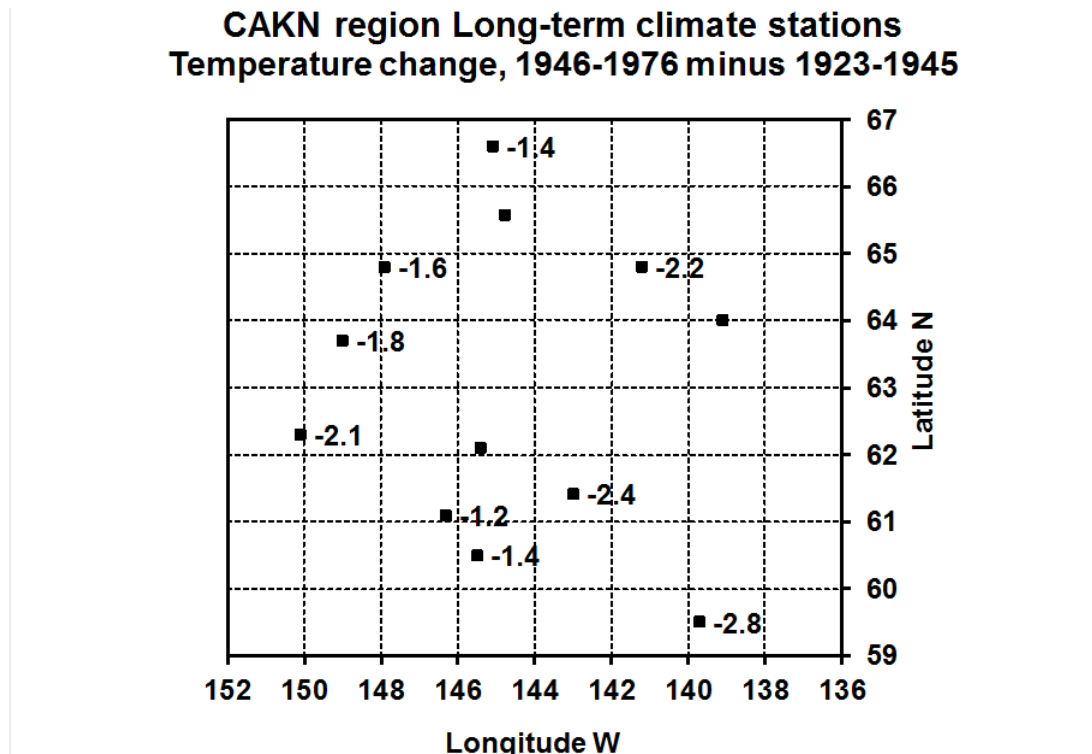


Figure 59. Average Annual Temperature change (degrees F) associated with the PDO shift of 1946.

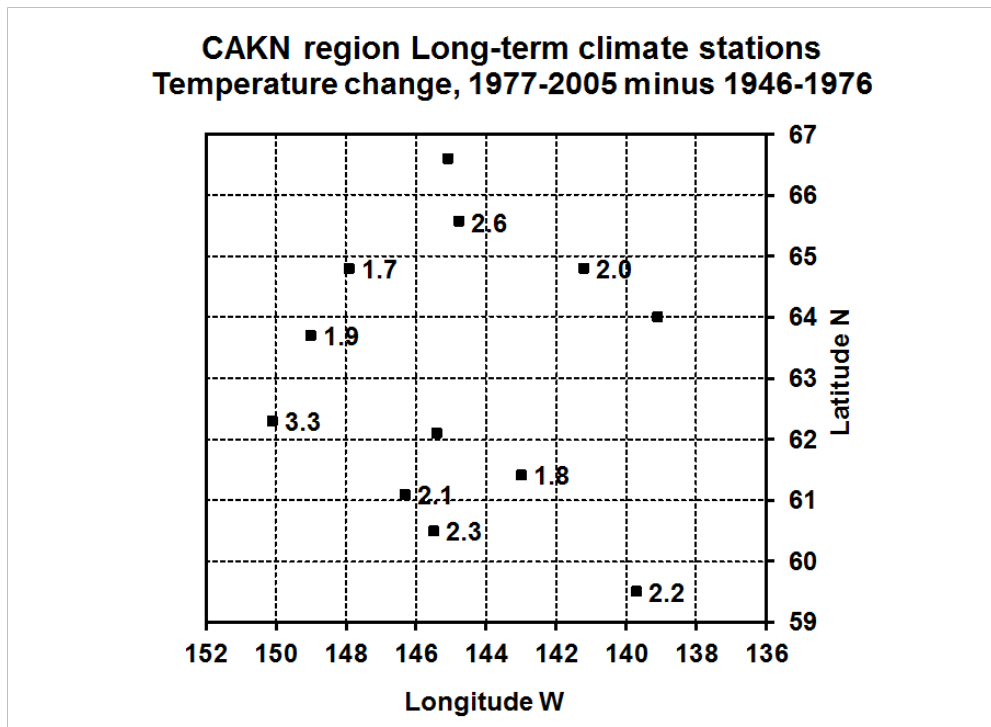


Figure 60. Annual Temperature change (degrees F) associated with the PDO regime shift of 1977.

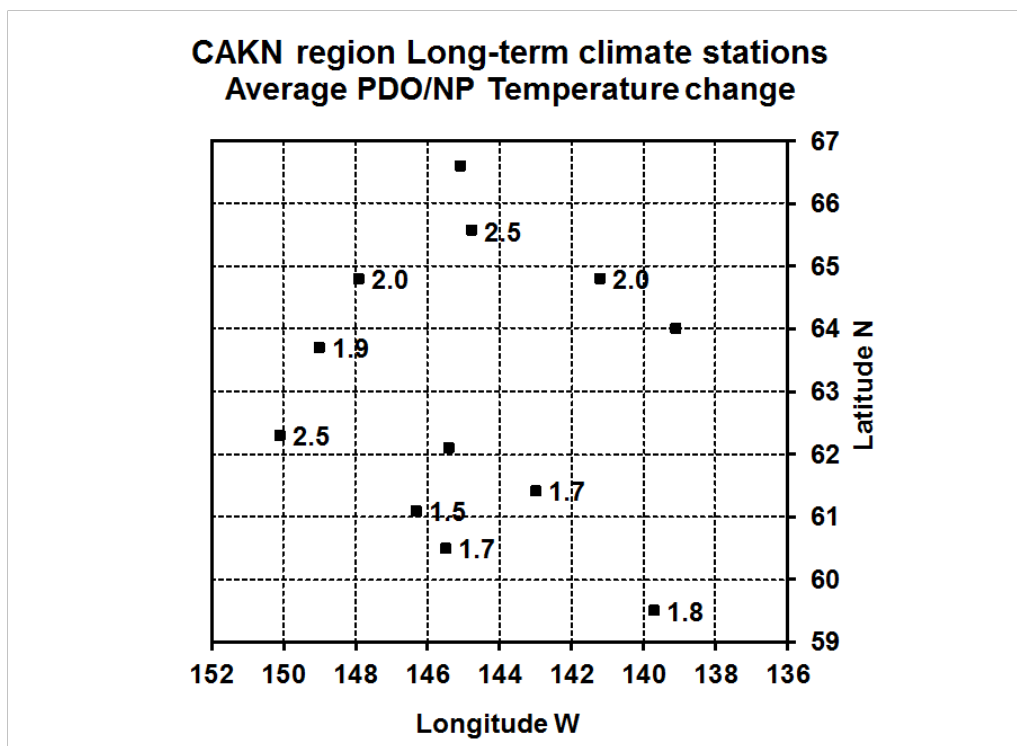


Figure 61. Average magnitude (degrees F) of the three PDO regime shifts of 1923, 1946, and 1977.

## Century Scale Variations of the PDO

Instrumental records of the climate of central Alaska began in 1899, as did direct measurements of circulation indices in the region. It is possible to extend climate records to earlier years by examining proxy data, such as tree rings. D'Arrigo et al. examined tree ring records from Alaska and Oregon to reconstruct the North Pacific (NP) index back to 1600 and found the following list of NP/PDO phase shifts.

Table 5. NP/PDO regime shifts since 1600

| Regime shift    | 1627 | 1695 | 1762 | 1806 | 1833 | 1853 | 1922 | 1947 | 1976 | Average duration |
|-----------------|------|------|------|------|------|------|------|------|------|------------------|
| Duration, years |      | 68   | 67   | 44   | 27   | 20   | 69   | 25   | 29   | 44               |

The current low NP (positive PDO, warm Alaska) regime began in 1977, and if it persists for 44 years (the average duration of a regime), Alaska will shift to colder conditions around 2021. However, NP regime durations have ranged from 20 to 69 years, with a bimodal distribution centered around 28 years and 68 years. A 30-year cycle would have a change occurring around 2006.

## NP/PDO Shift of 2006?

There is some evidence that the warm NP/PDO regime that began in 1977 may have actually ended around 2006. However, since it is a Decadal oscillation, one cannot be sure until a decade has passed and the resulting statistics show that the new phase has been in effect.

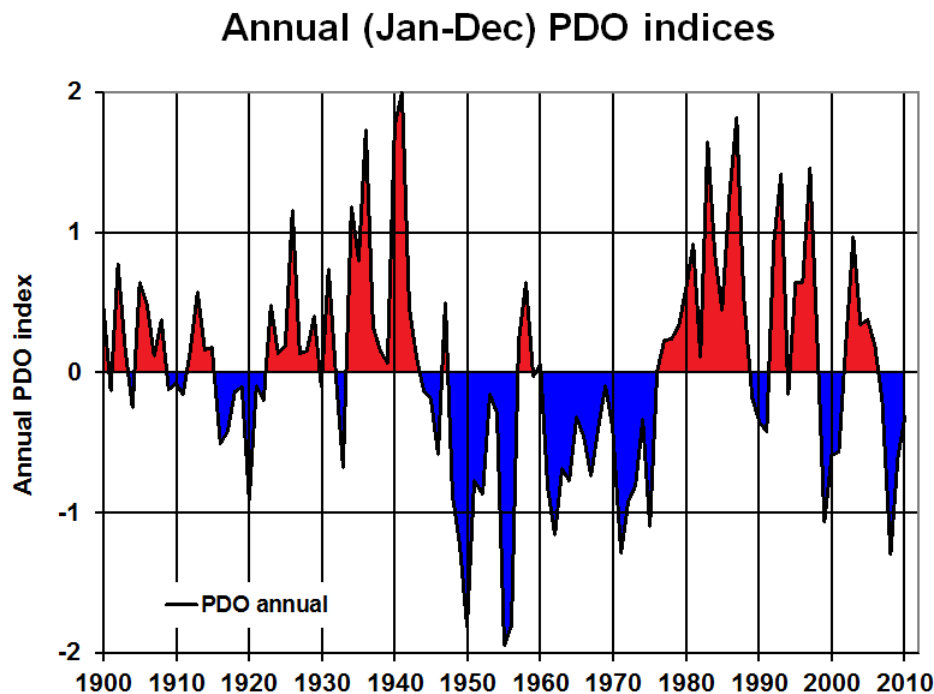


Figure 62. Annual PDO indices, 1900-2010. Annual indices have remained below zero for four continuous years, indicating that a shift to negative (cold) phase occurred around 2006.

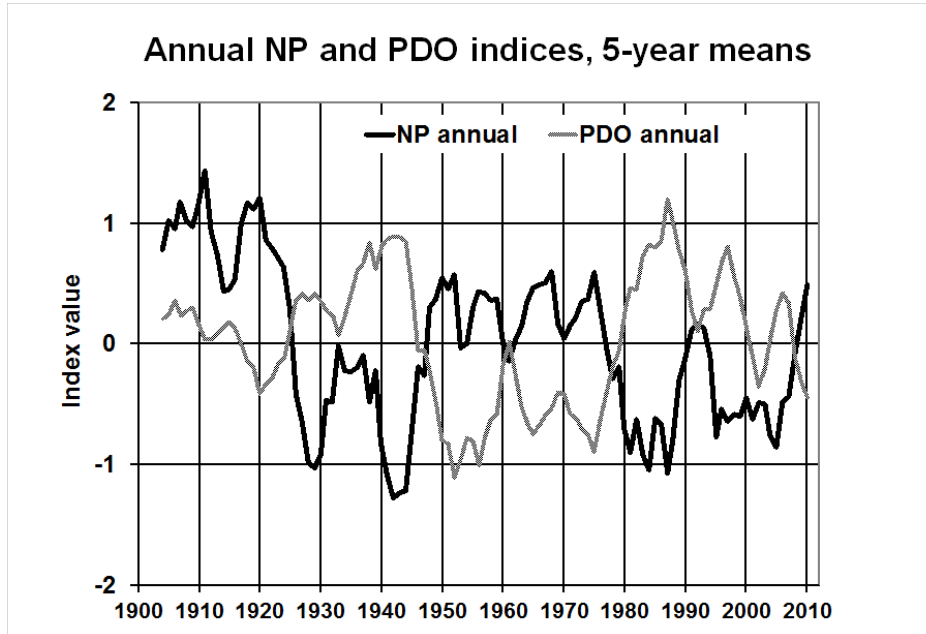


Figure 63. Five-year means of Annual NP and PDO indices, 1900-2010. Further evidence of a PDO/NP phase shift is the reversal of the signs of both indices (from warm to cold) in 2008 for the first time since 1978.

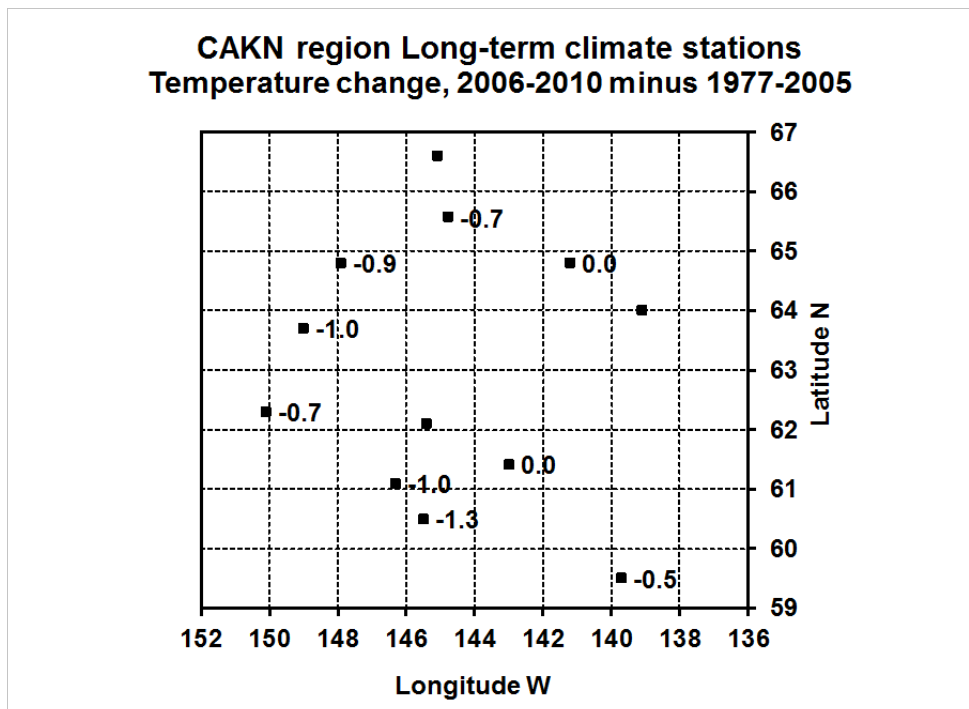


Figure 64. Annual Temperature change associated with the possible PDO regime shift of 2006. The cooling is only about half as large as that of 1946, but is well distributed among the different locations.

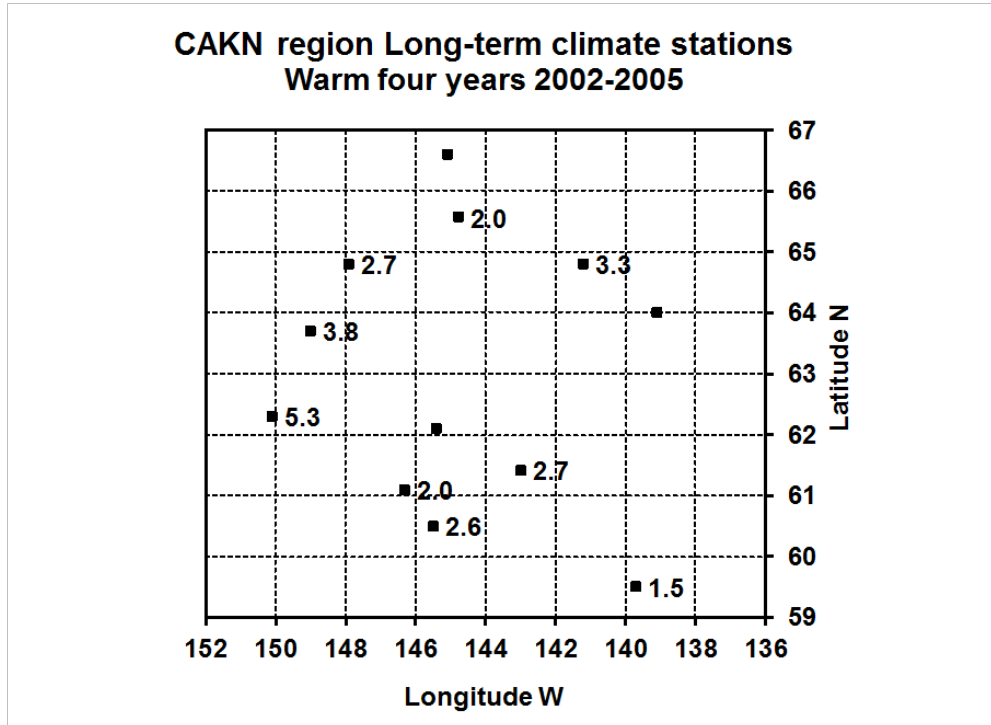


Figure 65. Average Annual Temperature departure during the four warm years, 2002-2005. These four years preceded a cooling.

