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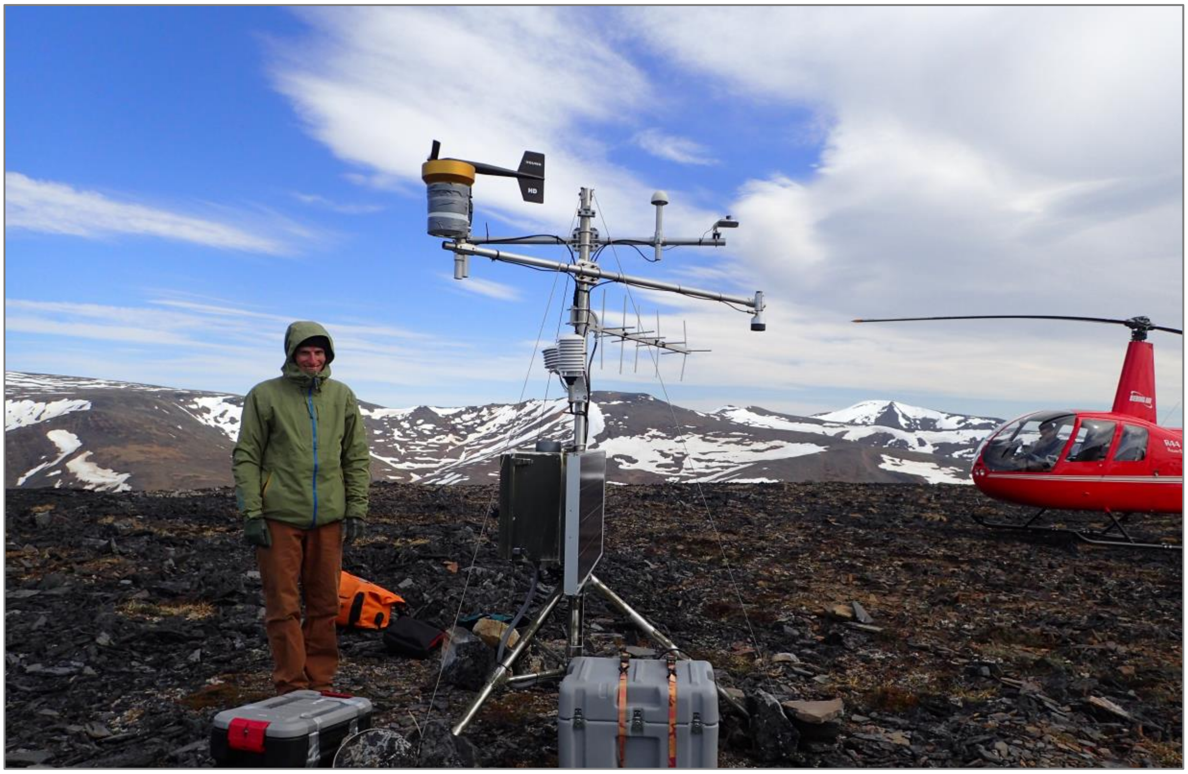
Climate Summary for the Arctic Parks

Arctic Inventory and Monitoring Network

Natural Resource Report NPS/ARCN/NRR—2017/1574



ON THIS PAGE
Annual maintenance at the Ella Creek climate station in Bering Land Bridge National Preserve.
Photograph by Pam Sousanes – NPS.

ON THE COVER
Killik climate station in Gates of the Arctic National Park and Preserve.
Photograph by Ken Hill – NPS.

Climate Summary for the Arctic Parks

Arctic Inventory and Monitoring Network

Natural Resource Report NPS/ARCN/NRR—2017/1574

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Arctic and Central Alaska Inventory and Monitoring Networks
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Contents

Page

Contents (continued)

Figures

Figures (continued)

Tables

Abstract

Climate is one of the key vital signs being monitored as part of the National Park Service (NPS) Arctic Inventory and Monitoring Network (ARCN). Seventeen new climate stations were installed between 2011 and 2014 across the five Arctic parks to provide relevant and credible weather data that could be used to look at long and short term climate trends that influence every aspect of park ecosystems. The data from weather stations at Bettles, Kotzebue, and Nome, with observations dating back >50 years, are used to provide the climate context for the park units. Annual and seasonal climate statistics and trends from the long-term records are summarized (through the fall of 2016) along with the first few years of data from the park sites.

Temperature trends across the region are non-monotonic with variability on seasonal, annual, and decadal scales primarily influenced by large-scale oceanic and atmospheric circulation patterns. Warm sea surface temperatures off the coast of Alaska in 1976 led to an abrupt upward shift in temperatures that was evident statewide, for the next few decades the temperatures were relatively stable, until recently. Over the past few years another uptick in temperatures has occurred with anomalously warm sea surface temperatures and air temperatures being observed over Alaska from 2014 through 2016. Meanwhile, sea ice continues to decrease with the influx of warm waters in northern latitudes, setting off a cascade of impacts that would be difficult to reverse.

The temperature patterns at the new park stations track very well with the index sites, for example a warm winter in Bettles generally means a warm winter at the higher elevation mountain sites, however the absolute values differ. Mountain sites, as expected, are cooler in the summer and warmer in the winter due to persistent inversions. Coastal site temperatures depend on the presence or absence of sea ice to moderate temperatures and provide moisture availability. As we obtain more data we can start to understand the gradients between the coastal and interior sites and tease out the North Slope effect on these high-latitude parks.

Precipitation is much more variable and difficult to measure at remote locations. Summer rainfall and snow depth is measured at the NPS stations, and in general, there seems to be more precipitation in the high mountains in summer and at mid-elevation coastal sites. Snowfall in the Arctic is relatively low, and what does fall is often redistributed by the wind. There is more persistent snow in areas of the parks within the boreal forest, where trees and vegetation can hold the snowpack. Mountain ridgelines and open tundra areas are often scoured free of snow, even in mid-winter.

This was part of a larger effort to assess the current condition of park resources to promote the ongoing effort towards an integrated and strategic approach to resource planning and decision making. See more on the Natural Resource Condition Assessment Program at: https://www.nps.gov/orgs/1439/nrca.htm.

Introduction

Weather and climate are key drivers in ecosystem structure and function and the high latitudes are undergoing rapid change. The Western Arctic Parklands (WEAR), Bering Land Bridge National Preserve (BELA), and Gates of the Arctic National Park and Preserve (GAAR) climate envelopes are influenced primarily by the presence or absence of sea ice in the Arctic Ocean and the sea surface temperatures of the northern Pacific Ocean. The high latitude drives the seasonal fluctuation of available solar radiation; the Arctic parks have limited incoming solar warmth in the winter and an abundance of available light in the summer.

The climate patterns in Alaska are primarily influenced by latitude, continentality, and elevation. GAAR, Noatak National Preserve (NOAT), Kobuk Valley National Park (KOVA), and Cape Krusenstern National Monument (CAKR) are all north of the Arctic Circle, or ~66°33’ north of the equator. By definition, lands north of this latitude are considered Arctic, making these the nation’s only Arctic parks. BELA, on the Seward Peninsula, is considered part of this group, and although it is just south of this demarcation, it retains much of the same characteristics of the Arctic parks.

Major topographical influences include the Brooks Range arcing through CAKR, NOAT, KOVA, and GAAR from the Chukchi Sea to the Canadian Border, and the Kigluaik and Bendeleben Mountains traversing the central Seward Peninsula in BELA. The proximity of both the Chukchi and Bering Seas to the parks in northwest Alaska and, more importantly, the presence or absence of sea ice influences land surface temperatures and available moisture for these parks. Sea ice concentration and temperature are strongly correlated in northern Alaska (Wendler et al. 2014). Over the past 30-years sea ice extent and volume have been decreasing (NSIDC 2016) and the sea surface temperatures of the north Pacific Ocean over the past several years have been strongly positive (above normal) leading to record warm temperatures over northwest Alaska.

The variability and persistence of weather patterns affect these parks and vary on both spatial and temporal scales. Observed changes in temperature and precipitation have been non-monotonic over the last century, linked to atmospheric and oceanic circulation indices that occur over annual, decadal, and multi-decadal time frames (Kittel et al. 2011). Given the importance of climate, it is one of the key vital signs being monitored by the National Park Service (NPS) Arctic Inventory and Monitoring Network (ARCN).

In 2007, an inventory of existing climate records was completed (Davey et al. 2007). Based on recommendations from the inventory report and a paucity of observation data in the Arctic as whole, it was determined that more climate stations were needed in this region. In an attempt to capture temperature and precipitation gradients many of the new sites were established at higher elevations within the Brooks Range and the mountainous areas of the Seward Peninsula.

This report will present the climate statistics from the long-term records, as well as the shorter local records from the new NPS sites that characterize the Arctic parks.

Climate Models

Over the past decade many studies have focused on either the statewide trends in temperature and precipitation (Chapin et al. 2014) or on the North Slope of Alaska where changes are projected to be the most significant (Wendler et al. 2014, Kittel et al. 2011, Hinzman et al. 2005). Few studies generate park specific information. The uncertainty in cumulative climate changes and how they will impact specific regions is one of the greatest challenges facing park managers. Because the temporal and spatial scale are a limiting factors in understanding patterns and changes, we utilize computer models. The NPS has been working closely with the PRISM Climate Group at Oregon State University to keep the climatological temperature and precipitation maps current for Alaska (Figure 1). PRISM (Parameter-elevation Relationships on Independent Slopes Model) integrates existing climate station data with scientific understanding of general climate processes and local climate features (Daly et al. 2008). New stations in remote areas of the Arctic parks are now providing critical in-situ measurements to validate and strengthen the models.

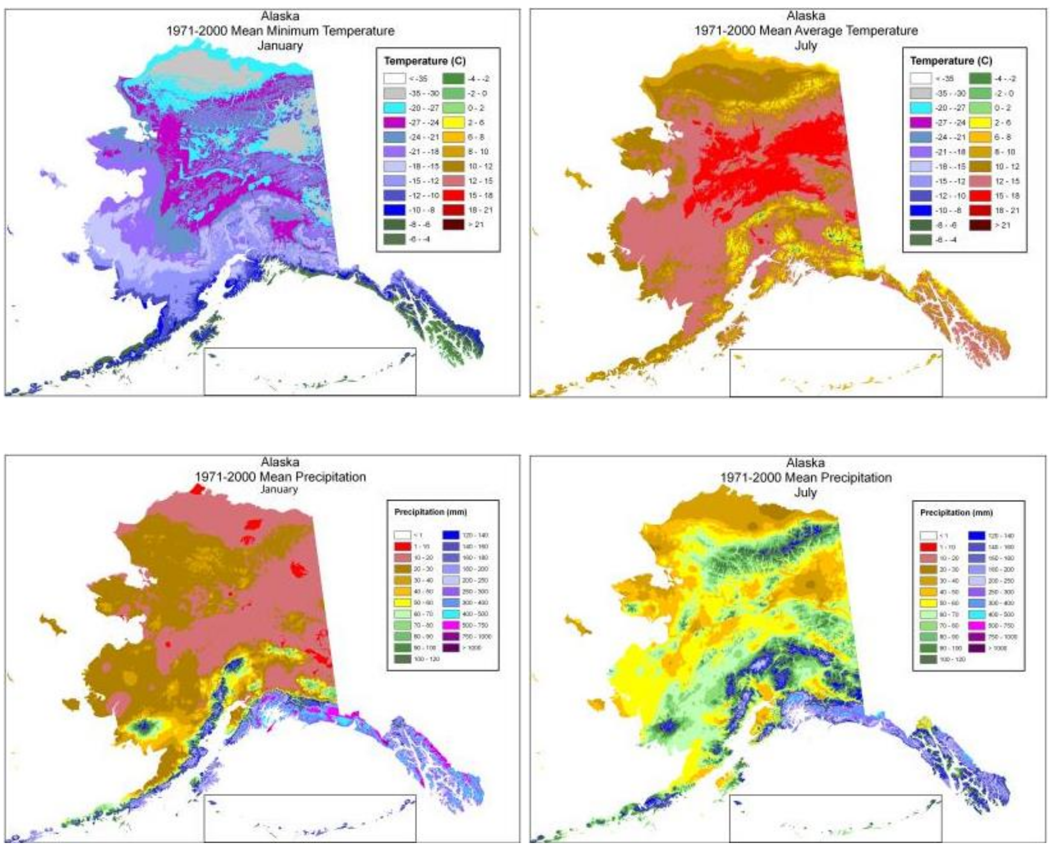


Figure 1. PRISM temperature and precipitation maps for Alaska (1971-2000).

Alaska Climate Divisions

According to the newly defined climate divisions of Alaska (Bieniek et al. 2012), the WEAR, BELA, and GAAR lands are within three distinct climate divisions: the northern portion of NOAT and GAAR are part of the North Slope; the southeast region of NOAT and the southern regions of GAAR are part of the Central Interior division, and southwest NOAT, KOVA and BELA are all in the West Coast division (Figure 2).

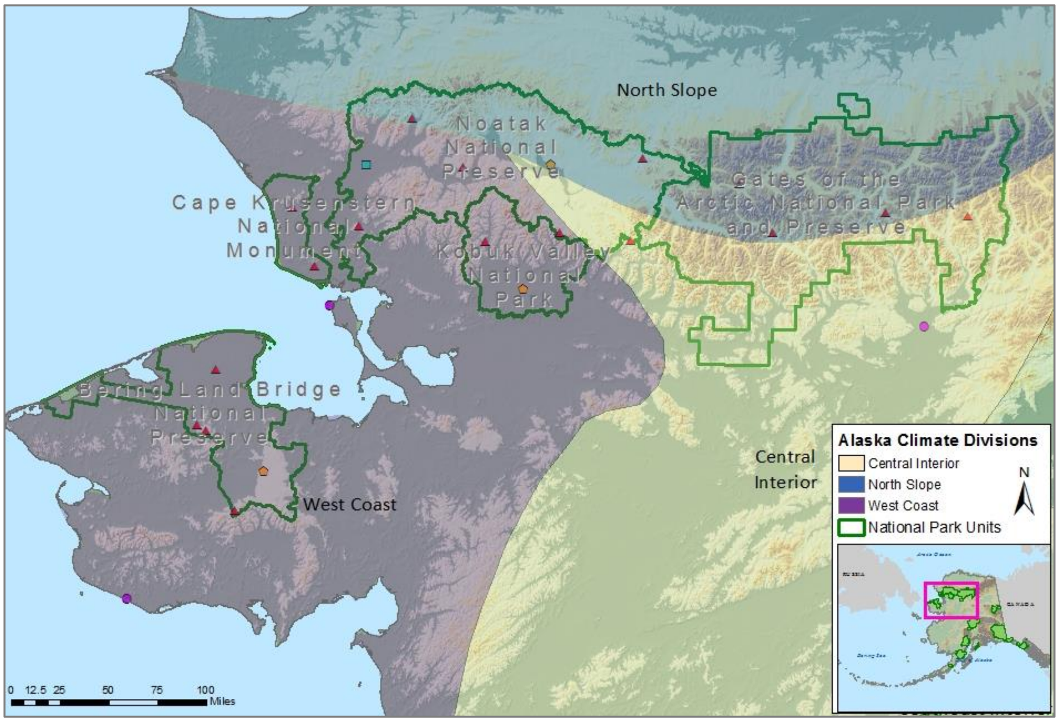


Figure 2. Alaska climate divisions and the NPS ARCN parks.

