ALASKA'S CHANGING ENVIRONMENT

Documenting Alaska's physical and biological changes through observations

SUMMER 2019

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WELCOME

Alaska has recently experienced profound environmental change related to extreme weather events and deviations from the historical climate. Sustained warmth, sea ice loss, coastal flooding, river flooding, and major ecosystem changes have impacted the daily lives of Alaskans around the state.

Temperatures have been consistently warmer than at any time in the past century. This warming varies greatly across the state, with northern and western regions warming at twice the rate of southeastern Alaska. The growing season has increased substantially in most areas, and the snow cover season has shortened. Precipitation overall has increased, and like temperature, the changes vary regionally. The ocean around Alaska is now regularly warmer than at any time in the past 150 years, affecting everything from algae to fisheries and human health.

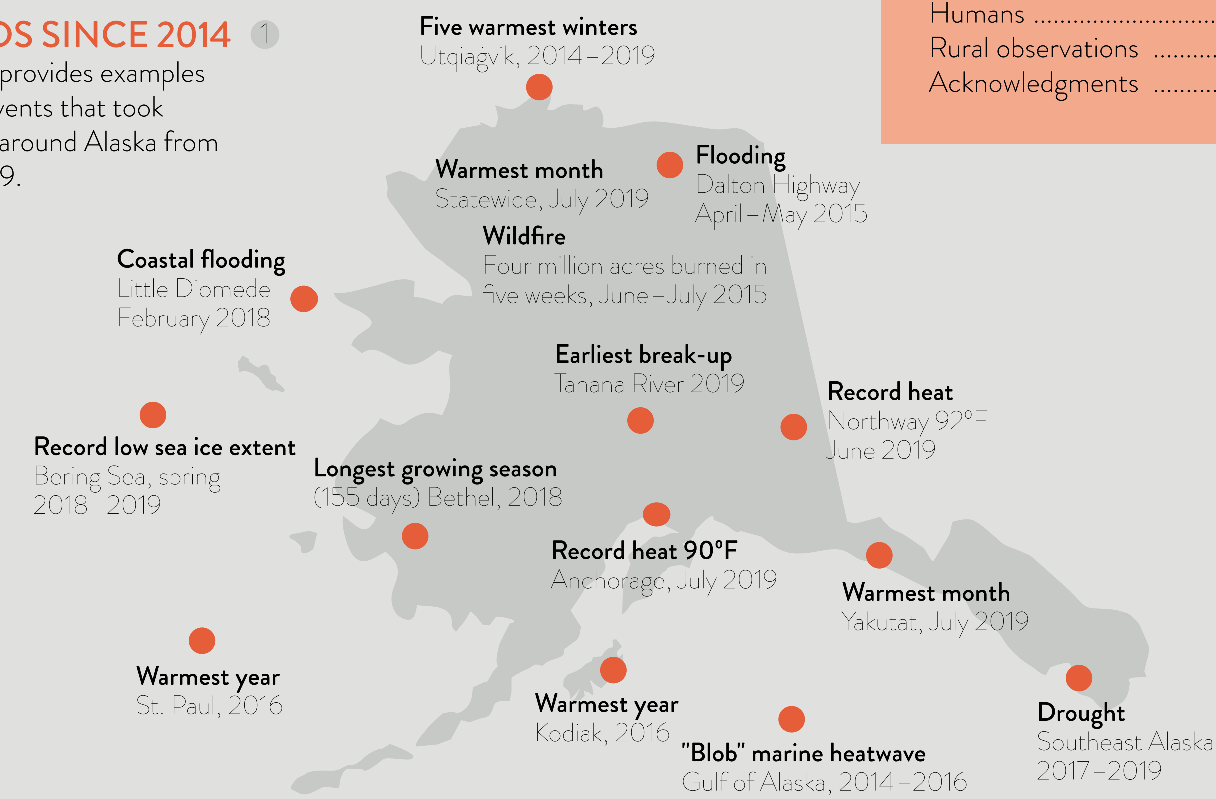
Coastal flooding during the autumn storm season has occurred on the Bering Sea coast throughout history, but recent winters have brought record low ice, which in the past has served as a buffer to big Bering Sea storms. This has resulted in out-of-season flooding occurring in places expecting stable sea ice.

Across the following pages we have compiled observations through August 2019 about the major changes currently affecting Alaska's physical and biological systems. We focus on the past five years, though we also provide information from earlier decades for historical context. This effort is by no means comprehensive, but serves to highlight the monumental shifts occurring in our state. We welcome additional contributions to future iterations of this product.

The International Arctic Research Center and the University of Alaska Fairbanks are providing individuals, Alaska businesses, communities, government, and others with the resources needed to better assess impacts and develop adaption strategies.

RECORDS SINCE 2014 (1)

This graphic provides examples of notable events that took place in and around Alaska from 2014 to 2019.



AUTHORS

Rick Thoman, John Walsh

DATA CONTRIBUTORS

Number in grey circle on each graphic links to source on p. 16

REVIEW

Hajo Eicken, Larry Hartig, Molly McCammon, Nate Bauer, Nikoosh Carlo, Scott Rupp, Tina Buxbaum, Uma Bhatt

LAYOUT & EDITING

Heather McFarland

CONTACT US

uaf-iarc@alaska.edu

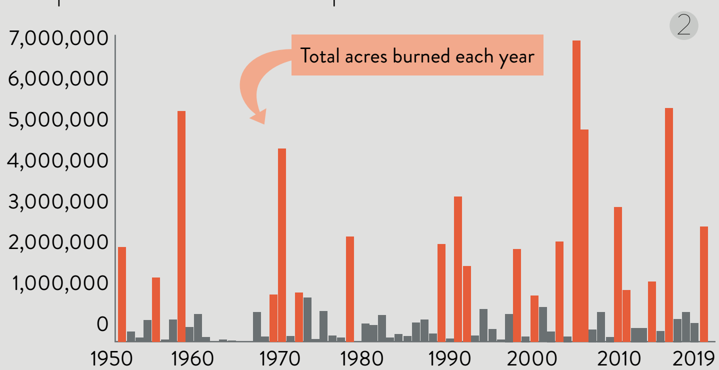
CONTENT

SEASONS

Many factors in Alaska's environment are specific to certain times of year: ice break-up of Alaska's big rivers is a sure sign of spring; wildfires are a summer issue, and the season is lengthening; costly coastal flooding along the Bering and Chukchi Seas has historically been an autumn concern. While powerful storms impacting maritime operations near the Aleutians and Gulf of Alaska can occur any time of year, the strongest storms nearly always happen in the fall and winter months. Many of these seasonal events have experienced profound changes in recent years.

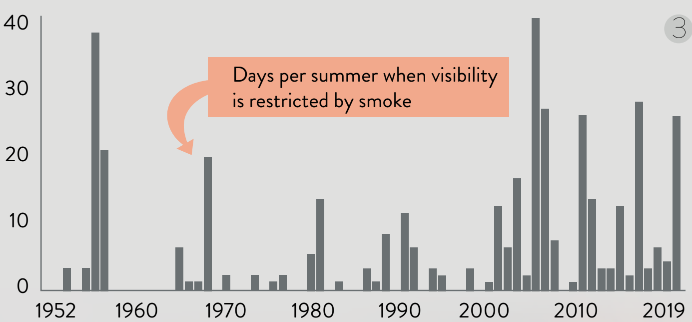
BIG FIRE SEASONS MORE FREQUENT

Warmer springs and earlier snow melt had lengthened the wildfire season to the point in 2006 when Alaska's interagency fire management organization changed the "start date" for wildfire response from May 1 to April 1. While the year-to-year variability of acreage burned has changed little, the frequency of large wildfire seasons has increased dramatically. Wildfire seasons with more than one million acres (red bars in graph) burned have increased by 50% since 1990, compared to the 1950–1989 period.



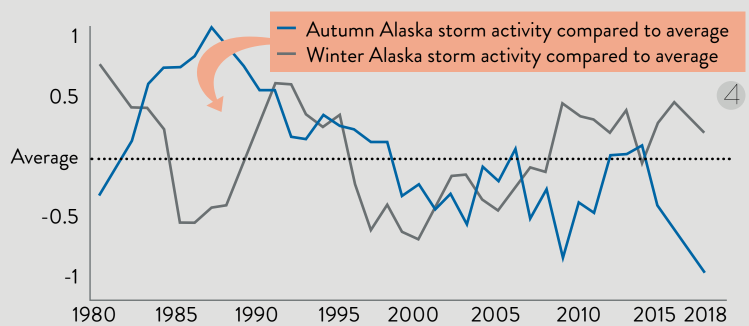
DRAMATICALLY MORE SMOKY DAYS

As the frequency of big (1+ million acres) wildfire seasons has increased, so has the frequency of smoky days, posing a significant health hazard. Prior to 2004, Fairbanks had only one summer (1957) in the previous half century when there were more than three weeks of significant smoke. Since 2004, it has occurred five times, including twice since 2014.



