Climate Science Primer:

Projections for the Middle Kuskokwim Region

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Introduction

People around the world are experiencing changing conditions that affect their daily lives. Many changes are due to anthropogenic climate change, caused by combustion of fossil fuels and deforestation. Climate change is a global problem, yet the impacts and opportunities for action are locally based. As climate change accelerates with continued greenhouse gas emissions, local communities will need to be prepared for impacts and take action to protect people and the natural resources we depend on. Alaska is experiencing some of the most rapid changes on earth, and people are seeking strategies to increase safety, wellness and sustainability.

Throughout western Alaska, residents report changes in weather, seasons, landscape, plants, and wildlife.[2] All of these changes can affect peoples' health, culture, and livelihoods. Local infrastructure is also at risk from flooding, permafrost melt, and wildfire. Many changes are already occurring, and many more are expected to occur in the future.

If aggressive global action to reduce greenhouse gas emissions is taken, the long term magnitude of climate change will be reduced, and local strategies to adapt will be more successful. Even if action is taken, however, the next few decades are expected to experience drastic change because of greenhouse gases already emitted. Local action and planning to reduce the impacts of those changes are needed.

This climate change primer provides information on the expected trends and impacts associated with climate change, specific to the Native Village of Georgetown and the surrounding region along the Kuskokwim River in southwestern Alaska. Understanding climate change trends and impacts is the first step in developing a vulnerability assessment for the village.

Historical Trends (1949–2016)

- Temp. ↑ 4° F on average
- Temp. ↑ 2° F in summer
- Temp. ↑ 8° F in winter

By mid-century (2050s)*

- Average temp. ↑ 9° F
- Summer temp. ↑ 6° F
- Winter temp. ↑ 12° F
- Precipitation ↑ 20%
- Snowfall ↓ 5%
- Moisture deficit ↑ 16%
- Frost-free days ↑ 34 days/yr.
- Change in dominant vegetation potentially with an increase in forest cover
- Increase in wildfire
- Thawing permafrost throughout much of the region

By late-century (2080s)*

- Average temp. ↑ 13° F
- Summer temp. ↑ 9° F
- Winter temp. ↑ 19° F
- Precipitation ↑ 32%
- Snowfall ↓ 19%
- Moisture deficit ↑ 17%
- Frost-free days ↑ 57 days/yr.
- Change in dominant vegetation potentially with an increase in grasslands and prairie
- Increase in wildfire
- Little permafrost left in the region

* Compared to the historical period 1961–1990

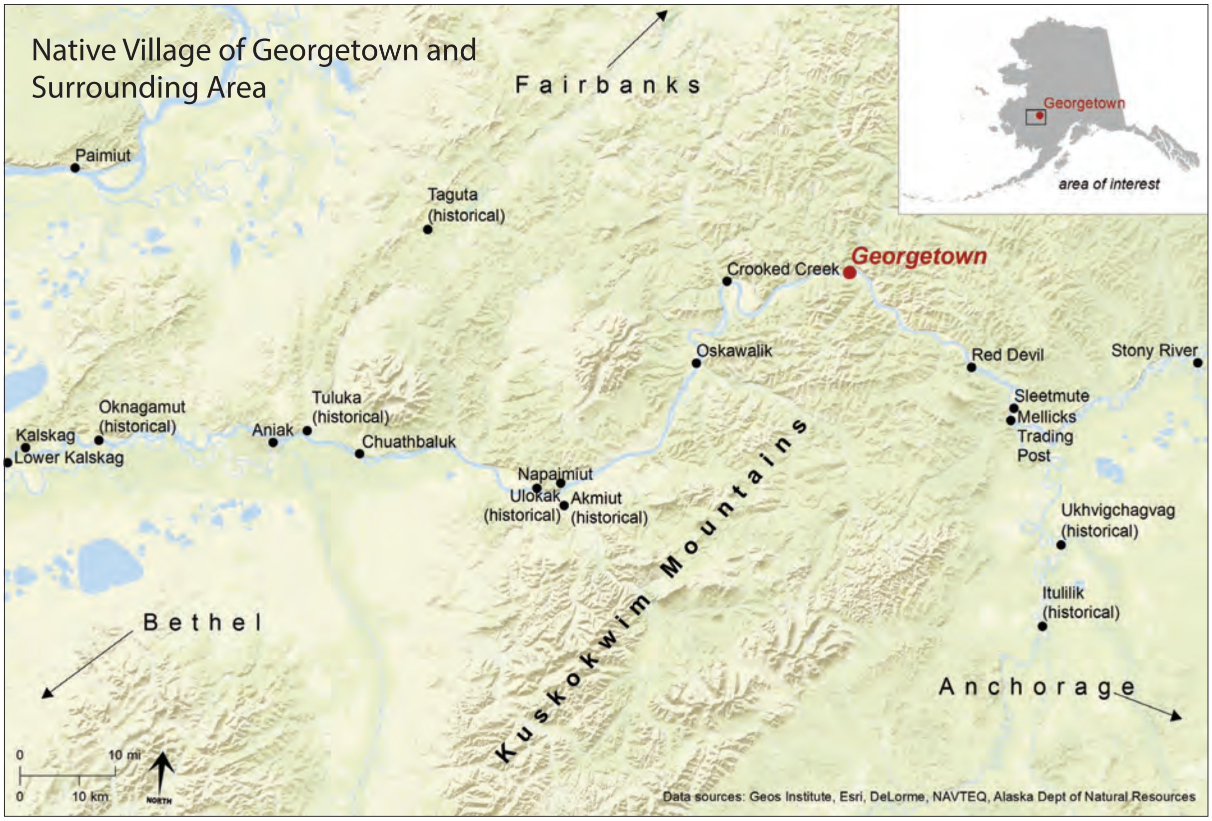


Figure 1 Location of the Native Village of Georgetown in the Middle Kuskokwim region. The Kuskokwim River runs east–west through the middle of the image, eventually flowing into the Bering Sea.

Vulnerability Assessment

The vulnerability assessment will combine Traditional Knowledge, local expertise, and climate science as the basis for identifying mid- and long-term vulnerabilities of the people and resources of the Native Village of Georgetown. The vulnerability assessment is composed of three primary variables. These include Exposure, Sensitivity, and Adaptive Capacity (see box).

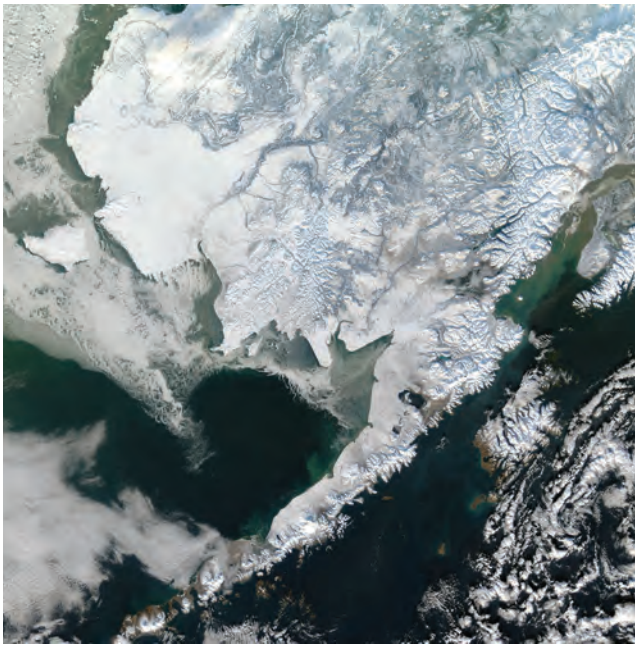
This climate science primer provides the information needed to assess exposure. In addition, Traditional Knowledge will provide invaluable information on how resources have responded to changing conditions and variability in the past, as well as how native Alaskans have adapted to change over time and remained resilient. Local experts on climate impacts and specific resources will also be consulted for the vulnerability assessment.

Three Components of Vulnerability

Exposure – Climate change trends and impacts are locally specific. Some areas will be hit harder by heat waves while others will experience more flooding.

Sensitivity – Some populations or resources experience greater impacts than others, even with the same level of change. For example, people with respiratory illnesses are more sensitive to smoke from wildfires than the general population.

Adaptive Capacity – Many resources or behaviors are already in place, allowing people to respond to the changes ahead. For example, if alternative subsistence foods are available and/or affordable, then people are less vulnerable when primary foods become unavailable.



Alaska in winter – photo by Jeff Schmaltz at NASA Earth Observatory

Climate Change Data and Models

The Earth's climate is regulated by a layer of gases commonly referred to as greenhouse gases for their role in trapping heat and keeping the earth at a livable temperature. These gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and water vapor (H_2O). CO_2 plays an especially large role due to its long residence time and relative abundance. The atmospheric concentration of CO_2 in the atmosphere has risen from 280 to more than 400 parts per million (ppm) in the past century, driven largely by fossil fuel combustion, deforestation, and other human activity.[1]

Information from ice cores provides us a glimpse into CO_2 levels over hundreds of thousands of years. This data shows us that CO_2 has fluctuated between about 175 and 300ppm over the last 800,000 years. The current level of 400ppm is far above anything detected in the ice core analyses. As CO_2 has fluctuated in the past, it has tracked closely with changes in temperature, and we can expect this relationship to hold in the future as CO_2 and other greenhouse gases continue to increase.

For over a century, we have known that increases in the concentration of greenhouse gases in the atmosphere will result in warmer temperatures.[??] Long-term tracking data from weather stations and other research support this expected trend. Traditional Knowledge also indicates that there has been significant change in conditions over time.