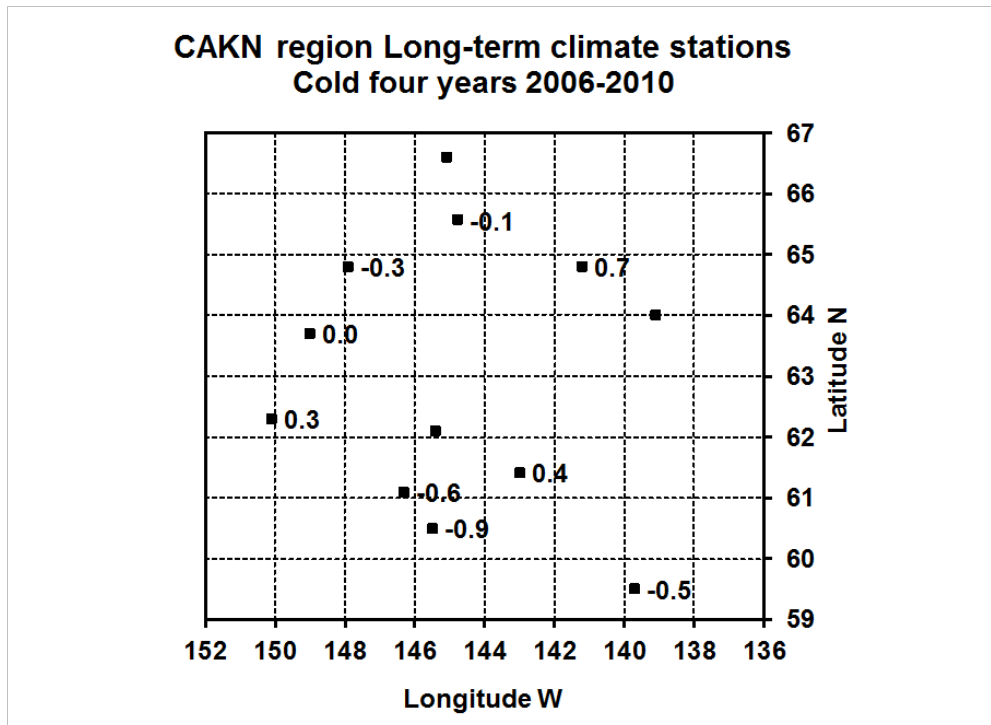


Figure 66. Average Annual Temperature departure during the four cold years, 2006-2010. There was a sudden drop in annual mean temperatures.

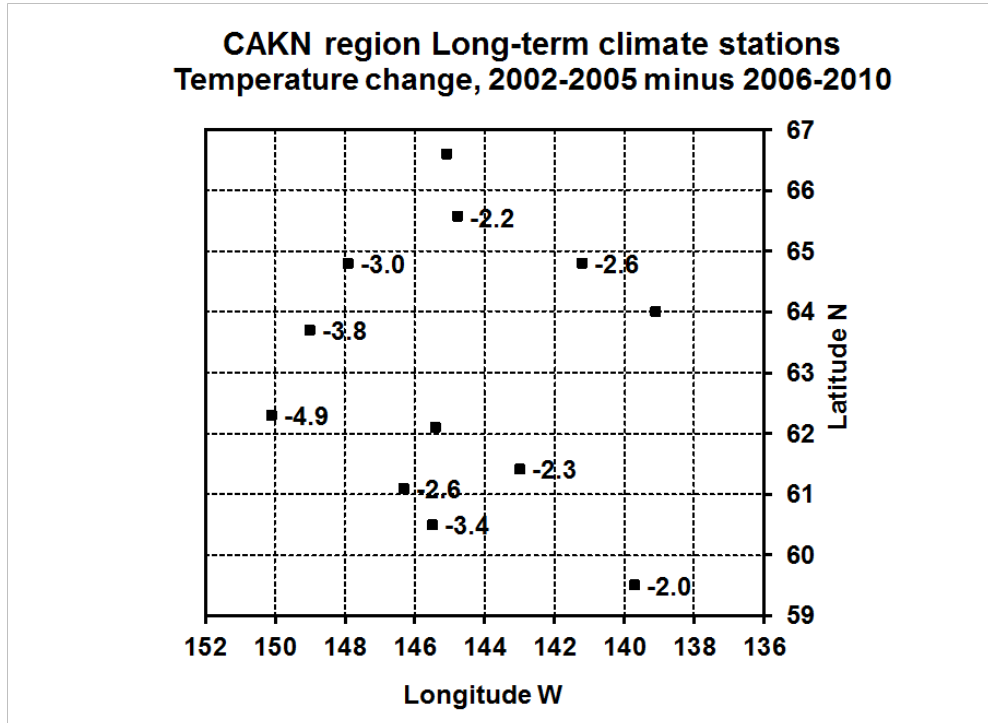


Figure 67. Stepwise temperature change, 2006-2010 minus 2002-2005. Although this stepwise cooling took place on a shorter time scale than the NP/PDO, it could be a “close-up” of a longer-term shift.

### CAKN Summer Temperatures

Unlike winter temperatures, which have a well- defined and physically plausible correlation with the NP/PDO, the search for cause and effect related to summer temperature is more elusive.

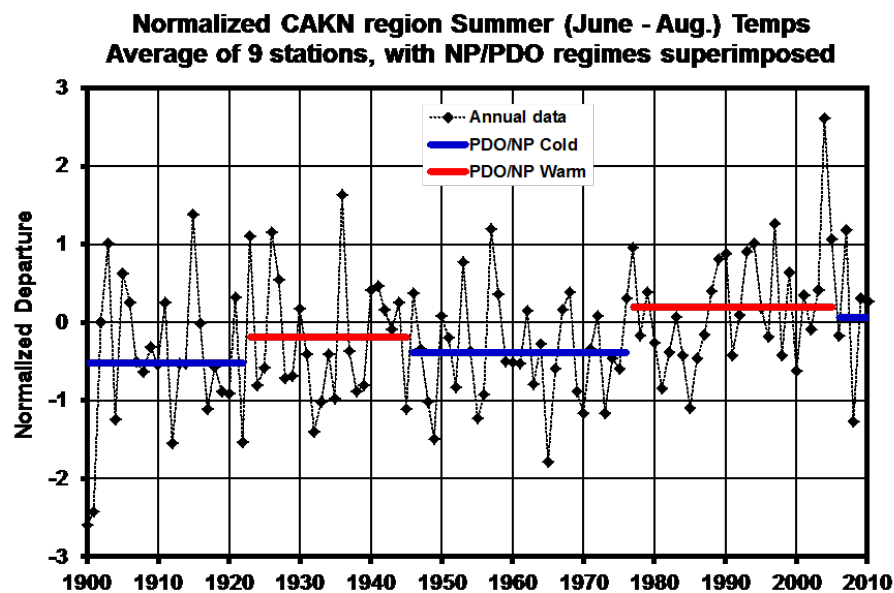


Figure 68. 105 year record of regional Summer Average Temperature with PDO regimes superimposed.

### CAKN region Long-term climate stations Standard Deviation of 5-year Summer Temperatures

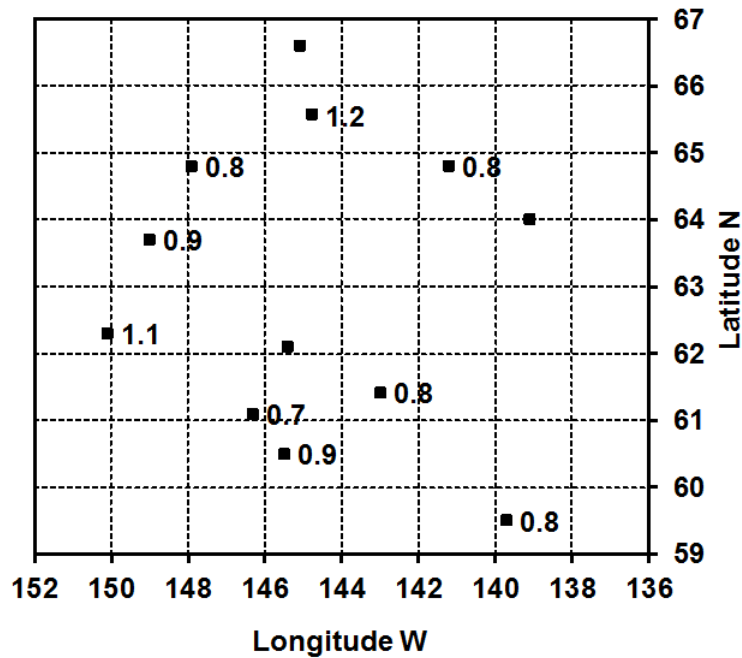


Figure 69. Standard deviation of five-year averages of Summer mean station temperatures (degrees F).

As seen below, summer correlations with the NP/PDO are not very large, and we will see that other correlations are also small. Following are maps of individual stations “explained variances”, i.e.,  $R$  times StDev, for some of the leading suspects for climate change.

**CAKN region Long-term climate stations**  
**Variation of 5-year Summer Temps correlated with NP**

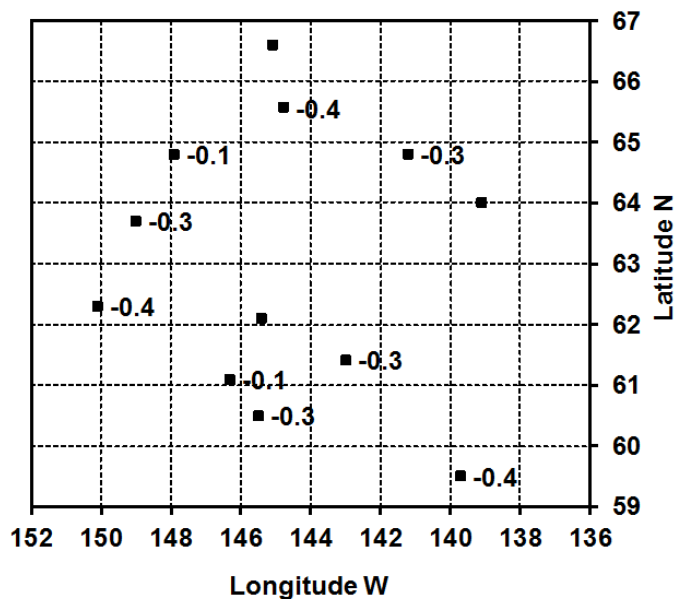


Figure 70. Variation of five-year Summer temperatures (degrees F) correlated with North Pacific index. Variation equals Correlation R times Standard Deviation.

**CAKN region Long-term climate stations**  
**Variation of 5-year Summer Temps correlated with AO**

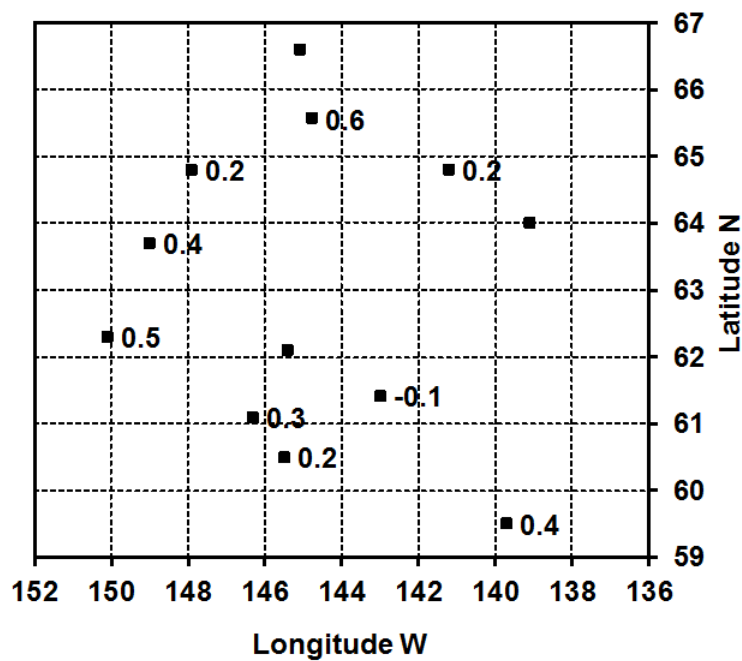


Figure 71. Amount of Variation of five-year Summer temperatures (degrees F) correlated with the Arctic Oscillation (AO) index.

### CAKN region Long-term climate stations Variation of 5-year Summer Temps correlated with CO<sub>2</sub>

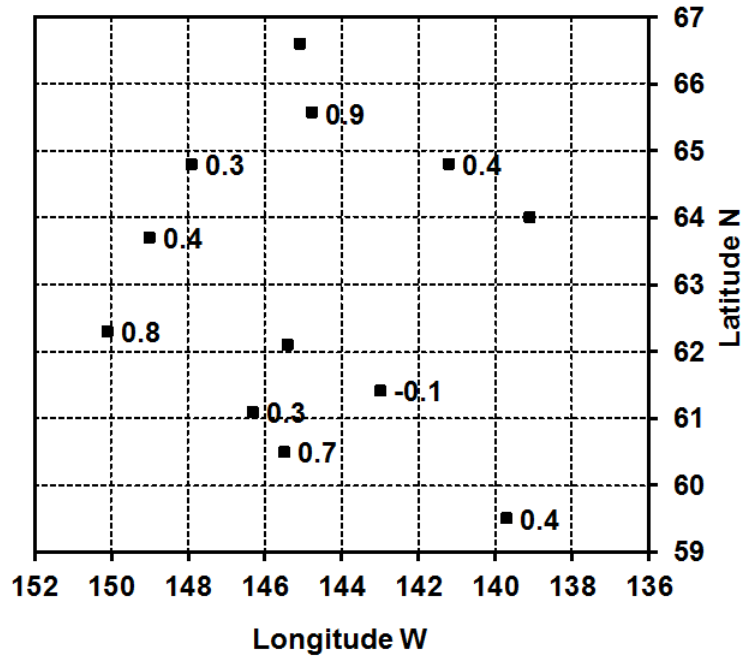


Figure 72. Amount of Variation of five-year mean station temperatures (degrees F) correlated with Carbon Dioxide (CO<sub>2</sub>). The average is 0.5 degrees F.

Although correlations of summer temperatures with the AO and CO<sub>2</sub> are statistically significant for the regional average, they vary greatly among the nine stations, and any true cause and effect due to the AO and CO<sub>2</sub> on summer temperatures is questionable.

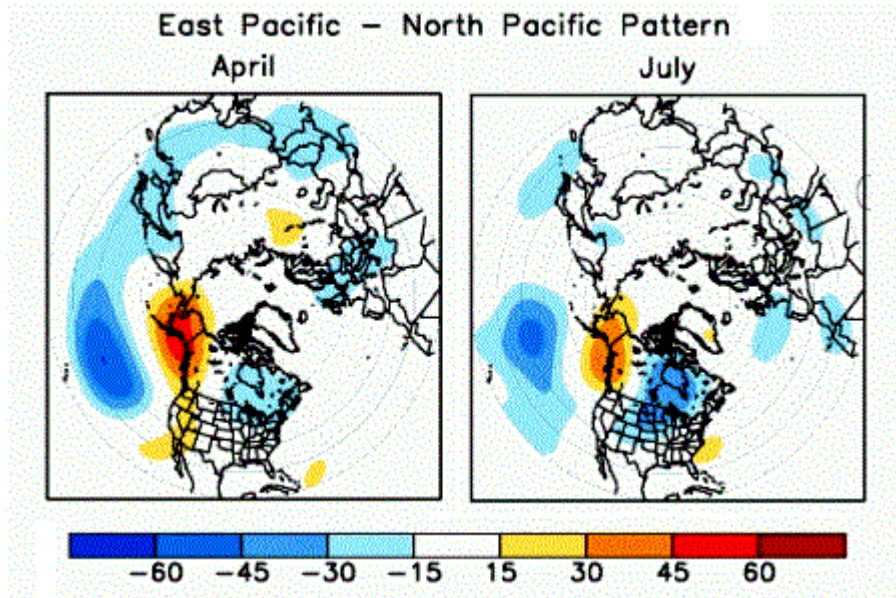


Figure 73. Another index – the East Pacific – North Pacific (EP) pattern. It features anomalous low pressure north of Hawaii, and high pressure over Alaska. This pattern resembles the “Omega Block” in the atmosphere, with nearly stationary high-latitude Highs and low-latitude Lows that cause persistent local weather.

