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

Including
Denali National Park and Preserve,
Wrangell-St. Elias National Park and Preserve,
and Yukon-Charley Rivers National Preserve.

Prepared for:
National Park Service
Central Alaska Inventory and Monitoring Network

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Abstract of project

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.

1. 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 this study 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.

2. 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.

A. Climate (COOP) stations.

These stations, operated by various agencies ranging from the National Weather Service, the Federal Aviation Administration, the National Park Service, and many individual volunteers, provide daily observations of temperature, precipitation, and snowfall. Since all of these stations report their data to the NWS Cooperative Observer Program, they will be referred to as Co-op (or COOP) stations. Twenty-seven of the stations had a long enough period of record (generally, ten years or more) to allow the National Weather Service and National Climate Data Center to compute standard normals of temperature and precipitation for the 1971-2000 base period. In addition, 7 stations had more complete records, allowing the NWS/NCDC to publish more detailed "CLIM20" summaries. Furthermore, 9 stations (or combinations of adjacent stations) had complete enough and long enough records to allow the construction of monthly and annual temperature time series extending back to 1923 or earlier, and as far back as 1899 in the case of Eagle. These 9 stations form the basis of the analysis and interpretation of the long-term climate variations. Unfortunately, with only one exception – the long-term station at McKinley National Park – none of the climate stations had continuous or consistent enough records of precipitation and snowfall to allow a similar reconstruction of the precipitation history.

B. Snow monitoring stations.

According to the Natural Resources Conservation Service (NRCS), "snow surveys in the West date back to around 1906, when the University of Nevada's Dr. James Church laid out the first western snow course. Dr. Church also invented key sampling procedures and equipment."

"A snow course is a permanent site where manual measurements of snow depth and snow water equivalent are taken by trained observers. Measurements are usually taken around the first of the month during the winter and spring. Generally, the courses are about 1,000 feet long and are situated in small meadows protected from the wind." In addition, "NRCS installs, operates, and maintains an extensive, automated system to collect snowpack and related climatic data in the Western United States called SNOTEL (for SNOwpack TELemetry). Basic SNOTEL sites have a pressure sensing snow pillow, storage precipitation gage, and air temperature sensor." Monthly tabulations of snow depth and Snow Water Equivalent (SWE) are available from the NRCS; of these two, the SWE is a more robust and useful indicator of climate (since snow depth depends on the density of snow, which is of little importance once the water enters the hydrological system).

Of the 61 SNOTEL and Snow Survey stations within and near the three CAKN units, 56 are still in operation. Thirty sites have long enough records (as with Co-op sites, generally ten years or more) to allow the NRCS to compute standard 1971-2000 normals. For each of these sites, the SWE can be expressed as a percent of normal, and the maximum SWE in the spring, expressed as a percent of the normal maximum SWE, is a good indicatory of the total fall-winter-spring seasonal precipitation.

C. Remote Automated Weather Stations (RAWS)

Remote Automated Weather Stations (RAWS) are operated by a variety of federal and state agencies, and the real-time data is managed by the National Interagency Fire Center (NIFC) in Boise, Idaho, and archived by the Western Regional Climate Center (WRCC) in Reno, Nevada. Although the real-time data is immensely useful to land managers, and particularly wildland fire agencies, the periods of record are too short (the longest record in the area of interest begins in 1988) and the archived data has too many gaps to be useful for climate studies. Among the problems with the data are: A large number of completely missing months, particularly winter months; frequent gaps of several days or longer within a month (preventing the computation of a valid mean or total for that month); and under reporting of precipitation, particularly during the colder months, presumably due to problems with the tipping bucket rain gauges. Because of these issues, data from the 36 RAWS stations in and near CAKN units are not analyzed in this report.

3. 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. 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:

A. National Climate Data Center (NCDC)

National Climate Data Center home page:
http://www.ncdc.noaa.gov/oa/ncdc.html
Under "Data and Products", you may "Find a Station", which will take you to:
Locate Weather Observation Station Record
http://www.ncdc.noaa.gov/oa/climate/stationlocator.html

Or, from the home page, "Start Here..." will take you to...
"Search NCDC's Most Popular Products" (select country, data type, etc.):
http://www.ncdc.noaa.gov/oa/mppsearch.html

Or, go more directly to the data by going to "Get/View Online Climate Data":
http://www.ncdc.noaa.gov/oa/climate/climatedata.html
Select "Climatology & Extremes" for 1971-2000 normals.
Select "Surface Data", then "Monthly", then "Data Files: U.S. High Resolution--Select by Station (Cooperative, NWS)" to get to "Monthly Surface Data" for individual coop stations.

Annual climate summaries (monthly means, extremes, totals) for Coop stations:
http://hurricane.ncdc.noaa.gov/ancsum/ACS

NNDC Climate data online (select country; data type, e.g., monthly surface data; state; station):
http://cdo.ncdc.noaa.gov/CDO/cdo

The previous link will eventually take you to "Monthly Surface Data", where you select the state, station, data, etc.:
http://cdo.ncdc.noaa.gov/pls/plclimprod/somdmain.somdwrapper?datasetabbv=DS3220&countryabbv=&georegionabbv=&forceoutside=
The data in this link has a price, but is free to users on .gov and .edu servers.

U.S. Climate Normals (daily and monthly temperature and precipitation normals and probabilities for 1971-2000; CLIM20 station summaries for McKinley and other stations):
http://hurricane.ncdc.noaa.gov/cgi-bin/climatenormals/climatenormals.pl

B. Environment Canada.

The Canadian equivalent of NCDC is at Environment Canada. Daily and monthly data, and climatological summaries, are at:
http://www.climate.weatheroffice.ec.gc.ca/advanceSearch/searchHistoricData_e.html

C. Western Regional Climate Center (WRCC)

The WRCC is, in many ways, a “one-stop shopping” location for climate information for most observation sites. Climate averages and extremes, and monthly data (generally beginning around 1949 and regularly updated) are at:
http://www.wrcc.dri.edu/summary/climsmak.html

D. NASA Goddard Institute for Space Studies (GISS)

“GISS Surface Temperature Analysis” tables of monthly temperatures can be found at:
http://data.giss.nasa.gov/gistemp/
These tables go back to the very beginning of observations, in some cases to the 19th century. The record for some stations ends around 1990, but more recent data can be found from other sources. Some station records are combined records from two or more stations in the same locale (e.g., city and airport records), while two Alaskan stations - Anchorage and Fairbanks - have an "urban heat island" correction applied. However, the data records can be accessed either combined or individually, and with or without the heat island correction.

E. Alaska Climate Research Center (ACRC)

The ACRC (at the Geophysical Institute, University of Alaska Fairbanks), maintains a climatology web site:
http://climate.gi.alaska.edu/Climate/
Normals (1971-2000), extremes, etc. for Alaskan Coop stations are at:
http://climate.gi.alaska.edu/Climate/Location/
Monthly time-series data for some stations are at:
http://climate.gi.alaska.edu/Climate/Location/TimeSeries/index.html

F. Snow Surveys

Alaskan Snow Surveys are operated by Alaska Snow, Water and Climate Services (U.S. Department of Agriculture):
http://www.ambcs.org/
Current monthly and semi-monthly snow course data can be accessed from the U.S. Department of Agriculture / Natural Resources Conservation Service / National Water and Climate Center (NWCC):
http://www.wcc.nrcs.usda.gov/snowcourse/snow_rpt.html
While archived data is at:
http://www.wcc.nrcs.usda.gov/snowcourse/sc-data.html
More information (wind, temperature, etc.) from automated SNOTEL sites is at:
http://www.wcc.nrcs.usda.gov/snow/sntllist.html

G. Climate Diagnostics Center (CDC)

The Climate Diagnostics Center (CDC), a NOAA - University of Colorado cooperative research center, has climate summaries for Alaskan stations at:
http://www.cdc.noaa.gov/cgi-bin/USclimate/state.pl?lane=scroll&state=AK
However, the data is somewhat dated.
CDC also has descriptions of, and monthly and annual values of, all of the widely used Climate Indices (PDO, NP, etc.):
http://www.cdc.noaa.gov/ClimateIndices/List/
The CDC is also a source for the “NCEP/NCAR Reanalysis Monthly Means and Other Derived Variables”. According to the CDC web site, “the NCEP/NCAR (National Center for Environmental Prediction and the National Center for Atmospheric Research) Reanalysis project is using a state-of-the-art analysis/forecast system to perform data assimilation using past data from 1948 to the present. A subset of this data has been processed to create monthly means of a subset of the original data.” In other words, archived surface and radiosonde data has been reanalyzed to produce

4-times daily surface and upper level weather maps. In this study, the upper level analyzed data has been used to reconstruct the climate of the summit of Denali. The reanalysis is at:
http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.derived.html

H. Remote Automated Weather Stations (RAWS)

Remote Automated Weather Stations (RAWS) are operated by the National Interagency Fire Center (NIFC) in Boise, Idaho:
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/
Archived RAWS data is managed by the WRCC. For the purposes of this study, the data are not complete enough to the useful for climate studies. Data for Alaskan stations:
http://www.wrcc.dri.edu/wraws/akF.html
Stations inside National Parks:
http://www.wrcc.dri.edu/NPS.html

4. Alaska climate monitoring stations – list and maps

A. Appendix 1, Alaska Station Data Inventory

Appendix 1, "Alaska Station Data Inventory", lists all of the Coop, Snow course and SNOTEL, and RAWS stations in and adjacent to CAKN units for which data was located. The stations are sorted by type of station, then by location (inside or surrounding a CAKN unit), and then alphabetically by name. Information given includes the latitude, longitude, and elevation of the site, the period of record, the availability of climatological normals, and sources of data for the station.

Figure 1. Location of NWS Coop stations in central Alaska (from NOAA/NCDC)

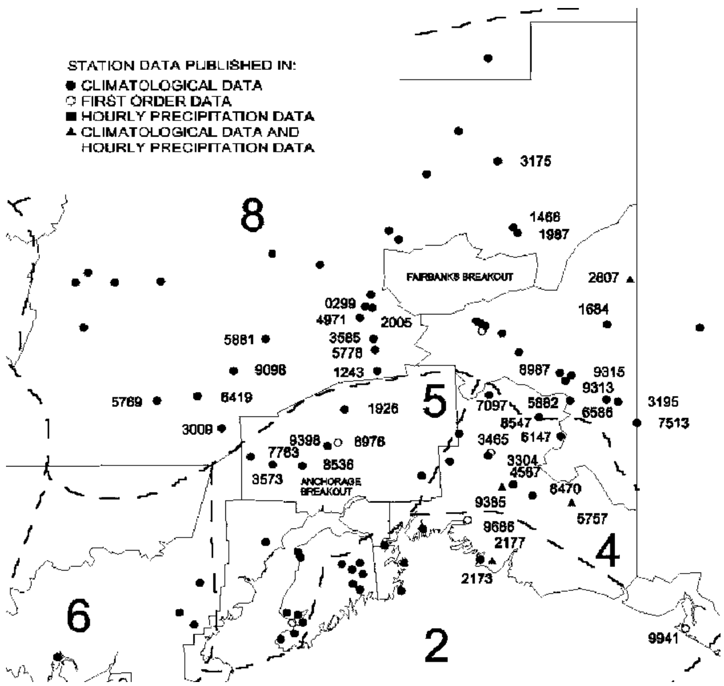
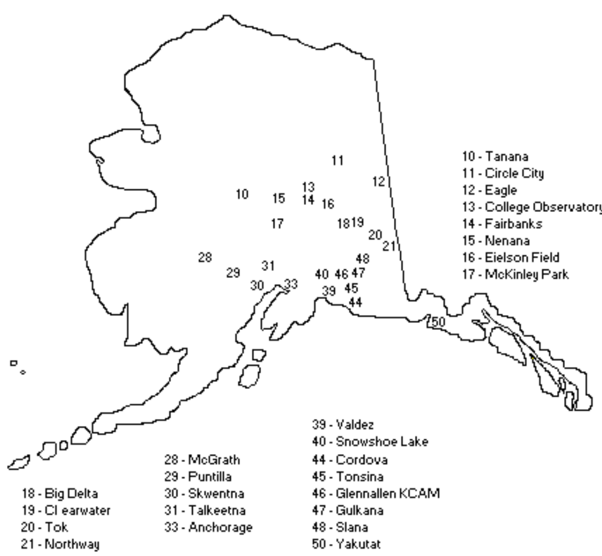


Figure 2. Stations in Alaska for which the WRCC has data files and summaries (from WRCC)



The following four maps (Figs. 3 through 6) show the Cartesian locations of all stations in the inventory, and the locations of each type of station,plotted on a latitude-longitude grid..

Figure 3. All stations (NWS Coop, Snow Survey, and RAWS)

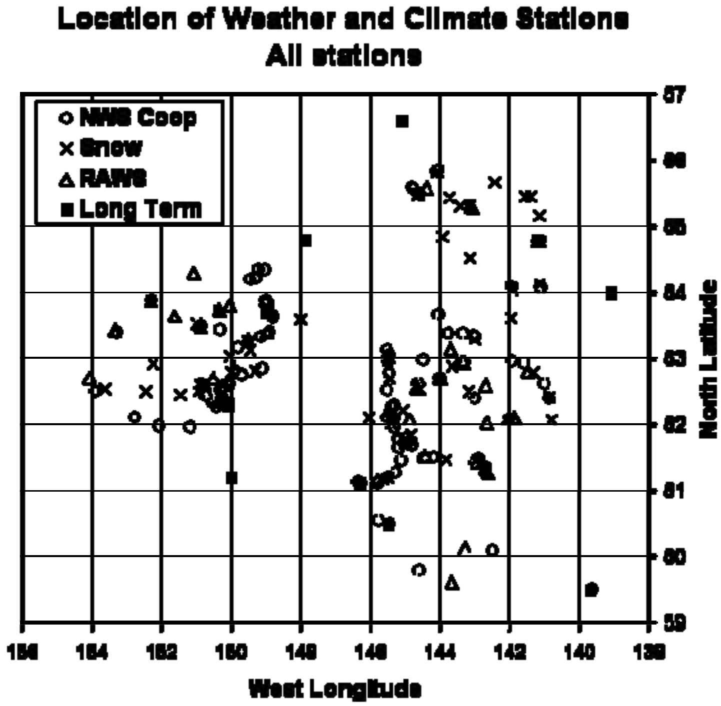


Figure 4. NWS Cooperative Stations

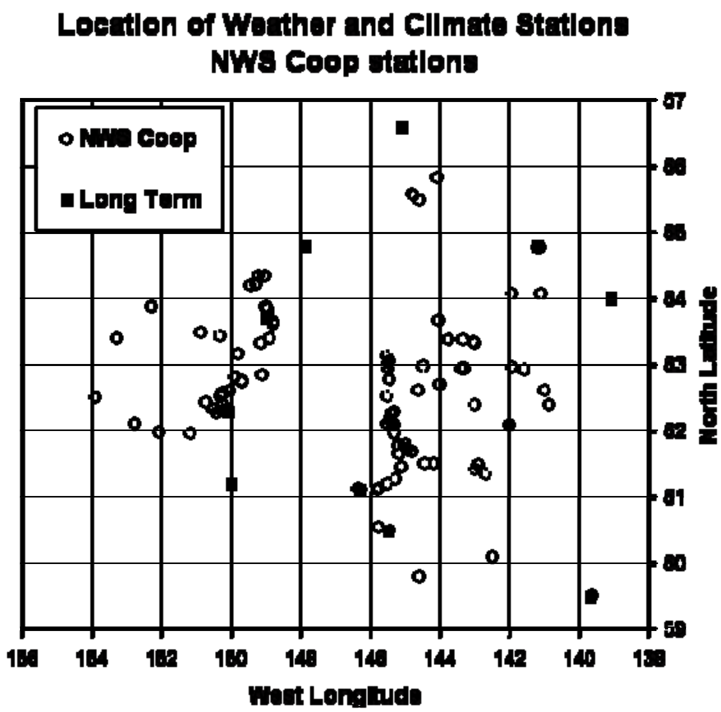


Figure 5. Snow Survey sites

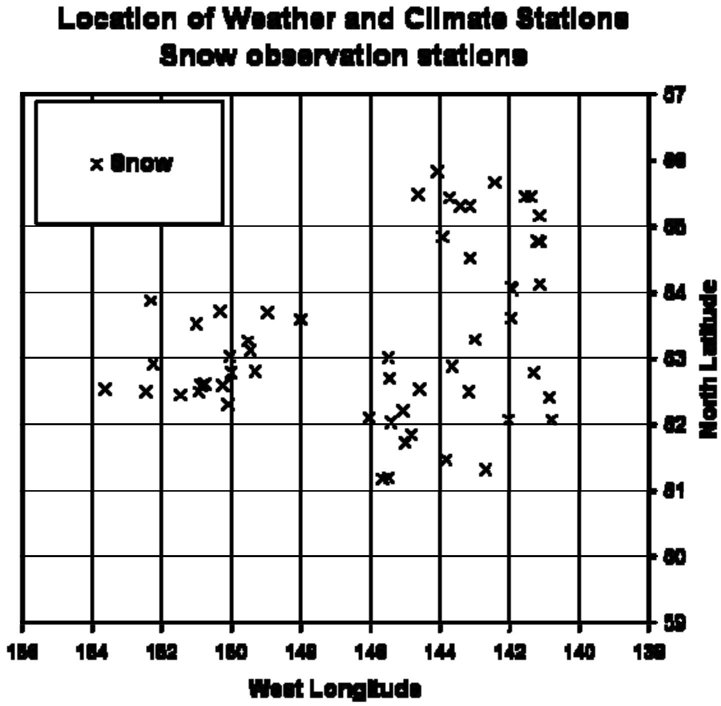
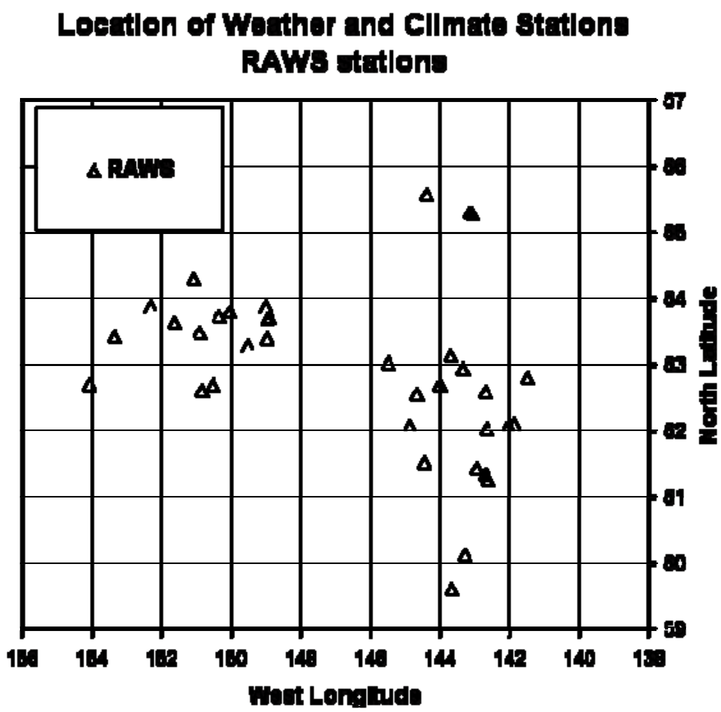


Figure 6. RAWS Stations



The next two figures (7 and 8) show the locations of snow survey sites in central and south central Alaska (from NRCS):

Figure 7. Snow Survey sites in interior Alaska.

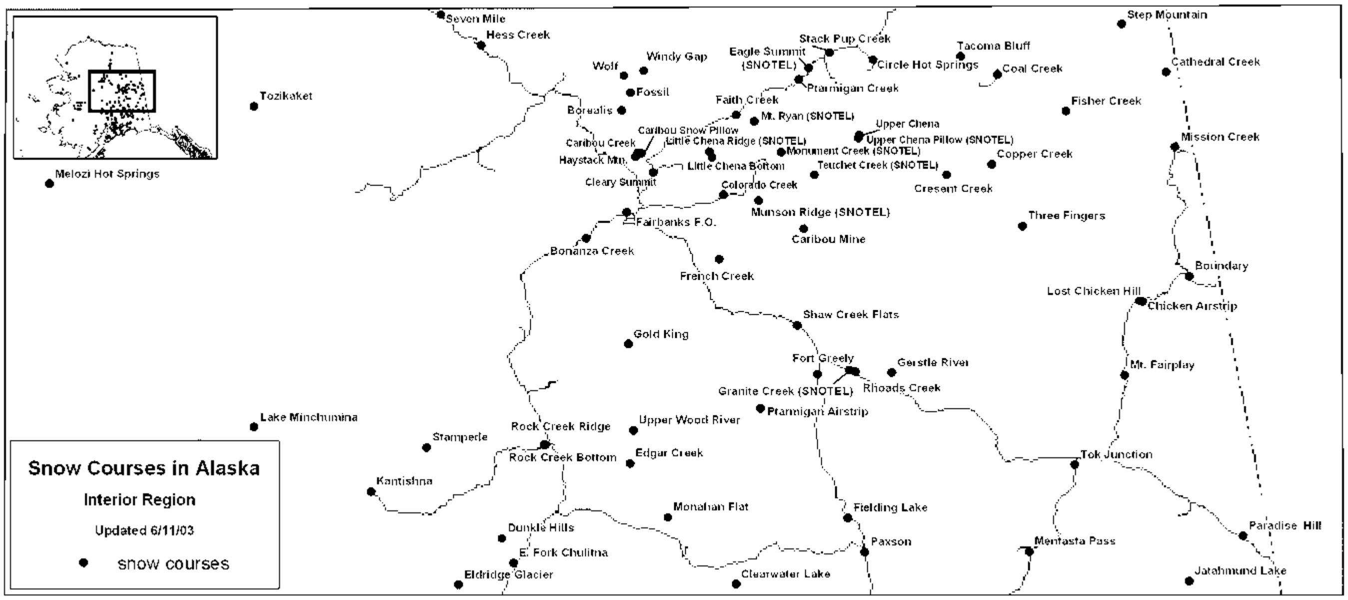
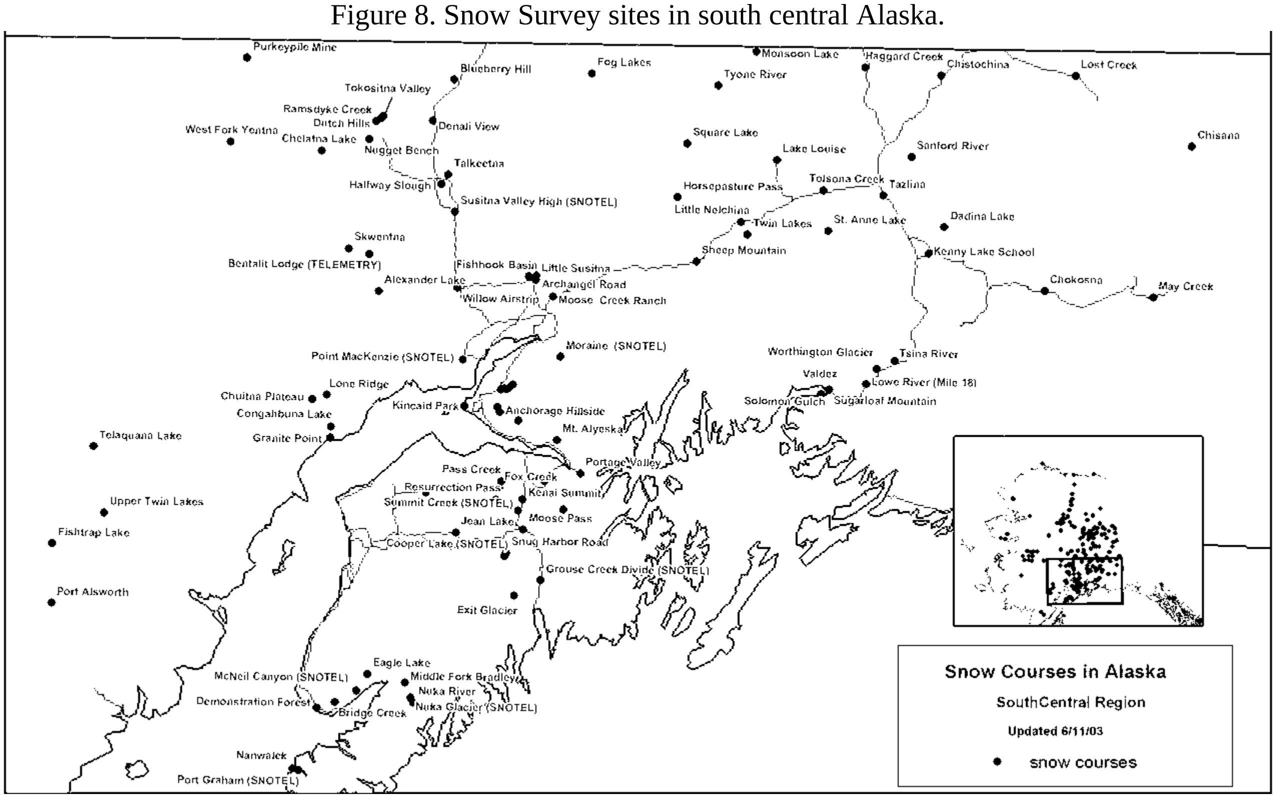


Figure 8. Snow Survey sites in south central Alaska.



5. Data Summaries – Normals, means, extremes

A. Appendix 2, "Coop Station Normals"

According to World Meteorological Organizations (WMO) standards for computing climatological normals for the standard 1971-2000 period, a station must have at least 10 years of record for each calendar month. The station must also have been active since 1999. The NWS and NCDC have computed normals for all qualifying stations, and the temperature and precipitation normals for stations in the CAKN region are tabulated in Appendix 2, "Coop Station Normals".

B. Appendix 3, "Alaska Snow Course SWE Averages 1971-2000

Similarly, the National Water and Climate Center (NWCC) has published 1971-2000 averages for qualifying snow survey sites, and these normals are listed in Appendix 3, "Alaska Snow Course SWE Averages 1971-2000".

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

NCDC has also published more comprehensive CLIM20 (Climatography of the United States NO.20, 1971-2000) summaries for 18 stations in central and south-central Alaska, including eight stations inside and adjacent to CAKN units. The locations and periods of records for these stations are listed in Appendix 4, "CAKN area stations with published CLIM20 Summaries". The CLIM20 summary for the McKinley National Park station (the only CLIM20 station located within a CAKN unit) is included in the Appendix.

6. 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.

A. Temperature

The 99 catalogued Coop stations have periods of record ranging from 1 to 106 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 > 10 years
- 9 stations have records > 80 years

In some cases, stations can be combined with nearby stations with different periods of record to produce longer times series.

The 36 RAWS stations have periods of record ranging from 1 to 17 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 82 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	83	<1	
Fairbanks (Univ Exp Stn)	101	1	Fairbanks City, Eagle
Talkeetna	87	2	Anchorage
Yakutat	88	2.5	Cordova
Cordova	88	3	Valdez
Valdez	95	5	Cordova
Eagle	96	19	Dawson
Fort Yukon	106	29	Eagle 3 years, Circle City 1 year, Circle Hot Springs 1 year, Central No.2 24 years (including 1997-present)
McCarthy	87	---	Gulkana 1914-20, 1948-50 Kennecott 1922-47 Chitina 1950-63 May Creek 1963-67 McCarthy 1 NE 1967-83 McCarthy 3 SW 1984-present

The following figures (9 through 12) show the locations, length of record, and annual mean temperature for these long term stations.

Figure 9. Cooperative stations with 82 or more years of record. The records from pairs of stations connected by lines were combined for producing continuous time series.

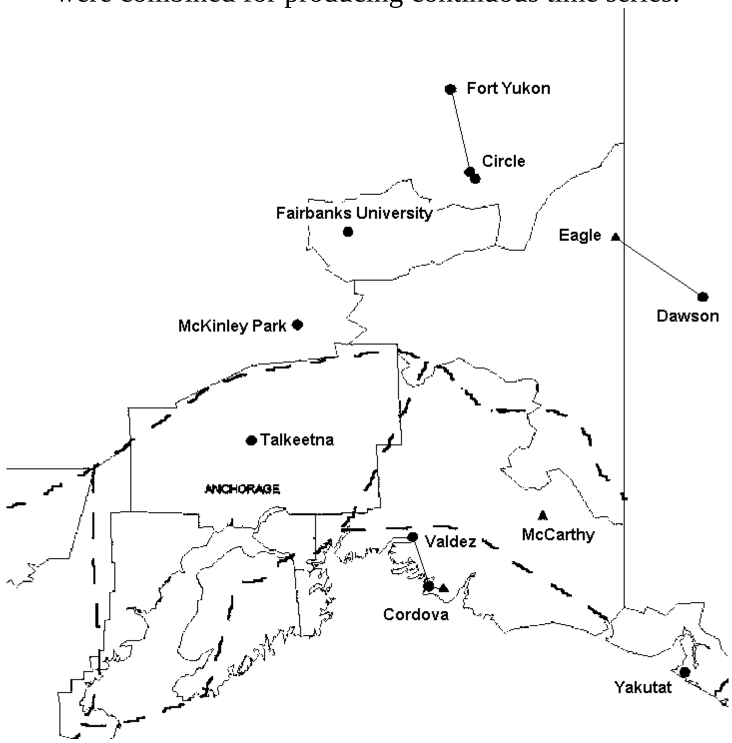


Figure 10. Location of 12 long-term climatological stations.

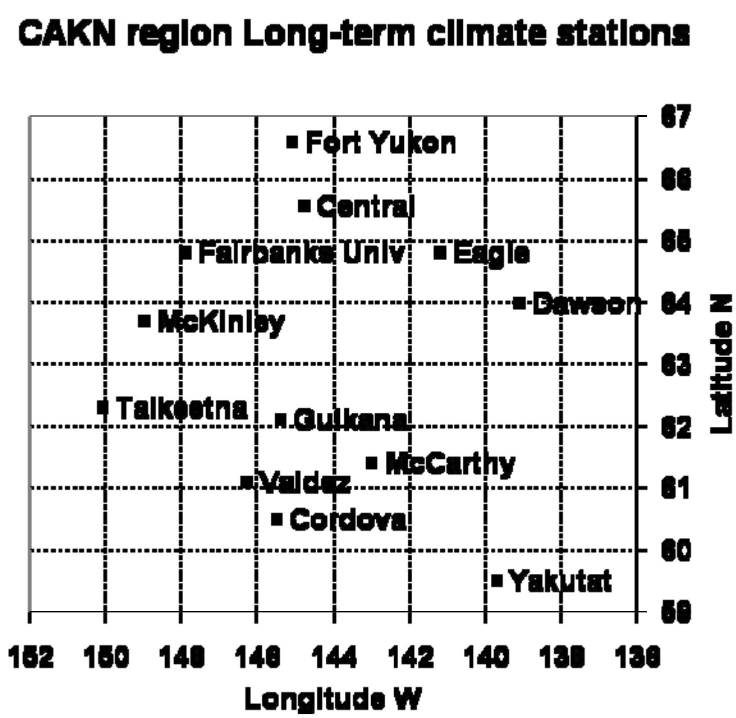


Figure 11. First year of continuous record for 12 stations

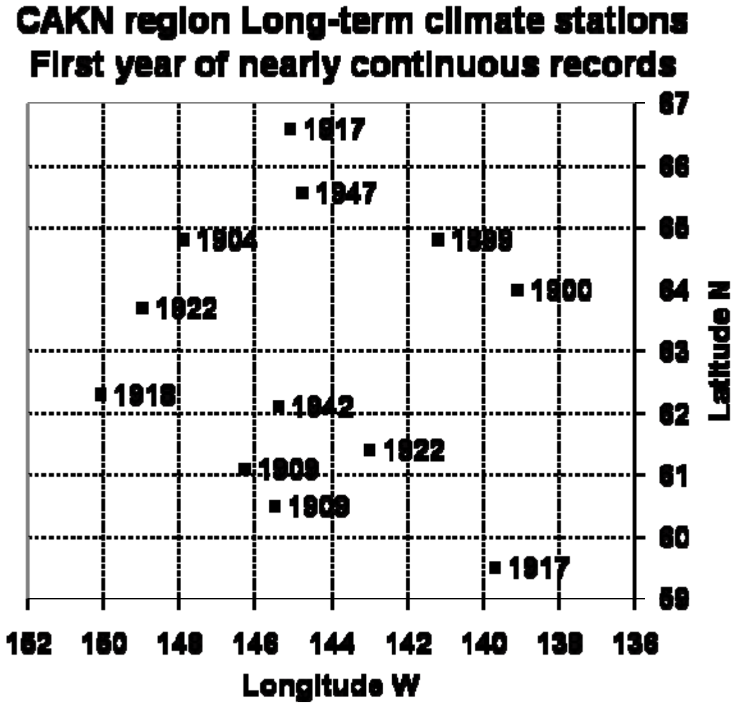
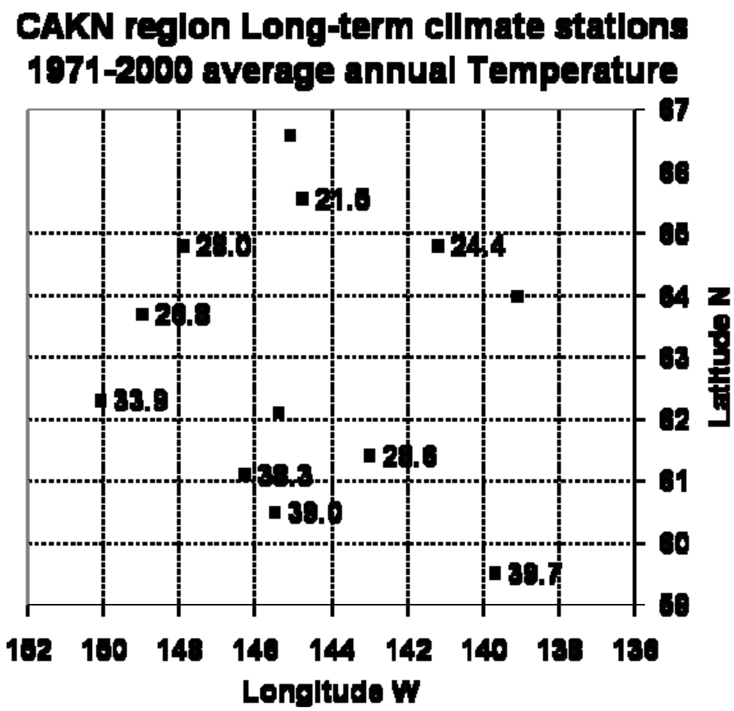


Figure 12. 1971-2000 climatological normal annual temperatures for 9 stations.



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.

Figure 13. 105 year record of Eagle annual temperatures.