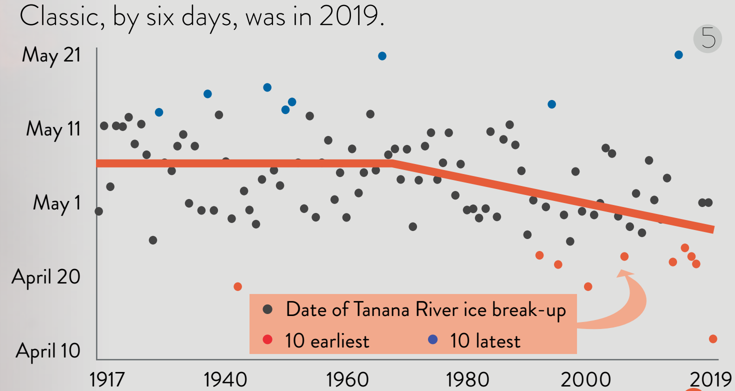
STORMINESS NOT INCREASING

Storminess, related to the frequency, duration, and intensity of wind, is one of the most important aspects of day-to-day weather for Alaskans. In and around Alaska there has been a slight overall decline in autumn (September–November) storminess over the past 40 years. Winter (December–February) storminess has shown no clear trend since 1990. There has also been no detectable trend in the number of moderate and strong storms during the past 70 years over the Bering and Chukchi Seas, where sea ice has retreated. However, even without an increase in storms, coastal flooding and erosion in these waters are increasing as the sea ice-free open water season lengthens.



RIVER BREAK-UP HAPPENING EARLIER

Alaskans have closely watched spring river ice break-up for millennia, and for generations have monitored the timing of the break-up of the Tanana River at Nenana. Break-up has trended earlier, especially in recent years. Four of the past six years have seen break-up earlier than all but one year prior to 1990. The earliest break-up in the history of the Nenana Ice Classic, by six days, was in 2019.



TEMPERATURE

Recent years have brought many temperature extremes to Alaska, including the warmest year (2016), the warmest month (July 2019), and in places like Anchorage, the warmest day (July 4, 2019). Air temperatures in Alaska are rising twice as fast as in other parts of the United States and, apart from sea ice, are the most obvious sign of change. Factors contributing to this warming include decreases in sea ice and snow cover, warming ocean, and increasing greenhouse gases. Of course, there is considerable day-to-day and even year-to-year variability, depending on average storm tracks, but these trends are unmistakable.

WARMER TEMPERATURES

Annual average temperatures are widely used as a measure for long term changes, and modern techniques allow reasonable estimates of temperatures over large areas back to the 1800s. Temperatures in and around Alaska have been rising since the 1970s, with typical annual average statewide temperatures now 3 to 4°F warmer than during the early and mid-20th century. Recent years have all been exceptionally warm. In fact, four of the past five years (2014–16, 2018) were warmer than any year prior to 2014.

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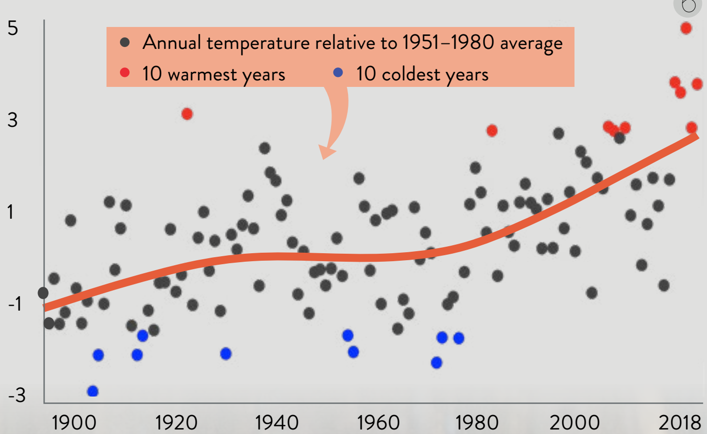

FEWER VERY COLD DAYS

One of the most dramatic changes in interior and northern Alaska has been the decrease in the number of very cold days in winter. This graphic shows that the typical number of days in Northway, Alaska with low temperatures of -30°F or lower has fallen from more than 40 days prior to 1960 to less than 30 days in the past decade. This trend is representative of most interior Alaska locations, including Fairbanks.

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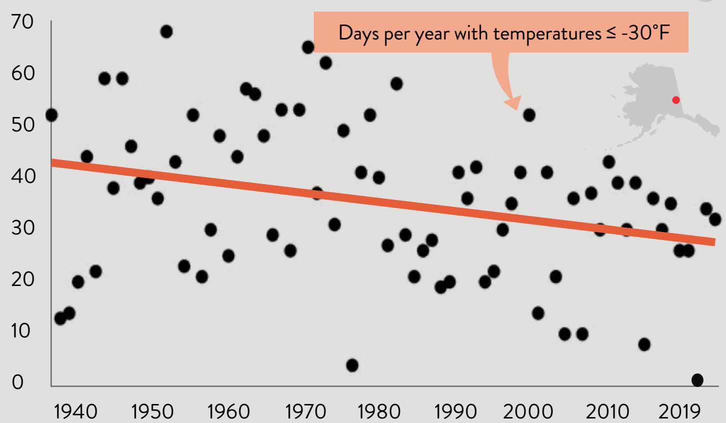

RECORD HIGHS OUTNUMBER LOWS

Daily high and low temperature records are a widely reported measure of extreme weather. Given a stable climate (i.e., no warming or cooling trend) we would expect fewer than 10 percent of both high and low daily temperature records, for the period 1953–2018, to have been set during the past five years. However, since 2014, there have been five to 30 times more record highs set than record lows.

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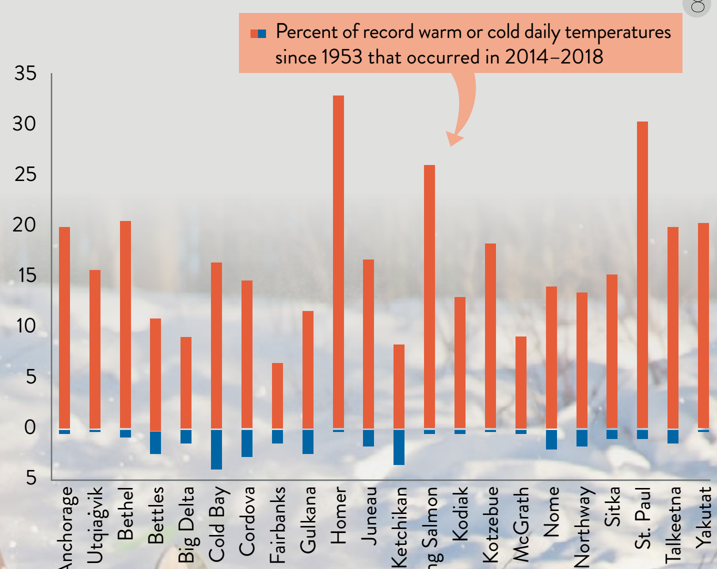
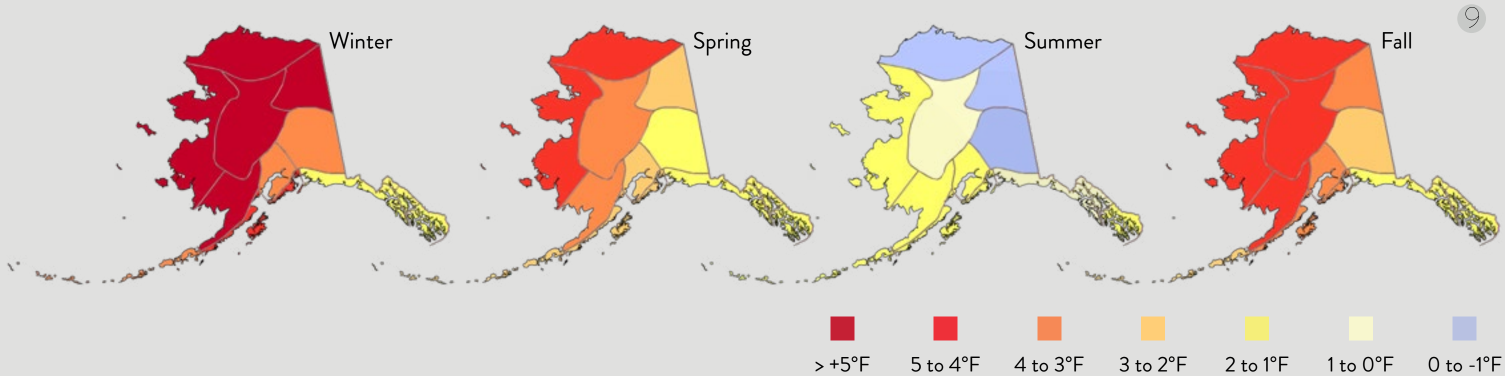


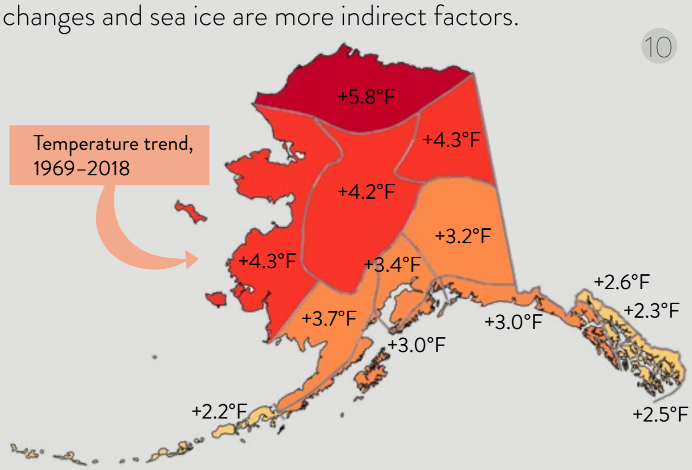
FALL & WINTER WARMER THAN AVERAGE

2014–2018 average temperatures in most regions and seasons have been dramatically warmer than the average for 1981–2010. The exception is summer, when the past five years have been close to normal over much of the state.