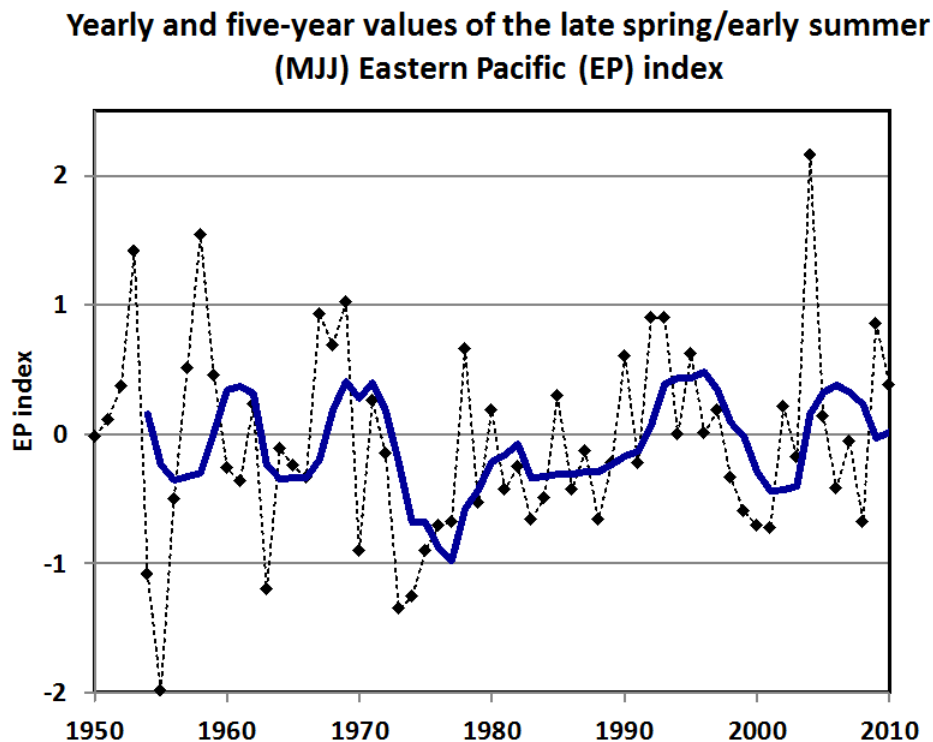


Figure 74. Late spring/early summer (May-June-July) values of the EP index. There is no trend, but it was exceptionally low in 1955 and high in 2004.

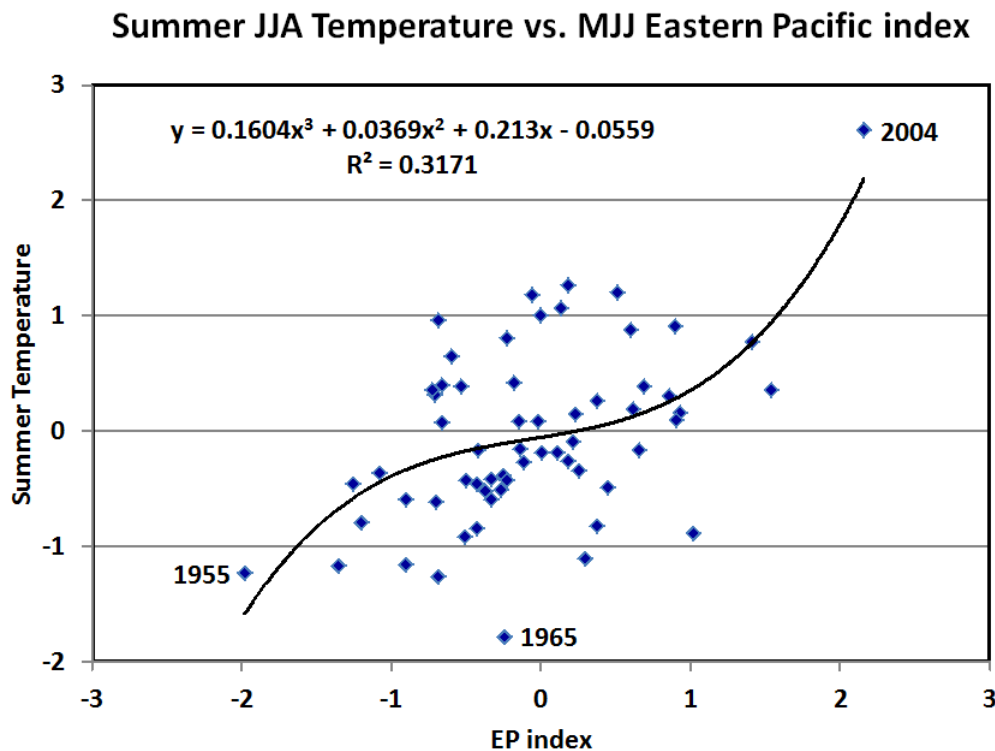


Figure 75. Correlation of Summer CAKN temperatures with the late spring/early summer (May-June-July) values of the EP index. The correlation is dominated by two outliers, the warm summer and high index of 2004, and the cool summer and low index of 1955.

The two end points of the regression line are responsible for most of the correlation. Removing 1955 and 2004 from the sample trims the R-squared from 0.32 to 0.14. Thus, the extreme EP pattern responsible for the anomalous summer of 2004 should be thought of not as a climate trend or other large-scale forcing, but rather as an unusual and almost freak combination of planetary scale atmospheric waves leading to a very high amplitude ridge over Alaska – an atmospheric equivalent to a rogue wave at sea. A similar pattern over Europe-Asia caused the extremely hot Russian summer of 2010.

There is, however, one event that may have directly impacted the summer temperatures across the CAKN region. At the two stations with the longest record, Eagle and Dawson, the summer of 1912 was the coldest on record (although it was not the coldest averaged across the region, due to the use of normalized averages). That same year saw the largest volcanic eruption of the 20<sup>th</sup> century, that of Katmai in June of 1912. Katmai was also the only large high latitude eruption of the century, since the other major volcanic events all occurred at low latitudes (in Java, Sumatra, Mexico, and the Philippines). Therefore, the volcanic aerosols that summer were confined to high latitudes. It is likely, but not statistically provable with a sample of one, that the low temperatures that summer were due to the volcano. The next figure shows the temperature departures (degrees F) for the summer at the four stations then operating. This figure is corrected from that appearing in the original report.

The high-latitude eruptions in Alaska, Kamchatka, and Iceland in recent years have been of much smaller magnitude than Katmai, and have had no discernible effect on the Alaskan climate.

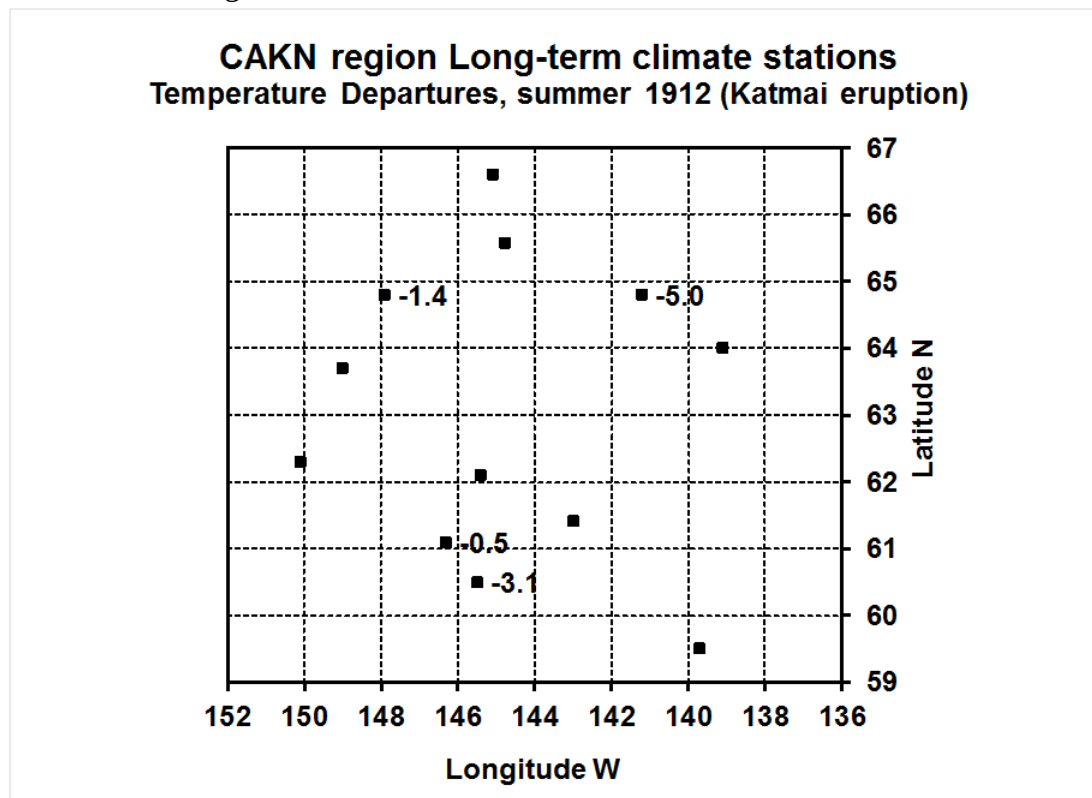


Figure 76. CAKN Temperature departures, Cold summer of 1912, following the eruption of Katmai.

### Trends in Annual Temperatures

The simplest form of time series analysis is to apply a linear trend to a time series, thereby allowing one to make some statement about the past behavior of the statistic and to make a crude forecast of the future behavior. In the case of temperatures in the CAKN region, this approach can be misleading and produce quite flawed interpretations. This is due to the quasi-periodical nature of the temperatures in the region, which is in turn due to the fluctuations of the Aleutian Low described by the NP and PDO indices. To illustrate the problematic nature of linear trends, the following figure shows a century of CAKN normalized temperatures with six trend lines added. One trend line is for the entire period of record, while the others start and end at the beginning and/or end of NP/PDO phases. This emphasizes the effect that the timing of NP/PDO cycles can have on trends. The slopes of the trends range from +3.3 degrees F per century to -3.3 degrees F per century. The rate of warming during the first 40 years of the 20<sup>th</sup> century was six time greater than the warming rate since 1977. Clearly, one's interpretation of climate change in Alaska depends greatly on the period of time being looked at.

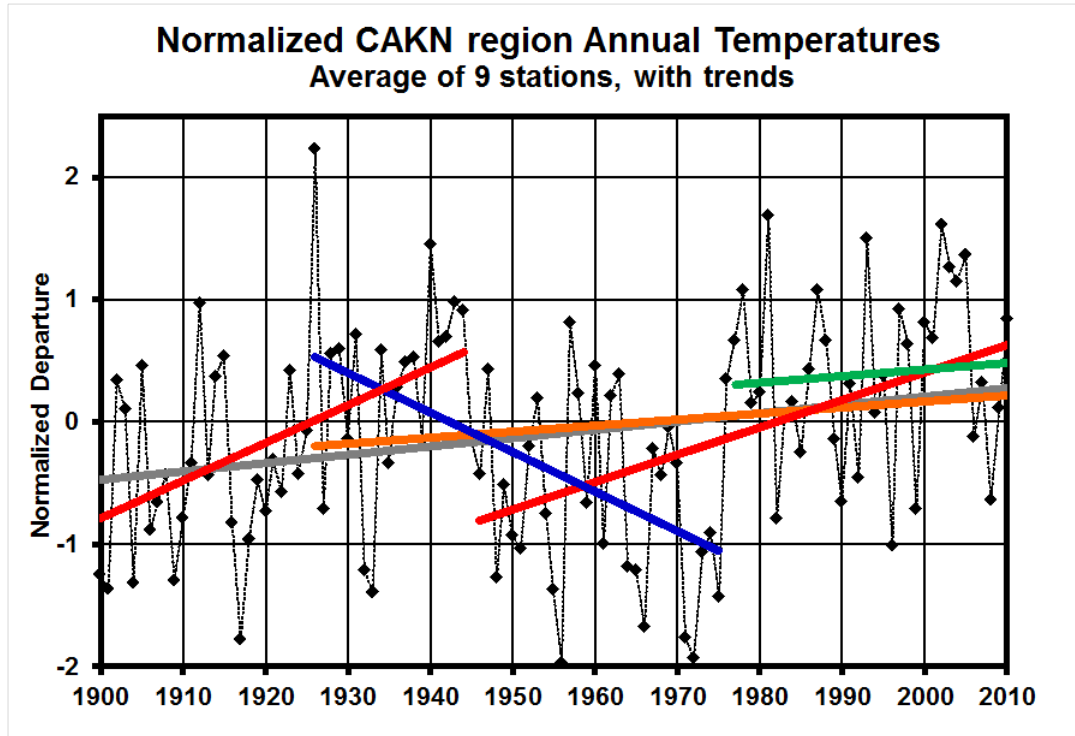


Figure 77. Normalized CAKN annual Temperature, 1900-2010, with six different trend lines.

The most realistic trends are likely those that begin and end during the same phase of the NP/PDO, and thus do not capture half-cycle pseudo trends. The longest such period is 1923 to present. Although the NP/PDO may have shifted in 2006, the five years of recent “cool phase” data won’t alter the trend much.

Below is a comparison of the 1923-2008 trends from this study compared with those from two sources of global temperature compilations. The end year of 2008 was determined by data availability. The two sources are the Global Historical Climate Network (GHCN) and the NASA Goddard Institute of Space Studies (GISS). Both provide data on 2 and/or 5 degree grids. For GHCN, the grid area 60 to 65 North, 140 to 155 West was chosen; for NASA GISS, the grid point centered on 63 North, 145 West was selected. These are the closest approximations to the centroid of the nine CAKN stations, 63.0 North, 144.8 West. The trends computed from the three time series are:

|               |                |
|---------------|----------------|
| CAKN stations | 0.46 C/century |
| NASA GISTEMP  | 0.72 C/century |
| GHCN          | 0.63 C/century |

The GHCN trends are much lower than the values reported in the previous report, and are now only slightly higher than the CAKN station trends. The NASA GISS trend is 0.25 C/century greater than the CAKN trend.

In the next section of this study, it will be shown that the temperature history of the region is better described as quasi-cyclical, and that trend analyses do not accurately describe the long-term climate history of the region.

#### NOTES:

The Global Historical Climate Network (GHCN) data set is produced by the National Climatic Data Center, Arizona State University, and the Carbon Dioxide Information Analysis Center, and is composed of annual temperature data at a grid-box resolution of 5° latitude by 5° longitude.

Peterson, T.C. and Vose, R.S. 1997. An overview of the Global Historical Climatology Network temperature data base. *Bulletin of the American Meteorological Society* **78**: 2837-2849.

The NASA GISS data set is available at <http://data.giss.nasa.gov/work/gistemp>

Another approach to assessing trends in a NP/PDO dominated climate is to compare two successive warm phases (or cold phases) of the NP/PDO. This is equivalent to measuring sea level changes from successive wave crests. Below is the difference between the “warm” episodes of 1977-2005 minus 1925-1946. Across the region, the net changes range from -0.6 F to +1.2 F. Thus, the “warm” period 1977-2005 was slightly warmer (about +0.3 degrees F), than the previous “warm” period 1925-1946, although three of the nine stations were cooler. An interpretation of this would be that over the past century, the variability of the annual and winter temperatures of southern and central Alaska has been to a large extent quasi-periodic, rather than dominated by trends.

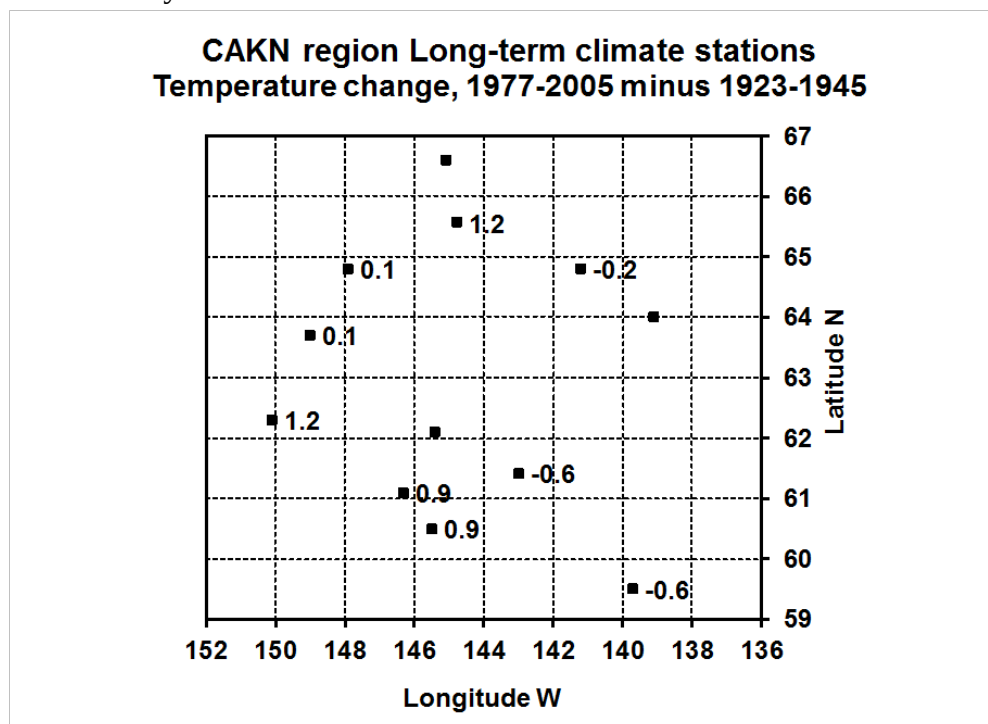


Figure 78. Average Annual Temperature difference between the warm PDO regimes of 1923-45 and 1977-2005. This is an indicator of climate change on times scales greater than the multi-decadal PDO.

A third approach to finding a trend is to remove the dominant NP/PDO cycle and test the residual. Earlier in this report it was shown that the residual trend after removing the NP was 0.07 degrees F per century, and 0.04 degrees F/century after removing the NP and AO. This approach is applied to the individual long-term stations in the next map. Individual station trends range from +0.6 degrees F per century to -0.3 degrees F per century, with an average of +0.1 degrees F per century.