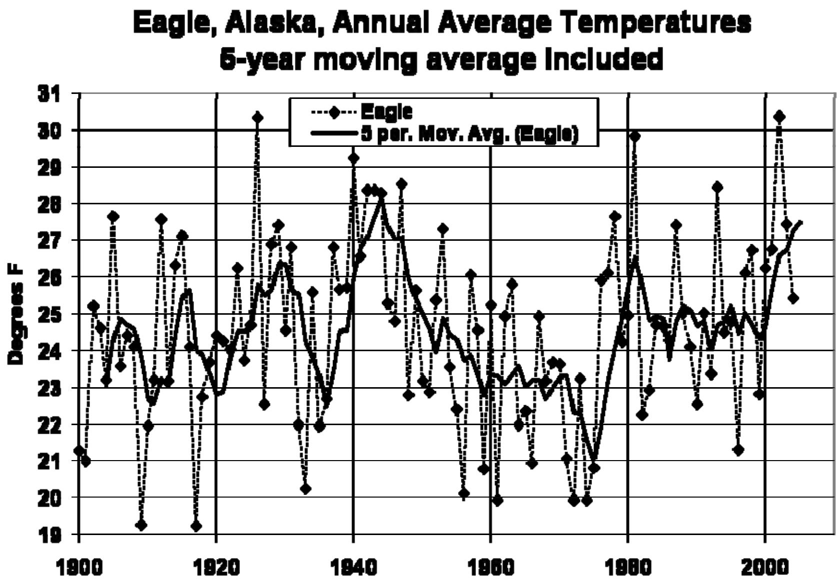
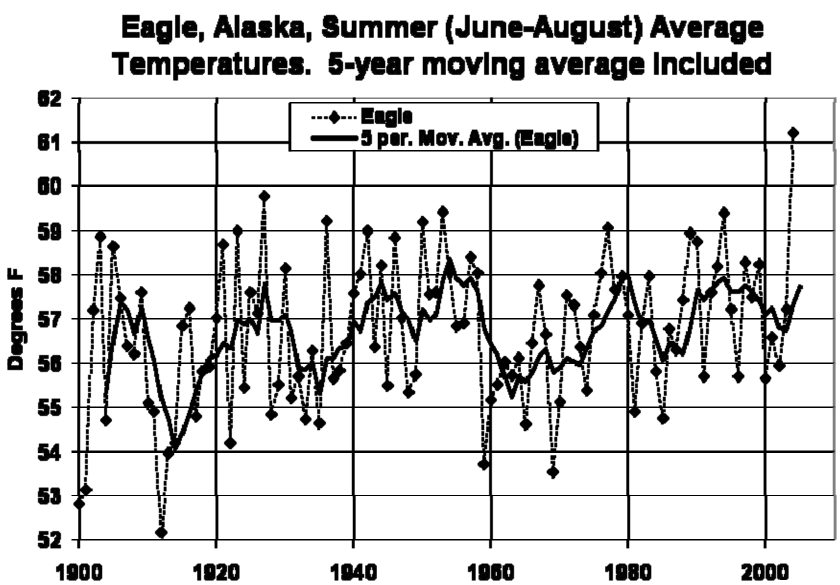


Figure 14. 105 year record of Eagle summer temperatures.



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:

Figure 15. 80 years of summer maximum temperatures at McKinley.

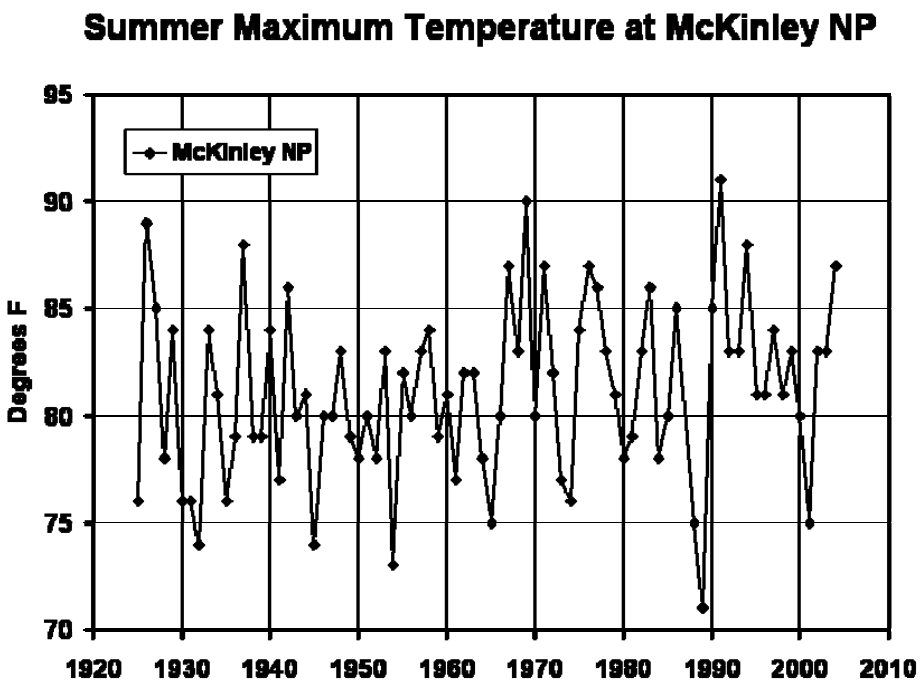


Figure 16. 80 years of summer maximum temperatures at Eagle and Cordova.

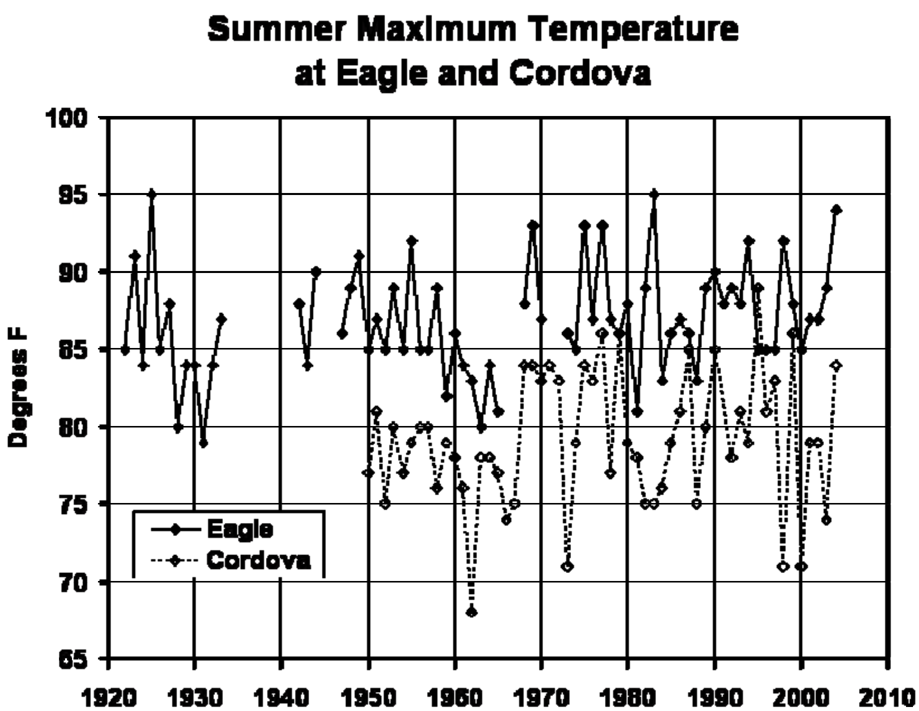
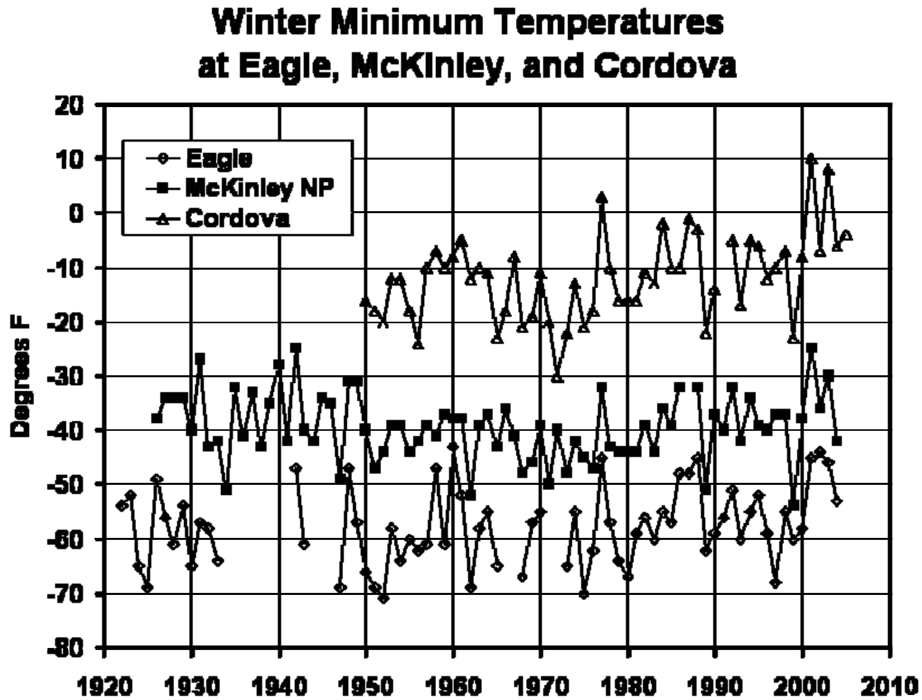
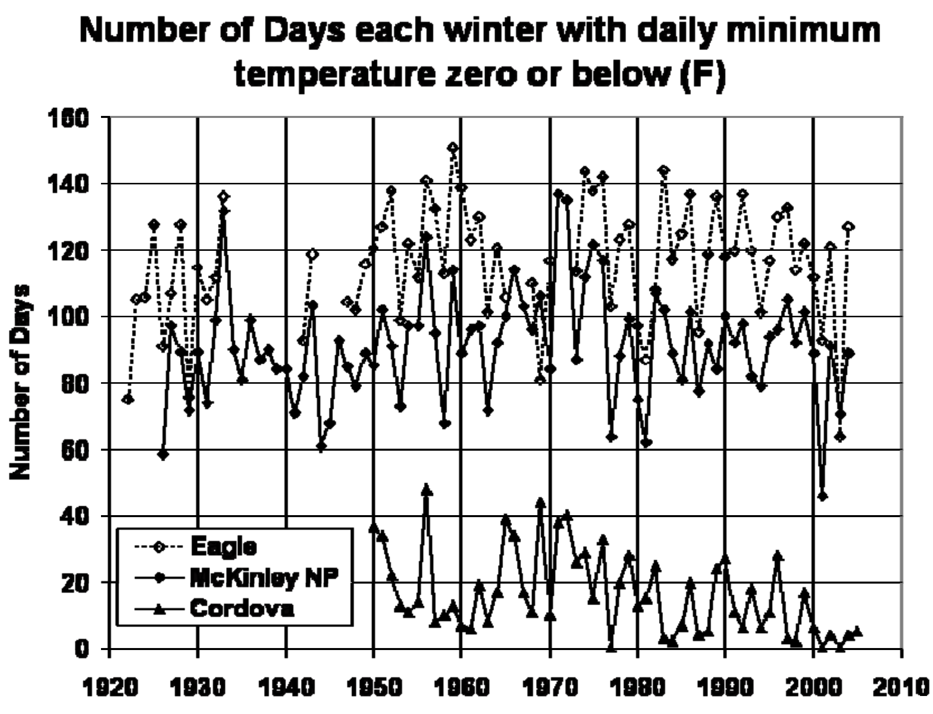


Figure 17. Winter minimum temperatures at Eagle, McKinley, and Cordova.



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



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 19. CAKN Temperature departures, Coldest year 1956

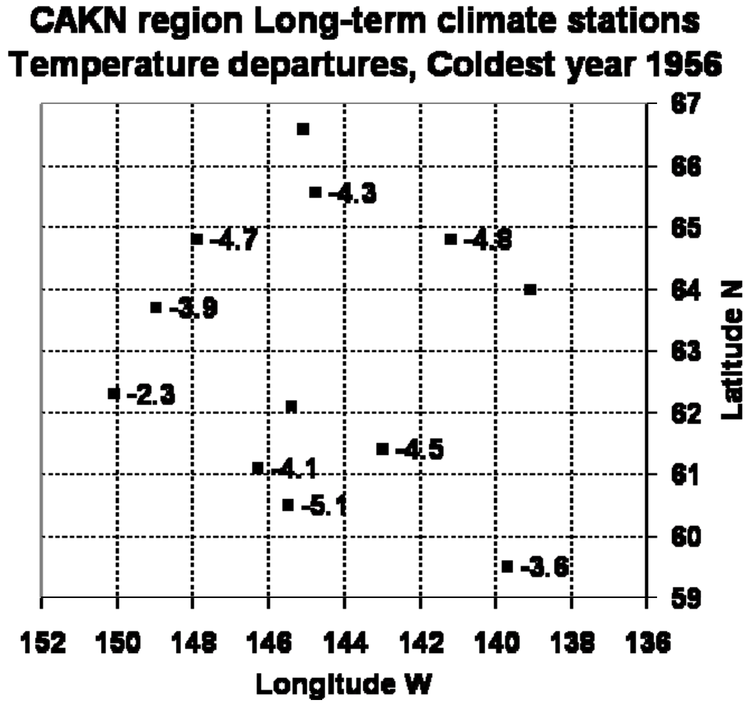


Figure 20. CAKN Temperature departures, 2nd coldest year 1972

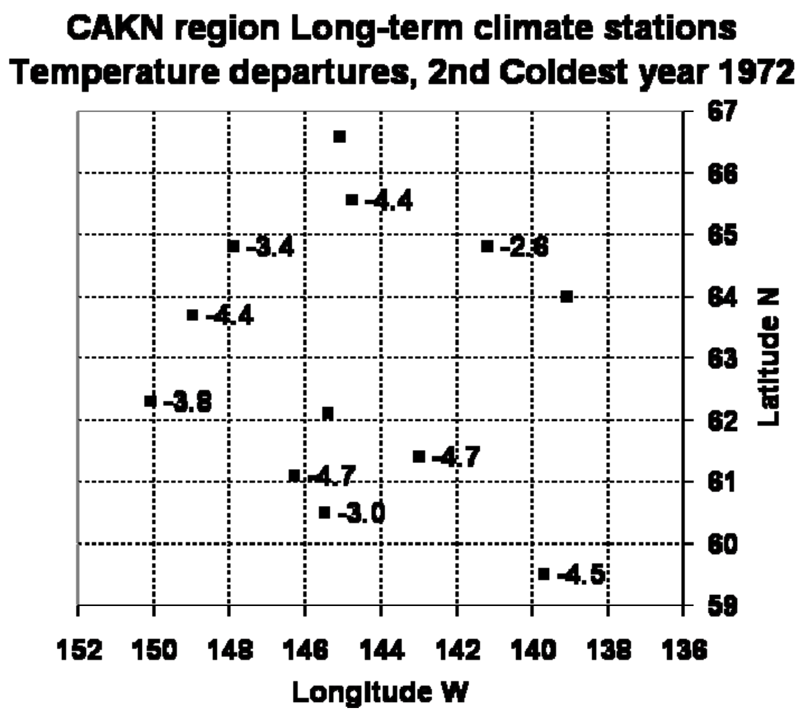


Figure 21. CAKN Temperature departures, Cold year 1996

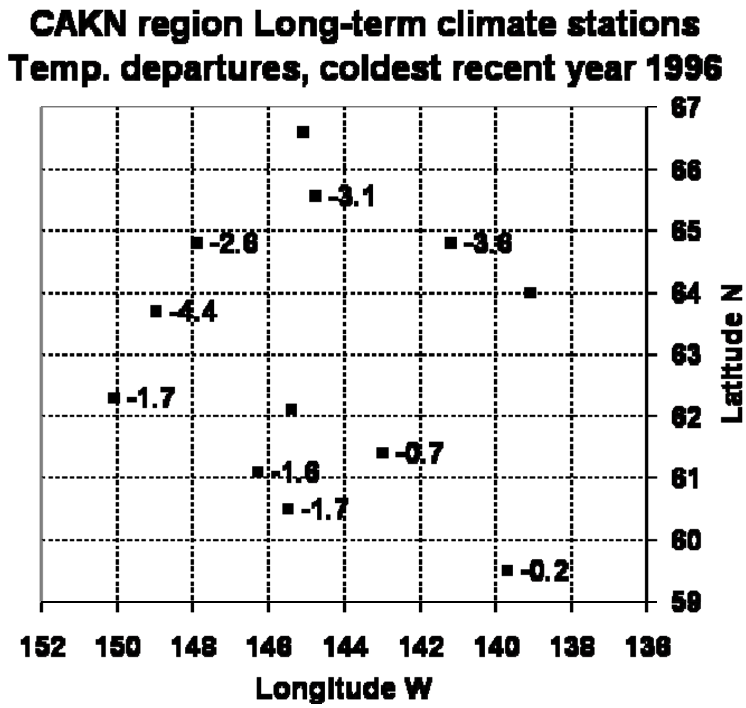


Figure 22. CAKN Temperature departures, Coldest winter 1965

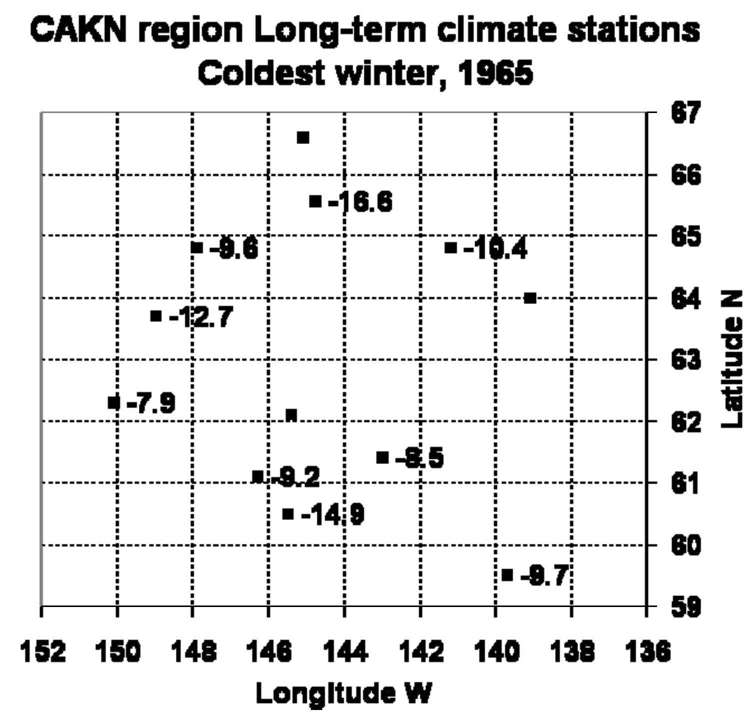


Figure 23. CAKN Temperature departures, Cold winter 1999

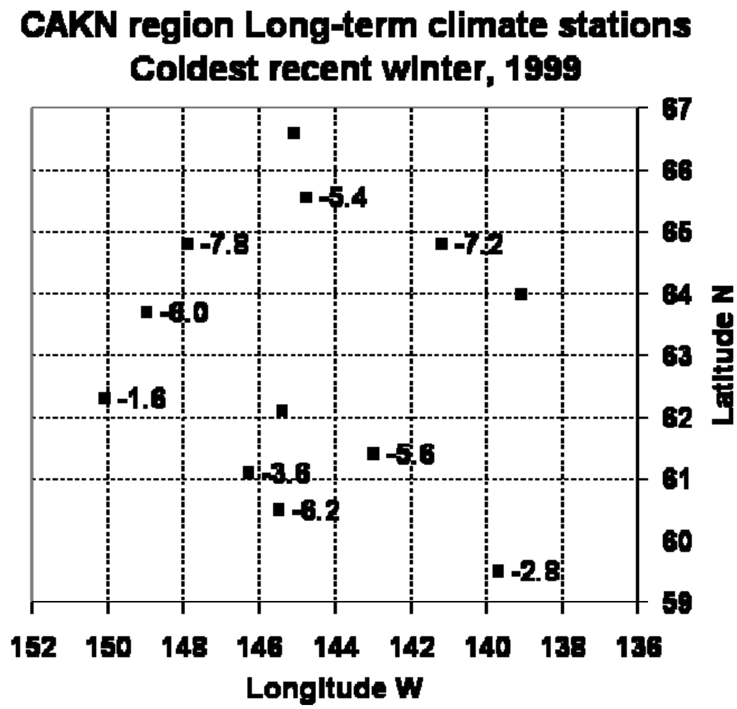


Figure 24. CAKN Temperature departures, Coldest summer1965

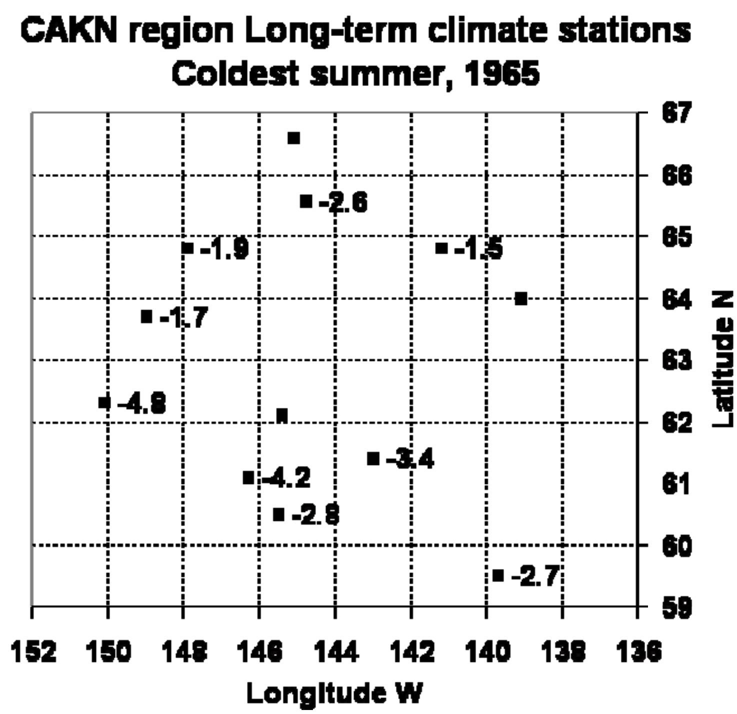


Figure 25. CAKN Temperature departures, Warmest year 1926

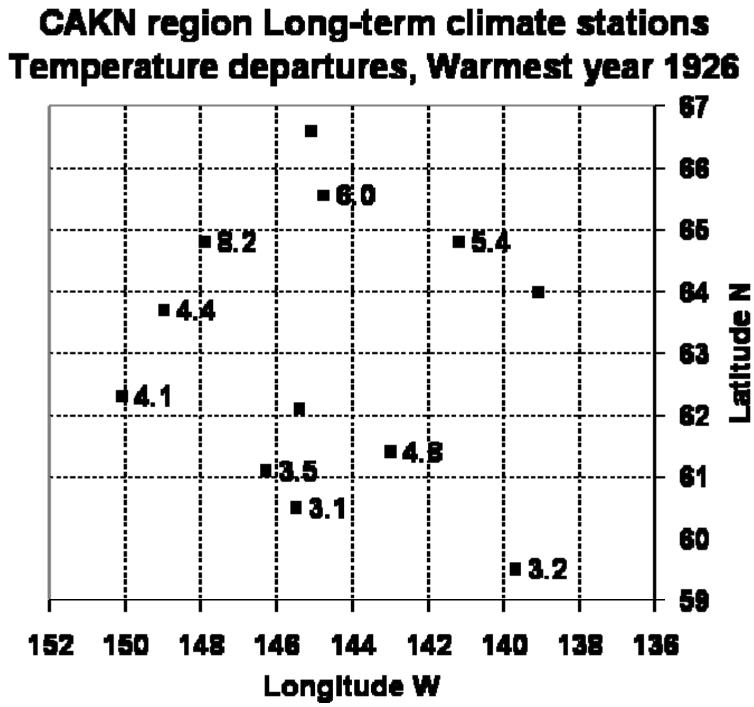


Figure 26. CAKN Temperature departures, Warm year 2002

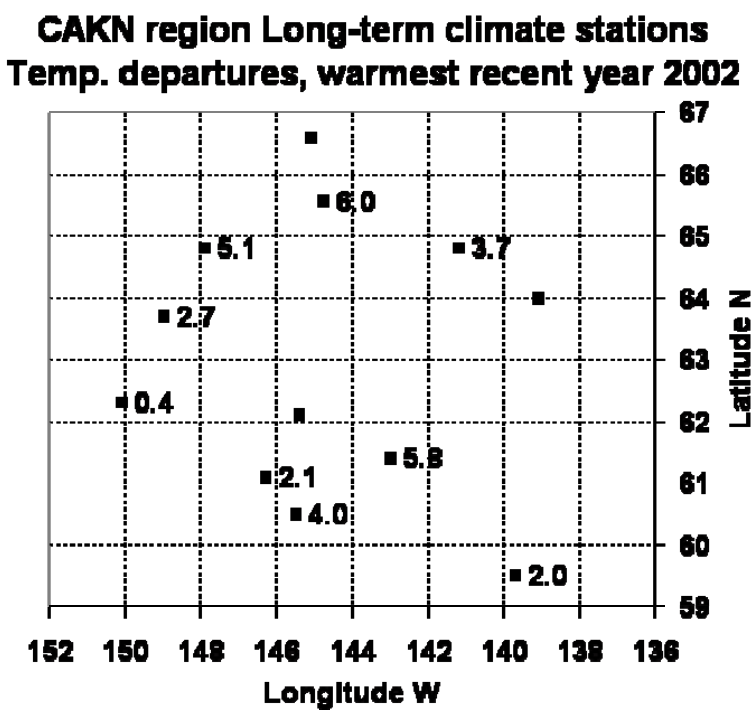


Figure 27. CAKN Temperature departures, Warmest summer 2004

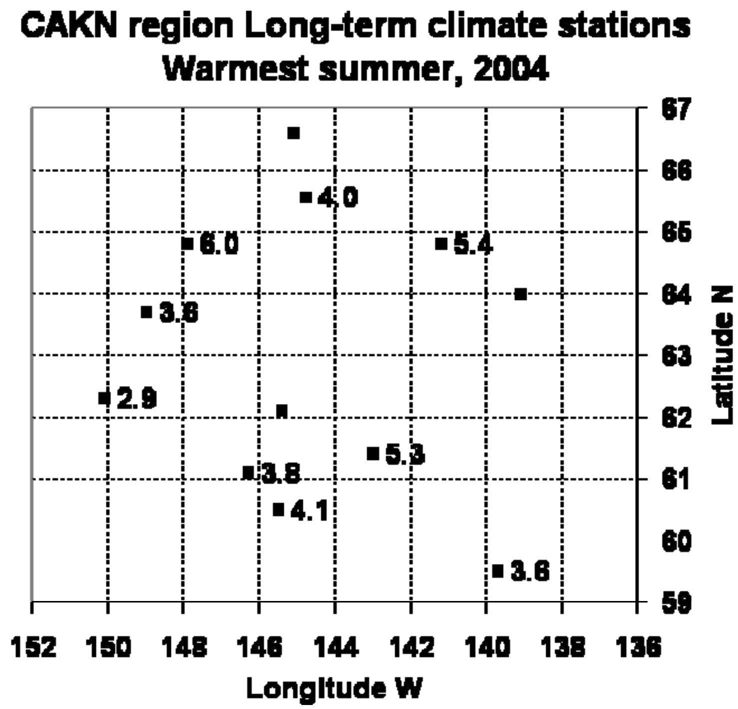


Figure 28. CAKN Temperature departures, Warmest winter 1977

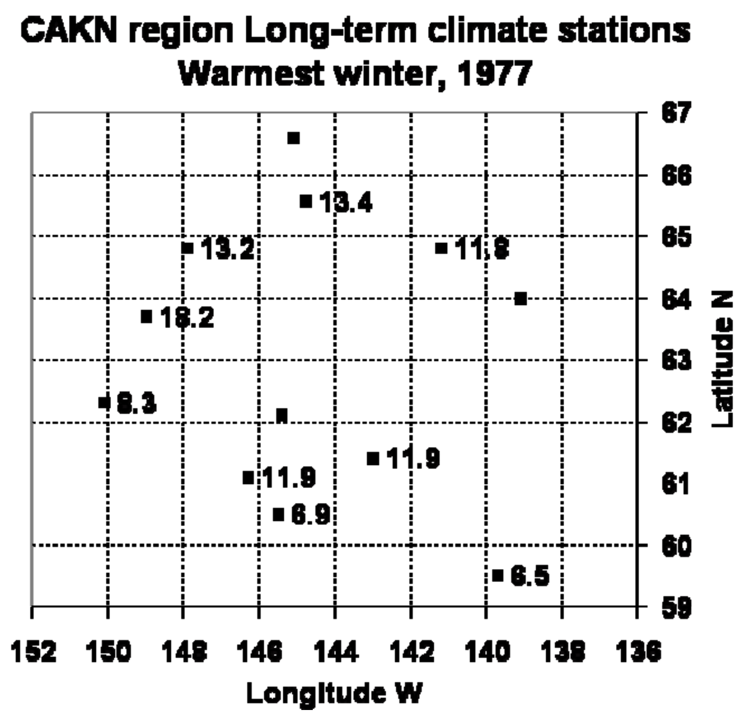
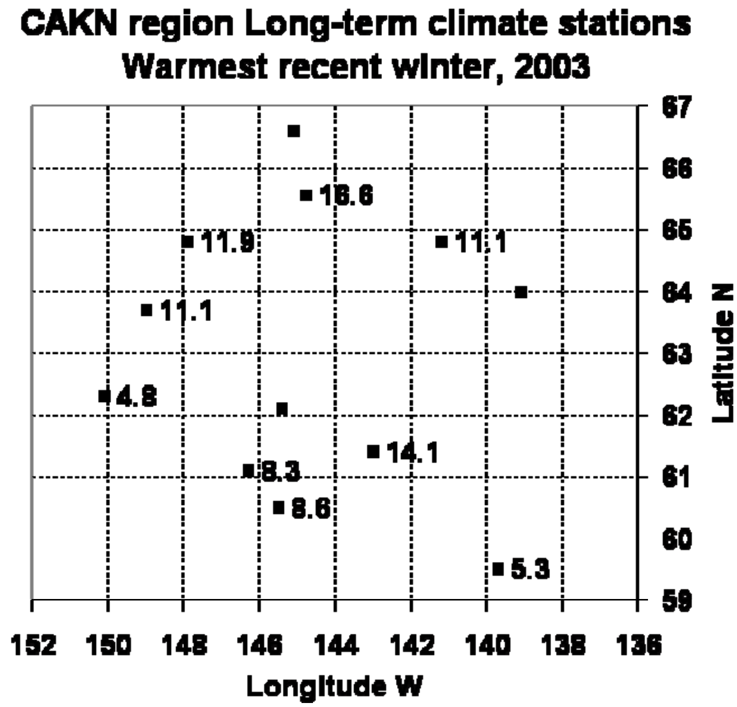


Figure 29. CAKN Temperature departures, Warm winter 2003



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 0.65 to 0.89. For winter (December-February) temperatures, the correlations are even better, ranging from 0.84 to 0.94. Correlations for annual mean temperatures range from 0.77 to 0.92.

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.

Figure 30. 105 year record of regional Annual Average Temperature

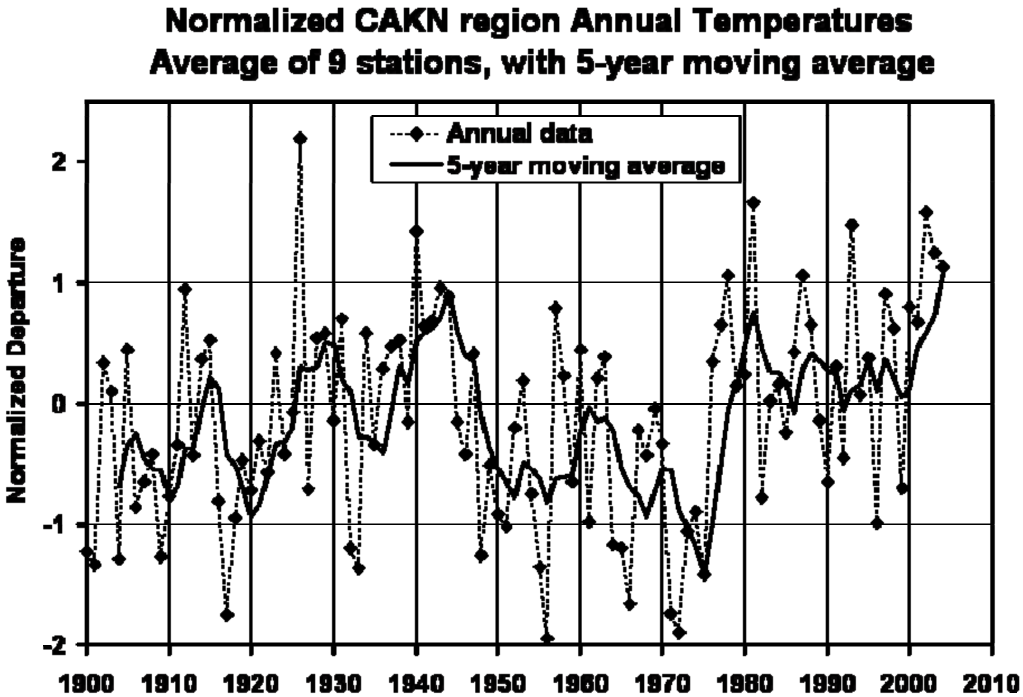


Figure 31. 105 year record of regional Summer Average Temperature

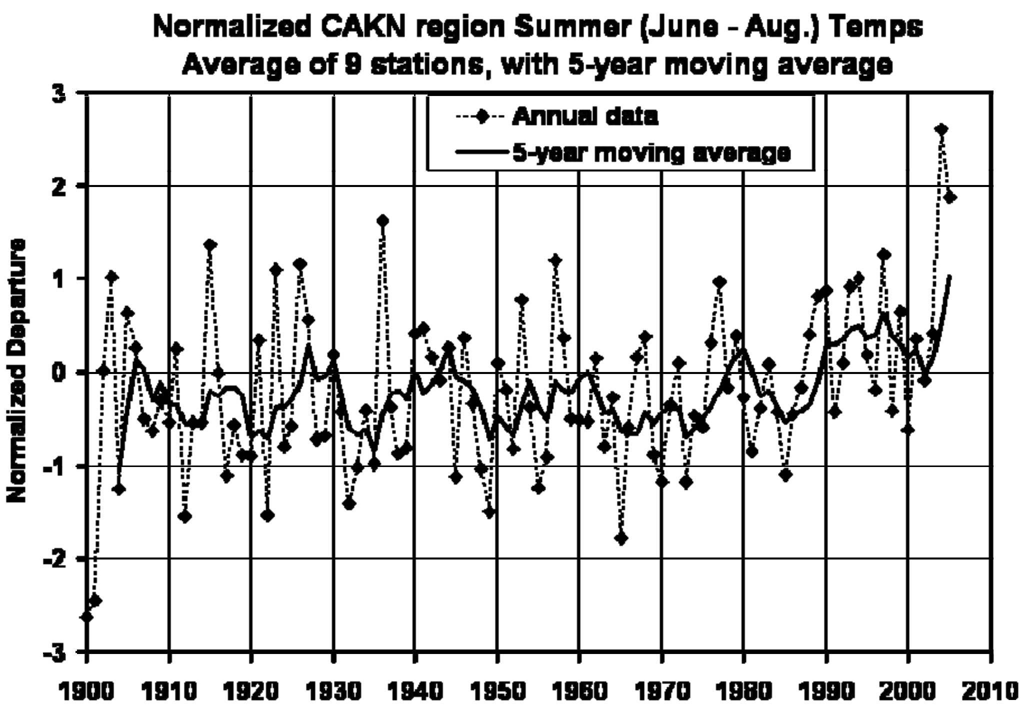
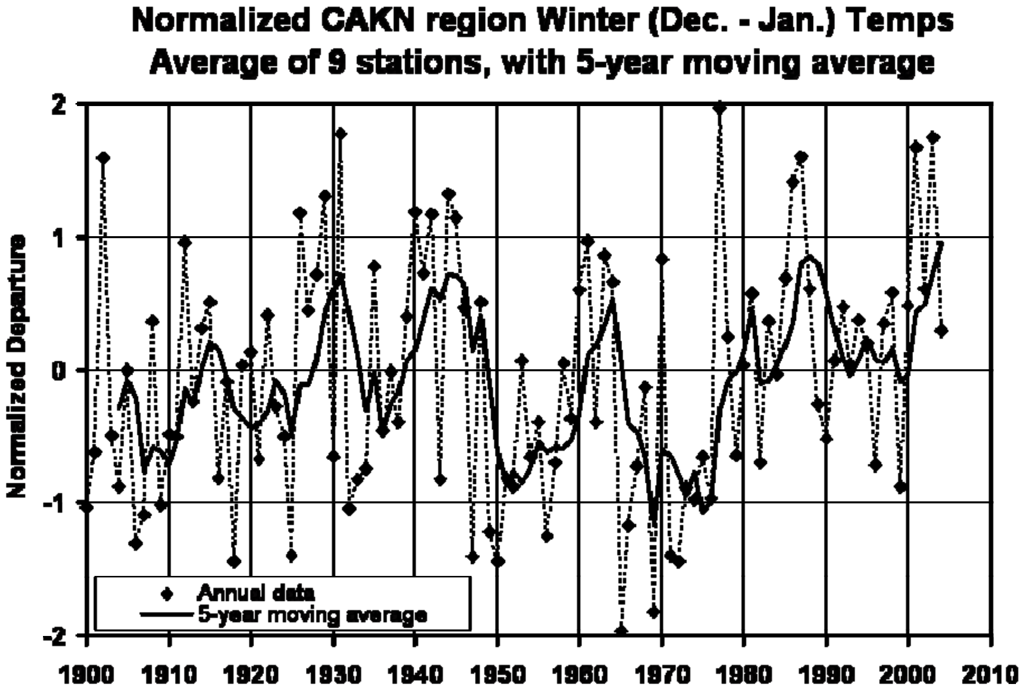


Figure 32. 105 year record of regional Winter Average Temperature



The next three figures show the annual normalized departures converted to degrees C, for comparison with annual temperatures for the grid area 60 to 65 North, 140 to 155 West, from the global temperature data sets of the Global Historical Climate Network (GHCN) and Jones et al.