Climate models are used to project future climate trends, based on our understanding of the Earth's complex ocean-atmospheric systems. The Intergovernmental Panel on Climate Change (IPCC), which is made up of thousands of leading scientists from around the world, has created a suite of 22+ global climate models (GCMs) from different institutions with which to assess future trends. These models were created independently, and vary substantially in their output. Yet most of the uncertainty in future conditions comes not from the variation among models, but from the level of action (or inaction) on addressing climate change. The models are based on different potential "pathways" for future greenhouse gas concentrations (called Regional Concentration Pathways, or RCPs), which depend on whether or not the international community cooperates on reducing greenhouse gas emissions (Fig. 3). In this report, we provide projections based on a lower emissions pathway (RCP 4.5) and a higher emissions pathway (RCP 8.5) that is similar to the current global trajectory.

Much of the data on future trends in this report are compiled from an "ensemble" or average across 15 GCMs, which have been adjusted from the global scale (coarse scale) to local scales (fine scale) using fine scale climatological data that reflects variation across the local landscape. When ensembles are used, it is important to understand the range of variation among the different models in the ensemble, as it can be quite great (see Appendix 1 for the variation specific to Georgetown). In general, precipitation projections are associated with higher uncertainty (i.e. more variation among models) while temperature projections are associated with lower uncertainty. Also, short to mid-term projections have lower uncertainty than long-term projections.

Global Trends

The hottest year on record was 2016, which was the third consecutive year that a new global annual temperature record was set (Fig. 2). The average global temperature across land and ocean surface areas for 2016 was 1.7° F (about 1° C) above the 20th century average.[3]

Models project continued average global warming of 1.5° to 4° C (2.7° to 7.2° F) by the end of this century, and continued warming for the next two centuries if business-as-usual emissions continue (Fig. 3). Because higher latitudes warm faster than areas closer to the equator, Alaska is expected to warm significantly more than the global average.

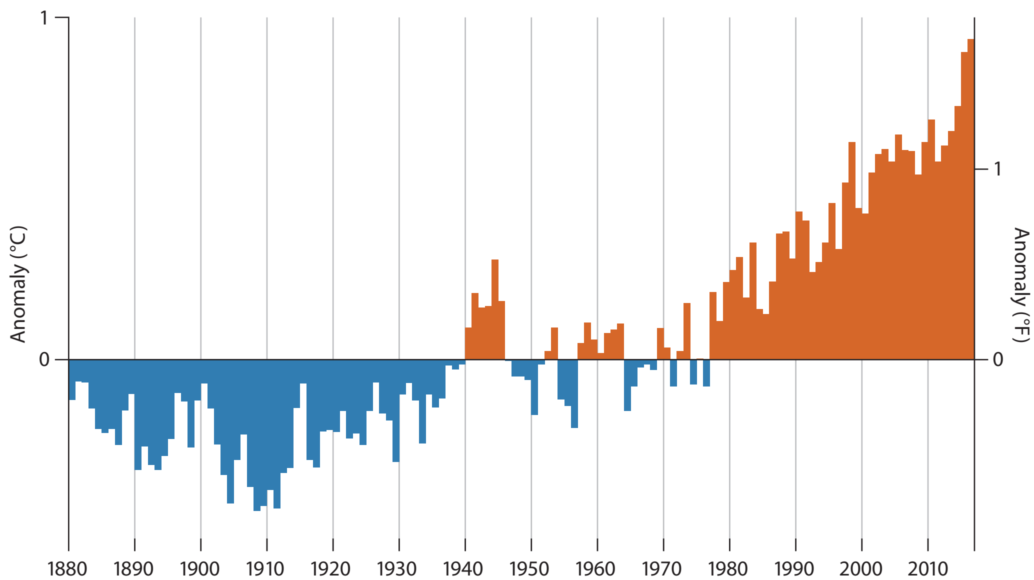


Figure 2 Temperature departure from the 20th century average, for the years 1880–2016. From NOAA/National Centers for Environmental Information (NCEI).

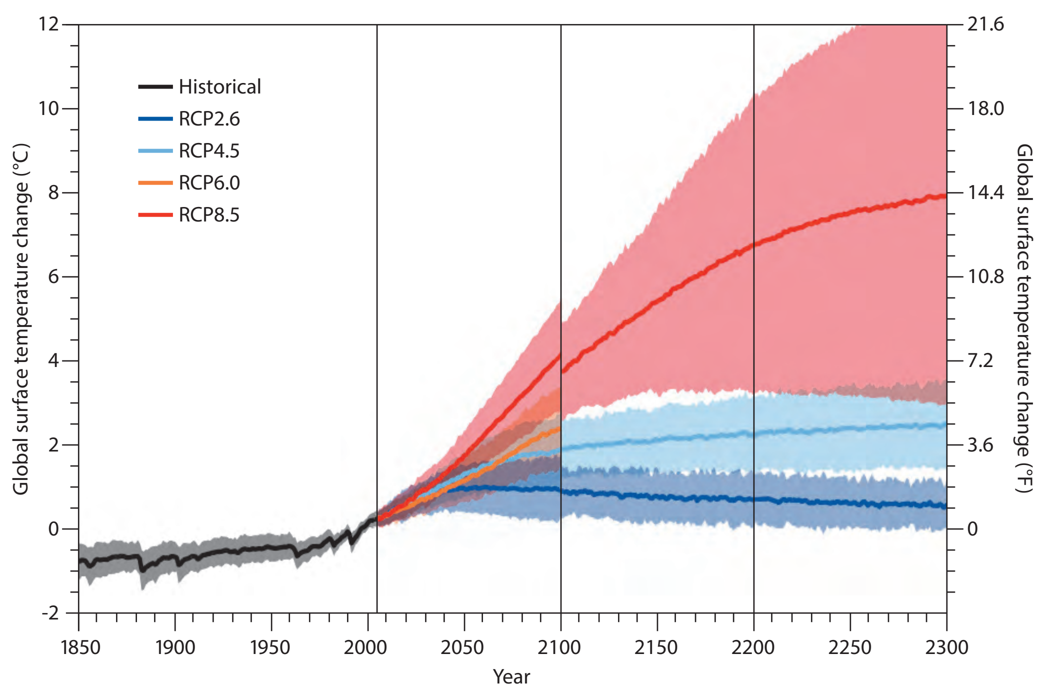


Figure 3 Future warming based on four different potential Regional Concentration Pathways (RCPs). RCP2.6 is the only pathway that stays below the internationally agreed upon limit of average global warming below 1.5–2.0° C. Our current trajectory is closest to RCP8.5.

Historical Trends in Alaska

Temperature – Over the past 60 years, Alaska has warmed more than twice as rapidly as the rest of the U.S., with average annual air temperature increasing by 3° F and average winter temperature by 6° F, with substantial year-to-year and regional variability (Fig. 4 and Table 1).[4]

The length of the growing season has already increased by 45% over the last century.[4] The number of extremely hot days has been increasing, while the number of extremely cold days has been decreasing over time.

Precipitation – Precipitation in Alaska has increased by about 10% statewide, with annual and regional variability.[4] Two areas of the state have experienced reduced precipitation—Annette (SE panhandle) and Barrow, AK.

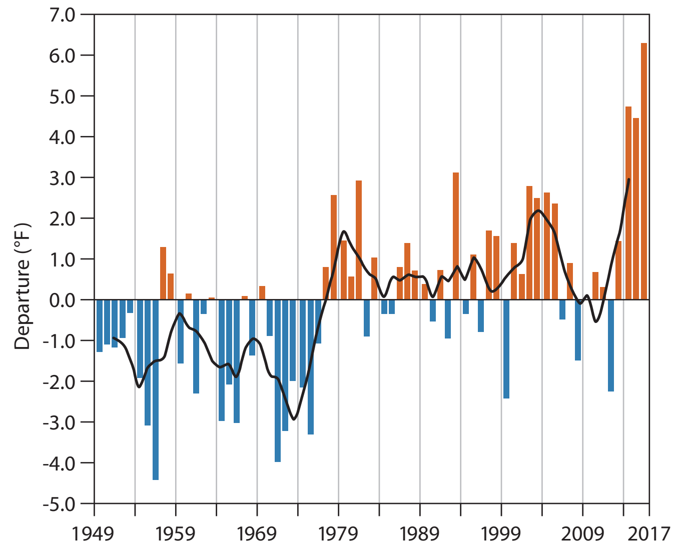


Figure 4 Deviation in average annual temperature from the long term mean (1949–2016) across Alaska. The 5-year moving average is also shown (black line). Data from Alaska Climate Research Center.

Change in Mean Seasonal Annual Temperature (°F), 1949–2016						
Region	**Location**	**Winter**	**Spring**	**Summer**	**Autumn**	**Annual**
Arctic	Barrow	8.1	6.1	3.7	6.9	6.3
Interior	Bettles	7.8	4.7	1.6	2.1	4.1
	Fairbanks	7.8	4.2	2.1	1.1	3.7
	Delta Junction	9.7	4.1	0.8	1.1	3.9
	McGrath	8.8	5.0	2.6	2.7	4.8
West Coast	Kotzebue	8.1	2.5	3.2	3.5	4.4
	Nome	5.6	3.3	2.3	1.8	3.3
	Bethel	8.0	4.5	2.2	1.2	4.0
	King Salmon	9.9	4.8	1.8	2.0	4.7
	St. Paul	1.1	1.7	2.9	1.7	1.9
	Cold Bay	2.4	1.7	2.3	1.4	2.0
Southcentral	Talkeetna	9.8	5.6	2.9	3.6	5.4
	Gulkana	8.3	3.1	0.9	0.3	3.0
	Anchorage	6.7	4.0	1.8	2.0	3.6
	Homer	7.1	4.2	3.4	2.6	4.3
	Kodiak	1.9	2.4	1.8	0.4	1.6
Southeast	Yakutat	5.9	3.3	2.3	1.2	3.1
	Juneau	7.0	3.4	2.2	1.6	3.5
	Annette	3.8	2.6	2.0	1.0	2.3
	Average	6.7	3.7	2.3	2.0	3.7

Table 1 Geographic variation in average seasonal and annual warming throughout Alaska. Data from the Alaska Climate Research Center.

