CHAPTER 2. CLIMATE CHANGE AND ALASKA

This chapter is not a product of the Adaptation Advisory Group. The information in this chapter provides a scientific backdrop for the recommendations and options for adaptation in each sector. It presents findings from the scientific community regarding observed and projected climatic changes for Alaska, and attendant potential impacts on the Alaskan economy and lifestyles.

The *Arctic Climate Impact Assessment (ACIA)*, a comprehensive assessment conducted by hundreds of scientists and indigenous peoples, projects increases in temperature, glacial melt, permafrost temperature, ocean acidification, and continued loss of sea ice extent and thickness in Arctic regions (ACIA 2004 and 2005).

Over the past 50 years, Alaska has warmed at more than twice the rate of the rest of the United States (Karl et al. 2009). As a result, climate change impacts are much more pronounced than in other regions. Higher temperatures are already contributing to earlier spring snowmelt, reduced sea ice, widespread glacier retreat, and permafrost warming. These observed changes are consistent with climate model projections of greater warming over Alaska, especially in winter, as compared with the rest of the country (Karl et al. 2009). Warmer temperatures are expected to be accompanied by overall drier conditions and reduced soil moisture, changes in sea level, and other changes.

Changes in climate will pose challenges for Alaskans and the Alaska economy. Climate change will also provide economic opportunities due to a longer summer tourism season, increased navigation potential, and other changes. Addressing these challenges and taking advantage of the opportunities requires understanding the likely changes in climate that Alaska is to experience, and the concomitant changes in natural resources, infrastructure, and other human and natural systems on which urban and rural communities depend. This chapter summarizes relevant literature on projected climate for Alaska and potential impacts on natural and human systems.

Climate Change Science and Projections for Alaska

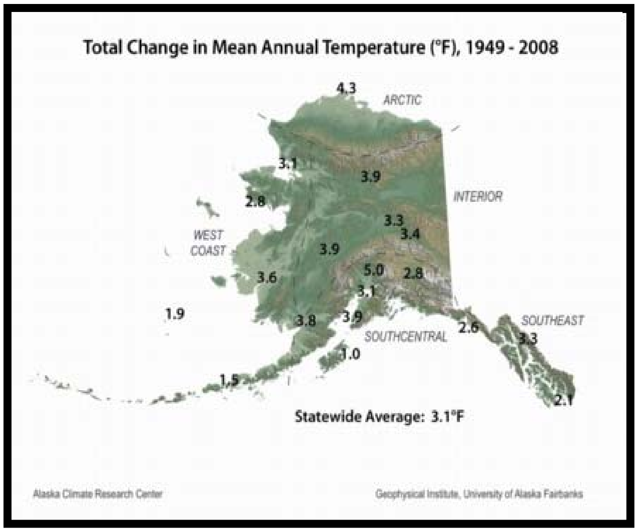
Climate has historically played a key role in shaping Alaska's natural environment, a vast and varied land spanning 586,400 square miles with over 33,000 miles of coastline. Current and projected changes in climate are occurring rapidly with impacts to society, the environment, infrastructure, and economic drivers throughout the state. While natural variability spread over many centuries is well-documented, the present rate of change and global mean surface temperature are higher than during any similar period since 1600 AD (Overpeck et al., 1997). Alaska's climate is particularly sensitive to these changes. Temperature and precipitation in Alaska are driven in large part by the state's high latitude and corresponding seasonal extremes in solar radiation, the influence of ocean waters and sea ice, and variations in elevation (ACRC 2009). A general understanding of projected conditions is critical to planning for the future and anticipating the types of adaptation measures that should be developed.

Temperature

Despite the considerable interannual and interdecadal influence of large-scale regime shifts, most notably the Pacific Decadal Oscillation (PDO), average annual temperatures in Alaska have risen by 3.1° F in the past 60 years (ACRC 2009). This is consistent with the general warming trend observed throughout the circumpolar Arctic. The distribution across Alaska is displayed in Figure 2.1.

An analysis of mean seasonal and annual temperature data for Alaskan communities over the past 60 years shows the greatest changes occurring during the winter months as depicted in Figure 2.2. Multiple communities have experienced increases of greater than 8° F in the winter months. This poses significant implications to the natural ecosystems and the built environment in Alaska.

Figure 2-1. Total Change in Mean Annual Temperature (°F), 1949-2008



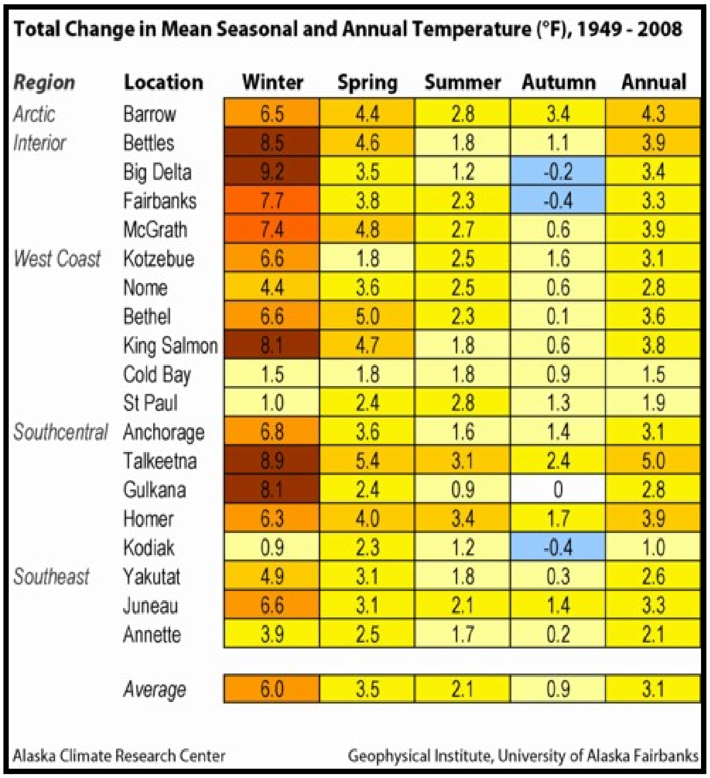
Source: ACRC 2009.

