22. Alaska and the Arctic

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Key Messages

1. **Summer sea ice is receding rapidly and is projected to disappear by mid-century. This is altering marine ecosystems and leading to greater ship access, offshore development opportunity, and increased community vulnerability to coastal erosion.**
2. **Most glaciers in Alaska and British Columbia are shrinking, a trend that is expected to continue. This shrinkage contributes 20% to 30% as much to sea level rise as does shrinkage of the Greenland Ice Sheet. Rapid glacier melt in Alaska has implications for hydropower production, ocean circulation patterns, major U.S. fisheries, and global sea level rise.**
3. **Permafrost temperatures in Alaska are rising, a trend that is expected to continue. Thawing permafrost causes multiple vulnerabilities through drier landscapes, more wildfire, increased cost of maintaining infrastructure, and the release of heat-trapping gases that increase climate warming and jeopardize efforts to offset fossil-fuel emissions through carbon management.**
4. **Current and projected increases in Alaska's ocean temperatures and changes in ocean chemistry are expected to alter the distribution and productivity of Alaska's marine fisheries, which lead the U.S. in commercial value.**
5. The cumulative effects of climate change in Alaska strongly affect Native communities, which are highly vulnerable to these rapid changes but have a deep cultural history of adapting to change.

Introduction

Alaska is America's only arctic region. Its marine, tundra, boreal (northern) forest, and rainforest ecosystems differ from most of those in other states and are relatively intact. Millions of migratory birds, hundreds of thousands of caribou, some of the world's largest salmon runs, a significant proportion of the nation's marine mammals, and half of the nation's fish catch are found in Alaska (NMFS 2010).

Energy production is the main driver of the state's economy, providing over 80% of state government revenue and thousands of jobs (Leask et al. 2001). Continuing pressure for oil, gas, and mineral development on land and offshore in ice-covered waters increases the demand for infrastructure, placing additional stresses on ecosystems. Climate also affects hydropower generation (Cherry et al. 2010). Mining and fisheries are the second and third largest industries in the state, with tourism rapidly increasing since the 1990s (Leask et al. 2001). Fisheries are vulnerable to changes in fish abundance and distribution that result from both climate change and fishing pressure. Tourism might respond positively to warmer springs and autumns (Yu et al. 2009) but negatively to less favorable conditions for winter activities and increased summer smoke from wildfire (Trainor et al. 2009).

Alaska is home to 40% (229 of 566) of the federally recognized tribes in the U.S. (BIA 2012). The small number of jobs, high cost of living, and rapid social change in rural, predominantly Native communities make them highly vulnerable to climate change through impacts on traditional hunting and fishing and cultural connection to the land and sea. Because most of these communities are not connected to the state's road system or electrical grid, costs are high, and it is challenging to supply food, fuel, materials, health care, and other services. However, Alaskan Native communities have for centuries dealt with scarcity and high environmental variability and thus have deep cultural reservoirs of flexibility and adaptability. Climate impacts on these communities are magnified by additional social and economic stresses.

Observed Climate Change

Over the past 60 years, Alaska has warmed more than twice as rapidly as the rest of the U.S., with state-wide average annual air temperature increasing by 3°F and average winter temperature by 6°F. This warming involves more extremely hot days and fewer extremely cold days (Stewart et al. 2013; U.S. Global Climate Change Science Program 2008). Because of its cold-adapted features and rapid warming, climate-change impacts on Alaska are already pronounced, including earlier spring snowmelt, reduced sea ice, widespread glacier retreat, warmer permafrost, drier landscapes, and more extensive insect outbreaks and wildfire, as described below.

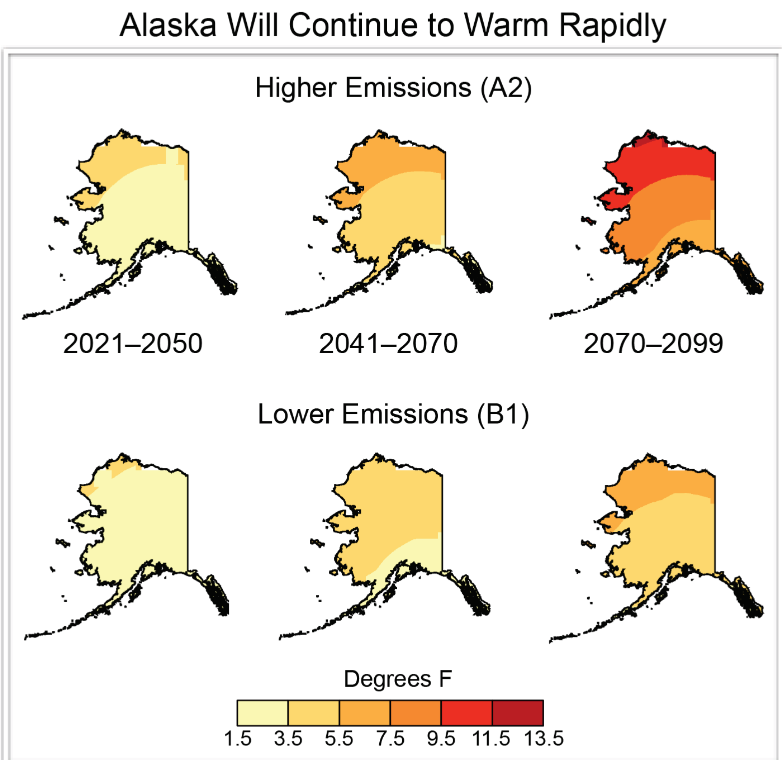

Figure 22.1: Alaska Will Continue to Warm Rapidly

Caption: Northern latitudes are warming faster than more temperate regions, and Alaska has already warmed much faster than the rest of the country. Map shows projected changes in temperature (°F), relative to 1971-1999, projected for Alaska in the early, middle, and late parts of this century, if heat-trapping gas emissions continue to grow (higher emissions, A2), or are substantially reduced (lower emissions, B1). (Figure source: Adapted from Stewart et al. 2013)

Projected Climate Change

Average annual temperatures in Alaska are projected to rise by an additional 2°F to 4°F by the middle of this century. If global emissions continue to increase during this century, temperatures can be expected to rise 10°F to 12°F in the north, 8°F to 10°F in the interior, and 6°F to 8° in the rest of the state. Even with substantial emission reductions, Alaska is projected to warm by 6°F to 8°F in the north and 4°F to 6°F in the rest of the state by the end of the century (Markon et al. 2012; Stewart et al. 2013).

Annual precipitation is projected to increase, especially in northwest Alaska (Stewart et al. 2013). Over the region, the range of model projections for annual precipitation is an increase of 11% to 35%, with an average increase of 25% by late this century if global emissions continue to increase (A2). All models project increases in all four seasons (Stewart et al. 2013). However, increases in evaporation due to higher air temperatures and longer growing seasons are expected to reduce water availability in most of the state (Hinzman et al. 2005). The projected 15 to 25 day increase in length of the snow-free and frost-free seasons (University of Alaska Fairbanks

2012) could improve conditions for agriculture where moisture is adequate, but will reduce water storage and increase the risks of more extensive wildfire and insect outbreaks across much of Alaska (Kasischke et al. 2010; McGuire et al. 2010). Changes in dates of snowmelt and freeze-up would influence seasonal migration of birds and other animals, increase the likelihood and rate of northerly range expansion of native and non-native species, alter the habitats of both ecologically important and endangered species, and affect ocean currents.

Disappearing Sea Ice

Summer sea ice is receding rapidly and is projected to disappear by mid-century. This is altering marine ecosystems and leading to greater ship access, offshore development opportunity, and increased community vulnerability to coastal erosion.

Arctic sea ice extent has declined substantially, especially in late summer when there is now only about half as much sea ice as at the beginning of the satellite record in 1979 (Stroeve et al. 2011). The six Septembers with the lowest ice extent all occurred in the past six years. As sea ice declines, it becomes younger and thinner, and therefore more vulnerable to further melting (Stroeve et al. 2011). Models that best match historical trends project seasonally ice-free northern waters by the 2030s (Stroeve et al. 2007; Wang and Overland 2009, 2012). Within the general downward trend in sea ice there will be periods of a decade or more with both rapid ice loss and temporary recovery (Tietsche et al. 2011), making it challenging to predict short-term changes in ice conditions.

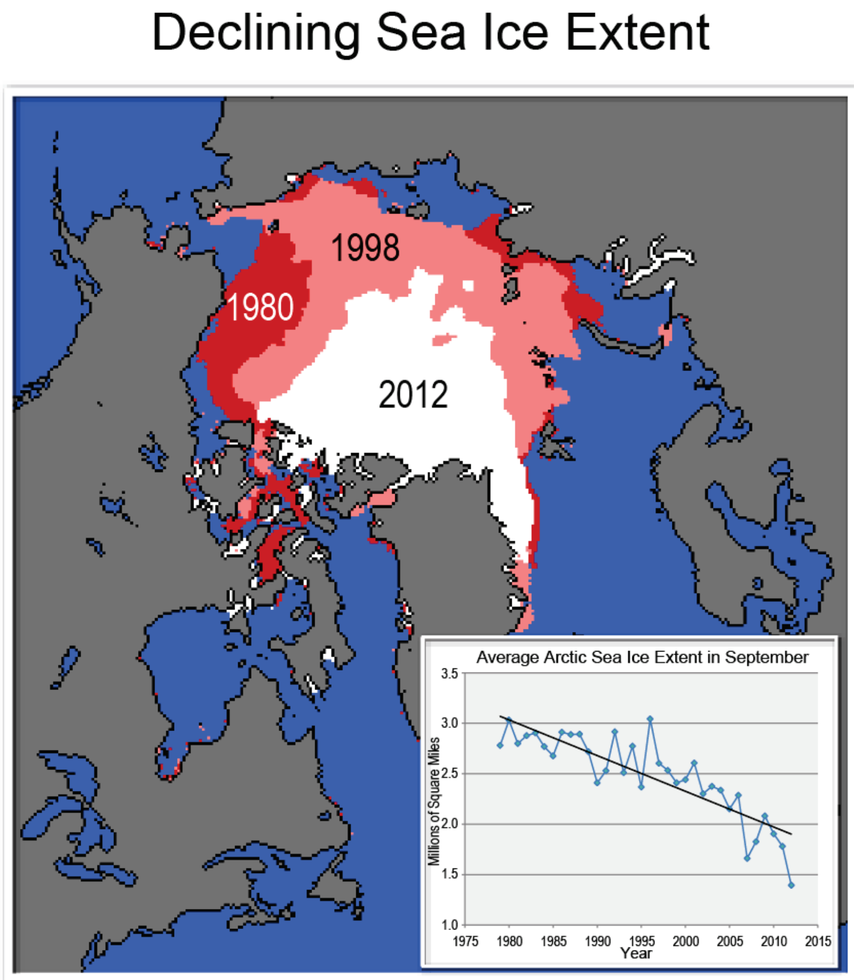

Figure 22.2: Declining Sea Ice Extent

Caption: Average September extent of arctic sea ice in 1980 (second year of record and year of greatest September sea ice extent; outer red boundary), 1998 (about halfway through the time series; outer pink boundary) and 2012 (most recent year of record and year of least September sea ice extent; outer white boundary). September is typically the month when sea ice is least extensive. Inset is the complete time series of average September sea ice extent (Source: NSIDC 2012).

Reductions in sea ice increase the amount of the sun's energy that is absorbed by the ocean. This leads to a self-reinforcing climate cycle, because the warmer ocean melts more ice, leaving more dark open water that gains even more heat. In autumn and winter, there is a strong release of this extra ocean heat back to the atmosphere. This is a key driver of the observed increases in air temperature in the Arctic (Screen and Simmonds 2010; Serreze et al. 2008). This strong warming linked to ice loss can influence atmospheric circulation and patterns of precipitation, both within and beyond the Arctic (for example, Porter et al. 2012). There is growing evidence that this has already occurred (Francis and Vavrus 2012) through more evaporation from the ocean, which increases water vapor in the lower atmosphere (Serreze et al. 2012) and autumn cloud cover west and north of Alaska (Wu and Lee 2012).

Figure 22.3: Sea Ice Loss Brings Big Changes to Arctic Life

Caption: Reductions in sea ice alter food availability for many species from polar bear to walrus, make hunting less safe for Alaska Native hunters, and create more accessibility for Arctic Ocean marine transport. Photographs by Gary Hufford and Carleton Ray; Caleb Pungowiyi; and Patrick Kelley, respectively.

With reduced ice extent, the Arctic Ocean is more accessible for marine traffic, including trans-arctic shipping, oil and gas exploration, and tourism. This facilitates access to the substantial deposits of oil and natural gas under the seafloor in the Beaufort and Chukchi seas, as well as raising the risk to people and ecosystems from oil spills and other drilling and maritime-related accidents. An ice-free Arctic Ocean also increases sovereignty and security concerns as a result of potential new international disputes and increased possibilities for military and commercial marine traffic between the Pacific and Atlantic Oceans (Markon et al. 2012).