Historical and Future Trends in the Middle Kuskowim Region

Temperature – Average annual temperatures in the Native Village of Georgetown and surrounding area are expected to rise an additional **9° F by mid-century and 13° F by late-century**, as compared to the historical period (1961–1990), based on an assumption of continued high greenhouse gas emissions (Figs. 5 and 6). Winters are expected to continue to warm more than summers (Fig. 6). **By mid-century, winters are expected to be 12° F warmer and summers 6° F warmer. By late-century, winters are projected to be 19° F warmer and summers 10° F warmer.**[5]

The number of frost free days each year is expected to increase from 135 (historical) to 169 by mid-century and 193 by late-century. **The length of the frost free period is projected to increase by two months by late-century.**[5]

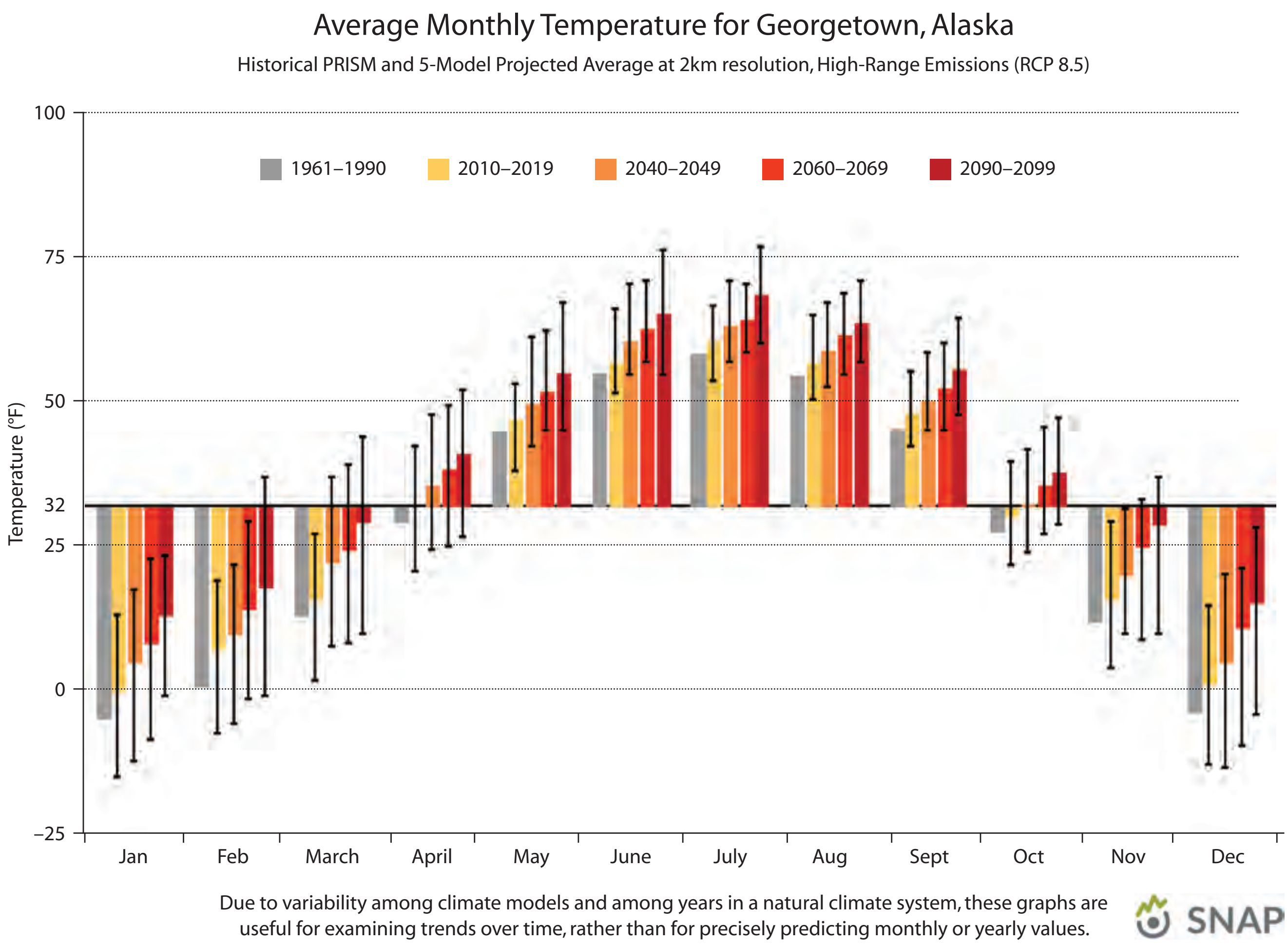


Figure 5 Average monthly temperature for Georgetown, Alaska, assuming continued higher emissions (RCP 8.5). Historical temperature is based on PRISM data and future projections are based on a 5-model ensemble at 5km resolution. Error bars show the standard deviation among the 5 models. Data and graph from the Scenarios Network for Alaska and Arctic Planning (SNAP).

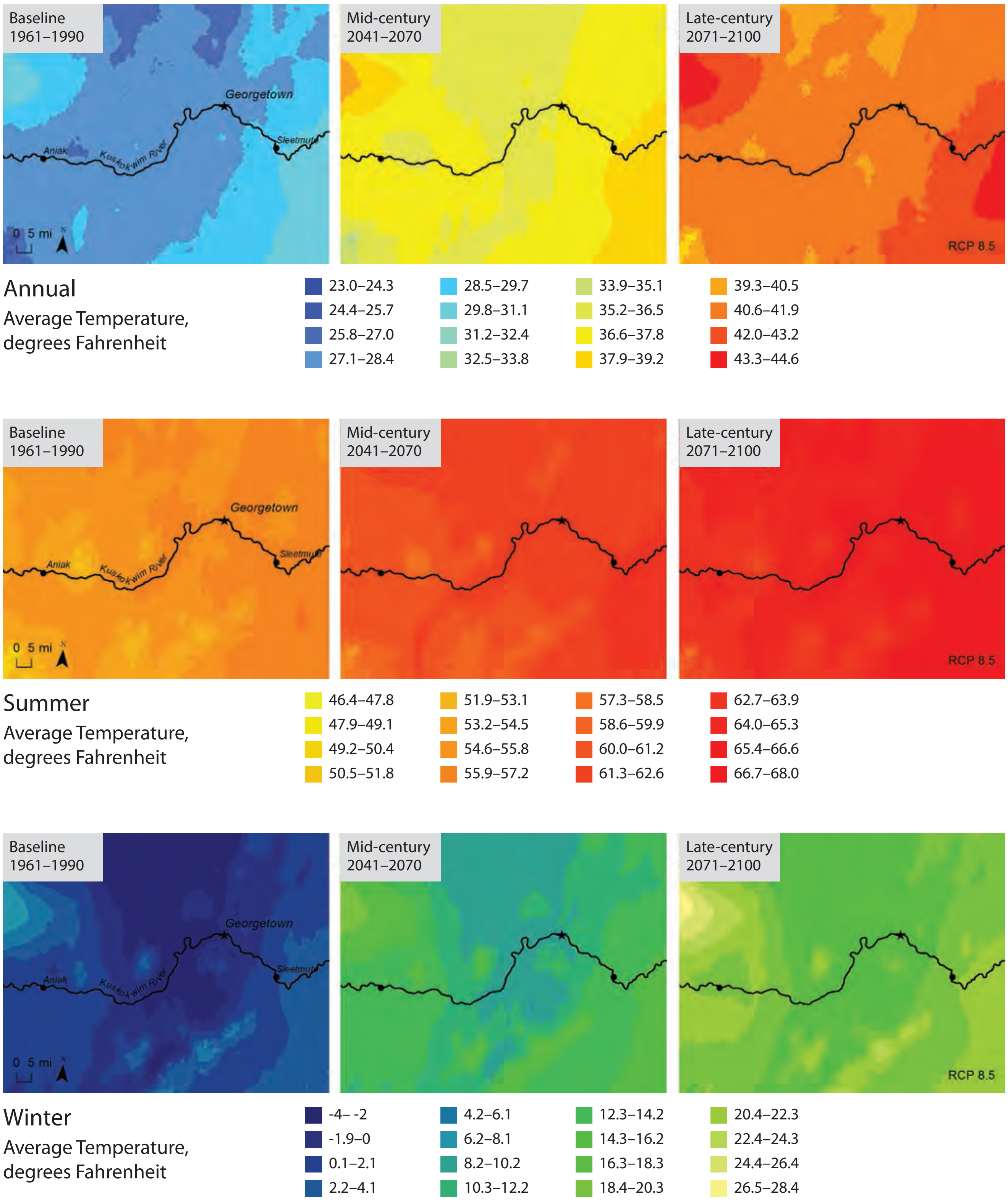


Figure 6 Temperature increase across the Middle Kuskokwim region, comparing the baseline period (1961–1990) to mid-century and late-century, both averaged over 30-year periods. Projections are based on a 15 global climate model ensemble, assuming continued higher greenhouse gas emissions (RCP 8.5).

Precipitation and Drought Stress – **Precipitation is projected to increase 19% by mid-century and 30% by late-century**, assuming continued high greenhouse gas emissions (Fig. 7 and 8). Even with higher precipitation, however, water availability and soil moisture could decline due to increased evaporation from longer growing seasons and higher temperatures, as well as the soil desiccation as permafrost melts.