In summary, three methods of trend seeking have revealed CAKN regional warming rates of 0.1, 0.3, or 0.8 degrees F per century. Earlier in the report a CO<sub>2</sub> signal of 0.2 degrees F was squeezed out of the data. Superimposed on this is the much larger PDO/NP signal.

**CAKN region Long-term climate stations  
88-year Trend of annual temperatures after removal of  
NP component.**

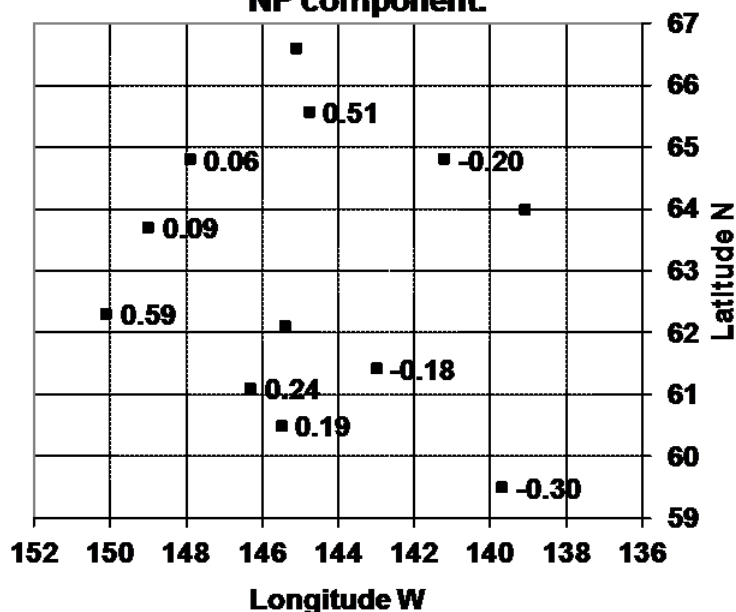


Figure 79. Residual trend at 9 CAKN stations after removal of the NPO/PDO signal at each location.

### Climate Models

There is no shortage of climate models attempting to make a forecast (or at least a projection) of Alaska's future climate. Perhaps the grandest compendium of such models is in "Climate Change 2007, the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change", or, simply, IPCC AR4. Below are three of the 22 model results shown in IPCC AR4. The "MEAN " panel is the average of the other 21 model forecasts of the warming of North America by 2100 due to increased carbon dioxide in the atmosphere (and resulting feedbacks). All 21 models predict warming for Alaska, with the CAKN regional temperature rising by 2 to 7 degrees C. The MEAN forecast for central Alaska is +3.5 to 4 degrees C.

## Annual Mean Surface Air Temp Response (°C)

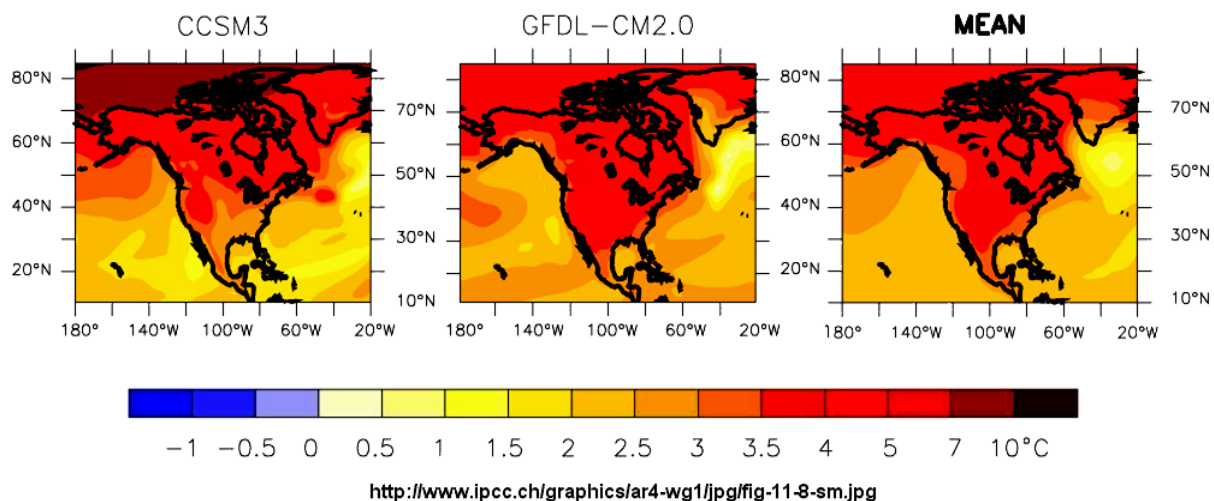


Figure 80. Three forecasts of Annual Mean surface temperature for North America, from IPCC AR4.

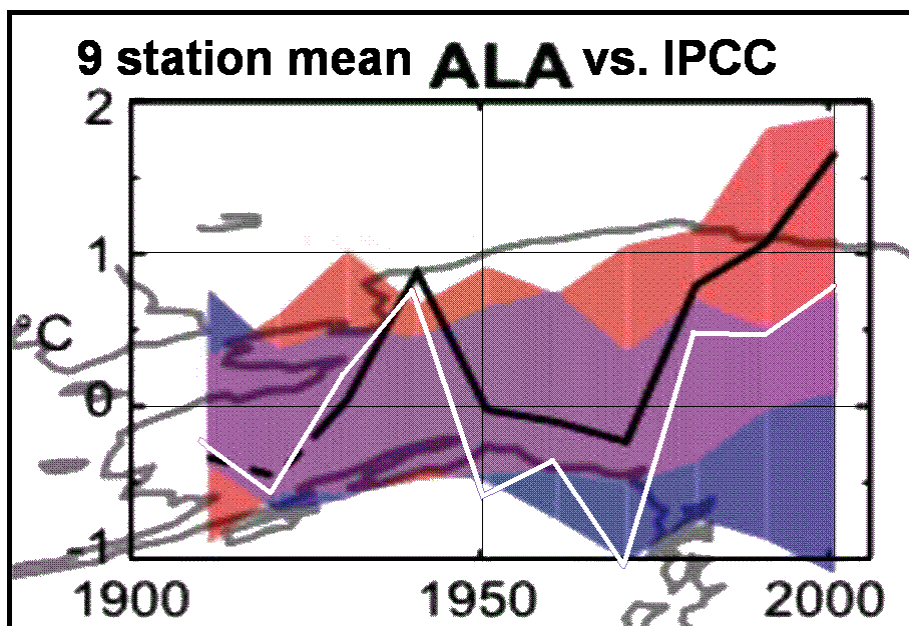


Figure 81. IPCC AR4 fig-9-12. The figure shows post-forecasts of Alaska's annual mean temperature from 1905 to 2005 using models including "natural forcing" only and natural forcing plus anthropogenic greenhouse gases. Superimposed is IPCC's analyzed temperatures for Alaska (black line). Ten-year averages of CANK temperatures from this report have been added.

Figure AR4-9-12 shows that the enhanced warming due to greenhouse gases began around 1950, and should already amount to about 1 degree C, according to the models. Since the figure AR4-9-12 is difficult to read in black-and-white, numbers have been read off the figure to produce Figures 82 and 83.

In the next chart the IPCC temperatures run increasing higher than the CAKN temperatures at a rate of +0.11 degrees C per decade, or 1.1 degrees C per century. Thus, by 2005 the IPCC records over 1 degree C of warming that is not evident in the CAKN record. Reasons for the difference could include:

- Inclusion of data from areas of Alaska outside the CAKN, and perhaps fewer stations inside the CAKN;
- Inclusion of urban stations with artificial warming; and
- Application of “corrections” and adjustments to raw data.

The second chart compares the model “forecast” of past temperatures with the CAKN record. The model predicts that a steady rise in temperature should have occurred since the early 20<sup>th</sup> century, with about half of the 1 degree C rise occurring since 1980. The actual increase since the early 20<sup>th</sup> century in the CAKN region has been less than 0.5 degrees C, and perhaps even zero, depending on which assessment of the observed CAKN trend is accepted.

The most glaring shortfall to the models is the absence of any NP/PDO signal, or of any ocean-atmosphere process occurring on similar time scales. Since the NP/PDO is apparently absent from the models, the residual CAKN temperature with the NP/PDO subtracted out is shown for comparison. The model’s upward trend is not apparent in the observations. Individual and MEAN models for Alaska do not accurately represent the past century’s climate, and their forecasts for the coming century should be given low confidence.

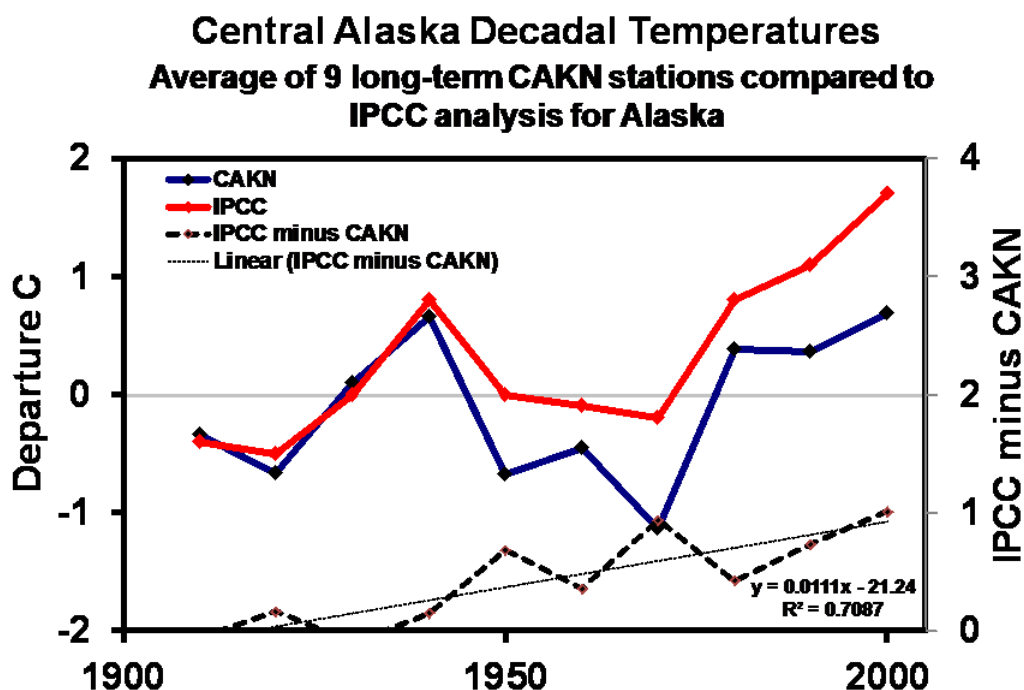


Figure 82. Decadal temperatures for Alaska from IPCC AR4 fig-9-12, compared with decadal temperatures from this CAKN report. The plotted data are ten-year averages of annual temperatures, plotted at the mid-point of the averaging period (so, 1910 shows an average from 1905-1915).

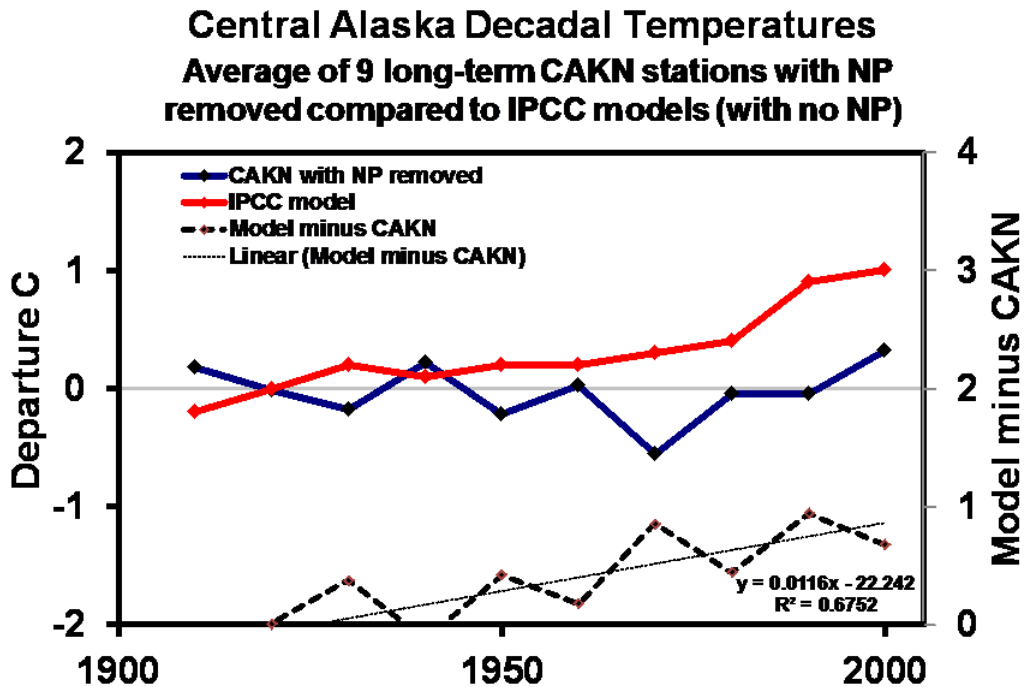


Figure 83. Retroactively forecast Decadal temperatures for Alaska from IPCC AR4 fig-9-12, compared with decadal temperatures from this CAKN report. The plotted data are ten-year averages of annual temperatures, plotted at the mid-point of the averaging period (so, 1910 shows average from 1905-1915). The NP/PDO effect has been removed from the CAKN record.

### CAKN Precipitation (SWE) and other Indices

The following table lists correlations between the yearly SWE at the three CAKN units, and the three-unit average, with the NP and AO indices. With approximately 50 years of data, correlation coefficients of 0.27 and 0.35 are significant at the  $p=0.05$  and  $p=0.01$  levels, respectively. The best correlation on the grid is between Denali SWE and the NP index, indicating that a weaker Aleutian Low is linked to greater snowfall at Denali (and to a lesser extent, Yukon-Charley). Curiously, the correlation is weakest at the most coastal unit, Wrangell-St. Elias, and is opposite to an intuitive expectation that a stronger low would bring more coastal storms and more precipitation. This indicates that the physical mechanism is complex and likely involves an interaction between the Aleutian Low and a different set of cyclones that traverse interior Alaska.

Table 6. Correlation of CAKN Snow Water Equivalents with winter NP and AO Climate Indices

| CAKN Unit         | Annual |        | 5-year |        |
|-------------------|--------|--------|--------|--------|
|                   | NP     | AO     | NP     | AO     |
| Wrangell-St Elias | 0.25   | 0.21   | 0.07   | 0.67** |
| Denali            | 0.46** | 0.38** | 0.60** | 0.50*  |
| Yukon-Charley     | 0.38** | 0.30*  | 0.39   | 0.69** |
| Average           | 0.39** | 0.28*  | 0.42   | 0.65** |

The correlation between Average SWE and the NP index rises from 0.39 to 0.42 when 5-year moving average values of both are used. However, the significance of the correlation is less since there are only 10 independent samples.

The correlation with the Arctic Oscillation (AO) index, however, increases from 0.29 to 0.68 when 5-year moving averages are used. Thus, the AO appears to have a long-term correlation with the slowly varying component of seasonal snowfall across the region. The next figure shows the annual and 5-year moving averages of area averaged SWE, along with the AO index. There is an obvious correspondence between the SWE and the AO index for the smoothed values (dashed lines). Furthermore, the correspondence appears to be dominated by two extreme periods: low values of SWE and AO around 1970, and high values around 1990. The second of the following figures is a scatter plot of annual values of SWE vs. AO. Here it appears that during most years there is little correlation, but the three lowest SWE years – 1969, 1970, and 2010 – had very negative AO indices, and that the five years with the most positive AO indices had well above normal SWE.

It thus appears that the AO, for which positive values indicate (from the previous discussion) “stronger than normal zonal westerly winds at the surface and a stronger jet stream which is displaced poleward, which in turn leads to a northward displacement of the normal cyclone tracks in the north Pacific Ocean”, can, in extreme years, lead to excessively abundant (or meager, for negative AO) snowfall across the CAKN region.

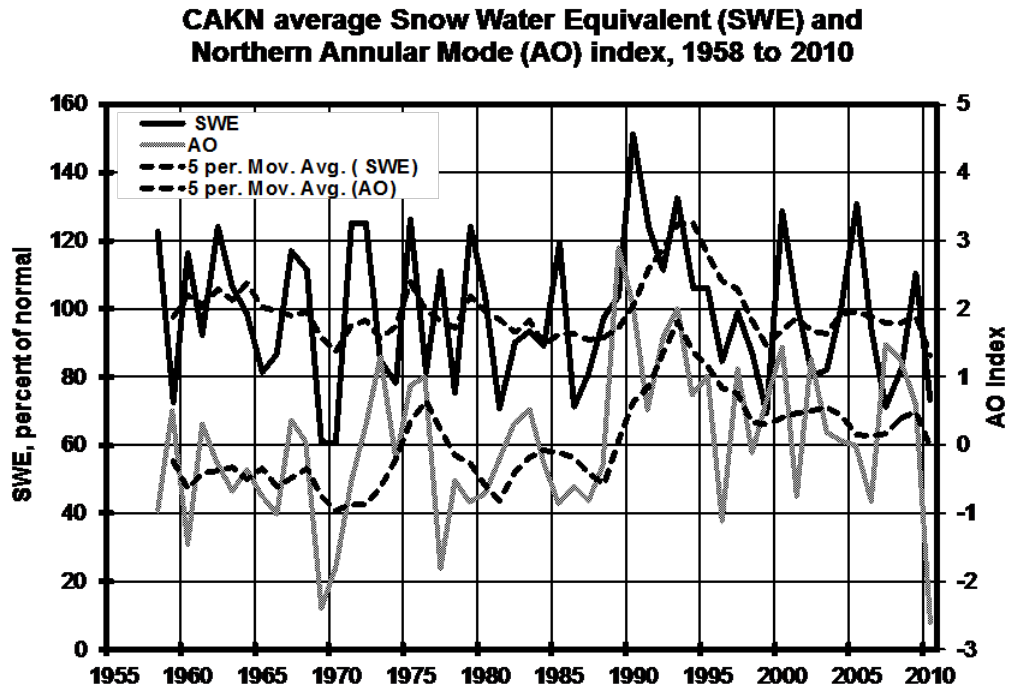


Figure 84. Annual (solid lines) and 5-year moving averages (dashed) of CAKN SWE and AO index.