Methods

The data from the National Weather Service cooperative observer network (COOP) and Automated Surface Observation Systems (ASOS) included in this summary were obtained through the National Oceanic and Atmospheric Administration and have been quality controlled and archived through the National Centers for Environmental Information (NCEI, formerly the National Climatic Data Center). Data from the NPS ARCN climate stations (referred to as NPS stations in this report) are archived at the Western Regional Climate Center; certified datasets are available from the NPS Integrated Resource Management Applications (IRMA) Data Store (links through NPS I&M Climate Vital Signs website, https://science.nature.nps.gov/im/units/arcn/vitalsign.cfm?vsid=5).

Sites

The three index sites used for analysis include Bettles, Kotzebue, and Nome, Alaska (Table 1, Figure 3). These sites were selected based on their proximity to the parks and the length and quality of the records available. Because long-term datasets are limited in Alaska, the data quality, data gaps, and length of record for each dataset are included (Table 1). NPS stations were added to park units between 2011 and 2014 and these shorter records are analyzed to compare with the long term index sites (Table 2, Figure 3).

Climate Normals

Climatically speaking, ‘normal’ is the average climate over a 30-year period. The climate windows are updated every ten years; the current reference period is 1981-2010. Climate statistics and climate change models for Alaska are based on these normal periods and are calculated from the few stations that do exist. Monthly, annual, and seasonal temperature and precipitation values for the three index sites were compiled and the period of records for each site (which vary) were analyzed for trends. For all analyses in this paper, the winter season consists of December, January, and February, spring consists of March, April, and May, summer is June, July, and August, and fall is defined as September, October, and November.

Summaries and Statistics

The detection of trends and associated statistical significance are important aspects of climate research. Given a mean annual air temperature time series, the trend is the rate at which the temperature changes over a time. The trend may be linear or non-linear. Simple linear regressions are commonly used to estimate the linear trend (slope) and statistical significance (via a Student-t test). The null hypothesis is no trend, an unchanging climate (NCAR 2017). Multiple-period moving averages were also calculated. The moving average smooths the fluctuations in the data to show a pattern or trend more clearly; a 10-year average was selected to look at decadal changes.

Table 1. Long-term climate stations and period of record.

Station Name	Location	Elevation (m)	National Park Unit	Period of Record	Period of Good Quality Data
Bettles	66.917, -151.515	196	GAAR, NOAT	1951-present	1952-present
Kotzebue	66.867, -162.633	9	NOAT, CAKR, KOVA, BELA	1898-present	1943-present
Nome	64.511, -165.440	6	BELA	1900-Present	1930-present

Table 1. NPS climate stations: NPS stations and fire RAWS*.

Station Name	Location	Elevation (m)	Period of Record	Park Unit
Asik	67.475, -162.266	405	2012-Present	NOAT
Chimney Lake	67.714, -150.585	1,128	2012-Present	GAAR
Devil Mtn.	66.296, -164.520	87	2011-Present	BELA
Ella Creek	65.275, -163.820	707	2012-Present	BELA
Howard Pass	68.156, -156.896	628	2011-Present	NOAT
Imelyak	67.545, 157.077	1103	2012-Present	NOAT
Kaluich	67.573, -158.432	735	2012-Present	NOAT
Kavet Creek*	67.139, -159.044	22	1992-Present	KOVA
Killik Pass	67.984, -155.013	1,329	2012-Present	GAAR
Kugururok	68.317, -161.492	311	2014-Present	NOAT
Mt. Noak	67.141, -162.995	247	2011-Present	CAKR
Pamichtuk Lake	67.766, -152.164	956	2012-Present	GAAR
Ram Creek	67.624, -154.345	1,250	2012-Present	GAAR
Salmon River	67.460, -159.841	385	2011-Present	KOVA
Serpentine	65.852, -164.708	158	2011-Present	BELA
Sisiak	67.995, -160.396	556	2011-Present	NOAT
Tahinichok	67.550, -163.567	294	2011-Present	CAKR

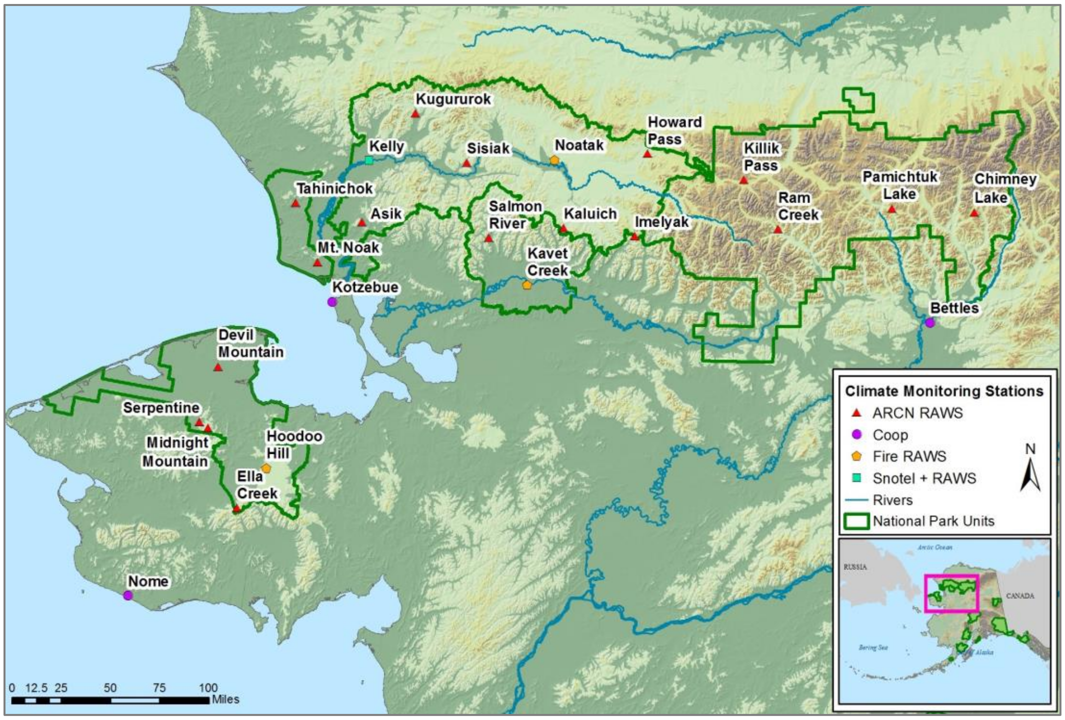


Figure 3. NPS climate stations in the ARCN parks.

The Climate of Gates of the Arctic National Park and Preserve

The Bettles long-term climate station provides context for the climate in Gates of the Arctic National Park and Preserve (GAAR). The 8.4 million acre park is defined by the Brooks Range, in which waves of mountains and meandering river valleys dominate the landscape. The park is far from coastal influences and has the characteristics of a continental interior climate, defined by Bieniek et al. (2012) as the Central Interior climate division of Alaska. The winters are cold, the summers are warm in the valleys, and the annual precipitation is low. The high mountain areas tend to be cooler than the surrounding valley bottoms in the summer and warmer in the winter as persistent inversions and cold pooling often reverse the temperature gradient.

Bettles Climate Normals (1981-2010)

Using the 1981-2010 normal period, the mean annual temperature at Bettles is -4.7°C. July, averaging just over 15°C, is the warmest month and January, which is on average ~ -23°C, is the coldest. Annual precipitation is 379 mm, with most falling as rain during the summer and fall months of July, August, and September. The annual snowfall total is ~232 cm; November and December have the highest monthly snowfall totals (Tables 3 and 4).

Table 3. Bettles 1981-2010 annual and seasonal climate normals (NOAA 2016).

Season	Average Temp.		Max Temp.		Min Temp.		Precipitation		Snowfall	
	°F	°C	°F	°C	°F	°C	(in.)	(mm)	(in.)	(cm)
Annual	23.5	-4.7	32.8	0.4	14.2	-9.9	14.90	378.5	91.4	232.2
Winter	-7.0	-21.7	1.3	-17.1	-15.3	-26.3	2.58	65.5	43.5	110.5
Summer	56.9	13.8	67.1	19.5	46.7	8.2	6.40	162.6	0.0	0.0
Spring	24.0	-4.4	35.2	1.8	12.8	-10.7	2.06	52.3	16.9	42.9
Autumn	19.5	-6.9	26.8	-2.9	12.1	-11.1	3.86	98.0	31.0	78.7

Table 4. Bettles 1981-2010 monthly normal (NOAA 2016).

Month	Average Temp.		Max Temp.		Min. Temp.		Precipitation		Snowfall	
	°F	°C	°F	°C	°F	°C	(in.)	(mm)	(in.)	(cm)
January	-10.0	-23.3	-2.2	-19.0	-17.9	-27.7	0.81	20.6	13.9	35.3
February	-5.0	-20.6	4.5	-15.3	-14.5	-25.8	0.85	21.6	14.0	35.6
March	4.4	-15.3	16.7	-8.5	-8.0	-22.2	0.58	14.7	9.3	23.6
April	23.3	-4.8	34.3	1.3	12.3	-10.9	0.60	15.2	6.3	16.0
May	44.4	6.9	54.6	12.6	34.2	1.2	0.88	22.4	1.3	3.3
June	58.5	14.7	69.3	20.7	47.6	8.7	1.40	35.6	0.0	0.0
July	59.7	15.4	69.8	21.0	49.6	9.8	2.36	59.9	0.0	0.0
August	52.5	11.4	62.1	16.7	42.9	6.1	2.64	67.1	0.0	0.0
September	40.6	4.8	48.9	9.4	32.3	0.2	1.91	48.5	2.5	6.4
October	18.9	-7.3	25.6	-3.6	12.1	-11.1	1.04	26.4	12.4	31.5
November	-1.0	-18.3	6.0	-14.4	-8.1	-22.3	0.91	23.1	16.1	40.9
December	-5.7	-20.9	1.9	-16.7	-13.4	-25.2	0.92	23.4	15.6	39.6

Bettles Temperature and Precipitation Trends

Bettles has been getting warmer and wetter over the past 63 years. The observed temperature trend shows great variability, with multi-decadal variations (Figure 4). The increase in the mean annual temperature is significant with temperatures warming by ~2.1°C when a simple linear regression is applied to the record (1952-2015). Considering just a linear trend masks important variability in the time series; this record spans the phase shift of the Pacific Decadal Oscillation (PDO) in 1976 where annual temperatures at this location, and at most locations around the state, abruptly shifted up in a single year and then persisted in a warmer phase for the next several decades. The trend in annual temperatures since 1977 has been relatively stable. However, over the past several years the PDO index has been persistently positive, coinciding with a strong El Niño pattern during the winter of 2015-2016, which has resulted in two of the warmest years on record for the state of Alaska.

Annual precipitation totals, including rainfall in summer and melted snow in winter, are also variable over the period of record between 1952 and 2015 (Figure 4). There has been an increase in precipitation over the period of record of ~74 mm, but the trend is not significant. Figure 5 shows the mean annual temperature and total annual precipitation departures from the 1981-2010 normals.

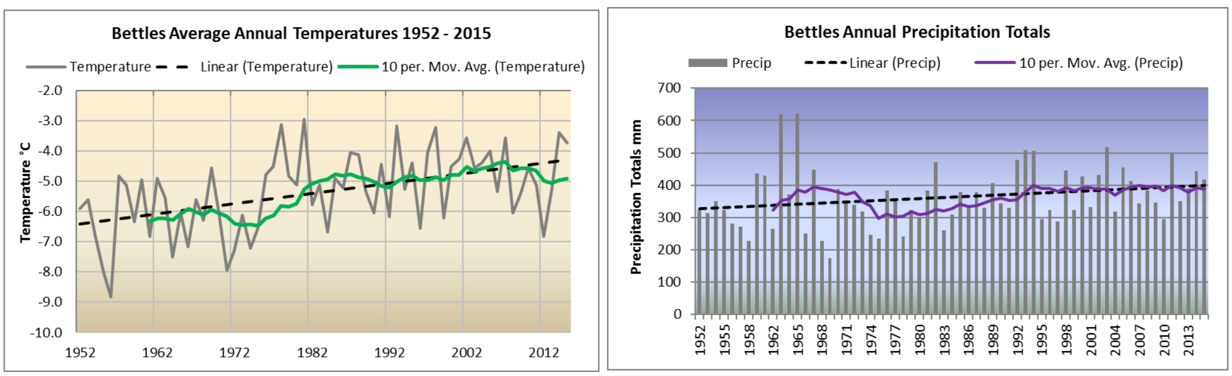


Figure 1. Mean annual temperatures and annual precipitation totals at Bettles 1952-2015.