Climatic moisture deficit (Fig. 8), a measure of **drought stress from both temperature and precipitation change is expected to increase over time by 16–17%** (ranging as much as 49%). Climatic moisture deficit has a strong link to wildfire.[6] **Precipitation as snow is expected to decline by 5% by mid-century and 19% by late-century.**[5]

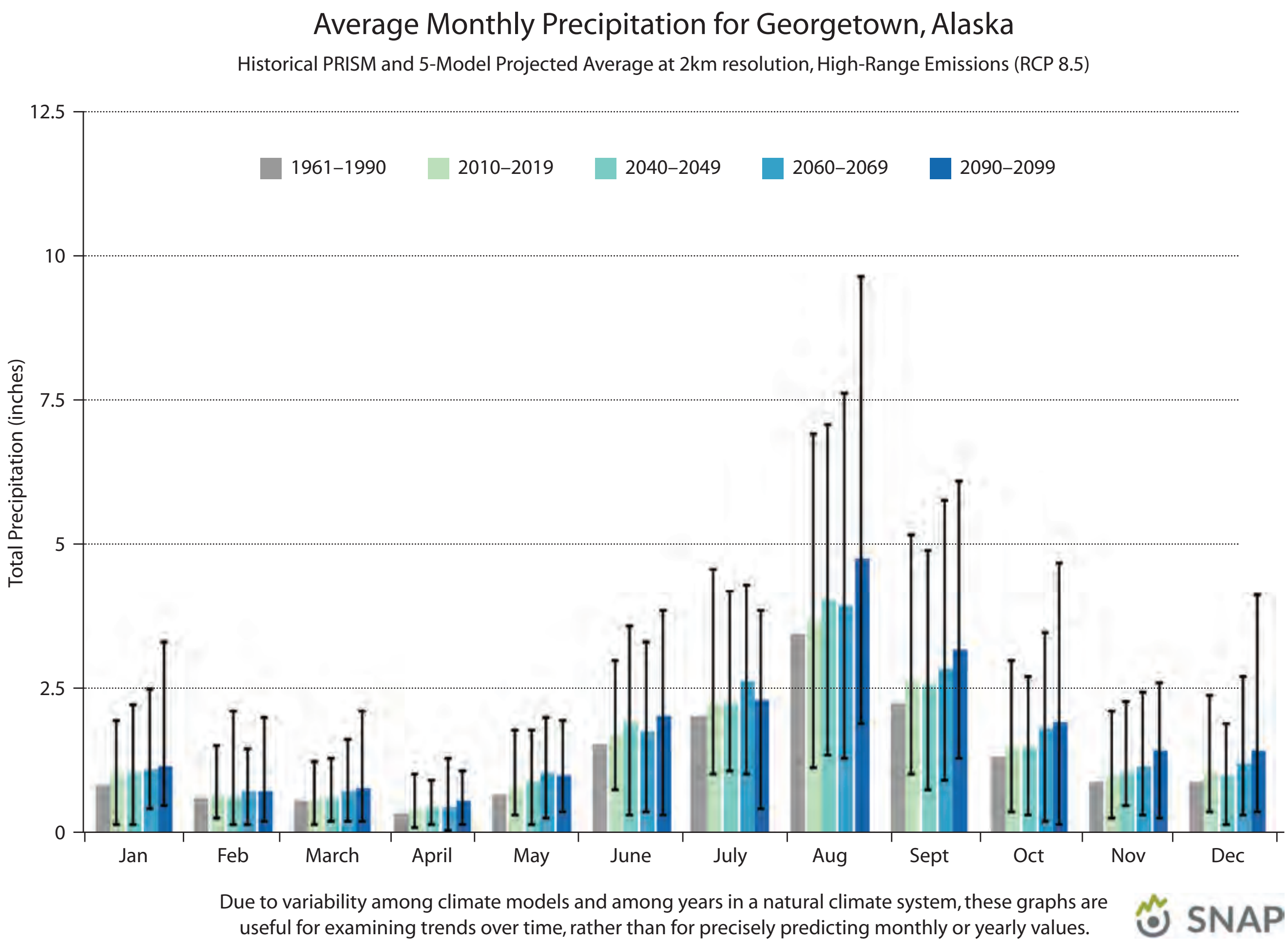


Figure 7 Average monthly precipitation for Georgetown, Alaska. Figure from Scenarios Network for Alaska and Arctic Planning (SNAP).

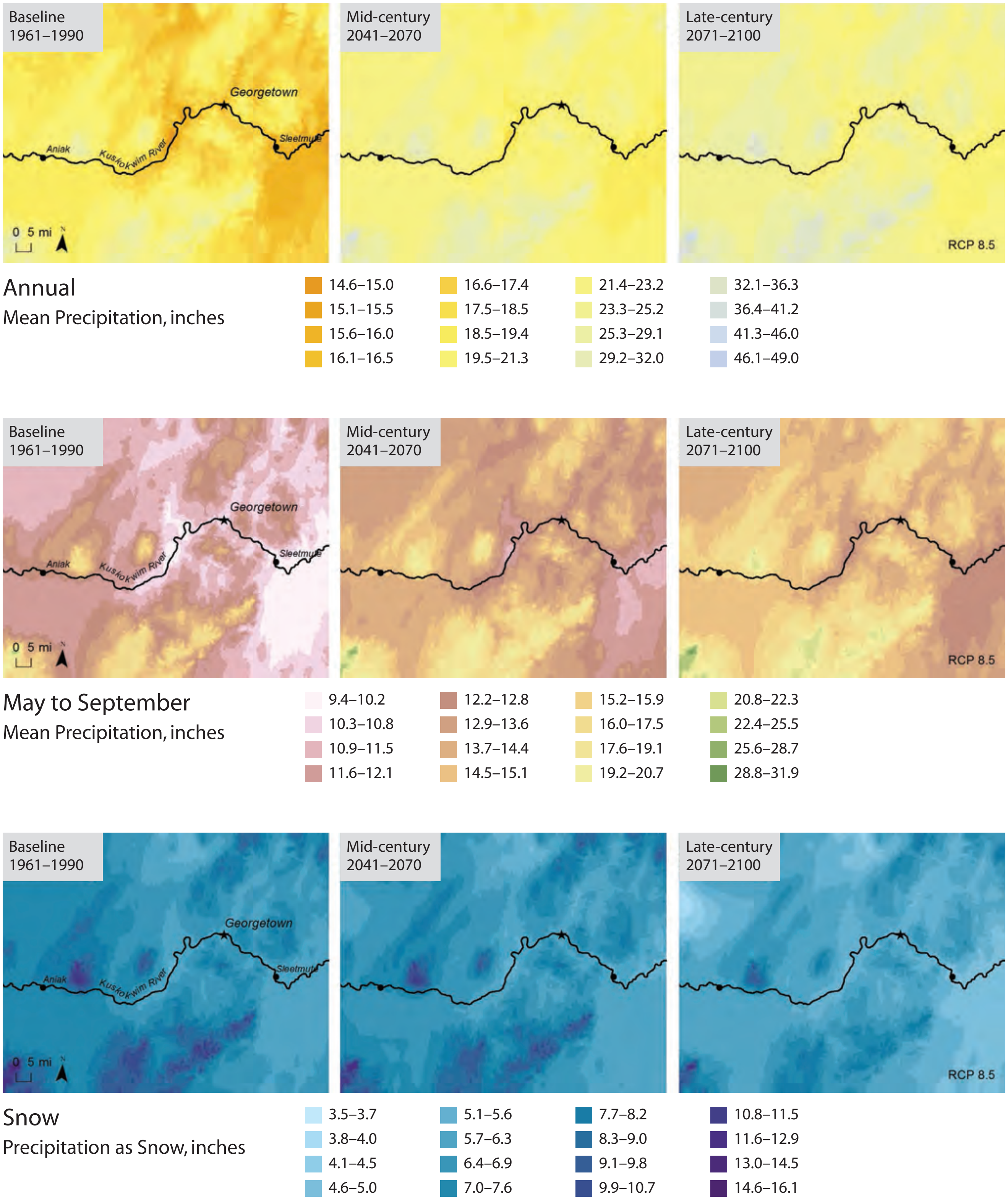


Figure 8 Precipitation change across the Middle Kuskokwim region, comparing the baseline period (1961–1990) to mid-century and late-century, both averaged over 30-year periods. Climate data created with ClimateNA v5.21. Projections are based on 15 global climate models.

Permafrost – Permafrost is ground (soil, sediment, or rock) that remains at or below 0° C for at least 2 years, and underlies 22% of the Earth's land surface.[7] In Alaska, 80% of land is underlain by permafrost (Fig. 9). The "active" permafrost on top is the layer that freezes and thaws seasonally.

When soils contain large amounts of ice (histels) in the permafrost, thawing can leave large depressions and/or hills called thermokarst terrain. Ice-rich permafrost currently is widespread in the region and strongly influences terrestrial and aquatic habitats, including local topography, vegetation, soil hydrology, and the water balance of lakes.[8] Permafrost temperatures in the Georgetown area are near the thaw point. Widespread loss of lakes and ponds in the region has already been attributed to permafrost thaw.