Precipitation and Hydrology

Atmospheric temperature is positively correlated with the amount of precipitable water (PW) in the atmosphere, and thus the potential for precipitation. During 1979 to 2005, precipitable water in the atmosphere at the northern latitudes increased by approximately 5 to 10% per decade during spring, increased 5% per decade in summer, and declined (over land masses) in autumn and winter (White et al. 2007). Available precipitation gauge data from across the northern latitudes (between 55° and 85°N) suggests precipitation has increased during winter and spring, with a slight decrease during autumn (e.g., Serreze et al. 2000).

Snow distribution and redistribution data is difficult to gather and the stations that gather such data provide only sparse coverage across Alaska. Increases in

Figure 2-2. Total Change in Mean Seasonal and Annual Temperature (°F), 1949 -2008



Total Change in Mean Seasonal and Annual Temperature (°F), 1949 - 2008

Region	Location	Winter	Spring	Summer	Autumn	Annual
Arctic	Barrow	6.5	4.4	2.8	3.4	4.3
Interior	Bettles	8.5	4.6	1.8	1.1	3.9
	Big Delta	9.2	3.5	1.2	-0.2	3.4
	Fairbanks	7.7	3.8	2.3	-0.4	3.3
	McGrath	7.4	4.8	2.7	0.6	3.9
West Coast	Kotzebue	6.6	1.8	2.5	1.6	3.1
	Nome	4.4	3.6	2.5	0.6	2.8
	Bethel	6.6	5.0	2.3	0.1	3.6
	King Salmon	8.1	4.7	1.8	0.6	3.8
	Cold Bay	1.5	1.8	1.8	0.9	1.5
	St Paul	1.0	2.4	2.8	1.3	1.9
Southcentral	Anchorage	6.8	3.6	1.6	1.4	3.1
	Talkeetna	8.9	5.4	3.1	2.4	5.0
	Gulkana	8.1	2.4	0.9	0	2.8
	Homer	6.3	4.0	3.4	1.7	3.9
	Kodiak	0.9	2.3	1.2	-0.4	1.0
Southeast	Yakutat	4.9	3.1	1.8	0.3	2.6
	Juneau	6.6	3.1	2.1	1.4	3.3
	Annette	3.9	2.5	1.7	0.2	2.1
	Average	6.0	3.5	2.1	0.9	3.1

Alaska Climate Research Center Geophysical Institute, University of Alaska Fairbanks

Source: ACRC 2009

winter precipitation could lead to increased snowpack (Serreze et al. 2000), however, winter melting events and a shortening of the period of snow accumulation could have the opposite effect. If the latter conditions dominated and overall snowpack decreased, Alaska could expect a shorter spring melting period with lower runoff intensity and generally lower summer baseflows. In either event, changes in timing, duration, thickness, and distribution of seasonal snow cover significantly impacts many aspects of the hydrologic cycle including surface runoff, groundwater recharge, and river streamflow (White et al. 2007).

In addition, rain-on-snow events can have a profound impact on wildlife. For example, when a heavy crust forms on snow after a rain event, caribou may be unable to access food and large-scale die-offs may occur. To complicate potential impacts of snowpack and river dynamics, glacial runoff has a significant impact on many Alaskan rivers. For example, Hinzman et al. (2005) found increasing trends in discharge from glacially fed Alaskan rivers and decreasing trends in nonglacially fed rivers. With continued warming, the glacial contribution to rivers could increase. This effect would then decrease with diminishing glaciers.

The potential change in precipitation, snowpack, runoff, and riverflow could have many different effects on Alaskans. Due to the appreciable interannual variability and variation introduced by decadal cycles (i.e., Pacific Decadal Oscillation), longer term trends in precipitation will be difficult to discern and prepare for. However, both decadal variability and longer term trends should be incorporated into long term planning. While most attention is paid to net annual or seasonal precipitation, the nature of the precipitation events is important to human and natural ecosystems. For example, an increase in storminess could have a dramatic impact on erosion and, consequently, on infrastructure. Likewise, midwinter melting events could reduce the potential for spring flooding, particularly flooding caused by ice jams on rivers. As with all climate impacts, changes will be regional in nature.

Warmer spring and fall weather will result in longer growing seasons and a higher number of growing degree days statewide. This in turn will increase water loss from soils through evapotranspiration. This drying effect will generally result in a net loss of moisture, despite increased rainfall.

In the Arctic, drying of wetlands may alter the habitat of many species, and may also impact the oil and gas industry by reducing the availability of water for snow travel and ice roads. In the interior, hydrologic changes are likely to be felt most acutely in terms of the impacts of drying on fire cycles, as described below, as well as on changing drainage patterns as permafrost thaws. In western coastal regions, the greatest risks from changing hydrologic conditions are likely to be erosion (due in part to loss of sea ice and permafrost) and storms, although current models do not provide clear data on potential changes in storm frequency and severity. In southeast Alaska, glacial melt is already occurring, and is likely to continue. This change in conjunction with changes in the timing of spring runoff may affect a wide range of ecosystem functions and human activities, including tourism, hydropower generation, and subsistence harvest.