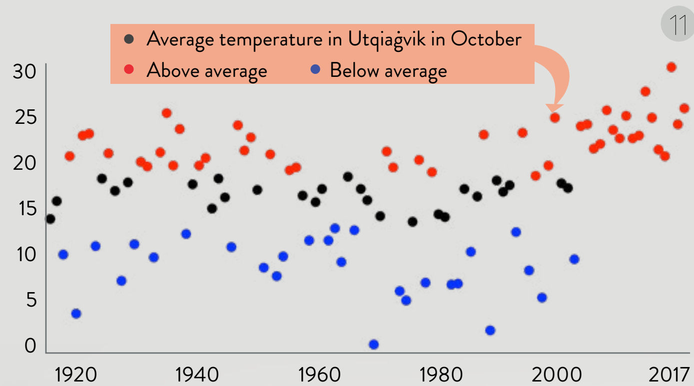
GREATEST WARMING IN WEST & NORTH

Temperatures are rising all across the state, but not uniformly. The changes are largest over northern and western Alaska, where snow and especially sea ice losses are impacting the regional climate. Temperatures have risen least dramatically in southeast Alaska and the Aleutians, where seasonal snowpack changes and sea ice are more indirect factors.



UTQIAĠVIK HIGH TEMPERATURES

The abrupt change in air temperatures due to the loss of sea ice is nowhere more obvious than in Utqiaġvik (formerly Barrow) during the month of October. Direct heating from the sun is weak during October, so the autumn air temperatures are controlled by the amount of open water offshore of Utqiaġvik. Prior to 2002, many Octobers had extensive ice through the entire month or at least by late October, allowing for much lower temperatures. In recent years, open water remained late into fall, and air temperatures were consistently warmer relative to the past.

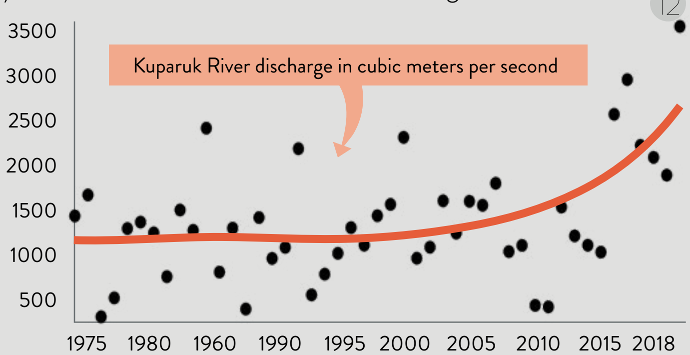


PRECIPITATION

Alaska's precipitation is increasing throughout the state. Even so, precipitation varies greatly over short distances and is very strongly influenced by the way air flows across Alaska's mountain ranges.

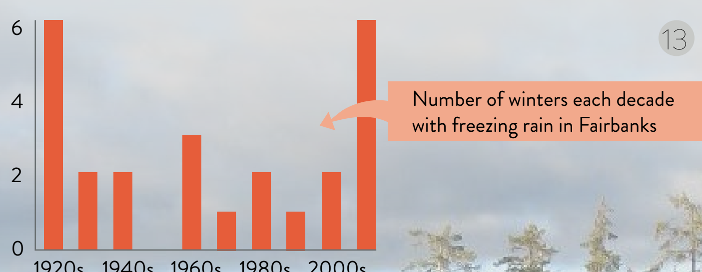
MORE RUNOFF ON NORTH SLOPE

The amount of water flowing in non-glacier fed rivers is a useful indicator of annual precipitation. The non-glacial Kuparuk River on the North Slope has been monitored since the days of Trans-Alaska oil pipeline construction. Since 2013, the Kuparuk River has experienced unprecedented high annual flow, indicating high (relative to the prior 40 years) snow and summer rains in this region.



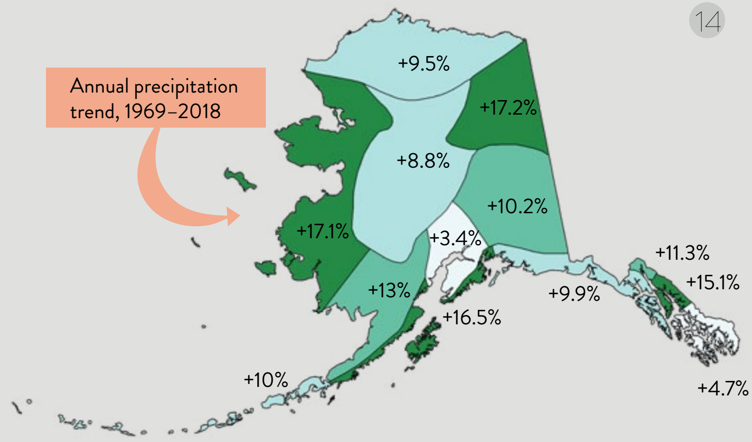
FREEZING RAIN

Freezing rain can pose significant threats to safety and wildlife. During the last decade, the number of winters with freezing rain in Fairbanks more than doubled what was typical for the 1930–2000 period. School day cancellations associated with freezing rain have also increased in recent years. In winters with heavy ice accumulation on vegetation, caribou die-offs have occurred because animals are unable to access their food.



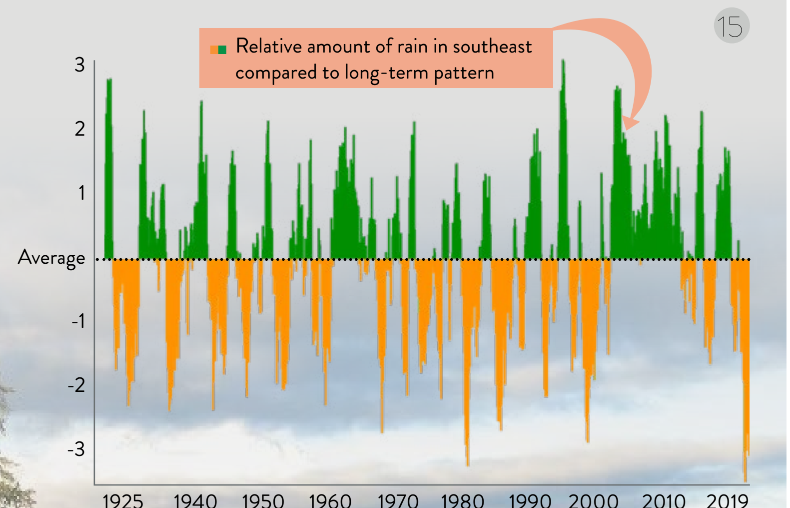
ANNUAL PRECIPITATION INCREASING

Over the past half century, annual precipitation has increased in all regions of the state. The best available estimates over the century time-scale suggest Alaska as a whole was relatively wet early in the 20th century, then drier from the 1940s–1990s, and wetter again recently.



A RAINFOREST DROUGHT

While precipitation over long time-scales is increasing, year-to-year variability remains important. Southeast Alaska is one of the wettest areas in the world. Below is the Standardized Precipitation Index for the region. The values reached in 2017–2019 were the lowest rainfall on record. This drought contrasts with the prolonged wet period of the early 2000s. Partly for this reason, the impacts of the recent drought have been tremendous, despite longer dry periods in the past. Some reservoir levels are now too low to reliably run hydropower, prompting short-term water conservation efforts.

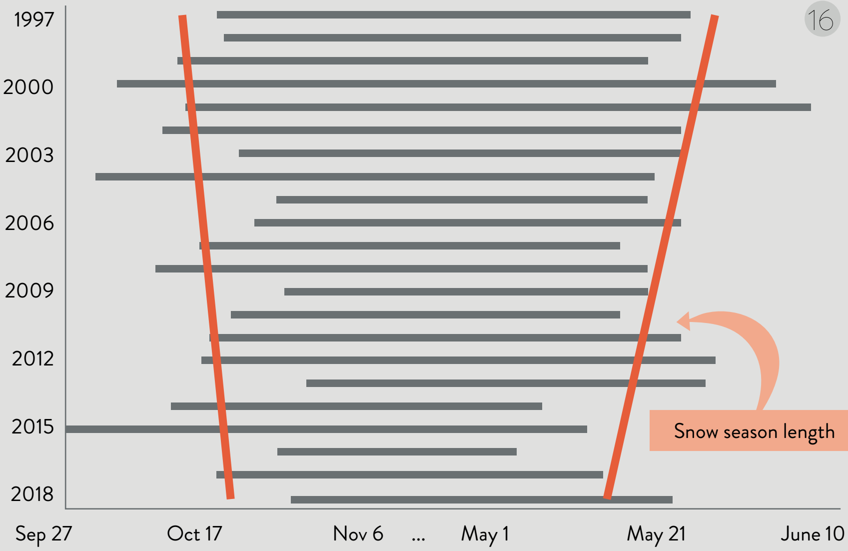


SNOW

Alaska now becomes 50% snow covered about a week later in October than in the 1990s. The snow-off date (when statewide snow coverage drops below 50%) is now nearly two weeks earlier than in the 1990s. The five earliest snow-off dates have all occurred since 2014. This shorter snow season impacts a wide variety of activities, ranging from overland travel by snow machine or dog sled to recreational skiing. Road maintenance is also affected by the delayed snow onset and earlier melt. However, a shorter snow season does not necessarily translate to less snowfall, as heavy snow events can occur in a compressed snow season. Despite the shorter snow season for the state as a whole, winter snowfall in some areas like Anchorage has not decreased significantly.