As permafrost melts, water can flow more freely through the substrate, causing the leaching of minerals into rivers and streams. Long term monitoring shows increases in calcium, sodium, phosphorus, magnesium, and sulfates, dramatically

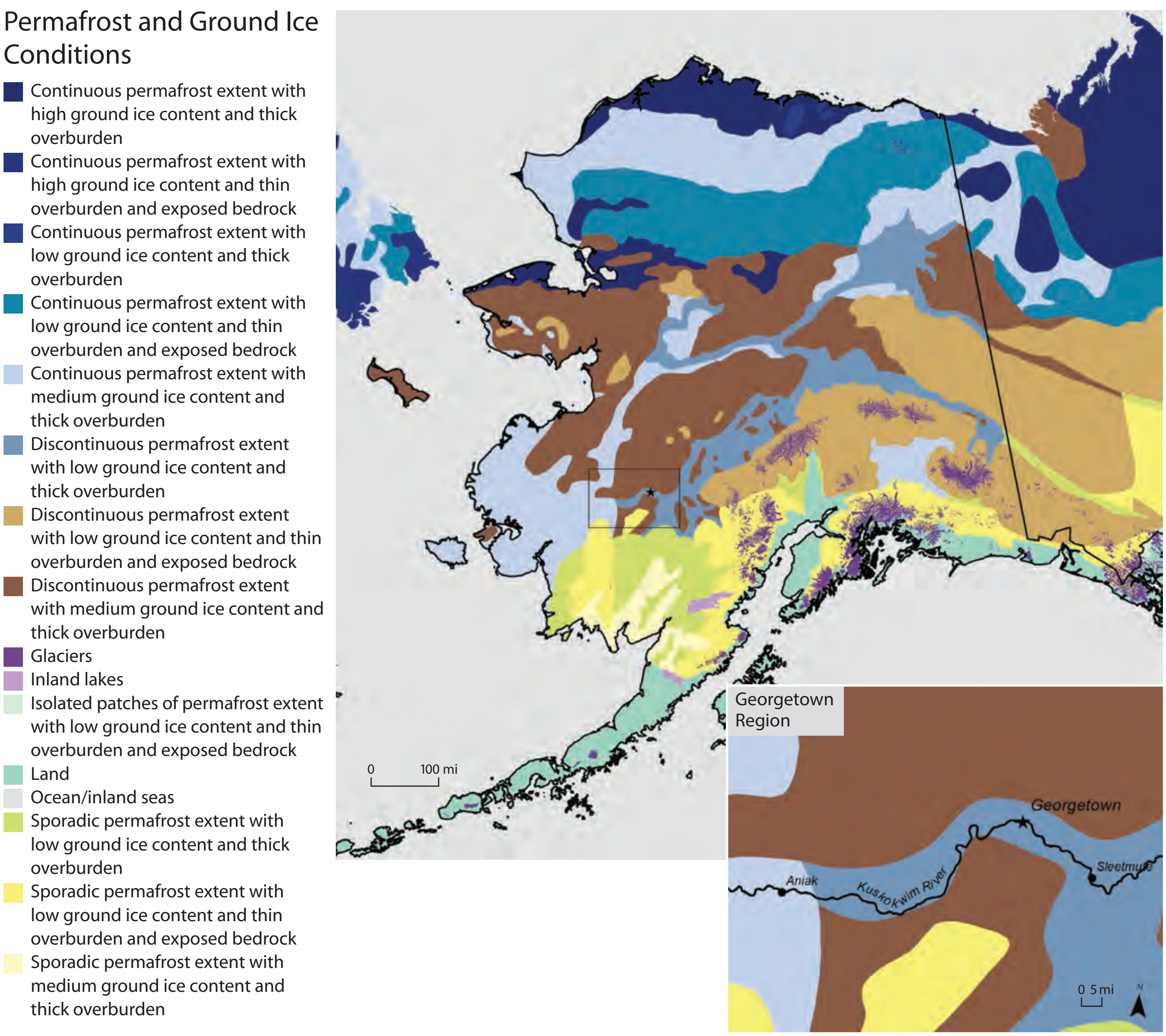
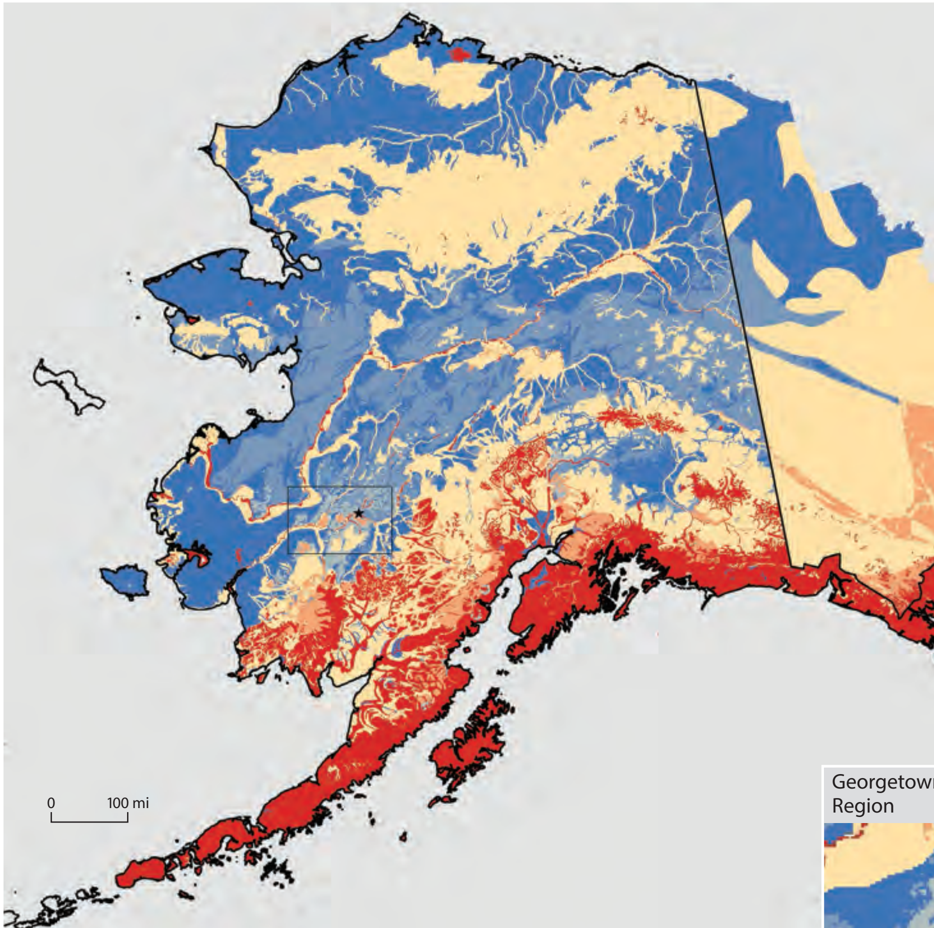


Figure 9 Historical permafrost and ground ice conditions for Alaska and for the Middle Kuskokwim region (inset). Data from the National Snow and Ice Data Center.



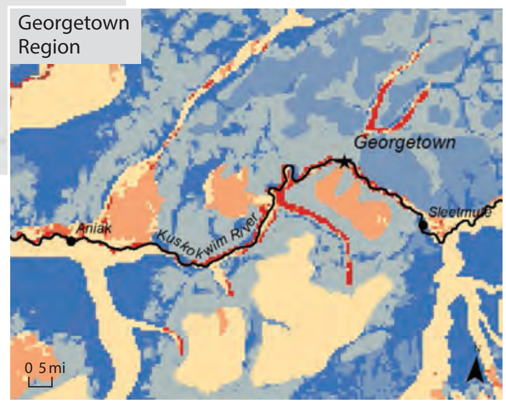


Figure 10 Thermokarst formation predisposition model output showing vulnerability to the formation of thermokarst. Areas in blue are highly vulnerable to thermokarst formation while areas in red are less vulnerable. Data from SNAP.

changing water chemistry.[9] Changes in chemistry are likely to have cascading and substantial effects on fish and wildlife.

Permafrost will continue to thaw and is expected to be largely lost from the region by the end of this century. Geological evidence demonstrates that past periods of warming resulted in depressions 65–130 feet deep, over large areas, causing substantial changes local topography.[10] Lakes and ponds could continue to disappear as the substrate becomes more porous. Continued warming is likely to severely disrupt land surface, water availability, forest cover, and infrastructure. Sudden and unexpected re-routing of major rivers due to changes in land surface is also a possibility. Permafrost is one of the primary ecological drivers in Alaska,[11] indicating a high likelihood of major change.

Scientists have mapped out areas most vulnerable to permafrost melt that causes disruption to the terrain, or thermokarst (Fig. 10).[12] The predisposition of an area to thermokarst is based on the amount of permafrost, the amount of ice (histels), and the local geography.

Dominant Vegetation – The Alaska-Canada Biome shift project developed "cliomes" to represent the combination of vegetation communities and climate variables across the landscape. The Cliomes project[11] used existing land cover data as well as historical and future projected climate data to identify areas more vulnerable to major ecological shifts or change. This project shows the Native Village of Georgetown and surrounding area as primarily "Dry boreal wooded grasslands," "More densely forested closed canopy boreal," and "Southern boreal mixed forest." On the ground, these classifications translate roughly into shrub tundra, deciduous forest, and white spruce forest. White spruce forest in interior Alaska has already begun to experience markedly lower growth from the warmer summers. Many lowland sites are expected to lose white spruce altogether.[13]

The Cliomes project indicates that natural communities in the Georgetown region will become stressed and in the process of change, as indicated by multiple shifts in the dominant cliome across the region over time (Fig. 11). The modeling exercise, which combined ecological system distribution with climate model projections, shows significant turnover in the dominant types of vegetation that would be suitable to the area (Fig. 11). By the end of the century, prairie and grasslands are expected to expand while boreal forest declines. Dry boreal wooded grasslands, which typically are underlain by permafrost, could give way to the hottest cliome—prairie and grasslands—which can be water limited. Future conditions could be more suitable for agriculture than current conditions.[11]