Figure 33. 105 year record of regional Annual Average Temperature, degrees C

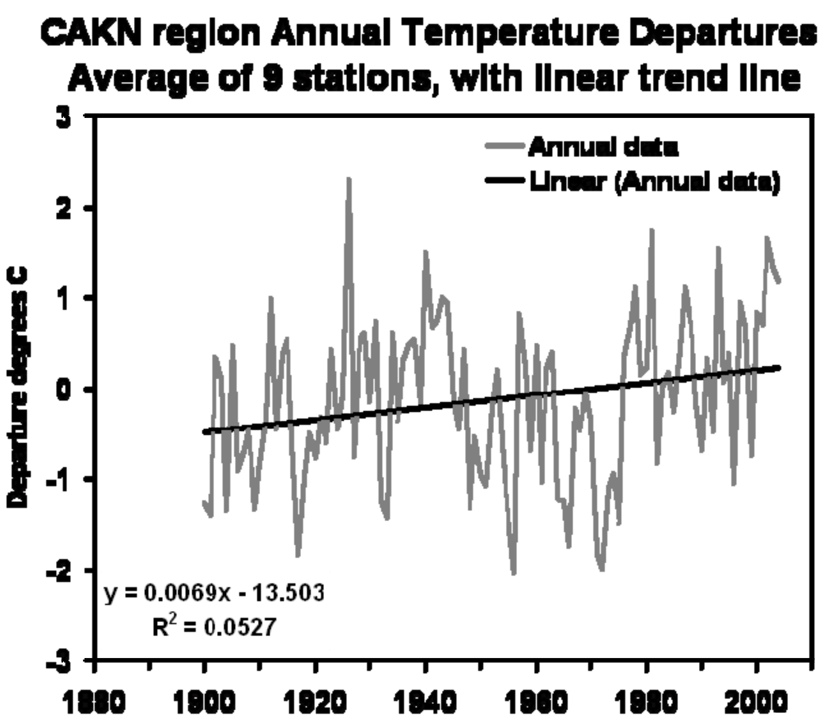


Figure 34. 105 year record of regional Annual Average Temperature, degrees C, from Jones et al.

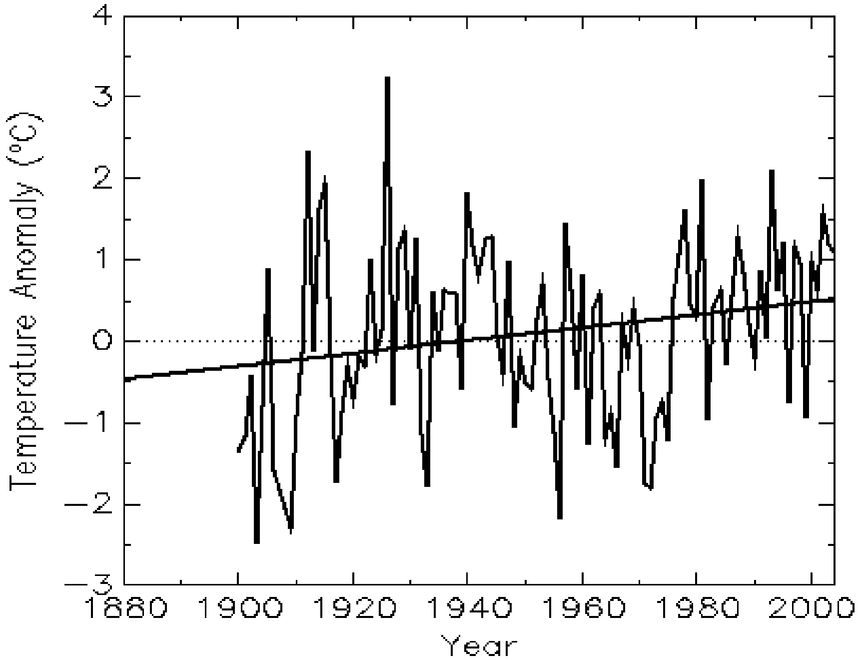
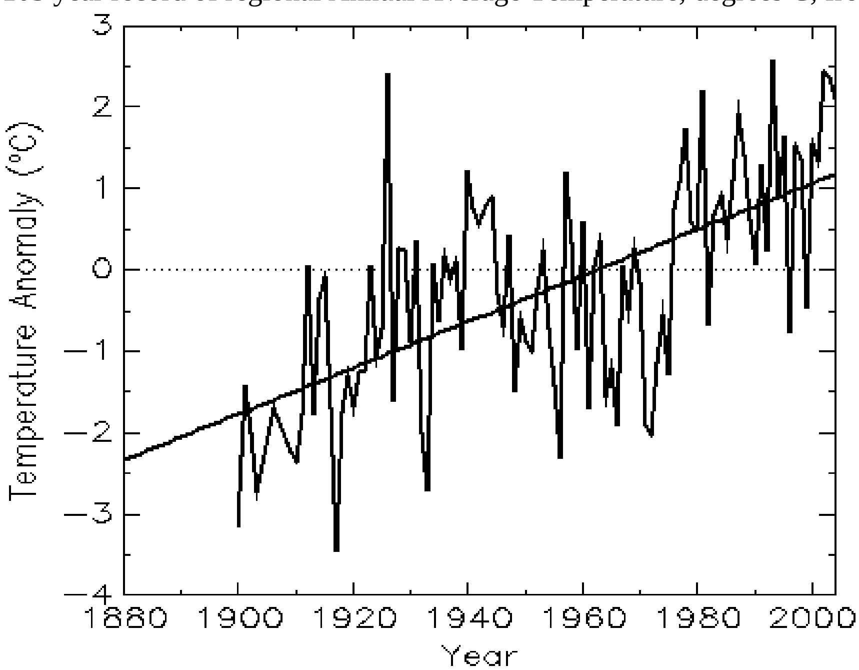


Figure 35. 105 year record of regional Annual Average Temperature, degrees C, from GHCN



The annual temperatures in this study are very similar to those of Jones et al., the largest difference being due to the normalizations procedure used in this study. The GHCN time series differs most dramatically, most likely because of a different selection and/or weighting of stations and because of a series of adjustments made to the GHCN data. The trends computed from the three time series are:

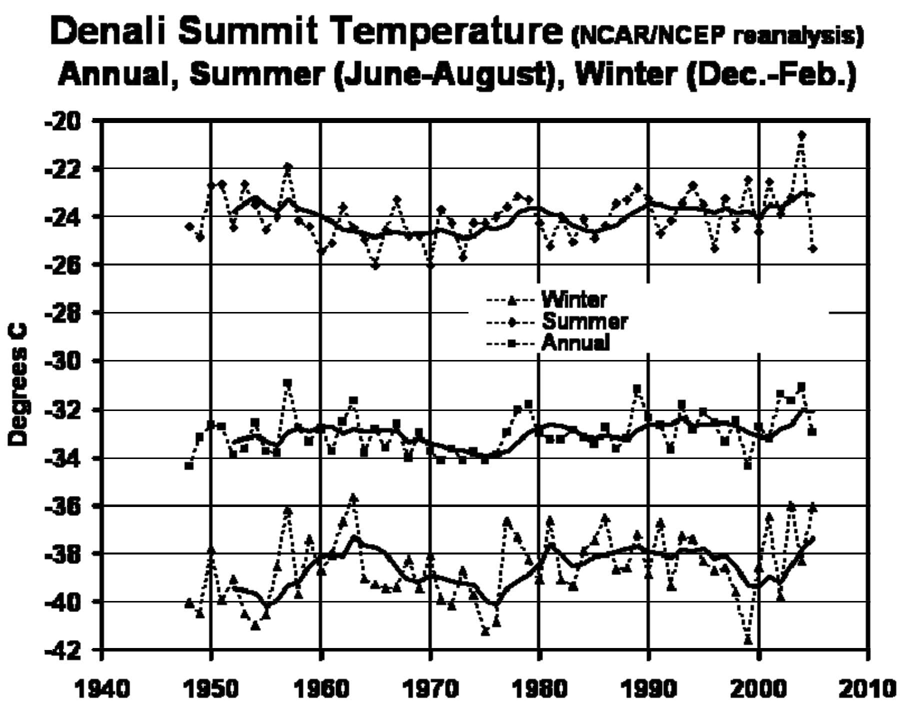
This Study	0.69 C/century
Jones et al.	0.79 C/century
GHCN	2.83 C/century

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 Jones et al. data set is produced by the Climate Research Unit of the University of East Anglia and the Hadley Center of the United Kingdom Meteorological Office, and also is composed of annual temperature data at a grid-box resolution of 5° latitude by 5° longitude.
Jones, P.D., Parker, D.E., Osborn, T.J. and Briffa, K.R. 1999. Global and hemispheric temperature anomalies -- land and marine instrument records. In *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, TN, USA.

Finally, although there has been no long-term climate observations made from the summit of Denali (despite several attempts to achieve this), summit temperatures can be estimated from upper air temperature and pressure data produced by the NCEP/NCAR Reanalysis project. The Reanalysis data, available from the Climate Diagnostics Center (CDC), includes temperature and pressure height data at 2.5-degree grid intervals of latitude and longitude. Denali summit temperatures are estimated from data for 62.5 degrees North, 210 degees 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, the temperatures at the 6194 meter summit of Denali can be interpolated. Interpolated annual, summer, and winter temperatures are shown in the next figure.

Figure 36. Denali summit temperatures, from NCAR/NCEP re-analysis.



B. 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
- 14 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 37. Denali area Snow Water Equivalent (SWE), from records at 19 snow survey sites.

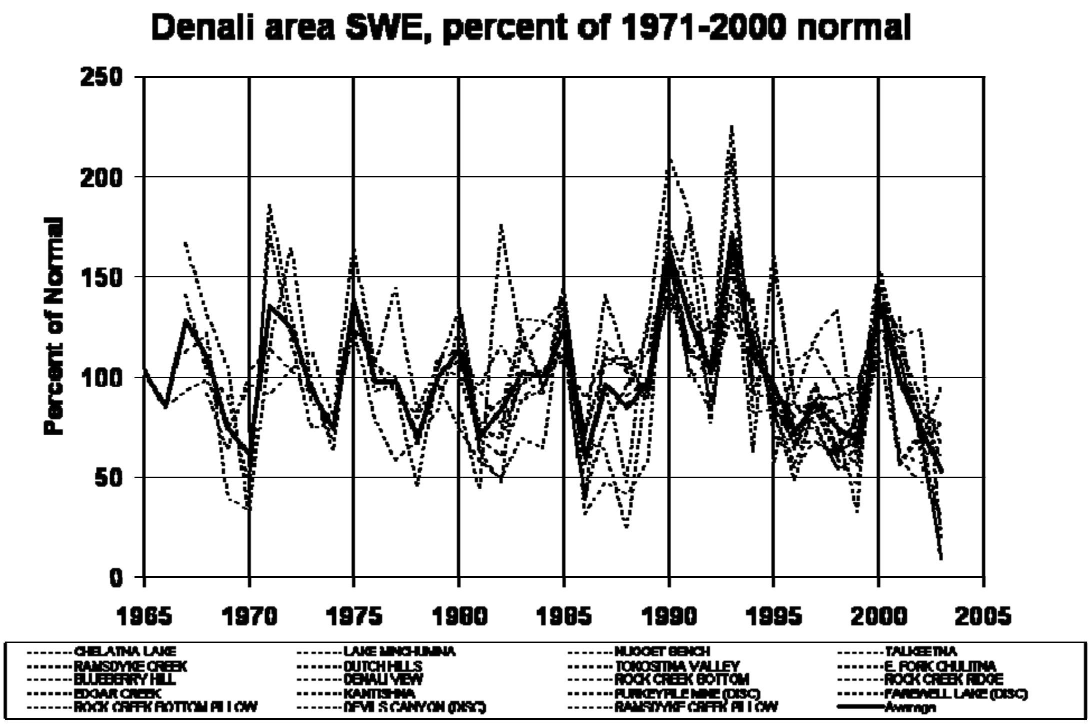


Figure 38. Wrangell-St. Elias area Snow Water Equivalent (SWE), from records at 18 snow survey sites.

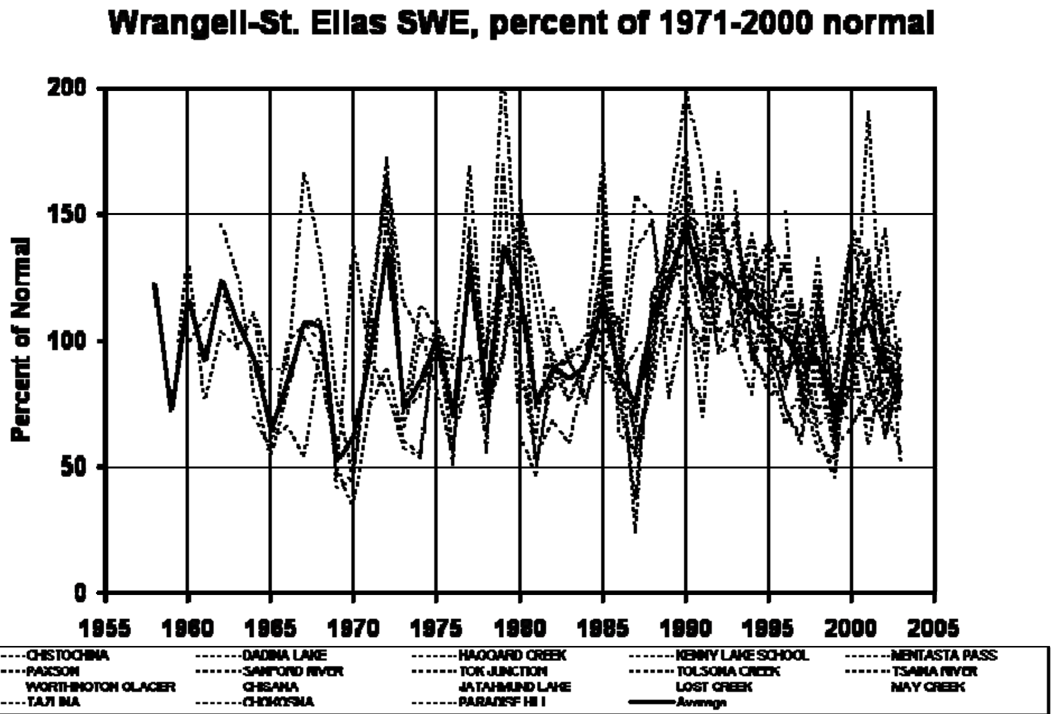
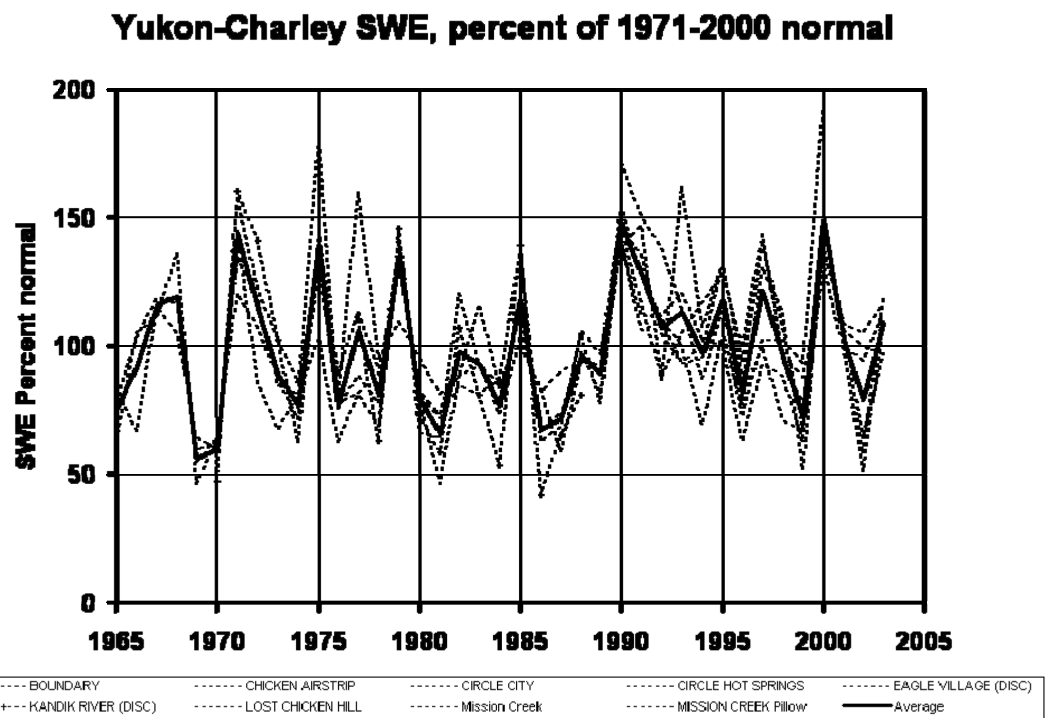


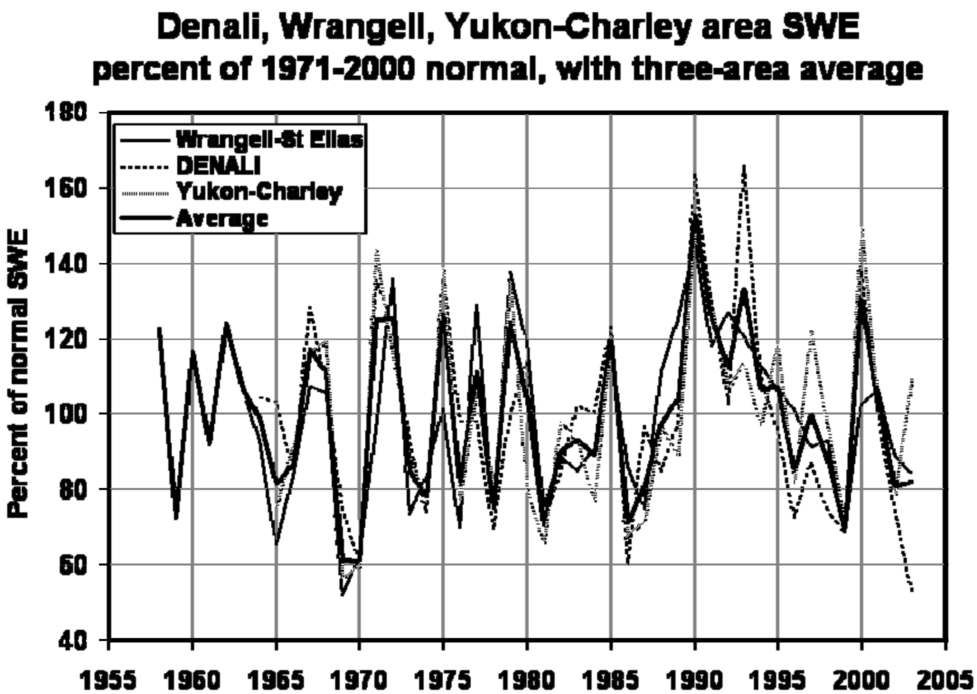
Figure 39. Yukon-Charley area Snow Water Equivalent (SWE), from records at 9 snow survey sites.



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 0.46 to 0.97, and the average of the 19 correlation coefficients is 0.83. For Wrangell-St. Elias, the 18 site correlation coefficients range from 0.36 to 0.84, averaging 0.65; within Yukon-Charley the 9 site correlations range from 0.78 to 0.95, and average 0.87.

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 0.61; between Denali and Yukon-Charley, 0.71; and between Wrangell-St. Elias and Yukon-Charley, 0.67. The respective correlations between Denali, Yukon-Charley, and Wrangell-St. Elias and the three-unit average are 0.89, 0.87, and 0.90. 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 40. CAKN regional Snow Water Equivalent (SWE), average of Denali, Wrangell-St. Elias, and Yukon-Charley SWE.



C. 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 nearly 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.

No pronounced climate signal is apparent in the annual precipitation and rainfall statistics. Precipitation has a statistically insignificant trend of +0.17 inches per decades, or roughly 1 percent per decade. It is likely this trend would disappear completely if the missing data from the 1930's had been included. Likewise, rainfall displays an increasing trend of +0.09 inches per year, or about 1 percent per decade. Snowfall has experienced an increasing trend of +1.5 inches per decade, or roughly 2 percent per decade. More importantly, McKinley seasonal snowfall is well correlated with the Denali region average SWE, with r = 0.71. Thus, the conclusions of the climate analysis of SWE in the next section will also apply to the measured snowfall.

Figure 41. Annual Precipitation (rain and melted snow) at the McKinley Park coop station. Points and dashed lines are annual data; solid line is a 5-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.

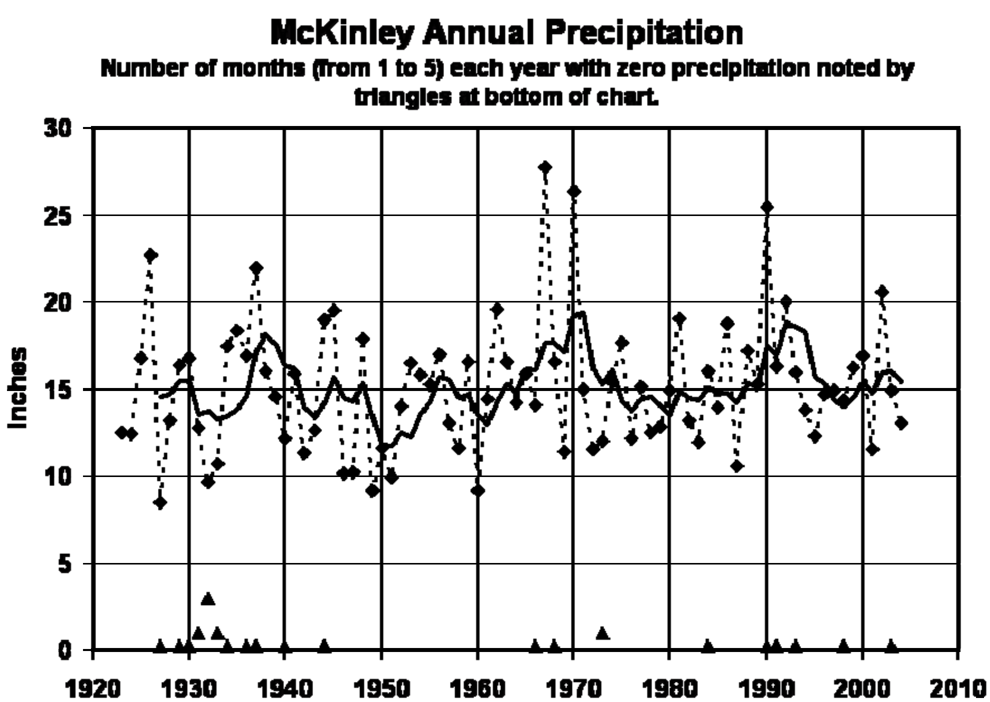


Figure 42. Seasonal (July to June) snowfall at the McKinley Park coop station. Points and dashed lines are annual data; solid line is a 5-year running mean. The small triangles along the bottom axis note the number of months (from 1 to 3) during the October to March period with zero snowfall, and indicate the likely amount of missing data each season.

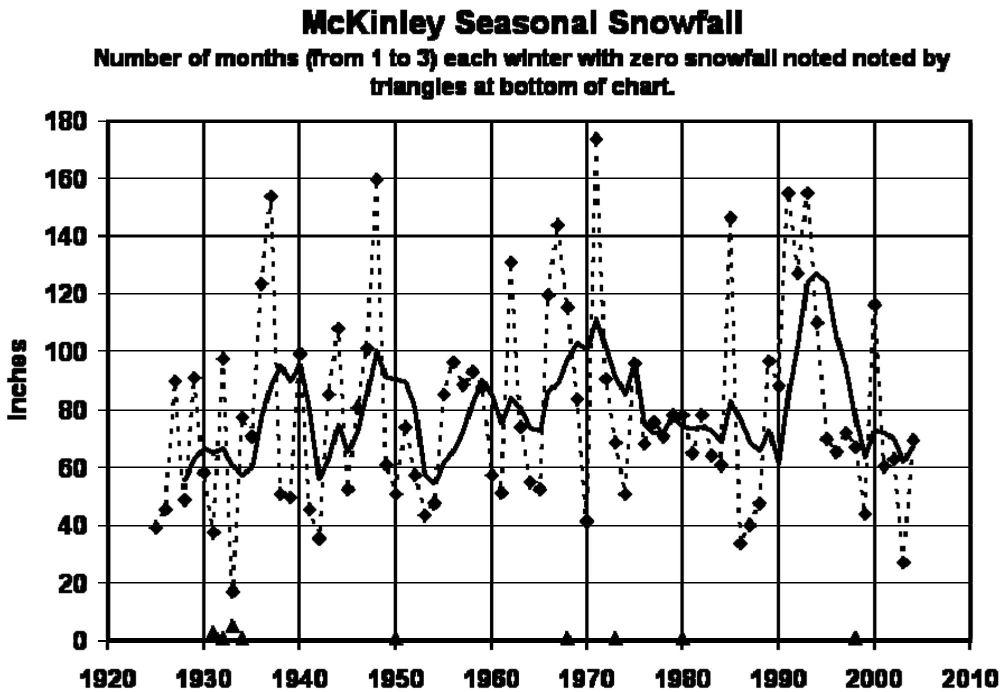
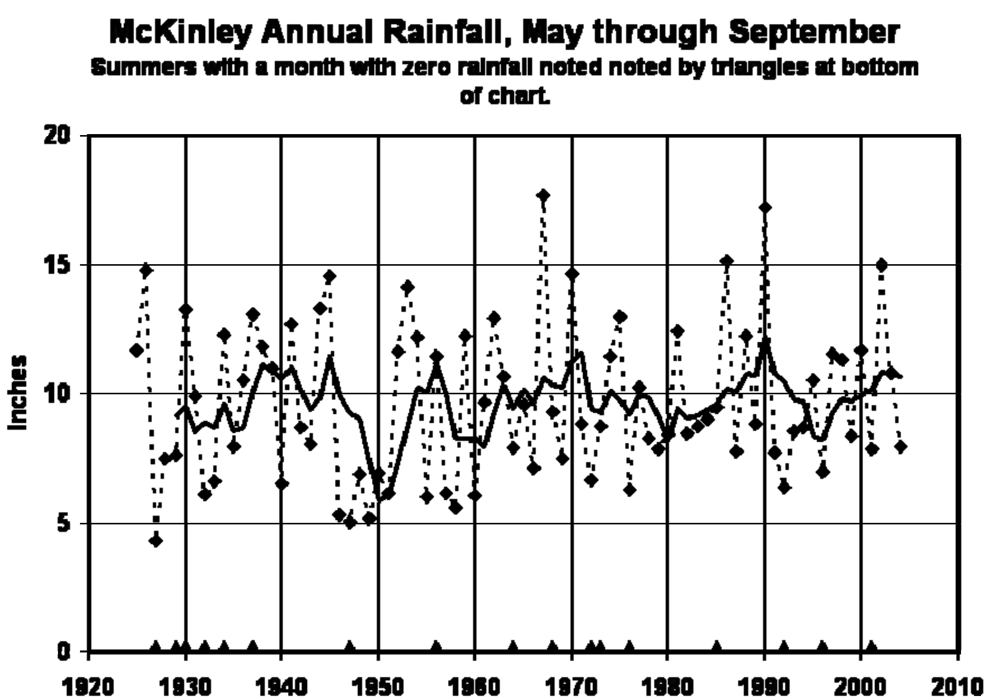


Figure 43. Annual Rainfall at the McKinley Park coop station. Points and dashed lines are annual data; solid line is a 5-year running mean. The small triangles along the bottom axis note seasons (May to September) having a month with zero precipitation, and indicate the likely amount of missing data.



7. Analysis of Climate change over the past century

A. 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.cdc.noaa.gov/ClimateIndices/List/

In addition, another index is included in this study, namely, the annual average surface temperature of the Arctic (64 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 the 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. The following table shows the results of this initial screening for some indices. The numbers shown are the highest correlation coefficients in the area 60 to 65 N, 140 to 155 W, for correlations between seasonal (Summer JJA and Winter DJF) surface temperatures and concurrent values of the indices.

Table 2. Correlations between surface temperature and Climate Indices:
Maximum correlation in Alaska

Index	DJF	JJA
AO	–0.4	–0.3
SOI	–0.3	–0.1
PNA	0.1	0.1
WP	–0.2	0.2
NP	–0.7	–0.3
PDO	0.8	0.2

After screening the indices for independent and significant correlations, the following indices (plus the “external forcings”, Solar variability and Carbon Dioxide) were selected for further and more extensive study. The next three figures show 5-year moving averages of annual values of these indices.

- 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.

- Carbon Dioxide (CO2) –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 (64 N to 90 N) compiled by NASA/GISS, found at: http://data.giss.nasa.gov/gistemp/tabledata/ZonAnn.Ts.txt

- 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

- 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 from Jim Hurrell at NCAR: http://www.cgd.ucar.edu/cas/jhurrell/npindex.html

- 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). Thus, inclusion of the PDO in this study is somewhat redundant, but the importance of the NP/PDO phenomena in the climate of Alaska justifies this redundancy. 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

Figure 44. Five-year smoothed values of Total Solar Irradiance (from Hoyt) and atmospheric Carbon Dioxide concentration (from NASA/GISS)

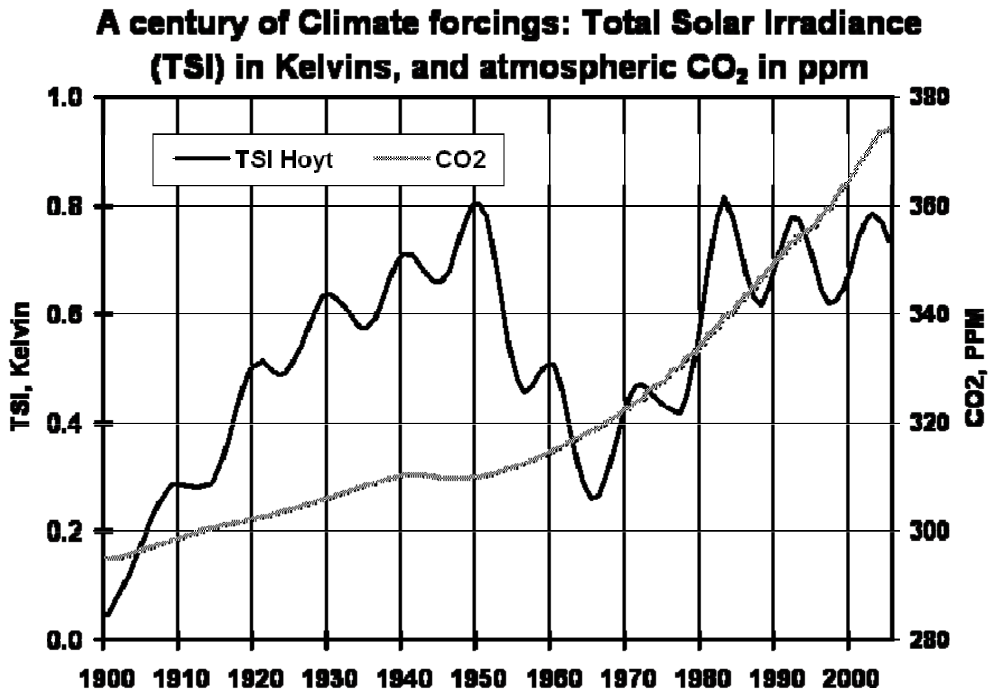


Figure 45. Five-year smoothed values of the Northern Annular Mode, or Arctic Oscillation (AO) index, and of Annual mean surface temperatures.

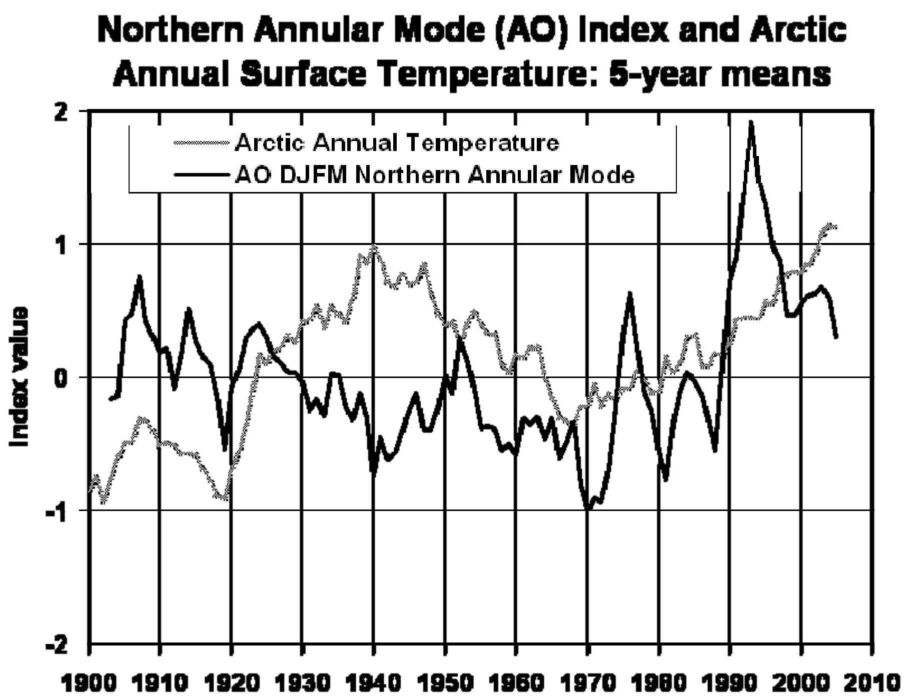
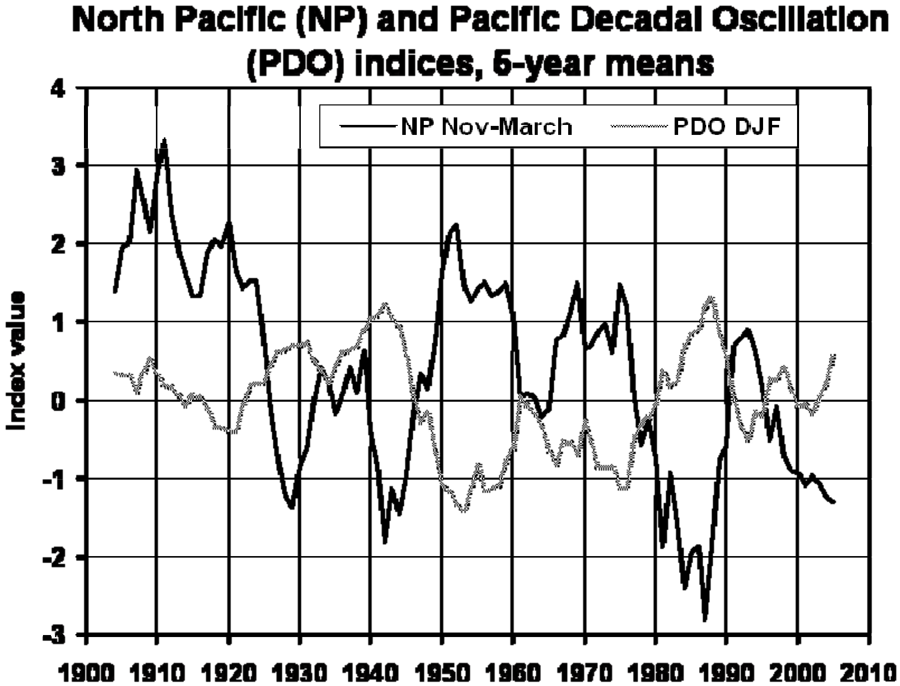


Figure 46. Five-year smoothed values of North Pacific and Pacific Decadal Oscillation indices.