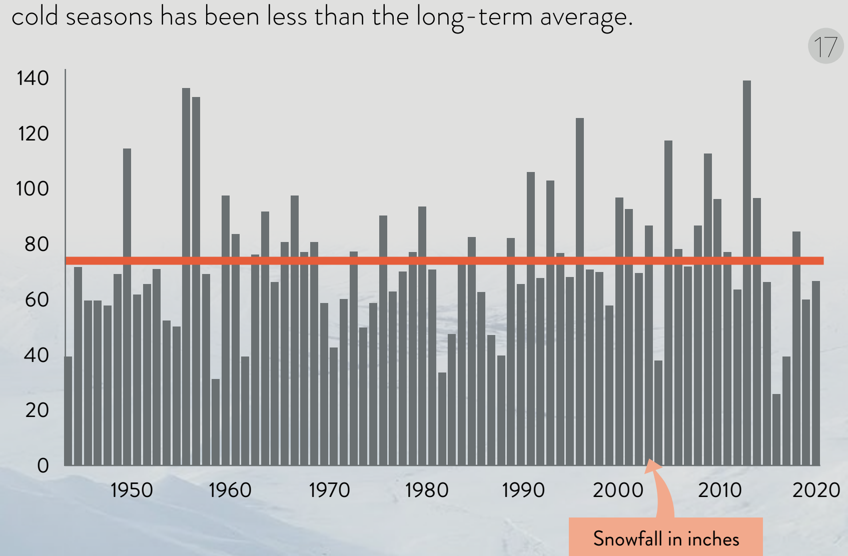
SHRINKING SNOW SEASON STATEWIDE

The snowpack now develops about a week later in autumn and melts nearly two weeks earlier in the spring compared to the late 1990s.



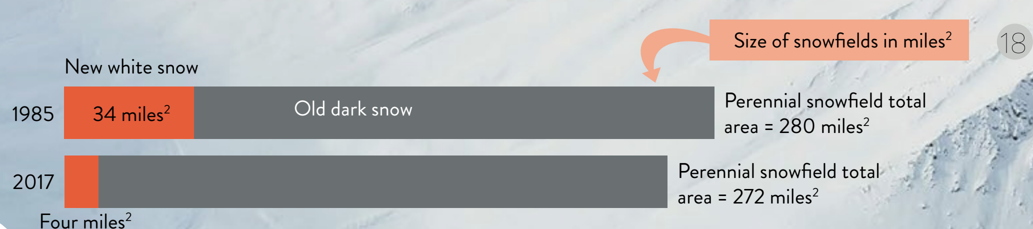
NO CHANGE IN ANCHORAGE

Anchorage's total seasonal snowfall shows no significant trend from the early 1940s to the present, even though snowfall for five of the past six cold seasons has been less than the long-term average.



SHRINKING SNOW FIELDS IN THE BROOKS RANGE

A different metric for changing snow is the area of year-round snow cover, also known as perennial snowfields. These thin snowfields are highly susceptible to changes in weather and climate. In Gates of the Arctic National Park and Preserve (colored red on the map) in the central Brooks Range, smaller areas of winter snowpack are now surviving the summer melt season (July 1–August 15) compared to 1985. The biggest change is related to the color of the snowfields, which are becoming darker. Since new snow is typically brighter than old snow, this suggests that fresh snow from the previous winter is not surviving the summer season, so the underlying dark dirty snow is left exposed. Because dark snow absorbs more sunlight, this change in color could make the snowfields even more likely to melt in summer. Of the 34 square miles of white snowfields seen in 1985, only four square miles remained by 2017.



SEA ICE

Sea ice plays a profound role in the climate, environment, and economies of Alaska. The presence of sea ice significantly modulates regional temperatures and moisture, determines the structure of the marine food web, and shapes the kinds of activities that people can or cannot do: from subsistence and travel to resource extraction to national security. Nothing in the Alaska environment is changing faster than sea ice.

SEA ICE FORMS LATER IN FALL

The extent, duration, and thickness of sea ice has changed significantly in the seas around Alaska. The changes have been most widespread in the late summer and autumn. The average sea ice concentration in September of 1988 (left) and 2018 (right), both of which are fairly typical for their eras, shows much lower ice concentrations (or no ice) in the Chukchi and Beaufort Seas in 2018 compared to 30 years prior.

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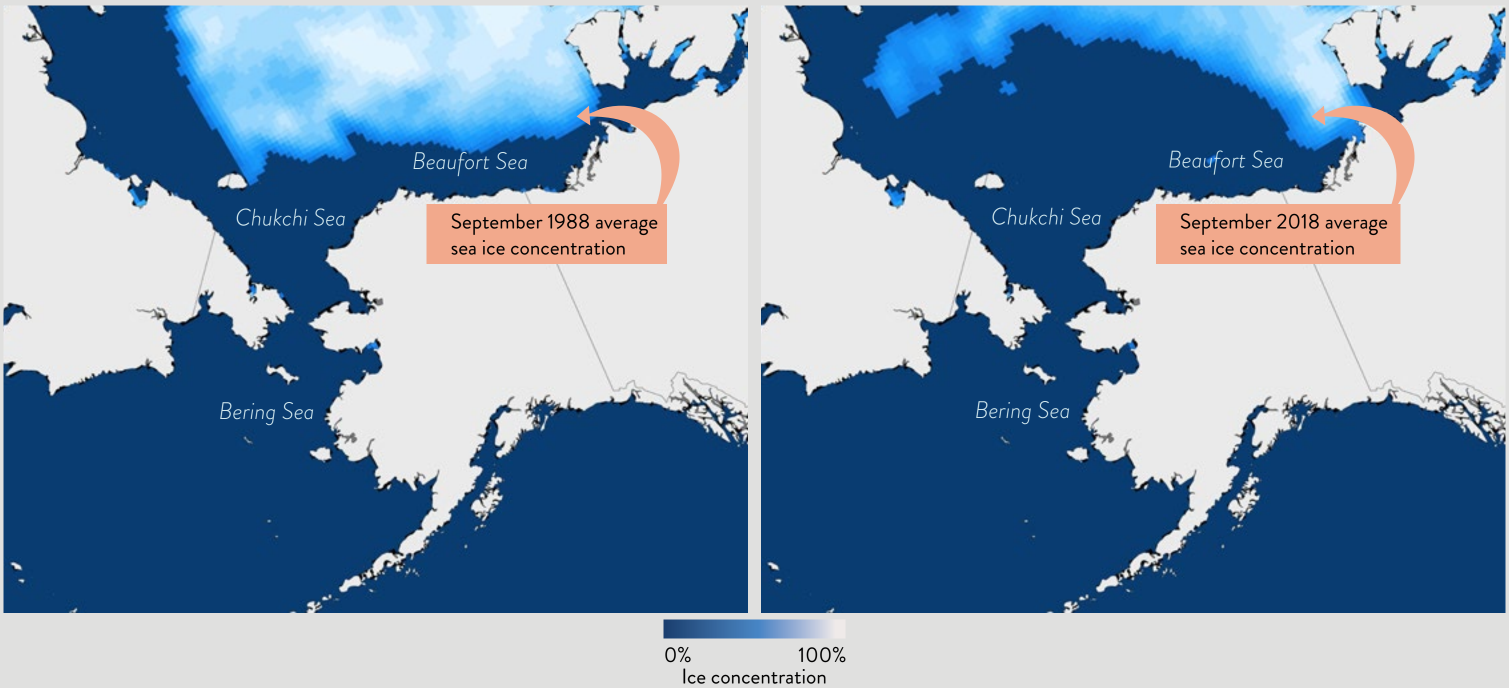

MORE LARGE OPEN WATER AREAS

Recent years have seen a dramatic increase in the duration of open water in the Chukchi and Beaufort Seas to the north and northwest of Alaska. In both seas there is now typically open water for three to four months.

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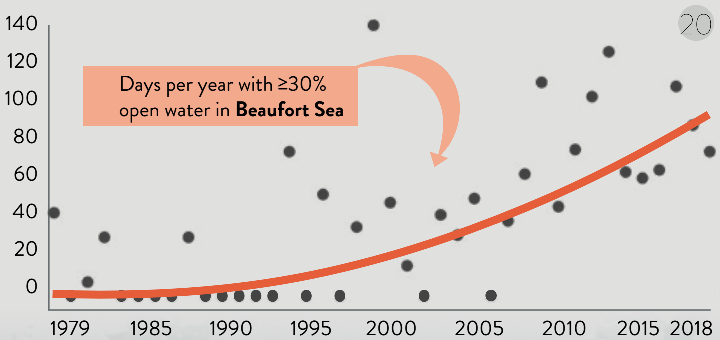

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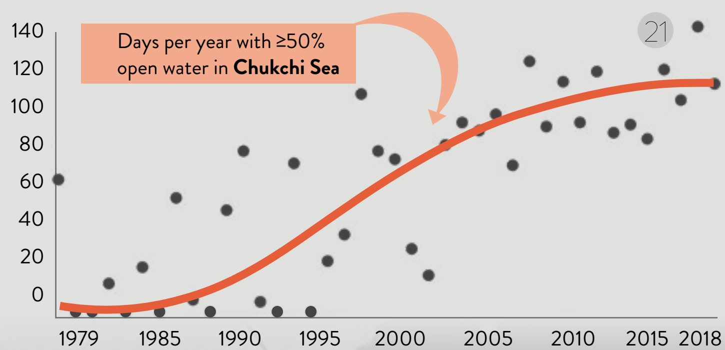