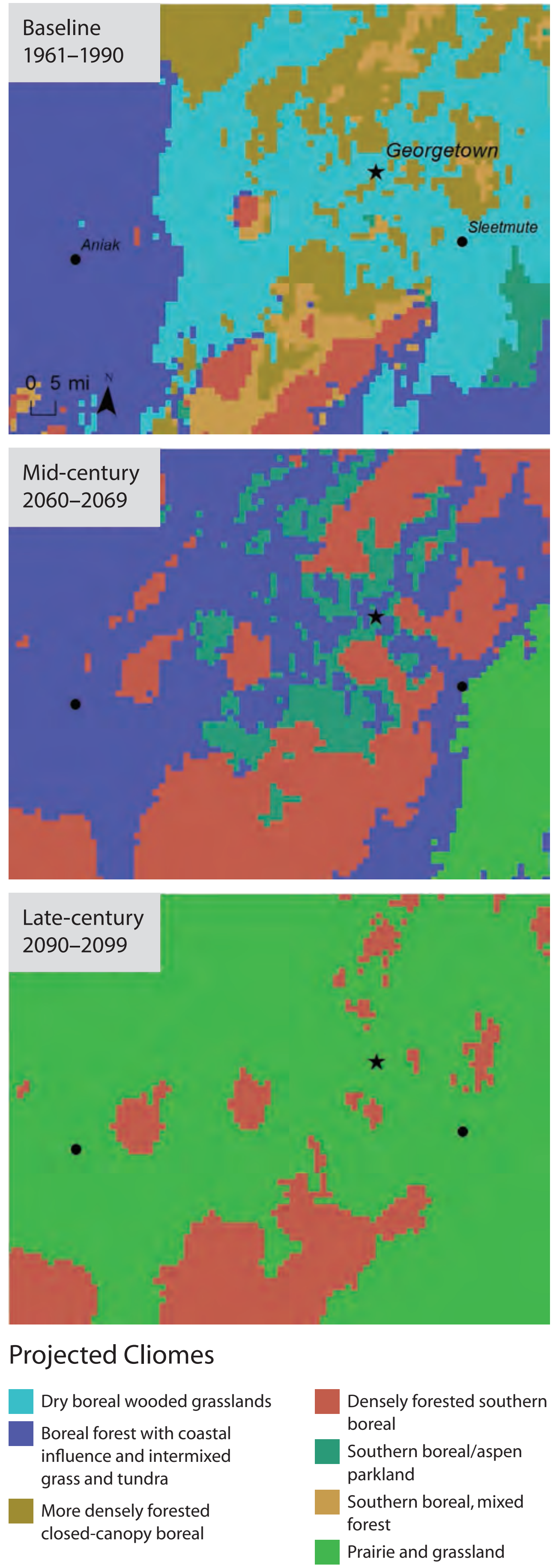


Figure 11 Distribution of unique "cliomes" across the Georgetown region, and shifts to new combinations of vegetation communities and climate variables over time. Projections are based on an assumption of continued higher greenhouse gas emissions.

Wildfire – Boreal forests have undergone pronounced changes in recent decades due to climate warming, including increased wildfire.[14] Recent years have been characterized by extreme fire, which has been linked to exceptionally warm and/or dry conditions.[15]

Studies of the influence of climate change on wildfire almost ubiquitously suggest increased frequency, size, and severity of burns in the coming decades. The strong connection between moisture deficit and wildfire indicates a likely increase in wildfire in the Middle Kuskokwim. Models indicate an approximate doubling in the frequency of wildfire for the Georgetown area (depending on the model, and based on a moderate level of greenhouse gas emissions).[16] Overall, the area burned is expected to double by mid-century and triple by late-century throughout the state.[4]

In another modeling study, an integrated model was developed to include vegetation projections as well as wildfire. This model indicates an increase in flammability by 25–37% in the Middle Kuskokwim through the end of the century (Fig. 12), assuming continued higher emissions levels.[17]

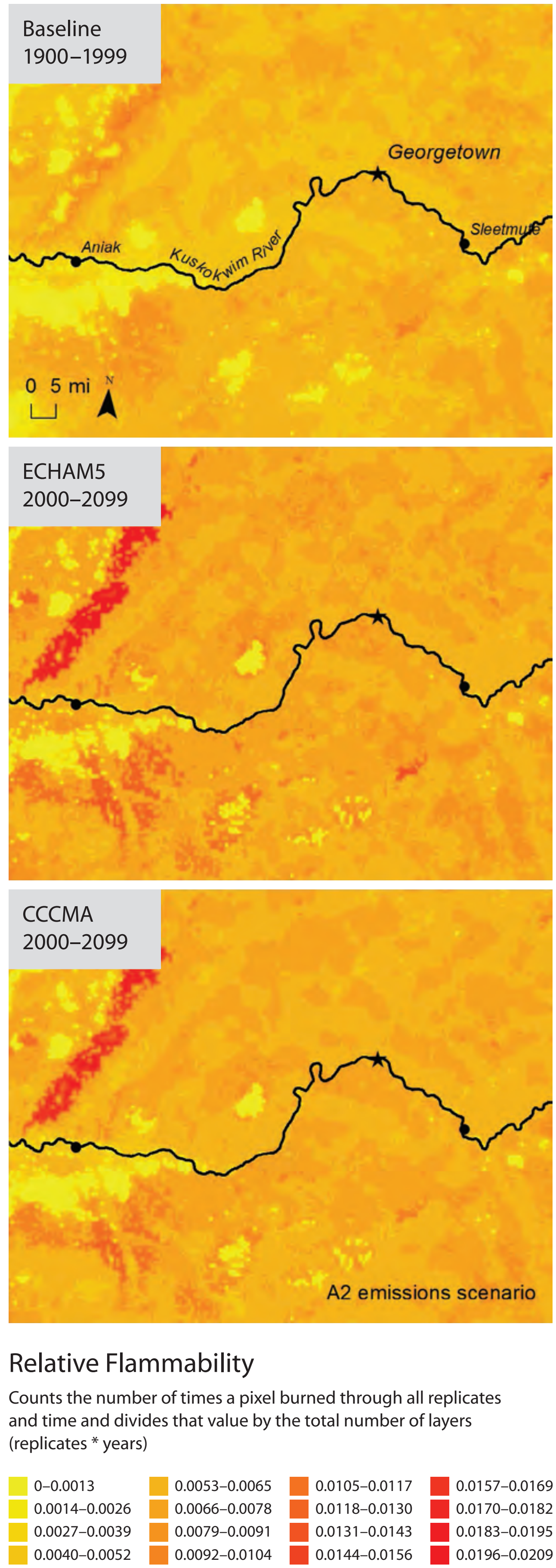


Figure 12 Relative flammability throughout the Georgetown region, showing changes from the baseline period (1900–1999) through the end of the century (averaged across 2000–2099), based on 2 different global climate models (ECHAM5 an CCCMA), and assuming continued higher greenhouse gas emissions.

Hydrology – Data on peak stream flow from the Crooked Creek gage (just downstream of Georgetown, see Fig. 1) show an overall decline of about 25% since 1952 (Fig. 13).[18] Future projections for stream flow in the region were not available for this project. Stream flow could continue to decline, even with increased precipitation in the area, due to increasing temperatures, evaporation rates, and water use by plants, as well as declining snow pack. Changes in the hydrograph, or timing of stream flow are expected, especially due to rain rather than snow during spring and fall.

Ice Breakup – Spring thaw is an important variable, which correlates with growing season length, spring and winter precipitation, temperature, and others. In addition, it is a socially important variable, and is affected by conditions throughout the entire watershed.[11] Ice break up dates for the Kuskokwim River were 6 days earlier, on average, between 1980 and 2017, based on data from the Crooked Creek, Sleetmute, and McGrath gaging stations. The longest available dataset was for McGrath, which shows no change from 1920–1980, and then a steep change in breakup date through 2017 (Fig. 14).

Invasive Species – Warmer winters, longer growing seasons, and greater human activity may contribute to current rapid expansion of invasive species across the state. Recently burned forest forms a major component of the vegetation of Interior Alaska, and this habitat is particularly vulnerable to invasion by early-successional non-native species. Sweetclover was introduced to Alaska in 1913 as potential forage and has expanded rapidly along roadsides and more recently along floodplains and into burns. Narrowleaf hawksbeard, Splitlip hempneedle, and Yellow toadflax are some of the invasive species currently established in the region.[19] Canada thistle, oxeye daisy, spotted knapweed, and meadow hawkweed all have established populations in Alaska as well, and could move into the Kuskokwim region. Elodia and reed canarygrass are of particular concern due to impacts to waterways and the potential to affect salmon spawning areas.