B. 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 the six 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. Regressions were done between annual values of temperature and indices, as well as between 5-year, 10-year, and 20-year moving averages of temperatures and indices.

Table 3. Correlations between CAKN temperatures and Climate indices

	Arctic Temp 64N-90N	NP Nov-March	AO/NAM Dec-March	PDO DJF	TSI Hoyt	CO2
Annual Temperatures						
1-year	0.50 **	–0.51 **	0.04	0.38 **	0.38 **	0.31 *
5-year	0.61 **	–0.74 **	0.16	0.67 **	0.59 **	0.40
10-year	0.68 *	–0.76 **	0.36	0.76 **	0.76 **	0.42
20-year	0.70	–0.74	0.52	0.80	0.87 *	0.36
Winter DJF Temperatures						
1-year	0.21	–0.60 **	–0.09	0.60 **	0.20	0.23
5-year	0.45	–0.72 **	0.11	0.67 **	0.44 *	0.35
10-year	0.55	–0.72 *	0.34	0.78 **	0.65 *	0.38
20-year	0.62	–0.69	0.60	0.81 *	0.80	0.37
Summer JJA Temperatures						
1-year	0.22	–0.10	0.17	0.15	0.26 *	0.33 **
5-year	0.44	–0.34	0.49 *	0.22	0.40	0.55 **
10-year	0.52	–0.46	0.73 *	0.29	0.55	0.75 *
20-year	0.44	–0.67	0.73	0.44	0.67	0.76

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
10-year	8	0.63	0.76
20-year	4	0.81	0.92

While no index explains more than 36 percent 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 table below summarizes the correlations between 5-year moving averages of temperature and climate indices, with significance levels noted:

Table 5. Correlations of CAKN regional temperatures with six climate indices.						
Average Temperature	Arctic Temp 64N-90N	NP Nov-March	AO/NAM Dec-March	PDO Dec-Feb	TSI Hoyt	CO2
Annual	0.61 **	–0.74 **	0.16	0.67 **	0.59 **	0.40
Winter DJF	0.45	–0.72 **	0.11	0.67 **	0.44	0.35
Summer JJA	0.44	–0.34	0.49 *	0.22	0.40	0.55 **

The following eight maps show the individual station correlations for the cases in which the nine-station average temperature has a significant correlation with one of the indices. The map of the locations of the stations is repeated here as Figure 47.

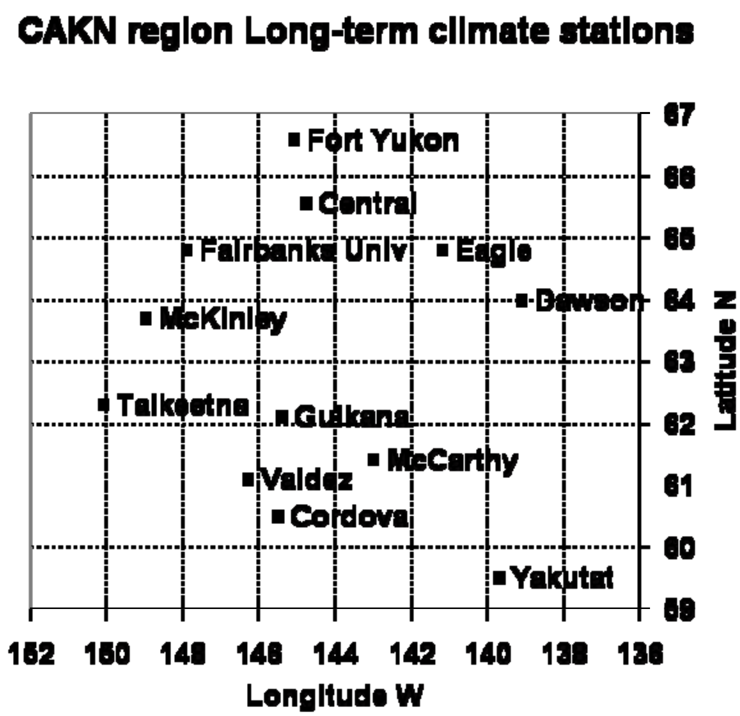


Figure 48. Correlation: Annual mean station temperature vs. Arctic mean temperature.

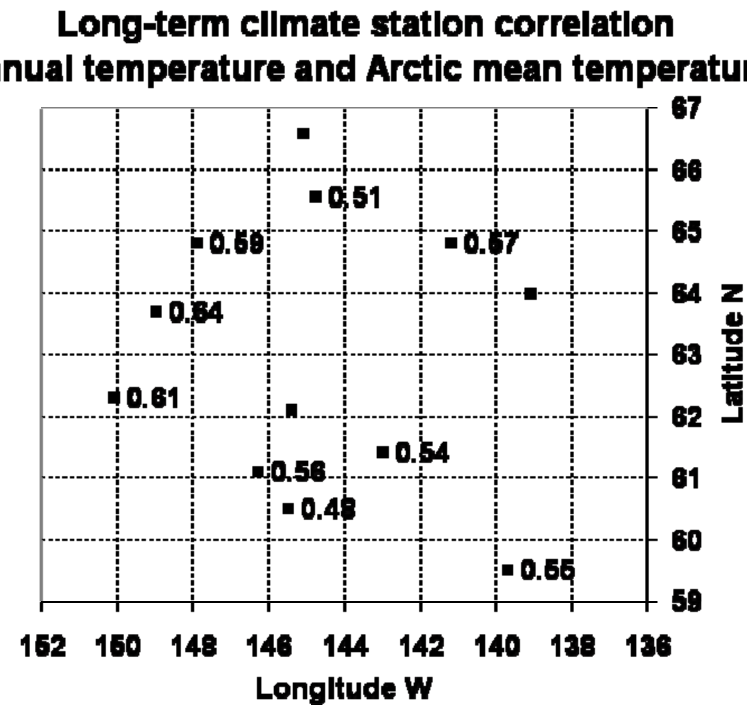


Figure 49. Correlation: Annual mean station temperature vs. North Pacific index.

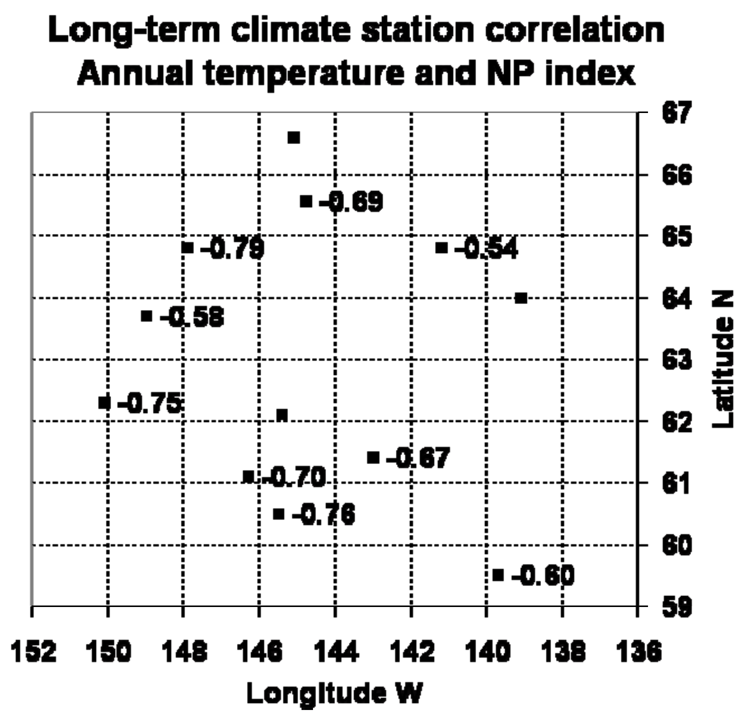


Figure 50. Correlation: Annual mean station temperature vs. Pacific Decadal Oscillation.

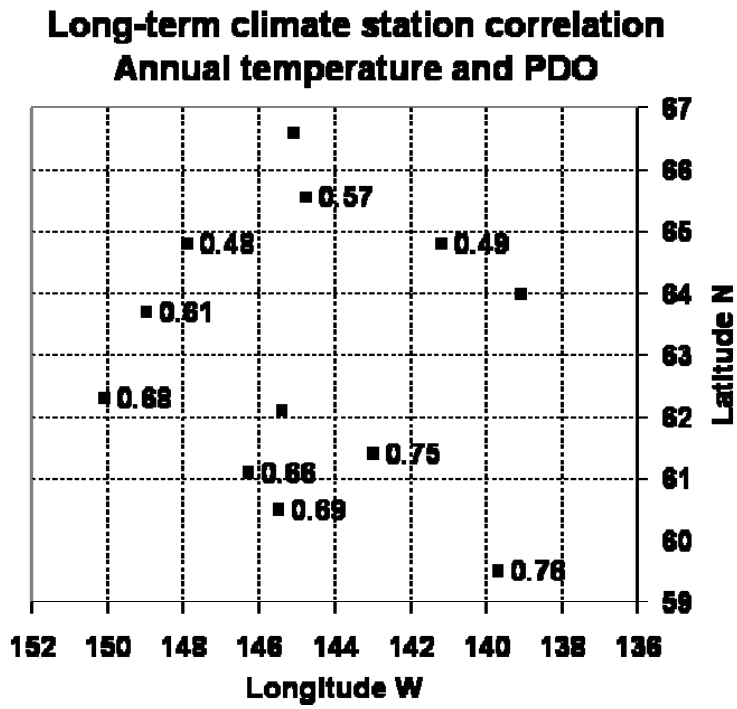


Figure 51. Correlation: Annual mean station temperature vs. Total Solar Irradiance.

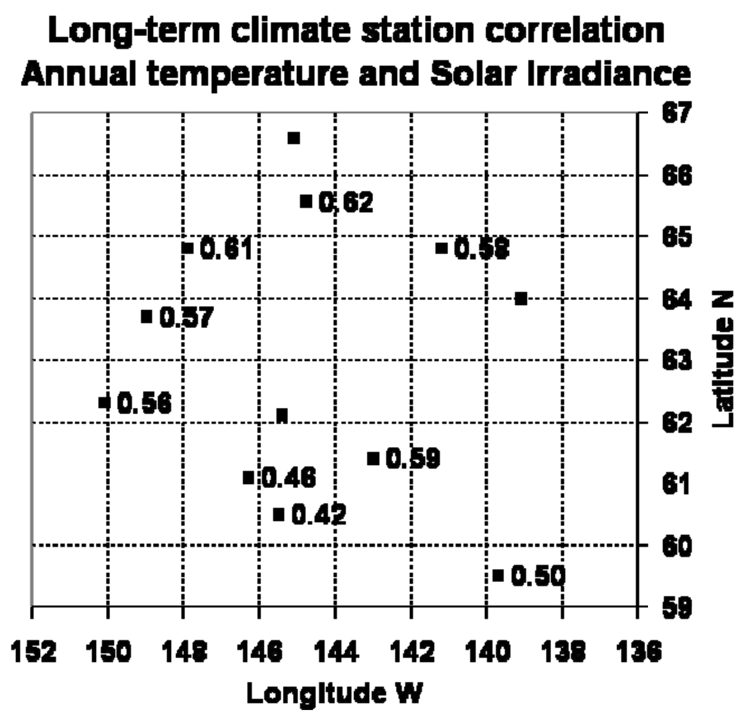


Figure 52. Correlation: Winter mean station temperature vs. North Pacific index.

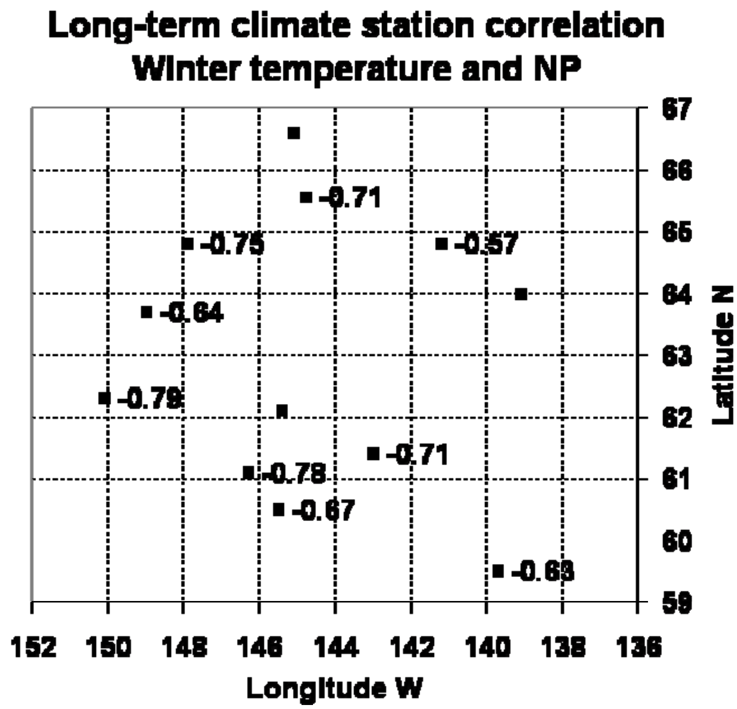


Figure 53. Correlation: Winter mean station temperature vs. Pacific Decadal Oscillation.

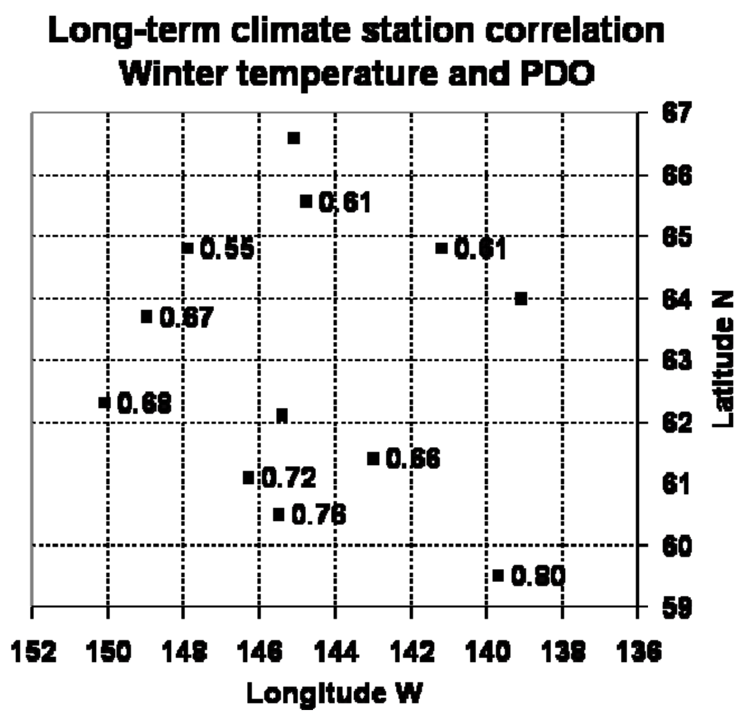


Figure 54. Correlation: Summer mean station temperature vs. Carbon Dioxide concentration.

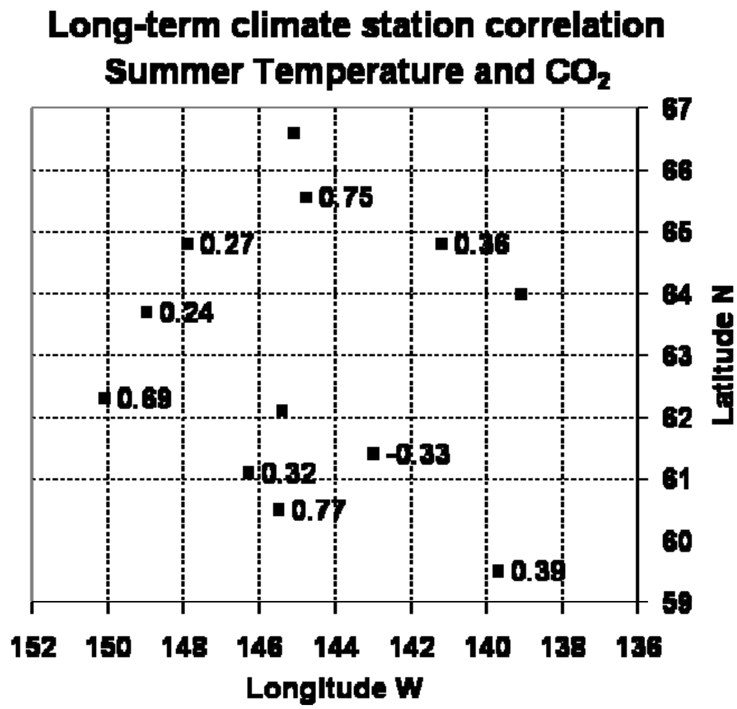
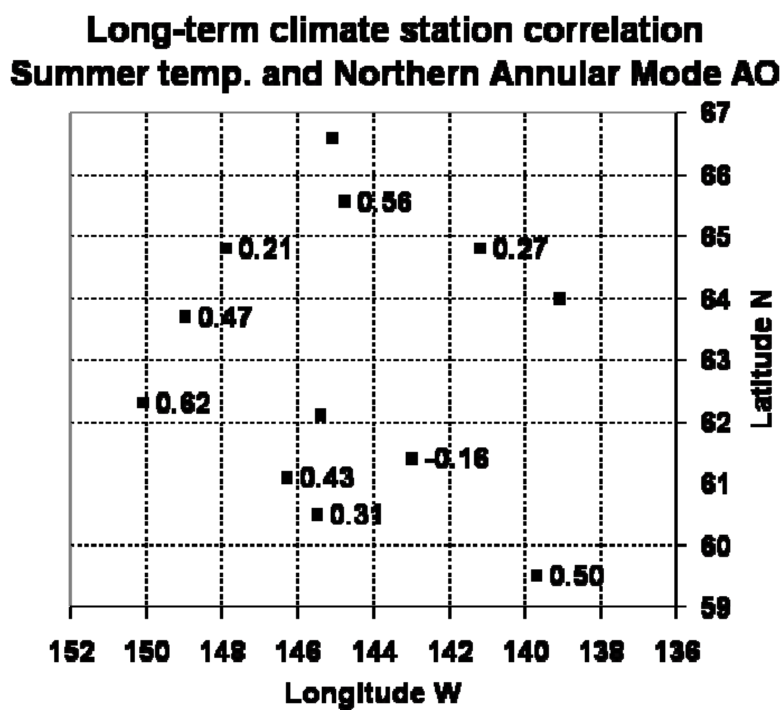


Figure 55. Correlation: Summer mean station temperature vs. Arctic Oscillation index.



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. Finally, the correlations of summer temperatures with the AO and CO_2, while statistically significant for the regional average, vary greatly among the nine stations, and any true cause and effect due to the AO and CO_2 on summer temperatures is questionable.

C. CAKN temperatures and the North Pacific mode and Pacific Decadal Oscillation

The strongest and most consistent of the observed correlations is between annual, and especially winter, temperature and the two indices related to the atmospheric and oceanic circulations of the North Pacific Ocean – namely, the NP and PDO indices. During low NP index phases, the Aleutian/Gulf of Alaska Low is stronger (lower pressure) than normal, and northerly winds around the west side of the low advect cold Siberian air over the ocean, cooling the western North Pacific. Meanwhile, the warm southerly winds east of the Low raise the temperatures of the eastern North Pacific. Thus, the stronger Aleutian Low generates a SST anomaly pattern that is the positive PDO index. The ocean temperature contrast in turn enhances the baroclinicity of the atmosphere in the vicinity of the Aleutian Low, maintaining or intensifying the Low. In effect, the NP is the atmospheric component and the PDO is the oceanic component of an ocean-atmosphere interaction that combines both phenomena. The next two maps show the spatial pattern of the correlation between winter surface temperature and the NP and PDO indices, calculated from NCEP/NCAR reanalysis data at CDC.

Figure 56. Correlation: Winter surface temperature vs. North Pacific index

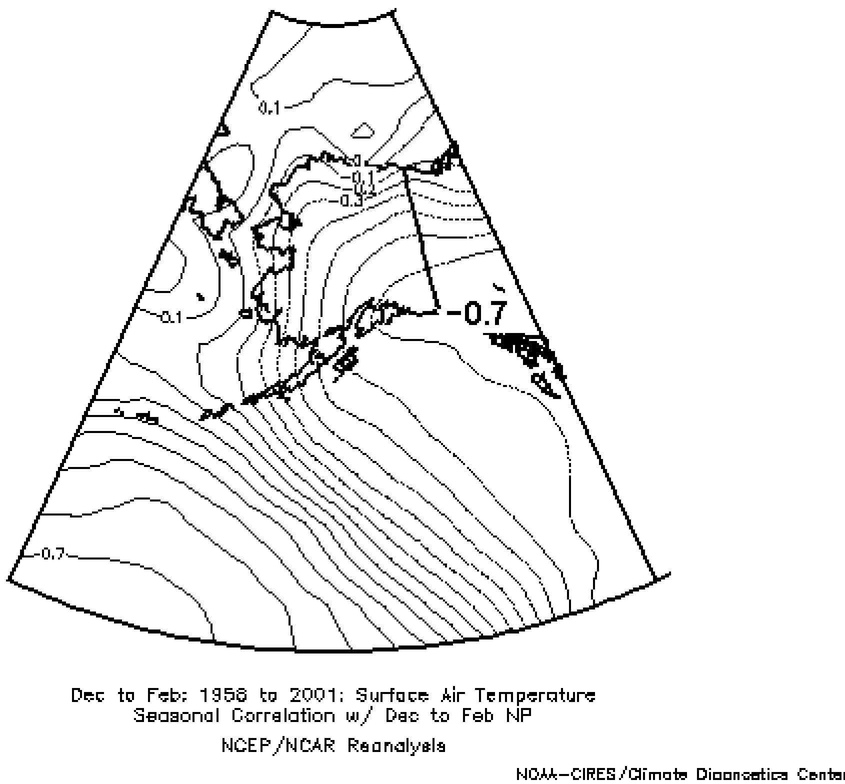
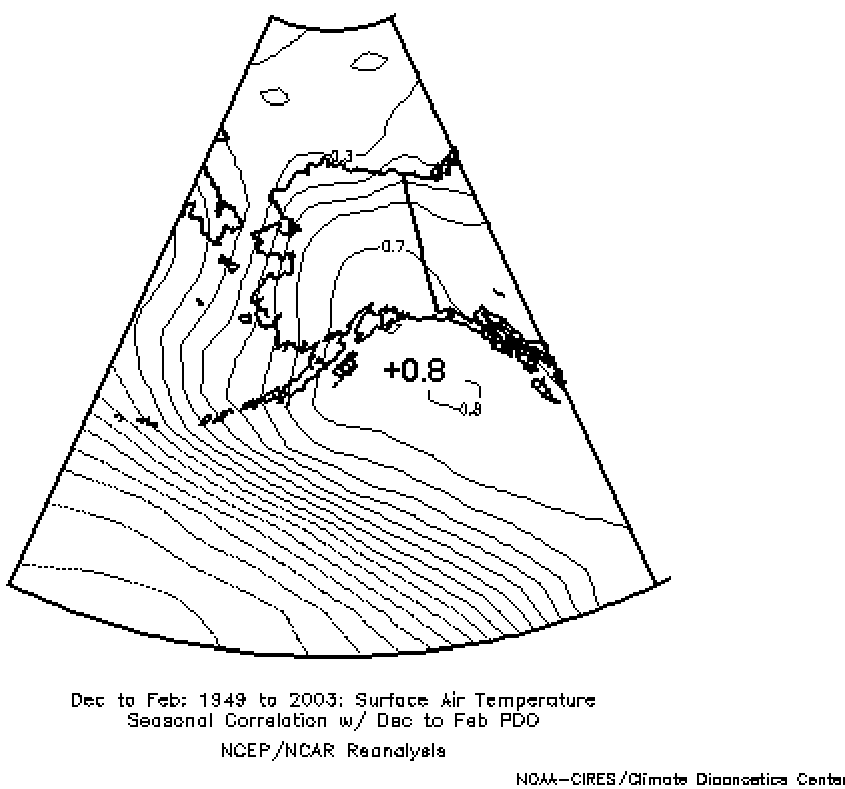


Figure 57. Correlation: Winter surface temperature vs. Pacific Decadal Oscillation.



Except for the reversal of sign, the correlation maps are very similar, and both show the strong correlation of southern Alaska's winter temperatures with the strength of the Aleutian Low. A vertical cross-section of winter correlations along longitude 150 W, from the surface to 500 millibars (approximately 5 km) reveals that the winter temperatures most closely follow the PDO near the surface and near the coast and over the ocean, and while the correlation remains strong inland at higher altitudes, the low-level wintertime inversion north of 64 N appears to act more independently of the PDO, reducing the temperature correlations at the surface in interior Alaska.

Figure 58. Correlation: January air temperature vs. Pacific Decadal Oscillation, shown as a height vs. latitude cross section. The height coordinate is pressure in millibars (1000 millibars is approximately sea level; 850 millibars is approximately 5000 feet).

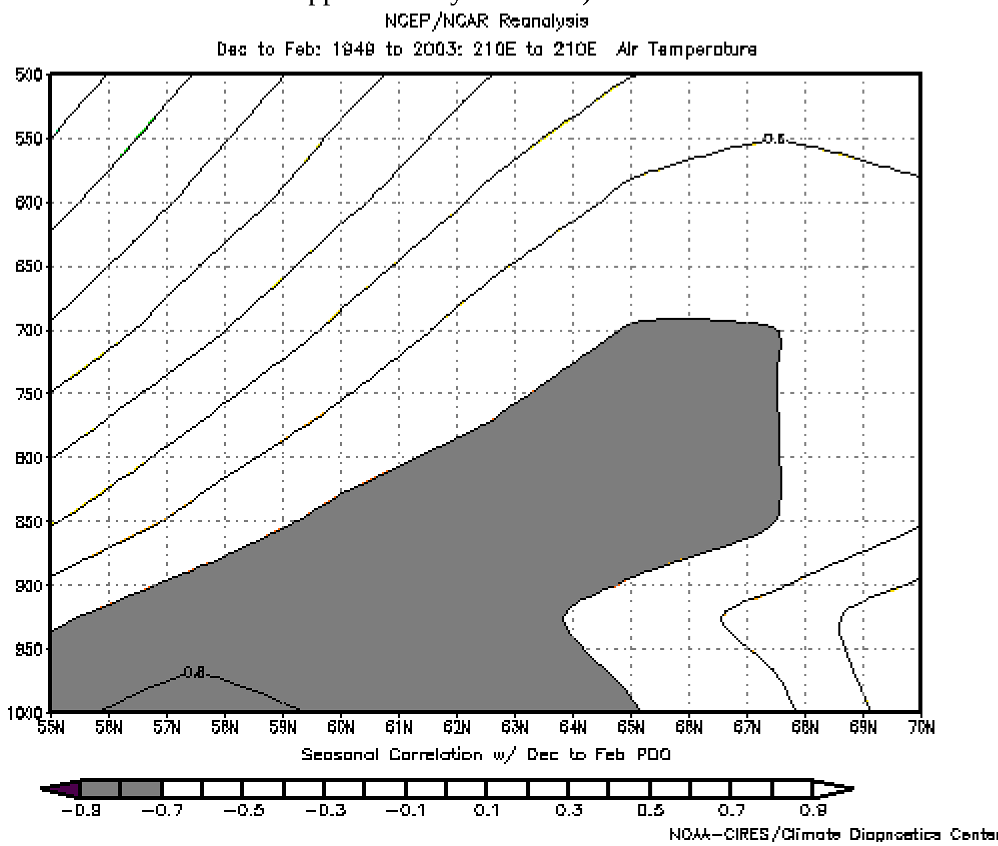
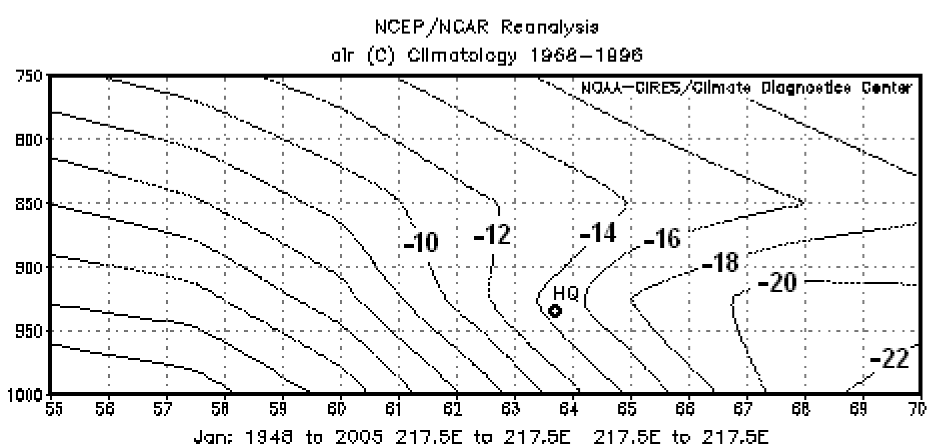
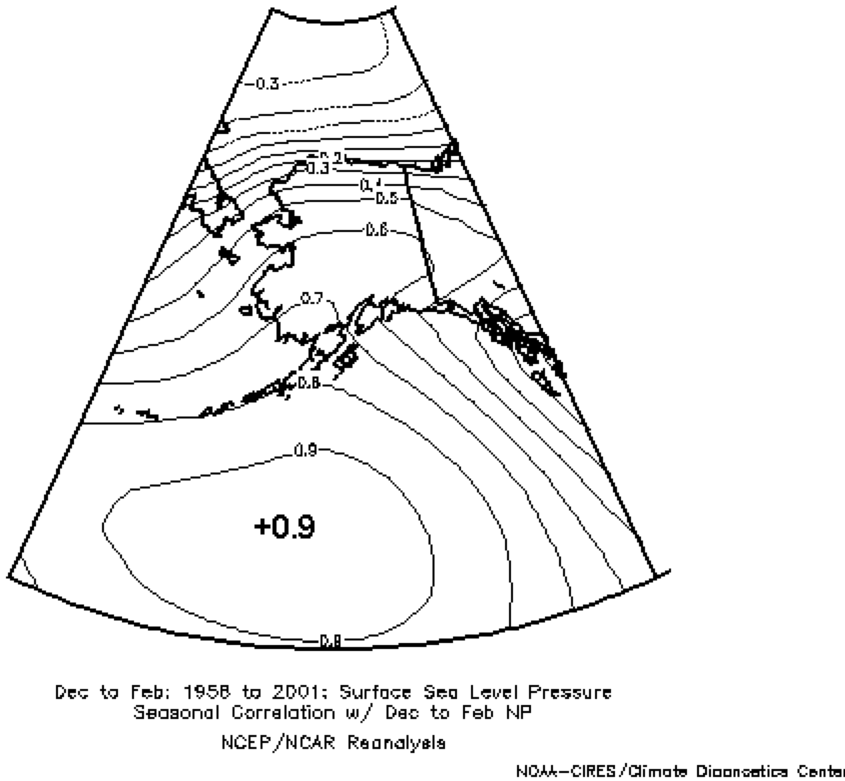


Figure 59. Height-Latitude cross-section of average January temperature along longitude 142.5 West. The location of the McKinley HQ co-op station is marked with a small circle. The wintertime inversion is apparent between about 920 and 850 millibars (2000 to 5000 feet) north of 62 degrees north.



Since it is the atmospheric component (NP) that directly affects the climate of Alaska, we now look at the spatial pattern of the correlation between winter sea level pressure and the NP index, calculated from NCEP/NCAR reanalysis data at CDC.

Figure 60. Correlation: Winter surface pressure vs. North Pacific index.



The highest correlation (+0.9) is found, not surprisingly, near the center of the Aleutian Low, with lesser correlations closer to Alaska. The correlation gradients correspond to actual pressure gradients, which in turn determine the atmospheric circulation of the region, as interpreted in the following annotated versions of the correlation map.

Figure 61. Surface pressure pattern characteristic of positive values of the North Pacific index, showing offshore flow from the Arctic High over interior Alaska.

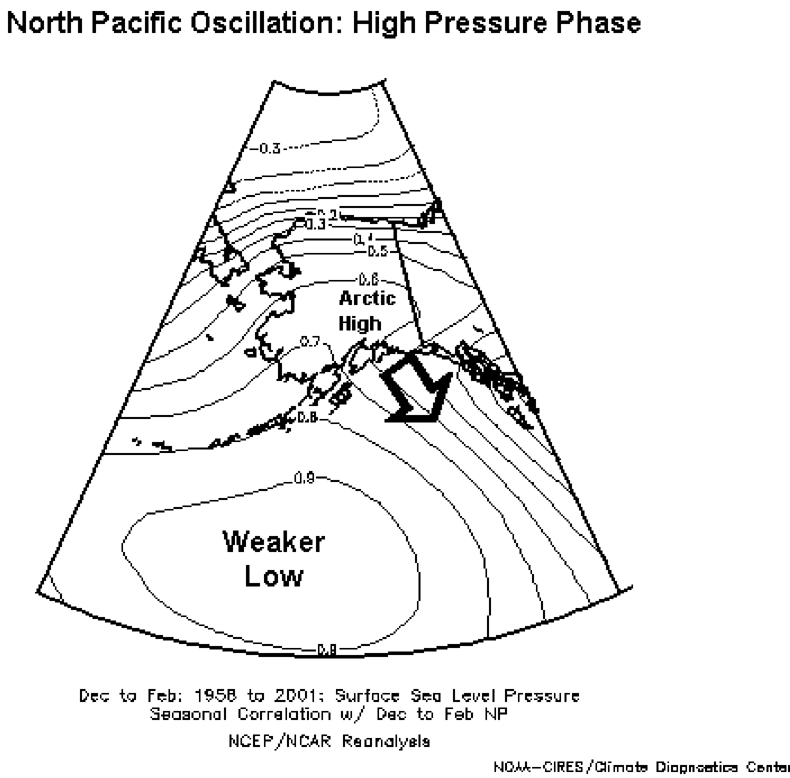
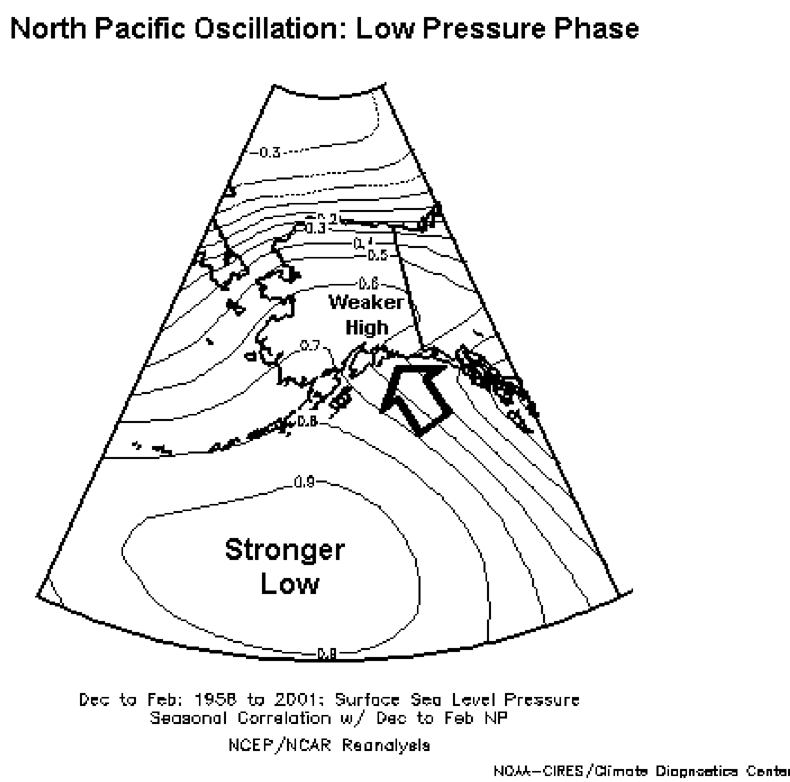


Figure 62. Surface pressure pattern characteristic of negative values of the North Pacific index, showing onshore flow from the Aleutian/Gulf of Alaska Low.