Polar bears are one of the most sensitive arctic marine mammals to climate warming because they spend most of their lives on sea ice (Laidre et al. 2008). Declining sea ice in northern Alaska is associated with smaller bears, probably because of less successful hunting of ice-dependent seals (Rode et al. 2010; Rode et al. 2012). Although bears typically give birth to cubs in dens on sea ice, increasing numbers of female bears now come ashore in Alaska in the summer and fall (Schliebe et al. 2008) and den on land (Fischbach et al. 2007). In the western Hudson Bay in eastern Canada, sea ice is now absent for three weeks longer than just a few decades ago, resulting in less body fat, reduced survival of both the youngest and oldest bears (Stirling et al. 1999), and a population now estimated to be in decline (Regehr et al. 2007).

Walrus depend on sea ice as a platform for giving birth, nursing, and resting between dives to the seafloor, where they feed (Fay 1982). In recent years, when summer sea ice in the Chukchi Sea retreated over waters that were too deep for walrus to feed (Douglas 2010), large numbers of walrus abandoned the ice and came ashore. The high concentration of animals results in increased competition for food and can lead to stampedes when animals are startled, resulting in trampling of calves (Fischbach et al. 2009). This movement to land first occurred in 2007 and has happened three times since then, suggesting a threshold change in the ecology of walrus.

With the late-summer ice edge located further north than it used to be, storms produce larger waves and more coastal erosion (Markon et al. 2012). At the same time, coastal bluffs that were "cemented" by permafrost are beginning to thaw in response to warmer air and ocean waters and are therefore more vulnerable to erosion (Overeem et al. 2011). Standard defensive adaptation strategies to protect coastal communities from erosion such as use of rock walls, sandbags, and rip-rap have been largely unsuccessful (State of Alaska 2011). Several coastal communities are seeking to relocate to escape erosion but, because of high costs and policy constraints on use of federal funds for community relocation, only one Alaskan village has begun to relocate (Bronen 2011; U.S. Government Accountability Office 2009) (See also Ch. 12: Tribal Lands and Resources)

Box 1. Living on the Front Lines of Climate Change

"Not that long ago the water was far from our village and could not be easily seen from our homes. Today the weather is changing and is slowly taking away our village. Our boardwalks are warped, some of our buildings tilt, the land is sinking and falling away, and the water is close to our homes. The infrastructure that supports our village is compromised and affecting the health and well-being of our community members, especially our children"

Alaska Department of Commerce and Community and Economic Development, (2012)

Newtok, a Yup'ik Eskimo community on the seacoast of western Alaska is on the front lines of climate change. Between October 2004 and May 2006, three storms accelerated the erosion and repeatedly "flooded the village water supply, caused raw sewage to be spread throughout the community, displaced residents from homes, destroyed subsistence food storage, and shut down essential utilities" (U.S. Army Corps of Engineers 2008a). The village landfill, barge ramp, sewage treatment facility, and fuel storage facilities were destroyed or severely damaged (U.S. Army Corps of Engineers 2008b). The loss of the barge landing, which delivered most supplies and heating fuel, created a fuel crisis. Salt water is intruding into the community water supply. Erosion is projected to reach the school, the largest building in the community, by 2017.

Figure 22.4: Newtok, Alaska

Caption: Residents in Newtok, Alaska are living with the effects of climate change, with thawing permafrost, tilting houses, sinking boardwalks, and aging fuel tanks and other infrastructure that cannot be replaced because of laws that prevent public investment in flood-prone localities. Photograph by Stuart Chapin, 2012.

Recognizing the increasing danger from coastal erosion, Newtok has worked for a generation to relocate to a safer location. However, current federal legislation does not authorize federal or state agencies to assist communities in relocating, nor does it authorize them to repair or upgrade storm-damaged infrastructure in flood-prone locations like Newtok (Bronen 2011). Newtok therefore cannot safely remain in its current location nor can it access public funds to adapt to climate change through relocation.

Newtok's situation is not unique. At least two other Alaskan communities, Shishmaref and Kivalina, also face immediate threat from coastal erosion and are seeking to relocate, but have been unsuccessful in doing so. Many of the world's largest cities are coastal and are increasingly exposed to climate-induced flood risks (Nicholls et al. 2007).

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Shrinking Glaciers

Most glaciers in Alaska and British Columbia are shrinking, a trend that is expected to continue. This shrinkage contributes 20% to 30% as much to sea level rise as does shrinkage of the Greenland Ice Sheet. Rapid glacier melt in Alaska has implications for hydropower production, ocean circulation patterns, major U.S. fisheries, and global sea level rise.

Alaska is home to some of the largest glaciers and fastest loss of glacier ice on Earth (Berthier et al. 2010; Jacob et al. 2012; Larsen et al. 2007), primarily as a result of rising temperatures (for example, Arendt et al. 2009; Arendt et al. 2002; Oerlemans 2005). Loss of glacial volume in Alaska and neighboring British Columbia, Canada currently contributes 20% to 30% as much surplus fresh water to the oceans as does the Greenland Ice Sheet – about 40 to 70 gigatons per year (Jacob et al. 2012; Kaser et al. 2006; Luthcke et al. 2008; Pelto 2011; Pritchard et al. 2010; Van Beusekom et al. 2010), comparable to 10% of the annual discharge of the Mississippi River (Dai et al. 2009). Glaciers continue to respond to climate warming for years to decades after warming ceases, so ice loss is expected to continue, even if air temperatures were to remain at current levels. The global decline in glacial and ice-sheet volume is predicted to be one of the largest contributors to global sea level rise during this century (Meier et al. 2007; Radić and Hock 2011).

Water from glacial landscapes is increasingly recognized as an important source of organic carbon (Bhatia et al. 2010; Hood et al. 2009), phosphorus (Hood and Scott 2008), and iron (Schroth et al. 2011) that contribute to the high productivity of nearshore fisheries (Fellman et al. 2010; Hood and Berner 2009; Hood et al. 2009; Royer and Grosch 2006).

Glaciers supply about half of the total freshwater input to the Gulf of Alaska (Neal et al. 2010). Glacier retreat currently increases river discharge and hydropower potential in southcentral and southeast Alaska but over the longer term might reduce water input to reservoirs and therefore hydropower resources (Cherry et al. 2010).

Thawing Permafrost

Permafrost temperatures in Alaska are rising, a trend that is expected to continue. Thawing permafrost causes multiple vulnerabilities through drier landscapes, more wildfire, increased cost of maintaining infrastructure, and the release of heat-trapping gases that increase climate warming and jeopardize efforts to offset fossil fuel emissions through carbon management.

Alaska differs from most of the rest of the U.S. in having permafrost – frozen ground that restricts water drainage and therefore strongly influences landscape water balance and the design and maintenance of infrastructure. Alaskan permafrost has warmed about 5°F since the mid-1970s (Osterkamp and Romanovsky 1999; Romanovsky et al. 2010). In Alaska, 73% of land with permafrost is vulnerable to subsidence upon thawing because of its variable-to-high ice content (Jorgenson et al. 2008). Thaw is already occurring in interior and southern Alaska, where permafrost temperatures are near the thaw point (Romanovsky et al. 2010; Romanovsky et al. 2010a). Models project that permafrost in Alaska will continue to thaw (Avis et al. 2011; Euskirchen et al. 2006; Lawrence and Slater 2008), and some models project that near-surface permafrost will be lost entirely from large parts of Alaska by the end of the century (Marchenko et al. 2012).

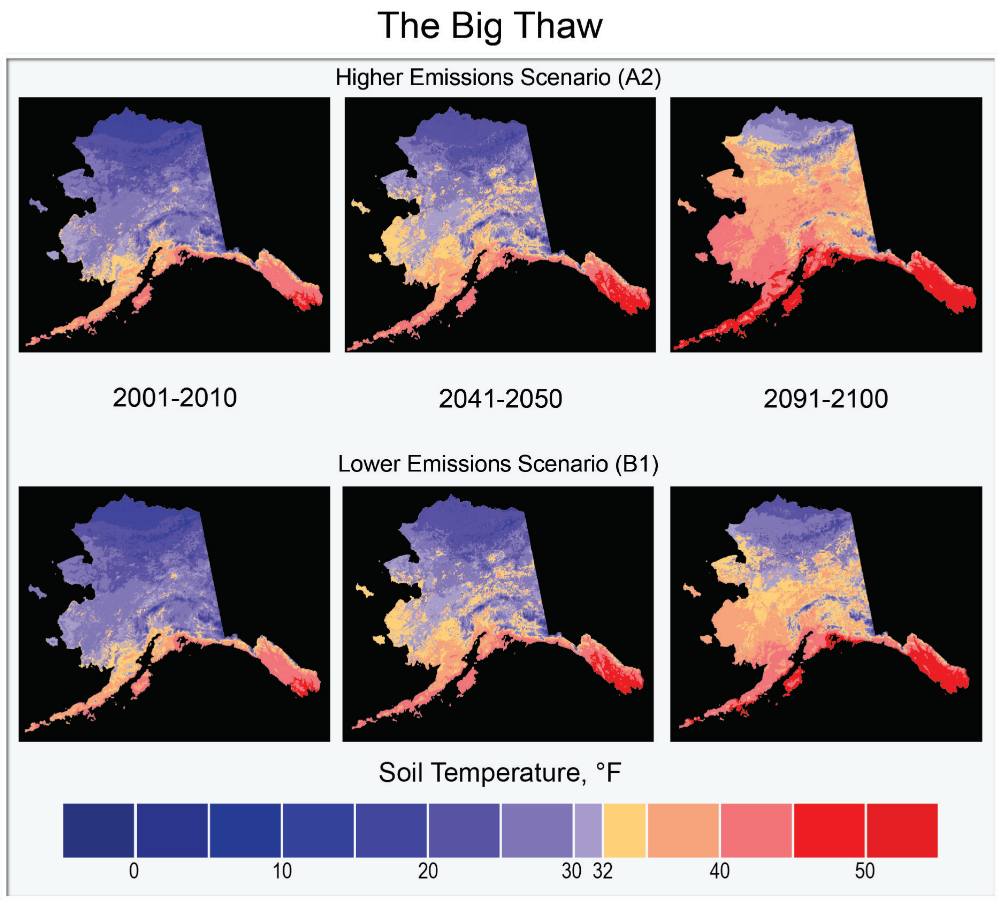

Figure 22.5: The Big Thaw

Caption: Projections for average annual ground temperature at 3.3-foot (one-meter) depth over time if emissions of heat-trapping gases continue to grow (higher emissions scenario, A2), and if they are substantially reduced (lower emissions scenario, B1). Blue shades represent areas below freezing (where permafrost is present at the surface), and yellow and red shades represent areas above freezing (permafrost-free at the surface) (Markon et al. 2012).

Uneven sinking of the ground in response to permafrost thaw is estimated to add between $3.6 and $6.1 billion (10% to 20%) to current costs of maintaining public infrastructure such as buildings, pipelines, roads, and airports over the next 20 years (Larsen et al. 2008). In rural Alaska, permafrost thaw will likely disrupt community water supplies and sewage systems (Alessa et al. 2008; Jones et al. 2009; White et al. 2007), with negative effects on human health (Brubaker et al. 2011). The time during which oil and gas exploration is allowed on tundra has decreased by 50% since the 1970s as a result of permafrost vulnerability (Hinzman et al. 2005).