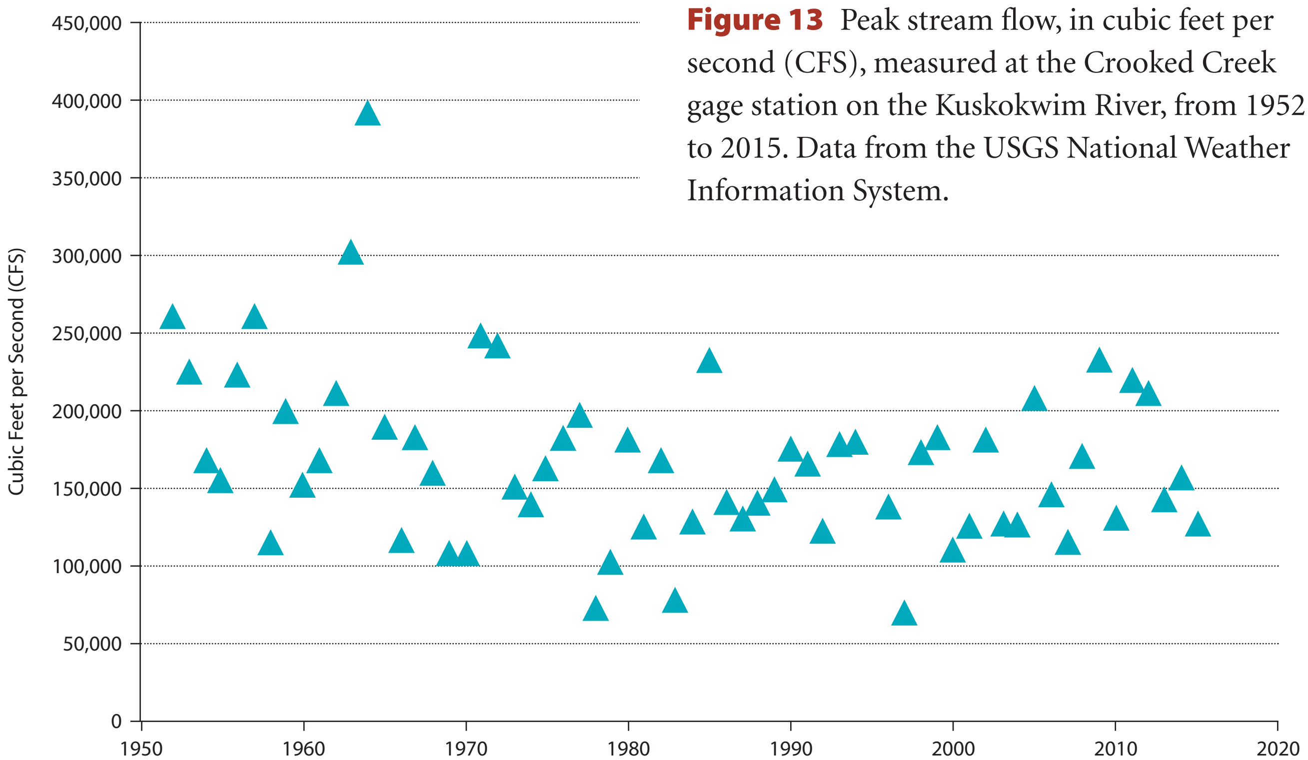


Figure 13 Peak stream flow, in cubic feet per second (CFS), measured at the Crooked Creek gage station on the Kuskokwim River, from 1952 to 2015. Data from the USGS National Weather Information System.

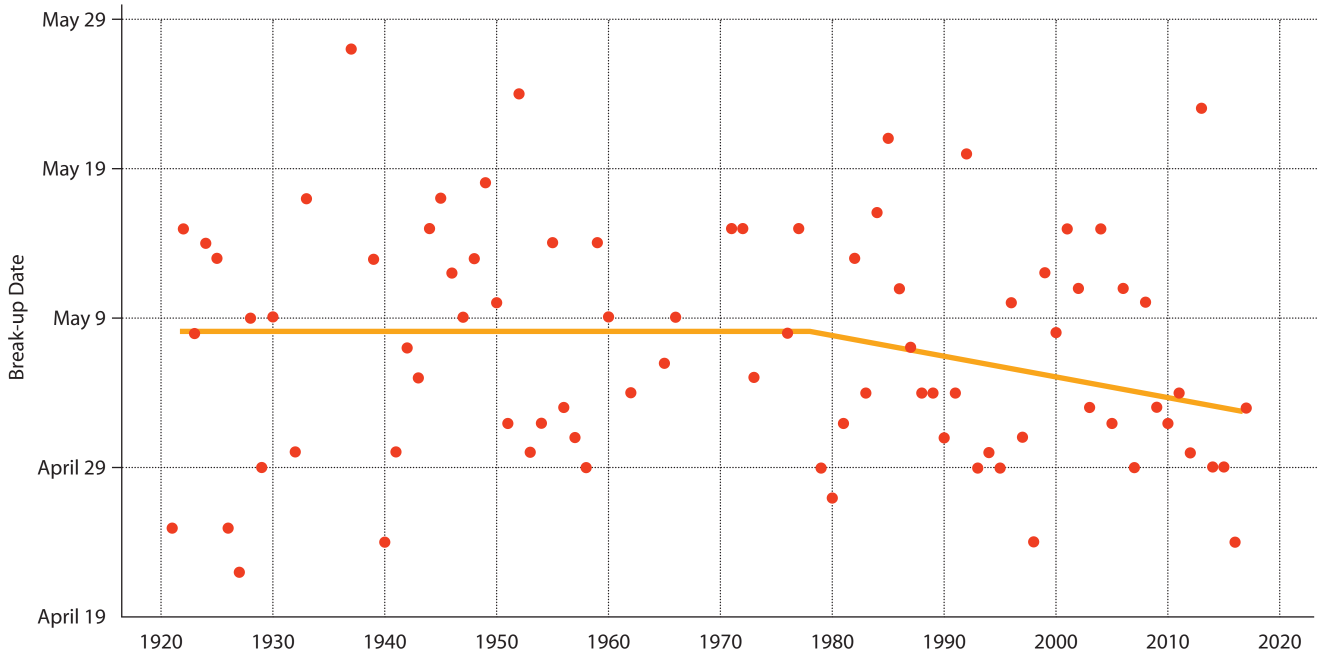


Figure 14 Changes in ice break-up dates on the Kuskokwim River, Alaska, at the McGrath gage station. Data from the National Weather Service/NOAA.

Subsistence Resources

Georgetown tribal members were surveyed in 2010 to determine which wild foods they harvest, receive, or give away.[20] Of surveyed households, 90% used at least one wild resource during the year. Total resources harvested (Fig. 15) included 4,793 pounds of salmon (mostly Chinook), 4,640 pounds of land mammals (mostly moose), 899 pounds of other fish, and 422 pounds of vegetation (mostly berries).

Salmon – The five species of salmon in the Kuskokwim River are Sockeye, King, Coho, Pink, and Chum. Salmon are affected by changes to freshwater systems as well as the ocean. Increasing CO_2 in the oceans has already caused ocean acidity to increase by 30%. This acidity prevents the development of shells in key plankton species that are important food for salmon.[4]

The Kuskokwim has the largest Chinook salmon subsistence fishery in the state, harvesting about 70,000 fish per year over the past decade (Fig. 16).[22]

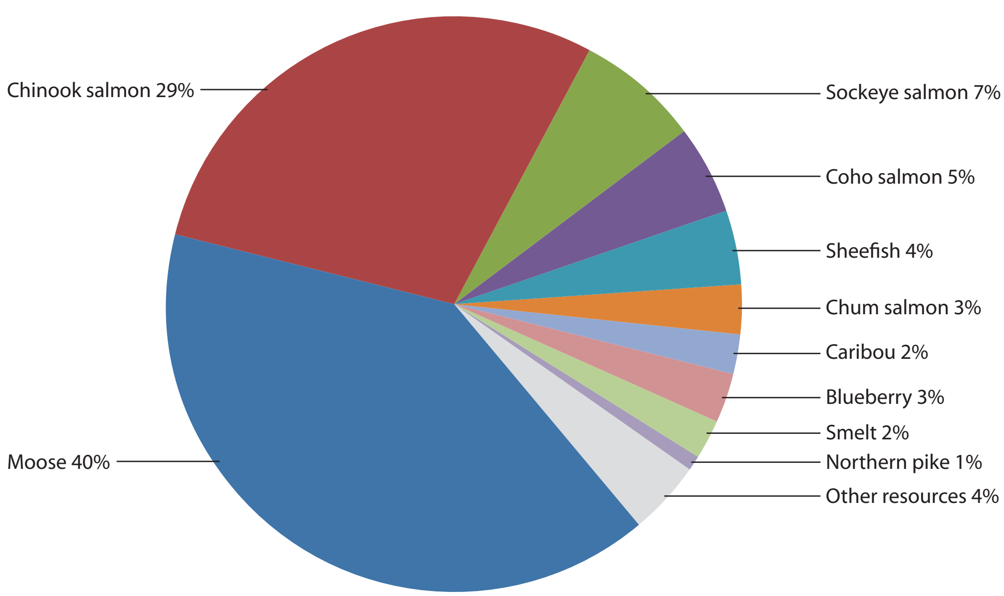


Figure 15 Top 10 species harvests ranked by estimated edible weight, Georgetown, 2010. Data and graph from Brown et al. 2013.

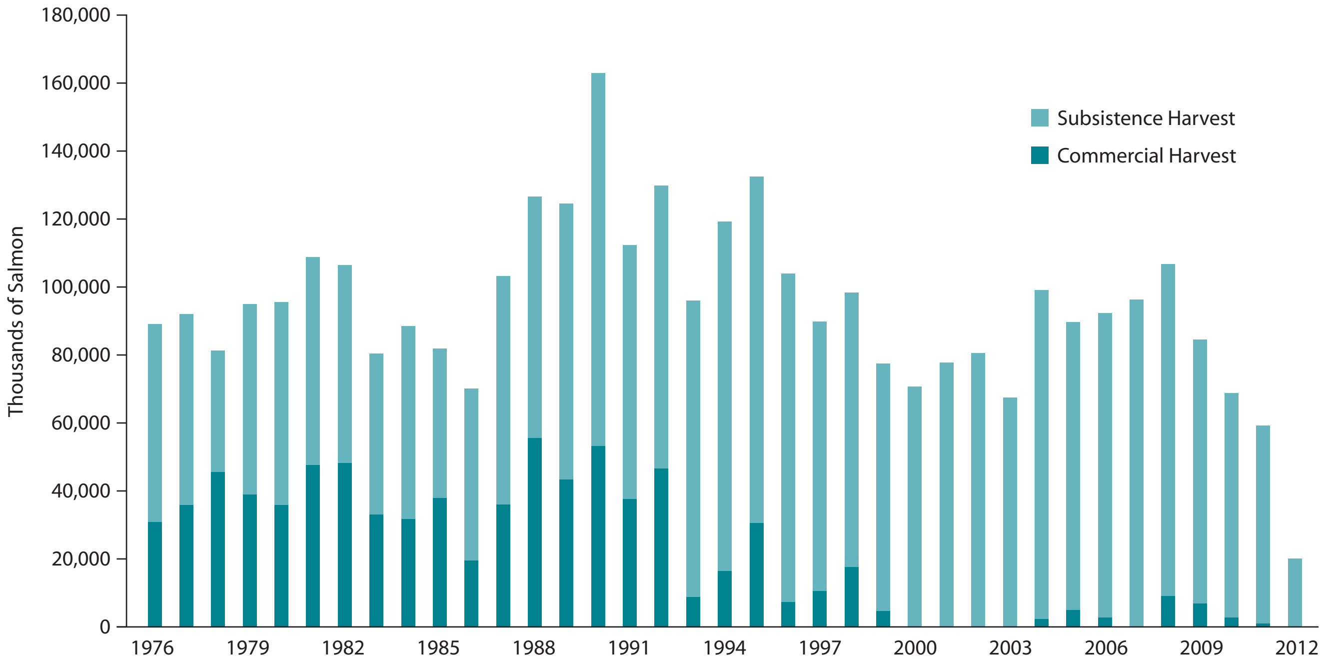


Figure 16 Estimated number of Chinook salmon harvested from the Kuskokwim River for subsistence and commercial harvest 1976–2012. Trends of harvest prior to 1984 are not considered indicative of overall stocks, while those after 1984 generally reflect abundance. From Schindler et al. 2013.