When the NP index (defined as the average pressure in the region of the Aleutian Low) is high, the pressure in the Low is higher; in other words, the Low is weaker. Over central Alaska, where high pressure is normally found in the winter, the pressure is also higher (but by not as much), so this High is somewhat stronger. This allows more cold Arctic air to settle in interior Alaska, and the weaker onshore winds associated with the weaker Low allows the Arctic air to reach the coast (indicated by the arrow). Thus, overall, the winters will be colder.

When the NP index is low, the Aleutian Low is stronger, the central Alaska High is weaker, and the onshore flow advects maritime air inland over southern and central Alaska. Thus, overall, the winters will be warmer.

The time series of NP and PDO indices reveal that shifts from predominately positive to predominately negative modes (or vice-versa) occurred around 1935, 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 are treated as step function changes 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 1900-1924 and 1947-1976, and the low NP/high PDO index (strong Aleutian Low) years 1925-1946 and 1977-2004.

Figure 63. 105 year record of regional Annual Average Temperature with PDO regimes superimposed.

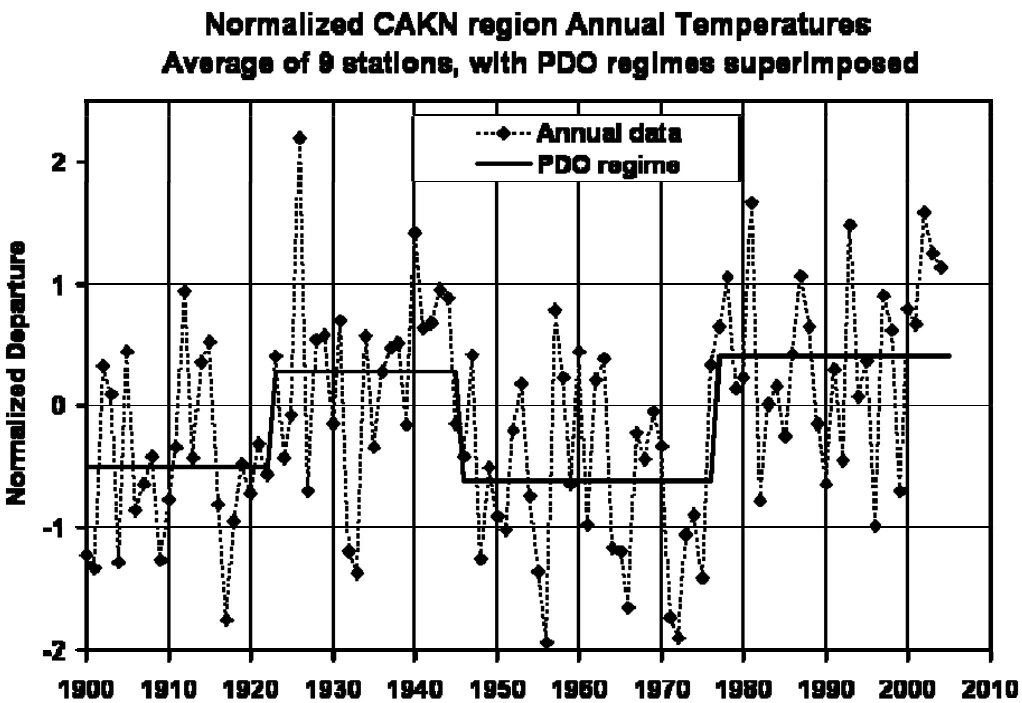


Figure 64. 105 year record of regional Winter Average Temperature with PDO regimes superimposed

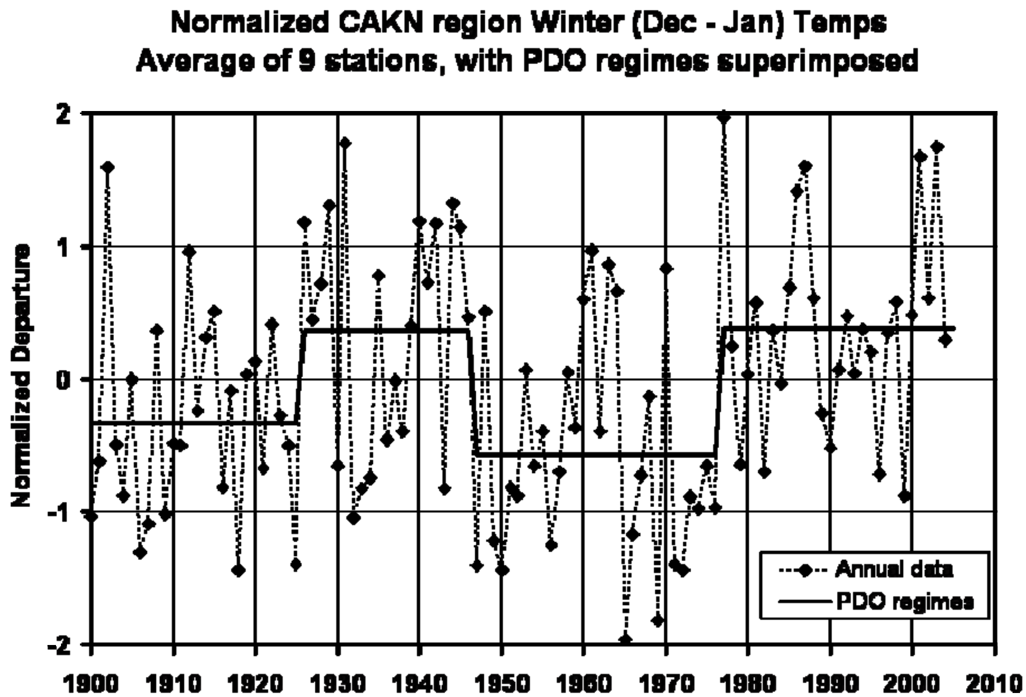
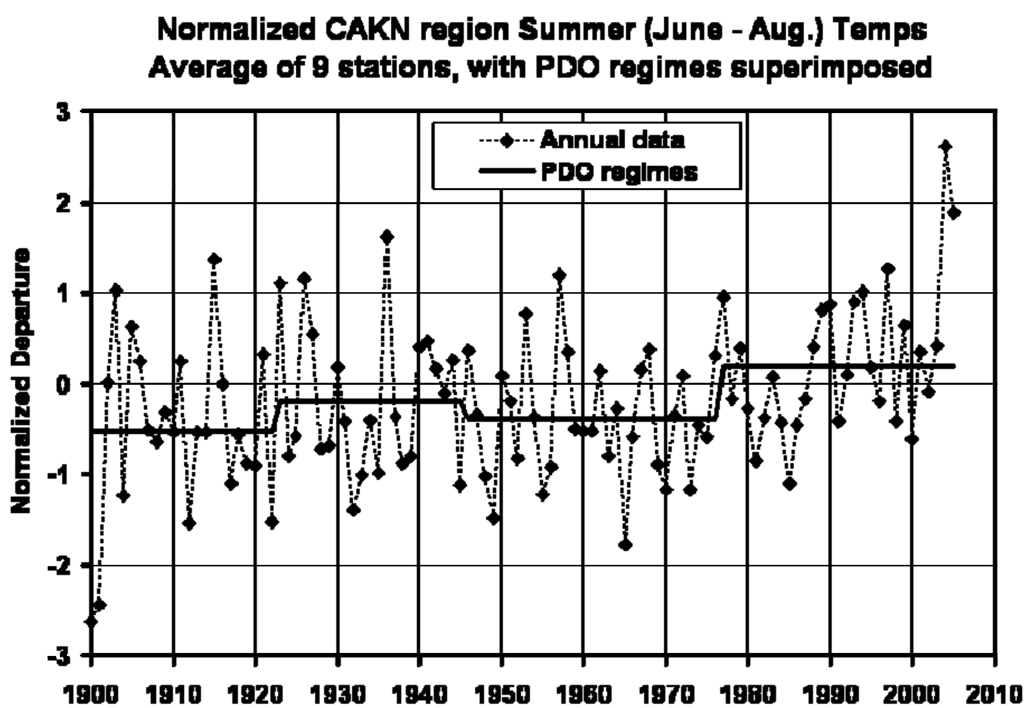


Figure 65. 105 year record of regional Summer Average Temperature with PDO regimes superimposed



The average annual and winter temperature shifts about 1 standard deviation 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 alternations.

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 the these maps is the net change resulting from the 1946 "cooling" and the 1977 "warming"; i.e., the difference between the "warm" episodes of 1977-2004 minus 1925-1946. Across the region, the net changes range from -0.7 F to +1.1 F. Thus, the "warm" period 1977-2004 was no warmer, or cooler, than the previous "warm" period 1925-1946. 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 66. Average Annual Temperature change associated with the PDO regime shift of 1946.

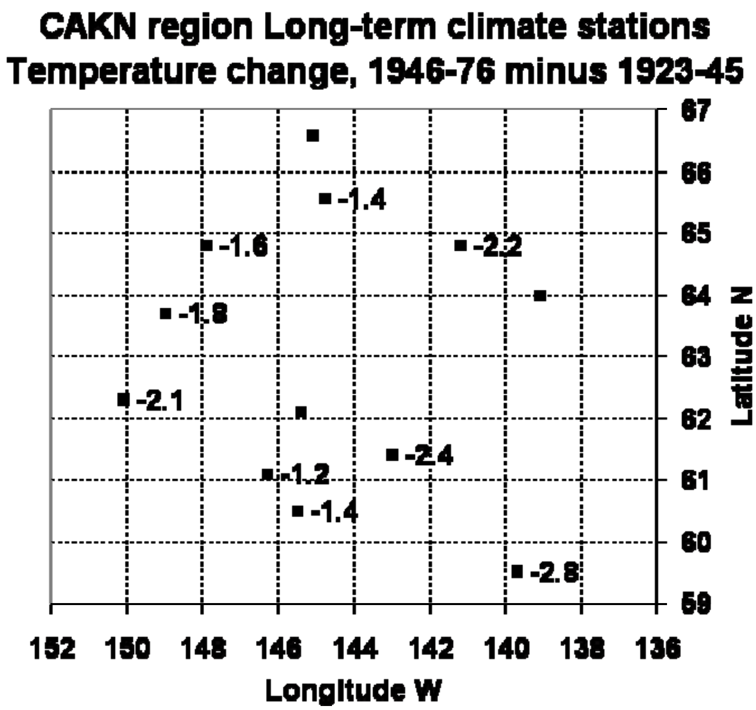


Figure 67. Annual Temperature change associated with the PDO regime shift of 1977.

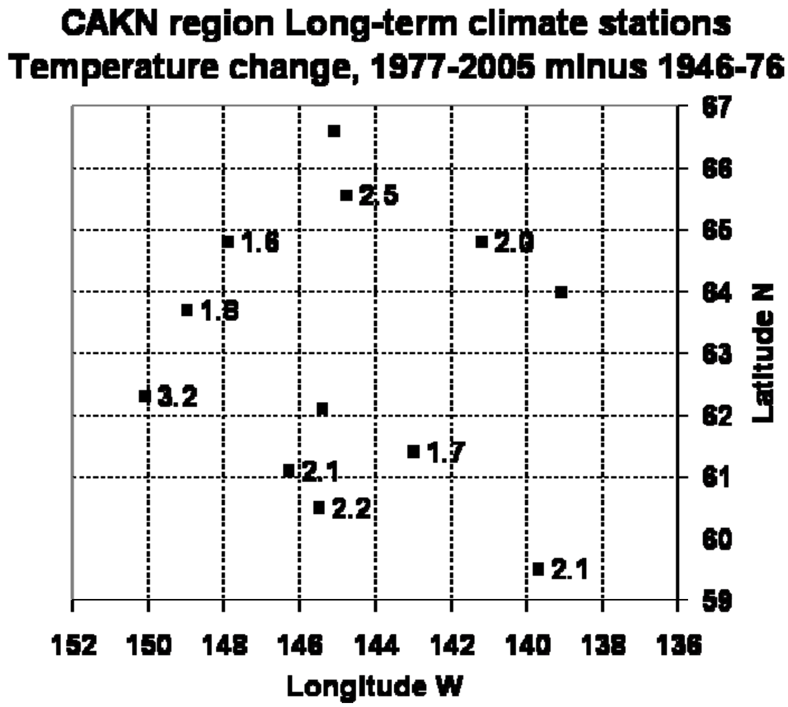
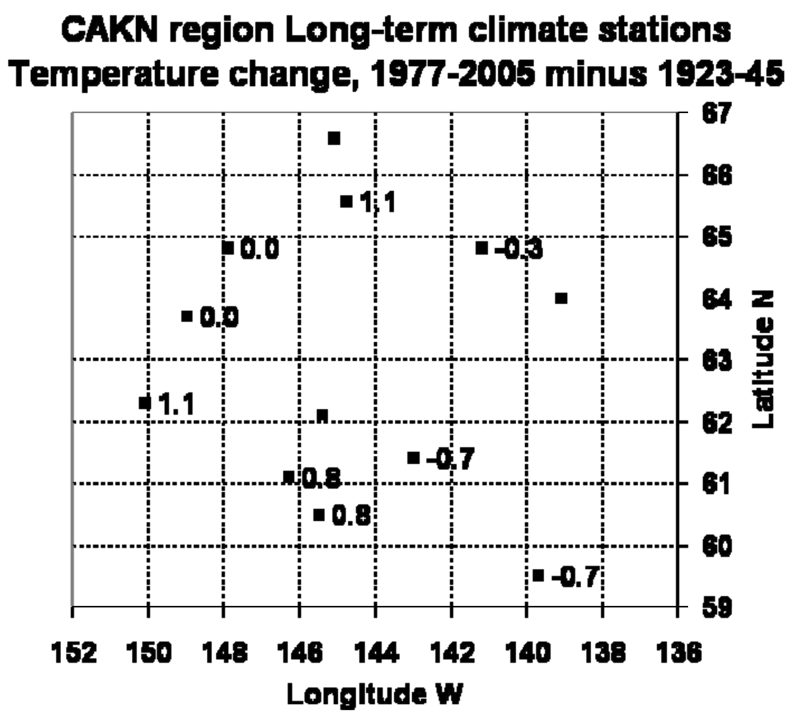
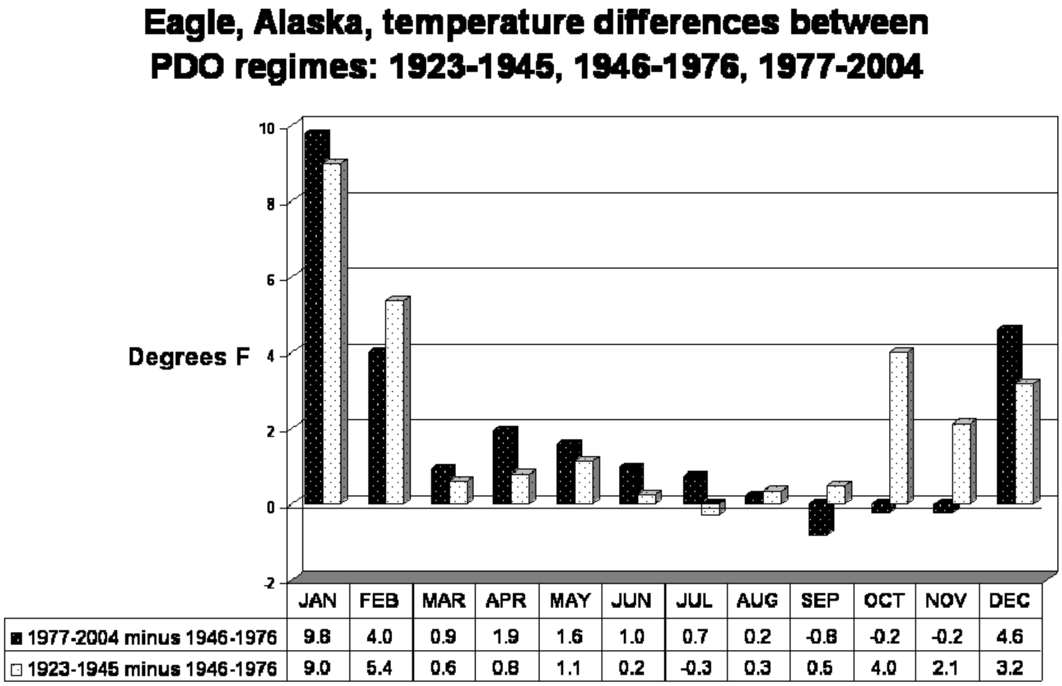


Figure 68. Average Annual Temperature difference between the warm PDO regimes of 1923-45 and 1977-2005. This is an indicator of climate change on times scales greater than the multi-decadal PDO.



The influence of the NP/PDO is strongest during the winter months, as shown in the following figure of monthly temperature changes at Eagle associated with NP/PDO regime shifts.

Figure 69. Eagle Monthly average temperature differences between the warm PDO regimes of 1923-45 and 1977-2005 and the cold PDO regime of 1946-76.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
■ 1977-2004 minus 1946-1976	9.8	4.0	0.9	1.9	1.6	1.0	0.7	0.2	-0.8	-0.2	-0.2	4.6
□ 1923-1945 minus 1946-1976	9.0	5.4	0.6	0.8	1.1	0.2	-0.3	0.3	0.5	4.0	2.1	3.2

The next three maps show the spatial distribution of the changes in mean winter temperatures associated with the NP/PDO regime changes of 1946 and 1977. The pattern is similar to the annual changes, except the magnitude is greater.

Figure 70. Winter temperature change associated with the PDO regime shift of 1946.

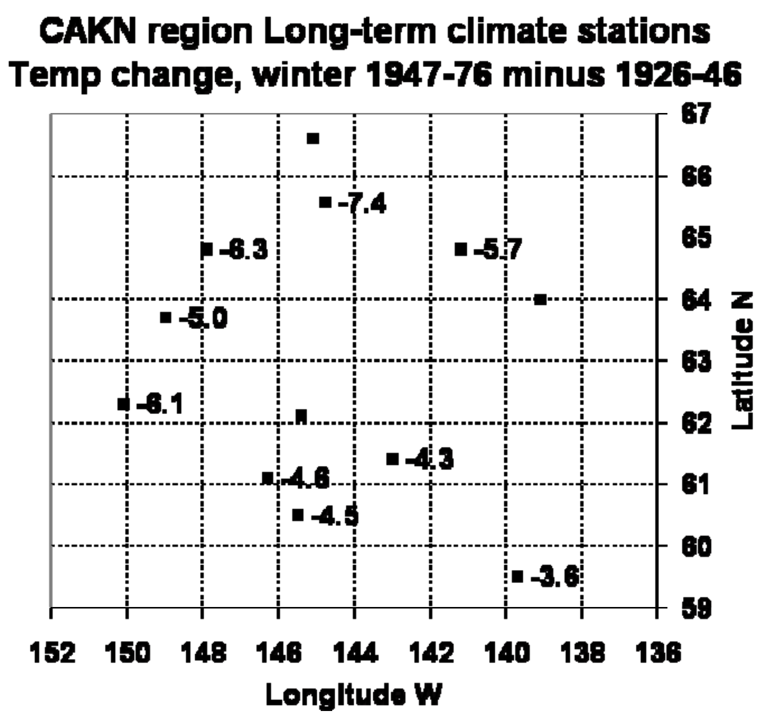


Figure 71. Winter temperature change associated with the PDO regime shift of 1976.

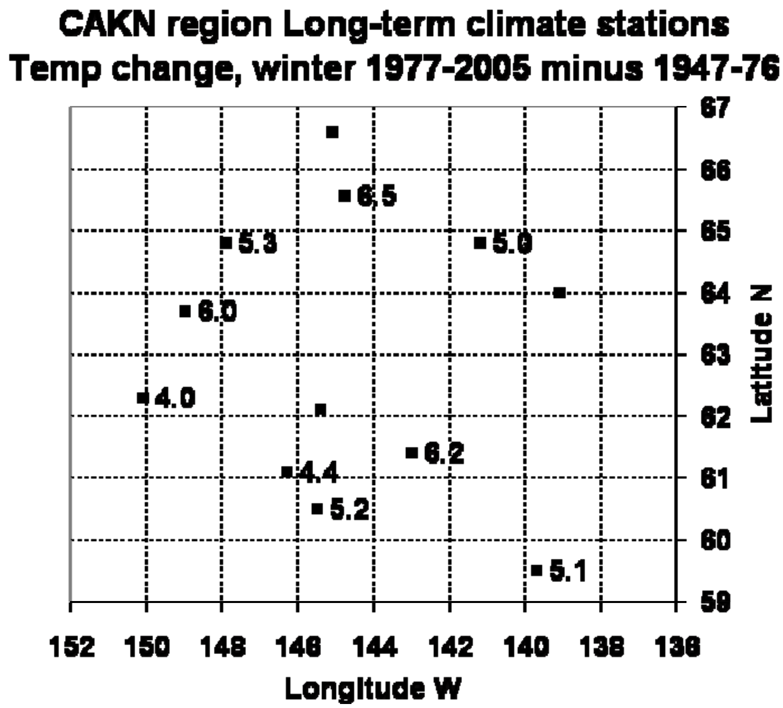
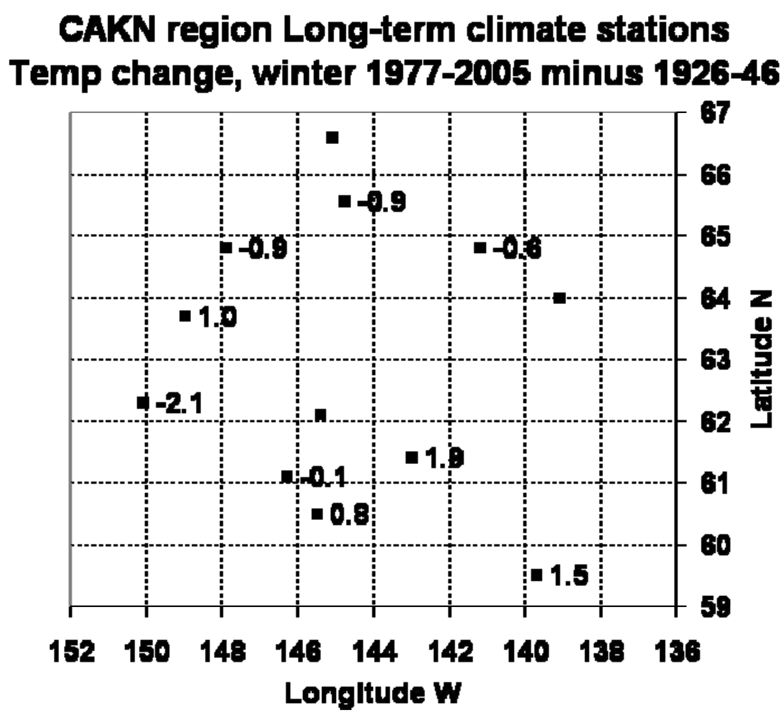


Figure 72. Winter Temperature difference between the warm PDO regimes of 1923-45 and 1977-2005. This is an indicator of climate change on times scales greater than the multi-decadal PDO.



Previously shown time series of winter minimum temperatures and number of days with daily minima at or below zero F are also strongly influenced by the NP/PDO.

D. 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 a tree rings. D'Arrigo et al. examined tree ring records from Alaska and Oregon to reconstruct the North Pacific (NP) index back to 1600; the time series of reconstructed NP index appears in panel (b) of the next figure. Panel (a) compares the reconstructed NP with the instrumental NP for the calibration period. D'Arrigo et al. identify ten regime shifts in their four-century record, including the 1923, 1946, and 1976 regime shifts already discussed (note some slight differences in the exact year of the events). The regime shifts are summarized in the table below. Note that the 1891 shift is not included, since it is not a "classical" shift from high to low, but a shift from high to an intermediate value.

Figure 73. Reconstructed North Pacific index from 1600 to 1983, from D'Arrigo et al.

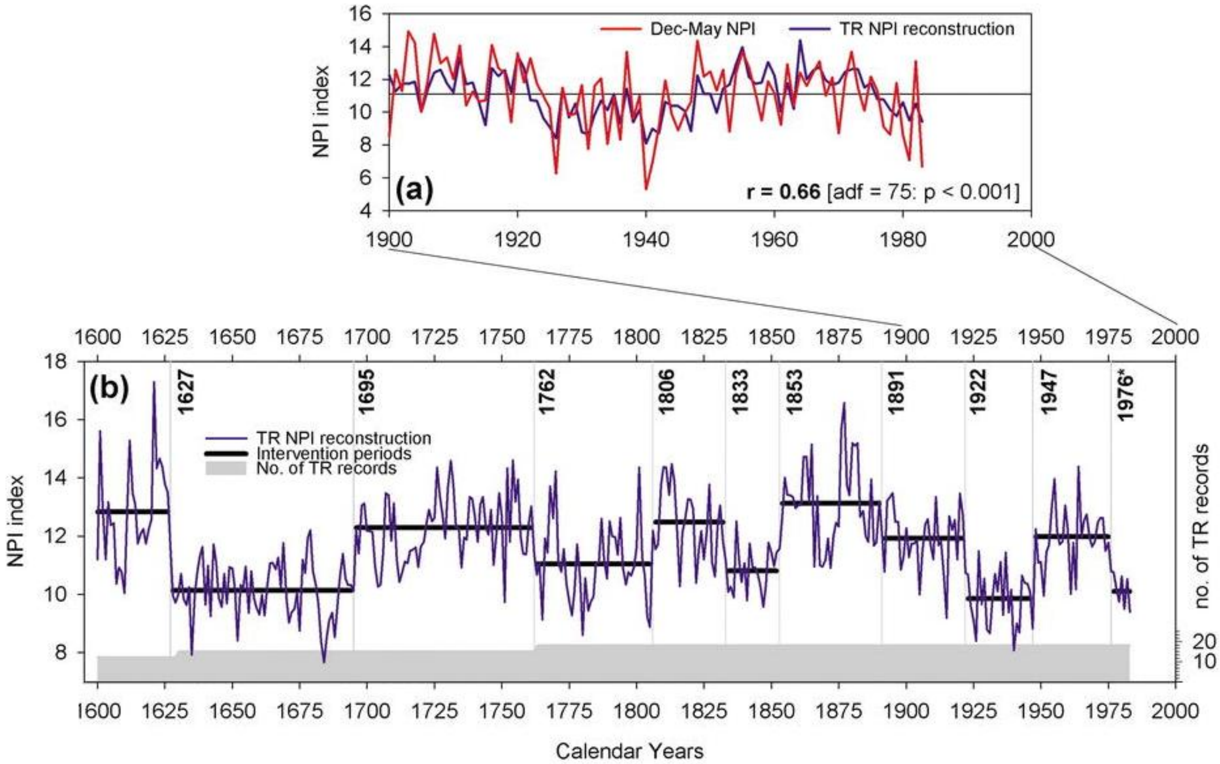


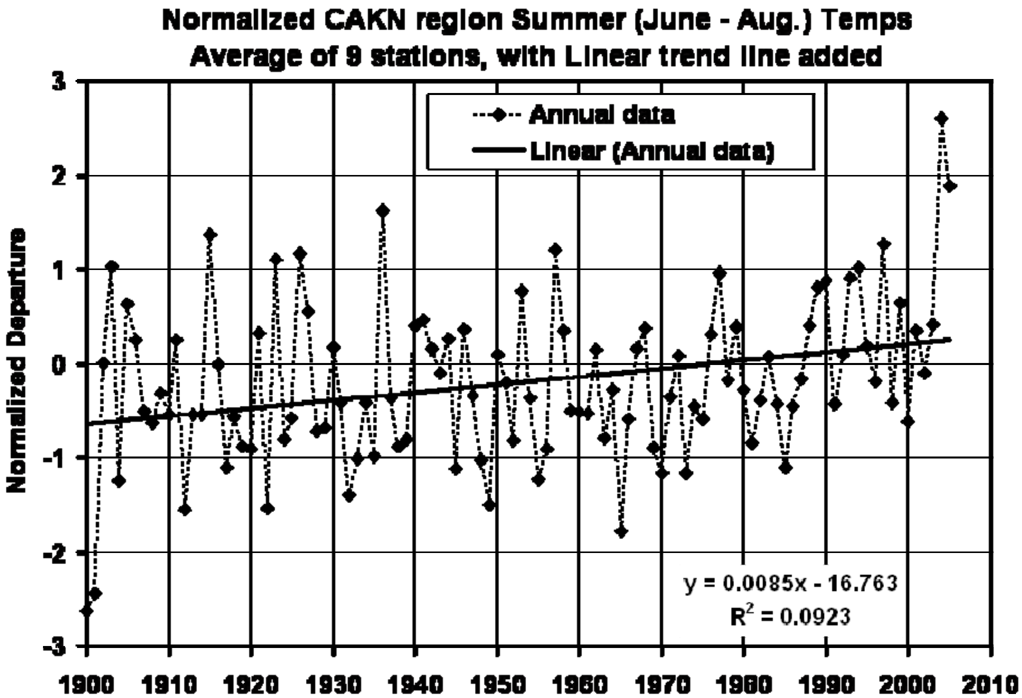
Table 6. NP/PDO regime shifts since 1600										
Regime shift	1627	1695	1762	1806	1833	1853	1922	1947	1976	Average duration
Duration, years		68	67	44	27	20	69	25	29	44

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, and taking those durations as the envelope of possiblities, the climate shift could occur (or should have occurred) sometime between 1997 and 2046. Clearly, climate forecasting is an uncertain endeavor.

E. CAKN Summer temperatures

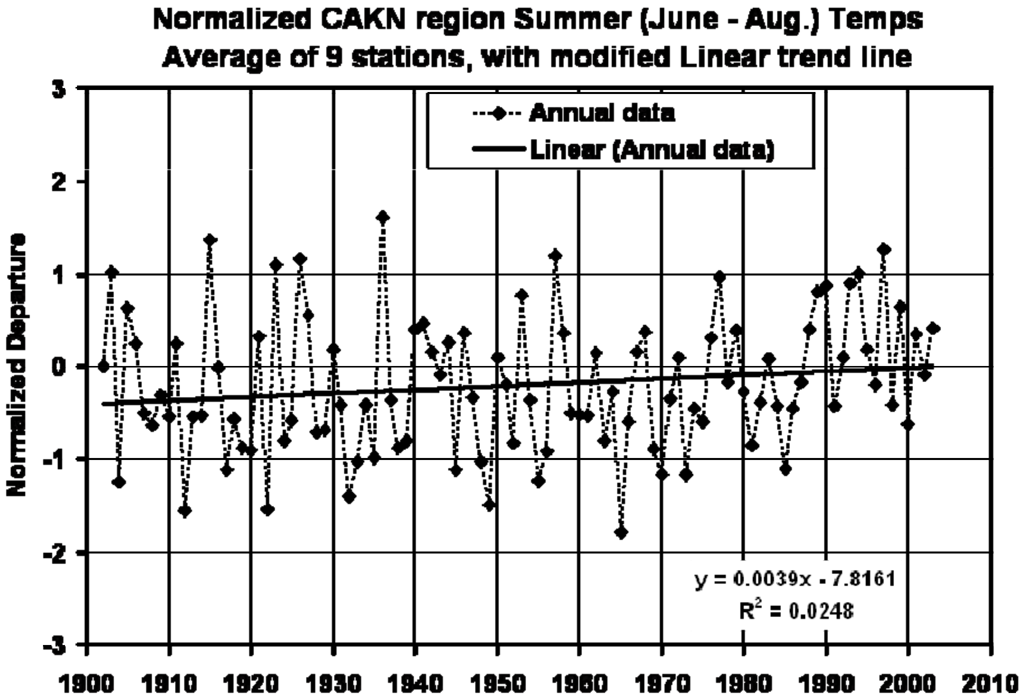
Unlike winter temperatures, which have a well defined and physically plausible correlation with the NP/PDO, the search for cause and effect related to summer temperature is more elusive. As seen before, the correlations with the AO and CO2 vary greatly among the nine stations, and a true physical link between summer temperatures and the AO and CO2 is not likely. That leaves us with the simplest of statistical time series analysis, the linear trend. The next figure shows the CAKN regional summer temperatures with a trend line added.

Figure 74. 106 year record of regional Summer Average Temperature, with trend line added.



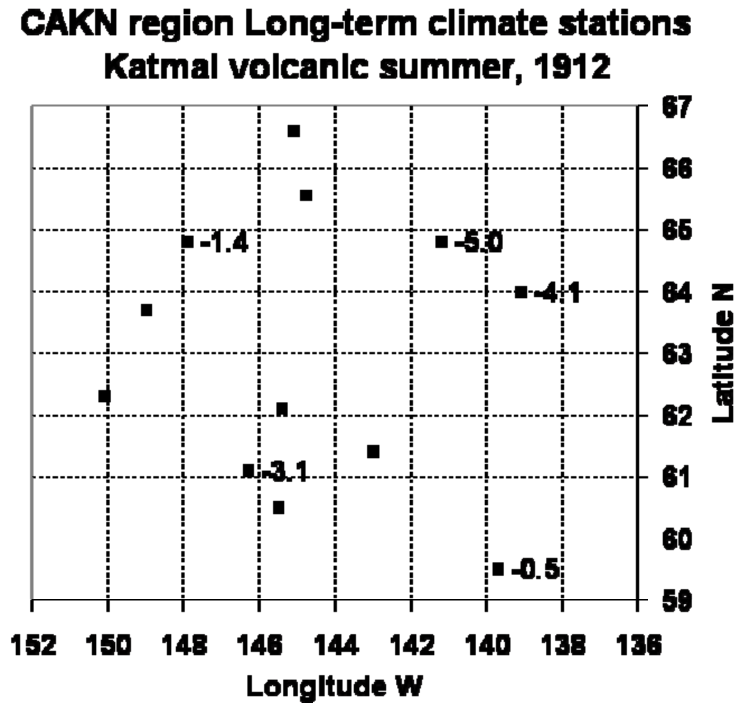
Since 1900, the upward trend in summer temperatures has been 0.85 F per century. However, the R-squared value is only 0.09, and the trend is statistically indistinguishable from zero. To illustrate the volatility of trends, note that the two coldest summers were also the first two summers of the record, and the warmest two summers were the last two in the record. Whether or not that is a remarkable coincidence, let us presume that this study was commissioned two years earlier and that gold wasn't discovered in the Klondike until 1901. Then the first two summers of record (at Eagle and Dawson) would not have been recorded, and the last two summers would not have happened yet. Removing the first and last two summers from the record results in the following modified time series of summer temperatures. The trend slope has shrunk to 0.25 F per century, well below any level of statistical significance and much less than the accuracy of the mean temperature produced by a mercury-in-glass thermometer mounted in a cotton region shelter.

Figure 75. 102 year record of regional Annual Average Temperature, with modified trend line.



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 20th 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 therefore likely, but not statistically proveable 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 five stations then operating.