Mounting Expenses from Permafrost Thawing

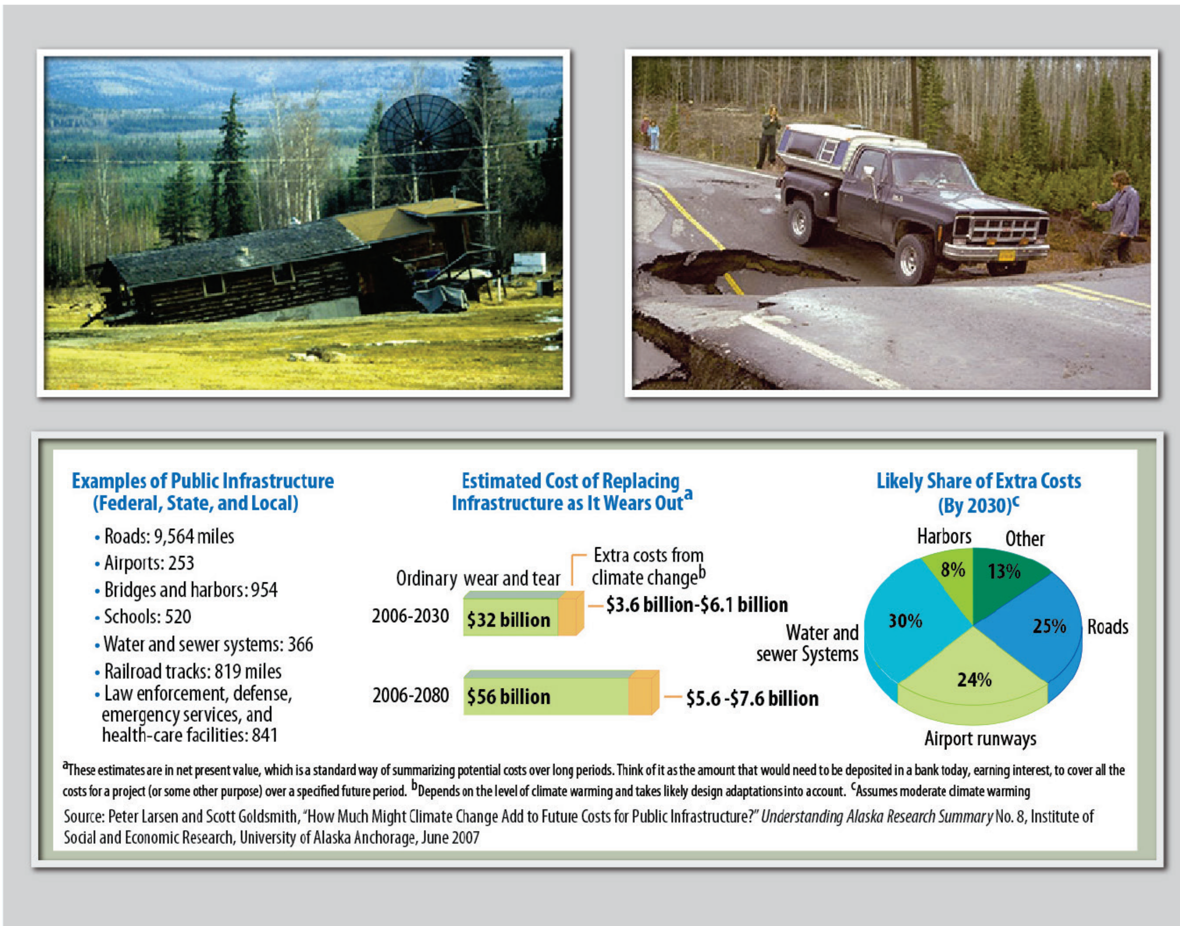

Figure 22.6: Mounting Expenses from Permafrost Thawing

Caption: Effects of permafrost thaw on houses in Interior Alaska (2001, top left), roads in eastern Alaska (1982, top right), and the estimated costs (with and without permafrost thaw) of replacing public infrastructure in Alaska (Larsen et al. 2008). Photographs by Larry Hinzman and Joe Moore.

On average, lakes have decreased in area in the last 50 years in the southern two-thirds of Alaska (Klein et al. 2005; Riordan et al. 2006; Roach 2011; Rover et al. 2012), due to a combination of permafrost thaw, greater evaporation in a warmer climate, and increased carbon accumulation during a longer season for plant growth. In some places, however, lakes are getting larger because of lateral permafrost degradation (Roach et al. 2011). Future permafrost thaw will likely increase lake area in areas of continuous permafrost and decrease lake area in the discontinuous permafrost zone (Avis et al. 2011).

Drying Lakes and Changing Habitat

Figure 22.7: Drying Lakes and Changing Habitat

Caption: Progressive lake drying in northern forest wetlands in the Yukon Flats National Wildlife Refuge, Alaska. Foreground orange area was once a lake. Mid-ground lake once extended to the shrub. Photograph by May-Le Ng.

A continuation of the current drying of Alaskan lakes and wetlands could affect waterfowl management nationally because Alaska accounts for 81% of the National Wildlife Refuge System and provides breeding habitat for millions of migratory birds that winter in more southerly regions of North America and on other continents (Griffith and McGuire 2008). Wetland loss would also reduce waterfowl harvest in Alaska, where it is an important food source for Native Peoples.

Both wetland drying and the increased frequency of warm dry summers and associated thunderstorms have led to more large fires in the last ten years than in any decade since record-keeping began in the 1940s (Kasischke et al. 2010). In Alaskan tundra, which was too cold and wet to support extensive fires for approximately the last 5,000 years (Hu et al. 2010), a single large fire in 2007 released as much carbon to the atmosphere as had been absorbed by the entire circumpolar arctic tundra during the previous quarter-century (Mack et al. 2011). Even if climate warming were curtailed by reducing heat-trapping gas (also known as greenhouse gas) emissions (as in the B1 scenario), the annual area burned in Alaska is projected to double by mid-century and to triple by the end of the century (Balshi et al. 2008), thus fostering a reinforcing cycle of increased heat-trapping gases, higher temperatures, and increased fires. In addition, thick, smog-like smoke produced in years of extensive wildfire represents a human health risk (Alaska Department of Air Quality 2011). More extensive and severe wildfires could shift the forests of Interior Alaska during this century from dominance by spruce to broadleaf trees for the first time in the past 4,000 to 6,000 years (Barrett et al. 2011; Johnstone et al. 2011).

Wildfire has mixed results on habitat: It generally improves habitat for berries, mushrooms, and moose (Maier et al. 2005; Nelson et al. 2008), but reduces winter habitat for caribou because lichens, a key winter food source for caribou, require 50 to 100 years to recover after wildfire (Joly et al. 2010; Rupp et al. 2006). These habitat changes are nutritionally and culturally significant for Alaska Native Peoples (Kofinas et al. 2010; Nelson et al. 2008). In addition, species that were introduced along roadways are now spreading onto river floodplains and recently burned forests (Cortes-Burns et al. 2008; Lapina and Carlson 2004), potentially changing the suitability of these lands for timber production and wildlife. Some invasive species are toxic to moose, on which local people depend for food (Grove 2011).

Changes in terrestrial ecosystems in Alaska and the Arctic may be influencing the global climate system. Permafrost soils throughout the entire Arctic contain almost twice as much carbon as the atmosphere (Schuur and Abbott 2011). Warming and thawing of these soils increases the release of carbon dioxide and methane through increased decomposition and methane production. Thawing permafrost also delivers organic-rich soils to lake bottoms, where decomposition in the absence of oxygen releases additional methane (Walter et al. 2006). Extensive wildfires also release carbon that contributes to climate warming (Balshi et al. 2008; French et al. 2004; Zhuang et al. 2007). The capacity of the Yukon River Basin in Alaska and adjacent Canada to sequester carbon has been substantially weakened since the 1960s by the combination of warming and thawing of permafrost and by increased wildfire (Yuan et al. 2012). Expansion of tall shrubs and trees into tundra makes the surface darker and rougher, increasing absorption of the sun's energy and further contributing to warming (Chapin et al. 2005). The shorter snow-covered seasons in Alaska further increase energy absorption by the land surface, an effect only slightly offset by the reduced energy absorption of highly reflective post-fire snow-covered landscapes (Euskirchen et al. 2009). This spectrum of changes in Alaskan and other arctic terrestrial ecosystems jeopardizes efforts by society to offset fossil fuel emissions through carbon management (McGuire et al. 2009; Schuur and Abbott 2011).

Changing Ocean Temperatures and Chemistry

Current and projected increases in Alaska's ocean temperatures and changes in ocean chemistry are expected to alter the distribution and productivity of Alaska's marine fisheries, which lead the U.S. in commercial value.

Ocean acidification, rising ocean temperatures, declining sea ice, and other environmental changes interact to affect the location and abundance of marine fish, including those that are commercially important, those used as food by other species, and those used for subsistence (Allison et al. 2011; Cooley and Doney 2009; Doney et al. 2009; Gaines et al. 2003; Pauly 2010; Portner and Knust 2007; Sumaila et al. 2011). These changes have allowed some near-surface fish species such as salmon to expand their range northward along the Alaskan coast (Grebmeier et al. 2010; Grebmeier et al. 2011; Moore and Huntington 2008). In addition, non-native species are invading Alaskan waters more rapidly, primarily through ships releasing ballast waters and bringing southerly species to Alaska (Markon et al. 2012; Ruiz et al. 2000). These species introductions could affect marine ecosystems, including the feeding relationships of commercially important fish.

Overall habitat extent is expected to change as well, though the degree of the range migration will depend upon the life history of particular species. For example, reductions in seasonal sea ice cover and warmer surface temperatures may open up new habitat in polar regions for some important fish species, such as cod, herring, and pollock (Loeng et al. 2005). However, continued presence of cold bottom-water temperatures on the Alaskan continental shelf could limit northward migration into the northern Bering Sea and Chukchi Sea off northwest Alaska (Sigler et al. 2011; Stabeno et al. 2012). In addition, warming may cause reductions in the abundances of some species, such as pollock, in the their current ranges in the Bering Sea (Mueter et al. 2011) and reduce the health of juvenile sockeye salmon, potentially resulting in decreased overwinter survival (Farley et al. 2005). If ocean warming continues, it is unlikely that current fishing pressure on pollock can be sustained (Hunt et al. 2011). Higher temperatures are also likely to increase the frequency of early Chinook salmon migrations, making management of the fishery more challenging (Mundy and Evenson 2011).

The North Pacific Ocean has been identified as "a sentinel region for signs of ocean acidification." Acidifying changes in ocean chemistry have potentially widespread impacts on the marine food web, including commercially important species (National Oceanic Atmospheric Administration Ocean Acidification Steering Committee 2010).

Box 2. Ocean Acidification in Alaska

Ocean waters globally have become 30% more acidic due to absorption of large amounts of human-produced carbon dioxide (CO_2) from the atmosphere. This CO_2 interacts with ocean water to form carbonic acid that lowers the ocean's pH (ocean acidification). The polar ocean is particularly prone to acidification because of low temperature (Orr et al. 2005; Steinacher et al. 2009) and low salt content, the latter resulting from the large fresh water input from melting sea ice (Yamamoto-Kawai et al. 2009) and large rivers. Acidity reduces the capacity of key plankton species and shelled animals to form and maintain shells and other hard parts, and therefore alters the food available to important fish species (Lombard et al. 2010; Moy et al. 2009; Orr et al. 2005). The rising acidity will have particularly strong societal effects on the Bering Sea on Alaska's west coast because of its high productivity of commercial and subsistence fisheries (Cooley and Doney 2009; Sambrotto et al. 2008).

Shelled pteropods, which are tiny planktonic snails near the base of the food chain, respond quickly to acidifying conditions and are an especially critical link in high-latitude food webs, as commercially important species such as salmon depend heavily on them for food (Fabry et al. 2009). A 10% decrease in the population of pteropods could mean a 20% decrease in an adult pink salmon's body weight (Mathis 2011). There was a 45% decrease in pteropod consumption by juvenile pink salmon in the northern Gulf of Alaska between 1999 and 2001, although the reason for this decrease is unknown (Armstrong et al. 2005).

At some times of year, acidification has already reached a critical threshold for organisms living on Alaska's continental shelves. Certain algae and animals that form shells such as clams, oysters, and crab, use carbonate minerals (aragonite and calcite) that dissolve below that threshold. These organisms form a crucial component of the marine food web that sustains life in the rich waters off Alaska's coasts. In addition, Alaska oyster farmers are now indirectly affected by ocean acidification impacts further south because they rely for oyster spat (attached oyster larvae) on Puget Sound farmers who are now directly affected by the recent upwelling of acidic waters along the Washington and Oregon coastline (Donkersloot 2012).

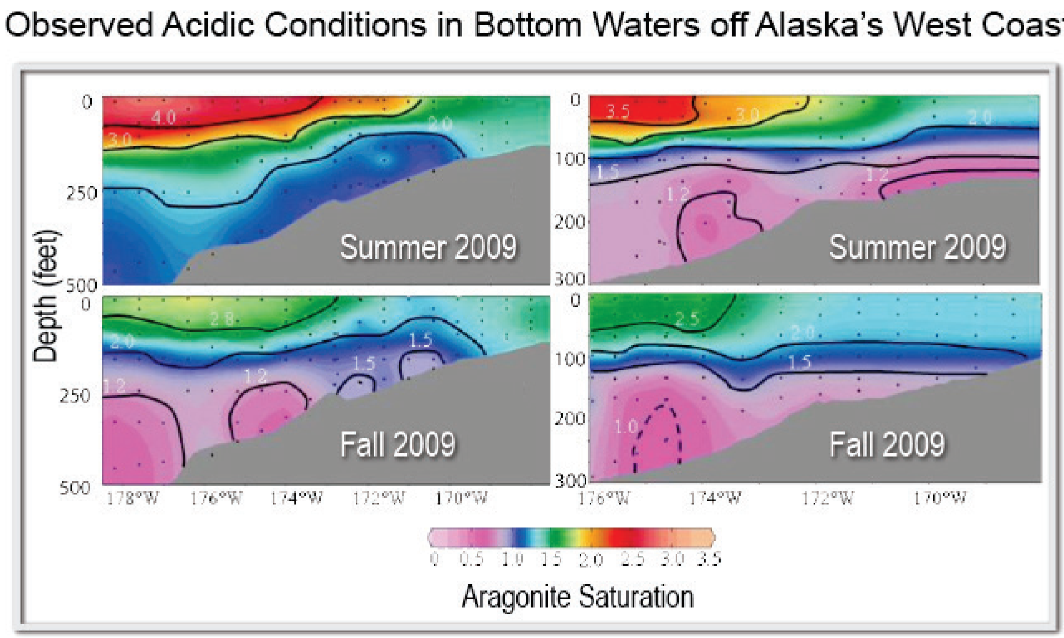

Figure 22.8: Observed Acidic Conditions in Bottom Waters Off Alaska's West Coast

Caption: The acidic conditions under which these minerals (aragonite and calcite) tend to dissolve (known as undersaturation) are shown in the graphs in purple for aragonite and within the dashed lines for calcite. Other colors are favorable for shell formation. Each panel shows the variation in depth of undersaturation along two east-west sampling lines (transect #1 and transect #2) off the west coast of Alaska in summer (upper graphs) and fall (lower graphs). At these sampling times water along the ocean floor was often undersaturated with respect to aragonite but seldom for calcite (Mathis 2011; Mathis et al. 2011). This undersaturation could significantly reduce the capacity of marine animals to produce shells, particularly the commercially important crab species.