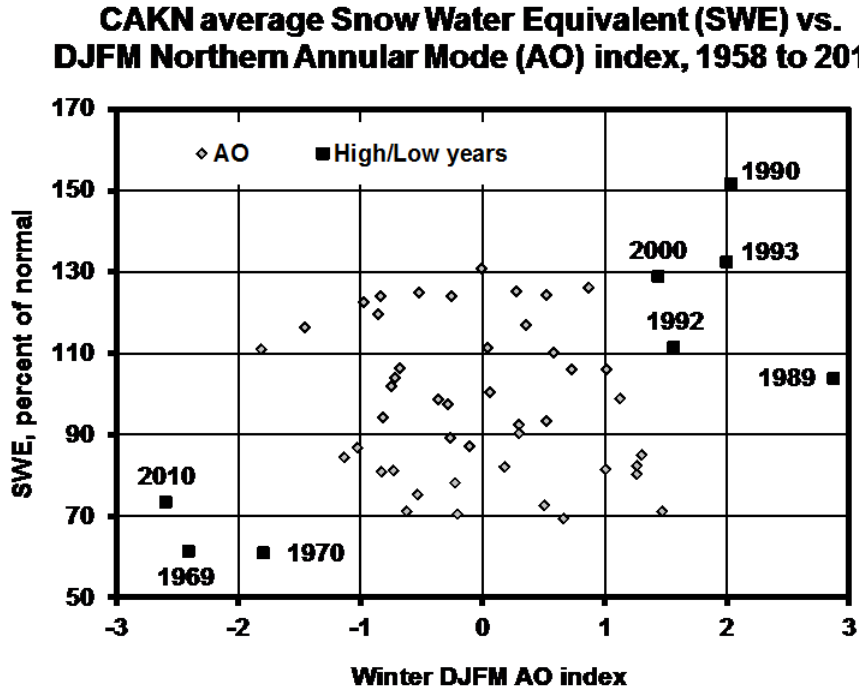


Figure 85. Scatter plot of annual SWE vs. AO index.

### CAKN Precipitation (SWE) and El Niño

Everybody likes to blame unusual weather on el Niño, and in much of the U.S. the blame is often deserved. However, el Niño appears to have only slight effect in Alaska. A search of correlation maps of various atmospheric maps revealed the map below, showing the difference in storm frequencies during strong el Niño events. Overall an increase in storm frequencies across lower latitudes of the North Pacific and North America is countered by a decrease at higher latitudes. The entire Pacific coast of Alaska, from Attu to the Southeast, has fewer cyclones during strong el Niños, according to this map.

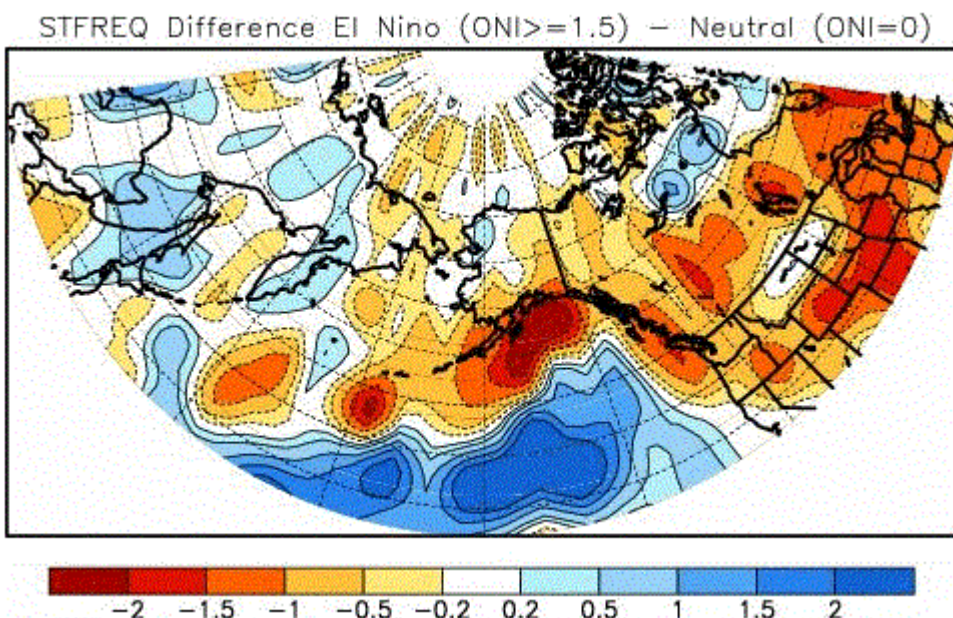


Figure 86. Composite map of North Pacific storm frequencies, Strong Niño minus neutral events (no Niño). From [http://www.cpc.ncep.noaa.gov/products/precip/CWlink/stormtracks/strackres\\_comp.shtml](http://www.cpc.ncep.noaa.gov/products/precip/CWlink/stormtracks/strackres_comp.shtml)

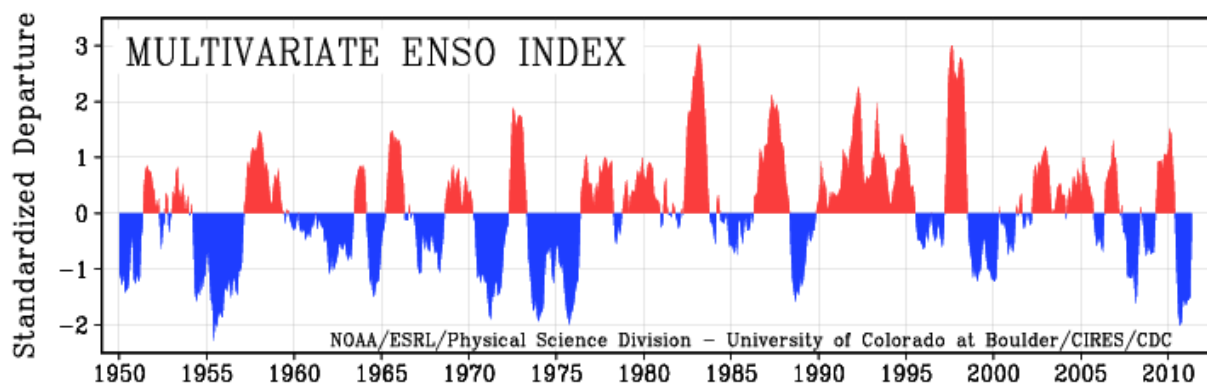


Figure 87. Multivariate ENSO index (MEI), from <http://www.esrl.noaa.gov/psd/enso/mei/>

The most comprehensive index of el Niño related events is the Multivariate Enso Index, which is used to search for Niño style correlations in the CAKN temperature and snow time series. Few correlations were found. Often el Niño connections appear only during extreme events, with a few points highly correlated but with the rest of the data creating an unimpressive overall correlation coefficient. This is the case with CAKN snow water equivalent (SWE). The two

charts below show that while the overall correlation between Denali region SWE and MEI is small ( $R = 0.14$ ), all years with MEI greater than 0.85 had near or below normal snowfall, consistent with the reduction in coastal storm activity. Again, the effect is more prominent at inland Denali than for coastal Wrangell-St. Elias. And, while strong el Niños tend to bring low snowfall, exactly half (14) of the winters with below normal SWE occurred during La Niña years (the opposite of el Niño).

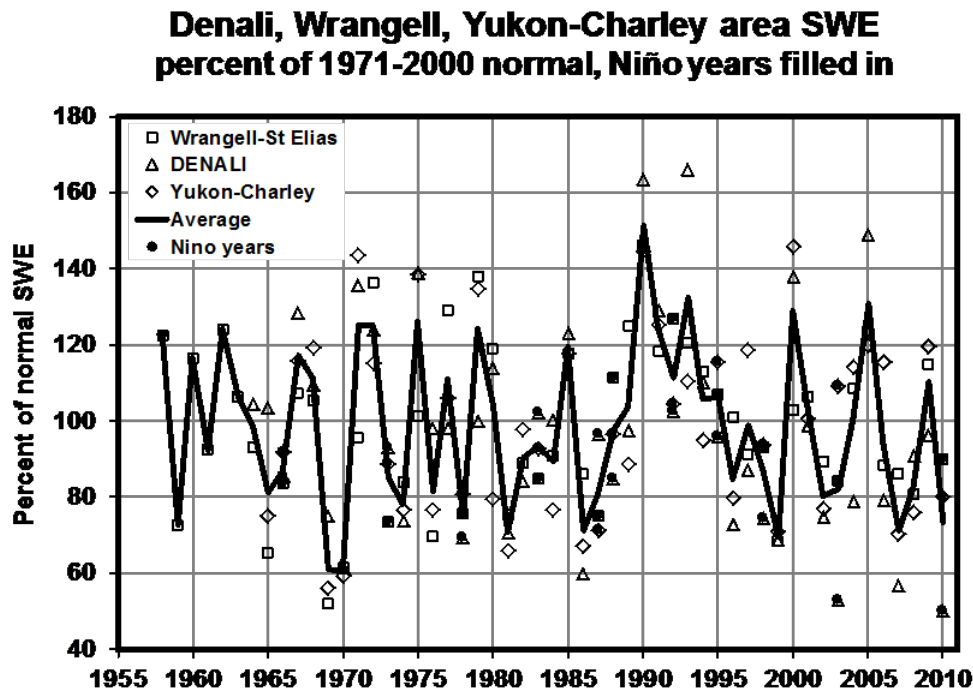


Figure 88. CAKN Snow Water Equivalent, with the eleven strongest el Niño events (measured by MEI) highlighted.

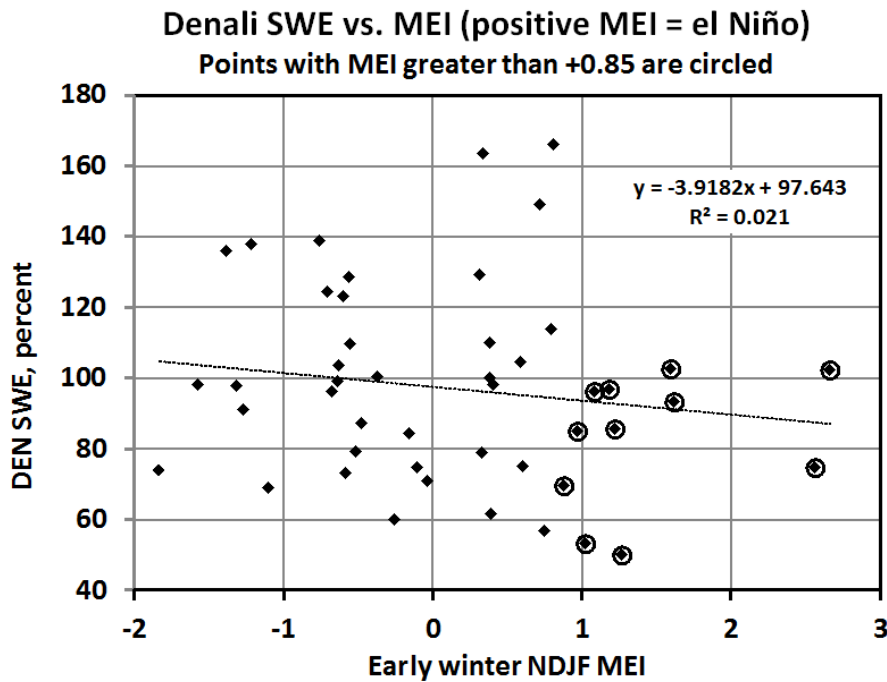


Figure 89. Denali region SWE vs. MEI, with the eleven strongest el Niño events highlighted.

Finally, there are suggestions that a warmer Alaskan climate might bring less snow. An easy test of this hypothesis is to compare observed snowfall with observed temperature in the past, as in the next figure. The correlation is tiny to negligible, and if the IPCC model forecast of +4 degrees C warming by 2100 were to occur, the insignificant and highly uncertain correlation below would indicate a 5 percent decrease in SWE.

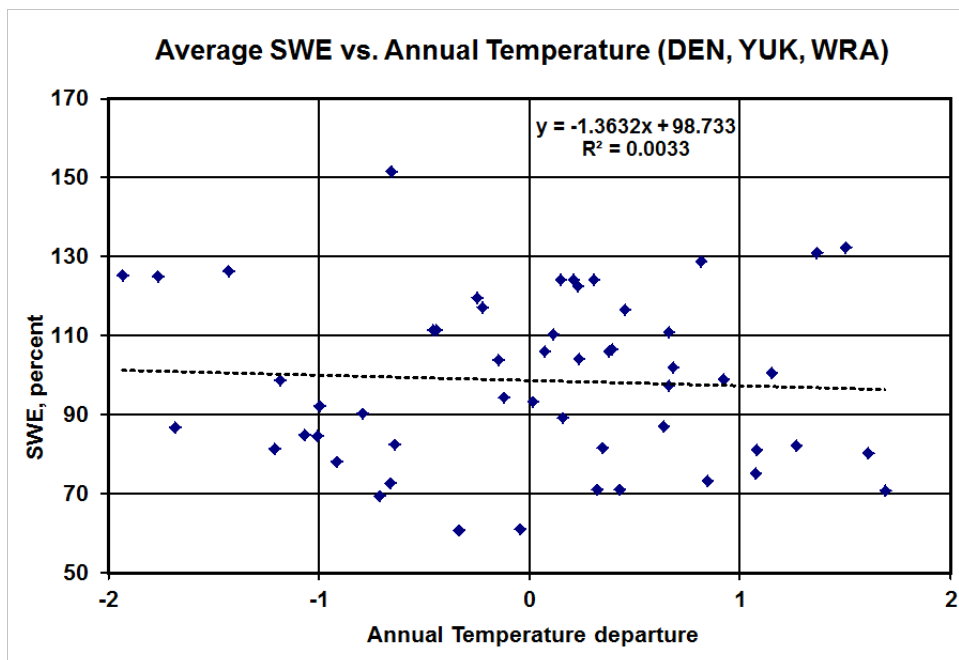


Figure 90. CAKN SWE vs. CAKN annual temperatures.

## Microclimatology of Denali, Wrangell-St. Elias, and Yukon-Charley Parks and Preserves

Eleven new RAWS stations were installed in the Denali, Wrangell-St. Elias and Yukon-Charley sections in 2004-2005. Nine of these stations, along with eight other existing RAWS stations and one co-op station were chosen to develop vertical profiles of the climate. Due to the short period of record (five years or less) and a fair amount of missing data from some automated sites, it was not possible to get robust statistics of climate variations. However, it was possible to find an amplitude of year-to-year variability due to the NP/PDO.

The 18 stations were subdivided into four vertical transects, one each in Denali and Yukon-Charley and two in Wrangell St.-Elias (one on the north side of the Wrangell Mountains and one on the south side).