Figure 76. CAKN Temperature departures, Cold summer of 1912 (possibly caused by the eruption of Katmai)



F. 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 table shows trends of CAKN regional annual temperatures for selected intervals. The years chosen for the trend analyses are the beginning and ending years of different phases of the NP/PDO.

Table 7. Trends of CAKN regional Annual Temperatures for selected intervals

Years	N	Degrees F/century	R	p=0.01
1900 to 2004	105	0.66	0.23	0.25
1926 to 2004	79	0.43	0.11	0.28
1946 to 2004	59	2.52	0.48	0.33
1926 to 1975	50	–3.18	0.50	0.35
1977 to 2004	28	1.40	0.16	0.46

The first line gives the trend slope for the entire period of record, 1900 to 2004. The slope of 0.66 F per century has a correlation R of 0.23, almost significant at the p=0.01 level (N = 105 years). However, the period of record began during a “cold” phase of the NP/PDO, and ended during a “warm” phase. If we take only the years since the beginning of the 20th century’s first “warm” phase in 1926, the trend drops to an insignificant 0.43 F per century. Likewise, the trend slope since the beginning of the second
”warm” phase in 1977 is also small and statistically insignificant.

The largest warming trend is obtained by using only data beginning with the second “cold” phase in 1946. The slope for this period is an impressive and significant 2.52 F per century. However, the largest trend slope of all is during the 50 years from the beginning of a “warm” phase in 1926 to the end of a “cold” phase in 1975; this trend is a cooling of -

3.18 F per century. It is clear that in a quasi-cyclical climate, as Alaska appears to be during the 20th century, trend analyses will give very different and even opposing results, depending on which phases of the NP/PDO quasi-cycle are sampled.

G. 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 six indices previously discussed. With approximately 40 years of data, correlation coefficients of 0.30 and 0.39 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 and PDO indices, 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, indicating 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 8. Correlation of CAKN Snow Water Equivalents with Climate Indices

CAKN Unit	Arctic Temp 64N-90N	NP Nov-March	AO/NAM Dec-March	PDO Dec-March	TSI Hoyt	CO2
Wrangell-St Elias	0.08	0.25	0.22	–0.11	0.21	0.10
Denali	–0.02	0.46 **	0.37 *	–0.37 *	–0.01	–0.10
Yukon-Charley	0.16	0.38 *	0.37 *	–0.29	0.13	0.15
Average	0.06	0.39 **	0.29	–0.31 *	0.07	0.01

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 8 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 two lowest SWE years – 1969 and 1970 – 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 77. Annual (solid lines) and 5-year moving averages (dashed) of CAKN SWE and AO index.

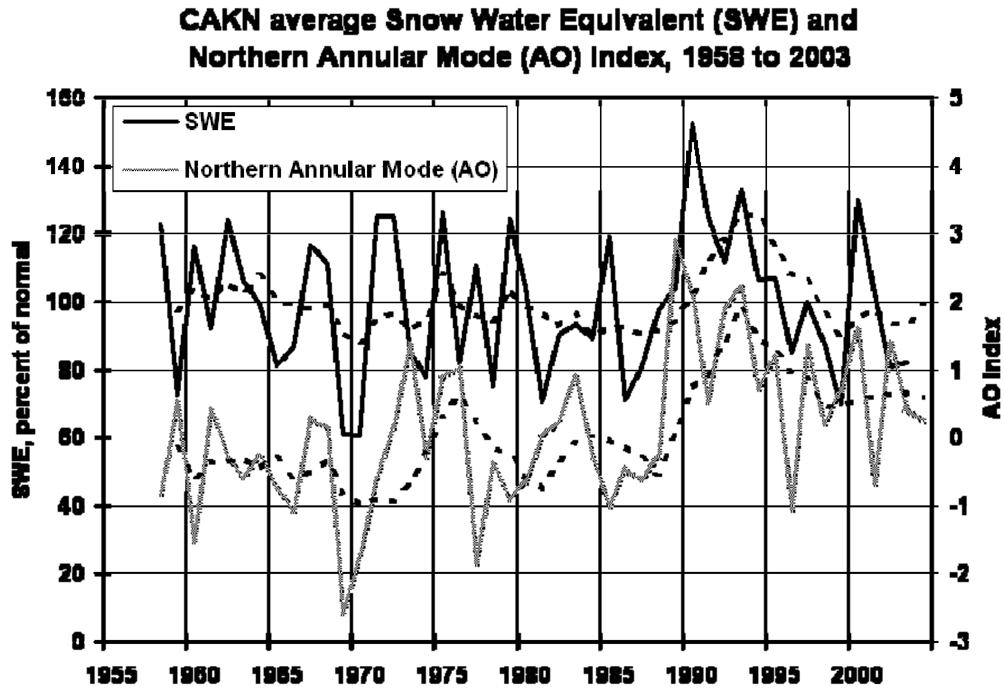
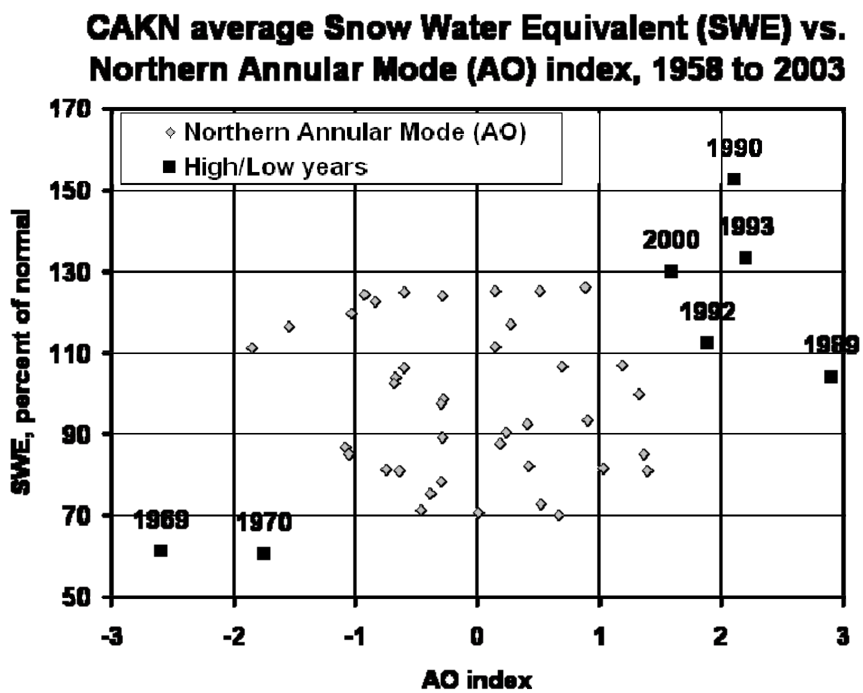


Figure 78. Scatter plot of annual SWE vs. AO index.



H. CAKN precipitation (SWE) and Arctic Sea Ice extent

In a study of "Long-term ice variability in arctic marginal seas", Polyakov et al. (2003) note that the extent of summer ice in four arctic seas (Kara, Laptev, East Siberian, and Chukchi); in the Siberia-Alaska sector, appear to decrease when the North Atlantic Ocsillation (NAO) is positive. The NAO, which is the Atlantic equivalent to the PDO, is in turn highly correlated with the AO (r=0.68). As discussed, the AO is positively correlated with CAKN Snow Water Equivalent. Skipping the intermediate steps (Sea Ice – NAO – AO – Snowfall), correlations between SWE and Arctic Sea Ice extent are listed in the next table.

Table 9. Correlation of CAKN Snow Water Equivalents with Arctic Sea Ice extent		
CAKN Unit	Annual	5-year
Wrangell-St Elias	–0.23	–0.72 **
DENALI	–0.43 **	–0.54 *
Yukon-Charley	–0.54 **	–0.80 **
Average	–0.35 *	–0.73 **

The longer time scale correlation (of 5-year running means) is most impressive; the negative sign means less sea ice in August, i.e., more open sea at the end of summer, is correlated with greater SWE during the winter. This suggest that the cyclones crossing interior Alaska draw much of their moisture from the Arctic Ocean, presumably in Fall and early winter before the open water freezes. The correlations are greatest for Yukon-Charley, the northernmost CAKN unit and the one farthest from the Pacific Ocean, suggesting that most of the moisture falling as snow there is derived from the Arctic Ocean. During years with positive AO, the cyclone track shifts northwards from the north Pacific to interior Alaska, and the open waters of the Arctic Ocean provide more moisture to these storms in interior Alaska.

Polyakov et al. refer to the longer time scale variations of the Arctic sea ice as a "Low-Frequency Oscillation", or LFO, with a period of 50-80 years. The state that "the time series and wavelet transform indicate two periods of minimum ice extent associated with positive LFO phases (and warming in the 1930-40s and late 1980s-90s) and two periods of maximum ice extent associated with negative LFO phases (and cooling prior to the 1920s and in the 1960-70s)". The 47 year long SWE record spans only one cycle of the LFO, making is difficult to verify the reality of the correlation; however, if the correlation is robust, it could provide a means of forecasting future snowfall in interior Alaska.

It is interesting to note that the AO, which is an index of zonal circulation around the Arctic, is largely determined by the strength of the circulation in the Atlantic sector (i.e, the NAO, related to the Icelandic Low), and that the long-term variations in the intensity of the Icelandic Low sets in play a sequence of events that has an enormous impact on the snowfall in interior Alaska. This sequence of events works quite independently of the ocean/atmospheric occurrences in the North Pacific, with correlations between the AO and the PDO and NP indices of only -0.24 and 0.28, respectively. Thus, while the PDO in the Pacific Ocean has the largest influence on annual and winter temperatures in south central Alaska, the NAO in Atlantic Ocean has the greatest long term influence on the snowfall, especially in the interior.

The next two figures show the full record of Arctic Sea Ice anomalies provided by Polyakov et al., and a comparison between Arctic Sea Ice extent and SWE for the period of record since 1958.

Figure 79. Arctic Sea Ice extent anomalies (departure from mean, in thousands of square kilometers).

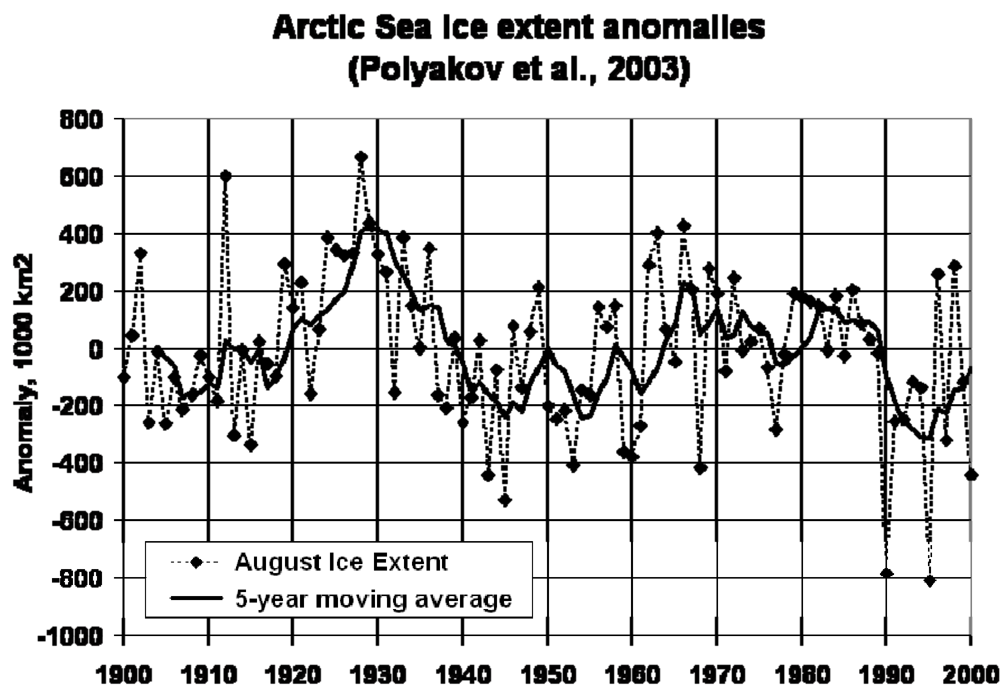
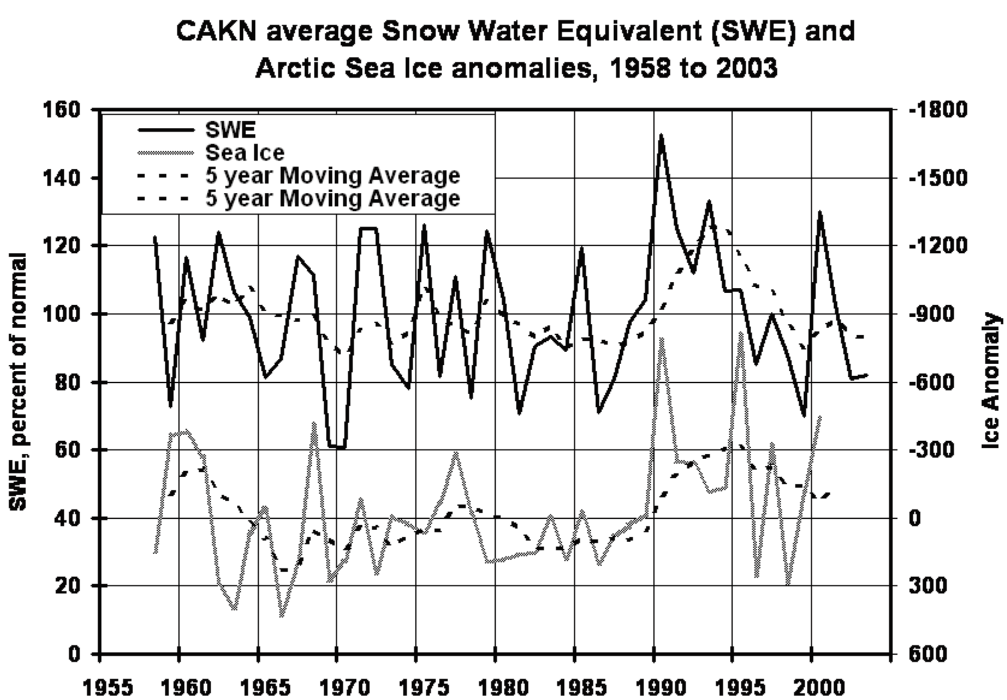


Figure 80. CAKN regional SWE compared with Arctic Sea Ice extent (plotted on an inverted scale).



8. Microclimatology of the Rock Creek Basin

In 1994, five “Long-term Ecological Monitoring” (LTEM) climatological stations began operation in Denali National Park. The five stations are in the Rock Creek Basin above the Denali NP Headquarters co-op station, and range in elevation from 2375 to 4390 feet above sea level. Along with the co-op station, the network provides a climatological transect with elevation from 2070 to 4390 feet. During the period of record (January 1994 through July 2004), the LTEM stations have large data gaps of several months duration, and several individual seasons (June to August and December to February) are missing completely for some stations. Overall, between 5 and 20 percent of the months since 1994 are missing for the individual station. Although the LTEM records are not complete enough to allow time series analysis for individual stations, the observations can be used to produce a climatological transect. This, in turn, helps provide some guidelines for station location and continuity.

The table below provides basic averages and extremes (degrees F) for the five LTEM stations, the summit of Denali (estimated from NCEP/NCAR reanalysis data), and for the McKinley HQ coop station (1994 to 2004). The “# of missing seasons” gives, for each station, the total number of winter and summer seasons (out of 22) for which mean temperatures could not be computed. The LTEM station means are adjusted slightly to account for the missing seasons at each station, thereby removing a bias that would be caused by a particularly warm or cold season being absent from the record at some (but not all) the stations. For example, the winter of 1998-1999, which averaged about 6 degrees F below average, is missing from the records for the Upper Ridge and Permafrost stations, and (in this case) a correction of about one-half degree is applied to lower the averages to what they would have been had that winter been included.. The extreme maximum and minimum temperatures are for the same 11 years. The extreme minimum temperatures for the Upper Ridge and Permafrost stations were estimated, since these stations were not operating at the time of the extreme cold event in February, 1999.

Table 10. Vertical Climatological Transect of LTEM stations in the Rock Creek Basin, Denali NP

	Elevation feet	# missing seasons	Winter average	Summer average	Maximum Temp.	Minimum Temp.	NP correlation
Denali Summit	20320	0	–37.2	–10.8			-0.33
Upper Ridge	4390	3	10.8	47.1	74	–42 est.	-0.70
Lower Ridge	3241	1	12.0	51.5	79	–41	-0.59
Treeline	3215	1	11.6	52.0	81	–41	-0.73
Forest	2411	5	8.8	53.7	87	–43	-0.58
Permafrost	2375	4	9.5	54.2	83	–44 est.	-0.68
McKinley HQ	2070	0	5.9	54.6	88	–54	-0.57

The next four figures show the 11-year average winter and summer temperatures, and extreme minimum and maximum temperatures, for these stations in graphical format. The sharp vertical temperature gradients associated with the wintertime inversion are apparent, with mean winter (December to February) temperatures increasing 3.6 degrees over the 305-foot elevation difference between the McKinley HQ and the Permafrost stations. The extreme minimum temperature increases 10 degrees over the same elevation rise. During mean winter conditions, the top of the inversion appears to be near the elevation of the Treeline and Lower Ridge stations (about 1200 feet above McKinley HQ), which is somewhat lower than the height of the inversion inferred from the NCEP/NCAR reanalysis (Figure 60). The inversion appears to be shallower during extreme cold events (such as February, 1999).

Summer temperatures behave more “nomally”, generally decreasing with altitude at a rate of about 2.5 degrees per 1000 feet. Above the Treeline and Lower Ridge stations, the lapse rate increases to about 4.0 degrees per 1000 feet; the smaller lapse rate at lower elevations is due to occasional inversions, particularly at night, that affect the seasonal average temperatures. The extreme maximum temperatures decrease roughly 6 degrees per 1000 feet, a rate that is almost the same as the adiabatic lapse rate of 5.5 degrees. This reflects the convective vertical mixing of the atmosphere during hot days.

Figure 81. Vertical transect of average winter temperature in the Rock Creek basin, Denali NP.

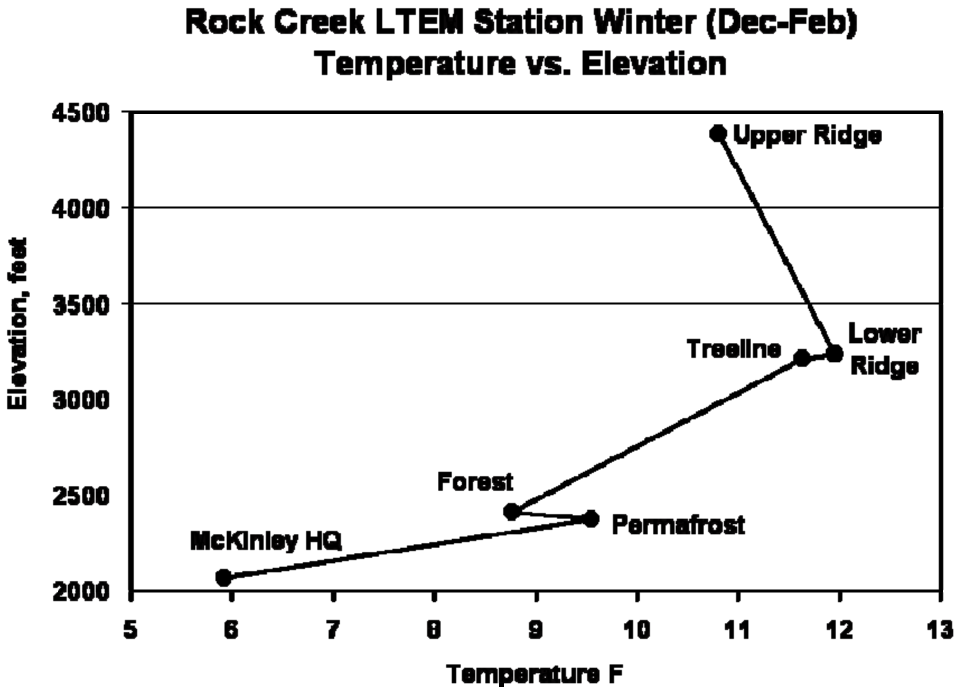


Figure 82. Vertical transect of average summer temperature in the Rock Creek basin, Denali NP.

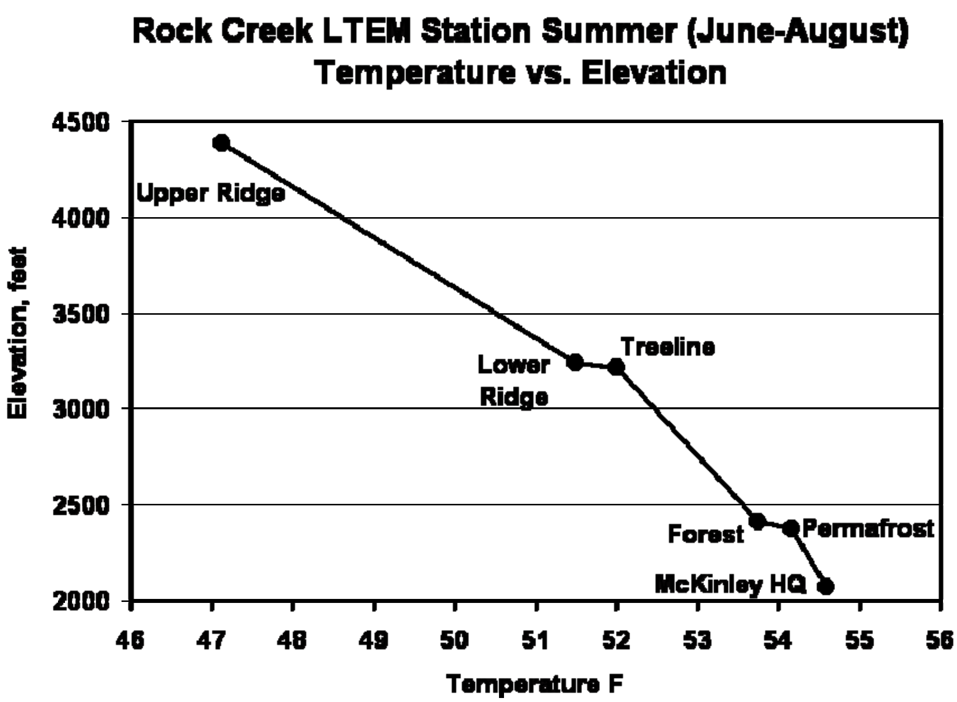


Figure 83. Vertical transect of average winter temperature in the Rock Creek basin, Denali NP.

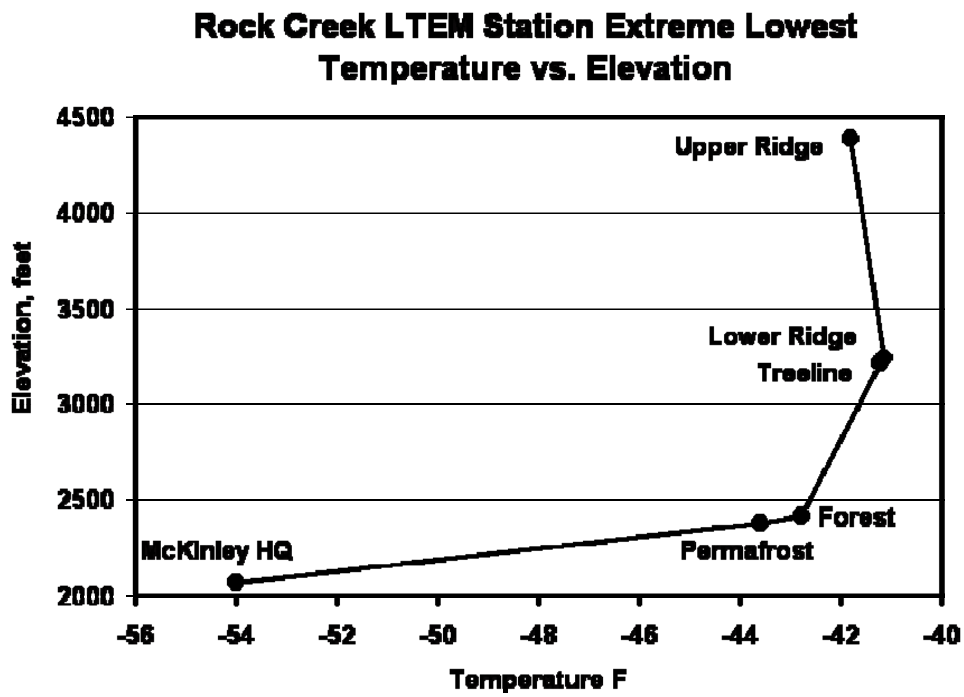
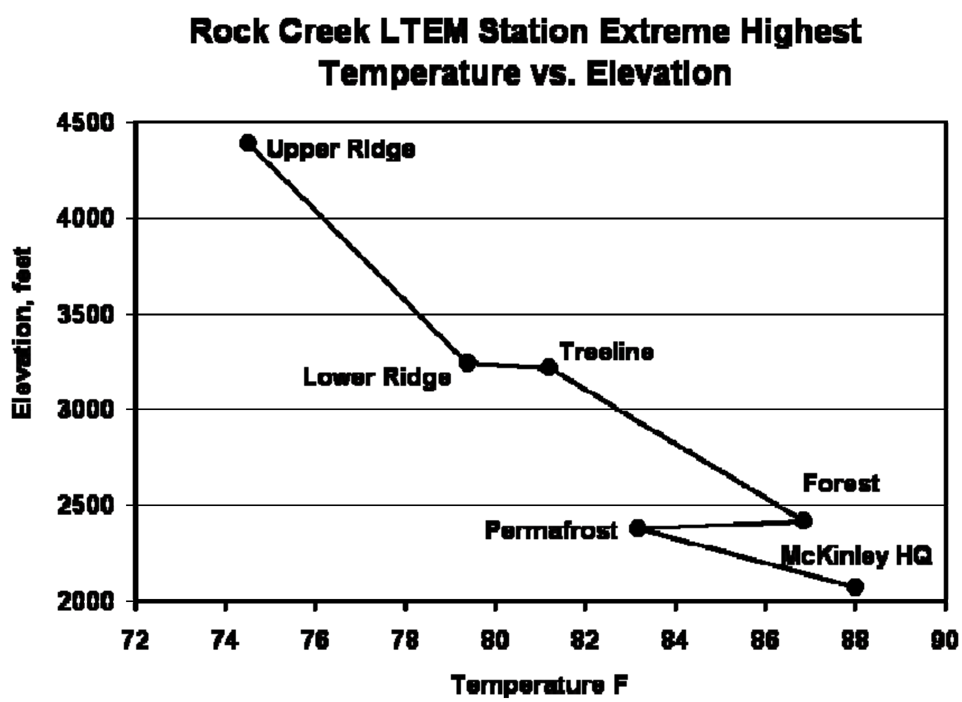


Figure 84. Vertical transect of average winter temperature in the Rock Creek basin, Denali NP.



The wintertime temperature inversion, and its associated vertical temperature gradients, has profound implications for the siting of climate monitoring stations. Any relocation of a climate station to a slightly different elevation could introduce an artificial "climate change" that would overwhelm the signal from a true climate change, shift, or trend. For example, moving the McKinley HQ station to a site 30 feet lower could completely negate the 0.3 degree observed warming since 1926.

The measurement of climatological means and extremes are extremely sensitive to the siting of the measuring station, which raises the question of how sensitive the measurement of climate *change* is to location (particularly elevation) of the station. The next two figures compare the time series of Winter and Summer seasonal temperature departures at the five LTEM stations, the McKinley HQ coop station, and the summit of Denali. With the occasional exception of the Denali summit, the seven locations display similar interannual variations.

Figure 85. Winter temperatures at seven locations in McKinley NP.

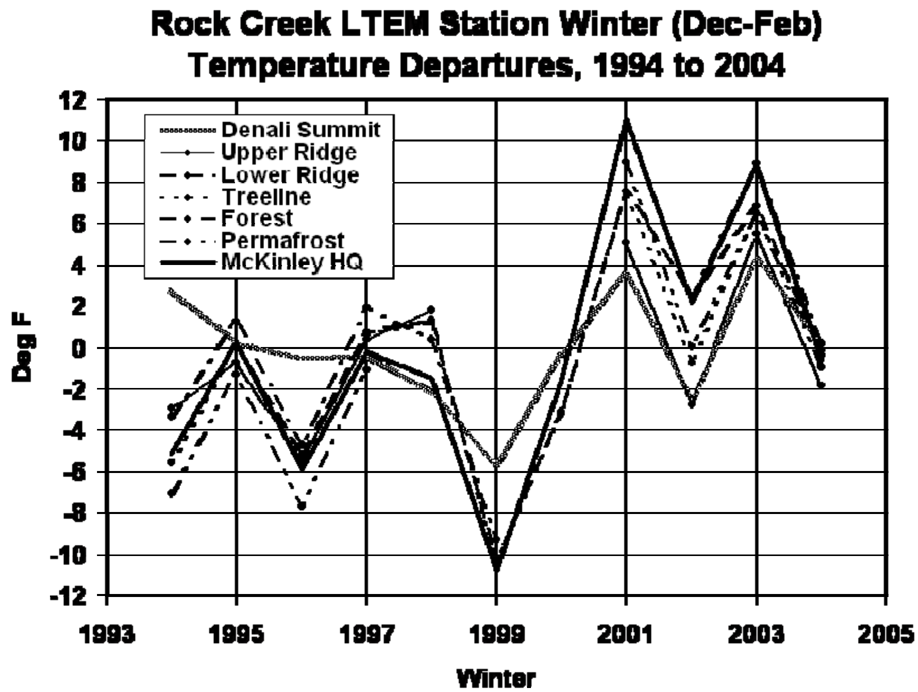
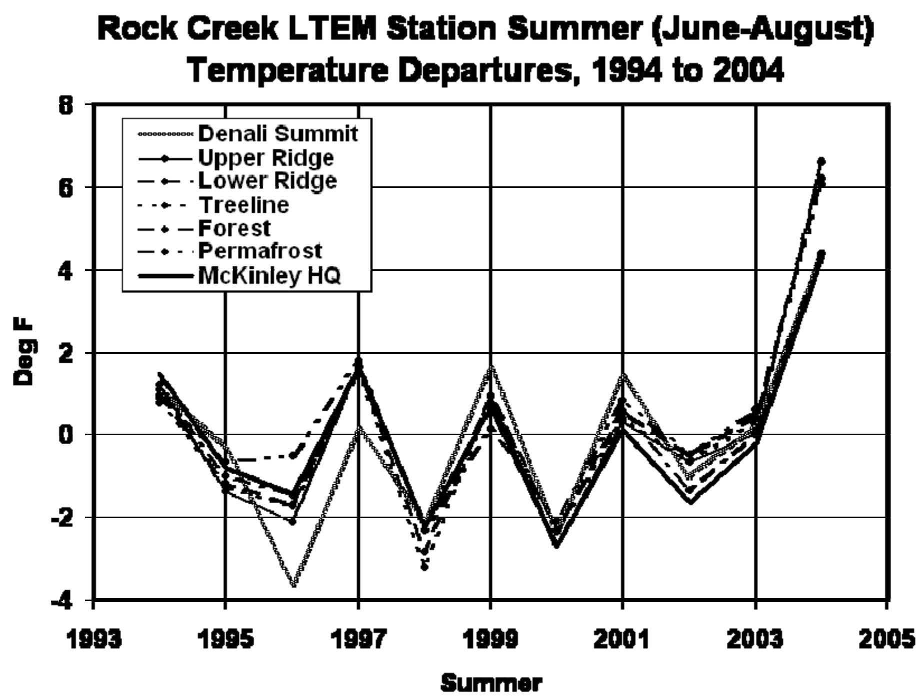


Figure 86. Summer temperatures at seven locations in McKinley NP.



The table of correlations below quantifies the coherence of interannual variability of winter and summer temperatures among the seven climate stations. Excluding the Denali Summit temperatures, all correlations are greater than 0.85 and are significant at the .01 level. Beneath the top of the wintertime inversion (Lower Ridge station and below), all correlations are 0.89 or greater, and when the Permafrost station is excluded, the other four lower stations all have correlations of 0.96 or greater. These high correlations imply that for climate time series analysis, the five lower stations (McKinley HQ, Permafrost, Forest, Treeline, and Lower Ridge) will yield nearly identical results. To test this hypothesis, winter temperatures at the seven stations were correlated with the concurrent North Pacific index (second table below). As we saw in section 7C of this report, the NP index (the atmospheric component of the Pacific Decadal Oscillation) has the best overall correlation with CAKN region winter temperatures. The five lower stations all had similarly good correlations (r = 0.57 to 0.68) with the NP index. There appears to be a slight increase in the correlation with height, from -0.57 at McKinley HQ to -0.70 at Upper Ridge. This increase in correlation with height was apparent in the NCEP/NCAR reanalysis data shown in Figure 59 (section 7C), where it was noted that "the low-level wintertime inversion north of 64 N appears to act more independently of the PDO, reducing the temperature correlations at the surface in interior Alaska"

Table 11. Correlations of seasonal temperatures among various stations in the Rock Creek Valley.
Winter (DJF) correlations are in the lower left section of the table
Summer (JJA) correlations are in the upper right.
Significance levels are indicated as follows: *.05 level **.01 level

DJF \ JJA	Denali Summit	Upper Ridge	Lower Ridge	Treeline	Forest	Permafrost	McKinley HQ
Denali Summit	X	0.90 **	0.90 **	0.90 **	0.91 **	0.68 *	0.89 **
Upper Ridge	0.55	X	1.00 **	1.00 **	0.98 **	0.91 **	0.96 **
Lower Ridge	0.80 **	0.90 **	X	1.00 **	0.98 **	0.95 **	0.96 **
Treeline	0.69 *	0.93 **	0.98 **	X	0.98 **	0.95 **	0.96 **
Forest	0.64 *	0.86 **	0.99 **	0.97 **	X	0.89 **	0.99 **
Permafrost	0.49	0.92 **	0.99 **	0.99 **	0.99 **	X	0.92 **
McKinley HQ	0.70 *	0.86 **	0.97 **	0.96 **	0.99 **	0.99 **	X

Table 12. Correlation of Winter temperature with North Pacific (NP) index in Denali NP: variation with station elevation.

	Elevation feet	NP correlation
Denali Summit	20320	–0.33
Upper Ridge	4390	–0.70 **
Lower Ridge	3241	–0.64 *
Treeline	3215	–0.68 **
Forest	2411	–0.59 *
Permafrost	2375	–0.62 *
McKinley HQ	2070	–0.57 *

From this analysis of observed conditions at a network of stations in the Rock Creek basin of McKinley National Park, we may conclude that while the measured temperature, particularly in winter, can differ greatly with elevation, the measured interannual variations of climate appear to be virtually identical at all stations within the inversion layer. Although similar networks do not exist within the Wrangell-St. Elias and Yukon-Charley units, we may conclude that the climates of those units are similar enough to that of McKinley (namely, there exist wintertime temperature inversions) that the same general conclusions apply.

9. Summary and Recommendations

As noted in the introduction, this study is limited to analysis and interpretation of long-term records of the most basic climate parameter, namely, temperature, snow, and rain. The recommendations will be aimed at obtaining the best possible long-term record of temperature, snow, and rain in the future.

Sections 2, 3, 4, and 5 of this study accomplished the mundane but necessary task of documenting available climate data (temperature, snow, and rain), including identification of stations, their periods of record, and sources from which the records can be accessed, and providing climate summaries for some of these stations. In section 6 the best existing records were combined, processed, and analyzed to produce the longest possible time series for each CAKN unit.

Of the three climate parameters examined in this study, temperature has the longest useful record in the CAKN region. Nine stations have records extending back 80 years or longer, with the earliest records beginning in 1899. However, not all of these records are complete or continuous, and in some cases records needed to the adjusted for station changes. In other cases, records from several nearby stations were spliced together to provide a more complete time series or to fill in gaps in the record. After all that was done, the resulting century-long record of temperature provided much insight into the nature and causes of climate variations in central Alaska.