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Native Communities

The cumulative effects of climate change in Alaska strongly affect Native communities, which are highly vulnerable to these rapid changes but have a deep cultural history of adapting to change.

With the exception of oil-producing regions in the north, rural Alaska is one of the most extensive areas of poverty in the U.S. in terms of household income, yet residents pay the highest prices for food and fuel (Huskey 1992). Alaska Native Peoples, who are the most numerous residents of this region, depend economically, nutritionally, and culturally on hunting and fishing for their livelihoods (Huntington et al. 2005; Kruse 1991). Hunters speak of thinning sea and river ice that makes harvest of wild foods more dangerous (Berner and Furgal 2005; Loring and Gerlach 2010; McNeeley and Shulski 2011; Moerlein and Carothers 2012), changes to permafrost that alter spring run-off patterns, a northward shift in seal and fish species, and rising sea levels with more extreme tidal fluctuations (Davis 2012; Downing and Cuerrier 2011; Krupnik and Jolly 2002; McNeeley 2012; University of Alaska Fairbanks 2012) (see Ch. 12: Tribal Lands and Resources). Coastal erosion is destroying infrastructure. Impacts of climate change on river ice dynamics and spring flooding are threats to river communities but are complex, and trends have not yet been well documented (Lindsey 2011).

Alaska Coastal Communities Damaged

Figure 22.9: Alaska Coastal Communities Damaged

Caption: One effect of the reduction in Alaska sea ice is that storm surges that used to be buffered by the ice are now causing more shoreline damage. Photos from 2005 show infrastructure damage from coastal erosion in Shishmaref, Alaska. Photographs by Tony Weyiouanna and Gary Braasch.

Major food sources are under stress due to lack of sea ice for marine mammals (Galloway McLean et al. 2009). Thawing of permafrost beneath lakes and ponds that provide drinking water cause food and water security challenges for villages. Sanitation and health problems also result from deteriorating water and sewage systems, and ice cellars traditionally used for storing food are thawing (Alessa et al. 2008; Brubaker et al. 2011) (See also Ch. 12: Tribal Lands and Resources). Warming also brings new diseases to arctic plants and animals, including subsistence food species, posing new health challenges, especially to rural communities

(McLaughlin et al. 2005; Virginia and Yalowitz 2011). Positive health effects of warming include a longer growing season for gardening and agriculture (Markon et al. 2012; Weller 2005).

Development activities in the Arctic (for example, oil and gas, minerals, tourism, and shipping) are of concern to indigenous communities, from both perceived threats and anticipated benefits (Kruse 1991). Greater levels of industrial activity might alter the distribution of species, disrupt subsistence activities, increase the risk of oil spills, and create various social impacts. At the same time, development provides economic opportunities, if it can be harnessed appropriately (Baffrey and Huntington 2010).

Alaska Native Elders say, "We must prepare to adapt." However, the implications of this simple instruction are multi-faceted. Adapting means more than adjusting hunting technologies and foods eaten. It requires learning how to garner information from a rapidly changing environment. Traditional knowledge that enabled people to safely use their environment now provides a guidepost to adapt to climate change as new local observations are linked with western science (Krupnik and Ray 2007; Laidler 2006; Riewe and Oakes 2006). The capacity of Native Peoples to survive for centuries in the harshest of conditions reflects their resilience (Kofinas et al. 2010). Communities must rely not only on improved knowledge of changes that are occurring, but also on strength from within in order to face an uncertain future.

Traceable Accounts

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Key Message Process: A central component of the assessment process was the AK Regional Climate assessment workshop that was held September 12-15, 2012 in Anchorage with approximately 20 attendees; it began the process leading to a foundational Technical Input Report (TIR) (Markon et al. 2012). The report consists of 148 pages of text, 45 figures, 8 tables, and 27 pages of references. Public and private citizens or institutions were consulted and engaged in its preparation by the various agencies and NGO's represented by the 11-member TIR writing team. The key findings of the report were presented at the Alaska Forum on the Environment and in a regularly scheduled, monthly webinar by the Alaska Center for Climate Assessment & Policy, with feedback then incorporated into the report.

The chapter author team engaged in multiple technical discussions via regular teleconferences. These included careful review of the foundational TIR (Markon et al. 2012) and of approximately 85 additional technical inputs provided by the public, as well as the other published literature, and professional judgment. These discussions were followed by expert deliberation of draft key messages by the writing team in a face-to-face meeting before each key message was selected for inclusion in the Report; these discussions were supported by targeted consultation with additional experts by the lead author of each message, and they were based on criteria that help define "key vulnerabilities".

Key message #1/5	**Summer sea ice is receding rapidly and is projected to disappear by mid-century. This is altering marine ecosystems and leading to greater ship access, offshore development opportunity, and increased community vulnerability to coastal erosion.**
Description of evidence base	The key message and supporting chapter text summarize extensive evidence documented in the AK Technical Input (Markon et al. 2012). Technical input reports (85) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Although various models differ in the projected rate of sea ice loss, more recent CMIP5 models (Wang and Overland 2012) that most accurately reconstruct historical sea ice loss project that late-summer sea ice will disappear by the 2030s. Evidence (reported by Markon et al. (2012) is strong that sea ice loss is having the impacts highlighted in the key message. Because the sea ice cover plays such a strong role in human activities and Arctic ecosystems, loss of the ice cover is nearly certain to have substantial impacts.
New information and remaining uncertainties	Important new evidence confirmed many of the findings from a prior Alaska assessment; see (http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/alaska). Evidence from improved models such as Wang and Overland (2012) and updated observational data from satellite, especially new results from the GRACE satellite, clearly show rapid decline in not only extent but also mass and thickness of multi-year ice that was not available in prior assessments. Nearly all studies to date published in the peer-reviewed literature agree that summer Arctic sea ice extent is rapidly declining and that, if heat-trapping gas concentrations continue to rise, an essentially ice-free Arctic ocean will be realized sometime during the 21st century – however there remains uncertainty in the rate of sea ice loss through the 21st century, with the models that most accurately project historical sea ice trends currently suggesting 2021 to 2043 (median 2035).

	Uncertainty across all models stems from a combination of large differences in projections between different climate models, natural climate variability, and future rates of fossil fuel emissions. **Ecosystems:** There is substantial new information that ocean acidification, rising ocean temperatures, declining sea ice, and other environmental changes are affecting the location and abundance of marine fish, including those that are commercially important, those used as food by other species, and those used for subsistence (Allison et al. 2011; Cooley and Doney 2009; Doney et al. 2009; Pauly 2010; Portner and Knust 2007; Sumaila et al. 2011). However, the relative importance of these potential causes of change is highly uncertain. Regarding offshore development, a key uncertainty is the price of fossil fuels. Viable avenues to improving the information base are determining the primary causes of scatter between different climate models and determining which climate models exhibit the best ability to reproduce the observed rate of sea ice loss. **Coastal erosion:** There is new information that lack of sea ice causes storms to produce larger waves and more coastal erosion (Markon et al. 2012). Also, coastal bluffs that were "cemented" by permafrost are beginning to thaw in response to warmer air and ocean waters and are therefore more vulnerable to erosion (Overeem et al. 2011). Standard defensive adaptation strategies to protect coastal communities from erosion such as use of rock walls, sandbags, and rip-rap have been largely unsuccessful (State of Alaska 2011). There remains considerable uncertainty, however, about the spatial patterns of future coastal erosion.
Assessment of confidence based on evidence	**Very high** confidence for summer sea ice decline. High confidence for summer sea ice disappearing by mid-century. **Very high** confidence for altered marine ecosystems, greater ship access, and increased vulnerability of communities to coastal erosion. **High** confidence regarding offshore development.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: See key message #1.

Key message #2/5	**Most glaciers in Alaska and British Columbia are shrinking, a trend that is expected to continue. This shrinkage contributes 20% to 30% as much to sea level rise as does the shrinkage of the Greenland Ice Sheet. Rapid glacier melt in Alaska has implications for hydropower production, ocean circulation patterns, major U.S. fisheries, and global sea level rise.**
Description of evidence base	The key message and supporting chapter text summarize extensive evidence documented in the Alaska Technical Input (Markon et al. 2012). Technical input reports (85) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Evidence that glaciers in Alaska and British Columbia are shrinking is strong and is based on field studies (Pelto 2011; Van Beusekom et al. 2010), energy balance models (Radić and Hock 2011), LIDAR remote sensing (Arendt et al. 2009; Arendt et al. 2002), and satellite data, especially new lines of evidence from the Gravity and Climate Recovery Experiment [GRACE] satellite (Arendt et al. 2009; Berthier et al. 2010; Luthcke et al. 2008; Pritchard et al. 2010). Evidence is also strong that Alaska ice mass loss contributes to global sea level rise (Meier et al. 2007), with latest results permitting quantitative evaluation of losses globally (Jacob et al. 2012). Numerous peer-reviewed publications (including many that are not cited but included in Markon et al. (2012) describe implications of recent increases, but likely longer-term declines, in water input from glacial rivers to reservoirs and therefore hydropower resources (Cherry et al. 2010; Neal et al. 2010). Since glacial rivers account for 47% of the fresh water input to the Gulf of Alaska (Neal et al. 2010) and are an important source of organic carbon (Bhatia et al. 2010; Hood et al. 2009), phosphorus, (Hood and Scott 2008), and iron (Schroth et al. 2011) that contribute to the high productivity of nearshore fisheries (Fellman et al. 2010; Hood and Berner 2009; Hood et al. 2009; Royer and Grosch 2006), it is quite likely that these changes in discharge of glacial rivers will affect ocean circulation patterns and major U.S. fisheries.
New information and remaining uncertainties	Improved models and observational data (cited above) confirmed many of the findings from prior Alaska assessment; see (http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/alaska). As noted above, major advances from GRACE and other datasets now permit analyses of glacier mass loss that were not possible previously. Key uncertainties remain related to large year-to-year variation, the spatial distribution of snow accumulation and melt, and the quantification of glacier calving into the ocean and lakes. Although most large glaciated areas of the state are regularly measured observationally, extrapolation to unmeasured areas carries uncertainties due to large spatial variability. Although there is broad agreement that near-shore circulation in the Gulf of Alaska (GOA) is influenced by the magnitude of freshwater inputs, little is known about the mechanisms of how near-term increases and subsequent longer-term decreases in glacier runoff (as the glaciers disappear) will affect the structure of the Alaska Coastal Current and smaller-scale ocean circulation, both of which have feedback

	to fisheries impacts. The magnitude and timing of effects on hydropower production depend on changes in glacial mass, as described above.
Assessment of confidence based on evidence	**High** confidence that glacier mass loss is high and among the highest on the planet based on physical measurements and satellite observations. **High** confidence that due to glacier mass loss there will be related impacts on hydropower production, ocean circulation and fisheries.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: See key message #1.

Key message #3/5	**Permafrost temperatures in Alaska are rising, a trend that is expected to continue. Thawing permafrost causes multiple vulnerabilities through drier landscapes, more wildfire, increased cost of maintaining infrastructure, and the release of heat-trapping gases that increase climate warming and jeopardize efforts to offset fossil fuel emissions through carbon management.**
Description of evidence base	The key message and supporting chapter text summarize extensive evidence documented in the AK Technical Input (Markon et al. 2012). Technical input reports (85) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Earlier evidence that permafrost is warming (Osterkamp and Romanovsky 1999) has been confirmed and enhanced by more recent studies (Romanovsky et al. 2010; Romanovsky et al. 2010a), and the most recent modeling efforts (e.g., Avis et al. 2011; Marchenko et al. 2012) extend earlier results (Euskirchen et al. 2006; Lawrence and Slater 2008) and project that permafrost will be lost from the upper few meters from large parts of Alaska by the end of the century. Evidence that permafrost thaw leads to drier landscapes (Roach 2011; Rover et al. 2012) is beginning to accumulate, especially as improved remote sensing tools are applied to assess more remote regions (Avis et al. 2011). Satellite data has expanded the capacity to monitor wildfire across the region, providing additional evidence of wildfire extent. This new evidence has led to increased study that is beginning to reveal impacts on ecosystems and wildlife habitat, but much more work is needed to understand the extent of natural resilience. Impacts of permafrost thaw on the maintenance of infrastructure (Alessa et al. 2008; Hinzman et al. 2005; Jones et al. 2009; Larsen et al. 2008; White et al. 2007) is moderate but rapidly accumulating. Evidence that permafrost thaw will jeopardize efforts to offset fossil fuel emissions is suggestive (McGuire et al. 2009; Schuur and Abbott 2011).
New information and remaining uncertainties	Improved models and observational data confirmed many of the findings from prior Alaska assessment; see (http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/alaska). This evidence included results from improved models and updated observational data, and the assessment included insights from stakeholders collected in a series of distributed engagement meetings that confirm it relevance and significance for local decision-makers. Key uncertainties involve: 1) the degree to which increases in evapotranspiration vs. permafrost thaw are leading to drier landscapes; 2) the degree to which these drier landscapes associated with permafrost thaw vs. more severe fire weather associated with climate change is leading to more wildfire; 3) the degree to which the costs of the maintenance of infrastructure are associated with permafrost thaw caused by climate change vs. human disturbance of permafrost; and 4) the degree to which climate change is causing Alaska to be a sink versus a source of greenhouse gases to the atmosphere.