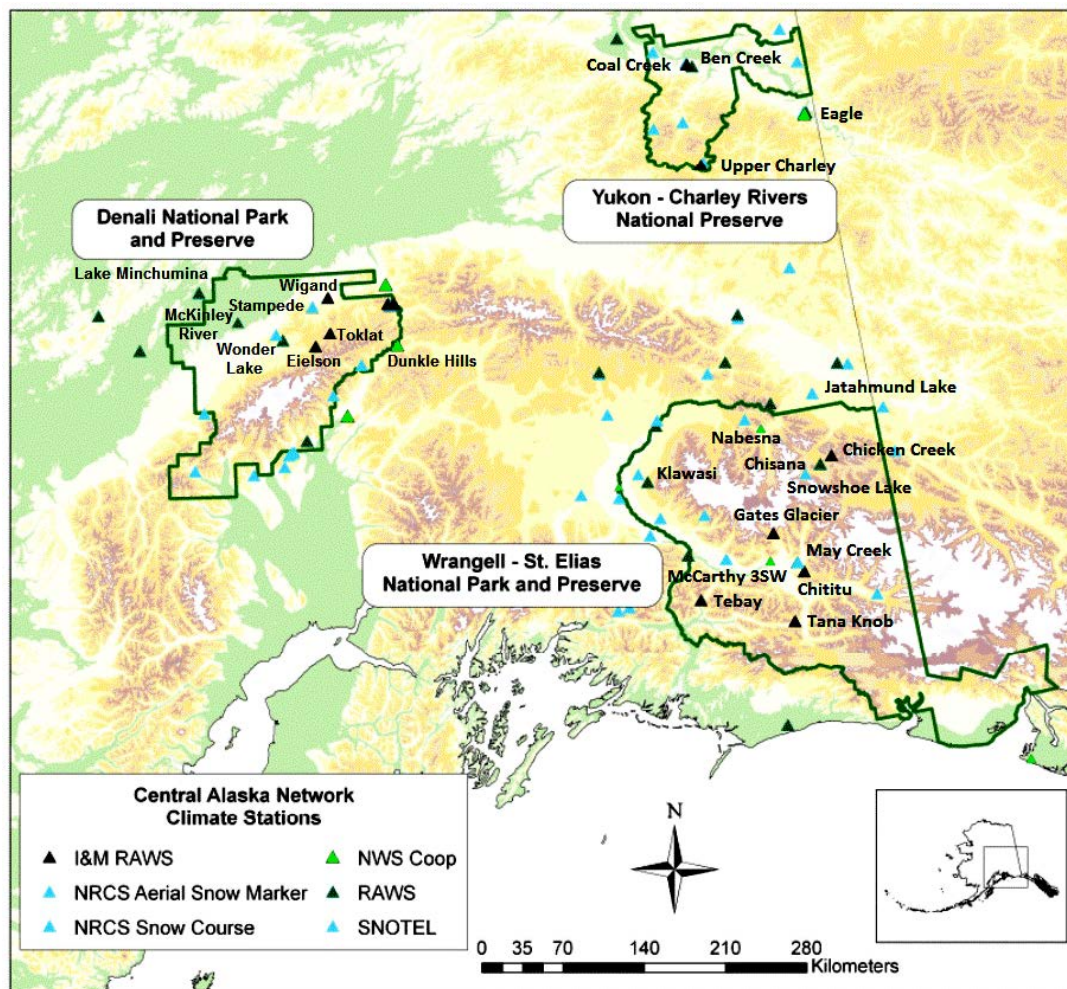


Figure 91. Map of the CAKN sections, with locations of RAWS and some co-op sites in Denali, Wrangell-St. Elias and Yukon-Charley noted.

The table below provides basic averages and extremes (degrees F) for the 18 sites.

Table 7. Vertical Climatological Transects in the Denali, Yukon-Charley, and Wrangell-St. Elias Preserves

| <b>Records for<br/>2004-2010</b> | <b>Elevation<br/>feet</b> | <b>Average<br/>Annual</b> | <b>Summer</b>  |                | <b>Winter</b>  |                | <b>Extreme<br/>Temperatures</b> |        |
|----------------------------------|---------------------------|---------------------------|----------------|----------------|----------------|----------------|---------------------------------|--------|
| CAKN section                     |                           | Average<br>Temp.          | Average<br>Max | Average<br>Min | Average<br>Max | Average<br>Min | Highest                         | Lowest |
| Denali                           |                           |                           |                |                |                |                |                                 |        |
| Lake Minchumina                  | 740                       | 28.9                      | 70.5           | 48.7           | 5.2            | -7.4           | 93                              | -48    |
| McKinley River                   | 840                       | 24.8                      | 68.3           | 42.4           | 1.9            | -15.7          | 92                              | -50    |
| Stampede                         | 1800                      | 24.5                      | 62.2           | 41.7           | 8.7            | -11.9          | 84                              | -51    |
| Wonder Lake                      | 2119                      | 26.4                      | 63.3           | 42.5           | 12.2           | -6.2           | 84                              | -46    |
| Dunkle Hills                     | 2651                      | 26.9                      | 56.7           | 40.4           | 14.6           | 2.2            | 81                              | -34    |
| Toklat                           | 2920                      | 26.4                      | 56.4           | 41.4           | 15.4           | -1.0           | 79                              | -43    |
| Eielson Visitor Center           | 3730                      | 29.0                      | 53.3           | 42.3           | 20.8           | 7.8            | 75                              | -33    |
|                                  |                           |                           |                |                |                |                |                                 |        |
| Yukon-Charley                    |                           |                           |                |                |                |                |                                 |        |
| Coal Creek                       | 820                       | 24.8                      | 67.8           | 43.6           | 0.2            | -14.4          | 90                              | -58    |
| Ben Creek                        | 1850                      | 27.3                      | 68.1           | 46.9           | 1.1            | -8.9           | 89                              | -43    |
| Upper Charley                    | 3654                      | 22.9                      | 55.8           | 42.5           | 3.8            | -4.5           | 80                              | -38    |
|                                  |                           |                           |                |                |                |                |                                 |        |
| Wrangell St. Elias N             |                           |                           |                |                |                |                |                                 |        |
| Jatahmund Lake                   | 2300                      | 29.9                      | 69.6           | 46.8           | 3.7            | -3.4           | 95                              | -43    |
| Nabesna                          | 2900                      | 26.0                      | 62.7           | 42.1           | 6.5            | -7.3           | 87                              | -44    |
| Chisana                          | 3320                      | 23.2                      | 67.4           | 35.4           | 7.7            | -14.5          | 90                              | -53    |
| Chicken Creek                    | 5260                      | 25.5                      | 51.3           | 40.5           | 15.1           | 4.5            | 74                              | -36    |
|                                  |                           |                           |                |                |                |                |                                 |        |
| Wrangell St. Elias S             |                           |                           |                |                |                |                |                                 |        |
| McCarthy 3SW                     | 1250                      | 30.1                      | 69.9           | 40.1           | 11.2           | -6.8           | 89                              | -49    |
| McCarthy                         | 1490                      | 30.8                      | 67.5           | 45.5           | 8.6            | -4.4           | 88                              | -45    |
| May Creek                        | 1650                      | 28.8                      | 69.5           | 39.3           | 12.2           | -8.2           | 92                              | -49    |
| Gates Glacier                    | 4060                      | 28.9                      | 51.3           | 42.0           | 20.5           | 10.6           | 73                              | -26    |
| Chititu                          | 4554                      | 28.2                      | 51.2           | 40.7           | 18.9           | 9.3            | 72                              | -30    |

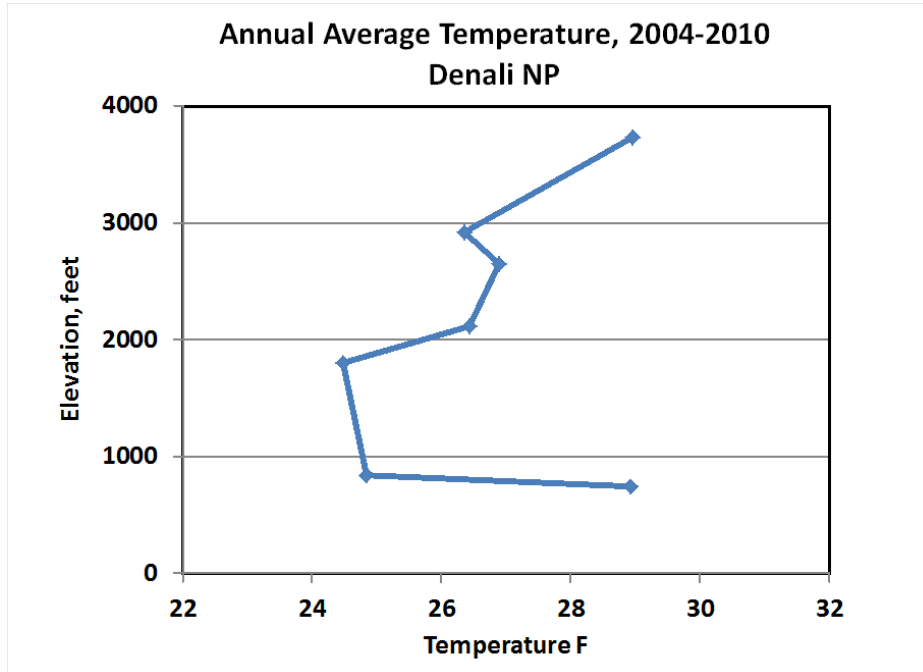


Figure 92. Average annual temperature vs. elevation for the Denali. Average temperatures are remarkably uniform, with a total range of only 5 degrees F among the 7 sites. With the exception of the lowest station, Lake Minchumina, temperatures increase with height, showing the dominance of the wintertime inversion on annual temperatures.

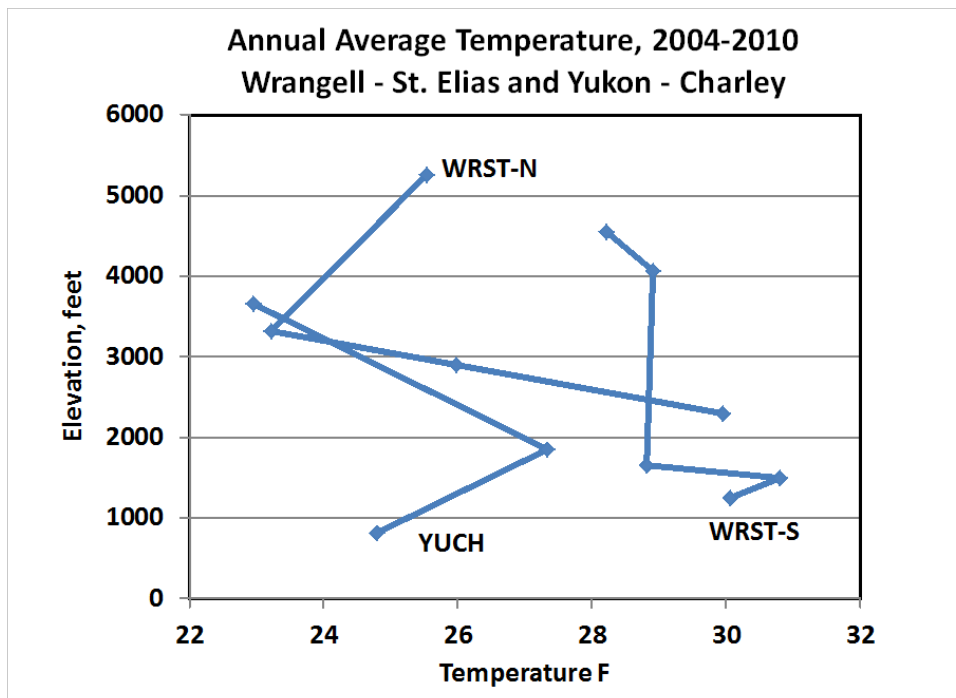


Figure 93. Average annual temperature vs. elevation for Wrangell-St. Elias and Yukon-Charley. The total range of average temperatures is only 8 degrees F among the 11 sites. That is about half of the “typical” temperature range over an equivalent elevation difference (3 degree F per 1,000 feet over 4440 feet).

The next six figures show the average summer and winter daily maximum and minimum temperatures for the Denali, Wrangell-St. Elias and Yukon-Charley transects.

Above the normal inversion in the lowest 1000 feet or so, daytime summer temperatures generally decrease with altitude at a rate near or a little greater than the adiabatic lapse rate of 5.5 degrees F per 1000 feet. Nighttime temperatures are more constant with height, with average minimum temperatures in each transect generally within 5 degrees of each other.

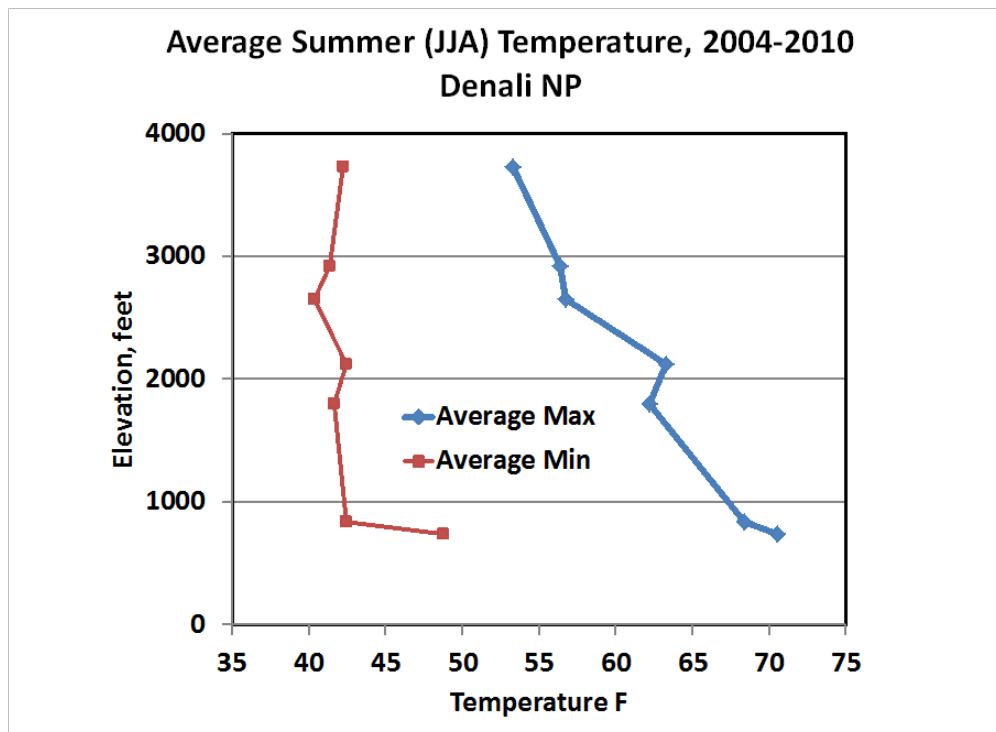


Figure 94. Vertical transect of average summer temperatures in Wrangell-St. Elias Preserve.

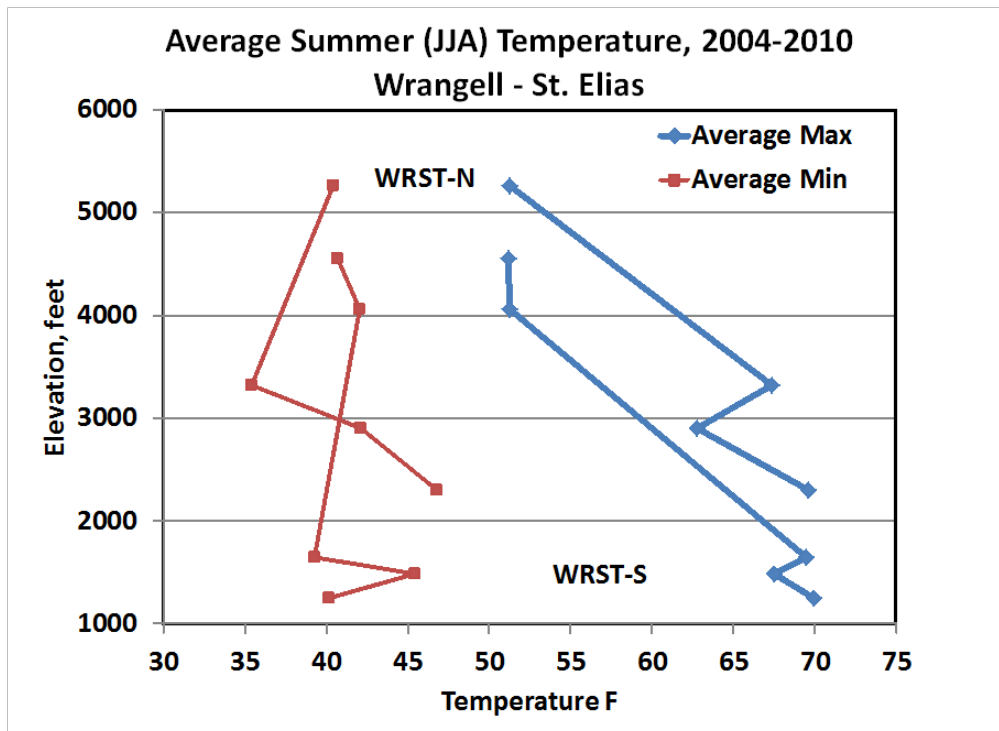


Figure 95. Vertical transect of average summer temperatures in Wrangell-St. Elias Preserve.

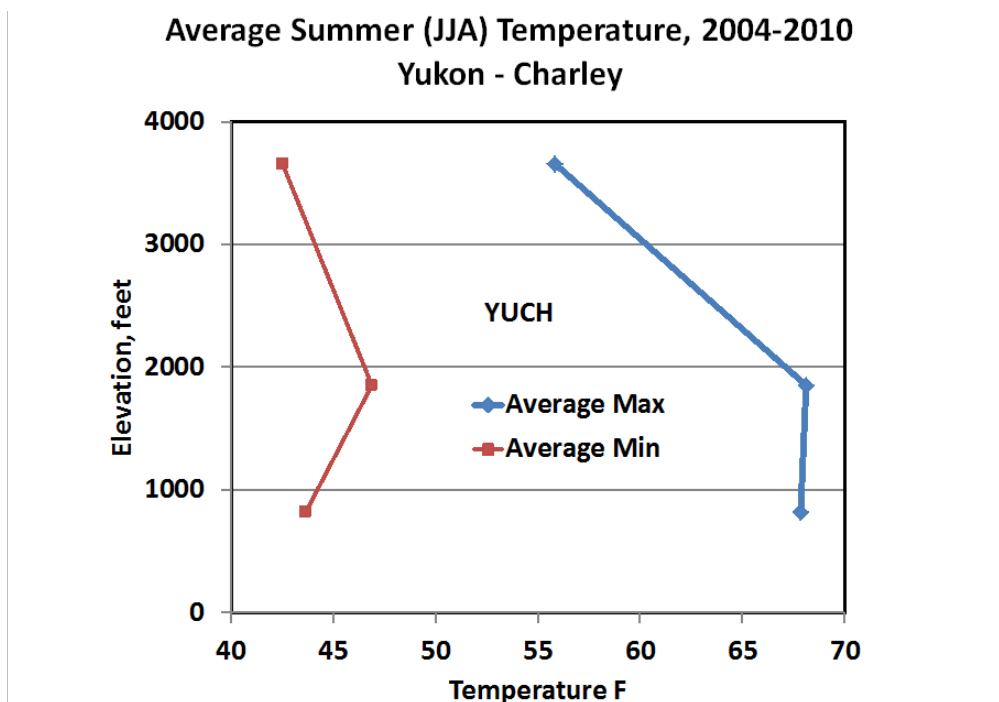


Figure 96. Vertical transect of average summer temperatures in Yukon-Charley Preserve.