Next in longevity is the Snow Survey record of snow water equivalents measured at 61 sites, which extends back to 1958. Of these sites, 32 have long enough records for climatological normals to be calculated. Annual departures from these normals provide an effective measurement of winter precipitation. The observations at different sites were quite coherent within and among the CAKN units, and it is felt that record of winter precipitation from this network is robust and useful.

The records of the third parameter, rainfall, leave much to be desired. Most coop station rainfall records are either short, replete with missing months and years of data, or suspiciously low. Because of the localized nature of warm season rainfall, records from nearby stations are not as readily spliced together as they are for temperature. As a result, the only reasonably complete long-term rainfall record in the region is that taken at the McKinley HQ station. Of the three parameters, the measurement of rainfall begs for the most improvement in the future.

Section 7 examines possible causes of observed climate variations and possible connections between climate change in central Alaska and other regions of the world. The largest and most obvious connection is between CAKN winter temperature and the Pacific Decadal Oscillation (or North Pacific oscillation), and nearly all of the long-term changes in Alaska's winter climate appear to be due to the fluctuations in the strength of the Aleutian/North Pacific Low and the associated sea surface temperature gradients. Causes of changes of summer temperature changes and winter snowfall are more elusive.

Section 8 explores the microclimate of the Rock Creek basin, the results of which provide some insight into the importance of selecting and maintaining climate station locations.

With a century of recorded Alaskan climate behind us, here are some recommendations that will hopefully make the record of the next century as accurate and useful as possible. Specific recommendations will be made for measurement of each of the three main climatological parameters, temperature, snowfall, and rainfall.

A. Temperature

Times series of monthly temperatures for nine coop stations (or combinations of stations) with records of 83 years and longer have been compiled, and these time series can be updated regularly. In all cases, coop station data can be read directly from summaries published by NCDC or WRCC. However, of these stations, only two (McKinley HQ and McCarthy 3 SW) are within CAKN units, and only one station (McKinley) is operated by the NPS. Because of this, any of the long-term stations analyzed in this study and used for future climate monitoring could close, move, or otherwise change without any input from the NPS. The only exception is, of course, McKinley HQ. Therefore, it is recommended that the NPS do the following:

1. Maintain the McKinley station in the current location and operation. This station, along with the Fairbanks University Experimental Station station, has the longest, most continuous, and most reliable climate record in Alaska.

2. Open and permanently operate “benchmark” coop stations inside Wrangell-St. Elias and Yukon-Charley preserves.

All three stations should be instrumented and operated according to World Meteorological Organization (WMO) and National Climate Data Center principles and specifications for “benchmark” stations.
Details of WMO specifications for the Global Climate Observing System (GCOS), and specifically the GCOS Surface Network (GSN), may be found in the following WMO publications:

1. Manual on the Global Observing System, WMO-No. 544, 2.10.3.17, pages III-8 to III-10
    http://www.wmo.int/web/www/OSY/Manual/WMO544.pdf or…
    http://www.wmo.ch/pages/prog/www/OSY/Manuals_GOS.html
2. Guide to the GCOS Surface and Upper-Air Networks: GSN and GUAN (Ver. 1.1) GCOS-73
    http://www.wmo.int/pages/prog/gcos/Publications/gcos-73.pdf
3. Development of the GCOS Networks and Data
    http://gosic.org/gcos/GCOS-dev.htm
4. WMO Guide to Meteorological Instruments and Methods of Observation (CIMO Guide) 7th ed (2006)
    http://www.wmo.ch/pages/prog/www/IMOP/publications/WMO-8-Guide-contents.html
    http://www.wmo.ch/pages/prog/www/IMOP/publications/CIMO-Guide/Draft-7-edition.html
5. US GCOS: http://www.ncdc.noaa.gov/oa/usgcos/index.htm

The “GCOS Climate Monitoring Principles”, available at:
http://gosic.org/gcos/GCOS-climate-monitoring-principles.htm , state that:

“Effective monitoring systems for climate should adhere to the following principles:
1. The impact of new systems or changes to existing systems should be assessed prior to implementation.
2. A suitable period of overlap for new and old observing systems is required.
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations.
5. Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.
6. Operation of historically-uninterrupted stations and observing systems should be maintained.
7. High priority for additional observations should be focused on data-poor regions, poorly-observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.
8. Long-term requirements should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.
9. The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted.
10. Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.”

Of the ten points listed, perhaps number 6 is most relevant, and will be repeated:
“Operation of historically-uninterrupted stations and observing systems should be maintained.”

The specifications published by the WMO are quite detailed, but here are some essential excerpts from “Best Practices for GSN Stations” in the Manual on the Global Observing System (also available in “Observing Requirements for the GSN”, http://gosic.org/gcos/gsnspec.htm):

“Long-term continuity should be provided for each GSN station. This requires the provision of the necessary resources, including well-trained staff, and keeping changes of location to a minimum.

In case of significant changes in sensor devices or station location, Members should provide for a sufficiently long period of overlap (at least one, but preferably two years) with dual operation of old and new systems to enable comparisons to be made and the identification of inhomogeneities and other measurement characteristics.
"The Guide to Instruments and Methods of Observation (WMO No 8) provides the appropriate recommendations.

- The site layout should follow the recommended form (Guide on the GOS, WMO No 488).
- The site and instruments should be inspected regularly and maintained according to WMO recommended practices (Guide to Instruments and Methods of Observation (WMO No 8). As part of the maintenance, the necessary calibration practices should be traceable to the standards provide by the Guide.
- A national plan should be developed to archive daily data and metadata pertaining to each climate station. Metadata should include data concerning a station's establishment, subsequent maintenance, and changes in exposure, instrumentation and staff. The data and metadata should be in its original form as well as in digital format.
- Detailed metadata and historical climate data for each GSN station should be provided to the GSN Archive. Both data and metadata should be up-to-date.

A short report from Howard Diamond and Mike Helfert, of the NOAA/NESDIS/NCDC Climate Observations and Analysis (COA) Program, "High Latitude Surface Observing (land) Sites - Benchmark Climate Reference Network" (Arctic Observing Network (AON) Planning Meeting with NSF Program Managers, Silver Spring, MD, 31 January 2007), at http://www.climate.noaa.gov/cp_oa/pdf/gcosaon.pdf
provides some practical advice for planning long term climate monitoring stations in the Arctic, based on experience with several prototype AK "Climate Reference Network" stations. They advise:

- Sturdiest possible equipment to withstand wildlife curiosity
- Use multiple sensors in case one fails
- Plan for deep snow, & raise station vertically
- Record data locally in case communications go out
- Build stations in places where there is power
- Data must be in the public domain and made easily accessible immediately
- Data must be highest confidence, irrefutable.

Piecing all the principles, specifications, and advice together, the CAKN benchmark stations should be:

- A standard co-op station with standard equipment, on the model of the McKinley HQ station.
- Located near a ranger station or other permanently occupied facility, so the station can be operated and maintained continuously. A remote site will likely experience data loss when it is not accessible.
- Select a site whose environment is not likely to change over the next century. Change could include future construction of large numbers of buildings, new forest growth, construction or draining of lakes and ponds (such as beaver ponds, reservoirs), and so on. The environment around the station should be stable. Likewise, do not plan on moving the station to another location, even a short distance away.
- Try not to locate the station in an extreme microclimate, such as a cold depression or an excessively windy ridge. However, results from the microclimate study of the Rock Creek Basin (section 8 of this report) imply that interannual and longer term climate changes will be nearly equally detectable at a wide variety of locations, and that the exact location of the station is not critical.
- Use multiple sensors. I (the author of this report) am a coop observer, and in addition to the standard max-min thermometers and precipitation gauge, I've added alternate max-min thermometers, two temperature data loggers, several precipitation gauges of different designs, and more. All of these other sensors have, on occasion, provided data when the primary sensors failed or were in error for a variety of reasons.
- Use primary sensors that are not likely to be changed or replaced. The US coop network is replacing liquid in glass thermometers in Cotton Region Shelters (CRS) with electronic Max-Min Temperature System (MMTS) units, and differences between the two can be several degrees. Select one or the other, but plan to stay with the chosen sensor.
- If sensors are changed, the WMO recommends a "sufficiently long period of overlap (at least one, but preferably two years) with dual operation of old and new systems to enable comparisons to be made". I recommend an even longer period of overlap, three to five years, in order to define the mean difference between the two systems (and therefore, the correction to be applied to the earlier records) to one or two tenths of a degree.

- NOAA and the US GCOS program is proposing a network of 29 Climate Reference Network stations in Alaska (Diamond and Helfert), and coordination between NPS and NOAA might lead to jointly operated stations within CAKN units.

B. Snow and Snow Water Equivalent.

The present network of Snow Survey sites in and near CAKN units are adequately recording interannual changes in local and CAKN unit wide SWE, and no changes are needed. The time series of SWE can be regularly updated from the Natural Resources Conservation Service / National Water and Climate Center (NWCC) web site,
http://www.wcc.nrcs.usda.gov/snowcourse/snow_rpt.html
Data can be converted into percentages of the 1971-2000 normal; these normals are listed in the same table as the recent observations.
Each coop station will also measure snowfall and SWE (as daily water equivalent)

C. Precipitation (rainfall).

Warm season precipitation – rainfall – is the most poorly recorded of the three main climate parameters. Aside from the record taken at the McKinley HQ coop station, there are no reasonably complete and continuous records from any stations in or near CAKN units. Rainfall is one of the standard observations made at a benchmark climate station. However, summer rainfall is often convective in nature and much more spatially variable than SWE, and even the best of records from a single benchmark coop station might not be very representative of overall rainfall. A network of rain gauge stations throughout each of the CAKN units is needed. The best candidate for filling this need is the existing network of RAWS automated stations. To date, these stations haven't been reliable enough or their records complete enough to allow climatological analysis of each station's data. Furthermore, winter precipitation (SWE) is severely underestimated, or often not even measured, due to issues with the heated tipping bucket design and to problems with accessibility and maintenance in the winter. However, liquid precipitation can be accurately measured with tipping bucket gauges, and from these measurements, daily and monthly averages could be compiled for each CAKN unit. It is recommended that the agencies operating the various RAWS stations be encouraged to improve the reliability of RAWS stations.

D. RAWS stations.

Although their main purpose is real-time monitoring, the network of 36 RAWS stations in and near CAKN units, many in locations not well sampled by other measuring systems, has the potential to produce useful climatological observations. As mentioned above, RAWS observations of summer rainfall would be quite useful. In the winter, temperature reports from different elevations could help define the climatology of the winter temperature inversion (e.g., frequency of occurrence, height of the top of the inversion, strength of the inversion). However, for this data to be useful, some effort must be made to make the RAWS stations operate more consistently and reliably, especially during the winter, and quality control on the output needs to be improved. Although it is not likely that remote and sometimes inaccessible stations will be able to produce benchmark quality data, the geographic distribution of RAWS stations makes them uniquely suited to measuring meteorological and climatological phenomena that are highly spatially variable, such as summer rainfall, the winter inversion, and wind events.

E. Rock Creek Basin Microclimatology Stations.

Since January 1994, five "Long-term Ecological Monitoring" (LTEM) climatological stations, along with the Denali NP Headquarters co-op station, have monitored the climate along a climatological transect between 2070 to 4390 feet elevation. In Section 8, "Microclimatology of the Rock Creek Basin", it is noted that the top of the winter inversion appears to be near the elevation of the Treeline and Lower Ridge stations (about 1200 feet above McKinley HQ), and that within the inversion layer (i.e., below the Lower Ridge station), measured interannual variations of climate appear to be virtually identical at all stations. For example, correlations between the McKinley HQ and the other four stations within the inversion range from 0.97 to 0.99 in the winter and 0.92 to 0.99 in the summer. Thus, for monitoring climate variations, there is a high level of redundancy among these stations, and the quality of climate monitoring would suffer little if four stations (Lower Ridge, Treeline, Forest, and Permafrost) were closed, leaving only the McKinley HQ station in operation. If this is done, proper operation and maintenance of the McKinley HQ becomes all the more essential. To avoid possible gaps or inconsistencies in the record, one of the remote stations could be relocated at the McKinley HQ site as a backup.

Above the inversion, climate variations at the Upper Ridge station differ from those at the lower stations. The Upper Ridge location is apparently affected more by large scale climate variations, such as the PDO, with which is has the strongest winter correlation (R = -0.70) of any of the Rock Creek Basin stations. It is there recommended to continue the Upper Ridge station, with the Lower Ridge station (which is permanently located) operated as a backup site.

10. References

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Appendix 1. Alaska Station Data Inventory

Table 1a. Climate observation (Coop) observing stations in and near CAKN units
Table 1b. Snow Course (S Course) and SNOTEL sites in and near CAKN units
Table 1c. Remote Automated Weather Stations (RAWS) in and near CAKN units

Notes:
Park Region:
DEN In : Denali, inside Park
DEN Surr : Denali, surrounding area
WSE In : Wrangell-St. Elias, inside Park
WSE Surr : Wrangell-St. Elias, surrounding area
YC In : Yukon-Charley, inside Park
YC Surr : Yukon-Charley, surrounding area
ID number is number given in the source list.
The 4-digit co-op station numbers are sometimes preceded by the state number (50) or division number (1 through 8)

Record Begins/Ends : Month and year of beginning and end of mostly continuous periods of record.
Record Years : Number of years of mostly continuous data, excluding breaks and gaps in the record.
State Div : Alaska state climatological division
Hydro Unit : Hydrological unit for Snow observation sites
Record Notes:
Y : Climatological Normals for 1971-2000 have been computed by the NWS/NCDC or NWCC
CLIM20 : Detailed CLIM20 reports are published by NCDC
"Also ..." : Additional station codes used for this station or an earlier station at nearly the same location.
Precip Only : Temperature not observed at this site.
Disc : Station discontinued, record ends before 2003
Data Sources
NCDC : National Climate Data Center
WRCC : Western Regional Climate Center
GISS : NASA Goddard Institute for Space Sciences
GI : Geophysical Institute, Alaska State Climate Center
EC : Environment Canada

Table 1a. Climate observation (Coop) observing stations in and near CAKN units

Park Region	Station Name from NCDC or GISS list	Station Type	ID Number	Lat N	Long W	Elev feet	Record begins	Record ends	Record begins	Record ends	Record Years	State Div	Record Notes	Data sources
DEN In	Eielson Visitor Center	COOP	2711	63° 26'	150° 18'	3700	6/69	8/73			4	8		NCDC
DEN In	McKinley Park (HQ)	COOP	5778	63° 43' 10.	148° 57' 5	2070	12/22	7/05			83	8	Y CLIM20	NCDC WRCC GISS GI
DEN In	Mount McKinley	COOP	6089	63° 44'	148° 55'	1730	10/49	11/49			0	8		NCDC
DEN In	Wonder Lake	COOP	9883	63° 29'	150° 52'	2100	6/67	9/73			6	8		NCDC
DEN Surr	Anchorage Int	COOP	0280	61° 12'	150° 00'	132	2/16	5/05			89	5	Y CLIM20	NCDC WRCC GISS GI
DEN Surr	Anderson	COOP	0299	64° 21'	149° 12'	510	6/96	4/03			7	8		NCDC
DEN Surr	Cantwell 2 E	COOP	1243	63° 24'	148° 54'	2150	10/83	7/05			22	8	Y	NCDC WRCC
DEN Surr	Chelatna Lake	COOP	1525	62° 26'	150° 44'	0	8/89	1/92			2	5		NCDC
DEN Surr	Chulitna River Lodge	COOP	1926	62° 49'	149° 50'	1400	8/71	7/05			34	5	Y	NCDC WRCC
DEN Surr	Clear 4 N	COOP	2005	64° 18'	149° 03'	495	12/65	7/98			33	8	Y	NCDC WRCC
DEN Surr	Curry	COOP	2266	62° 37'	150° 02'	540	1/42	12/47			6	5		NCDC
DEN Surr	Edgemire Lakes	COOP	2665	62° 32'	150° 17'	760	10/71	2/81			9	5		NCDC
DEN Surr	Fairbanks Intl AP	COOP	2968	64° 48'	147° 53'	432	1/29	1/05			76	8		NCDC WRCC GISS GI
DEN Surr	Farewell AP/Farewell Lake	COOP	2988	62° 31'	153° 53'	1500	1/42	2/78	11/84	7/05	57	8	Y also3009	NCDC WRCC GISS
DEN Surr	Gold Creek	COOP	3347	62° 46'	149° 41'	700	9/75	12/81			6	5	Precip only	NCDC
DEN Surr	Hayes River	COOP	3573	61° 59'	152° 05'	1000	11/80	7/05			25	5	Y	NCDC WRCC
DEN Surr	Healy	COOP	3581	63° 51'	148° 58'	1240	4/72	7/05			33	8		NCDC
DEN Surr	Healy 2 NW	COOP	3585	63° 53'	149° 01'	1490	11/76	7/05			29	8	Y	NCDC WRCC
DEN Surr	High Lake Lodge	COOP	3628	62° 51'	149° 07'	2400	6/64	8/68			4	5		NCDC
DEN Surr	Igloo Lodge	COOP	3871	63° 10'	149° 47'	2160	7/01	7/05			4	5		NCDC
DEN Surr	Kobe Hill	COOP	4971	64° 12'	149° 26'	800	10/97	7/05			8	8		NCDC
DEN Surr	McKinley Park View	COOP	5789	62° 35'	150° 14'	650	8/65	4/70			5	5		NCDC
DEN Surr	Minchumina	COOP	5366	63° 53'	152° 17'	700	9/49	5/67			18	8		NCDC WRCC GISS
DEN Surr	Minchumina	COOP	5881	63° 53'	152° 18'	690	10/75	6/92	12/96	7/05	25	8	Y Prec only	NCDC WRCC
DEN Surr	Mount McKinley Natl Park	COOP	6093	63° 39'	148° 48'	2050	11/75	4/76			0	8		NCDC
DEN Surr	Puntilla	COOP	7783	62° 06'	152° 45'	1832	1/42	7/05			63	5	Y	NCDC WRCC GISS
DEN Surr	Rex	COOP	7967	64° 13'	149° 17'	650	6/69	9/85			16	8		NCDC
DEN Surr	Skwentna FAA Airport	COOP	8536	61° 58'	151° 11'	150	9/49	2/59	9/70	7/05	44	5	Y	NCDC WRCC
DEN Surr	Summit FAA Airport	COOP	8811	63° 20'	149° 08'	2410	9/46	10/76			30	8		NCDC WRCC
DEN Surr	Susitna Meadows	COOP	8886	62° 45'	149° 42'	750	10/68	3/75			6	5		NCDC
DEN Surr	Talkeetna 5 W	COOP	8970	62° 19'	150° 15'	430	6/60	12/62			2	5		NCDC
DEN Surr	Talkeetna Railroad Bridge	COOP	8979	62° 20'	150° 07'	300	6/85	1/92			7	5		NCDC
DEN Surr	Talkeetna WSCMO AP	COOP	8976	62° 19' 18"	150° 05' 3	345	7/18	7/05			87	5	Y CLIM20	NCDC WRCC GISS GI
DEN Surr	Telida	COOP	9098	63° 24'	153° 16'	650	4/97	7/05			8	9		NCDC
DEN Surr	The Harris S	COOP	9142	63° 37'	148° 47'	2070	6/71	1/74			3	8		NCDC
DEN Surr	Trapper Creek 10W	COOP	9402	62° 20'	150° 32'	815	10/03	7/05			2	5		NCDC
DEN Surr	Trapper Creek 7 SW	COOP	9398	62° 16'	150° 25'	425	5/97	7/05			8	5		NCDC
DEN Surr	Trappers Creek	COOP	9396	62° 19'	150° 14'	360	2/68	6/70	5/72	12/81	12	5		NCDC
DEN Surr	Trappers Creek Camp	COOP	9397	62° 24'	150° 15'	500	6/70	7/80			10	5		NCDC
DEN Surr	University Exp Stn	COOP	9641	64° 51'	147° 52'	475	9/04	7/05			101	8		NCDC WRCC GISS GI
WSE In	Kennecott	COOP	4555	61° 29'	142° 53'	2210	1/22	12/47			26	4		NCDC
WSE In	May Creek	COOP	5810	61° 21'	142° 41'	1500	11/63	12/66			3	4		NCDC
WSE In	McCarthy 3 SW	COOP	5752	61° 25'	143° 00'	1250	6/68	7/05			37	4	Y also 5754 5757	NCDC WRCC
WSE In	Nabesna	COOP	6147	62° 24'	143° 00'	2901	10/66	7/05			39	4	Y	NCDC WRCC
WSE In	Silver Lake	COOP	8470	61° 31'	144° 11'	1200	6/93	7/05			12	4		NCDC
WSE Surr	Beaver Creek	Canadian		62° 24'	140° 52'	2130	12/69	7/05			36			EC
WSE Surr	Cape St Elias	COOP	1321	59° 48'	144° 36'	50	7/36	9/74			38	2		NCDC WRCC GISS
WSE Surr	Cathedral Bluffs	COOP	1452	63° 23'	143° 45'	1550	7/68	9/76			8	8		NCDC
WSE Surr	Chicken	COOP	1684	64° 04'	141° 56'	1360	4/53	5/54	8/96	7/05	10	8		NCDC

Park	Station Name	Station	ID	Lat	Long	Elev	Record	Record	Record	Record	Record	State	Record	Data
Region	from NCDC or GISS list	Type	Number	N	W	feet	begins	ends	begins	ends	Years	Div	Notes	sources
WSE Surr	Chisana	COOP	1814	62° 05'	142° 01'	3175	10/66	8/72			6	4		NCDC
WSE Surr	Chistochina 4 NNE	COOP	1821	62° 37'	144° 37'	1945	9/02	7/05			3	4		NCDC
WSE Surr	Chitina	COOP	1824	61° 31'	144° 26'	600	1/22	4/71			49	4		NCDC WRCC
WSE Surr	Copper Center	COOP	2156	61° 58'	145° 19'	1030	7/61	7/62	6/69	5/82	14	4		NCDC
WSE Surr	Copper Valley School	COOP	2161	62° 05'	145° 18'	1030	8/62	2/71			9	4		NCDC
WSE Surr	Cordova	COOP	2173	60° 34'	145° 47'	25	5/09	7/04			95	2	Y	NCDC WRCC GISS
WSE Surr	Cordova FAA AP	COOP	2177	60° 29'	145° 27'	38	9/46	7/05			59	2	Y CLIM20	NCDC WRCC GI
WSE Surr	Crooked Teapot	COOP	2252	62° 57'	143° 18'	2100	11/71	2/73			1	8		NCDC
WSE Surr	Dot Lake	COOP	2522	63° 40'	144° 02'	1100	10/64	5/75			11	8		NCDC
WSE Surr	Ernestine	COOP	2835	61° 27'	145° 07'	1900	6/65	3/77			12	4		NCDC
WSE Surr	Frontier	COOP	3195	62° 56'	141° 35'	1850	6/97	7/05			8	8		NCDC
WSE Surr	Gakona	COOP	3204	62° 18'	145° 18'	1400	7/69	12/81			12	4		NCDC
WSE Surr	Gakona 1 N	COOP	3205	62° 18'	145° 18'	1460	11/71	7/79	9/82	5/89	14	4		NCDC WRCC
WSE Surr	Glannallen KCAM	COOP	3304	62° 07'	145° 32'	1456	12/65	7/05			40	4	Y	NCDC WRCC
WSE Surr	Gulkana	COOP	3466	62° 16'	145° 23'	1360	7/69	12/81			12	4		NCDC WRCC GI
WSE Surr	Keisters Store	COOP	4524	61° 41'	144° 48'	1230	9/69	10/70			1	4		NCDC
WSE Surr	Kenny Lake 7 SE	COOP	4560	61° 44'	144° 57'	1200	7/61	5/69	3/00	7/05	13	4	also 4567	NCDC
WSE Surr	Kenny Lake School	COOP	4564	61° 43'	144° 56'	1302	3/70	3/70			0	4		NCDC
WSE Surr	Mankomen Lake	COOP	5607	62° 59'	144° 29'	3030	6/65	7/05			40	4		NCDC WRCC
WSE Surr	Meier	COOP	5843	62° 47'	145° 27'	2720	6/50	4/56			6	4		NCDC
WSE Surr	Mile 47 Camp	COOP	5878	61° 16'	145° 16'	1150	10/59	6/65			6	4		NCDC
WSE Surr	Mineral Lakes	COOP	5882	62° 57'	143° 23'	2098	8/96	7/05			9	8		NCDC
WSE Surr	Northway FAA Airport	COOP	6586	62° 58'	141° 56'	1713	9/42	7/05			63	8	Y CLIM20	NCDC WRCC GISS GI
WSE Surr	Old Edgerton	COOP	6777	61° 48'	144° 59'	1320	3/70	2/96			26	4		NCDC WRCC
WSE Surr	Paxson	COOP	7095	63° 03'	145° 27'	2700	1/22	12/44			23	4		NCDC WRCC
WSE Surr	Paxson	COOP	7097	63° 02'	145° 30'	2700	7/60	1/68	2/75	7/05	38	4	Y	NCDC WRCC
WSE Surr	Paxson River	COOP	7105	62° 57'	145° 30'	2750	10/68	8/79			11	4		NCDC
WSE Surr	Slana	COOP	8547	62° 43'	143° 59'	2192	4/57	7/05			48	4	Y	NCDC WRCC
WSE Surr	Sourdough 1 N	COOP	8625	62° 32'	145° 31'	1960	9/71	2/98			26	4		NCDC WRCC
WSE Surr	Summit Lake	COOP	8813	63° 08'	145° 32'	3230	11/67	1/73	8/96	2/98	7	4		NCDC
WSE Surr	Tanacross	COOP	8987	63° 23'	143° 20'	1500	9/49	5/74	5/99	7/05	31	8		NCDC WRCC
WSE Surr	Thompson Pass	COOP	9146	61° 08'	145° 45'	2500	1/52	4/74			22	2		NCDC WRCC
WSE Surr	Tok	COOP	9313	63° 21'	143° 03'	1620	6/54	7/05			51	8	Y CLIM20	NCDC WRCC
WSE Surr	Tok School	COOP	9318	63° 20'	142° 59'	1650	9/76	7/05			29	8		NCDC
WSE Surr	Tonsina Lodge	COOP	9385	61° 39'	145° 10'	1575	7/63	7/05			42	4	Y CLIM20	NCDC WRCC
WSE Surr	Tsaina Lodge	COOP	9428	61° 12'	145° 32'	1650	11/71	1/75			3	4		NCDC
WSE Surr	Valdez	COOP	9686	61° 08'	146° 21'	23	10/09	7/05			96	2	Y CLIM20	NCDC WRCC GISS GI
WSE Surr	Valdez 18E	COOP	9690	61° 07'	145° 47'	640	8/01	7/05			4	2		NCDC
WSE Surr	Willow Lake	COOP	9865	61° 47'	145° 11'	1400	3/70	4/78			8	4		NCDC
WSE Surr	Yakataga FAA Airport	COOP	9930	60° 05'	142° 30'	30	9/49	6/83			34	2		NCDC WRCC
WSE Surr	Yakutat WB Airport	COOP	9941	59° 31'	139° 38'	28	4/17	7/05			88	2	Y	NCDC WRCC GISS
YC Surr	Boundary	COOP	0910	64° 04'	141° 07'	2600	10/47	11/57			10	8		NCDC
YC Surr	Central 2	COOP	1458	65° 35'	144° 48'	870	9/49	5/54	8/62	10/80	23	8		NCDC WRCC
YC Surr	Central 2	COOP	1466	65° 34'	144° 46'	920	6/96	7/05			9	8	Y	NCDC WRCC
YC Surr	Circle City	COOP	1977	65° 50'	144° 04'	598	6/57	6/62	5/77	10/99	27	8	Y Prec only	NCDC WRCC
YC Surr	Circle Hot Springs	COOP	1987	65° 29'	144° 36'	940	9/49	10/74	2/00	7/05	30	8		NCDC WRCC
YC Surr	Dawson,Y.T.	Canadian		64° 00'	139° 06'	1050	10/00	12/89			89			EC GISS
YC Surr	Eagle	COOP	2607	64° 47'	141° 12'	850	9/1/189	7/05			106	8	Y	NCDC WRCC GISS GI
YC Surr	Fort Yukon	COOP	3175	66° 34'	145° 14'	433	6/17	10/63			46	8		NCDC WRCC GISS
YC Surr	Port Alcan	COOP	7513	62° 37'	141° 00'	1932	8/85	7/05			20	8	Y	NCDC

Table 1b. Snow Course (S Course) and SNOTEL sites in and near CAKN units											
Park	Station Name	Station	ID	Lat	Long	Elev	Record	Record	Record	Hydro	Record
Region	from NWCC list	Type	Number	N	W	feet	begins	ends	Years	Unit	Notes
DEN In	Dunkle Hills	S Course	49O02	63° 16' 5.6	149° 32' 1	2770	1/03	5/03	0	Chu	New 2003
DEN In	Eldridge Glacier	S Course	50O02	63° 02' 48.	150° 03' 2	3260	1/03	5/03	0	Chu	New 2003
DEN In	Kantishna	S Course	50O01	63° 32' 18.	150° 59' 0	1670	2/95	5/03	8	Kan	
DEN In	Rock Creek Bottom	SNOTEL	48O03	63° 43' 24.	148° 57' 5	2100	5/92	5/03	11	Nen	
DEN In	Rock Creek Bottom Pillow	SNOTEL	48O03S	63º 43'	148º 58'	2250	1/93	6/95	2	Nen	Disc
DEN In	Rock Creek Ridge	S Course	48O02	63° 43' 39.	149° 00' 0	2600	5/92	5/03	11	Nen	
DEN In	Stampede	S Course	50O03	63° 44' 58.	150° 19' 4	1800	1/03	6/03	0	Tok	New 2003
DEN In	West Fork Yentna	S Course	52N02	62° 31' 00.	152° 27' 3	900	1/03	5/03	0	Yen	New 2003
DEN Surr	Blueberry Hill	S Course	49N07	62º 48'	149º 59'	1200	2/88	5/03	15	Chu	Y
DEN Surr	Chelatna Lake	S Course	51N01	62° 27' 52.	151° 27' 3	1650	2/64	5/03	39	Yen	Y
DEN Surr	Denali View	S Course	50N06	62º 36'	150º 14'	700	2/88	5/03	15	LSu	Y
DEN Surr	Devils Canyon (Disc)	S Course	49N02	62º 49'	149º 18'	1350	2/77	3/81	4	US	Disc
DEN Surr	Dutch Hills	S Course	50N03	62° 36' 18.	150° 51' 1	3100	2/80	5/03	23	Chu	Y
DEN Surr	E. Fork Chulitna	S Course	49O01	63º 08'	149º 26'	1800	2/88	5/03	15	US	Y
DEN Surr	Edgar Creek	S Course	48O04	63º 36'	148º 01'	2400	1/94	5/03	9	Nen	
DEN Surr	Farewell Lake	S Course	53N01	62º 33'	153º 37'	1090	3/67	4/90	23	FL	Disc
DEN Surr	Lake Minchumina	S Course	52O01	63° 53' 13.	152° 18' 0	730	3/67	5/03	36	Kan	Y
DEN Surr	Nugget Bench	S Course	50N01	62° 31' 4.1	150° 56' 2	2010	2/68	5/03	35	Yen	Y
DEN Surr	Purkey Pile Mine (Disc)	S Course	52N01	62° 56' 43.	152° 15' 2	2025	1/80	4/03	23	NFK	Y
DEN Surr	Ramsdyke Creek	S Course	50N04	62° 37' 0.6	150° 48' 3	2220	2/80	5/03	23	Chu	Y
DEN Surr	Ramsdyke Creek Pillow	SNOTEL	50N04S	62º 37'	150º 48'	2220	1/80	6/85	5	Yen	Disc
DEN Surr	Talkeetna	S Course	50N02	62º 19'	150º 06'	350	2/67	5/03	36	MNC	Y
DEN Surr	Tokositna Valley	S Course	50N05	62° 37' 45.	150° 46' 3	850	2/80	5/03	23	Chu	Y
WSE In	Chisana	S Course	42N01	62° 04' 19"	142° 03' 5	3320	12/92	5/03	10	NC	Y
WSE In	Chokosna	S Course	43M01	61° 28'	143° 50'	1550	1/93	5/03	10	Chi	Y
WSE In	Dadina Lake	S Course	44M01	61° 51'	144° 49'	2160	2/85	5/03	18	MC	Y
WSE In	Lost Creek	S Course	43N02	62° 31'	143° 10'	3020	1/93	5/03	10	NC	
WSE In	May Creek	S Course	42M01	61° 20' 54"	142° 41' 3	1650	12/92	5/03	10	Chi	
WSE In	Sanford River	S Course	45N02	62° 13'	145° 04'	2280	2/67	5/03	36	UC	Y
WSE Surr	Beaver Creek BC	S Course		62° 25'	140° 51'	2150				Can	
WSE Surr	Chair Mountain BC	S Course		62° 04'	140° 48'	3800				Can	
WSE Surr	Chistochina	S Course	44N01	62° 33'	144° 36'	2300	1/85	5/03	18	UC	Y
WSE Surr	Haggard Creek	S Course	45N01	62° 42'	145° 27'	2400	2/64	5/03	39	MC	Y
WSE Surr	Jatahmund Lake	S Course	41N01	63° 37'	141° 58'	2300	1/93	5/03	10	NC	Y
WSE Surr	Kenny Lake School	S Course	45M05	61° 44'	144° 59'	1300	2/80	5/03	23	MC	Y
WSE Surr	Mentasta Pass	S Course	43N01	62° 54'	143° 40'	2430	2/62	5/03	41	UC	Y
WSE Surr	Paradise Hill	S Course	41N02	62° 48'	141° 18'	2200	2/93	5/03	10	NC	
WSE Surr	Paxson	S Course	45O11	63° 01'	145° 30'	2650	1/82	5/03	21	MC	Y
WSE Surr	Tazlina	S Course	45N03	62° 02' 30"	145° 25'	1225	2/96	5/03	7	MC	
WSE Surr	Tok Junction	S Course	43O01	63° 18'	143° 00'	1650	2/60	5/03	43	Tok	Y
WSE Surr	Tolsona Creek	S Course	46N04	62° 06'	146° 03'	2000	1/85	5/03	18	US	Y
WSE Surr	Tsaina River	S Course	45M04	61° 12'	145° 30'	1650	2/72	5/03	31	MC	Y
WSE Surr	Upper Tsaina River	SNOTEL	45M07S	61º 11'	145º 39'	1750	3/04	5/04	0	MC	New 2004
WSE Surr	Worthington Glacier	S Course	45M02	61° 11'	145° 41'	2100	3/58	5/03	45	MC	Y
YC In	Cathedral Creek	S Course	42Q02	65° 10'	141° 09'	1800	1/02	5/03	1	EC	New 2002
Park	Station Name	Station	ID	Lat	Long	Elev	Record	Record	Record	Hydro	Record
YC In	Coal Creek	S Course	43Q02	65° 19'	143° 08'	802	1/02	5/03	1	EC	New 2002
YC In	Crescent Creek	S Course	43P02	64° 51'	143° 56'	2600	1/03	5/03	0	EC	New 2003
YC In	Fisher Creek	S Course	42Q01	65º 40'	142º 24'	800	1/02	2/02	0	EC	New 2002