Sea Level Change

Generally speaking, global sea levels are rising via thermal expansion resulting from warming of the ocean, as well as freshwater input from the melting of a majority of Earth’s glaciers and ice sheets. Approximately 47% of Gulf of Alaska freshwater input is derived from glacier melting (Neal et al., in review). Consequently, IPCC models estimate that through the end of the 21st century, global sea levels may rise between 0.6 ft and 1.9 feet (IPCC 2007).

However, these projections do not consider extreme increases in ice-sheet flow velocities or acceleration in the volume and rate of ice loss (Alley et al. 2005; Gregory and Huybrechts 2006; and Hansen 2005). Several recent studies suggest that the IPCC models underestimate ice loss from the Greenland and Antarctic ice sheets (Shepherd and Wingham 2007; Csatho et al. 2008) and ice loss from mountain glaciers (Meier et al. 2007). Further, IPCC results for sea level projections might underestimate sea level rise due to changes in global precipitation (Wentz et al. 2007; Zhang et al. 2007).

Recent glacier retreat in the Gulf of Alaska coastal area of southeast and southcentral Alaska has resulted in the land surface rising as it readjusts to the loss of glacial ice. This isostatic rebound, combined with active regional tectonic deformation, results in a rate of land uplift that is greater than the projected rate of global sea level rise. Thus, over the next century, the relative sea level in these areas will decrease between 2.1 and 3.4 feet (Larsen et al. 2004; Kelly et al. 2007; Pyare 2009).

In contrast, communities in low-lying areas such as the Yukon-Kuskokwim Delta are likely to face increased flooding and changing storm surge and storm tracks. In northwest Alaska, overall, decreasing sea ice extent and resulting increasing wave surge will have greater impact on coastal erosion than will sea level rise.

Ocean Acidification

Ocean acidification, occurring as a result of increasing concentrations of CO_2 in the atmosphere, is considered to be the greatest threat to living marine resources and those who rely on them. The world's largest bodies of water are effective absorbers of both CO_2 and excess heat associated with climate change (Sabine et al. 2004). While this has a mitigating effect on the changes to climate, absorption of CO_2 is making the oceans more acidic posing grave danger to all marine life with calcifying shells. This includes marine plants and zooplankton, the basis of the food chain (Feely 2006).

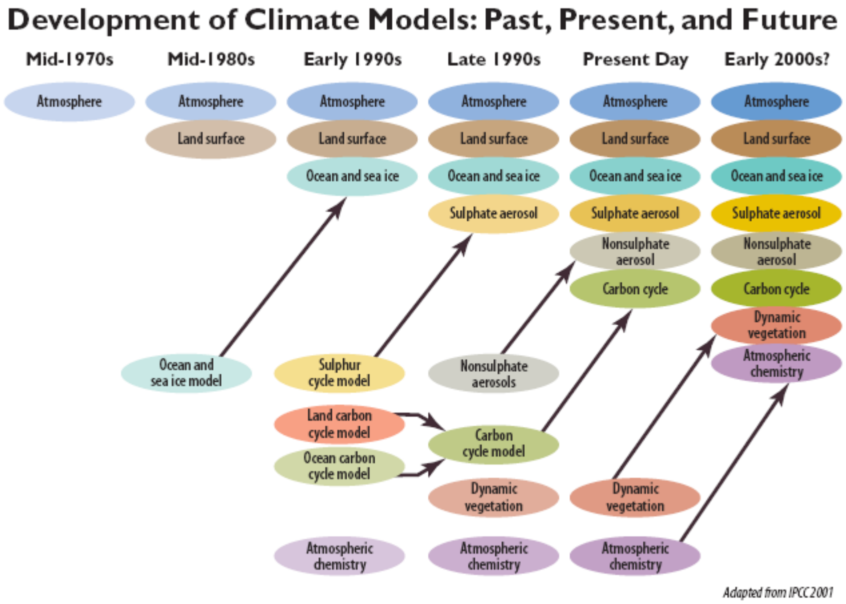
Acidification processes are more pronounced in colder waters (Orr et al. 2005). Since over 50% of the fish consumed in the U.S. comes from the Bering Sea, this has the potential to significantly alter the conditions that support commercially important species. Even though it has been noted that some stocks are migrating further north and into Arctic waters due to ocean warming, acidification is projected to be a challenge there as well (Orr et al. 2005).

Estimates of future atmospheric and oceanic carbon dioxide concentrations suggest that by the middle of this century, the atmospheric carbon dioxide level could reach more than 500 parts-per-million (ppm), and could rise to over 800 ppm near the end of the century. This would result in an additional surface water pH decrease of approximately 0.3 pH units by 2100 (PMEL n.d.). Box 2-1 describes effects of ocean acidification on marine ecosystems.

Projections – What the Models Predict

Scientists extensively use mathematical models of Earth's climate to examine hypotheses about past and present day climates. These climate simulations provide a framework within which enhanced understanding of climate-relevant processes, along with improved observations, are merged into coherent projections of future climate change (CCSP 2008). Over time, these models have evolved into modern coupled atmosphere-ocean general circulation models (AOGCMs), which incorporate detailed representations of the atmosphere, land surface, oceans, and sea ice (see Figure 2.3). These models form the basis of the projections for temperature, precipitation, and other variables reported in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment (IPCC 2007).

Figure 2-3. Historical Development of Climate Models



Source: CCSP, 2008.

Predicting the site-specific magnitude of these changes is crucial to interpreting their impacts. In order to produce projections that are useful for impacts analysis at the regional level, the coarse-resolution global climate model output must be “downscaled” to provide higher resolution results. Different methodologies are available for downscaling, with different degrees of success and reliability (CCSP 2008).