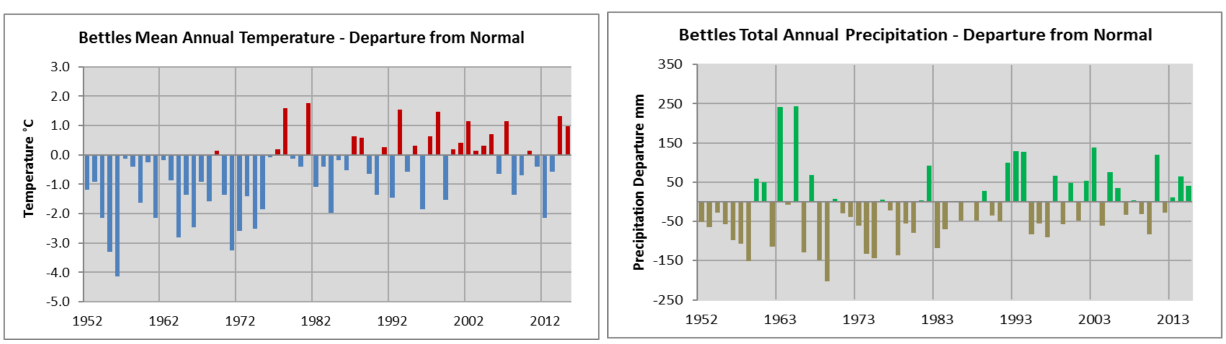


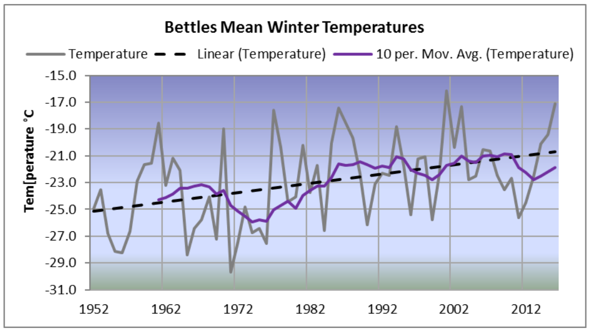
Figure 2. Bettles annual temperature and precipitation departures from the 1981-2010 normal.

Bettles Seasonal Summaries

Winter

Over the past 64 years, Bettles' winters have been getting significantly warmer and wetter (Figure 6). Winter temperatures have shown the greatest increase of any season. Over the period of record (1952-2016), the average winter temperature has increased by a significant 4.4°C. The average winter temperature for Bettles for the latest normal period is -21.7°C (-22.9°C for the 1952-2016 period of record). The winter temperatures range from -29.7°C (1971) to -16.2°C (2001).

Bettles receives on average about 65.5 mm of precipitation (snow water equivalent) during the winter season. Winter precipitation has been variable over the past half century with an increasing trend of 18.6 mm over the 64-year record. The trend is not significant. The winter precipitation totals range from a low of 19.6 mm in 1960-1961 to a high of 172.2 mm in 1992-1993.



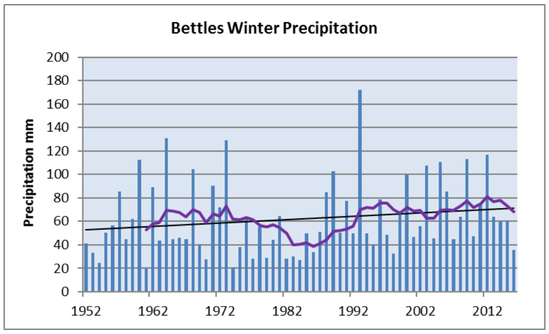
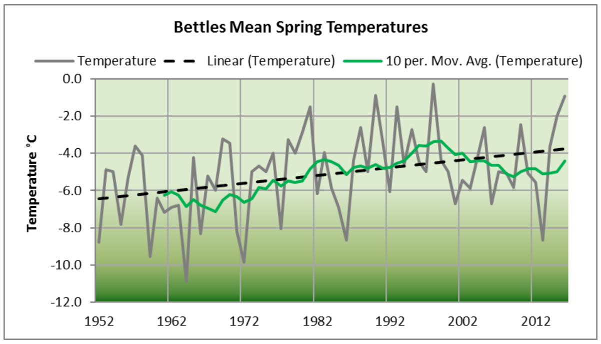


Figure 6. Bettles winter temperatures and total precipitation 1952-2016.

Spring

The average spring temperature for the latest climate normal period is -4.4°C. Seasonal temperatures range from a low of -10.9°C (1964) to a high of -0.3°C (1998). Spring temperatures have increased by a significant ~ 2.7°C over the past 65 years (Figure 7). Spring is the driest season for Bettles with precipitation totals ranging from a low of 6.1 mm (1969) to 131.3 mm (1963). There is variability from year to year, but no obvious trends in the spring precipitation data (Figure 7).



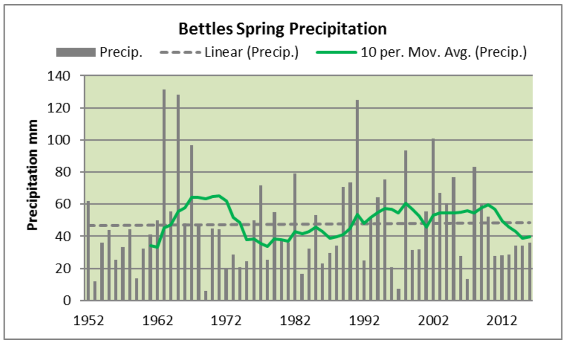


Figure 7. Spring temperature and precipitation trends in Bettles 1952-2016.

Summer

Summers have been getting warmer, with no trend in summer rainfall totals (Figure 8). The average summer temperature for Bettles based on the 1981-2010 normal period is 13.8°C. Over the period of record (1951-2016) average summer temperatures have been as low as 11.9°C (1963) and as warm as the summer of 2004 at 16.2°C. Summer temperatures have increased by a significant 1.0°C from 1951 to 2016.

Summer is the wettest season in Bettles; the average summer rainfall total is 163 mm. Rainfall totals range from a low of 43 mm (1962) to 330 mm (1963). Summer of 2014, with 329.2 mm recorded over the summer season, is the wettest recent summer on record. Summer rainfall totals are variable with no obvious trend.

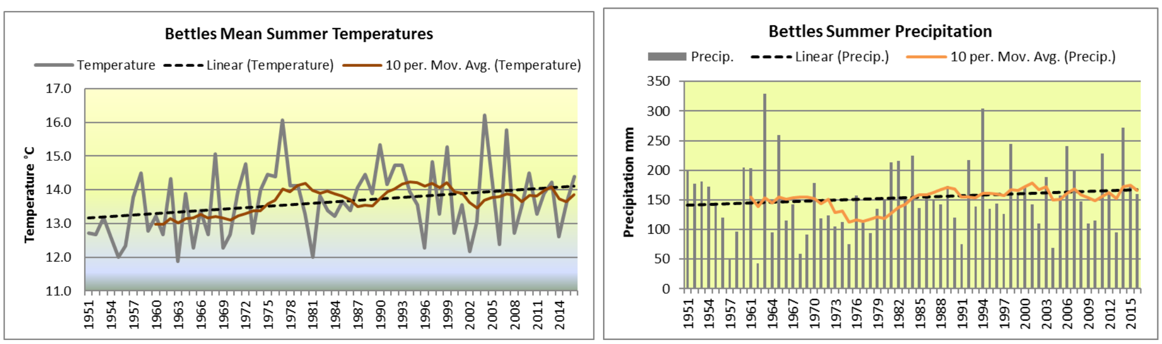


Figure 8. Summer temperature and precipitation trends in Bettles 1951-2016.

Fall

Fall seasons have been getting slightly warmer and wetter (Figure 9). The average fall temperature for Bettles is -6.9°C. There has been a 1.1°C increase in fall temperatures over the record analyzed, the trend is not significant. Fall temperatures range from a low of -11.6°C (1956) to a high of -1.6°F in 1979. Precipitation has increased slightly over the period of record, but the trend is not significant.

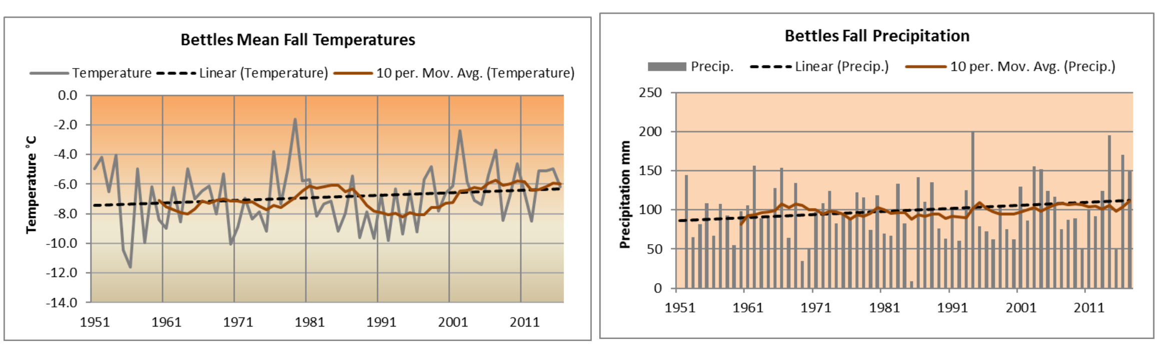


Figure 9. Fall temperature and precipitation trends for Bettles 1951-2016.

Frost /Freeze Dates for Bettles

For the time period between 1952 and 2016, the graph below shows the shows the dates of the date of the last freeze in spring and the first freeze in fall (Figure 10).

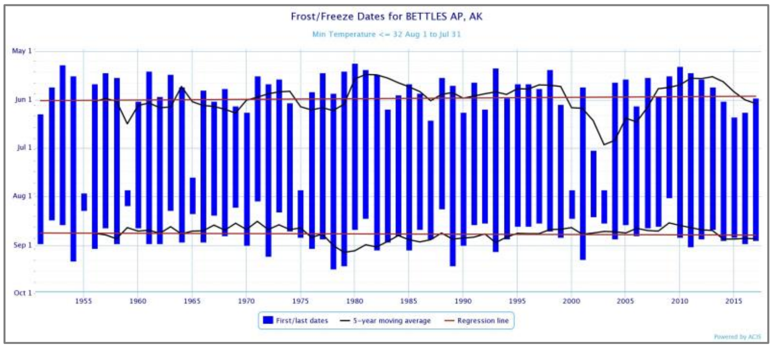


Figure 10. Frost and freeze dates for Bettles 1952-2016 (generated from xmACIS).

Snow-on and snow-off dates Bettles

The date of the first persistent snow over the past 64 years has been a few days earlier in the fall, and the melt-out or snow-off date is a about a week earlier in the spring. The period of record for snow depth data at Bettles is from 1952-2016. The snow season is calculated from July 1 through June 30 (Figure 11).

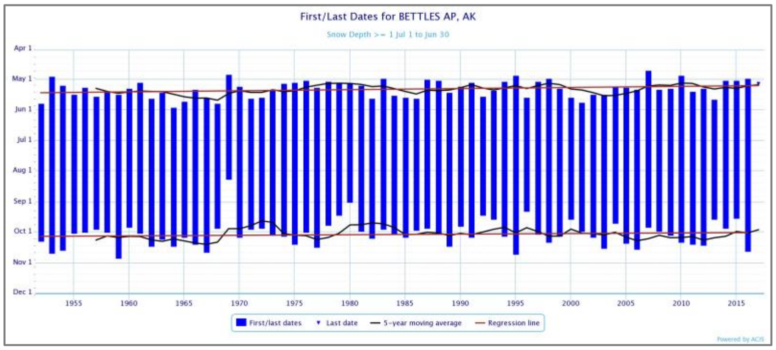


Figure 11. First and last dates of snow season at Bettles 1952-2016 (generated from xmACIS).

NPS Climate Stations - GAAR

Four mid-elevation sites were added in GAAR during 2012 to help understand the mountain environments and quantify temperature differences at elevation (Figure 12). The highest instrumented location (Killik Pass) has the coldest mean annual temperature of the five sites. Killik Pass is the highest in elevation and also the site that is the farthest north, and is located at the headwaters of three major rivers at the crest of the continental divide. Over the first few years of record, all of the mid-elevation sites have been cooler overall than Bettles. Figure 13 clearly shows that the mountain sites are cooler during the peak summer months and warmer during the winter months. The spring and fall seasons are also cooler at the mountain sites.

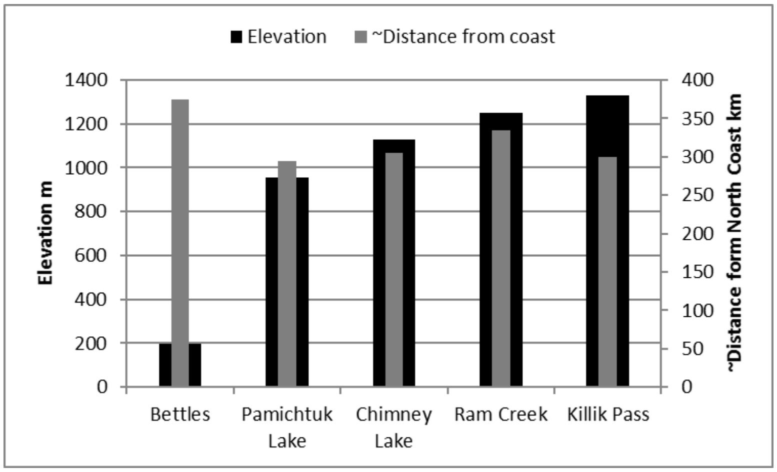


Figure 12. GAAR Climate Stations - Elevation and distance from the Arctic Ocean (north).

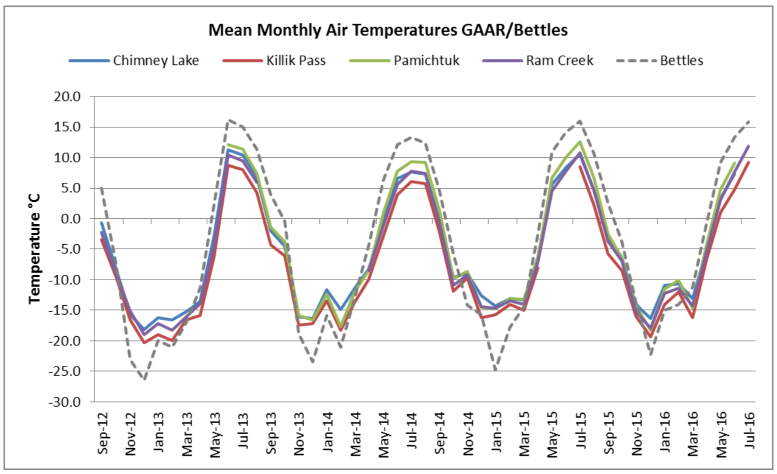


Figure 13. Temperatures at the GAAR climate stations and Bettles 2012-2016.