Assessment of confidence based on evidence	**Very high** confidence that permafrost is warming. **High** confidence that landscapes in interior Alaska are getting drier, although the relative importance of different mechanisms is not completely clear. **Medium** confidence that thawing permafrost results in more wildfires. There is **high** confidence that wildfires have been increasing in recent decades, even if it is not clear whether permafrost thaw or hotter and drier weather is more important. **High** confidence that climate change will lead to increased maintenance in future decades. Low confidence that climate change has led to increased maintenance costs of infrastructure in recent decades. **Very high** confidence that Alaska is vulnerable to being a source of greenhouse gases to the atmosphere, even though there is not currently strong evidence that Alaska has already become a source of greenhouse gases to the atmosphere.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Chapter 22: Alaska and the Arctic

Key Message Process: See key message #1.

Key message #4/5	**Current and projected increases in Alaska's ocean temperatures and changes in ocean chemistry are expected to alter the distribution and productivity of Alaska's marine fisheries, which lead the U.S. in commercial value.**
Description of evidence base	The key message and supporting chapter text summarize extensive evidence documented in the AK Technical Input (Markon et al. 2012). Technical input reports (85) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Numerous peer-reviewed publications (including many cited in Markon et al. (2012) describe evidence that ocean temperatures are rising and ocean chemistry, especially pH, is changing. New observational data from buoys and ships document increasing acidity and aragonite undersaturation in Alaskan coastal waters. Accumulating strong evidence suggests that these changes in ocean temperature and chemistry, including pH, will likely affect major Alaska marine fisheries, although the relative importance of these changes and the exact nature of response of each fishery are uncertain (Allison et al. 2011; Cooley and Doney 2009; Doney et al. 2009; Gaines et al. 2003; Pauly 2010; Portner and Knust 2007; Sumaila et al. 2011). Alaska's commercial fisheries account for roughly 50 percent of the United States' total wild landings and led all states in terms of both volume and ex-vessel value of commercial fisheries landings in 2009, with a total of 1.84 million metric tons (MT) worth 1.3 billion dollars (NMFS 2010).
New information and remaining uncertainties	Improved models and observational data confirmed many of the findings from prior Alaska assessment; see (http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/alaska). This evidence included results from improved models and updated observational data, and the assessment included insights from stakeholders collected in a series of distributed engagement meetings that confirm it relevance and significance for local decision-makers. A key uncertainty is what the actual impacts of rising temperatures and changing ocean chemistry, including increase in ocean acidification, will be on a broad range of marine biota and ecosystems. More monitoring is needed to document the extent and location of changes. Additional research is needed to assess how those changes will affect productivity of key fishery resources and their food and prey base.
Assessment of confidence based on evidence	**High** confidence of increased ocean temperatures and changes in chemistry. **Medium** confidence that fisheries will be impacted.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Key Message Process: See key message #1.

Key message #5/5	**The cumulative effects of climate change in Alaska strongly affect Native communities, which are highly vulnerable to these rapid changes but have a deep cultural history of adapting to change.**
Description of evidence base	The key message and supporting chapter text summarize extensive evidence documented in the AK Technical Input (Markon et al. 2012). Technical input reports (85) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. Evidence exists in recorded local observational accounts as well as in the peer reviewed scientific literature of the cumulative effects of climate-related environmental change on Native communities in Alaska as well as that these effects combine with other socio-economic stressors to strain rural Native communities (Galloway McLean et al. 2009; Huntington et al. 2005; Kruse 1991). Increasing attention to impacts of climate change is revealing new aspects (e.g., Baffrey and Huntington 2010; Brubaker et al. 2011). There is also strong evidence for the cultural adaptive capacity of these communities and peoples over time (Kofinas et al. 2010; Krupnik and Ray 2007; Laidler 2006; Lindsey 2011; Riewe and Oakes 2006).
New information and remaining uncertainties	Improved observational data confirmed many of the findings from prior Alaska assessment; see (http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/regional-climate-change-impacts/alaska). The precise mechanisms by which climate change affects Native communities are poorly understood, especially in the context of rapid social, economic, and cultural change. Adaptive responses are poorly documented. More research is needed on the ways that Alaska Natives respond to biophysical climate change and to the factors that enable or constrain adaptation. Alaska Native communities are already being affected by climate-induced changes in the physical and biological environment, from coastal erosion threatening the existence of some communities, to alterations in hunting, fishing, and gathering practices that undermine the intergenerational transfer of culture, skill, and wisdom. At the same time, these communities have a long record of adaptation and flexibility. Whether such adaptability is sufficient to address the challenges of climate change depends both on the speed of climate-induced changes and on the degree to which Native communities are supported rather than constrained in the adaptive measures they need to make.
Assessment of confidence based on evidence	There is **High** confidence that cumulative effects of climate change in Alaska strongly affect Native communities.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

References

Alaska Department of Air Quality, cited 2011: Wildfire smoke/Particulate Information. [Available online at http://www.dec.state.ak.us/air/am/smoke.htm]

Alaska Department of Commerce and Community and Economic Development, 2012: Strategic Management Plan: Newtok to Mertarvik, Alaska Department of Commerce and Community and Economic Development,

Alessa, L., A. Kliskey, R. Busey, L. Hinzman, and D. White, 2008: Freshwater vulnerabilities and resilience on the Seward Peninsula: Integrating multiple dimensions of landscape change. *Global Environmental Change*, **18,** 256-270, [Available online at http://linkinghub.elsevier.com/retrieve/pii/S0959378008000113]

Allison, E.H., M.-C. Badjeck, and K. Meinhold, 2011: The Implications of Global Climate Change for Molluscan Aquaculture. *Shellfish Aquaculture and the Environment*, S. E. Shumway, Ed., Wiley-Blackwell, 461-490. [Available online at http://doi.wiley.com/10.1002/9780470960967.ch17]

Arendt, A.A., S.B. Luthcke, and R. Hock, 2009: Glacier changes in Alaska: can mass-balance models explain GRACE mascon trends? *Annals of Glaciology*, **50,** 148-154

Arendt, A.A., K.A. Echelmeyer, W. Harrison, C.S. Lingle, and V.B. Valentine, 2002: Rapid Wastage of Alaska Glaciers and Their Contribution to Rising Sea Level. *Science*, **297,** 382-386, [Available online at http://www.sciencemag.org/cgi/doi/10.1126/science.1072497]

Armstrong, J.L., J.L. Boldt, A.D. Cross, J.H. Moss, N.D. Davis, K.W. Myers, R.V. Walker, D.A. Beauchamp, and L.J. Haldorson, 2005: Distribution, size, and interannual, seasonal and diel food habits of northern Gulf of Alaska juvenile pink salmon, *Oncorhynchus gorbuscha*. *Deep Sea Research Part II: Topical Studies in Oceanography*, **52,** 247-265, [Available online at http://linkinghub.elsevier.com/retrieve/pii/S0967064504002401]

Avis, C.A., A.J. Weaver, and K.J. Meissner, 2011: Reduction in areal extent of high-latitude wetlands in response to permafrost thaw. *Nature Geoscience*, **4,** 444-448, [Available online at http://www.nature.com/doifinder/10.1038/ngeo1160]

Baffrey, M. and H.P. Huntington, 2010: Social and economic effects of oil and gas activities in the Arctic. *Assessment of Potential Effects of Oil and Gas Activities in the Arctic, a report of the Arctic Monitoring and Assessment Programme of the Arctic Council, 2008*, Arctic Monitoring and Assessment Program, 3.1-3.71-73.71-73.71

Balshi, M.S., A.D. McGuire, P. Duffy, M. Flannigan, J. Walsh, and J. Melillo, 2008: Assessing the response of area burned to changing climate in western boreal North America using a Multivariate Adaptive Regression Splines (MARS) approach. *Global Change Biology*, **15,** 578-600

Barrett, K., A.D. McGuire, E.E. Hoy, and E.S. Kasischke, 2011: Potential shifts in dominant forest cover in interior Alaska driven by variations in fire severity. *Ecological Applications*, **21,** 2380-2396, [Available online at http://www.esajournals.org/doi/abs/10.1890/10-0896.1]

Berner, J. and C. Furgal, 2005: Human Health. *Arctic Climate Impact Assessment*, Cambridge University Press, 863-906. [Available online at www.acia.uaf.edu/pages/scientific.html]

Berthier, E., E. Schiefer, G.K.C. Clarke, B. Menounos, and F. Rémy, 2010: Contribution of Alaskan glaciers to sea-level rise derived from satellite imagery. *Nature Geoscience*, **3,** 92-95, [Available online at http://www.nature.com/doifinder/10.1038/ngeo737]

Bhatia, M.P., S.B. Das, K. Longnecker, M.A. Charette, and E.B. Kujawinski, 2010: Molecular characterization of dissolved organic matter associated with the Greenland ice sheet. *Geochimica et Cosmochimica Acta*, **74,** 3768-3784, [Available online at http://linkinghub.elsevier.com/retrieve/pii/S0016703710001730]

BIA, 2012: Alaska Region Overview, U.S. Department of the Interior

Bronen, R., 2011: Climate-induced relocations – Creating an adaptive governance framework based in human rights doctrine. *New York University Review of Law and Social Change*, **35,** 356-406

Brubaker, M., J. Berner, R. Chavan, and J. Warren, 2011: Climate change and health effects in Northwest Alaska. *Global Health Action*, **4,** 8445 doi: 10.3402/gha.v4i0.8445

Chapin, F.S., M. Strum, M.C. Serreze, J.P. McFadden, J.R. Key, A.H. Lloyd, A.D. McGuire, T.S. Rupp, A.H. Lynch, J.P. Schimel, J. Beringer, W.L. Chapman, H.E. Epstein, E.S. Euskirchen, L.D. Hinzman, G. Jia, C.L. Ping, K.D. Tape, C.D.C. Thompson, D.A. Walker, and J.M. Welker, 2005: Role of Land-Surface Changes in Arctic Summer Warming. *Science*, **310,** 657-660, [Available online at http://www.sciencemag.org/cgi/doi/10.1126/science.1117368]

Cherry, J.E., S. Walker, N. Fresco, S. Trainor, and A. Tidwell, 2010: Impacts of Climate Change and Variability on Hydropower in Southeast Alaska: Planning for a Robust Energy Future 31-31 pp. [Available online at http://ine.uaf.edu/accap/documents/seak_report_final.pdf]

Cooley, S.R. and S.C. Doney, 2009: Anticipating ocean acidification's economic consequences for commercial fisheries. *Environmental Research Letters*, **4,** 8-8, [Available online at http://iopscience.iop.org/1748-9326/4/2/024007/pdf/1748-9326_4_2_024007.pdf]

Cortes-Burns, H., I. Lapina, S. Klein, M. Carlson, and L. Flagstad, 2008: Invasive Plant Species Monitoring and Control: Areas Impacted by 2004 and 2005 Fires in Interior Alaska - A survey of Alaska BLM lands along the Dalton, Steese, and Taylor Highways 162-162 pp. [Available online at http://aknhp.uaa.alaska.edu/wp-content/uploads/2010/11/Cortes_etal_2008.pdf]

Dai, A., T. Qian, K.E. Trenberth, and J.D. Milliman, 2009: Changes in Continental Freshwater Discharge from 1948 to 2004. *Journal of Climate*, **22,** 2773-2792, [Available online at http://journals.ametsoc.org/doi/abs/10.1175/2008JCLI2592.1]

Davis, M., 2012: Climate Change - Our Voices, Sharing Ways Forward, Alaska Forum on the Environment, February 7, 2012

Doney, S.C., V.J. Fabry, R.A. Feely, and J.A. Kleypas, 2009: Ocean Acidification: The Other CO_2 Problem. *Annual Review of Marine Science*, **1,** 169-192 doi: 10.1146/annurev.marine.010908.163834, [Available online at http://www.annualreviews.org/doi/abs/10.1146/annurev.marine.010908.163834]

Donkersloot, R., 2012: Ocean Acidification and Alaska Fisheries - Views and Voices of Alaska's Fisherman, Marine Industries and Coastal Residents, Alaska Marine Conservation Council. [Available online at http://www.akmarine.org/publications/ocean-acidification-alaskas-fisheries-final-full-report-spring-2012]