For Alaska, the Scenarios Network for Alaska Planning (SNAP) has taken one approach to developing fine-scale projections of future climate. SNAP

Box 2-1 Ocean Acidification and Its Effect on Marine Species

The oceans have absorbed about 50% of the carbon dioxide (CO_2) released from the burning of fossil fuels, resulting in chemical reactions that lower ocean pH. This has caused an increase in hydrogen ion (acidity) of about 30% since the start of the industrial age through a process known as “ocean acidification.” A growing number of studies have demonstrated adverse impacts on marine organisms, including:

- The rate at which reef-building corals produce their skeletons decreases
- The ability of marine algae and free-swimming zooplankton to maintain protective shells is reduced
- The survival of larval marine species, including commercial fish and shellfish, is reduced

This research shows that pH will affect the processes by which animals such as corals, mollusks and crustaceans make their support structures. Because these organisms depend on calcium carbonate, increasing acidity threatens their survival. Pteropods, small planktonic mollusks critically situated at the bottom of the food chain and a key food source for salmon and other species, are particularly vulnerable to increasing acidity in Alaska's marine waters. Other marine organisms at risk from increasing acidification include corals and coralline algae commonly found in reef communities. Cold water coral communities along the Aleutian Islands form important fish habitat. Forminifera and coccolithophorids, planktons that are abundant in most surface waters, are also at risk. Some commercial species like clams and crabs will be directly impacted by reductions in calcium carbonate. Others, like most fish populations, will be affected indirectly as acidification impacts their key prey species.

Continued in next text box…

Box 2-1 Ocean Acidification and Its Effect on Marine Species (continued)

Ocean Acidification Will Impact Polar and Sub-Polar Regions First

Ocean acidification is likely to alter the biodiversity of the world's marine ecosystems and may affect the total productivity of the oceans. New findings indicate that an increasingly acidic environment could cause problems in high-latitude marine ecosystems within just a few decades. Currently, the oceans' surface water layers have sufficient amounts of calcium carbonate for organisms to use (known as saturated conditions). This calcium carbonate rich layer is deeper in warmer regions and closer to the surface in colder regions. Because calcium carbonate is less stable in colder waters, marine life in the polar oceans will be affected by calcium carbonate loss first. A study published in *Nature* by 27 U.S. and international scientists stated, "Some polar and sub-polar waters will become under-saturated [at twice the pre-industrial level of CO2, 560 ppm], probably within the next 50 years (Orr et al., 2005)."

What Are the Potential Socio-Economic Consequences of Ocean Acidification?

Ocean acidification will have long-term implications for the global carbon cycle and climate, although the range and magnitude ofbiogeochemical and biological effects and their socio-economic impacts are currently too uncertain to accurately quantify. However, we do know that such impacts are likely to be substantial.

Feedback to Climate Changes

As the oceans absorb more and more CO2 from the atmosphere, their capacity to continue to sequester greenhouse gases diminishes, thereby limiting their ability to reduce the greenhouse effect. This then inhibits their potential to reduce subsequent warming.



Sources (including photos and chart): PMEL, 2008 and Alaska Marine Conservation Council, n.d.

projections are based on downscaled global models used by the IPCC. The IPCC used fifteen different GCMs to prepare its Fourth Assessment Report (IPCC 2007). Each model was created by a different nation or group using slightly different data and assumptions. Thus, models can be expected to perform with varying degrees of accuracy in any particular region.

To downscale IPCC results to Alaska, SNAP investigators compared model output for past years to actual climate data for the same time period, and analyzed how well each model predicted monthly mean values for three different climate variables (surface air temperature, precipitation, and sea level air pressure) over four overlapping northern regions (Alaska, Greenland, latitude 60-90˚N, and latitude 20-90˚N) for the period from 1958–2000 (Walsh et al. 2008). They noted that models that performed well in one northern region tended also to perform well in others. SNAP climate models rely on output from the five models that provided the most accurate overall results. Results are scaled down to match local conditions using data from Alaskan weather stations and various analytical tools.

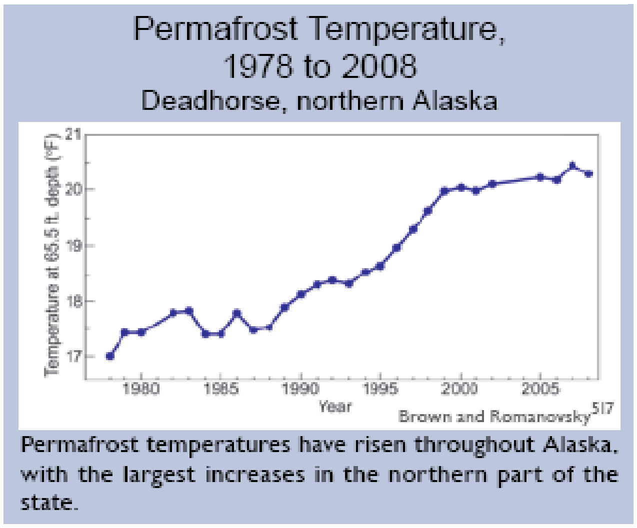
Results of SNAP modeling efforts are used to inform the predictions for the changes to human and natural systems described below, including vegetation and wildlife species shifts, changes in fire cycles, and loss of permafrost. Data can be accessed via the SNAP website (www.snap.uaf.edu).

Additional linked models connecting climate data to variables such as transportation and construction parameters, hydrologic shifts, or optimal conditions for tourism, recreation, hunting, and fishing will improve the connections between SNAP climate data and landscape changes of concern to Alaskans (Walsh et al. 2008).