Precipitation is difficult to measure on the high exposed ridgelines in GAAR. The climate stations have simple tipping bucket rain gauges that measure rainfall (when temperatures are above freezing). The rain gauges are mounted on top of a three-meter tripod tower and are not shielded or heated. Collectively the average wind speed at the NPS stations is 4 m/s; it is calm at the sites <1.0% of the time during the summer season. Because of the exposure and the persistent winds, the observed rainfall totals likely represent a much lower value than reality, but all of the sites have similar characteristics (high and exposed) and therefore allow for a crude look at seasonal and month-to-month rainfall patterns. Over the first few years, all of the sites show that July is the wettest month in GAAR, followed by August, and then June. The mountain sites compare well with the Bettles site in terms of total summer rainfall.

Snow depth is measured throughout the winter season using an acoustic sensor. To date, Ram Creek has the most consistent and deepest snowpack of the GAAR sites with an average maximum depth over the past few years of ~337 mm. Winds blow primarily out of the northeast through the winter season and snow deposition trapped by the station tripod legs may account for some of the snow that is measured at the Ram Creek site, and at the other sites in GAAR. The Killik Pass site has no defined snowpack signal over the past few years, indicating that this site gets scoured by wind on a regular basis. The Pamichtuk Lake and Chimney Lake sites show modest snowpack development with maximum snow depths averaging ~ 152 mm and ~178 mm respectively. The images from the phenology camera at the Pamichtuk Lake site confirm the snow depth signal.

Phenology camera image of snow stake at Pamichtuk Lake in Gates of the Arctic on March 30, 2016.

The Climate of Noatak National Preserve

The entire six million acres of Noatak National Preserve (NOAT) are north of the Arctic Circle. The preserve encompasses strong climate gradients, from the maritime climates in the western region of the preserve near the Chukchi Sea to the strongly continental climate found in the upper reaches of the Noatak River. It includes portions of the North Slope, Central Interior, and West Coast climate divisions. A transitional climate region lies between the coast and the interior influenced by major mountain ranges, which act not only as the environmental control to drive climate but also contribute to the highly localized micro-climates found in complex mountain terrain. Temperature inversions are common through much of the year as a result of low water vapor content, extended periods of snow cover, and low solar radiation.

There are two long-term climate stations that anchor the major climate zones of NOAT. Kotzebue provides context for the West Coast climate division and Bettles for the Central Interior region of the preserve (Bettles was described in the Gates of the Arctic section). Four years of data from five high elevation climate stations in NOAT provide context for the mountainous regions of the park. The results provide a snapshot of climate patterns in an area of Alaska that in the past had little to no climate data available.

Kotzebue Climate Normals

Using the 1981-2010 normal period, the mean annual temperature at Kotzebue is -5.1°C. July, averaging just under 13°C, is the warmest month and January, which is on average ~ -19°C, is the coldest. June, July, August, and September have average temperatures above freezing. Annual precipitation is 279 mm, with most falling as rain during the summer and fall months of July, August, and September. The annual snowfall total (total falling snow not snow depth) is ~152 cm; November and December have the highest monthly snowfall totals (Tables 5 and 6).

Table 5. Kotzebue 1981-2010 annual and seasonal climate normals (NOAA 2016).

Season	Average Temperature		Maximum Temp.		Minimum Temp.		Precipitation		Snowfall	
	(°F)	(°C)	(°F)	(°C)	(°F)	(°C)	(In.)	(mm)	(In.)	(cm)
Annual	22.9	-5.1	28.7	-1.8	17.0	-8.3	11.00	279.4	59.8	151.9
Winter	-0.4	-18.0	6.3	-14.3	-7.1	-21.7	2.04	51.8	30.2	76.7
Summer	50.7	10.4	55.8	13.2	45.7	7.6	4.21	106.9	0.0	0.0
Spring	15.4	-9.2	22.6	-5.2	8.3	-13.2	1.39	35.3	12.2	31.0
Autumn	25.2	-3.8	29.8	-1.2	20.7	-6.3	3.36	85.3	17.4	44.2

Table 6. Kotzebue 1981-2010 monthly normal [(NOAA 2016).]

Month	Average Temperature		Maximum Temperature		Minimum Temperature		Precipitation		Snowfall	
	(°F)	(°C)	(°F)	(°C)	(°F)	(°C)	(In.)	(mm)	(In.)	(cm)
January	-2.8	-19.3	3.9	-15.6	-9.5	-23.1	0.62	15.7	9.1	23.1
February	-0.8	-18.2	6.3	-14.3	-7.8	-22.1	0.66	16.8	9.6	24.4
March	1.1	-17.2	8.8	-12.9	-6.7	-21.5	0.44	11.2	5.9	15.0
April	13.3	-10.4	21.2	-6.0	5.4	-14.8	0.54	13.7	5.1	13.0
May	31.9	-0.1	37.8	3.2	26.0	-3.3	0.41	10.4	1.2	3.0
June	45.7	7.6	51.5	10.8	39.9	4.4	0.58	14.7	0.0	0.0
July	54.6	12.6	59.5	15.3	49.7	9.8	1.45	36.8	0.0	0.0
August	51.7	10.9	56.1	13.4	47.3	8.5	2.18	55.4	0.0	0.0
September	42.3	5.7	46.7	8.2	37.9	3.3	1.58	40.1	0.8	2.0
October	24.3	-4.3	28.5	-1.9	20.1	-6.6	1.01	25.7	6.1	15.5
November	9.1	-12.7	14.2	-9.9	4.0	-15.6	0.77	19.6	10.5	26.7
December	2.3	-16.5	8.7	-12.9	-4.1	-20.1	0.76	19.3	11.5	29.2

Kotzebue Temperature and Precipitation Trends

Overall, Kotzebue has been getting warmer and wetter over the past 74 years, which is the period of record that has the best available data for this site. The observed temperature trend has multi-decadal variations (Figure 14). The increase in the mean annual temperature is significant with temperatures warming ~2.1°C when a linear regression is applied to the >70 year record (1943-2015). Considering just a linear trend masks important variability in the time series; this record spans the phase shift of the Pacific Decadal Oscillation (PDO) in 1976 where annual temperatures at this location, and at most locations around the state, abruptly shifted up in a single year and then persisted in a warmer phase for the next several decades.

Annual precipitation totals, including rainfall in summer and melted snow in winter, are also variable over the period of record between 1944 and 2015 (Figure 14). The increasing trend of 86.1 mm over the past 72 years is significant. The annual precipitation data begins with 1944; there were missing values in 1943. Temperature and precipitation departures from the 1981-2010 averages are shown in Figure 15.

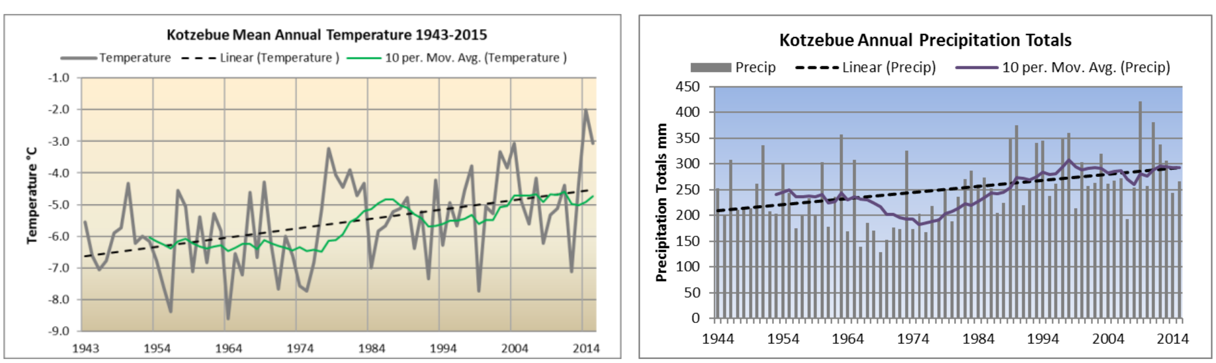


Figure 14. Mean annual temperatures and annual precipitation totals at Kotzebue.

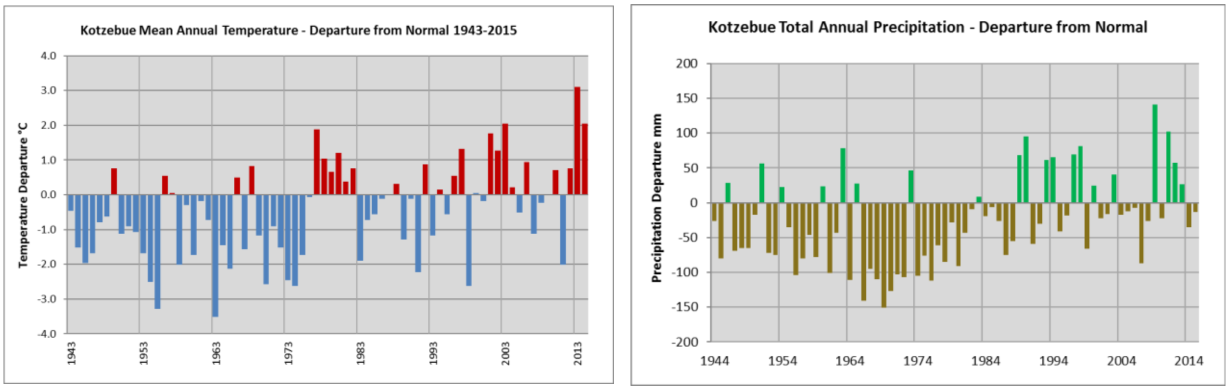


Figure 15. Temperature and precipitation departures from normal (1981-2010) at Kotzebue.

Seasonal Summaries Kotzebue

Winter

Over the past 74 years Kotzebue winters have been getting significantly warmer and wetter (Figure 16). Winter temperatures have shown the greatest increase of any season. Over the period of record (1943-2016) the average winter temperature has increased by a significant 4.3°C. The average winter temperature for Kotzebue for the latest normal period is –18.0°C (-19°C for the 1943-2016 period of record). The winter temperatures over the period of record range from -24.2°C (1955 and 1971) to -11.3°C in 2001. The latest three winter seasons (2014-2016) have been, on average, 4.7°C warmer than normal.

Kotzebue receives, on average, about 51.8 mm of precipitation (rain and snow water equivalent) during the winter season. Winter precipitation has steadily increased over the past half century by a statistically significant 47.4 mm (Figure 16). The winter precipitation totals range from a low of 7.1 mm (1957-1958) to a high of 151.1 mm (2008-2009).

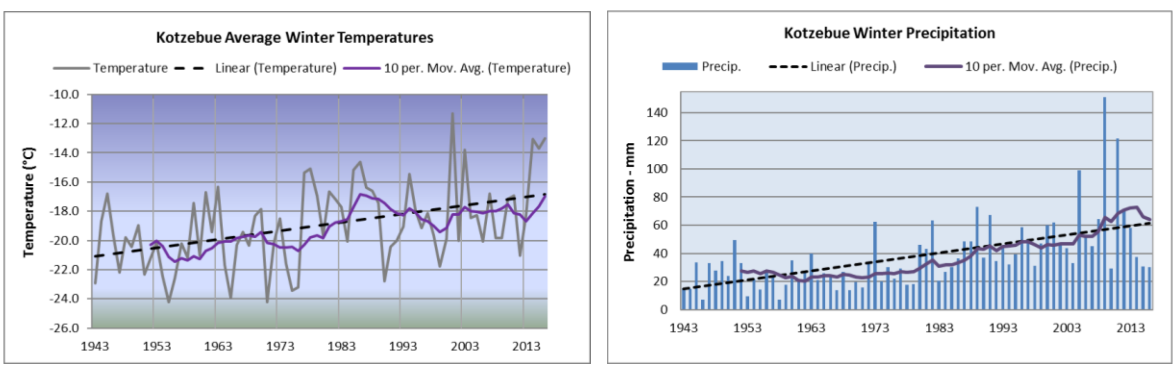


Figure 16. Kotzebue winter temperatures and total precipitation 1943-2016.

Spring

The average spring temperature for Kotzebue is -9.2°C. Seasonal temperatures range from a low of -14.7°C (1985) to a high of -4.6°C (1998). Temperatures have increased by a significant ~ 1.9°C over the past 74 years. Total spring precipitation significantly increased by 15 mm (Figure 17). Spring is the driest season for Kotzebue with an average seasonal total of 35.3 mm (1981-2010). Spring precipitation totals range from a low of 4.3 mm (1974) to 88.1 mm (2009).

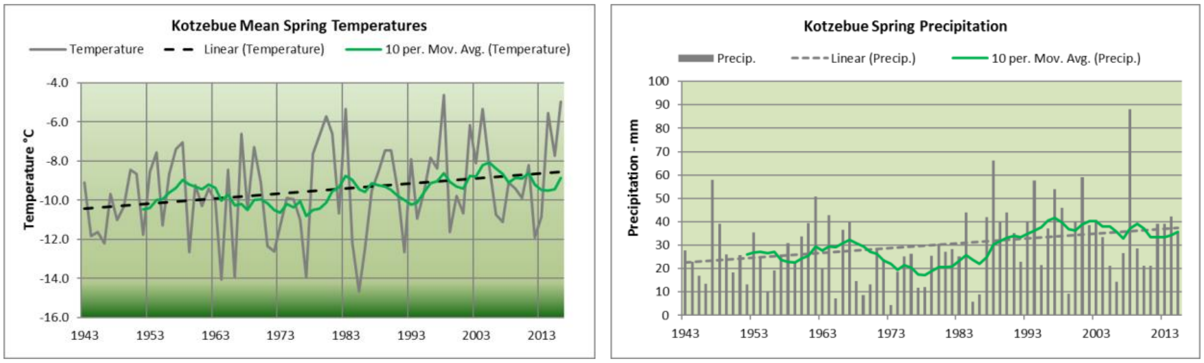


Figure 17. Spring temperature and precipitation trends in Kotzebue 1943-2016.