Patterns of salmon productivity and abundance generally have varied over time. While 2017 was a good harvest year for Chinook, overall declines of productivity, abundance, and inshore harvest appear widespread and persistent.[22] Continued warming, changes in stream flow, changes in water chemistry, and declines in water quality indicate that declines could continue.

Primary impacts associated with warmer temperatures include increased incidence of disease and parasites. Chinook salmon in the Yukon, Tanana, and Kuskokwim Rivers, for instance are experiencing deadly outbreaks of the microscopic parasite called Ichthyophonus hoferi, or white spot disease. Ich (pronounced "ick") was newly detected in Alaska in the 1980s and is now found in 30–40% of many runs. The disease causes many individuals to die before they reach the upper reaches of the river for spawning.[23]

Bull moose –

Moose – Moose have extended their range and increased in number in Alaska, in response to increased shrub growth and height, which allow moose to forage more successfully during the winter.[24] Increasing wildfire may improve habitat for moose in the short term, but long term

projections are unknown. More shrubs, less snow, and longer growing seasons could all benefit moose in the Georgetown region.[4] While moose in Alaska may currently be benefitting from climate change, they may soon experience deleterious impacts like those in Maine and Minnesota. Moose in those states have declined as much as 50% as parasites and disease have become more prevalent.

Berries – Many types of berries, including blueberries, salmon berries, blackberries, and cranberries are important subsistence resources for local residents of the Kuskokwim region. Years with low berry productivity can mean a significant loss of subsistence food for native Alaskans. Berries can also be important forage for species such as moose, caribou, snowshoe hare, ptarmigan, and grouse. Berry distribution, abundance, and productivity/variability are all expected to be impacted by climate change, but specific impacts are not well understood at this time. Ongoing research includes the coupling of standard modeling approaches with local observer data to determine how berries are impacted over time.[25]

Access – While changes to subsistence resources are documented, studies indicate that, at this time, the primary disruption to subsistence hunting and gathering is largely an issue of access.[26] As snow and ice conditions become more unstable and unpredictable, many areas have become dangerous to access. Additionally, seasons for hunting and gathering have become less predictable, often with a shorter window of availability.

Conclusions

Climate change is already widely apparent across the Middle Kuskokwim landscape. Change in forests, wildlife, ice and snow, lakes and ponds, and other natural features have been well documented as warming has progressed. This region is experiencing some of the fastest warming on Earth, and is expected to continue to warm at least over the next 2–3 decades and possibly longer if greenhouse gas emissions are not reduced by the international community.

Two of the biggest impacts of climate change to the Native Village of Georgetown and surrounding area are likely to be permafrost thaw and changing vegetation. Permafrost thaw has far-reaching implications, including changes to land stability, hydrology, and natural systems. Specific impacts of permafrost melt are difficult to predict at the local level. However, increased aridity and loss of water bodies are likely.

Vegetation change, as indicated by the models, is likely to be dramatic, as systems shift from boreal forest to deciduous forest, grasslands, and prairie. Vegetation change will also affect wildlife and wildfire.

The information provided in this primer is intended to inform a vulnerability assessment that combines the best available science, local expertise, and traditional knowledge. The vulnerability assessment will be used to determine the best strategies for protecting Georgetown residents from the negative impacts of climate change, maintaining resilience in the face of change, and taking advantage of new opportunities that may become available.

What does climate change mean for the Native Village of Georgetown and the Middle Kuskokwim region?

Climate is an important component of any locality. The local climate is a key factor in the relationship that people have with the natural world and with each other. Changes in climate in the Middle Kuskokwim region are projected to occur more quickly than changes in other parts of the world, and much more quickly than they have occurred in the past, on a scale of decades rather than thousands of years. This Climate Change Primer will inform a vulnerability assessment for the Native Village of Georgetown, which will help us better understand how these changes will affect the people and resources of the region. Some potential impacts of continued climate change in the region include:

- More opportunities for outdoor activities in warm weather[27]
- Increased opportunities for agriculture and gardening
- Less predictable harvest and potentially lower availability of wild foods, resulting in less healthy foods and higher food cost
- Changes in water availability and security with more potential for flood and drought[27]
- Increased erosion and disruption of land surfaces from flooding and melting permafrost
- Continued loss of lakes and ponds, with impacts to birds and other wildlife[4]
- Reduced seasonal window for safe travel by snow machine[26]
- Health impacts from increased heat, including heat stroke in adults and febrile seizures in infants[27]
- More insects and pests, affecting people, pets, and wildlife[28]
- Mental health impacts from stress caused by unusual environmental conditions and disruptions to cultural and subsistence practices[27]
- Displacement of native species by invasive and/or non-native species[4]
- Storm, flooding, and melting permafrost impacts to infrastructure, disrupting roads, buildings, electricity, water and sewage infrastructure[27,4]

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Appendix 1

Native Village of Georgetown

Climate Change Projections

Climate Variable	Season	Baseline 1961-90	LOWER EMISSIONS PATHWAY (RCP 4.5) 2050s* Low	Mean	High	2080s* Low	Mean	High	HIGHER EMISSIONS PATHWAY (RCP 8.5) 2050s* Low	Mean	High	2080s* Low	Mean	High
Mean Temperature (°F)	Annual	28	+6	**+7**	+8	+7	**+8**	+9	+7	**+9**	+10	+12	**+13**	+14
Mean Temperature (°F)	Summer	55	+3	**+4**	+6	+4	**+5**	+7	+5	**+6**	+7	+8	**+9**	+11
Mean Temperature (°F)	Winter	1	+6	**+10**	+13	+8	**+11**	+15	+9	**+12**	+15	+15	**+19**	+22
Mean Precipitation (% change)	Annual	19	-1%	**+13%**	+33%	+1%	**+18%**	+35%	+2%	**+19%**	+37%	+13%	**+32%**	+51%
Mean Precipitation (in.)	Summer	12	-4%	**+13%**	+42%	-2%	**+16%**	+34%	-2%	**+17%**	+35%	+7%	**+27%**	+47%
Precipitation as snow (% change)	Annual	7	-19%	**-2%**	+14%	-21%	**-5%**	+11%	-21%	**-5%**	+11%	-33%	**-19%**	-4%
Mean warmest month temp. (°F)	Monthly	57	+3	**+4**	+6	+4	**+5**	+7	+4	**+6**	+7	+8	**+9**	+11
Mean coldest month temp. (°F)	Monthly	-1	+6	**+10**	+13	+8	**+12**	+15	+9	**+12**	+16	+16	**+19**	+22
Extreme max. temp (°F)	30-year	85	86	**88**	89	86	**88**	89	87	**88**	90	89	**91**	92
Climatic moisture deficit (in.)	Annual	5	-17%	**+12%**	+42%	-17%	**+13%**	+44%	-17%	**+16%**	+46%	-16%	**+17%**	+49%
Number of frost free days	Annual	135	156	**162**	168	161	**167**	173	162	**169**	175	185	**193**	200
Length of frost free period (days)	Annual	108	128	**136**	143	136	**142**	149	138	**144**	150	158	**165**	171
Beginning of frost free period	Annual	May 27	May 14	**May 7**	Apr 30	May 10	**May 3**	Apr 26	May 9	**Apr 12**	Apr 26	Apr 26	**Apr 19**	Apr 12
End of the frost free period	Annual	Sept 12	Sept 22	**Sept 20**	Sept 18	Sept 24	**Sept 22**	Sept 20	Sept 21	**Sept 23**	Sept 25	Sept 28	**Oct 1**	Oct 3

*Future projections are based on an ensemble of 15 global climate models averaged over a 30-year period. Low, mean, and high refer to the 10th percentile, mean, and 90th percentile of all models. This provides a range of possible future conditions to consider.

Data Sources: Climate data generated with the ClimateNA v5.21 software package, available at *http://tinyurl.com/ClimateNA*, based on methodology described by Wang et al.[1] Baseline averages for the period 1961-1990 come from interpolated PRISM data that has been downscaled using the delta method of Mitchell and Jones.[2]

Projections are based on 15 AOGCMs of the CMIP5 multi-model dataset corresponding to the IPCC Assessment Report 5 (2013). The 15 AOGCMs are CanESM2, ACCESS1.0, IPSL-CM5A-MR, MIROC5, MPI-ESM-LR, CCSM4, HadGEM2-ES, CNRM-CM5, CSIRO Mk 3.6, GFDL-CM3, INM-CM4, MRI-CGCM3, MIROC-ESM, CESM1-CAM5, GISS-E2R.

More information can be found on the ClimateNA website – https://sites.ualberta.ca/~ahamann/data/climatena.html.

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