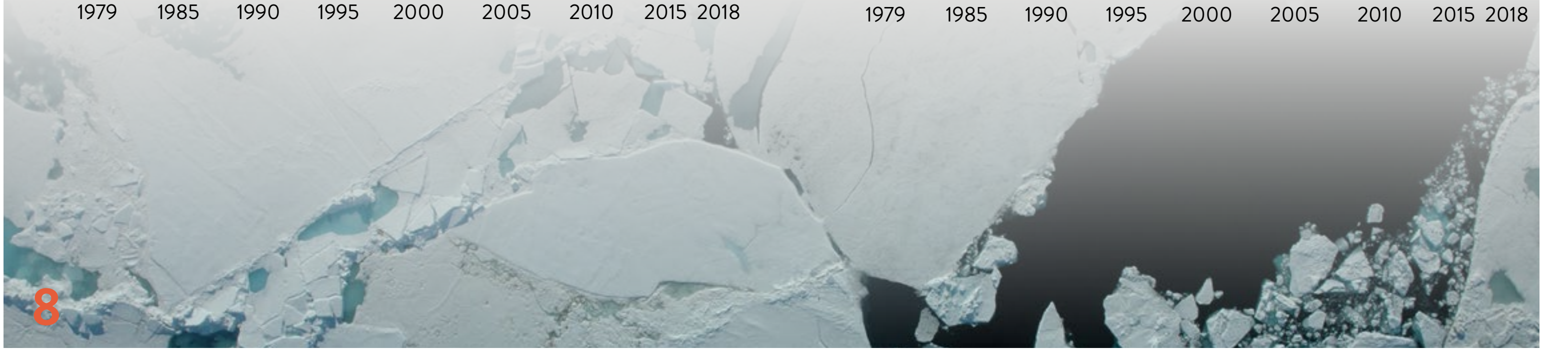

CHUKCHI SEA ICE EXTENT DECLINE

Sea ice extent in the Chukchi Sea has declined dramatically outside of winter in recent years, especially during the late summer. Typical ice extent in summer is only 10% of what it was in the early 1980s, and the September Chukchi Sea ice edge is now regularly hundreds of miles northwest of the Alaska coast.

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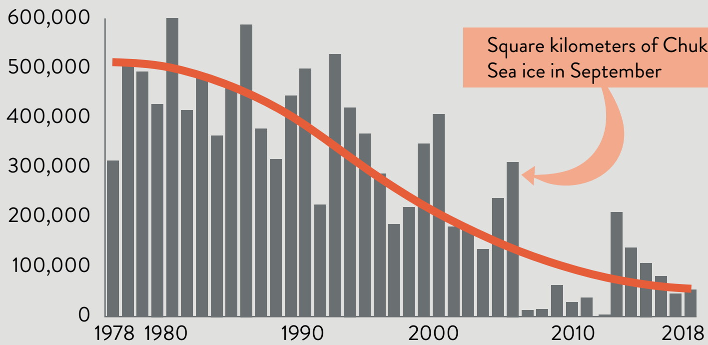

BERING SEA ICE EXTENT DECLINE

For decades, communities in the Bering Sea region have reported that sea ice quality has been changing, with little or no old ice and thinner ice than in the past. Data show that the extents of spring and autumn ice have been declining, but until recently there has been no long term trend in the winter and early-season ice extent. However, in 2018 and 2019, late winter ice coverage in the Alaska waters of the Bering Sea was far lower than any winter in the past 170 years.

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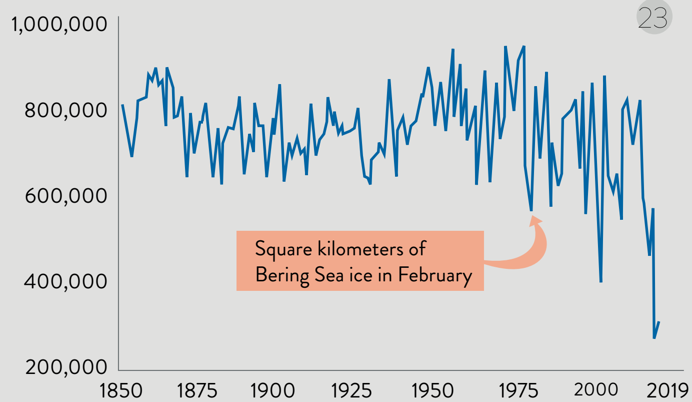

LATE BEAUFORT & CHUKCHI FREEZE-UP

Both the Beaufort and Chukchi Seas become entirely ice covered during the winter (though there are always cracks and leads). However, ice-over is now happening significantly later in the fall than in past decades, with recent years generally two to three weeks later than was typical in the 1980s.

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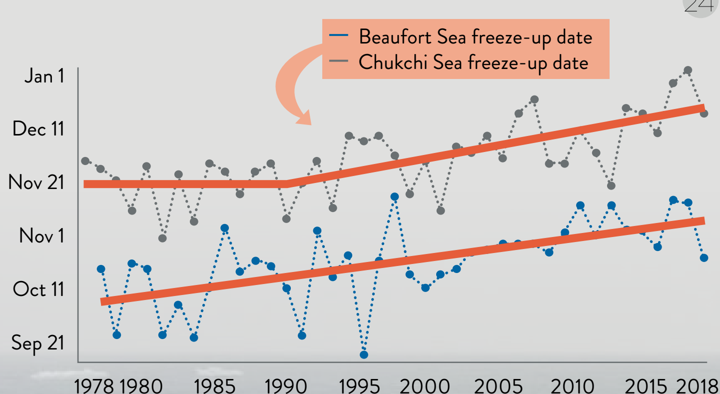
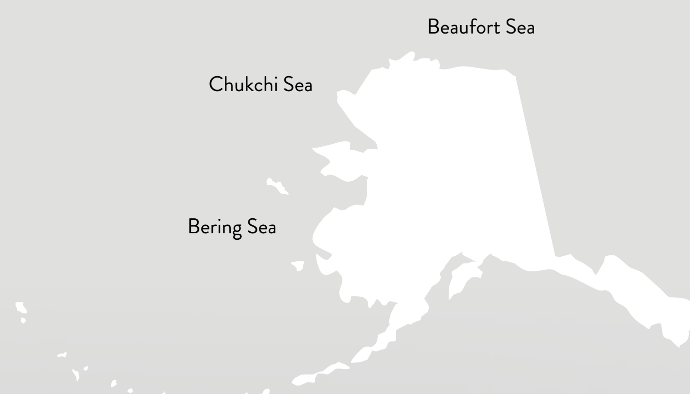


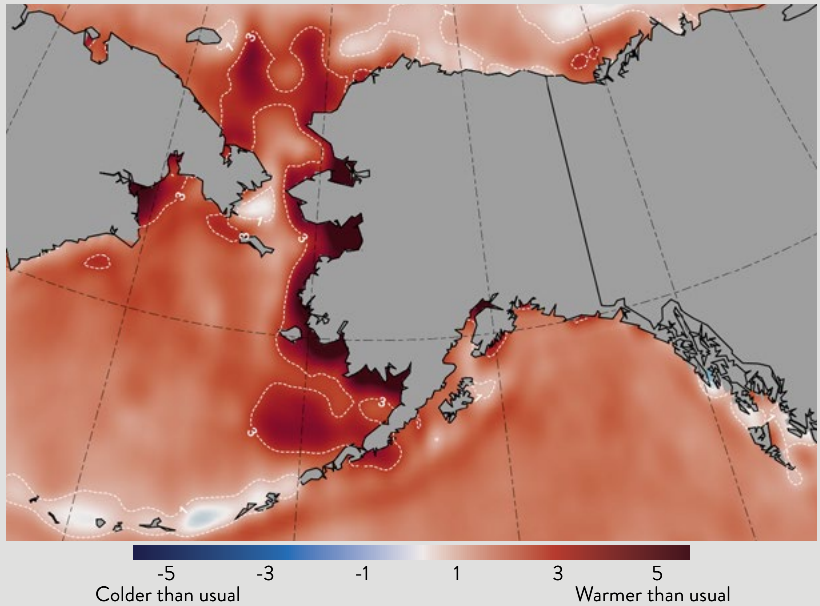


OCEAN

The seas surrounding Alaska have been unusually warm in recent years, with unprecedented warmth in some cases. This warmth can be seen throughout the Alaska region, including the Gulf of Alaska as well as the Bering, Chukchi, and Beaufort Seas. The years 2015–2016 coincided with the occurrence of the "blob" of exceptionally warm water in the North Pacific Ocean. This warmth has persisted and even become more extreme in the 2017–2019 period in association with the unprecedented loss of sea ice. The past two winters (2017–18 and 2018–19) have seen "marine heat waves" in the Bering Sea. The heat content of the entire water column was greater in 2018 than ever recorded. The "cold pool" of water usually near the bottom of the Bering Sea disappeared during this time. This disappearance has major implications for the region, as the cold pool served as a barrier to northward migration of various aquatic species.