Impacts on Human and Natural Systems in Alaska

Alaska is already experiencing climate warming, with key effects occurring to permafrost and sea ice, forests and other vegetation, coastline communities and infrastructure, marine ecosystems and fisheries, and subsistence livelihoods (NAST 2000). Over the past three decades, Alaska has experienced a sharp reduction in snow-cover extent and duration, shorter river- and lake-ice seasons, melting of mountain glaciers, sea-ice retreat and thinning, permafrost retreat, and increased depth of summer thaw (Weller 2005). The climatic and other changes associated with warming will not only affect the environment, but will also affect the economy and daily life and culture in Alaska (see Box 2-2).

Figure 2-4. Permafrost Temperature, 1978 to 2008.



Permafrost Temperature, 1978 to 2008

Deadhorse, northern Alaska

Permafrost temperatures have risen throughout Alaska, with the largest increases in the northern part of the state.

Source: Karl et al. 2009

Permafrost Thawing and Sea Ice Melting

Permafrost underlies most of Alaska. Air temperature, snow cover, and vegetation affect the temperature of the frozen ground and the depth of seasonal thawing. Recent decades of warmer temperatures have produced extensive warming and thawing of permafrost (Brown and Romanovsky 2008), as illustrated in Figure 2.4. This warming and thawing has resulted in increased coastal erosion, landslides, high elevation rock and ice avalanches, and sinking of the ground surface, and consequent disruption and damage to forests, buildings, infrastructure,

Box 2-2. Impacts on the Economy and on People's Lives

The effects of climate change on the environment in Alaska will have consequences for natural resources and production that may affect the Alaskan economy and the lives and livelihood of indigenous and non-indigenous populations.

Impacts on the Economy

Climate change may affect the economy via effects on natural resources and on transportation and other infrastructure. Large oil and gas reserves exist in Alaska along the Beaufort Sea coast in the Mackenzie River/Beaufort Sea area of Canada. While climate change impacts on this industry have been minor thus far, in the future both negative and positive effects are likely. For example, offshore oil exploration and production is likely to benefit from less extensive and thinner sea ice (Weller 2005). Conversely, ice roads, now used widely for access to offshore activities and facilities, are likely to be less safe and usable for shorter periods (Weller 2005). The thawing of permafrost, on which buildings, pipelines, airfields, and coastal installations supporting oil development are located, is very likely to affect these structures adversely and greatly increase the cost of maintaining or replacing them. (Weller 2005). One study (Larsen et al, 2007, 2008) suggests that strategic adaptation to different future scenarios of climate change could add $3.6–$6.1 billion (+10% to +20% above normal wear and tear) to future costs for public infrastructure from now to 2030, and $5.6–$7.6 billion (+10% to +12%) from now to 2080.

It is difficult to project impacts on the lucrative Bering Sea fisheries because many factors other than climate are involved (Weller 2005). However, large northward changes in the distribution of fish and shellfish are likely with a warmer climate, which might result in substantial costs to relocate infrastructure supporting commercial fishing (Weller 2005). Warmer waters are likely also to lead to increase primary production in some regions, but a decline in cold-water species such as salmon and pollock.

Other economic sectors in this region, including forestry and agriculture are less developed and less important economically than oil and gas and fish and wildlife. Impacts on these other economic sectors are difficult to assess. For example, impacts on tourism will depend on how the Alaskan features that draw tourists change; large undeveloped landscapes will not be directly affected by climate change, whereas marine mammal populations and accessible glaciers are likely to experience major changes. Impacts on agriculture are also difficult to predict. Growing-degree days have increased by 20%, with benefits for agriculture and forest productivity on some sites, and reduced growth on others (Weller 2005, ACIA 2004).. Moreover, the benefits of a longer growing season will be balanced against the negative effects of decreased soil moisture (Karl et al. 2009).

Impacts on People's Lives

Traditional lifestyles are already being threatened by the environmental effects associated with climate change, including reduced or displaced populations of marine mammals, seabirds, and other wildlife, and reductions in the extent and thickness of se ice, making hunting more difficult and dangerous (Weller 2005). Climate change is likely to have significant impacts on the availability of key marine and terrestrial species used as food sources, by shifting the range and abundance of species such as salmon, herring, char, cod, walrus, seals, whales, caribou, moose, and various species of seabird (Weller 2005). Such changes will require major local adjustments in harvest strategies (Weller 2005). These activities play important roles in the lives of many indigenous populations, including making significant contributions to diet and nutrition, providing opportunities for physical activity, contributing monetary income, and providing other important social and cultural functions (Weller 2005).

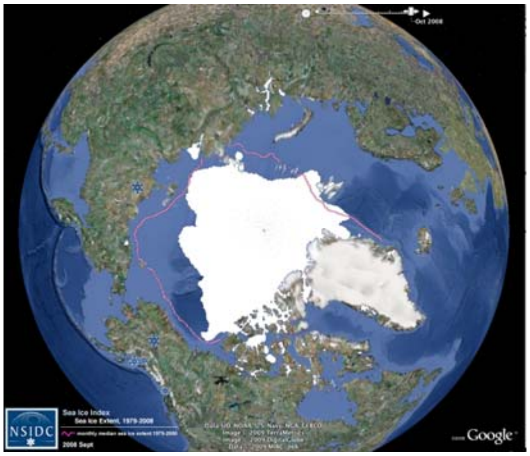
Impacts have already been observed on lifestyles in indigenous villages and communities in Alaska and Canada that depend heavily on fishing and hunting. Such impacts included reduced access to tundra and offshore food resources, decreases in the anadromous fish stocks and marine mammals harvested for food; threats to villages resulting from coastal erosion, and infrastructure affected by thawing permafrost. Other impacts are likely to occur in the future, due to decreasing area of pack ice, further changes in habitat and migration routes, zoonotic diseases posing a greater threat to humans and wildlife, lower water levels, and other changes.

and coastal communities (NAST 2000; Nelson et al. 2003). Land subsidence associated with the thawing of permafrost presents substantial challenges to engineers attempting to preserve infrastructure in Alaska (Nelson et al. 2003; Karl et al. 2009; Larsen et al. 2008).