Douglas, D.C., 2010: Arctic sea ice decline - projected changes in timing and extent of sea ice in the Bering and Chukchi Seas 32-32 pp. [Available online at http://pubs.usgs.gov/of/2010/1176]

Downing, A. and A. Cuerrier, 2011: A synthesis of the impacts of climate change on the First Nations and Inuit of Canada. *Indian Journal of Traditional Knowledge*, **10,** 57-70

Euskirchen, E.S., A.D. McGuire, F.S. Chapin III, S. Yi, and C.C. Thompson, 2009: Changes in vegetation in northern Alaska under scenarios of climate change, 2003-2100: Implications for climate feedbacks. *Ecological Applications*, **19,** 1022-1043

Euskirchen, E.S., A.D. McGuire, D.W. Kicklighter, Q. Zhuang, J.S. Clein, R.J. Dargaville, D.G. Dye, J.S. Kimball, K.C. McDonald, J.M. Melillo, V.E. Romanovsky, and N.V. Smith, 2006: Importance of recent shifts in soil thermal dynamics on growing season length, productivity, and carbon sequestration in terrestrial high-latitude ecosystems. *Global Change Biology*, **12,** 731-750, [Available online at http://doi.wiley.com/10.1111/j.1365-2486.2006.01113.x]

Fabry, V.J., J.B. McClintock, J.T. Mathis, and J.M. Grebmeier, 2009: Ocean Acidification at high latitudes: The Bellwether. *Oceanography*, **22,** 160-171, [Available online at http://www.tos.org/oceanography/archive/22-4_fabry.html]

Farley, J.E.V., J.M. Murphy, B.W. Wing, J.H. Moss, and A. Middleton, 2005: Distribution, Migration Pathways, and size of Western Alaska Juvenile Salmon Along the Eastern Bering Sea Shelf. *Alaska Fishery Research Bulletin*, **11,** 15-26

Fay, F.H., 1982: *Ecology and Biology of the Pacific Walrus, Odobenus rosmarus divergens Illiger*. U.S. Department of the Interior, Fish and Wildlife Service.

Fellman, J.B., R.G.M. Spencer, P.J. Hernes, R.T. Edwards, D.V. D'Amore, and E. Hood, 2010: The impact of glacier runoff on the biodegradability and biochemical composition of terrigenous dissolved organic matter in near-shore marine ecosystems. *Marine Chemistry*, **121,** 112-122, [Available online at http://linkinghub.elsevier.com/retrieve/pii/S0304420310000320]

Fischbach, A.S., S.C. Amstrup, and D.C. Douglas, 2007: Landward and eastward shift of Alaskan polar bear denning associated with recent sea ice changes. *Polar Biology*, **30,** 1395-1405, [Available online at http://www.springerlink.com/index/10.1007/s00300-007-0300-4]

Fischbach, A.S., D.H. Monson, and C.V. Jay, 2009: Enumeration of Pacific Walrus Carcasseson Beaches of the Chukchi Sea in Alaska Following a Mortality Event, September 2009, U.S. Geological Survey. [Available online at http://pubs.usgs.gov/of/2009/1291/]

Francis, J.A. and S.J. Vavrus, 2012: Evidence linking Arctic amplification to extreme weather in mid-latitudes. *Geophysical Research Letters*, **39,** L06801 doi: 10.1029/2012GL051000 [Available online at http://www.agu.org/pubs/crossref/2012/2012GL051000.shtml]

French, N.H.F., P. Goovaerts, and E.S. Kasischke, 2004: Uncertainty in estimating carbon emissions from boreal forest fires. *Journal of Geophysical Research*, **109,** D14S08, [Available online at http://www.agu.org/pubs/crossref/2004/2003JD003635.shtml]

Gaines, S.D., B. Gaylord, and J.L. Largier, 2003: Avoiding Current Oversights in Marine Reserve Design. *Ecological Applications*, **13,** S32-S46-S32-S46

Galloway McLean, K., A. Ramos-Costillo, T. Gross, S. Johnston, M. Vierros, and R. Noa, 2009: Report on the Indigenous Peoples' Global Summitton Climate Change -20-24 April 2009, Anchorage, Alaska, United Nations University – Traditional Knowledge Initiative. [Available online at http://www.unutki.org/downloads/File/Publications/UNU_2009_Climate_Change_Summit_Report.pdf]

Grebmeier, J.M., S.E. Moore, J.E. Overland, K.E. Frey, and R. Gradinger, 2010: Biological Response to Recent Pacific Arctic Sea Ice Retreats. *Eos, Transactions American Geophysical Union*, **91,** 161-161, [Available online at http://www.agu.org/pubs/crossref/2010/2010EO180001.shtml]

Grebmeier, J.M., J.C. Priscu, R. D'Arrigo, H.W. Ducklow, C. Fleener, K.E. Fray, and C. Rosa, 2011: *Frontiers in understanding climate change and polar ecosystems summary of a workshop.* National Academies Press.

Griffith, B. and A.D. McGuire, 2008: National Wildlife Refuges Case Study - Alaska and the Central Flyway. *Annex A of Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystesms and Resources - A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*, S. H. Julius, J. M. West, J. S. Baron, B. Griffith, L. A. Joyce, P. Kareiva, B. D. Keller, M. A. Palmer, C. H. Peterson, and J. M. Scott, Eds., U.S. Environmental Protection Agency, A-36 - A-46-A-36 - A-46

Grove, C., 2011: Chokecherry trees are deadly for 3 Anchorage moose. *Anchorage Daily News*.

Hinzman, L.D., N.D. Bettez, W.R. Bolton, F.S. Chapin III, M.B. Dyurgerov, C.L. Fastie, B. Griffith, R.D. Hollister, A. Hope, H.P. Huntington, A.M. Jensen, G.J. Jia, T. Jorgenson, D.L. Kane, D.R. Klein, G. Kofinas, A.H. Lynch, A.H. Lloyd, A.D. McGuire, F.E. Nelson, W.C. Oechel, T.E. Osterkamp, C.H. Racine, V.E. Romanovsky, R.S. Stone, D.A. Stow, M. Sturm, C.E. Tweedie, G.L. Vourlitis, M.D. Walker, D.A. Walker, P.J. Webber, J.M. Welker, K.S. Winker, and K. Yoshikawa, 2005: Evidence and Implications of Recent Climate Change in Northern Alaska and Other Arctic Regions. *Climatic Change*, **72,** 251-298, [Available online at http://www.springerlink.com/index/10.1007/s10584-005-5352-2]

Hood, E. and D. Scott, 2008: Riverine organic matter and nutrients in southeast Alaska affected by glacial coverage. *Nature Geoscience*, **1,** 583-587, [Available online at http://www.nature.com/doifinder/10.1038/ngeo280]

Hood, E. and L. Berner, 2009: Effects of changing glacial coverage on the physical and biogeochemical properties of coastal streams in southeastern Alaska. *Journal of Geophysical Research*, **114,** G03001, [Available online at http://www.agu.org/pubs/crossref/2009/2009JG000971.shtml]

Hood, E., J. Fellman, R.G.M. Spencer, P.J. Hernes, R. Edwards, D. D’Amore, and D. Scott, 2009: Glaciers as a source of ancient and labile organic matter to the marine environment. *Nature*, **462,** 1044-1047, [Available online at http://www.nature.com/doifinder/10.1038/nature08580]

Hu, F.S., P.E. Higuera, J.E. Walsh, W.L. Chapman, P.A. Duffy, L.B. Brubaker, and M.L. Chipman, 2010: Tundra burning in Alaska: linkages to climatic change and sea ice retreat. *Journal of Geophysical Research*, **115,** G04002

Hunt, G.L., K.O. Coyle, L.B. Eisner, E.V. Farley, R.A. Heintz, F. Mueter, J.M. Napp, J.E. Overland, P.H. Ressler, S. Salo, and P.J. Stabeno, 2011: Climate impacts on eastern Bering Sea foodwebs: a synthesis of new data and an assessment of the Oscillating Control Hypothesis. *ICES Journal of Marine Science*, **68,** 1230-1243, [Available online at http://icesjms.oxfordjournals.org/cgi/doi/10.1093/icesjms/fsr036]

Huntington, H.P., S. Fox, F. Berkes, and I. Krupnik, 2005: The changing Arctic - Indigenous perspectives. *Arctic Climate Impact Assessment*, Cambridge University Press, 61-98

Huskey, L., 1992: The Economy of Village Alaska, University of Alaska Anchorage. [Available online at http://www.iser.uaa.alaska.edu/Publications/fuelcosts_viabilityref/Huskey%20Economy%20of%20Village%20Alaska.pdf]

Jacob, T., J. Wahr, W.T. Pfeffer, and S. Swenson, 2012: Recent contributions of glaciers and ice caps to sea level rise. *Nature*, **482,** 514-518, [Available online at http://www.nature.com/doifinder/10.1038/nature10847]

Johnstone, J.F., T.S. Rupp, M. Olson, and D. Verbyla, 2011: Modeling impacts of fire severity on successional trajectories and future fire behavior in Alaskan boreal forests. *Landscape Ecology*, **26,** 487-500, [Available online at http://www.springerlink.com/content/403k627x2210t162/]

Joly, K., F.S. Chapin III, and D.R. Klein, 2010: Winter habitat selection by caribou in relation to lichen abundance, wildfires, grazing, and landscape characteristics in northwest Alaska. *Ecoscience*, **17,** 321-333

Jones, B.M., C.D. Arp, K.M. Hinkel, R.A. Beck, J.A. Schmutz, and B. Winston, 2009: Arctic Lake Physical Processes and Regimes with Implications for Winter Water Availability and Management in the National Petroleum Reserve Alaska. *Environmental Management*, **43,** 1071-1084, [Available online at http://www.springerlink.com/index/10.1007/s00267-008-9241-0]

Jorgenson, T., K. Yoshikawa, M. Kanevskiy, Y. Shur, V. Romanovsky, S. Marchenko, G. Grosse, J. Brown, and B. Jones, 2008: Permafrost characteristics of Alaska, University of Alaska Fairbanks 183-184 pp

Kaser, G., J.G. Cogley, M.B. Dyurgerov, M.F. Meier, and A. Ohmura, 2006: Mass balance of glaciers and ice caps: Consensus estimates for 1961–2004. *Geophysical Research Letters*, **33,** L19501, [Available online at http://www.agu.org/pubs/crossref/2006/2006GL027511.shtml]

Kasischke, E.S., D.L. Verbyla, T.S. Rupp, A.D. McGuire, K.A. Murphy, R. Jandt, J.L. Barnes, E.E. Hoy, P.A. Duffy, M. Calef, and M.R. Turetsky, 2010: Alaska's changing fire regime — implications for the vulnerability of its boreal forests. *Canadian Journal of Forest Research*, **40,** 1313-1324, [Available online at http://www.nrcresearchpress.com/doi/abs/10.1139/X10-098]

Klein, E., E.E. Berg, and R. Dial, 2005: Wetland drying and succession across the Kenai Peninsula Lowlands, south-central Alaska. *Canadian Journal of Forest Research*, **35,** 1931-1941, [Available online at http://www.nrcresearchpress.com/doi/abs/10.1139/x05-129]

Kofinas, G.P., F.S. Chapin III, S. BurnSilver, J.I. Schmidt, N.L. Fresco, K. Kielland, S. Martin, A. Springsteen, and T.S. Rupp, 2010: Resilience of Athabascan subsistence systems to interior Alaska's changing climate. *Canadian Journal of Forest Research*, **40,** 1347-1359

Krupnik, I. and G.C. Ray, 2007: Pacific walruses, indigenous hunters, and climate change: bridging scientific and indigenous knowledge. *Deep Sea Research Part II: Topical Studies in Oceanography*, **54,** 2946-2957

Krupnik, I.I.i. and D. Jolly, 2002: *The earth is faster now.* Arctic Research Consortium of the United States.

Kruse, J.A., 1991: Alaska Inupiat subsistence and wage employment patterns - understanding individual choice. *Human Organization*, **50,** 317-326

Laidler, G.J., 2006: Inuit and Scientific Perspectives on the Relationship Between Sea Ice and Climate Change: The Ideal Complement? *Climatic Change*, **78,** 407-444

Laidre, K.L., I. Stirling, L.F. Lowry, Ø. Wiig, M.P. Heide-Jørgensen, and S.H. Ferguson, 2008: Quanifying the sensitivity of Arctic marine mammals to climate-induced habitat change. *Ecological Applications*, **18,** S97-S125-S197-S125, [Available online at http://www.esajournals.org/doi/abs/10.1890/06-0546.1]

Lapina, I. and M. Carlson, 2004: Non-Native Plant Species of Susitna, Matanuska, and Copper River Basins: Summary of Survey Findings and Recommendatiosn for Control Actions, University of Alaska Anchorage 64-64 pp. [Available online at http://www.uaa.alaska.edu/enri/publications/upload/Non-native_Plants_final-report.pdf]

Larsen, C.F., R.J. Motyka, A.A. Arendt, K.A. Echelmeyer, and P.E. Geissler, 2007: Glacier changes in southeast Alaska and northwest British Columbia and contribution to sea level rise. *Journal of Geophysical Research*, **112,** 1-11, [Available online at http://www.agu.org/pubs/crossref/2007/2006JF000586.shtml]

Larsen, P., S. Goldsmith, O. Smith, M. Wilson, K. Strzepek, P. Chinowsky, and B. Saylor, 2008: Estimating future costs for Alaska public infrastructure at risk from climate change. *Global Environmental Change*, **18,** 442-457, [Available online at http://linkinghub.elsevier.com/retrieve/pii/S0959378008000216]

Lawrence, D.M. and A.G. Slater, 2008: Incorporating organic soil into a global climate model. *Climate Dynamics*, **30,** 145-160, [Available online at http://www.springerlink.com/index/10.1007/s00382-007-0278-1]

Leask, K., M. Killorin, and S. Martin, cited 2001: Trends in Alaska's People and Economy. Institute of Social and Economic Research, University of Alaska. [Available online at http://www.iser.uaa.alaska.edu/Publications/Alaska2020.pdf]

Lindsey, S., 2011: Spring breakup and ice-jam flooding in Alaska. Alaska Center for Climate Change Assessment and Policy.