WARM SURFACE WATERS

Summer sea surface temperatures in Alaska waters have been much warmer (colored red below) than average (colored white) during 2014–2018, especially along the west coast, where the surface waters were 4–11°F warmer than average in the summer of 2019. [25]

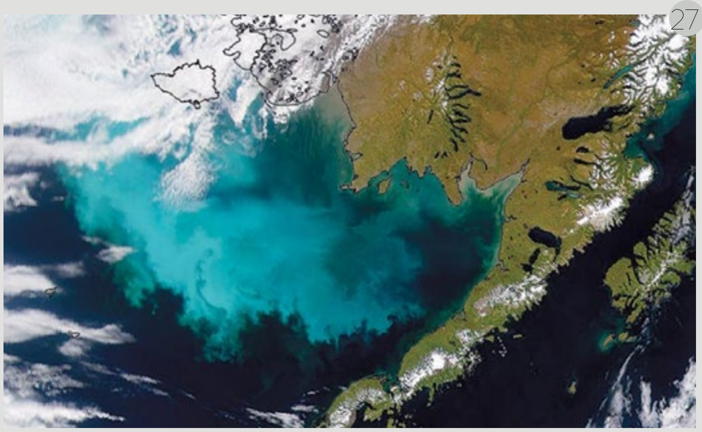


OCEAN ACIDIFICATION [26]

As atmospheric carbon dioxide concentrations increase, the ocean absorbs the additional CO_2, leading to a decrease in pH. Ocean acidification poses major risks to marine ecosystems, and the risks are especially high in polar regions, because CO_2 dissolves more readily in cold water. Trends toward acidification have been detected north of Alaska in the Chukchi Sea and in the waters of the Canadian Arctic and the Greenland Sea, although the pre-2010 study periods pre-date the 2014–2019 focus of this report. Because ocean acidification threatens commercial fishing and subsistence activities in Alaska, the associated risks were recently mapped. The economic and social risks are highest in southwestern and southeastern Alaska. Systematic measurements of the chemistry of seawater west and south of Alaska are now underway, so that ocean acidification can be monitored in near-real time.

WIDESPREAD ALGAL BLOOMS

The abnormally warm waters have had other consequences, including earlier and more widespread spring and summer algal blooms in Alaska waters (turquoise colored Bering Sea bloom shown in photo). Algal blooms sometimes produce harmful toxins. In recent years there have been increasing reports of harmful algal blooms linked to instances of human shellfish poisoning in the Gulf of Alaska. Algal toxins have been documented in both stranded and harvested marine mammals, as well as healthy and die-off seabirds across the state, but their effects on Alaska wildlife are not yet known.



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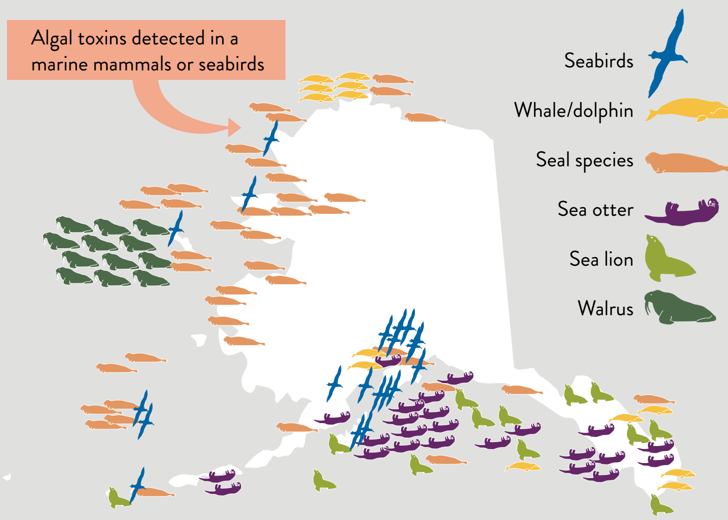
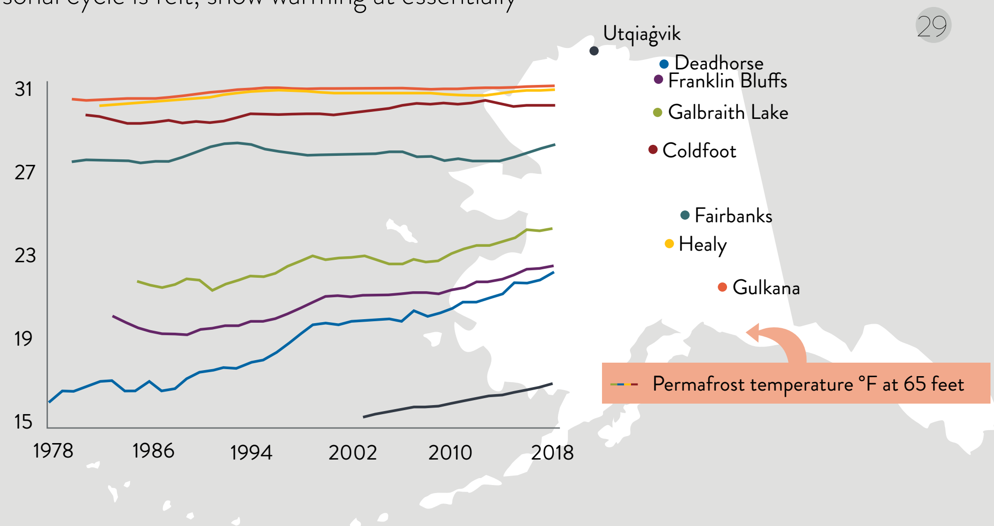


[28]

WARMING PERMAFROST

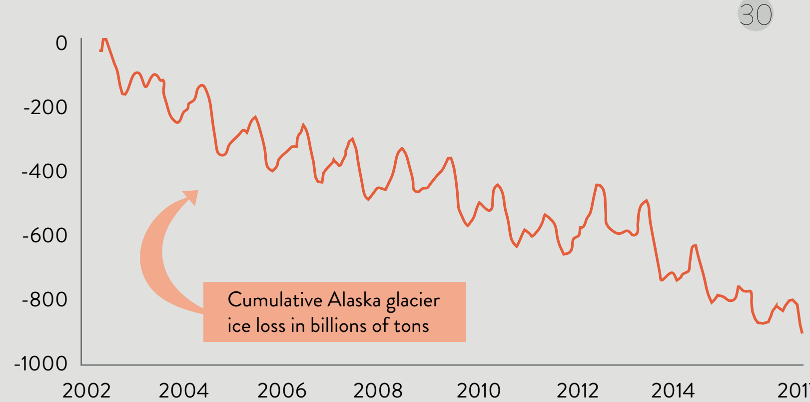
Permafrost is warming in Alaska. Measurements of permafrost temperatures at depths of 30–65 feet, well below levels where the seasonal cycle is felt, show warming at essentially all monitoring sites in northern and interior Alaska. The warming is especially strong on the North Slope, where sites along the Dalton Highway have warmed by 2–5°F from the 1980s to 2018. Warming at Deadhorse, for example, would bring the temperature at 65-feet depth to the melting point of ice by 2100 if it were to continue at the current rate. In the interior the warming rates are smaller because permafrost temperatures are already reaching the melting point of ice and, as permafrost thaws, some heat is used in melting ice.



Another measure of permafrost change is the depth of seasonal thaw, also known as active layer depth. Measurements at Council on the Seward Peninsula show that the thaw depth reached 33 inches in 2018, in contrast to much smaller values of 20–24 inches in the early part of the decade. The large thaw depths in recent years are consistent with high air temperatures of the 2016–2018 period.

LOSS OF GLACIAL ICE

Each year the mass of glaciers increases due to snow in winter and then decreases during the summer melt season. Largely because of increasing air temperatures, summer melt has exceeded winter gain in recent years, resulting in the retreat and mass loss of Alaska glaciers. More than 90% of Alaska's glaciers are retreating. Between 2002 and 2017, Alaska glaciers thinned on average by several feet per year. Overall mass loss during this period was nearly 60 billion tons of ice per year. Alaska's glaciers contain enough ice to raise sea level by about 1.5 inches if all their ice were to melt.



GULKANA GLACIER RETREAT

The Gulkana Glacier in the eastern Alaska Range has been photographed and measured annually for over 50 years. The comparison photos below clearly show that the glacier has retreated, and mass data indicate that it thinned almost 100 feet between 1966 and 2018.


Gulkana Glacier 1967

Gulkana Glacier 2016

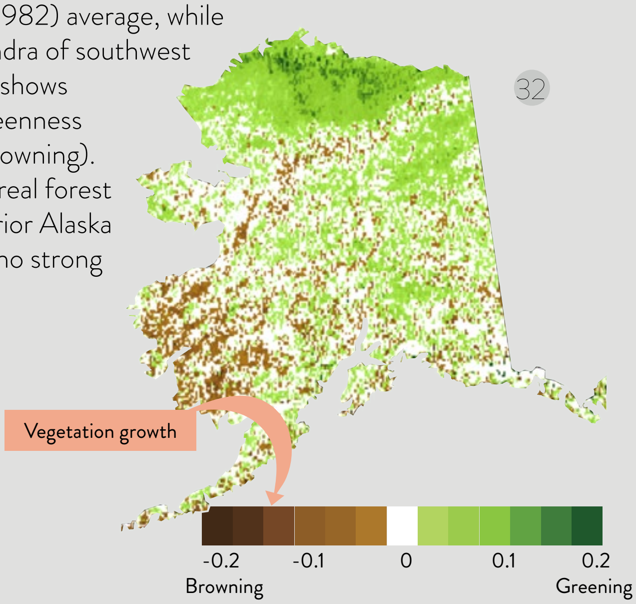
PLANTS

Satellite measurements have been used to monitor the growth of vegetation over the past several decades. Satellites provide a measure of photosynthetic activity, which correlates with plant growth. An increase in this metric is referred to as “greening,” while a decrease is referred to as “browning” of the vegetation. Compared to other regions of the state, the tundra of the North Slope shows the most greening, or more plant growth, in the past five years relative to the longer-term average.