Summer

Summers have been getting warmer, with no trend in summer rainfall totals (Figure 18). The average summer temperature for Kotzebue based on the 1981-2010 normal period is 10.4°C. Over the period of record (1943-2016) average summer temperatures have been as low as 7.3°C (1945) and as warm as the summer of 2004 at 14.1°C. Summer temperatures have increased by a significant 2.1°C from 1943 to 2015. Summer is the wettest season in Kotzebue; the average summer rainfall total is 106.9 mm. Rainfall totals range from a low of 18.8 mm in 1977 to 211.1 mm in 1963. Summer of 2012, with 204.2 mm of rain recorded over the summer season, ranks as the third wettest summer following 1963 with 211.1 mm and 1998 with 207.5 mm. Summer rainfall totals are variable with no obvious trend.

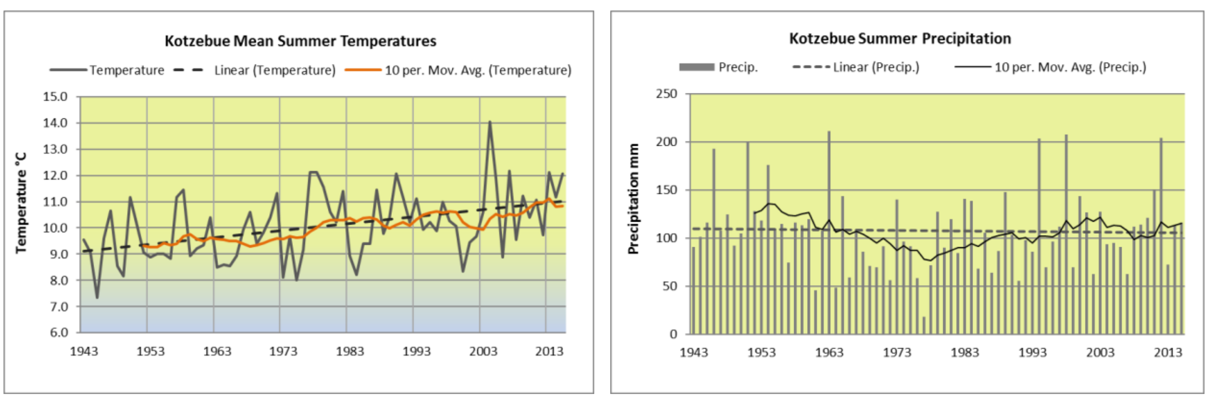
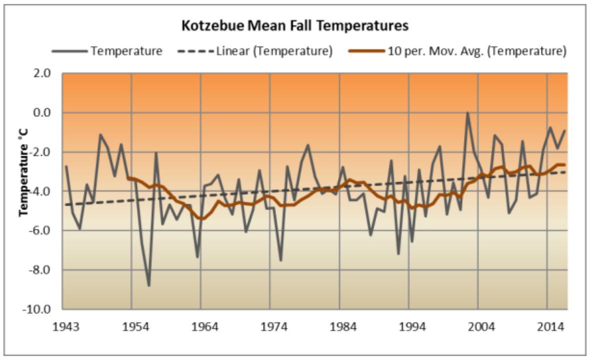


Figure 18. Summer temperature and precipitation trends in Kotzebue 1943-2016.

Fall

Fall seasons have been getting warmer and wetter (Figure 19). The average fall temperature for Kotzebue is -3.8°C. There has been a 1.6°C increase in fall temperatures over the record analyzed (p=0.02). Fall temperatures range from a low of -8.8°C (1956) to a high of 0°F (2002). Precipitation has increased by ~ 3.6 mm per decade; the trend is marginally insignificant (p=0.06).



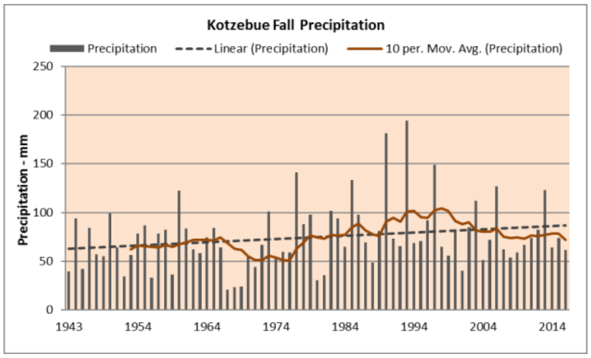


Figure 19. Fall temperature and precipitation trends for Kotzebue 1943-2016.

Frost /Freeze Dates for Kotzebue

For the time period between 1930 and 2016, the date of the last freeze in spring is getting earlier and the first freeze in fall is getting later (Figure 20).

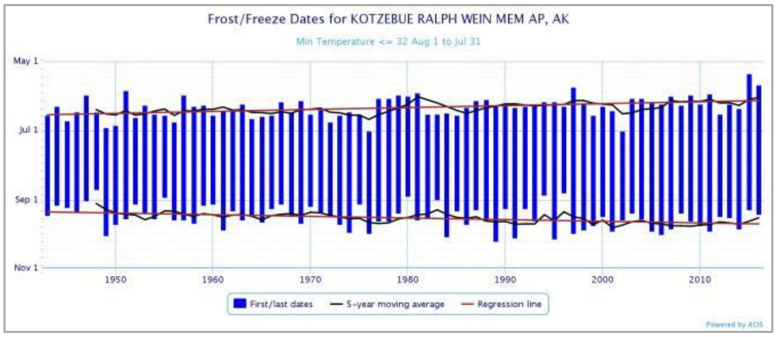


Figure 20. Frost and freeze dates for Kotzebue 1943-2016 (generated from xmACIS).

Snow on and snow off dates Kotzebue

The date of the first persistent snow is later in the fall, while the melt-out or snow-off date is earlier in the spring. The period of record for snow depth data at Kotzebue is from 1949-2016. Records before this date are sporadic. The snow season is calculated from July 1 through June 30 (Figure 21).

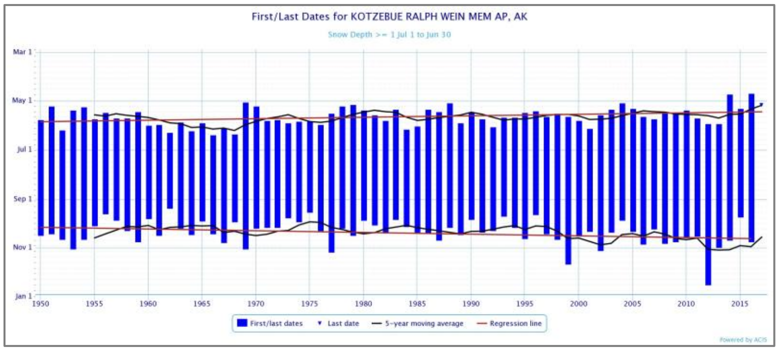


Figure 21. First and last dates of snow season at Kotzebue 1949-2016 (generated from xmACIS).

NPS Climate Stations – NOAT

Three complete years of data from five automated weather stations in NOAT at higher elevations in the Brooks Range are compared with long-term observations at the Kotzebue index site. Figure 22 shows the elevation differences among the sites and the approximate distance from the Chukchi Sea to the west.

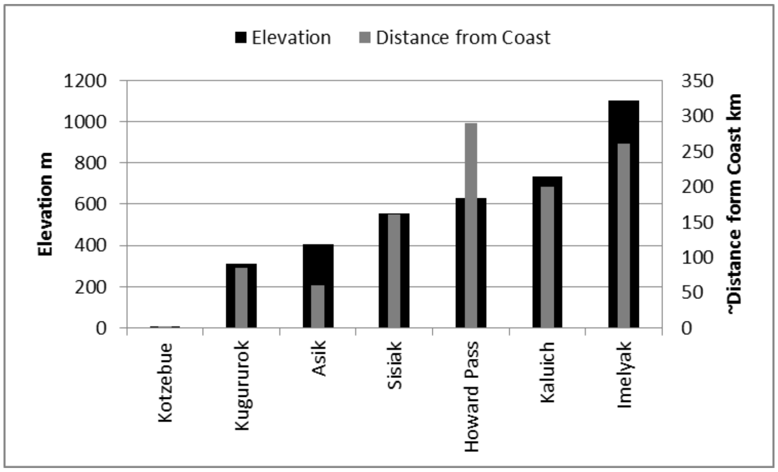


Figure 22. NPS climate stations in NOAT and Kotzebue - elevation and distance from coast.

Temperatures are cooler at the higher elevation Brooks Range sites in the summer than at the low elevation coastal site of Kotzebue. Winters are colder in the interior valleys than along the coast. Winter temperature gradients are interesting with the mid-elevation interior sites having cooler winter temperatures, on average than Kotzebue, except for Imelyak (the highest instrumented site on the southeastern boundary of the preserve) and Asik (the site closest to the coast in Noatak). Howard Pass and Kaluich, mid-elevation interior sites, have the coldest mean annual temperatures of the sites in Noatak, followed by Sisiak.

In the spring and summer, the interior locations that are farther from the coast are warmer. In the fall the coastal areas are warmer due to the proximity to the relatively warm water of the open ocean. Interestingly, as with other regions in the state, the month-to-month variations in temperature have similar patterns, although the absolute values differ between the sites (Figure 23).

High exposed ridgelines are difficult locations to measure summer rainfall. Persistent winds and instrumentation are the challenge. The NPS stations have simple rain gauges mounted on the top of a tripod; the gauges are unshielded and unheated. Because of the exposure, the observed values likely represent a severe under-catch; however all of the sites have similar characteristics, so a crude comparison of the data is possible. The sites measure summer rainfall only, when temperatures are above freezing. At the NPS stations in NOAT, the wettest month of the summer is August, followed by July. June, is relatively dry. The high mountain sites in NOAT receive, on average, twice as much precipitation as Kotzebue in the summer. Imelyak, Kaluich, and Asik are the three wettest locations. Persistent winds are common at all of the sites and average ~ 5 m/s; the sites are calm <1.0% of the time during summer .

There are acoustic distance sensors on the stations that measure the snow depth at the sites. Many of the sites are scoured free of snow or show very low snow depths in the winter, again due to the exposure and the winds. Snowfall totals are relatively low in the Arctic parks; the maximum snow depths measured to date are on average ~ 280 mm.

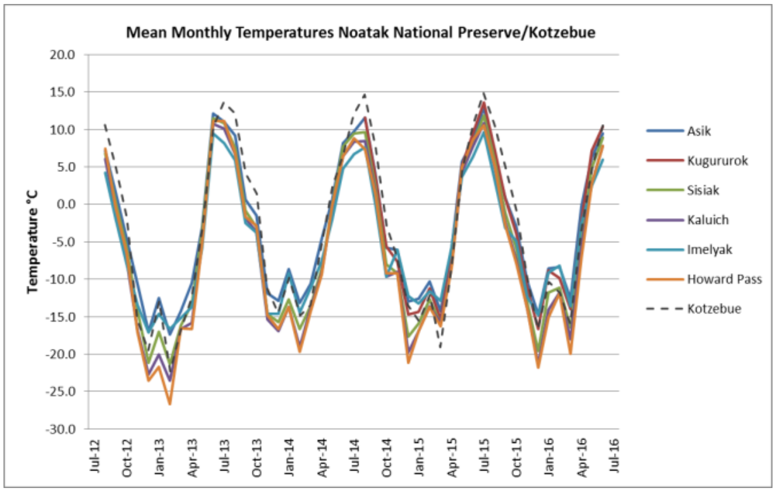


Figure 23. Monthly temperatures at the NOAT and Kotzebue climate sites 2012-2016.

The Climate of Cape Krusenstern National Monument

Cape Krusenstern National Monument (CAKR) is just north and west of Kotzebue. The monument hosts the westernmost mountains of the Brooks Range as they meet the Chukchi Sea. The monument is bounded on the west by the Arctic Ocean and on the east by the Noatak River valley. The monument is entirely within the West Coast climate division. The coastal influence, and the presence or absence of sea ice, are the main environmental controls that influence the climate here. The Kotzebue climate station provides the context for the park (described in the Noatak section).

Four years of data from two new climate stations in CAKR provide data from inside the monument boundary. The sites are located at mid-elevations near the coast (Figure 24). The variations in temperatures at the new stations track very well with the Kotzebue site, but the sites are warmer in the winter and cooler in the summer (Figure 25).

Summer rainfall totals are measured at the two NPS CAKR sites; both sites are much wetter than Kotzebue. The seasonal totals, to date, are on average ~244 mm, while Kotzebue averages ~107 mm between June 1 and August 31. August is the wettest month, followed by July, and then September. The Mt. Noak site, which is 32 km northwest of Kotzebue, and just over 200 m higher in elevation, is the wetter of the two sites. Summer winds at these exposed locations are persistent and average ~ 5 m/s; the sites are calm < 1.0% of the time. The wind direction is variable in the summer at both locations, originating from all directions about the same percentage of time. For all other seasons, and overall, the dominant wind direction is from the NNE. Snow depth is measured at the two CAKR sites using an acoustic distance sensor. In 2014, the snowpack at both sites reached a maximum of ~ 400 mm in mid-March; the maximum snow depth for the 2015 snowpack was about half that amount.

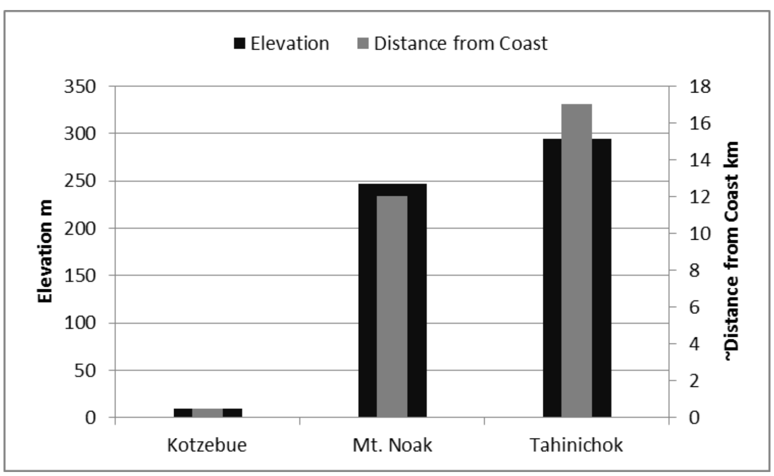


Figure 24. NPS climate stations in CAKR and Kotzebue - elevation and distance from coast.