Public infrastructure at risk of damage includes roads, runways, and water and sewer systems (Karl et al. 2009), as well as local, municipal, Borough, State and Federal buildings. While most permafrost-related damage to infrastructure is due to the heat of the infrastructure itself, many mitigation measures rely on sufficiently cold winter temperatures to balance the heating. Many industrial activities (such as oil and gas exploration which requires travel on the tundra) depend on frozen ground surfaces, and many northern communities rely on ice roads for transport of groceries and other materials. Continued warming will further impair transport by shortening the seasonal use of ice roads (ACIA 2004). Thawing is projected to accelerate under future warming, with as much as the top 10 to 30 feet of discontinuous permafrost thawing by 2100 (NAST 2000; Romanovsky et al. 2007; Romanovsky 2009).

All components of the cryosphere in the Arctic are experiencing change, including snow cover, mountain and valley glaciers, permafrost, sea ice, and lake and river ice (Parson et al. 2000). For example, most glaciers in Alaska, as throughout the Arctic, have been retreating for many decades. Many small lower elevation glaciers have melted away, while most large valley glaciers are thinning several feet per year.

Figure 2-5. Sea Ice Extent in 2008 and 1979



Source: Richter-Menge et al., 2008

Sea ice off the Alaskan Coast is retreating and thinning, with widespread effects on marine ecosystems, coastal climate, human settlements, and subsistence activities. Recent studies estimate arctic-wide reductions in annual average sea-ice extent of about 5-10% and a reduction in average thickness of about 10-15% over the past few decades (ACIA 2004). Figure 2-5 depicts the extent of sea ice in September 2008. The magenta line represents median sea ice extent between 1979 and 2008. The annual maximum sea ice extent typically occurs in March. This annual maximum level has been gradually declining since 1979, and experienced a record low in 2006, with a slight rebound since the low (Richter-Menge et al. 2008). Retreat of sea ice allows larger storm surges to develop, increasing the risk of inundation and increasing erosion on coasts already made vulnerable by permafrost thawing (NAST 2000). Loss of sea ice also causes large scale changes in marine ecosystems, and threatens populations of marine mammals and polar bears that depend on ice (NAST 2000).

At the same time, the continued reduction of sea ice is very likely to increase the navigation season, and seasonal opening of the Northern Sea Route is likely to make trans-arctic shipping feasible during summer months. This could occur within several decades, although increasing ice movement will initially make shipping more difficult in some channels of the Northwest Passage.

Lakes are also declining in area. Across the southern two-thirds of Alaska, the area of closed-basin lakes (lakes without stream inputs and outputs) has decreased over the past 50 years (Karl et al. 2009). This is likely due to the greater evaporation and thawing of permafrost that result from warming (Karl et al. 2009). Continued decline in the area of surface water would present challenges for the management of natural resources and ecosystems on National Wildlife Refuges in Alaska (Karl et al. 2009). These refuges, which cover 77 million acres (21 percent of Alaska) and comprise 81 percent of the U.S. National Wildlife Refuge System, provide breeding habitat for millions of waterfowl and shorebirds that winter in the lower 48 states (Karl et al. 2009).

Threats to Coastal Communities, Habitats, and Fishing Fleets

Alaska has more coastline than the other 49 statescombined (Karl et al. 2009). Coastal erosion is causing the shorelines of some areas to retreat at average rates of tens of feet per year (Karl et al. 2009). Frequent storms in the Gulf of Alaska and the Bering, Chukchi, and Beaufort Seas already affect the coasts during much of the year (Karl et al. 2009). Alaska's coastlines, many of which are low in elevation, are increasingly threatened by a combination of the loss of their protective sea ice buffer, increasing storm activity, and thawing coastal permafrost (Karl et al. 2009). Increases in the frequency and intensity of storm surges have triggered increased coastal erosion that is threatening a number of coastal villages (see Figure 2-6). A recent report from the Government Accountability Office (GAO) indicated that, since 2003, federal, state, and village officials have identified 31 villages that face imminent threats (see Box 2-3).

Figure 2-6. Coastline Erosion in Shishmaref, Alaska.

Shishmaref, where the coastline has eroded 100-300 feet in the past 30 years. Source: The Nome Nugget

Storm surges have also reduced the protection that barrier islands and spits provide to coastal habitats. Commercial fishing fleets and other marine traffic are also strongly affected by Bering Sea storms. High–wind events have become more frequent along the western and northern coasts (Karl et al. 2009). The same regions are experiencing increasingly long sea-ice-free seasons and hence longer periods during which coastal areas are vulnerable to wind and wave damage (Karl et al. 2009).

Forest and Vegetation Changes

The Arctic region, particularly Alaska, is already experiencing major ecological impacts of warming. Rising temperatures have caused northward expansion of boreal forest in some areas, significant increases in fire frequency and intensity, and unprecedented insect outbreaks (Weller 2005; ACIA 2004). During the 1990s, for example, south-central Alaska experienced the largest outbreak of spruce beetles in the world, attributable to the combination of rising temperatures speeding up the life cycle of the beetle and extended drought weakening the trees (Karl et al. 2009). Large areas of dead trees, such as those left behind by pest infestations, are highly flammable and more vulnerable to wildfire than living trees (Karl et al. 2009).