Growing Degree Days are widely used in agriculture to assess accumulated warmth over the course of the warm season. Higher values indicate more overall warmth. Many crops require a minimum amount of warmth to reach maturity. For example, peas require about 800 growing degree days before they are ready to be harvested, but canola requires 2000. Over the past five years, all regions of the state have had more total warmth than the long term normal, with the largest changes in southwest Alaska.

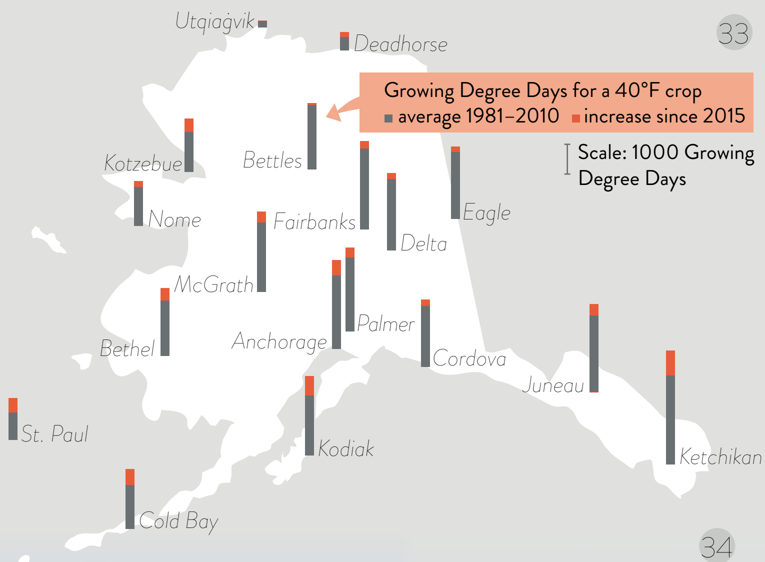
NORTH SLOPE TUNDRA GREENING

The tundra of Alaska’s North Slope shows increased greenness in 2014–2018 relative to the longer-term (post-1982) average, while the tundra of southwest Alaska shows less greenness (i.e., browning). The boreal forest of interior Alaska shows no strong trend.



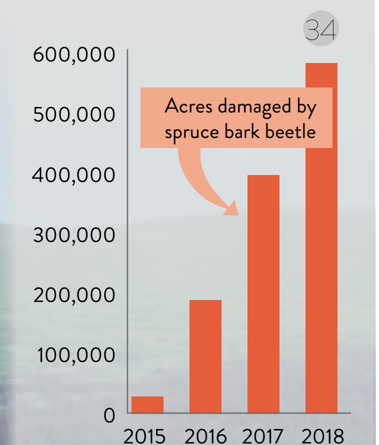
GROWING SEASON WARMTH

Growing Degree Days relate the average daily temperature of a location compared to a threshold below which a specific crop would not grow, like peas below 40°F. This value for a single day accumulates across an entire growing season and can be used to estimate which crops will reach maturity. Since 2014, the number of Growing Degree Days have increased across Alaska.



SPRUCE BARK BEETLE DEVASTATION

A major outbreak of spruce bark beetles has been spreading through southcentral Alaska during the past several years. The area affected by the outbreak increased from 33,000 acres in 2015 to 593,000 acres in 2018. Spruce bark beetle outbreaks have occurred previously in Alaska, most recently on the Kenai Peninsula in the late 1990s. While small populations of the beetles are always present in spruce forests, sudden increases in their populations are favored by a dry summer, which reduces trees’ capacity to produce sap, a defense against the beetle. Longer and warmer summers also increase beetles’ reproductive capacity, while milder winters increase over-winter survival rates. Damage from the spruce bark beetle is apparent in the large areas of gray and brown in this NASA aerial photo of the Susitna Valley during the summer of 2018.



ANIMALS & FISH

DELAYED BELUGA MIGRATION

Beluga whales migrate from the Bering Sea to the Chukchi and Beaufort Seas during the summer, followed by a return to the Bering in autumn. Data from beluga whales tagged with satellite-linked transmitters show that, comparing 1998–2002 to 2007–2012, beluga whales from the Chukchi Sea population delayed fall migration by about 33 days, resulting in a prolonged presence in the Beaufort Sea correlated with significantly later sea ice freeze-up.

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SHRINKING WALRUS HABITAT

In the past four years, a dramatic shift in Bering Strait ice conditions has impacted ice habitat for walruses. Walruses use sea ice for molting, mating, and nursing, and as a platform for dives to the bottom of shallow shelf seas for clams and other food. As sea ice recedes beyond the shallow shelf seas of northern Alaska, female walruses and calves must either remain on sea ice in water too deep for feeding or come onshore where stampedes are a risk.

For the past decade walruses have gathered on the shores of a barrier island near Point Lay. These haul-outs are associated with declining sea ice. During summer 2019, several thousand walruses hauled out on the island, marking the earliest walrus haul-out since they were first observed in 2007.

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HEAT & SALMON DIE-OFFS

In June and July of 2019, thousands of salmon died as they migrated to their spawning grounds of western Alaska. Although the cause is not confirmed, the leading suspect is unusually warm water temperatures above the range that causes stress to adult salmon. Warm water causes several problems: it contains less life-sustaining dissolved oxygen than cool water, greatly accelerates metabolism, resulting in faster burning of stored energy in the migrating fish, and promotes the growth of parasites and fungus that can weaken fish. Surveys of the Koyukuk River (a major tributary of the Yukon River) confirmed thousands of dead summer Chum salmon, which most likely succumbed to the heat, as the river did contain sufficient levels of dissolved oxygen.

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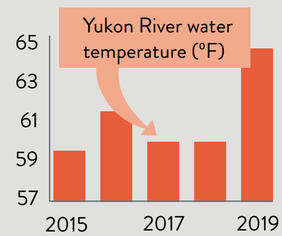
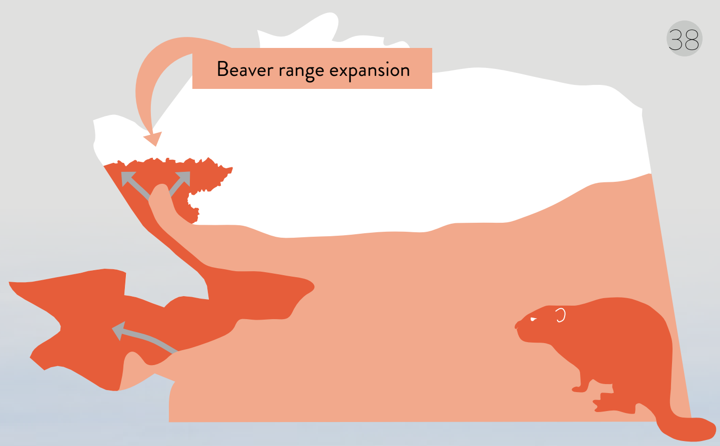


BEAVER COLONIZATION IN ARCTIC

North American beavers are migrating into Arctic tundra areas and altering the landscape of northwestern Alaska. Beavers have historically occupied forested regions (light orange). There is new evidence, however, that beavers have moved from forest into tundra regions since 1999 (dark orange), re-engineering rivers and streams of northwest Alaska. Possible reasons for the expansion of beavers include a population rebound from over-trapping and environmental changes such as warming temperatures, creating beaver habitat and changing the Arctic tundra.

38



HUMANS

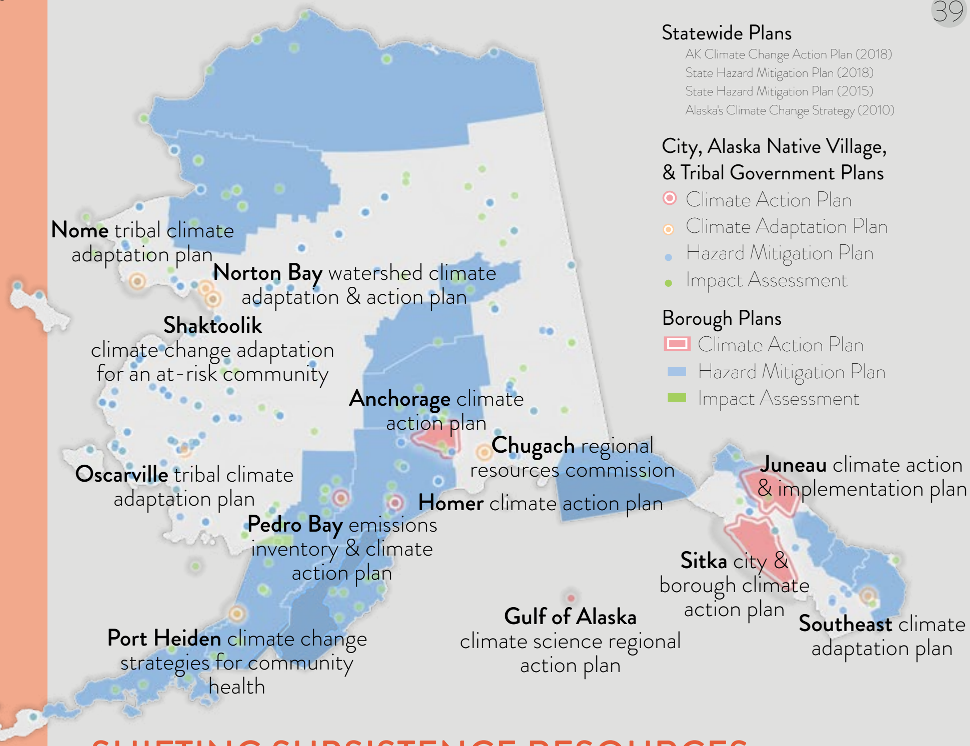
Responding to a changing environment is a complex undertaking, occurring at many levels across Alaska. From rural communities to the Municipality of Anchorage to State agencies, Alaskans are grappling with environmental change. In 2003, 184 out of 213 Alaska Native villages were affected by flooding or erosion. Since that time, tribal governments, cities, municipalities, boroughs, and the State of Alaska have developed plans to respond to climate change. In 2008, the Alaska Climate Change Impact Mitigation Program and the Coastal Impact Assistance Program were established to provide technical assistance and funding to communities preparing impact assessments that characterize, diagnose, and project risks or impacts of environmental change on people and communities. Across the state over 200 of these assessments—often focused on erosion threats—have been completed.