Winter transects (next three graphs) show that for all three sections, the inversions reach to the tops of the ridges on which the highest RAWS stations are located. Daytime maxima increase

about 2 to 5 degrees F per thousand feet, and nighttime minima increase from 5 to 10 degrees F per thousand feet. In Wrangell-St. Elias, the north side of the Wrangell Mountains is 10 to 20 degrees colder than the south side, since the range is often the boundary between maritime and interior arctic air masses. Likewise, in Denali, the average minimum temperature at Dunkle Hills on the south side of the Alaska Range is about 5 degrees F warmer than would be interpolated for the same elevation on the north side of the Range. Interestingly, Yukon-Charley is a few degrees warmer than sites at the same elevation on the Wrangell-St. Elias transect, presumably because the lower valley elevation in Yukon-Charley places the Upper Charley station closer to the top of the inversion, and therefore warmer.

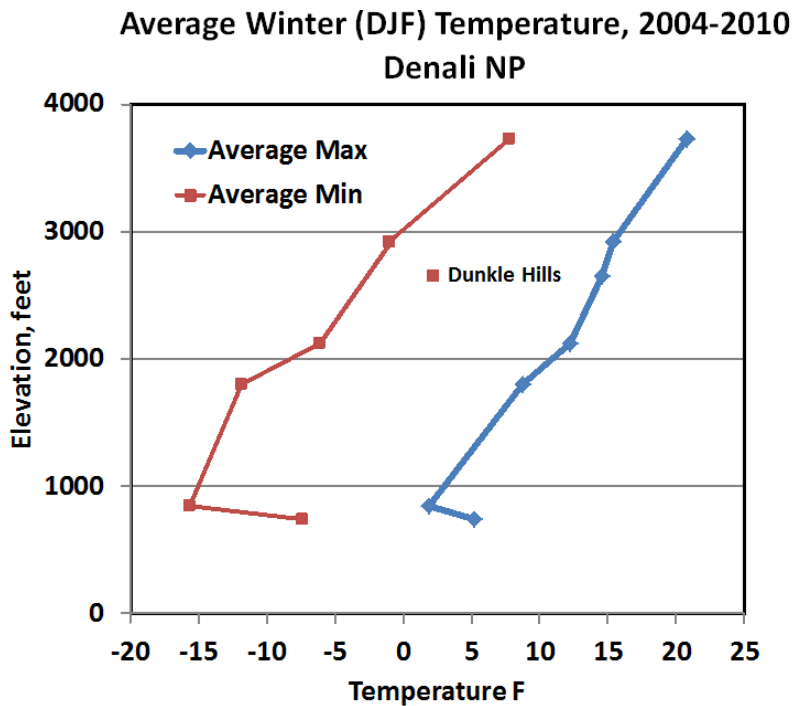


Figure 97. Vertical transect of average winter temperatures in Denali NP.

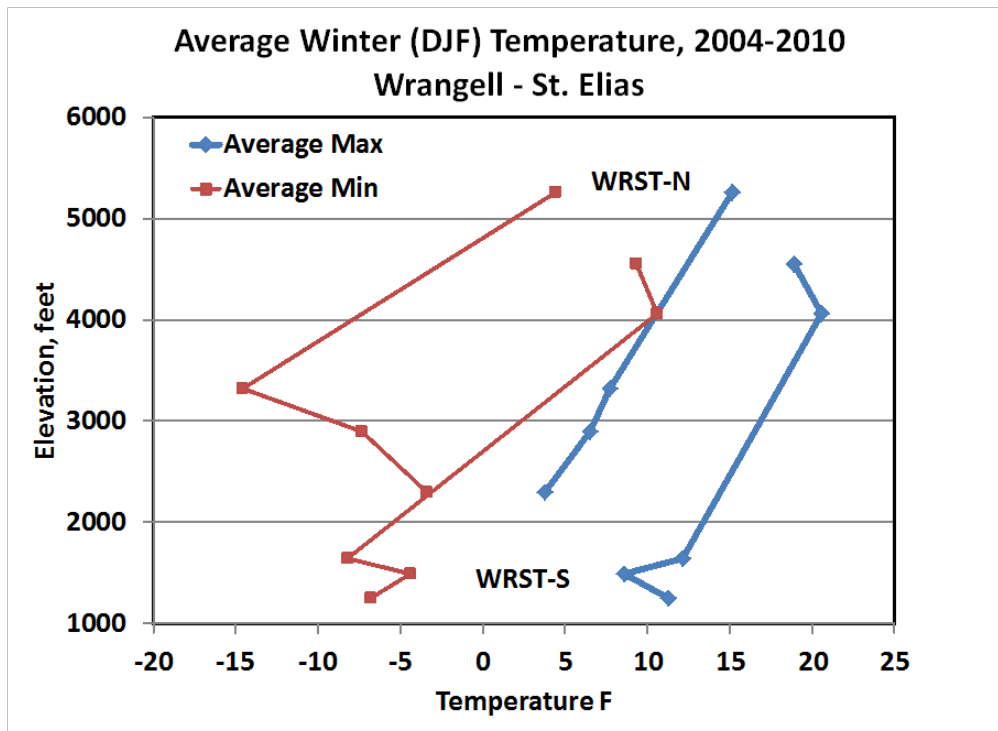


Figure 98. Vertical transect of average winter temperatures in Wrangell-St. Elias Preserve.

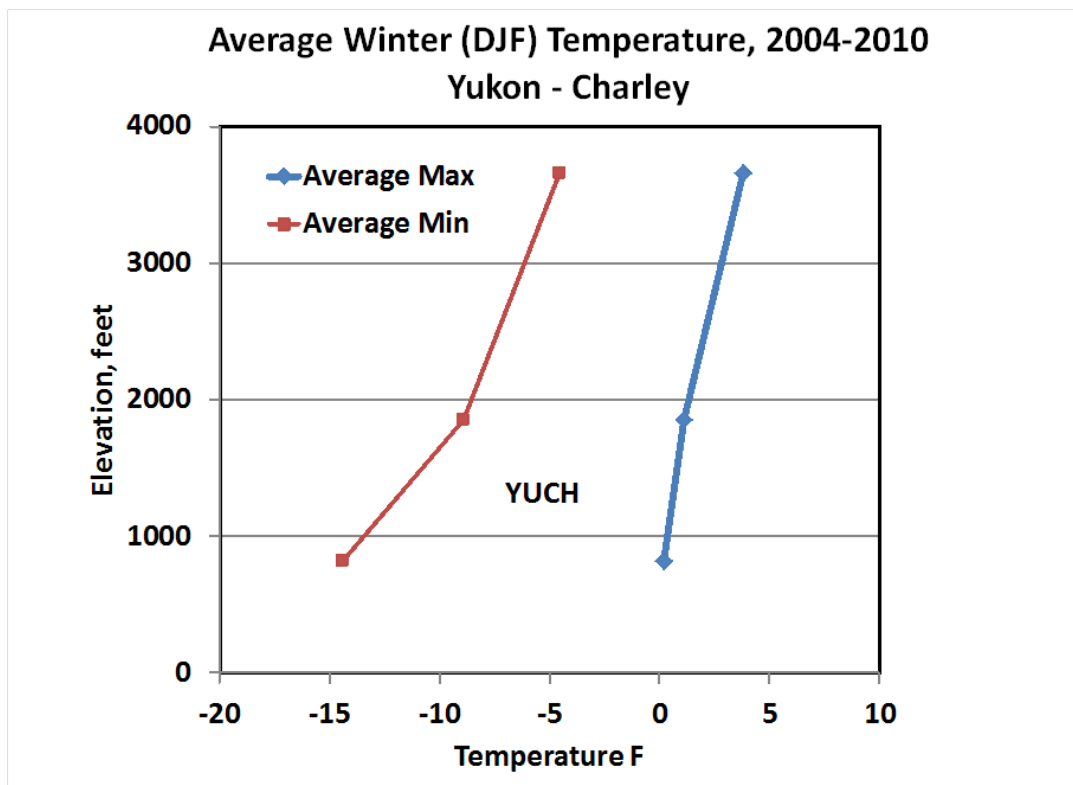


Figure 99. Vertical transect of average winter temperatures in Yukon-Charley Preserve.

Extreme maximum temperatures decrease from 3 to 6 degrees per 1000 feet, roughly equivalent to the adiabatic lapse rate of 5.5 degrees. This reflects the convective vertical mixing of the atmosphere during hot days. Some of the local variations may be due to station exposure issues, which tend to be exacerbated on calm days with bright sunshine.

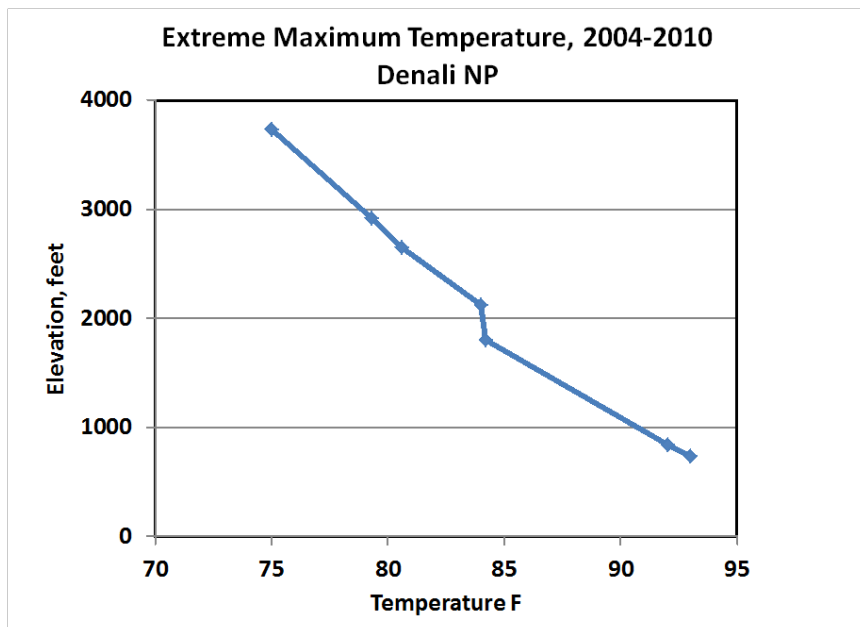


Figure 100. Vertical transect of extreme maximum temperature in Denali NP, from records 2004-2010.

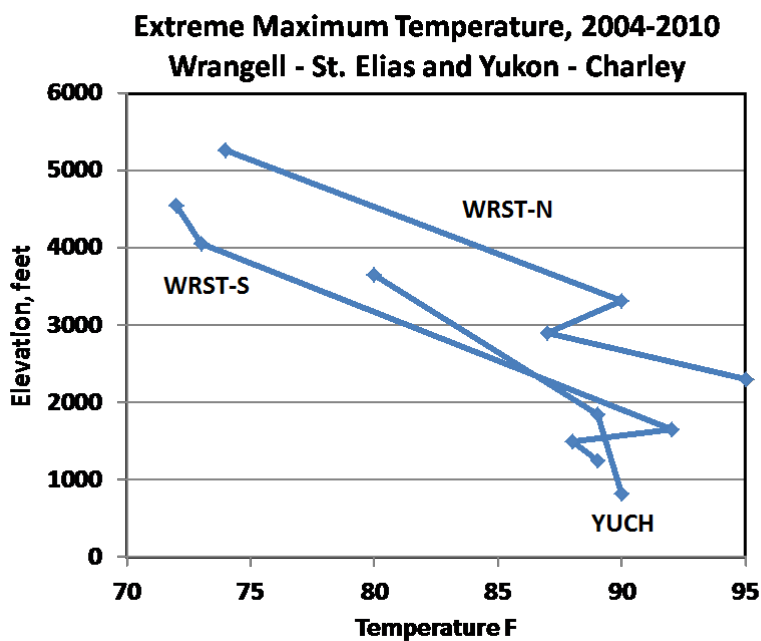


Figure 101. Vertical transect of extreme maximum temperature in Wrangell-St. Elias and Yukon-Charley preserves, from records 2004-2010.

Extreme minimum temperatures generally increase with height at a rate of 7 to 10 degrees F per 1000 feet, showing the strength of the inversion during periods of extreme cold. In Wrangell-St. Elias, minima on the south side of the Wrangell Mountains range run 10 to 20 degrees F warmer than those on the north side at the same elevation, while Dunkle Hills' minimum is about 10 degrees warmer than at similar sites on the north side of the Alaska Range.

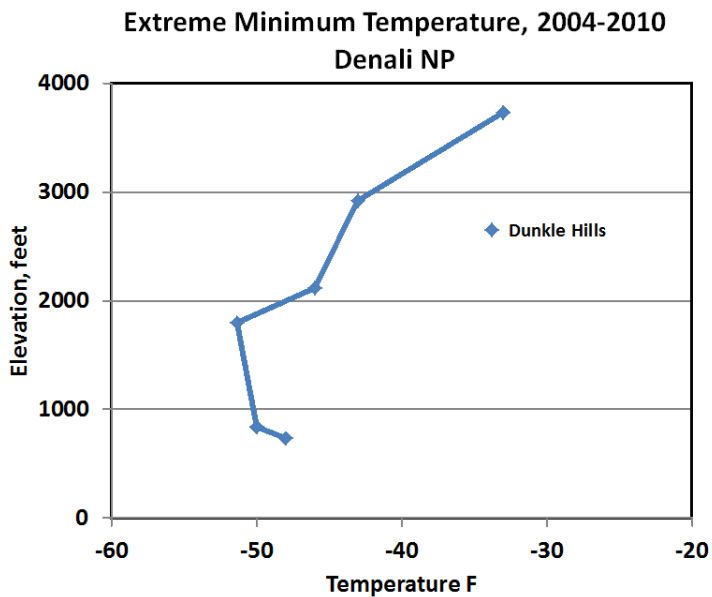


Figure 102. Vertical transect of extreme minimum temperature in Wrangell-St. Elias and Yukon-Charley preserves, from records 2004-2010.

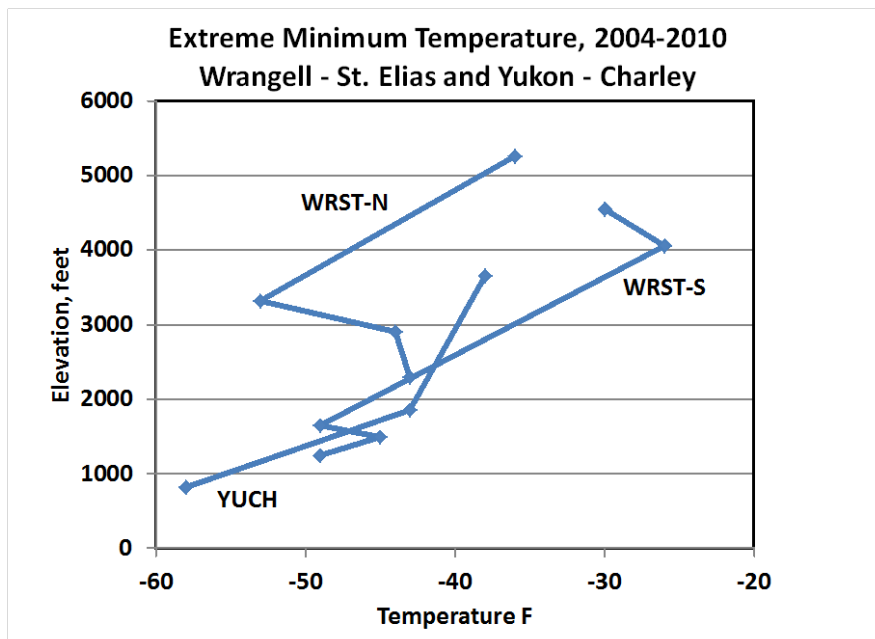


Figure 103. Vertical transect of extreme minimum temperature in Wrangell-St. Elias and Yukon-Charley preserves, from records 2004-2010.

The final eight charts show the elevation dependence of some correlations of annual or seasonal mean temperature with some important climate indices. The selection of pairs of variables includes four with the highest overall correlation coefficients. Although the correlations are based on six or fewer years of data, these charts give a consistent story: correlations are either consistent with height or, more often, improve (get stronger) with elevation. The big exception to this is in the first chart below, in which the correlation between annual temperature and the annual NP index grows weaker with height.