YC In	Kandik River (Disc)	S Course	41Q01	65º 27'	141º 23'	2850	3/70	4/02	32	EC	Disc
YC In	Tacoma Bluff	S Course	43Q01	65° 26'	143° 44'	1450	1/02	6/03	1	EC	New 2002
YC In	Three Fingers	S Course	43P03	64° 32'	143° 09'	3350	1/02	5/03	1	EC	New 2002
YC In ??	Copper Creek	S Course	43P01	65º 19'	143º 24'	?	1/02	5/03	1	EC	New 2002
YC Surr	Boundary	S Course	41P03	64º 08'	141º 08'	3500	3/67	5/03	36	For	Y
YC Surr	Chicken Airstrip	S Course	41P02	64º 04'	141º 57'	1650	3/65	5/03	38	For	Y
YC Surr	Circle City	S Course	44Q03	65º 50'	144º 04'	600	3/65	5/03	38	BB	Y
YC Surr	Circle Hot Springs	S Course	44Q05	65º 29'	144º 38'	860	3/75	5/03	28	BB	Y
YC Surr	Eagle Village (Disc)	S Course	41P01	64º 47'	141º 08'	900	3/65	3/89	24	EC	Disc
YC Surr	Lost Chicken Hill	S Course	41P05	64º 03'	141º 55'	2100	4/90	5/03	13	For	
YC Surr	Mission Creek	S Course	41P06	64° 47'	141° 12'	900	1/89	5/03	14	EC	Y
YC Surr	Mission Creek Pillow	SNOTEL	41P06S	64º 48'	141º 12'	900	1/90	6/02	12	EC	
YC Surr	Step Mountain	S Course	41Q02	65° 27'	141° 33'	2850	1/02	5/03	1	EC	New 2002

Hydro Unit
Kan = Kantishna River
MC = Middle Copper
For = Fortymile River
LSu = Lower Susitna
MNC = Mid-N Fork Chandalar
NC = Nabesna-Chisana
NC = Nabesna-Chisana
EC = Eagle to Circle
FL = Farewell Lake
Chi = Chitina River
Chu = Chulitna River
Nen = Nenana River
NFK = N Fork Kuskokwim
UC = Upper Copper River
Yen = Yentna River
Tok = Tok
BB = Birch-Beaver Creeks
Can = Canada
US = Upper Susitna River

Table 1c. Remote Automated Weather Stations (RAWS) in and near CAKN units									
Park	Station Name	Station	Lat	Long	Elev	Record	Record	Record	Record
Region	from WRCC or NIFC list	Type	N	W	feet	begins	ends	Years	Notes
DEN In	Denali Visitor Center	RAWS	63° 43' 56"	148° 54' 2	1800	7/04	7/05	1	New 2004
DEN In	Dunkle Hills	RAWS	63° 16' 30"	149° 32' 2	2850	8/04	7/05	1	New 2003
DEN In	McKinley Park AP	RAWS	63° 44' 00"	148° 55' 0	1719	11/03	7/05	2	New 2003
DEN In	McKinley River	RAWS	63° 38' 95"	151° 38' 2	840	6/90	7/05	15	
DEN In	Ruth Glacier	RAWS	62° 42' 35.	150° 32' 2	3300	8/98	7/05	7	
DEN In	Stampede Airstrip	RAWS	63° 44' 52"	150° 19' 4	1800	9/04	7/05	1	New 2003
DEN In	Tokositna	RAWS	62° 37' 26"	150° 48' 4	2200	8/96	8/98	2	
DEN In	Wigand Creek	RAWS	63° 48' 43.	150° 02' 5	5640	9/04	7/05	1	New 2003
DEN In	Wonder Lake	RAWS	63° 29' 24"	150° 52' 4	2119	7/95	7/05	10	
DEN Surr	Cantwell AP	RAWS	63° 24' 00"	148° 57' 0	2192	11/03	7/05	2	New 2003
DEN Surr	Farewell	RAWS	62° 43' 24"	154° 04' 3	775	8/96	7/05	9	
DEN Surr	Healy River AP	RAWS	63° 53' 00"	149° 01' 0	1293	11/03	7/05	2	New 2003
DEN Surr	Lake Minchumina	RAWS	63° 53' 36"	152° 18' 3	740	6/92	7/05	13	
DEN Surr	Telida	RAWS	63° 26' 24"	153° 21' 2	650	5/91	7/05	14	
DEN Surr	Wein Lake	RAWS	64° 18' 54"	151° 05' 0	1050	5/88	7/05	17	
WSE In	Chicken Creek	RAWS	62° 07' 27"	141° 50' 4	5240	9/04	7/05	1	New 2004
WSE In	Chisana	RAWS	62° 04' 39"	142° 03'	3320	7/88	7/05	17	
WSE In	Chititu	RAWS	61° 16' 26"	142° 37' 0	4554	9/04	7/05	1	New 2004
WSE In	Klawasi	RAWS	62° 04' 50"	144° 52' 1	3100	6/91	7/05	14	
WSE In	May Creek	RAWS	61° 20' 53"	142° 42' 1	1650	5/99	7/05	6	
WSE In	McCarthy	RAWS	61° 26'	142° 56'	1493	11/03	7/05	2	New 2003
WSE Surr	Alaska Hwy Mile 1244	RAWS	62° 49'	141° 28'	1900	6/90	7/05	15	
WSE Surr	B46082 84nm SE Cordova	RAWS	59° 36' 51"	143° 40' 0	0	8/02	7/05	3	Buoy New 2002
WSE Surr	Bering Glacier	RAWS	60° 07' 07"	143° 17' 0	75	4/98	7/05	7	
WSE Surr	Chistochina	RAWS	62° 33' 55"	144° 39' 5	2300	6/01	7/05	4	New 2001
WSE Surr	Chitina	RAWS	61° 31' 55"	144° 26' 2	581	10/98	7/05	7	
WSE Surr	Jatahmund Lake	RAWS	62° 36'	142° 42' 1	2300	7/99	7/05	6	
WSE Surr	Natohona Creek	RAWS	63° 09' 00"	143° 41' 0	2650	5/93	1/94	1	
WSE Surr	Paxson	RAWS	63° 02' 04"	145° 29' 4	2670	8/96	7/05	9	
WSE Surr	Slana AP	RAWS	62° 42' 00"	143° 58' 4	2395	10/03	7/05	2	New 2003
WSE Surr	Snowshoe Lake	RAWS	62° 02' 00"	142° 40' 0	2411	11/03	7/05	2	New 2003
WSE Surr	Tok River Valley	RAWS	62° 57' 26"	143° 20' 4	2300	8/99	7/05	6	
YC In	Ben Creek	RAWS	65° 17'	143° 04'	1850	5/99	7/05	6	
YC In	Coal Creek	RAWS	65° 18' 50"	143° 07' 5	802	11/04	7/05	1	New 2004
YC Surr	Birch Creek	RAWS	65° 35' 05"	144° 21' 4	850	7/98	7/05	7	
YC Surr	Eagle AP	RAWS	64° 46' 36"	141° 08' 5	880	10/03	7/05	2	New 2003

Appendix 2. CAKN region NWS Coop stations for which 1971-2000 normals have been published.

<u>CLIMATOGRAPHY OF THE UNITED STATES NO. 81: Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1971-2000 ALASKA</u>

This Climatography includes 1971-2000 normals of monthly and annual maximum, minimum, and mean temperature (degrees F), monthly and annual total precipitation (inches). Normals stations include both National Weather Service Cooperative Network and Principal Observation (First-Order) locations (indicated by FLAG1 = *).

No. = Station Number in State Map. Latitude, Longitude = in degrees, minutes, and hemisphere (N=North, W=West). Elev = Elevation in feet above mean sea level.

COOP ID = Cooperative Network ID (1:2=State ID, 3:6=Station Index). WBAN ID = Weather Bureau Army Navy ID, if assigned. Call = 3-Letter Station Call Sign, if assigned.

Elements = Input Elements (T= Temperature, P=Precipitation)

MAX = Normal Maximum Temperature (degrees Fahrenheit). MEAN = Average of MAX and MIN. MIN = Normal Minimum Temperature

Note: In 1989, the World Meteorological Organization (WMO) prescribed standards of data completeness for WMO Standard Normals. For full qualification, no more than three consecutive year-month values can be missing for a given month or no more than five overall values can be missing for a given month (out of 30 values). Stations meeting these standards are indicated with a '+' sign in Flag 2. Otherwise, stations are included in the normals if they have at least 10 year-month values for each month and have been active since January 1999 or were a previous normals station. A climate normal is defined, by convention, as the arithmetic mean of a climatological element computed over three consecutive decades (WMO,1989). Ideally, the data record for such a 30-year period should be free of any inconsistencies in observational practices (e.g., changes in station location, instrumentation, time of observation, etc.) and be serially complete (i.e., no missing values).

No.	COOPID	ELEMENTS	STATION NAME	CALL	LATITIDE	LONGITUDE	ELEV	FLAG1	FLAG2
18	1243	TP	CANTWELL 2 E	Z68	63 24 N	148 54 W	2150		
19	1466	TP	CENTRAL NO 2		65 34 N	144 46 W	920		
21	1926	TP	CHULITNA RIVER LODGE		62 49 N	149 54 W	1400		
22	1977	P	CIRCLE CITY	CRC	65 50 N	144 04 W	598		
23	2005	TP	CLEAR 4 N		64 21 N	149 03 W	495		
30	2173	TP	CORDOVA NORTH		60 33 N	145 46 W	25		
31	2177	TP	CORDOVA AP	CDV	60 29 N	145 27 W	38	+	
34	2607	TP	EAGLE		64 47 N	141 12 W	850		
41	3009	TP	FAREWELL LAKE	Z42	62 32 N	153 38 W	1060		
47	3304	TP	GLENNALLEN KCAM		62 07 N	145 32 W	1456		
48	3465	TP	GULKANA AP	GKN	62 10 N	145 27 W	1571	*	+
53	3573	TP	HAYES RIVER	5HR	61 59 N	152 05 W	1000		
54	3585	TP	HEALY 2 NW	5EA	63 53 N	149 01 W	1490		
76	5757	TP	MCCARTHY 3 SW		61 25 N	143 00 W	1250		
77	5769	TP	MCGRATH AP	MCG	62 57 N	155 36 W	344	*	
78	5778	TP	MCKINLEY PARK	MPK	63 43 N	148 58 W	2070	+	
79	5881	P	MINCHUMINA	MHM	63 53 N	152 18 W	690		
82	6147	TP	NABESNA		62 24 N	143 00 W	2901		
86	6586	TP	NORTHWAY AP	ORT	62 58 N	141 56 W	1713	+	
89	7097	TP	PAXSON	PXK	63 02 N	145 30 W	2700		
91	7513	T	PORT ALCAN		62 37 N	141 00 W	1932		
97	7783	TP	PUNTILLA		62 06 N	152 45 W	1832		
108	8536	TP	SKWENTNA	SKW	61 58 N	151 11 W	150		
109	8547	TP	SLANA	5SZ	62 43 N	143 59 W	2192		
113	8976	TP	TALKEETNA AP	TKA	62 19 N	150 06 W	345	*	+
115	9313	TP	TOK	TOK	63 21 N	143 03 W	1620		
116	9385	TP	TONSINA		61 39 N	145 10 W	1575	+	
120	9641	TP	UNIVERSITY EXP STA		64 51 N	147 52 W	475	+	

121	9686	TP	VALDEZ	VDZ	61 08 N 146 21 W	23
+						
127	9941	TP	YAKUTAT AP	YAK	59 31 N 139 38 W	28
*	+					

TEMPERATURE NORMALS (Degrees Fahrenheit)

NO. STATION NAME	ELEMENT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
018 CANTWELL 2 E	MAX	10.2	15.9	26.5	37.8	52.1	63.9	66.1	60.3	49.8	31.6	16.9	12.3	37.0
	MEAN	-0.2	4.2	12.6	26.0	40.0	50.6	54.7	50.1	40.2	22.7	7.8	2.6	25.9
	MIN	-10.5	-7.5	-1.3	14.1	27.9	37.2	43.3	39.9	30.5	13.8	-1.3	-7.2	14.9
019 CENTRAL NO 2	MAX	-8.6	-0.6	18.1	39.7	59.9	71.1	73.9	67.5	53.3	27.3	4.5	-4.1	33.5
	MEAN	-17.3	-12.0	3.2	24.4	45.9	57.4	60.7	54.3	41.0	18.5	-4.8	-12.9	21.5
	MIN	-26.0	-23.3	-11.8	9.0	31.9	43.7	47.4	41.1	28.7	9.6	-14.1	-21.6	9.6
021 CHULITNA RIVER LODGE	MAX	19.1	22.2	29.9	40.7	53.0	63.7	66.4	61.6	51.8	35.7	24.8	21.4	40.9
	MEAN	12.5	15.2	21.1	31.6	43.9	54.0	57.5	53.6	44.1	29.4	18.1	14.7	33.0
	MIN	5.8	8.2	12.2	22.4	34.8	44.2	48.5	45.5	36.4	23.1	11.3	7.9	25.0
023 CLEAR 4 N	MAX	2.1	6.6	22.4	41.8	58.8	69.7	71.9	65.9	53.9	29.5	11.0	5.0	36.6
	MEAN	-8.0	-3.7	9.7	30.6	47.5	58.6	61.6	55.6	43.3	21.1	1.4	-4.7	26.1
	MIN	-18.1	-14.0	-3.1	19.4	36.1	47.4	51.2	45.2	32.6	12.7	-8.2	-14.3	15.6
030 CORDOVA NORTH	MAX	35.4	36.4	38.4	44.1	51.3	56.8	61.1	60.8	55.1	46.2	39.6	36.7	46.8
	MEAN	30.5	31.0	33.0	38.2	45.1	51.1	55.6	55.3	49.8	41.5	34.9	31.9	41.5
	MIN	25.5	25.5	27.6	32.2	38.8	45.4	50.1	49.7	44.4	36.7	30.2	27.0	36.1
031 CORDOVA AP	MAX	31.6	34.8	39.0	45.6	52.8	58.5	61.8	61.8	56.1	46.4	36.8	33.1	46.5
	MEAN	24.6	27.2	31.1	37.7	44.8	50.9	54.5	53.9	48.1	39.5	30.1	26.7	39.1
	MIN	17.6	19.6	23.1	29.7	36.8	43.2	47.2	45.9	40.0	32.5	23.3	20.2	31.6
034 EAGLE	MAX	-3.3	4.4	21.9	42.0	58.6	70.0	73.1	66.7	53.7	31.0	10.0	1.4	35.8
	MEAN	-11.6	-6.1	7.8	28.8	46.0	57.5	60.8	54.8	42.8	23.3	2.2	-6.8	25.0
	MIN	-19.8	-16.6	-6.3	15.5	33.4	45.0	48.5	42.9	31.9	15.6	-5.6	-14.9	14.1
041 FAREWELL LAKE	MAX	6.9	16.8	28.0	41.3	56.7	66.2	69.7	65.0	54.6	34.0	18.8	12.4	39.2
	MEAN	-3.1	4.5	14.5	30.1	45.0	54.5	58.6	54.6	44.5	24.6	8.9	1.8	28.2
	MIN	-13.1	-7.9	0.9	18.8	33.3	42.7	47.5	44.1	34.3	15.2	-1.0	-8.9	17.2
047 GLENNALLEN KCAM	MAX	4.3	14.9	29.8	44.3	57.5	67.3	70.6	66.4	54.8	35.8	14.7	7.3	39.0
	MEAN	-6.4	1.5	14.1	30.3	42.9	52.5	56.5	52.3	42.3	25.2	4.3	-2.9	26.1
	MIN	-17.1	-11.9	-1.7	16.2	28.3	37.7	42.4	38.2	29.7	14.5	-6.2	-13.1	13.1
048 GULKANA AP	MAX	3.5	13.8	28.2	42.4	55.6	65.0	68.5	64.5	53.4	34.3	13.2	6.4	37.4
	MEAN	-4.7	3.2	15.3	31.1	43.9	53.1	57.0	53.1	43.1	26.4	5.5	-1.6	27.1
	MIN	-12.9	-7.4	2.3	19.7	32.2	41.1	45.4	41.7	32.8	18.4	-2.2	-9.5	16.8
053 HAYES RIVER	MAX	19.6	25.0	31.2	40.2	51.9	63.8	67.1	63.3	53.4	38.4	25.9	20.6	41.7
	MEAN	12.1	15.6	20.9	30.8	41.8	52.8	57.2	54.1	44.6	30.7	17.9	13.2	32.6

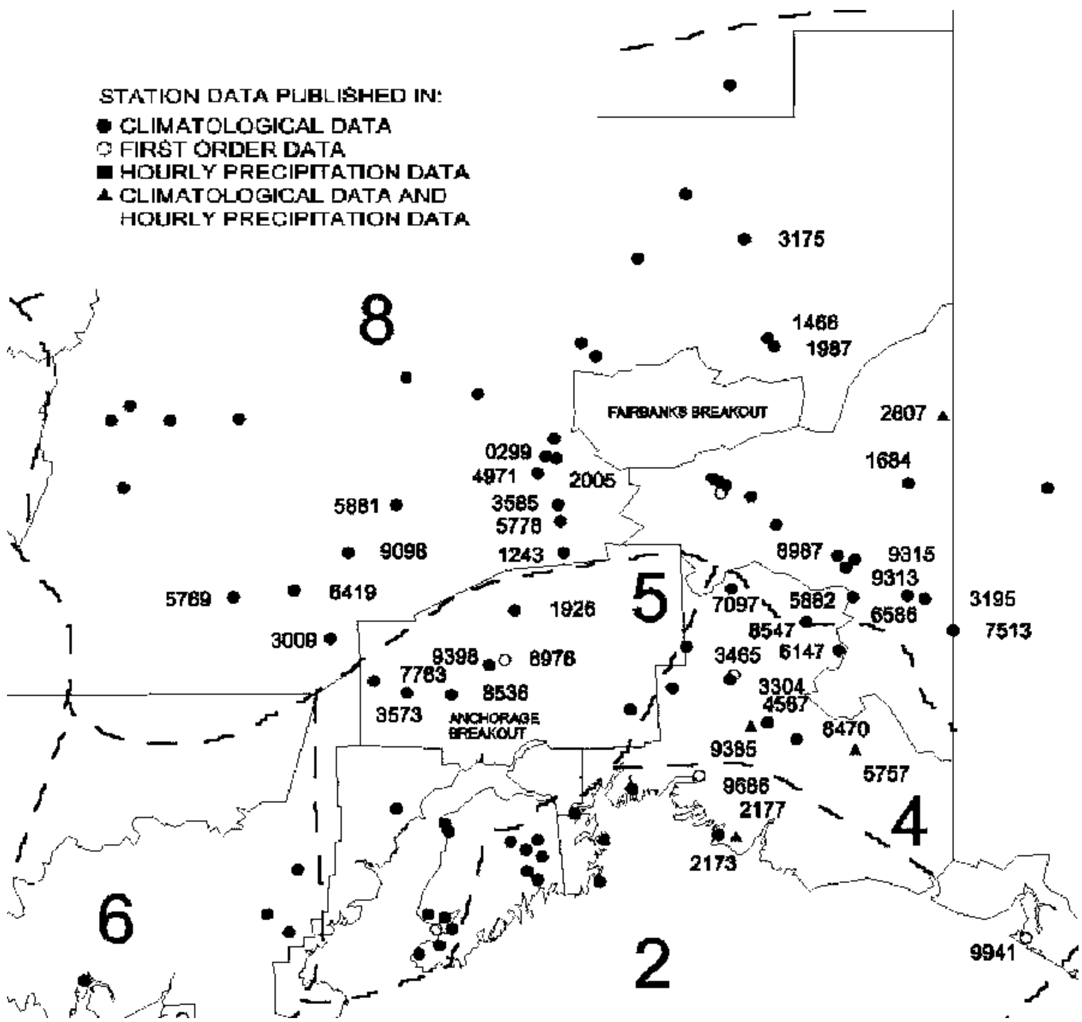
	MIN	4.5	6.1	10.6	21.3	31.7	41.8	47.3	44.8	35.8	22.9	9.9	5.8	23.5
054 HEALY 2 NW	MAX	9.9	15.4	26.4	41.2	57.1	67.8	69.9	64.3	53.4	32.4	17.9	13.9	39.1
	MEAN	0.6	4.4	14.9	30.6	46.3	56.1	59.5	54.8	44.3	24.2	9.1	3.9	29.1
	MIN	-8.7	-6.7	3.4	20.0	35.4	44.4	49.0	45.2	35.1	16.0	0.2	-6.2	18.9
076 MCCARTHY 3 SW	MAX	6.0	17.7	33.0	46.3	59.0	67.6	71.3	66.8	55.5	37.5	16.2	9.8	40.6
	MEAN	-2.4	6.0	18.0	33.2	44.0	52.0	55.9	52.2	43.3	28.3	7.2	1.6	28.3
	MIN	-10.8	-5.8	2.9	20.1	29.0	36.3	40.5	37.5	31.0	19.0	-1.8	-6.6	15.9
077 MCGRATH AP	MAX	2.3	10.7	25.3	40.5	56.8	67.6	69.7	64.1	53.4	32.2	13.8	4.8	36.8
	MEAN	-6.7	-0.9	11.8	29.1	46.2	56.7	59.8	54.9	44.7	25.3	5.8	-3.8	26.9
	MIN	-15.6	-12.5	-1.8	17.7	35.5	45.7	49.8	45.7	35.9	18.3	-2.2	-12.3	17.0
078 MCKINLEY PARK	MAX	10.6	14.5	25.2	39.0	54.1	64.8	67.6	61.8	50.8	32.2	18.0	13.7	37.7
	MEAN	2.0	4.5	13.1	27.2	42.0	52.2	55.6	50.9	40.5	22.5	9.1	4.9	27.0
	MIN	-6.6	-5.6	0.9	15.4	29.8	39.6	43.5	39.9	30.2	12.8	0.2	-4.0	16.3
082 NABESNA	MAX	-2.4	7.4	23.2	38.8	53.0	62.5	65.6	61.9	50.3	29.1	8.8	1.6	33.3
	MEAN	-7.8	-0.2	12.3	27.1	41.4	50.6	54.0	50.3	39.3	21.3	2.1	-3.9	23.9
	MIN	-13.2	-7.8	1.4	15.4	29.8	38.7	42.4	38.7	28.2	13.4	-4.6	-9.4	14.4
086 NORTHWAY AP	MAX	-9.0	2.6	24.6	43.0	57.2	66.8	69.9	65.0	52.5	28.9	5.0	-5.5	33.4
	MEAN	-16.3	-7.9	9.3	29.9	45.4	55.6	59.4	54.4	42.3	21.1	-2.7	-12.8	23.1
	MIN	-23.6	-18.3	-6.0	16.7	33.5	44.4	48.9	43.8	32.0	13.3	-10.4	-20.1	12.9
089 PAXSON	MAX	7.5	14.9	24.3	36.6	50.3	62.9	65.6	60.6	49.5	32.3	15.4	10.3	35.9
	MEAN	-1.8	3.8	11.6	24.9	39.0	50.0	53.4	49.3	39.8	23.8	6.8	1.7	25.2
	MIN	-11.0	-7.4	-1.1	13.1	27.7	37.0	41.1	37.9	30.0	15.2	-1.9	-7.0	14.5
091 PORT ALCAN	MAX	-7.5	2.7	23.4	42.2	57.0	66.3	69.8	65.9	52.5	30.1	6.6	-2.8	33.9
	MEAN	-14.1	-6.5	9.8	29.4	45.0	54.6	58.5	53.7	41.1	22.0	-0.8	-9.6	23.6
	MIN	-20.6	-15.6	-3.8	16.6	32.9	42.9	47.1	41.4	29.6	13.8	-8.1	-16.4	13.3
097 PUNTILLA	MAX	14.2	17.8	27.3	37.8	49.8	60.9	64.3	60.4	49.7	33.3	20.1	15.2	37.6
	MEAN	4.8	7.3	14.8	26.1	38.8	48.6	52.9	49.5	40.4	24.0	10.5	6.0	27.0
	MIN	-4.6	-3.2	2.3	14.3	27.8	36.3	41.5	38.5	31.0	14.7	0.8	-3.2	16.4
108 SKWENTNA	MAX	17.4	24.7	34.7	44.7	57.4	67.2	70.2	66.4	56.6	40.3	24.5	17.9	43.5
	MEAN	8.3	13.5	22.0	33.9	45.6	54.8	58.3	55.1	45.7	31.2	15.7	9.4	32.8
	MIN	-0.8	2.2	9.3	23.0	33.7	42.4	46.3	43.8	34.7	22.1	6.8	0.8	22.0
109 SLANA	MAX	5.7	15.1	28.5	42.7	56.0	65.5	68.8	64.1	52.1	33.6	14.7	7.8	37.9
	MEAN	-4.3	3.0	14.4	29.8	42.9	52.2	56.1	51.4	40.4	23.7	4.7	-2.0	26.0
	MIN	-14.3	-9.1	0.2	16.8	29.7	38.8	43.3	38.6	28.7	13.7	-5.3	-11.7	14.1

113 TALKEETNA AP	MAX	19.6	25.7	34.0	44.6	56.7	65.4	67.9	64.6	55.1	39.1	25.6	21.2	43.3
	MEAN	11.0	15.4	22.6	34.3	45.8	55.3	58.9	55.6	46.2	31.4	17.5	13.0	33.9
	MIN	2.3	5.0	11.1	23.9	34.9	45.1	49.9	46.5	37.3	23.6	9.4	4.8	24.5
115 TOK	MAX	-5.5	6.6	26.5	44.7	60.4	70.9	73.8	68.8	55.3	31.0	7.9	-1.6	36.6
	MEAN	-13.9	-4.6	11.6	31.3	45.5	55.7	59.4	53.9	42.8	21.9	-1.0	-10.1	24.4
	MIN	-22.3	-15.7	-3.4	17.8	30.6	40.5	44.9	39.0	30.3	12.7	-9.9	-18.6	12.2
116 TONSINA	MAX	3.4	14.0	28.9	43.2	55.7	65.8	69.3	65.3	53.7	35.2	14.6	6.5	38.0
	MEAN	-4.7	2.8	14.5	30.3	42.7	52.0	55.9	51.7	41.6	26.2	6.5	-1.3	26.5
	MIN	-12.7	-8.5	0.1	17.4	29.6	38.2	42.5	38.1	29.4	17.2	-1.7	-9.1	15.0
120 UNIVERSITY EXP STA	MAX	2.0	10.1	27.3	44.9	61.6	71.5	73.8	67.2	55.6	32.8	12.4	5.1	38.7
	MEAN	-6.4	-0.5	14.2	32.2	48.5	58.9	61.8	55.9	44.7	24.4	4.3	-3.1	27.9
	MIN	-14.8	-11.0	1.0	19.4	35.3	46.2	49.7	44.6	33.7	15.9	-3.8	-11.3	17.1
121 VALDEZ	MAX	26.6	30.0	35.8	44.4	52.9	59.4	62.3	60.8	53.3	43.0	32.7	29.1	44.2
	MEAN	21.9	24.8	29.8	37.7	45.8	52.2	55.2	53.6	47.1	38.2	28.3	24.7	38.3
	MIN	17.2	19.6	23.8	30.9	38.6	45.0	48.0	46.4	40.9	33.4	23.9	20.2	32.3
127 YAKUTAT AP	MAX	32.1	35.7	39.3	45.1	51.1	56.6	60.1	60.4	55.7	47.3	38.4	34.3	46.3
	MEAN	25.8	28.4	31.5	37.2	43.6	49.7	53.6	53.3	48.2	41.1	32.4	28.6	39.5
	MIN	19.4	21.0	23.6	29.2	36.1	42.7	47.1	46.2	40.6	34.8	26.3	22.9	32.5

PRECIPITATION NORMALS (Total in Inches)

NO.	STATION NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
018	CANTWELL 2 E	.89	.63	.49	.39	.68	1.70	2.73	3.07	2.61	1.09	.74	.93	15.95
019	CENTRAL NO 2	.38	.41	.28	.22	.51	1.56	2.03	2.05	1.27	1.14	.60	.58	11.03
021	CHULITNA RIVER LODGE	2.13	1.84	1.96	1.22	.90	1.95	3.65	5.35	5.74	3.12	2.44	2.63	32.93
022	CIRCLE CITY	.45	.40	.28	.22	.25	.75	1.12	1.29	.60	.88	.74	.62	7.60
023	CLEAR 4 N	.61	.49	.36	.18	.72	1.87	2.59	2.36	1.32	.93	.69	.76	12.88
030	CORDOVA NORTH	10.33	9.77	8.63	7.99	8.01	6.56	7.12	11.71	19.01	16.52	10.15	14.45	130.25
031	CORDOVA AP	7.14	6.51	6.06	5.67	6.24	5.47	5.61	9.42	14.30	12.62	7.60	9.62	96.26
034	EAGLE	.44	.47	.31	.30	1.17	1.78	2.13	1.85	1.17	.97	.67	.75	12.01
041	FAREWELL LAKE	.55	.53	.28	.30	.73	1.66	2.62	2.75	2.03	.78	.73	.63	13.59
047	GLENNALLEN KCAM	.56	.53	.37	.22	.49	1.42	1.64	1.77	1.15	1.06	.76	1.20	11.17
048	GULKANA AP	.45	.52	.36	.22	.59	1.54	1.82	1.80	1.44	1.02	.67	.97	11.40
053	HAYES RIVER	3.58	2.67	2.02	1.88	2.75	1.82	2.36	3.57	5.13	3.15	2.81	4.14	35.88
054	HEALY 2 NW	.61	.52	.36	.48	.74	2.29	2.66	2.41	1.56	1.21	.75	.82	14.41
076	MCCARTHY 3 SW	1.00	.84	.40	.23	.64	1.80	2.38	2.30	2.85	2.29	1.17	1.82	17.72
077	MCGRATH AP	1.04	.74	.81	.66	1.02	1.45	2.32	2.75	2.36	1.46	1.46	1.44	17.51
078	MCKINLEY PARK	.70	.54	.38	.27	.67	2.22	3.09	2.62	1.76	1.05	.78	.89	14.97
079	MINCHUMINA	.49	.40	.23	.25	.80	1.91	2.49	2.45	1.27	1.03	.65	.58	12.55
082	NABESNA	.24	.31	.16	.31	.75	2.78	2.73	1.74	1.02	.55	.46	.40	11.45
086	NORTHWAY AP	.24	.22	.20	.20	.99	1.90	2.30	1.38	.89	.49	.31	.25	9.37
089	PAXSON	.94	.68	.71	.61	1.10	2.65	3.04	3.20	2.97	2.16	1.15	1.24	20.45
097	PUNTILLA	1.31	1.49	1.12	.51	.53	1.92	2.07	2.37	3.16	1.50	1.21	1.52	18.71
108	SKWENTNA	2.02	1.70	1.00	.99	1.24	1.48	1.95	3.26	4.07	3.13	2.45	3.14	26.43
109	SLANA	.49	.55	.52	.33	.86	2.05	2.82	2.30	1.95	1.05	.84	.92	14.68
113	TALKEETNA AP	1.45	1.28	1.26	1.22	1.64	2.41	3.24	4.53	4.35	3.06	1.78	1.96	28.18
115	TOK	.34	.18	.13	.14	.45	1.99	2.30	.85	.73	.60	.51	.38	8.60
116	TONSINA	.86	.84	.45	.28	.47	1.24	1.75	1.44	1.40	1.30	1.17	1.27	12.47
120	UNIVERSITY EXP STA	.59	.36	.35	.18	.59	1.70	2.06	2.05	1.30	.88	1.33	.72	12.11
121	VALDEZ	6.02	5.53	4.49	3.55	3.08	3.01	3.84	6.62	9.59	8.58	5.51	7.59	67.41
127	YAKUTAT AP	13.18	10.99	11.41	10.80	9.78	7.17	7.88	13.27	20.88	24.00	15.17	15.85	160.38

Map of current and recently operating NWS Coop stations in and near CAKN park units, identified by the 4-digit Coop number.
The map is adapted from CLIMATOLOGICAL DATA ANNUAL SUMMARY, ALASKA 2004, VOLUME 90 NUMBER 13



Appendix 3. Alaska Snow Course SWE Averages: 1971-2000 (inches), from NWCC.

SNOW COURSE NAME	ELEV (FT)	JAN. 1		FEB. 1		MARCH 1		APRIL 1		MAY 1	
		Depth	SWE	Depth	SWE	Depth	SWE	Depth	SWE	Depth	SWE
BLUEBERRY HILL	1200			49	11.5	53	13.8	58	16.0	43	17.4
BOUNDARY	3500					24	4.6	25	5.3		
CHELATNA LAKE	1650			36	8.3	42	10.0	44	11.6	33	10.9
CHICKEN AIRSTRIP	1650					16	2.7	16	3.2		
CHISANA	3320		2.3	22	3.4	22	3.6				
CHISTOCHINA	2170			18	3.0	22	3.5	22	4.1	4	1.2
CHOKOSNA	1550					21	3.2	22	3.9		
CIRCLE CITY	600					25	3.9	26	4.5		
CIRCLE HOT SPRINGS	860					22	3.7	26	4.5		
DADINA LAKE	2160	19	3.0	24	4.1	29	5.1	27	5.9		
DENALI VIEW	700			42	9.6	46	11.4	50	13.4	30	12.3
DUTCH HILLS	3100			69	19.6	76	23.0	80	27.5	74	28.7
E. FORK CHULITNA	1800			45	10.5	51	12.7	54	14.0	44	15.7
HAGGARD CREEK	2540			24	4.5	27	5.6	29	6.3	18	5.2
JATAHMUND LAKE	2180			16	2.3	18	2.9	18	3.2		
KENNY LAKE SCHOOL	1300			14	2.6	18	3.4	17	3.7	3	0.9
LAKE MINCHUMINA	730			19	3.2	21	4.0	21	4.4	5	1.3
MENTASTA PASS	2430			24	4.8	26	5.8	28	6.7	16	4.8
MISSION CREEK	900	15	2.6	15	3.1	18	3.6	18	4.1	2	0.5
NUGGET BENCH	2010			45	10.9	51	12.9	55	15.5	46	15.3
PAXSON	2650			28	5.5	31	6.6	32	7.8	22	6.9
PURKEYPILE MINE	2025			20	3.9	21	4.2	21	4.1	10	2.5
RAMSDYKE CREEK	2220			61	16.3	66	18.9	69	22.0	57	21.9
SANFORD RIVER	2280	18	3.2	24	4.2	28	5.4	28	6.2	15	4.0
TALKEETNA	350			28	6.2	32	7.6	34	8.7	16	5.4
TOK JUNCTION	1650			17	2.6	19	3.2	19	3.6	3	0.9
TOKOSITNA VALLEY	850			55	13.6	67	15.7	62	18.7	43	17.0
TOLSONA CREEK	2000			19	3.2	22	3.8	22	4.1	5	2.1
TSINA RIVER	1650			50	12.5	56	15.7	57	17.6	41	14.6
WORTHINGTON GLACIER	2100			62	16.6	68	21.6	72	24.9	61	24.6

Appendix 4. CAKN area stations with published CLIM20 Summaries

CAKN area Coop stations for which CLIM20 (Climatography of the United States NO.20, 1971-2000) is published. Stations marked with (*) are inside or adjacent to CAKN units.

Map Num	COOP ID	Station Name	DIV	Period of Record
002	0280	ANCHORAGE INTL AP	5	1952-2001
003	0302	ANDERSON LAKE	5	1971-2001
010	0770	BIG DELTA ALLEN AAF	8	1937-2001
012	2107	COLLEGE OBSERVATORY	8	1949-2001
013	2112	COLLEGE 5 NW	8	1976-2001
015 *	2177	CORDOVA AP	2	1949-2001
018	2968	FAIRBANKS INTL AP	8	1949-2001
021 *	3465	GULKANA AP	4	1949-2001
032	5769	MCGRATH AP	8	1939-2001
033 *	5778	MCKINLEY PARK	8	1949-2001
036 *	6586	NORTHWAY AP	8	1949-2001
042	8594	SNOWSHOE LAKE	4	1963-2001
043 *	8976	TALKEETNA AP	5	1949-2001
044	9014	TANANA AP	8	1949-2001
045 *	9313	TOK	8	1954-2001
046 *	9385	TONSINA	4	1963-2001
047	9641	UNIVERSITY EXP STA	8	1931-2001
048 *	9686	VALDEZ	2	1964-2001