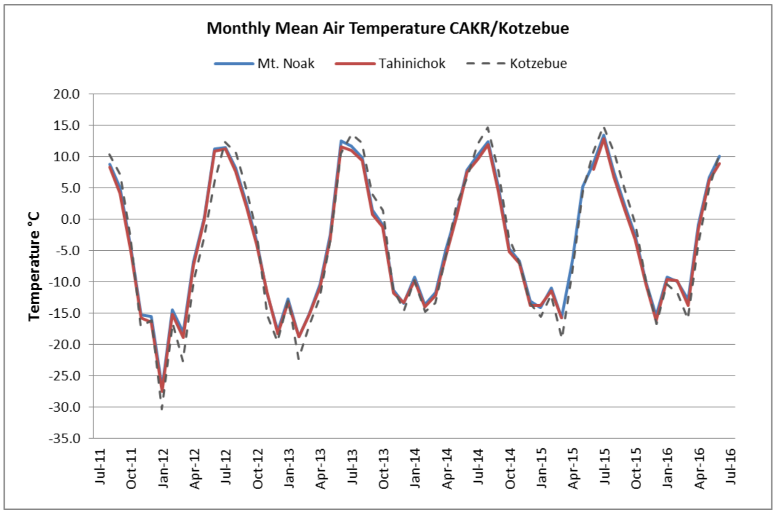


Figure 25. Mean monthly temperatures at the CAKR and Kotzebue climate stations 2011-2016.

The Climate of Kobuk Valley National Park

Kobuk Valley National Park (KOVA) is about 150 kilometers east of Kotzebue. The Kobuk River runs east-to-west across the southern area of the park, and to the north are the southern foothills of the Brooks Range. This region is still within the West Coast climate division with the Kotzebue index site providing context for the park's lower elevations. The Kavet Creek climate station is located on the Kobuk River with a record dating back to ~2008. The NPS Salmon River climate station was installed in the mountainous region of the park and has good quality data from only one complete year (2015; due to wildlife and equipment problems). For context, the data for 2015 from the two KOVA sites is compared with Kotzebue. Figure 26 shows the elevation differences at the KOVA sites and Kotzebue and the distance from the coast. The variations in temperatures at the KOVA stations track very well with the Kotzebue site. Kavet Creek, along the river corridor, has cooler temperatures than Salmon River or Kotzebue in the winter, and a tendency towards warmer summer temperatures (Figure 27).

Precipitation totals at Salmon River have only been successfully recorded for one summer season. In 2015, August was the wettest month, followed by September and then July. The total rainfall for the season was 176 mm, closer to the Bettles (163 mm) average summer rainfall than Kotzebue (106 mm). The wind blows primarily from the north at this site for the summer season, as well as annually, and averages ~ 3-4 m/s. So far, this site records the most snowfall of any of the NPS climate stations; the average over the past three seasons (2014-2016) was ~850 mm, with the maximum snow depth (1,070 mm) occurring during 2014-2015.

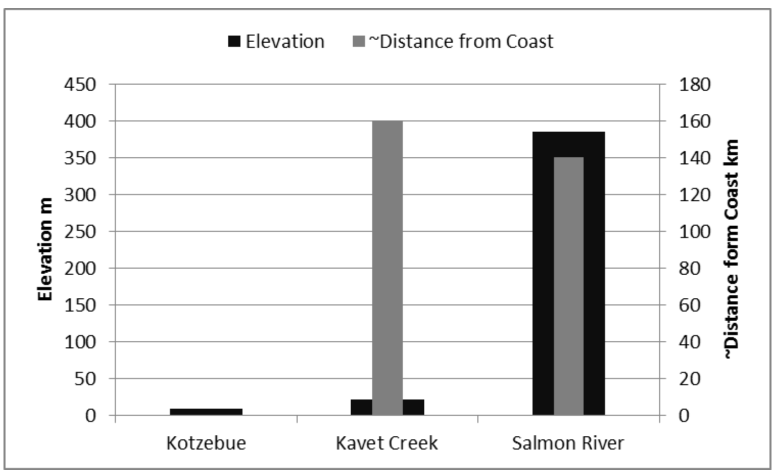


Figure 26. NPS climate stations in KOVA and Kotzebue - elevation and distance from coast.

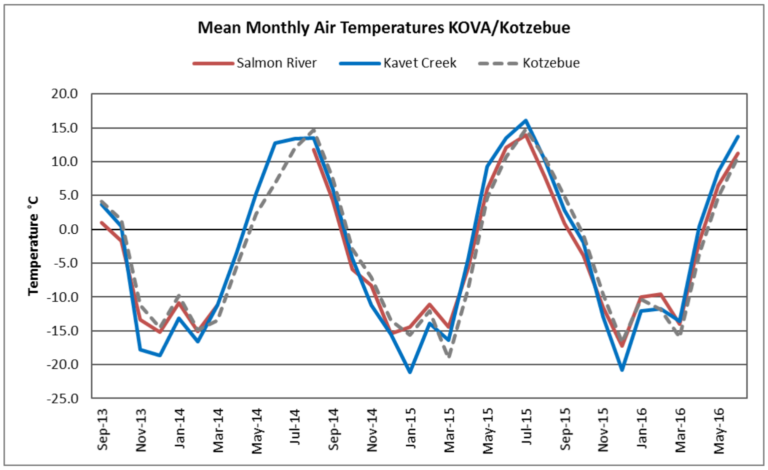


Figure 27. Mean monthly temperatures at the KOVA and Kotzebue climate stations 2013-2016.

The Climate of Bering Land Bridge National Preserve

Bering Land Bridge National Preserve (BELA) is located on the Seward Peninsula in northwest Alaska, bounded by the Bendeleben Mountains to the south and the Chukchi Sea and Kotzebue Sound to the north and east. BELA is within the West Coast climate division as defined by Bieniek et al. (2012). Given that the preserve is on a peninsula, the coastal influence, and the presence or absence of sea ice, is the main environmental control that drives the climate. The mountains on the southern boundary of the preserve buffer the interior of the peninsula from the direct effects of the Bering Sea maritime weather. The winters are cold, the summers are cool and the precipitation is relatively low. The higher elevation sites tend to be cooler than the surrounding valley bottoms in the summer and warmer in the winter as persistent inversions and cold pooling often reverse the temperature gradient.

There are two long-term climate stations that anchor the West Coast climate zone near the preserve; Kotzebue to the north and east (described in a previous section) and Nome on the southern coast of the Seward Peninsula.

Nome Climate Normals (1981-2010)

Using the 1981-2010 normal period, the mean annual temperature at Nome is -2.6°C. July, averaging just over 11°C, is the warmest month and January is the coldest (~ -15°C). Annual precipitation is 427 mm, with most falling as rain during the months of July, August, and September. The annual snowfall total is ~192 cm; December and January have the highest monthly snowfall totals (Tables 7 and 8).

Table 2. Nome annual and seasonal climate normals (1981-2010).

Season	Average Temperature		Maximum Temperature		Minimum Temperature		Precipitation		Snowfall	
	(°F)	(°C)	(°F)	(°C)	(°F)	(°C)	(In.)	(mm)	(In.)	(cm)
Annual	27.4	-2.6	34.2	1.2	20.7	-6.3	16.81	427.0	75.7	192.3
Winter	7.4	-13.7	15.1	-9.4	-0.3	-17.9	2.95	74.9	39.4	100.1
Summer	50.1	10.1	56.3	13.5	43.8	6.6	6.31	160.3	18.7	47.5
Spring	22.5	-5.3	29.7	-1.3	15.4	-9.2	2.27	57.7	0.3	0.8
Autumn	29.5	-1.4	35.4	1.9	23.5	-4.7	5.28	134.1	17.3	43.9

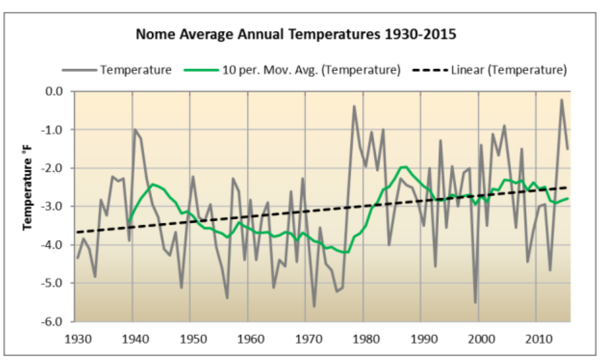
Table 3. Nome monthly climate normals 1981-2010.

Month	Average Temperature (°F)	Average Temperature (°C)	Maximum Temperature (°F)	Maximum Temperature (°C)	Minimum Temperature (°F)	Minimum Temperature (°C)	Precipitation (In.)	Precipitation (mm)	Snowfall (In.)	Snowfall (cm)
January	5.2	-14.9	13.1	-10.5	-2.8	-19.3	0.94	23.9	12.7	32.3
February	7.4	-13.7	15.4	-9.2	-0.5	-18.1	0.93	23.6	12.2	31.0
March	10.3	-12.1	18.5	-7.5	2.1	-16.6	0.65	16.5	8.9	22.6
April	20.5	-6.4	27.5	-2.5	13.5	-10.3	0.76	19.3	7.5	19.1
May	36.8	2.8	43.1	6.2	30.5	-0.8	0.86	21.8	2.3	5.8
June	47.8	8.8	54.9	12.7	40.7	4.8	0.98	24.9	0.3	0.8
July	52.2	11.2	58.2	14.6	46.2	7.9	2.11	53.6	0.0	0.0
August	50.1	10.1	55.9	13.3	44.3	6.8	3.22	81.8	0.0	0.0
September	42.8	6.0	48.7	9.3	36.9	2.7	2.45	62.2	0.6	1.5
October	28.7	-1.8	34.5	1.4	23.0	-5.0	1.61	40.9	4.6	11.7
November	16.9	-8.4	23.1	-4.9	10.7	-11.8	1.22	31.0	12.1	30.7
December	9.5	-12.5	16.8	-8.4	2.2	-16.6	1.08	27.4	14.5	36.8

Nome Temperature and Precipitation Trends

Over the past 86 years, Nome has gotten warmer and precipitation has been variable with no obvious trend. The observed temperature trend has multi-decadal variations. The increase in the mean annual temperatures over the period between 1930 and 2015 (the best available record) is significant with temperatures warming ~1.2°C when a linear regression is applied to the 86-year record (Figure 28 and 29). Considering just a linear trend masks important variability in the time series; this record spans the phase shift of the Pacific Decadal Oscillation (PDO) in 1976. Nome temperatures were particularly warm just after the shift from about 1978 through 1983. Over the past few years (2014-2016) the PDO index has had the highest, most persistent positive values since the 1980s, coinciding with a strong El Niño pattern, resulting in two of the warmest years on record in 2014 and 2015.

Annual precipitation totals, including rainfall in summer and melted snow in winter, are also variable over the period of record between 1931 and 2015. There is a slight decreasing trend of 32 mm over the past 86 years, although the trend is not significant. The annual precipitation data begins in 1931, before that date there were many missing values (Figure 28 and 29).



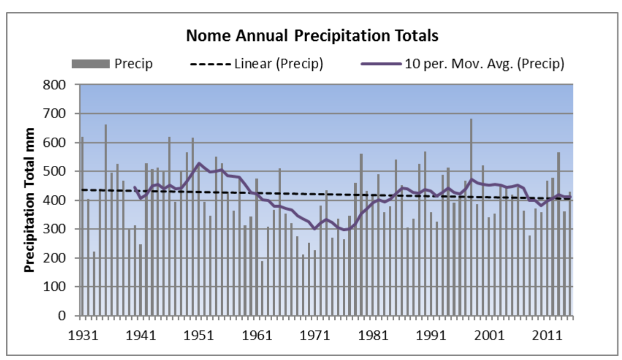


Figure 28. Mean annual temperatures and annual precipitation totals at Nome.

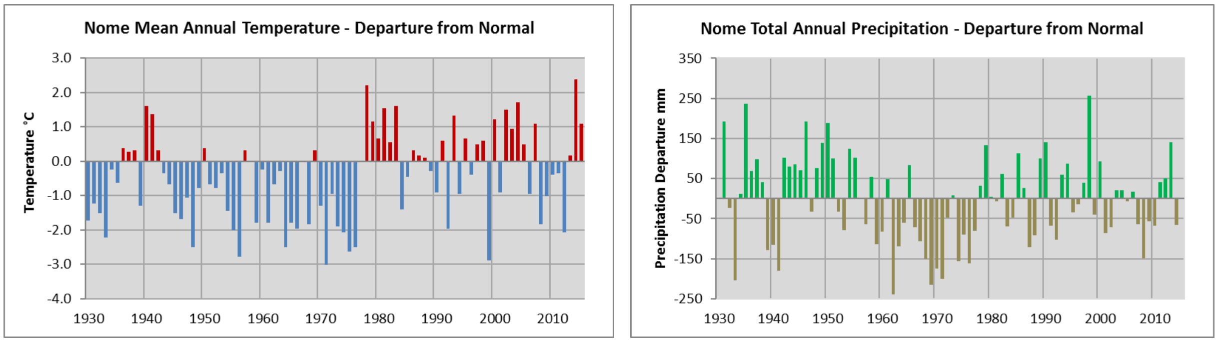


Figure 29. Temperature and precipitation departures from normal (1981-2010) at Nome.

Nome Seasonal Summaries

Winter

Over the past 86 years Nome winters have been getting warmer, the trend is statistically significant (Figure 30). The average winter temperature for Nome for the latest climate normal period is -13.7°C (-14.3°C for the longer period of record 1930-2016). The winter season temperatures over the entire period of record range from a low of -20.0°C (1970-1971) to a high of 6.9°C (2000-2001). The latest three winter seasons (2014-2016) have been, on average, 4.4°C warmer than normal.

The winter precipitation in Nome is on average ~75 mm (rain and snow water equivalent). The average annual snowfall is on average ~192 cm. The winter precipitation totals show a slight decrease over the past 86 years, while the snowfall totals for the season have shown a significant increase over the same time period. Perhaps during the early period of the record when precipitation totals were high and temperatures were warmer the snow water equivalent was greater than it has been over recent decades. Human error in measurements may also be a factor.