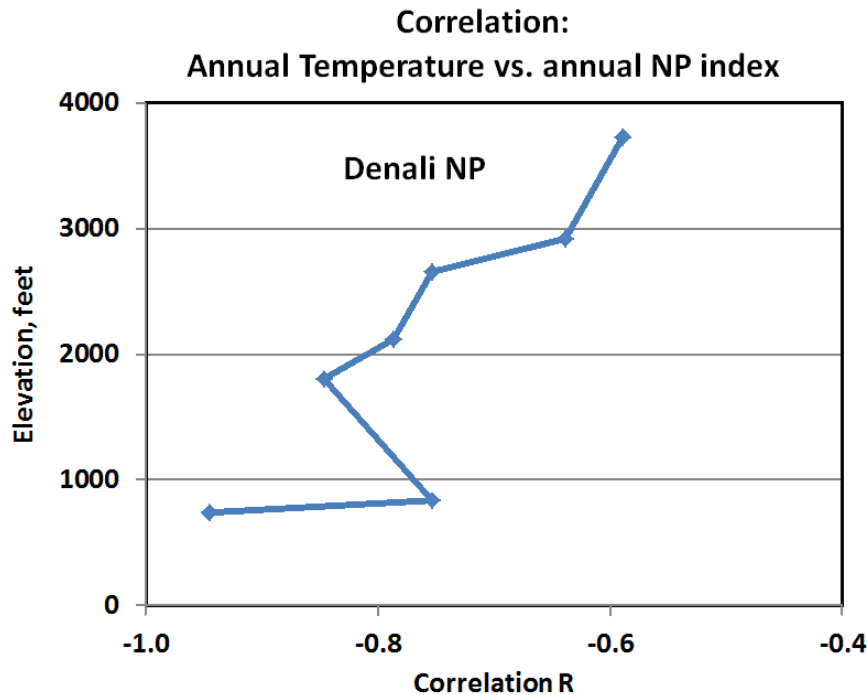


Figure 104. Vertical transect of correlation coefficients in Denali NP, from records 2004-2010.

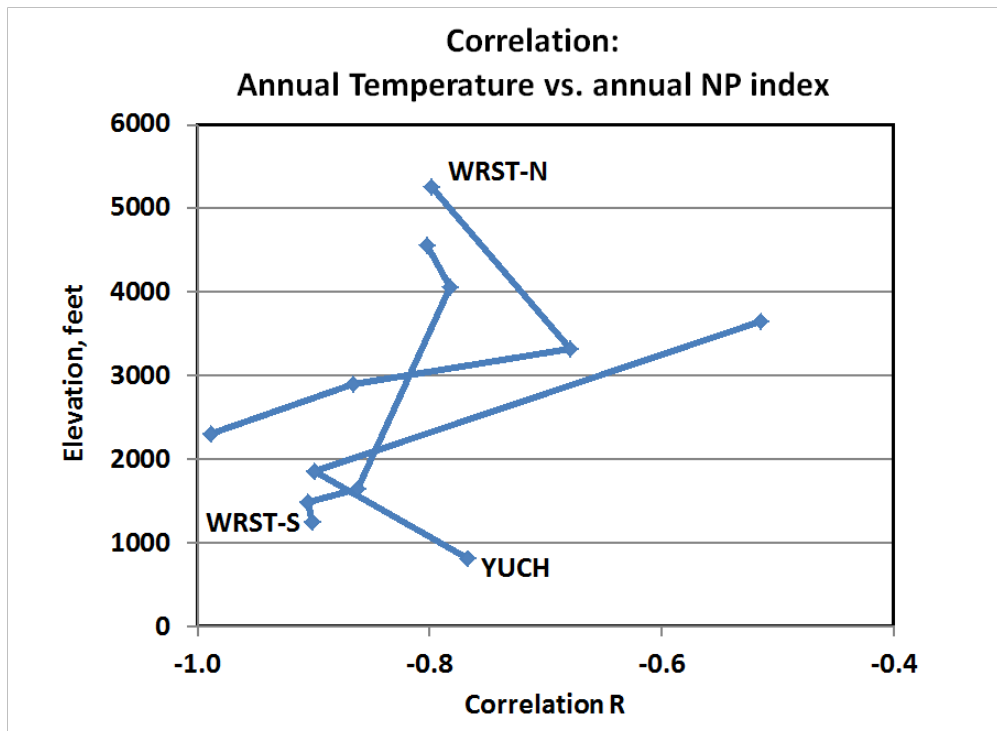


Figure 105. Vertical transect of correlation coefficients in Wrangell-St. Elias and Yukon-Charley preserves, from records 2004-2010.

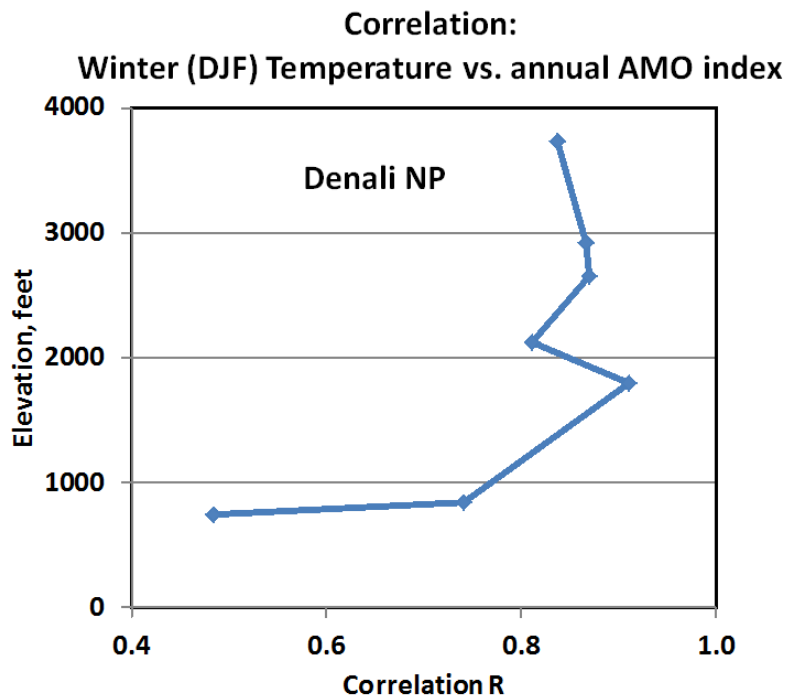


Figure 106. Vertical transect of correlation coefficients in Denali NP, from records 2004-2010.

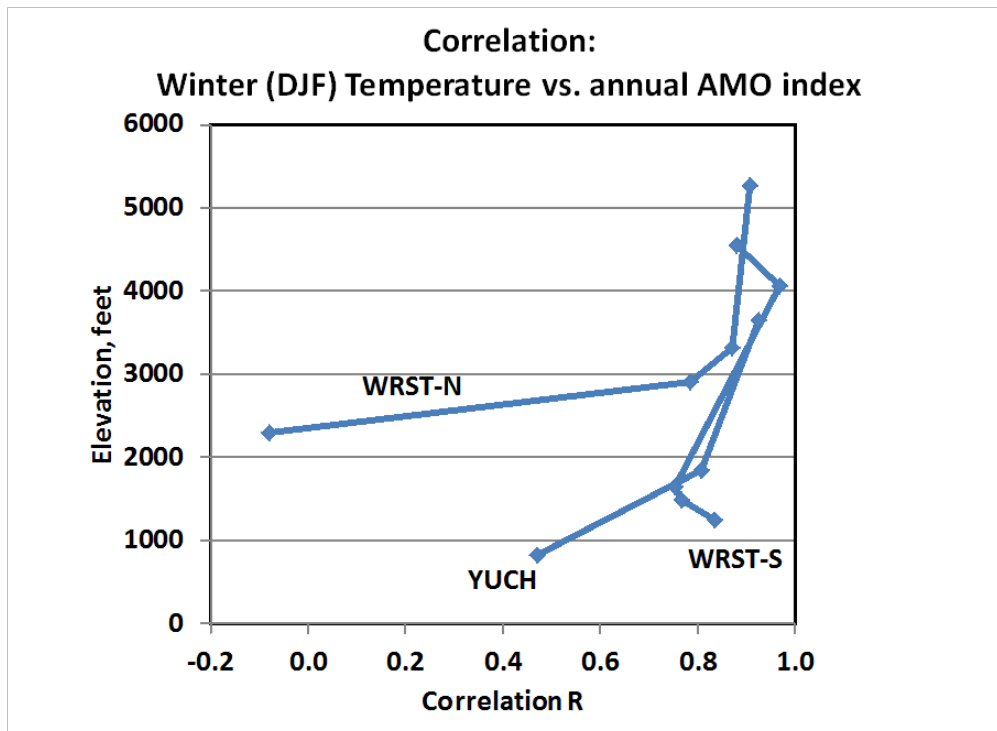


Figure 107. Vertical transect of correlation coefficients in Wrangell-St. Elias and Yukon-Charley preserves, from records 2004-2010.

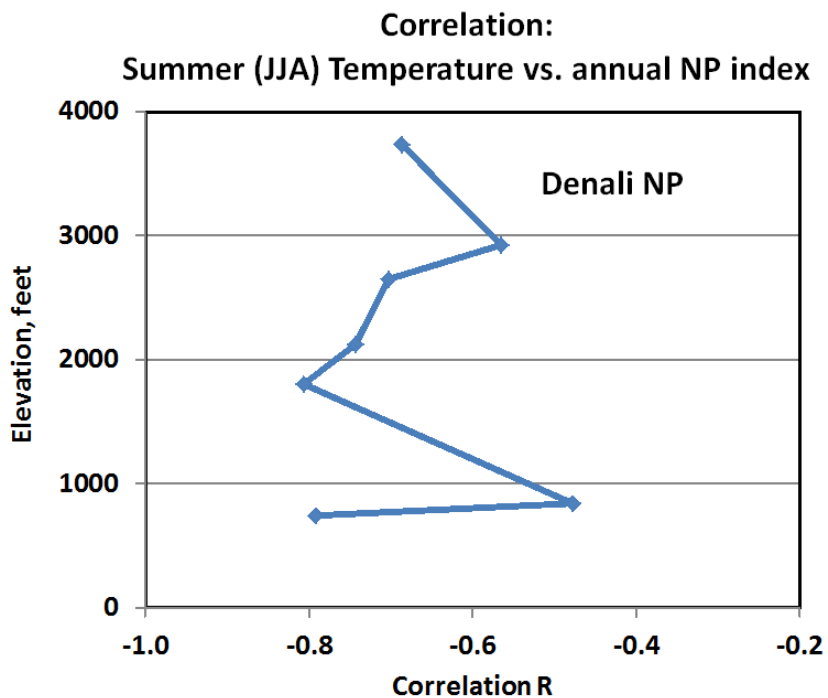


Figure 108. Vertical transect of correlation coefficients in Denali NP, from records 2004-2010.

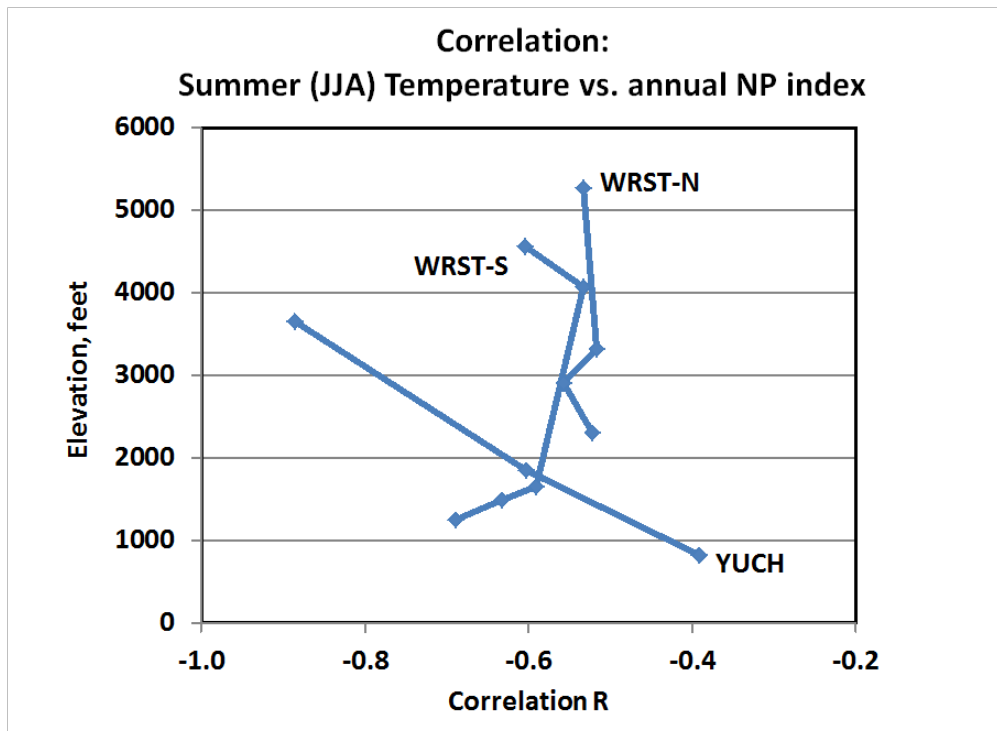


Figure 109. Vertical transect of correlation coefficients in Wrangell-St. Elias and Yukon-Charley preserves, from records 2004-2010.

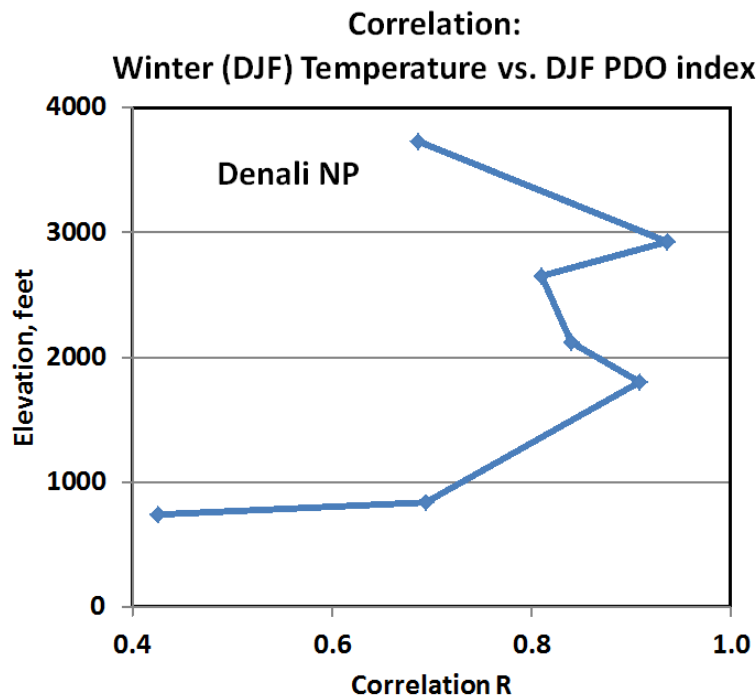


Figure 110. Vertical transect of correlation coefficients in Denali NP, from records 2004-2010.

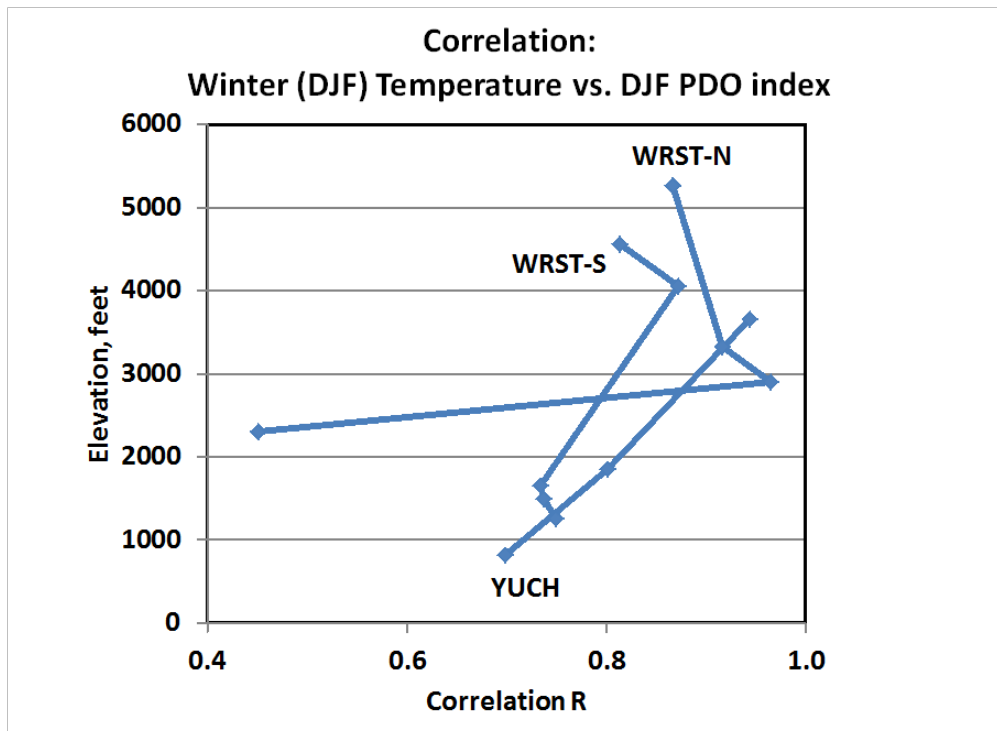


Figure 111. Vertical transect of correlation coefficients in Wrangell-St. Elias and Yukon-Charley preserves, from records 2004-2010.

## Summary

The summary of this report will be short. Climate observations of temperature and snowfall have been updated through 2010. Further analysis of the entire record (1900 to 2010) in relation to indices of the larger scale and global climate confirm that most of the longer-term variability of Central Alaska's climate is directly connected with the North Pacific (NP) and Pacific Decadal Oscillations (PDO), and that all other climate variables play a much smaller role.

The CAKN regional climate appears to have undergone a change in 2006 with a shift of the NP/PDO to a cold phase. However, the statistical nature of the Pacific DECADAL oscillation requires that another five years must pass before we can confirm an actual NP/PDO phase shift.



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