Climate plays a key role in determining the extent and severity of wildfires, as well as insect outbreaks (Karl et al. 2009). The amount of boreal forest in North America that burned annually tripled from the 1960s to the 1990s, and half of the severe fire years on record have occurred since 1990 (Kasischke and Turetsky 2006).

Fire in Alaska is tightly linked to climate (Duffy 2005) and the average area burned per year in Alaska is projected to double by the middle of this century (Balshi et al. 2008). Under a moderate projection of climate change, by the end of this century, the total area burned by fire is projected to triple (Karl et al. 2009). Current projections suggest that, due to increases in burn area per decade, the tundra-dominated landscape on Seward Peninsula will eventually be replaced by deciduous forest (ACIA 2004). In other areas, forested areas are likely to convert to bogs as permafrost thaws (ACIA 2004). Coupled trajectories of future climate and demographics are expected to directly increase the near-term threats to life and property from wildfire in Alaska (Trainor et al. 2009).

Box 2-3 Alaska Native Villages: Limited Progress Has Been Made on Relocating Villages Threatened by Flooding and Erosion

In December 2003, GAO reported that most of Alaska's more than 200 Native villages were affected to some degree by flooding and erosion (GAO, 2003). Since 2003, state officials have identified the growing impacts of climate change, increasing the urgency of federal and state efforts to identify imminently threatened villages and assess their relocation options.

Since 2003, federal, state, and village officials have identified 31 villages that face imminent threats. The U.S. Army Corps of Engineers' (Corps) March 2009 Alaska Baseline Erosion Assessment identified many villages threatened by erosion, but did not assess flooding impacts. At least 12 of the 31 threatened villages have decided to relocate—in part or entirely—or to explore relocation options.

Federal programs to assist threatened villages to prepare for and recover from disasters and to protect and relocate them are limited and unavailable to some villages. In the absence of a lead entity, federal agencies individually prioritize assistance to villages on the basis of their programs' criteria. These criteria do not necessarily ensure that the villages in greatest peril get the highest priority, and although the Corps has assessed erosion threats, there is no lead federal entity to prioritize and coordinate assistance using this information.

Of the 12 villages exploring relocation options, Newtok has made the most progress in its relocation efforts. The Newtok Planning Group, formed in 2006 by federal, state, regional, and village partners, has helped to accelerate the relocation process that the village proactively initiated in 1994. In 2007, the Newtok Planning Group reported that the lack of designated federal and state lead entities to guide, coordinate, and fund assistance impeded village relocation efforts and created uncertainty regarding the fulfillment of environmental analysis requirements under the National Environmental Policy Act. In 2008, the state designated a lead agency for village relocation assistance, and federal, state, and village officials told GAO that a similar lead federal entity is needed. Lead authority could be provided to an existing agency or commission, or a new entity could be formed for this purpose.

Source: GAO, 2009

Sensitivity of Marine Ecosystems and Fisheries

The Gulf of Alaska and Bering Sea support marine ecosystems of great diversity and productivity. Alaska leads the United States in the value of its commercial fishing catch, and most of the nation’s salmon, crab, halibut, and herring come from Alaska (Karl et al. 2009). One of the most productive areas for Alaska fisheries is the northern Bering Sea off Alaska’s west coast (Karl et al. 2009). Recent climate-related impacts observed in the Bering Sea include significant reductions in seabird and marine mammal populations, unusual algal blooms, abnormally high water temperatures, and low harvests of salmon on their return to spawning areas

(Weller 2005). While the Bering Sea Fishery has become one of the world's largest, the area has been undergoing change for several decades. The abundance of Stellar sea lions has declined by between 50% and 80%, and northern fur seal pups on the Pribilof Islands – the major Bering Sea breeding grounds – declined by 50% between the 1950s and 1980s (Weller 2005, ACIA 2004). Populations of some seabird species, including common the murre, have also declined significantly (Weller 2005).

Differentiating among the various factors affecting the Bering Sea ecosystem is a major focus of current and projected research (Weller 2005). However, future projections for the Bering Sea suggest productivity increases at the base of the food chain, poleward shifts of some cold-water species, and negative effects on ice-dwelling species (Weller 2005; ACIA 2004). Warmer temperatures will also affect commercial fisheries, with large northward shifts of fish and shellfish species, associated declines in production of cold-water species such as salmon and pollock, and increased production of other species (ACIA 2004).

Changes In the Diversity, Ranges, and Distributions of Species

The Arctic sub-region that includes Alaska, Chukotka, and the Western Canadian Arctic is home to over 70 percent of the rare plant species that occur only in the Arctic, and home to a number of plant and animal species already classified as "threatened" (ACIA 2004). Species concentrated in small areas, such as Wrangell Island, are particularly vulnerable to the direct effects of climate change combined with competition from migrating non-native species (ACIA 2004).

Increased Stress on Subsistence Livelihoods and Lifestyles

Subsistence makes an important contribution to livelihood in many isolated rural communities, especially but not exclusively for native peoples. Livelihoods that sustain indigenous communities include hunting, trapping, gathering, and fishing. These activities not only make significant contributions to the diet and health of many indigenous populations, but also play large and important social and cultural roles (ACIA 2004). Reduced or displaced populations of marine mammals, seabirds, and other wildlife, together with continuing thinning of sea-ice, have affected the safety, and the dietary and economic well-being of subsistence communities (ACIA 2004). Over the course of this century, the most productive commercial fisheries are likely to become more distant from existing fishing ports and processing infrastructure (Karl et al. 2009). These changes will also affect the ability of native peoples to successfully hunt and fish for food. Particularly for rural communities, adapting to climate change will pose some complex challenges (see Box 2-4).