Many state agencies take into account climate change in their daily work. A few climate change strategies and reports are listed here. In 2010, the Alaska Department of Fish and Game released their climate change strategy, which recognized unprecedented environmental change in the Arctic and outlined needed research and a strategy to respond to climate impacts. Since 2010, the Alaska Department of Environmental Conservation has released two greenhouse gas emission inventories describing the state's emissions from anthropogenic and natural sources. In 2018, the Department of Health and Social Services released a report on the health impacts of climate change.

Adaptation to environmental changes in the Beaufort-Chukchi-Bering region were recently addressed internationally by the Arctic Monitoring and Assessment Program, an Arctic Council Working Group. The group helps to inform policy and decision-making related to Arctic adaptation actions.

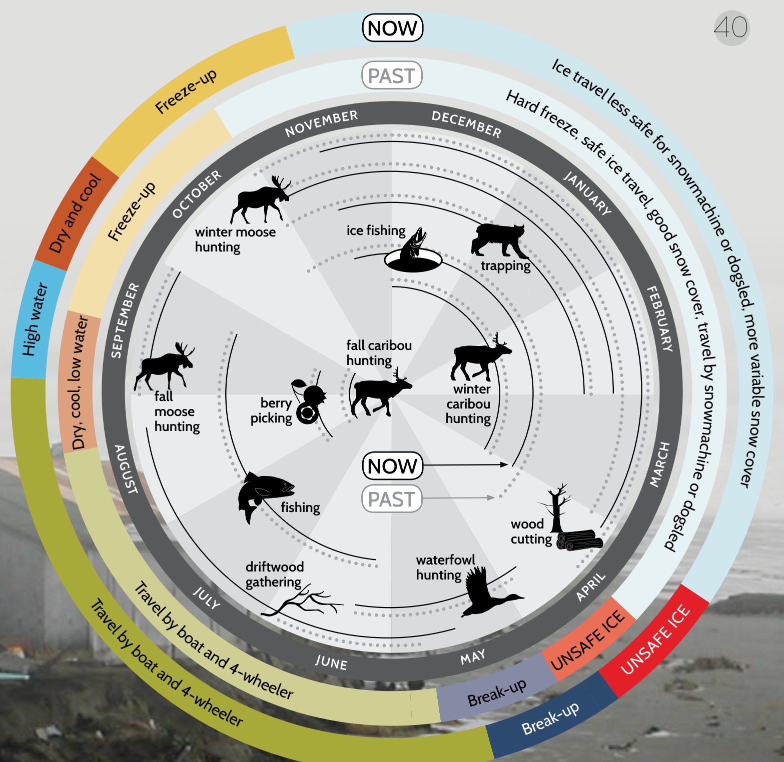
CLIMATE ADAPTATION

Climate adaptation planning is underway at various levels in Alaska, including statewide plans, borough plans (shaded areas on the map), and city and Alaska Native village plans (points on the map).



SHIFTING SUBSISTENCE RESOURCES

Environmental change is challenging travel and access to hunting, fishing, trapping, and gathering resources in interior Alaska (diagram below). Harvest windows are shrinking. Later freeze up and thinner river ice minimize the period of time it is safe to travel on rivers for hunting and trapping, while a shorter snow season reduces the window for travel over land. Accelerated permafrost thaw and changes in river break-up dynamics are influencing river navigability and fishing locations.



RURAL OBSERVATIONS

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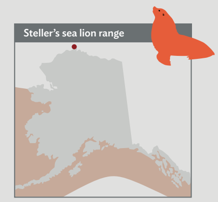
Jack Lane from Point Hope said, “The ice is not too safe this year. 8–24 inches [April 18, 2018]. Chasing lots of ducks, but the ice is thin... No [pressure] ridges. One whale, yet bad ice, lots of snow.”

Willard Neakok from Point Lay said, “in 1998 people would leave for fishing cabins in late August or early September, now [2015] it is as late as the end of November.”

Steven Patkotak from Wainwright wrote on July 10, 2018: “Ocean currents flow strong to NE and remaining ice from lagoon taken out. Someone tried boating out of inlet but rough water and waves higher than the normal..." He mentioned that only four days in the past month were calm enough for boating.

Billy Adams of Utqiaġvik reported on August 19, 2018 an unusual sighting of a Steller’s Sea Lion more than 520 miles outside its range. “My friend Mark Ahsoak Jr. sent me photos on his hunting trip and came across a Steller’s Sea Lion just about 12 miles south of Barrow [Utqiaġvik]! Looks like an old bull with a missing eye and some scarring which is natural.”



Noah Naylor from Kotzebue reported that they had little sea ice in spring 2018 and Ugruk (seal) hunting was short. Not everyone could get out in time to hunt.

Robert Tokeinna Jr. from Wales wrote on May 4, 2018, “this week we lost our shorefast ice. Really super early.”

Joe Turner of Nulato reported on June 22, 2017, "fire in Nulato during hot, dry summer. Very poor air quality."

Lee Kayotuk of Kaktovik reported in June 2019 that “spring came early. May 31, the Hulahula River came out to the coast. Open water ~1 mile offshore and Camden Bay didn’t freeze all winter.”

Cliff Adams of Beaver reported on June 18, 2016, "huge chunks of land eroding along the Yukon River, large sections of the shoreline falling in, even in areas that are not exposed to currents."

Ronnie Demientieff of Holy Cross reported on January 1, 2017 that there was "open water in January. Froze to the bottom then flooded over because of lack of snow."

Miki Collins of Lake Minchumina reported earlier snow melt than usual on April 7, 2017. "Dog team hauling gas during spring melt. Gravel exposed on Holek Spit grinds on sled runners, a problem especially when hauling heavy loads."

Misty Walsh of Tok reported later freeze-up on November 7, 2016, a change she started noticing in 2005. "Thin ice on river. Can't travel the river yet and there is not enough snow to go overland on snowmachines."

ACKNOWLEDGMENTS

This summary of Alaska environmental changes would not have been possible without the contributions of many individuals and organizations. Here we list photo credits and data sources. We also list the individual or entity who analyzed and produced each graphic. Each graphic and data source is associated with a number that can be found throughout the publication. We thank each of these contributors for their generosity and dedication to science and understanding Alaska's changing biological and physical systems.

PHOTO CREDITS

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GRAPHICS & DATA SOURCES

Number in publication – Individual, entity who produced graphic and/or analyzed data *(data source)*
1 – Rick Thoman, Alaska Center for Climate Assessment and Policy
2 – Rick Thoman, Alaska Center for Climate Assessment and Policy *(data source Alaska Interagency Coordination Center)*
3, 7, 9 –11, 13 –15, 17, 25 – Rick Thoman, Alaska Center for Climate Assessment and Policy *(data source NOAA/NCEI)*
4 – Xiangdong Zhang & Liran Peng, International Arctic Research Center *(data source ERA-Interim)*
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26 – *(data source AMAP Ocean Acidification Report, 2018; Nature Climate Change, 2017; Progress in Oceanography, 2015)*
27 – ORBIMAGE *(data sources SeaWiFS Project, NASA/Goddard Space Flight Center)*
28 – Heather McFarland, International Arctic Research Center *(data sources USGS Alaska Science Center, USGS National Wildlife Health Center, USFWS Alaska Region Migratory Bird Management, NOAA/Wildlife Algal-Toxins Research and Response Network WARRN-West)*
29 – Vladimir Romanovsky, Geophysical Institute *(data source GI Permafrost Lab Thermal State of Permafrost database, NSF)*
30 – Bert Wouters, Utrecht University/Delft University of Technology *(data source NASA/DLR GRACE mission; Frontiers in Earth Sciences, 2019)*
31 – *(data source Alaska Science Center USGS, L. Sass)*
32 – Uma Bhatt, Geophysical Institute *(NASA/GSFC)*
33 – Nancy Fresco, Scenarios Network for Alaska + Arctic Planning/Rick Thoman, ACCAP *(data source NOAA/NCEI, NDAWN, Canadian Journal of Plant Science, 2006)*
34 – John Walsh, International Arctic Research Center *(USDA Forest Service)*
35 – Donna Hauser, International Arctic Research Center *(Global Change Biology, 2017)*
36 – Olivia Lee, International Arctic Research Center
37 – Peter Westley, College of Fisheries and Ocean Sciences *(temperature graphic Rick Thoman, data source DOI/USGS)*
38 – Ken Tape, Geophysical Institute *(Global Change Biology, 2018)*
39 – Kelsey Aho, Center for Alaska Policy Studies *(data sources DEECD; Meeker and Kettle, 2017)*
40 – Krista Heeringa, Community Partnerships for Self-Reliance *(Environmental Impacts to Access in Interior Alaska)*
41 – Donna Hauser, Alaska Arctic Observatory & Knowledge Hub *(coastal observations)*
42 – Community Observers *(Interior observations; Environmental Impacts to Access in Interior Alaska)*

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