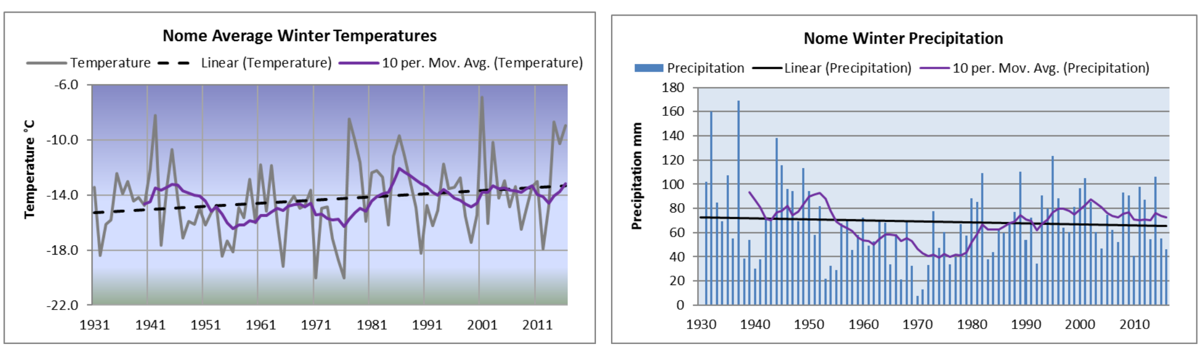


Figure 30. Nome winter temperatures and total precipitation 1930-2016.

Spring

The average spring temperature for the latest climate normal period is -5.3°C. Between 1930 and 2016 seasonal spring temperatures have ranged from a low of -10.9°C (1977) to a high of -1.3°C (2016). Temperatures have increased by ~ 1.1°C over the past 86 years, but the trend is not significant. Spring precipitation totals have decreased over the period of record, with the lowest spring totals occurring in the late 1960s and early 1970s (Figure 31). Spring is the driest season for Nome with an average seasonal total of ~58 mm (1981-2010).

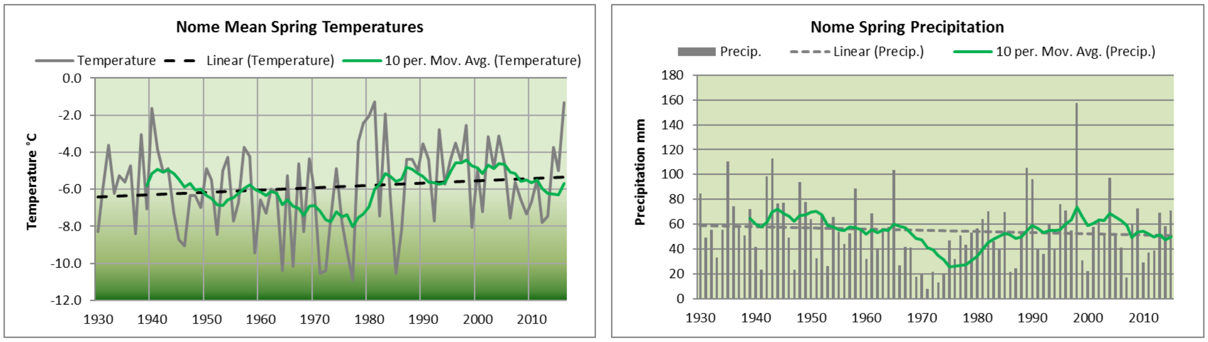


Figure 31. Nome spring temperatures and precipitation totals 1930-2016.

Summer

Summers have been getting warmer in Nome, with a significant increase of ~1.7°C since 1930; summer rainfall totals show a slight decrease over the period of record, but the trend is not significant (Figure 32). The average summer temperature for Nome is 10.1°C. Summer seasonal temperatures have been as low as 6.9°C in 1973 and as high as 12.5°C in 2004. The seasonal summer rainfall total is, on average, 160 mm.

Fall

Fall temperatures have been increasing and precipitation has been decreasing in Nome, although neither trend is significant (Figure 33). The average fall temperature for Nome is -1.4°C and the average fall precipitation total is 134 mm. Fall temperatures have been as cool as -5.3°C (1948) and as warm as 1.4°C (1974).

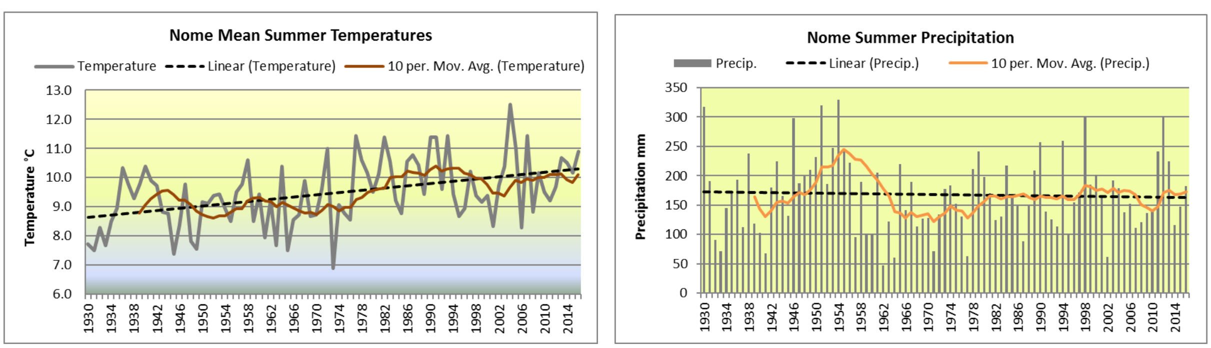


Figure 32. Nome summer temperatures and precipitation totals 1930-2016.

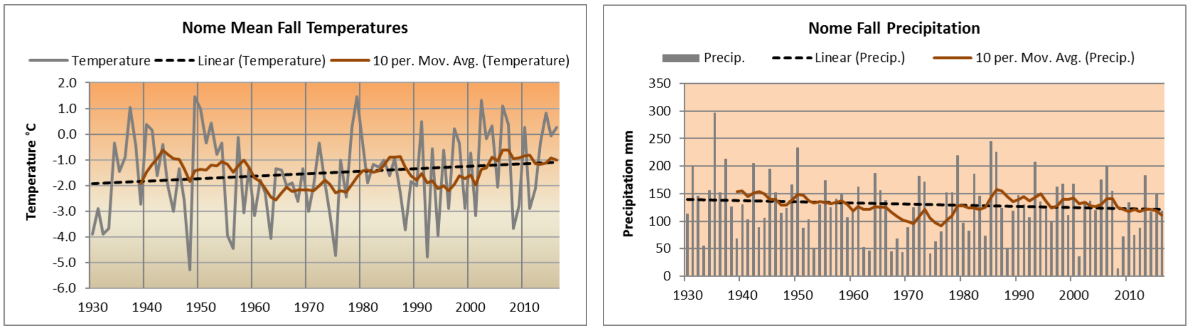


Figure 33. Nome fall temperature and precipitation totals 1930-2016.

Frost /Freeze Dates for Nome

For the time period between 1930 and 2016, the date of the last freeze in spring is ~10 days earlier and the first freeze in fall is ~ 7 days later (Figure 34).

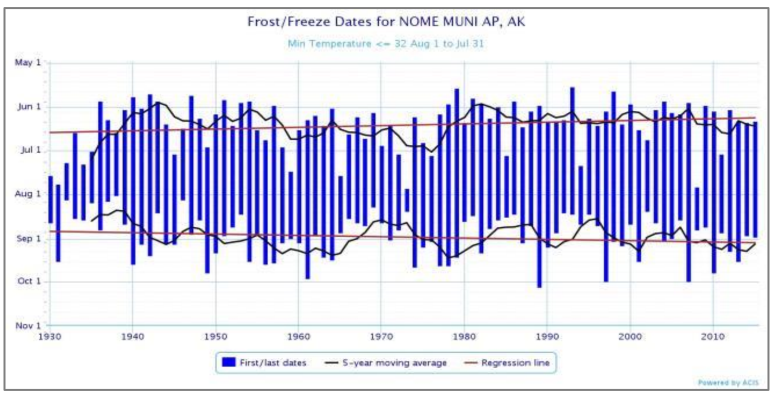


Figure 34. Frost/freeze dates for Nome.

Snow On and Off Dates for Nome

The date of the first persistent snow over the past 86 years is about a week later in the fall, and the melt-out, or snow-off date, is ~ 10 days earlier in the spring. The period of record for snow depth data at Nome is from 1930-2016. The snow season is calculated from July 1 through June 30 (Figure 35).

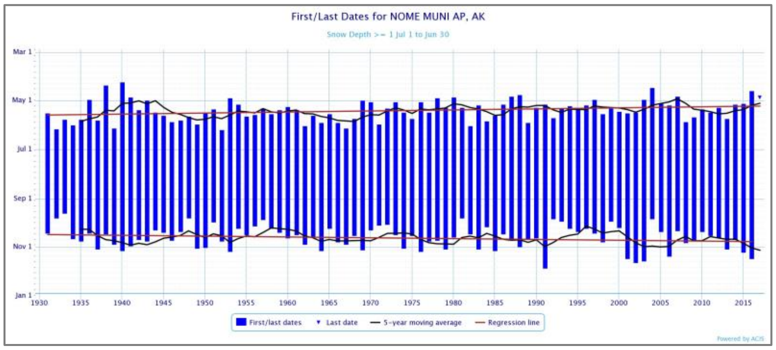


Figure 35. Snow on and snow off dates for Nome 1930-2016.

NPS Climate Stations – BELA

Four years of data from three new climate stations in BELA provide context for the preserve. Two sites are located at lower elevations and are closer to the northern coast, and the third site is at a high elevation in the Bendeleben Mountains about equidistant from the Bering Sea to the south and Kotzebue Sound to the northeast (Figure 36). In the winter, the monthly mean temperatures track better with Kotzebue than Nome, and in the summer the temperatures are more similar to Nome conditions. Nome has a more typical maritime climate with less pronounced temperature variations between the summer and winter seasons. Nome also has more direct exposure to the open ocean, while Kotzebue is surrounded by the shallower and more protected waters of Kotzebue Sound.

Ella Creek, the high elevation site, has cooler summer temperatures and warmer winter temperatures due to persistent inversions (Figure 37). Ella Creek also has the coldest mean annual temperature of the three sites. The site is the highest in elevation and the farthest from any coast, located at a high pass in the Bendeleben Mountains at the crest of the continental divide. All of the NPS sites in BELA have been cooler overall than Nome.

Summer rainfall totals are highest at Ella Creek, followed by Serpentine, and Devil Mountain. Precipitation is measured at the NPS stations in summer only when temperatures are above freezing. August is the wettest month for all sites, followed by July and September. To date, the summer rainfall totals at Serpentine and Devil Mountain are less than Nome totals.

Snow depth is measured at the three BELA sites with an acoustic distance sensor. The snowpack at the Ella Creek station is the most substantial, with maximum depths over the first few winter seasons averaging 477 mm, with a peak in the winter of 2014-2015 of 711 mm. Devil Mountain consistently shows a maximum seasonal snow depth of ~ 287 mm. Both Ella Creek and Devil Mountain show snowpacks that develop and persist through the winter. Serpentine had a substantial snowpack during the winter of 2012-2013, but since then the snowpack has been minimal with bare ground evident mid-winter during the last few years. The phenology camera at the site captured the fleeting mid-winter snow. These sites are all consistently windy, with Ella being the windiest location with persistent winds out of the SE. The average wind speed overall at the BELA sites is ~ 4 m/s. The Devil Mountain site is rarely calm in the summer. Serpentine has the lowest average wind speeds of the three sites.

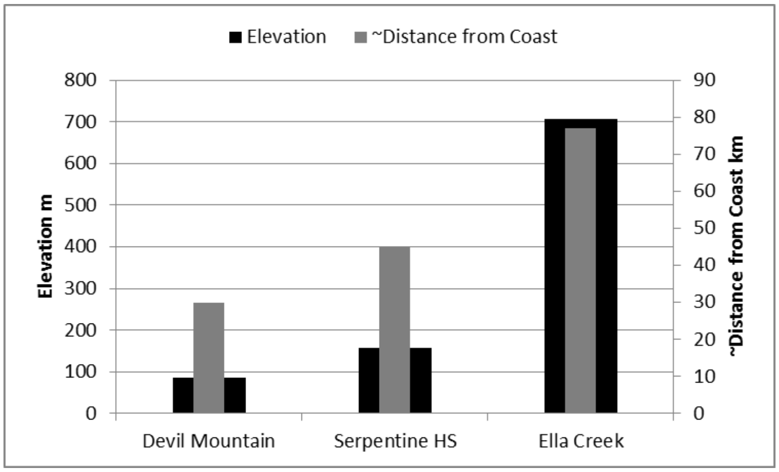


Figure 36. NPS climate stations in BELA - elevation and distance from coast.

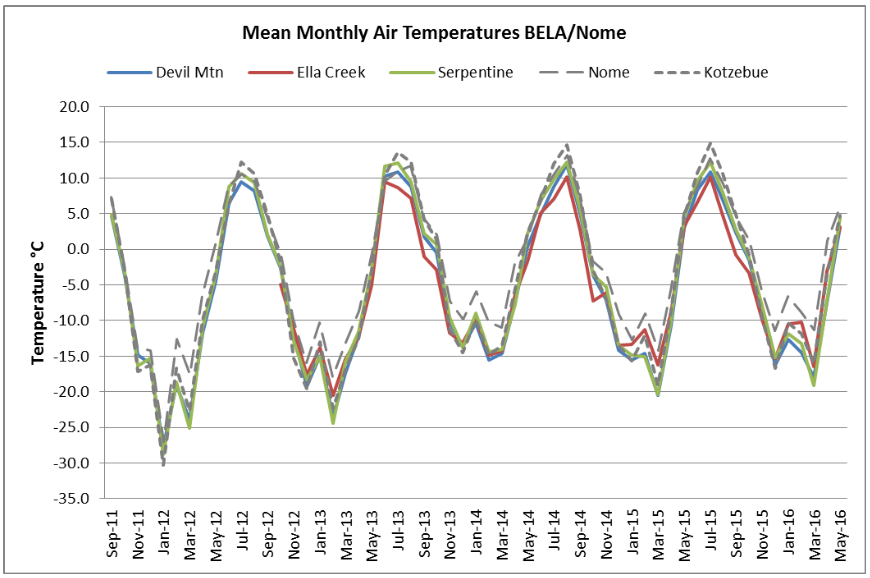


Figure 37. Mean monthly temperatures at the BELA, Nome, and Kotzebue climate stations 2011-2016.