Technical Working Groups Supporting Alaska's Adaptation Advisory Group

Prior to establishing Technical Work Groups (TWG) to help the Adaptation Advisory Group (AAG) formulate options, the Sub-Cabinet conducted an inventory of the potential ecological and socioeconomic impacts of climate change on Alaska. A thorough analysis of peer-reviewed literature, such as the Arctic Climate Impact Assessment (ACIA 2005), was conducted along with a review of impacts identified by appropriate state agencies, and the compilation put together by the Alaska Climate Impact Assessment Commission (ACIAC 2008). This laid the groundwork for categorizing the impacts into sectors that formed focal points for the TWGs. The AAG formed the TWGs to develop options to address potential impacts in four sectors: Health and Culture, Public Infrastructure, Natural Systems and Other Economic Activities. The four sectors are not entirely discrete; over the course of the strategy development process, the AAG and TWGs dealt with a number of issues in defining the scope and addressing potential overlaps among the impact categories.[1]

Health and Culture

This sector focuses on the human health, cultural, recreational, and quality-of-life impacts of climate change on Alaskans. Climate change is projected to be associated with increases in some diseases that flourish in warmer temperatures (such as paralytic shellfish poisoning). Water quality and availability—a decrease in quality of potable water due to drought, saltwater intrusion, and other issues—will also have health consequences. The health and culture of subsistence lifestyles are especially at risk, due to diminishment or change of the subsistence diet, due, in part, to reduced availability of traditional food supplies (waterfowl, fish, marine mammals, sea vegetables, berries, and plant medicines). Injuries, due to thinning and other changes in ice, wildfires, and insect bites and stings, are also likely to increase.

Box 2-4. Vulnerability to Climate Change and the Arctic

The majority of the Arctic's residents live in small to medium-sized communities, in many cases located in remote regions and dependent on climate-sensitive livelihoods, including hunting, fishing, herding, and forestry. This dependence on climate-sensitive resources and infrastructure will make the Arctic particularly sensitive to climate change. Climate change is already threatening activities such as hunting while raising questions about the long-term sustainability of traditional way.

In the Arctic, adaptation is increasingly prominent in policy discussions, with national and regional governments, non-governmental organizations, communities, and national and international research bodies stressing the need to strengthen the ability of communities, regions, and economic sectors to adapt to current and future climate change.

To identify adaptation needs and inform the development of policies to reduce the negative impacts of climate change, it is crucial to identify and characterize vulnerability. Vulnerability can be thought of as the capacity to be wounded: it is a measure of the susceptibility to harm in a system in response to a stimulus or stimuli. In this context, the stimuli are climate-related risks, and the "system" can range from an individual or household unit to the national state. In turn, vulnerability is related to both exposure and sensitivity to climatic risks and the adaptive capacity to deal with those risks.

Non-climatic factors can amplify or attenuate vulnerability to climatic stress. These include sources of livelihoods, assets, access to resources, globalization, institutional networks, education, gender, race, ethnicity, and poverty. These determinants are influenced by social, economic, cultural, and political conditions. Identifying viable options for adaptation requires both identifying technological and engineering-based responses and also understanding and applying the lessons of vulnerability science to the Arctic.

Source: Ford and Furgal, 2009.

Natural Systems and Associated Economies

This sector examines the impacts of climate change on biodiversity, ecosystem health, and associated human economic activity. In general, climate is projected to result in changes in growing seasons, and changes in the distribution, quantity, and ranges of many species. Consequently, this sector comprises a wide range of subsectors, including agriculture; boreal and temperate forests and dependent species; tundra and alpine ecosystems and dependent species; freshwater ecosystems and dependent species; marine, sea ice, coastal

---

[1] Additional information on the initial characterization of sectors can be found on Alaska's Climate Change Web site, associated with the first meeting of the AAG: http://www.climatechange.alaska.gov/aag/aag.htm

environments, and dependent species; other warm temperature impacts on animals; commercial and sport fishing; subsistence hunting, trapping, and gathering; and sport hunting, tourism, and wildlife viewing.

Public Infrastructure

This sector addresses the physical impacts of climate change on Alaska's built environment and transportation options. Infrastructure includes both publicly- and privately-owned infrastructure (the word public refers to "use" rather than "ownership"). Types of infrastructure considered by this sector include road transportation (highways, roads, and bridges), air transportation (airports and landing strips), sea walls and shoreline protection, utility and fuel infrastructure, landfills, sewage and septic systems, and water systems. As discussed above, impacts from thawing permafrost, increased freeze-thaw cycles, and erosion all pose challenges to road infrastructure and buildings. Other forms of infrastructure are similarly susceptible to these and other changes, including increased fire risk, increased coastal fog (affecting flying conditions), and other impacts.

Other Economic Activities

This sector focuses on Alaskan economies affected by a changing climate that are not directly dependent on living ecosystems. Key industries initially examined by the TWG included oil and gas, mining, ocean transportation and other transportation, tourism, and other business impacts and opportunities. The types of impacts addressed by this sector include the effects of climate change on industries such as oil and gas, which are expected to be negatively affected by difficulties in tundra ice travel and effects of sea level rise and erosion on buried or above-ground oil and gas pipelines. The sector also focuses on economic opportunities, such as increased shipping opportunities.

Figure 2-7 provides an overview of the four sectors and the issues covered by each TWG.

Figure 2-7. Effects of Climate Change on Each Sector.