Loeng, H., K. Brander, E. Carmack, S. Denisenko, K. Drinkwater, B. Hansen, K. Kovacs, P. Livingston, F. McLaughlin, and E. Saksburg, 2005: Marine Systems. *Arctic Climate Impact Assessment*, C. Symon, L. Arris, and B. Heal, Eds., Cambridge University Press, 453-538

Lombard, F., R.E. de Roacha, J. Bijma, and J.P. Gattuso, 2010: Effect of carbonate ion concentration and irradiance on calcification in planktonic foraminifera. *Biogeosciences*, **7,** 247-255

Loring, P.A. and S.C. Gerlach, 2010: Food Security and Conservation of Yukon River Salmon: Are We Asking Too Much of the Yukon River? *Sustainability*, **2,** 2965-2987, [Available online at http://www.mdpi.com/2071-1050/2/9/2965/]

Luthcke, S.B., A.A. Arendt, D.D. Rowlands, J.J. McCarthy, and C.F. Larsen, 2008: Recent glacier mass changes in the Gulf of Alaska region from GRACE mascon solutions. *Journal of Glaciology*, **54,** 767-777

Mack, M.C., M.S. Bret-Harte, T.N. Hollingsworth, R.R. Jandt, E.A.G. Schuur, G.R. Shaver, and D.L. Verbyla, 2011: Carbon loss from an unprecedented Arctic tundra wildfire. *Nature*, **475,** 489-492, [Available online at http://dx.doi.org/10.1038/nature10283]

Maier, J.A.K., J.M. Ver Hoef, A.D. McGuire, R.T. Bowyer, L. Saperstein, and H.A. Maier, 2005: Distribution and density of moose in relation to landscape characteristics: effects of scale. *Canadian Journal of Forest Research*, **35,** 2233-2243, [Available online at http://www.nrcresearchpress.com/doi/abs/10.1139/x05-123]

Marchenko, S., N.L. Fresco, V. Romanovsky, and T.S. Rupp, cited 2012: Permafrost Dynamics Modeling in Alaska uisng a High Spatial Resolution Dataset. [Available online at http://www.snap.uaf.edu/project_page.php?projectid=10]

Markon, C.J., S.F. Trainor, and S.F. Chapin III, 2012: The United States National Climate Assessment – Alaska Technical Regional Report. U.S. Geological Survey Circular 1379, U. S. Geological Survey 148 pp. [Available online at http://pubs.usgs.gov/circ/1379]

Mathis, J.T., 2011: The extent and controls on ocean acidification in the western Arctic Ocean and adjacent continental shelf seas. *Aritic Report Card*, National Oceanic and Atmpsheric Administration. [Available online at http://www.arctic.noaa.gov./reportcard/ocean_acidification.html]

Mathis, J.T., J.N. Cross, and N.R. Bates, 2011: The Role of Ocean Acidification in Systemic Carbonate Mineral Suppression in the Bering Sea. *Geophysical Research Letters*, **38,** L19602 doi: 10.1029/2011GL048884

McGuire, A.D., R.W. Ruess, A. Lloyd, J. Yarie, J.S. Clein, and G.P. Juday, 2010: Vulnerability of white spruce tree growth in interior Alaska in response to climate variability: dendrochronological, demographic, and experimental perspectives. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere*, **40,** 1197-1209 doi: 10.1139/x09-206, [Available online at <Go to ISI>://WOS:000281208900002]

McGuire, A.D., L.G. Anderson, T.R. Christensen, S. Dallimore, G. Laodong, D.Y. Hayes, M. Heimann, T.D. Lorenson, R.W. MacDonald, and N. Roulet, 2009: Sensitivity of the carbon cycle in the Arctic to climate change. *Ecological Monographs*, **79,** 523-555

McLaughlin, J.A., A. DePaola, C.A. Boop, K.A. Martinek, N.P. Napolilli, C.G. Allison, S.L. Murry, E.C. Thompson, M.M. Bird, and J.P. Middaugh, 2005: Outbreak of *vibrio parahaemolyticus* gastroenteritis associated with Alaskan oysters. *New England Journal of Medicine*, **353,** 1463-1470

McNeeley, S.M., 2012: Examining barriers and opportunities for sustainable adaptation to climate change in Interior Alaska. *Climatic Change*, **111,** 835-857

McNeeley, S.M. and M.D. Shulski, 2011: Anatomy of a closing window: Vulnerability to changing seasonality in Interior Alaska. *Global Environmental Change*, **21,** 464-473, [Available online at http://linkinghub.elsevier.com/retrieve/pii/S0959378011000252]]

Meier, M.F., M.B. Dyurgerov, U.K. Rick, S. O'Neel, W.T. Pfeffer, R.S. Anderson, S.P. Anderson, and A.F. Glazovsky, 2007: Glaciers dominate eustatic sea-level rise in the 21st century. *Science*, **317,** 1064

Moerlein, K.J. and C. Carothers, 2012: Total Environment of Change: Impacts of Climate Change and Social Transitions on Subsistence Fisheries in Northwest Alaska. *Ecology and Society*, **17**, [Available online at http://www.ecologyandsociety.org/vol17/iss1/art10/]

Moore, S.E. and H.P. Huntington, 2008: Arctic Marine Mammals and Climate Change: Impacts and Resilience. *Ecological Applications*, **18,** S157-S165-S157-S165, [Available online at http://www.esajournals.org/doi/abs/10.1890/06-0571.1]

Moy, A.D., W.R. Howard, S.G. Bray, and T.W. Trull, 2009: Reduced calcification in modern Southern Ocean planktonic foraminifera. *Nature Geoscience*, **2,** 276-280, [Available online at http://www.nature.com/doifinder/10.1038/ngeo460]

Mueter, F.J., N.A. Bond, J.N. Ianelli, and A.B. Hollowed, 2011: Expected declines in recruitment of walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea under future climate change. *ICES Journal of Marine Science*, **68,** 1284-1296, [Available online at http://icesjms.oxfordjournals.org/cgi/doi/10.1093/icesjms/fsr022]

Mundy, P.R. and D.F. Evenson, 2011: Environmental controls of phenology of high-latitude Chinook salmon populations of the Yukon River, North America, with application to fishery management. *ICES Journal of Marine Science*, **68,** 1155-1164, [Available online at http://icesjms.oxfordjournals.org/cgi/doi/10.1093/icesjms/fsr080]

National Oceanic Atmospheric Administration Ocean Acidification Steering Committee, 2010: Ch: 24: Oceans. *NOAA Ocean and Great Lakes Acidification Research Plan*, National Oceanic and Atmospheric Administration, 143-143. [Available online at http://www.research.noaa.gov/oceans/ocean-acidification/feel3500_without_budget_rfs.pdf]

Neal, E.G., E. Hood, and K. Smikrud, 2010: Contribution of glacier runoff to freshwater discharge into the Gulf of Alaska. *Geophysical Research Letters*, **37,** 1-5, [Available online at http://www.agu.org/pubs/crossref/2010/2010GL042385.shtml]

Nelson, J.L., E.S. Zavaleta, and F.S. Chapin III, 2008: Boreal Fire Effects on Subsistence Resources in Alaska and Adjacent Canada. *Ecosystems*, **11,** 156-171, [Available online at http://www.springerlink.com/content/a2254319816q781v/]

Nicholls, R.J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. McLean, S. Ragoonaden, and C.D. Woodroffe, 2007: Coastal Systems and Low-lying Areas. *Climate Change 2007: Impacts, Adaptations and Vulnerability*, M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. Van der Linden, and C. E. Hanson, Eds., Cambridge University Press, 316-356

NMFS, 2010: Fisheries Economics of the United States, 2009. U.S. Dept. Commerce, NOAA Tech. Memo. NOAA Fisheries-F/SPO-118. 172p.

NSIDC, cited 2012: Arctic sea ice reaches lowest extent for the year and the satellite record. The National Snow and Ice Data Center. [Available online at http://nsidc.org/news/press/2012_seaiceminimum.html]

Oerlemans, J., 2005: Extracting a Climate Signal from 169 Glacier Records. *Science*, **308,** 675-677, [Available online at http://www.sciencemag.org/cgi/doi/10.1126/science.1107046]

Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R.M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R.G. Najjar, G.-K. Plattner, K.B. Rodgers, C.L. Sabine, J.L. Sarmiento, R. Schlitzer, R.D. Slater, I.J. Totterdell, M.-F. Weirig, Y. Yamanaka, and A. Yool, 2005: Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature*, **437,** 681-686 doi: 10.1038/nature04095, [Available online at http://www.nature.com/nature/journal/v437/n7059/abs/nature04095.html]

Osterkamp, T.E. and V.E. Romanovsky, 1999: Evidence for warming and thawing of discontinuous permafrost in Alaska. *Permafrost and Periglacial Processes*, **10,** 17-37, [Available online at http://doi.wiley.com/10.1002/%28SICI%291099-1530%28199901/03%2910%3A1%3C17%3A%3AAID-PPP303%3E3.0.CO%3B2-4]

Overeem, I., R.S. Anderson, C.W. Wobus, G.D. Clow, F.E. Urban, and N. Matell, 2011: Sea ice loss enhances wave action at the Arctic coast. *Geophysical Research Letters*, **38,** L17503, [Available online at http://www.agu.org/pubs/crossref/2011/2011GL048681.shtml]

Pauly, D., 2010: *Gasping fish and panting squids : oxygen, temperature and the growth of water-breathing animals.* International Ecology Institute.

Pelto, M., 2011: Utility of late summer transient snowline migration rate on Taku Glacier, Alaska. *The Cryosphere*, **5,** 1127-1133

Porter, D.F., J.J. Cassano, and M.C. Serreze, 2012: Implications of reduced Arctic sea ice and a warming Arctic Ocean on the large-scale atmopsheric energy and moisture budgets. *Journal of Geophysical Research*, **in press**

Portner, H.O. and R. Knust, 2007: Climate Change Affects Marine Fishes Through the Oxygen Limitation of Thermal Tolerance. *Science*, **315,** 95-97, [Available online at http://www.sciencemag.org/cgi/doi/10.1126/science.1135471]

Pritchard, H.D., S.B. Luthcke, and A.H. Fleming, 2010: Understanding ice-sheet mass balance: progress in satellite altimetry and gravimetry. *Journal of Glaciology*, **56,** 1151-1161, [Available online at http://openurl.ingenta.com/content/xref?genre=article&issn=0022-1430&volume=56&issue=200&spage=1151]

Radić, V. and R. Hock, 2011: Regionally differentiated contribution of mountain glaciers and ice caps to future sea-level rise. *Nature Geoscience*, **4,** 91-94 doi: 10.1038/ngeo1052 [Available online at http://www.nature.com/ngeo/journal/v4/n2/full/ngeo1052.html]

Regehr, E.V., N.J. Lunn, S.C. Amstrup, and I. Stirling, 2007: Effects of Earlier Sea Ice Breakup on Survival and Population Size of Polar Bears in Western Hudson Bay. *Journal of Wildlife Management*, **71,** 2673-2683, [Available online at http://www.bioone.org/doi/abs/10.2193/2006-180]

Riewe, R. and J. Oakes, Eds., 2006: *Climate Change: Linking Traditional and Scientific Knowledge*. Aboriginal Issues Press, University of Manitoba, 289 pp.

Riordan, B., D. Verbyla, and A.D. McGuire, 2006: Shrinking ponds in subarctic Alaska based on 1950–2002 remotely sensed images. *Journal of Geophysical Research*, **111,** G04002, [Available online at http://www.agu.org/pubs/crossref/2006/2005JG000150.shtml]

Roach, J., 2011: Lake area change in Alaskan National Wildlife Refuages - Magnitude, mechanisms, and heterogeneity, Univeristy of Alaska Fairbanks.