Teleconnections

Climate in Alaska is dynamic with strong linkages to atmospheric and oceanic processes, such as the position of the polar jet stream or the frequency of El Niño events (Papineau 2001). An important climate pattern, evident in the relatively few long-term climate stations located in parks, is the Pacific Decadal Oscillation (PDO). Typical winter sea surface temperatures during the warm phase of the PDO are warmer off the Gulf Coast of Alaska, which moderate the air temperatures over the terrestrial areas of the state (Mantua et al. 1997; Figure 38). Much of the warming that has occurred since the middle of the 20th century occurred in 1976 as a stepwise shift, attributed to a climatic transition from a cool to a warm phase in the PDO (Hartmann and Wendler 2005; Figure 39). In the early 2000s the PDO shifted back to a cooler phase resulting in statewide temperatures that were cooler than the previous decades (Wendler et al. 2012). The most recent years have seen yet another shift back to a warm phase that has resulted in two of the warmest years on record for Alaska in 2014 and 2015 (NOAA 2016). The North Slope of Alaska has continued to warm despite changes in the PDO.

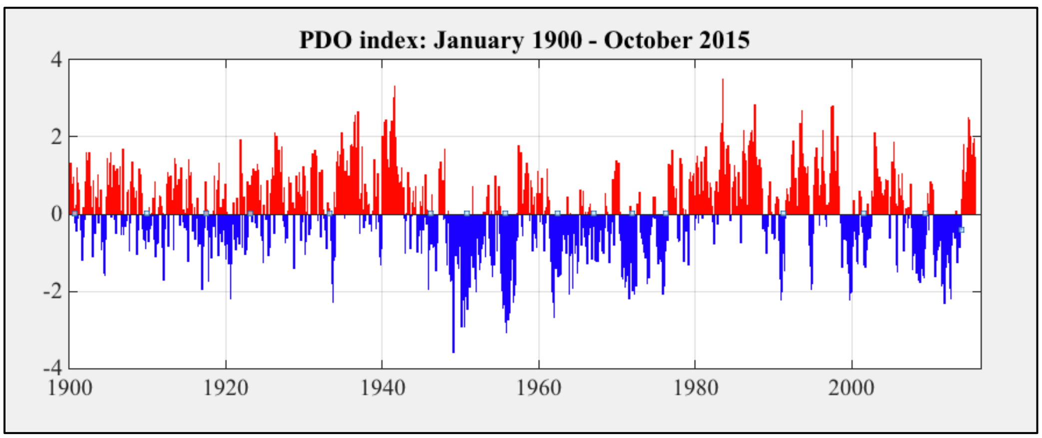


Figure 38. Pacific Decadal Oscillation (PDO) 1900-2015. Graph courtesy of the Joint Institute for the Study of the Atmosphere and the Ocean (JISAO 2016).

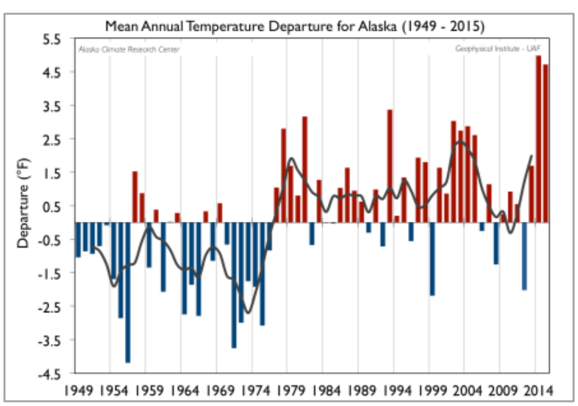


Figure 39. Mean annual air temperature for Alaska 1949-2015. Graph courtesy of the Alaska Climate Research Center (ACRC 2016).

While the North Pacific Ocean temperatures may help us understand some of the variation in temperatures in Alaska, the Arctic Ocean, and in particular the extent of sea ice, plays a crucial role in the Arctic climate. The National Snow and Ice Data Center (NSIDC) monitors and reports on the current extent of the Arctic sea ice. Figure 40 shows the continued and significant reduction in the extent of the summer sea ice cover and the decrease in the amount of relatively older, thicker ice in recent years (Perovich et al. 2015, Tschudi et al. 2016). The presence or absence of sea ice is a particularly important indicator of climate potential for BELA, CAKR, KOVA, and NOAT.

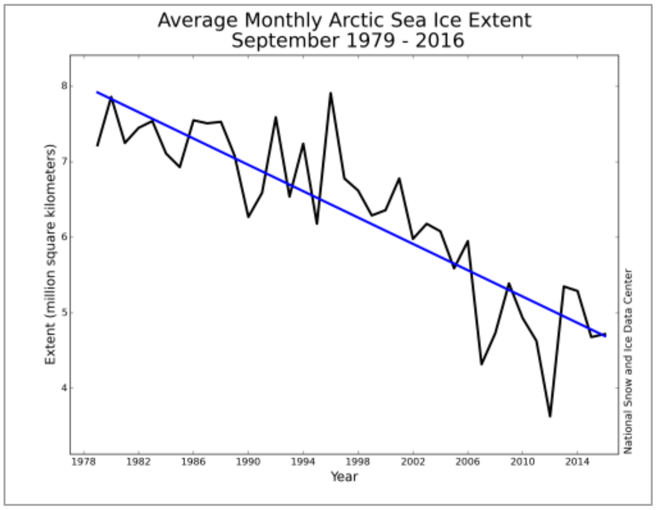


Figure 40. According to the NSIDC sea ice extent of September (generally the minimum extent) has declined by ~13% per decade using the 1979-2016 data record (NSIDC 2016).

Climate Change Projections

Temperatures are projected to increase for all seasons by mid-century, with the greatest increases likely in winter (IPCC 2013, SNAP 2016). There is general agreement among individual climate models in the direction and magnitude of warming over the coming decades. Warming temperatures pose serious threats to park resources when the average annual temperatures are near freezing. Warming will drive widespread loss of near-surface permafrost (Panda et al. 2016), increasing active layer thickness, and extensive thermokarst development (Jorgenson et al. 2006) that will lead to cascading hydrologic changes across the landscape (O'Donnell et al. 2014). Warming on the North Slope is closely linked to the decrease in sea ice (Wendler et al. 2014). Temperatures in coastal regions are moderated by open water, with longer ice free seasons; these regions will likely warm more than interior regions of Alaska.

Temperature and precipitation projections over the next century have been calculated on a monthly time scale for communities around the parks, including Bettles, Kotzebue, and Nome (Figure 41). The projections are based on the PRISM model historical baseline projected at a 2 km resolution using the mid-range emissions scenario (representative concentration pathway RCP 6.0). These graphs are useful for looking at overall trends in temperature increases versus specific values due to the inherent uncertainty in models and natural climate variability (SNAP 2016).

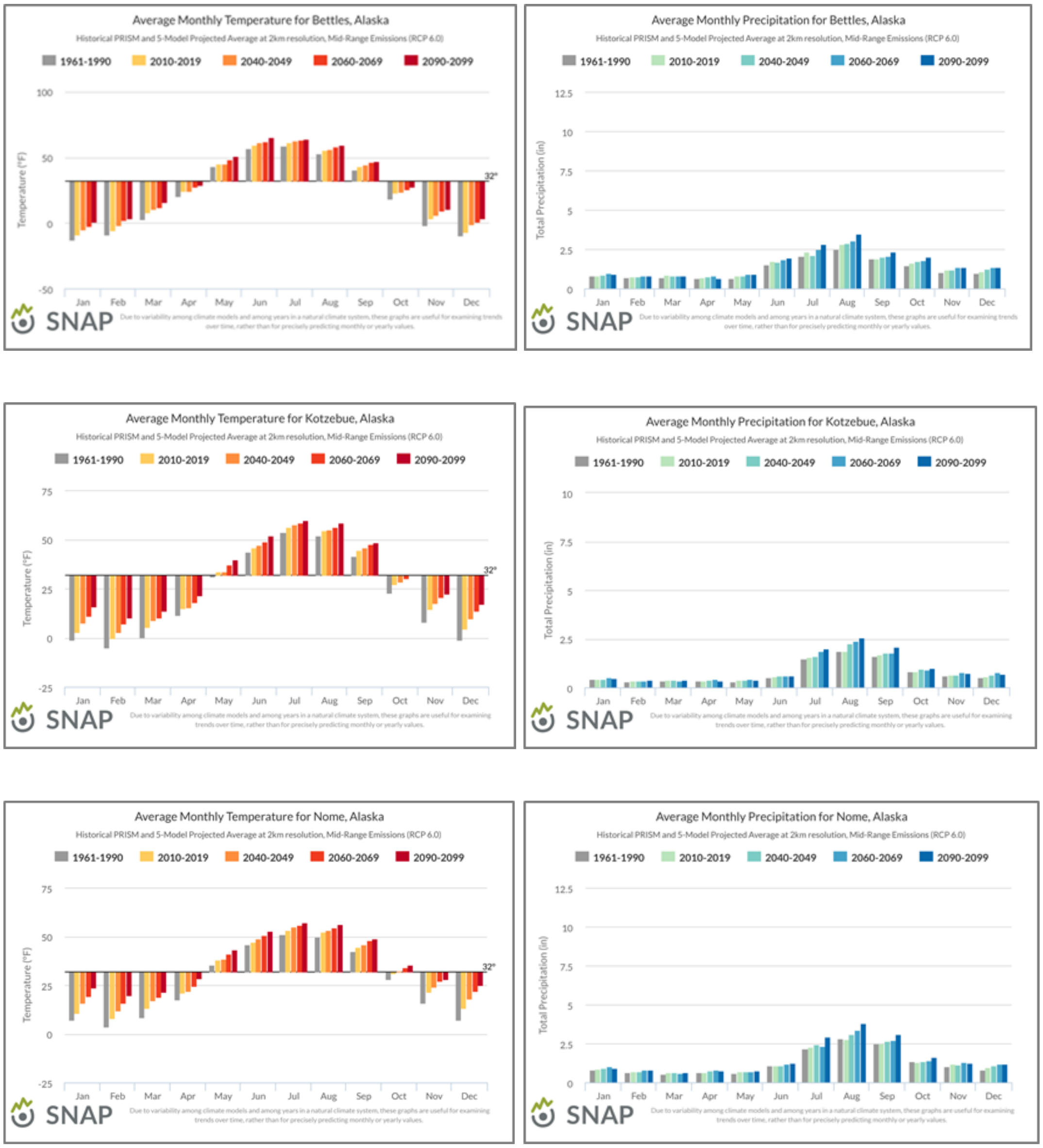


Figure 41. Projections of monthly temperature and precipitation changes in Bettles, Kotzebue, and Nome. Charts courtesy of SNAP 2016 (Data sources: Historical PRISM and CRU TS 3.2 climatology data (1961-1990) and downscaled outputs averaged from five GCMs).

Summary

Temperatures: Nome is the warmest location of the three index sites overall; it is the site that is the farthest south and west. The proximity to the Bering Sea moderates temperatures over land with a difference of ~23.8°C between average winter and summer temperatures. Every season shows increasing temperatures over the period of record in Nome, except for summer. Bettles summer temperatures, which are typical of a continental interior climate, are the warmest in the summer months. Bettles and Kotzebue have mean annual temperatures that vary by only 0.4°C. Bettles warms earlier in the spring and has warmer summers than Kotzebue. Fall temperatures in Kotzebue are warmer than Bettles due to the moderating effects of the open ocean prior to the formation of sea ice that develops later in the fall. Winter temperatures in Bettles are the coldest, characteristic of an interior climate. The variability between average winter temperatures and average summer temperatures in Bettles is 35.5°C and in Kotzebue is 28.4°C. Kotzebue has the coldest mean annual temperature of the three sites with cold winter and spring seasons and moderate temperatures during the summer season.

Although we only have a few years of data to compare, monthly temperature patterns between the NPS sites in the parks and the index sites track well, with the expected variations in temperature with elevation. In the central interior region, temperatures are cooler in summer and warmer in winter at higher elevations. This is very well established in GAAR with Bettles as the index site at a low elevation and newly instrumented sites at mid-elevations in the mountains. The mid-elevation interior sites in Noatak, which are the farthest north, have cooler overall temperatures (including winter) than Kotzebue, but are generally warmer in winter than Bettles. The new NPS sites at lower elevations in BELA track better with Kotzebue temperatures in the winter and in the summer the temperatures are more similar to Nome conditions. Ella Creek, the high elevation site, is the exception with cooler summer temperatures and warmer winter temperatures due to persistent inversions.

Precipitation: Nome is the wettest index site, in terms of total annual precipitation, with a total of 427 mm (summer rainfall and snow water equivalent). It is wetter in every season except for summer. Bettles is the second wettest (379 mm annually), with the highest summer rainfall totals. Bettles is wetter than Kotzebue in every season. Kotzebue is the driest of the three sites with a total of 279 mm, most likely due to the lack of available moisture when sea ice is present. Bettles has the highest annual snowfall totals, followed by Nome and Kotzebue.

The new NPS stations measure summer rainfall (when the temperature is above freezing) and snow depth (not snow water equivalent), therefore a direct comparison between precipitation totals at the park stations and the index sites is not possible. Precipitation is much more variable than temperature and more difficult to analyze. In general precipitation totals are higher in coastal areas (when there is open water and moisture availability) and at higher elevations in the mountains.

Snowfall is relatively low in the Arctic and is often redistributed by wind due to the lack of trees and the low density of shrubs that can trap snow. According to Swanson (2014) the median length of the continuous snow season for the Arctic parks was 6 to 7 months in most lowland areas (below 300 m), 7 to 8 months at most mid-elevations, and 8 to 9 months at most high elevations (above 1,200 m).

Many of the windy sites at high elevations are scoured free of snow even in mid-winter. Phenology cameras, installed on some of the NPS stations, have documented mid-winter warming events where the snowpack melts out completely. The snow depth sensors and cameras will provide more information on snow cover at discreet locations in the parks, but remote sensing provides the opportunity to look at snow cover and snow persistence at a region-wide scale (Swanson 2014, Lindsay et al. 2015).

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