Roach, J., B. Griffith, D. Verbyla, and J. Jones, 2011: Mechanisms influencing changes in lake area in Alaskan boreal forest. *Global Change Biology*, **17,** 2567-2583, [Available online at http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2011.02446.x/abstract]

Rode, K.D., S.C. Amstrup, and E.V. Regehr, 2010: Reduced body size and cub recruitment in polar bears associated with sea ice decline. *Ecological Applications*, **20,** 768-782, [Available online at http://www.esajournals.org/doi/abs/10.1890/08-1036.1]

Rode, K.D., E. Peacock, M. Taylor, I. Stirling, E.W. Born, K.L. Laidre, and Ø. Wiig, 2012: A tale of two polar bear populations: ice habitat, harvest, and body condition. *Population Ecology*, **54,** 3-18, [Available online at http://www.springerlink.com/index/10.1007/s10144-011-0299-9]

Romanovsky, V.E., S.L. Smith, and H.H. Christiansen, 2010: Permafrost thermal state in the polar Northern Hemisphere during the international polar year 2007-2009: A synthesis. *Permafrost and Periglacial Processes*, **21,** 106-116 doi: 10.1002/ppp.689, [Available online at http://doi.wiley.com/10.1002/ppp.689]

Romanovsky, V.E., D.S. Drozdov, N.G. Oberman, G.V. Malkova, A.L. Kholodov, S.S. Marchenko, N.G. Moskalenko, D.O. Sergeev, N.G. Ukraintseva, A.A. Abramov, D.A. Gilichinsky, and A.A. Vasiliev, 2010a: Thermal state of permafrost in Russia. *Permafrost and Periglacial Processes*, **21,** 136-155, [Available online at http://doi.wiley.com/10.1002/ppp.683]

Rover, J., L. Ji, B.K. Wylie, and L.L. Tieszen, 2012: Establishing water body areal extent trends in interior Alaska from multi-temporal Landsat data. *Remote Sensing Letters*, **3,** 595-604, [Available online at http://www.tandfonline.com/doi/abs/10.1080/01431161.2011.643507]

Royer, T.C. and C.E. Grosch, 2006: Ocean warming and freshening in the northern Gulf of Alaska. *Geophysical Research Letters*, **33,** L16605, [Available online at http://www.agu.org/pubs/crossref/2006/2006GL026767.shtml]

Ruiz, G.M., P. Fofonoff, J. Carlton, M.J. Wonham, and A.H. Hines, 2000: Invasion of Coastal Marine Communities in North America: Apparent Patterns, Processes, and Biases. *Annual Review of Ecology and Systematics*, **31,** 481-531

Rupp, T.S., M. Olson, L.G. Adams, B.W. Dale, K. Joly, J. Henkelman, W.B. Collins, and A.M. Starfield, 2006: Simulating the Influences of Various Fire Regimes on Caribou Winter Habitat. *Ecological Applications*, **16,** 1730-1743, [Available online at http://www.esajournals.org/doi/abs/10.1890/1051-0761%282006%29016%5B1730%3ASTIOVF%5D2.0.CO%3B2]

Sambrotto, R.N., C. Mordy, S.I. Zeeman, P.J. Stabeno, and S.A. Macklin, 2008: Physical forcing and nutrient conditions associated with patterns of Chl a and phytoplankton productivity in the southeastern Bering Sea during summer. *Deep Sea Research Part II: Topical Studies in Oceanography*, **55,** 1745-1760, [Available online at http://linkinghub.elsevier.com/retrieve/pii/S0967064508001227]

Schliebe, S., K.D. Rode, J.S. Gleason, J. Wilder, K. Proffitt, T.J. Evans, and S. Miller, 2008: Effects of sea ice extent and food availability on spatial and temporal distribution of polar bears during the fall open-water period in the Southern Beaufort Sea. *Polar Biology*, **31,** 999-1010, [Available online at http://www.springerlink.com/index/10.1007/s00300-008-0439-7]

Schroth, A.W., J. Crusius, F. Chever, B.C. Bostick, and O.J. Rouxel, 2011: Glacial influence on the geochemistry of riverine iron fluxes to the Gulf of Alaska and effects of deglaciation. *Geophysical Research Letters*, **38,** L16605, [Available online at http://www.agu.org/pubs/crossref/2011/2011GL048367.shtml]

Schuur, E.A.G. and B. Abbott, 2011: Climate change: High risk of permafrost thaw. *Nature*, **480,** 32-33, [Available online at http://dx.doi.org/10.1038/480032a]

Screen, J.A. and I. Simmonds, 2010: The central role of diminishing sea ice in recent Arctic temperature amplification. *Nature*, **464,** 1334-1337, [Available online at http://www.nature.com/doifinder/10.1038/nature09051]

Serreze, M.C., A.P. Barrett, and J. Stroeve, 2012: Recent changes in tropospheric water vapor over the Arctic as assessed from radiosondes and atmospheric reanalyses. *Journal of Geophysical Research*, **117,** D10104, [Available online at http://www.agu.org/pubs/crossref/pip/2011JD017421.shtml]

Serreze, M.C., A.P. Barrett, J.C. Stroeve, D.N. Kindig, and M.M. Holland, 2008: The emergence of surface-based Arctic amplification. *The Cryosphere Discussions*, **2,** 601-622, [Available online at http://www.the-cryosphere-discuss.net/2/601/2008/]

Sigler, M.F., M. Renner, S.L. Danielson, L.B. Eisner, R.R. Lauth, K.J. Kuletz, E.A. Longerwell, and G.L. Hunt, 2011: Fluxes, Fins, and Feathers: Relationships among the Bering, Chukchi, and Beaufort Seas in a Time of Climate Change. *Oceanography*, **24,** 250-265

Stabeno, P.J., E.V. Farley Jr, N.B. Kachel, S. Moore, C.W. Mordy, J.M. Napp, J.E. Overland, A.I. Pinchuk, and M.F. Sigler, 2012: A comparison of the physics of the northern and southern shelves of the eastern Bering Sea and some implications for the ecosystem. *Deep Sea Research Part II: Topical Studies in Oceanography*, **65-70,** 14-30

State of Alaska, cited 2011: Adaptation Advisory Group of the Governor's Sub-Cabinet on Climate Change. [Available online at http://www.climatechange.alaska.gov/aag/aag.htm]

Steinacher, M., F. Joos, T.L. Frölicher, G.K. Plattner, and S.C. Doney, 2009: Imminent ocean acidification in the Arctic projected with the NCAR global coupled carbon cycle-climate model. *Biogeosciences*, **6,** 515-533 doi: 10.5194/bg-6-515-2009, [Available online at http://www.biogeosciences.net/6/515/2009/]

Stewart, B.C., K.E. Kunkel, L.E. Stevens, L. Sun, and J.E. Walsh, 2013: *Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 7. Climate of Alaska*, NOAA Technical Report NESDIS 142-7, 60 pp.

Stirling, I., M.J. Lunn, and J. Iacozza, 1999: Long-term trends in the population ecology of polar bears in Western Hudson Bay in relation to climate change. *Arctic*, **52,** 294-306

Stroeve, J., M.M. Holland, W. Meier, T. Scambos, and M. Serreze, 2007: Arctic sea ice decline: Faster than forecast. *Geophysical Research Letters*, **34,** L09501, [Available online at http://www.agu.org/pubs/crossref/2007/2007GL029703.shtml]

Stroeve, J.C., M.C. Serreze, M.M. Holland, J.E. Kay, J. Malanik, and A.P. Barrett, 2011: The Arctic's rapidly shrinking sea ice cover: a research synthesis. *Climatic Change*, **110,** 1005-1027, [Available online at http://www.springerlink.com/index/10.1007/s10584-011-0101-1]

Sumaila, U.R., W.W.L. Cheung, V.W.Y. Lam, D. Pauly, and S. Herrick, 2011: Climate change impacts on the biophysics and economics of world fisheries. *Nature Climate Change*, **1,** 449-456, [Available online at http://www.nature.com/doifinder/10.1038/nclimate1301]

Tietsche, S., D. Notz, J.H. Jungclaus, and J. Marotzke, 2011: Recovery mechanisms of Arctic summer sea ice. *Geophysical Research Letters*, **38,** L02707, [Available online at http://www.agu.org/pubs/crossref/2011/2010GL045698.shtml]

Trainor, S.F., F. Stuart Chapin III, A.D. McGuire, M. Calef, N. Fresco, M. Kwart, P. Duffy, A.L. Lovecraft, T.S. Rupp, L.O. DeWilde, O. Huntington, and D.C. Natcher, 2009: Vulnerability and Adaptation to Climate-Related Fire Impacts in Rural and Urban Interior Alaska. *Polar Research*, **28,** 100-118

U.S. Army Corps of Engineers, 2008a: Revised environmental assessment: finding of no significant impact: Newtok Evacuation Center: Mertarvik, Nelson Island, Alaska.

U.S. Army Corps of Engineers 2008b: Section 117 Project fact sheet. A. U.S. Army Corps of Engineers, Ed.

U.S. Global Climate Change Science Program, 2008: Weather and Climate Extremes in a Changing Climate - Regions of Focus - North America, Hawaii, Caribean, and U.S. Pacific Islands, Department of Commerce, NOAA's National Climatic Data Center 164-164 pp. [Available online at http://downloads.climatescience.gov/sap/sap3-3/sap3-3-final-all.pdf]

U.S. Government Accountability Office, 2009: Limited Progress has been made on Relocating Villages Threatened by Flooding and Erosion. [Available online at http://www.gao.gov/products/GAO-09-551]

University of Alaska Fairbanks, cited 2012: Scenarios for Alaska and Arctic Planning. [Available online at http://snap.uaf.edu/]

Van Beusekom, A.E., S.R. O'Neel, R.S. March, L.C. Sass, and L.H. Cox, 2010: Re-analysis of Alaskan benchmark glacier mass-balance data using the index method. *U.S. Geological Survey Scientific Investigations Report*, **5247,** 14 pages

Virginia, R.A. and K.S. Yalowitz, 2011: A New Paradigm for Arctic Health - Challenges and Responces to Rapid Climate Change, Environmental, and Social Change - Report of an International Workshop, May 23-25, 2011, The Dickey Center for International Understanding, Dartmouth College and the University of the Arctic

Walter, K.M., S.A. Zimov, J.P. Chanton, D. Verbyla, and F.S. Chapin, 2006: Methane bubbling from Siberian thaw lakes as a positive feedback to climate warming. *Nature*, **443,** 71-75 doi: 10.1038/nature05040, [Available online at <Go to ISI>://WOS:000240313900041]

Wang, M. and J.E. Overland, 2009: A sea ice free summer Arctic within 30 years. *Geophysical Research Letters*, **36,** 5, [Available online at http://www.agu.org/pubs/crossref/2009/2009GL037820.shtml]

——, 2012: A sea ice free summer Arctic within 30 years: An update from CMIP5 models. *Geophysical Research Letters*, **39,** L18501

Weller, G., 2005: Summary and Synthesis of the ACIA. *Arctic Climate Impact Assessment*, Cambridge University Press. [Available online at http://www.acia.uaf.edu]

White, D.M., S.C. Gerlach, P. Loring, A.C. Tidwell, and M.C. Chambers, 2007: Food and water security in a changing arctic climate. *Environmental Research Letters*, **2,** 045018-045018, [Available online at http://stacks.iop.org/1748-9326/2/i=4/a=045018?key=crossref.d4de7703f8707536a0c7fa3cf28caf94]

Wu, D.L. and J.N. Lee, 2012: Arctic low cloud changes as observed by MISR and CALIOP: Implication for the enhanced autumnal warming and sea ice loss. *Journal of Geophysical Research*, **117**, [Available online at http://www.agu.org/pubs/crossref/2012/2011JD017050.shtml]

Yamamoto-Kawai, M., F.A. McLaughlin, E.C. Carmack, S. Nishino, and K. Shimada, 2009: Aragonite Undersaturation in the Arctic Ocean: Effects of Ocean Acidification and Sea Ice Melt. *Science*, **326,** 1098-1100 doi: 10.1126/science.1174190 [Available online at http://www.sciencemag.org/content/326/5956/1098.abstract]

Yu, G., Z. Schwartz, and J. Walsh, 2009: A weather-resolving index for assessing the impact of climate change on tourism related climate resources. *Climatic Change*, **95,** 551-573 doi: 10.1007/s10584-009-9565-7, [Available online at http://dx.doi.org/10.1007/s10584-009-9565-7]

Yuan, F.M., S.-H. Yi, A.D. McGuire, K.D. Johnson, J.-J. Liang, J.W. Harden, E. Kasischke, and W.A. Kurz, 2012: Assessment of historical boreal forest carbon dynamics in the Yukon River Basin - Relative roles of climate warming and fire regime changes. *Ecological Applications*, **in press**

Zhuang, Q., J.M. Melillo, A.D. McGuire, D.W. Kicklighter, R.G. Prinn, P.A. Steudler, B.S. Felzer, and S. Hu, 2007: Net Emissions of CH_4 and CO_2 in Alaska - Implications for the region's Greenhouse Gas Budget. *Ecological Applications*, **17,** 203-212, [Available online at http://www.esajournals.org/doi/abs/10.1890/1051-0761%282007%29017%5B0203%3ANEOCAC%5D2.0.CO%3B2]