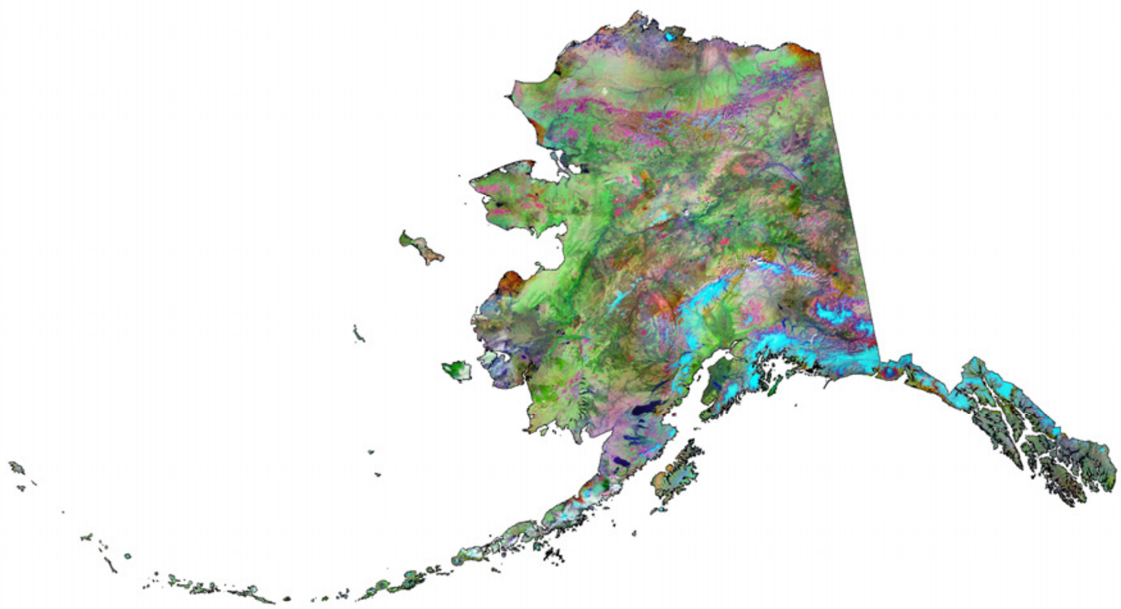
The Face of Alaska: *A look at land cover and the potential drivers of change*

By Benjamin M. Jones, Research Geographer, Alaska Science Center, U.S. Geological Survey



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The Face of Alaska: *A look at land cover and the potential drivers of change*

By Benjamin M. Jones

Abstract

The purpose of this report is to provide statewide baseline information on the status and potential drivers of land-cover change in Alaska. The information gathered for this report is based on a review and analysis of published literature and consists of prominent factors contributing to the current state of the land surface of Alaska as well as a synthesis of information about the status and trends of the factors affecting the land surface of Alaska. The land surface of Alaska is sparsely populated and the impacts from humans are far less extensive when compared to the contiguous United States. The changes in the population and the economy of Alaska have historically been driven by boom and bust cycles, primarily from mineral discoveries, logging, military expansion, and oil and gas development; however, the changes as a result of these factors have occurred in relatively small, localized areas. Many of the large-scale statewide changes taking place in the land surface however, are a result of natural or climate driven processes as opposed to direct anthropogenic activities. In recent times, reports such as this have become increasingly useful as a means of synthesizing information about the magnitude and frequency of changes imparted by natural and anthropogenic forces. Thus, it is essential to assess the current state of the land surface of Alaska and identify apparent trends in the surficial changes that are occurring in order to be prepared for the future.

Introduction

Alaska is the largest state in the Nation. It spans a land area of around 1,500,000 km^2. This corresponds to almost one-fifth the size of the conterminous United States (Figure 1). The northernmost point in Alaska is Point Barrow (71°23'N, 156°29'W) and the southernmost point is the southern tip of Amatignak Island (51°15'N, 179°06'W), located in the Aleutian Island arc. When considering the east to west expanse of Alaska, the eastern extreme is near Portland Canal in Southeast Alaska (55°00'N, 130°00"W) and the western extreme is Cape Wrangell, Attu Island (52°55'N, 172°27'E). Thus, Alaska spans an area roughly 20° in latitude by 58° in longitude. Alaska crosses the International Date Line, thus with respect to a global geographic perspective that is referenced from the prime meridian in Greenwich, England, it contains the western most location in the United States, Amatignak Island (51°15'N, 179°06'W), as well as the eastern most location in the United States, Pochnoi Point, Semisopochnoi Island (51°57'N, 179°47'E) (Figure 2).

Figure 1. Comparison of Alaska to the contiguous United States. Alaska is nearly one-fifth the size of the lower 48 states.

Alaska is bounded to the east by Canada (a border of 2,475 km), to the north by the Arctic Ocean (Beaufort and Chukchi Sea), to the west by the Bering Sea, and to the south by the Pacific Ocean (Figure 2). Measured in straight distance, the coastline of Alaska is 10,686 km in length. However, if each of the bays, fjords, islands and channels were considered, the length of the coastline of Alaska would be roughly 54,500 km, almost three times that of the conterminous United States.

The average elevation of Alaska is around 580 meters above sea level, but the topography across the state is extremely variable (Figure 3). It ranges from sea level along the Arctic Ocean, Bering Sea, and Pacific Ocean to the summit of Denali (Mt. McKinley) at an elevation of 6,194 meters above sea level. Denali (Mt. McKinley) represents the highest point in North America and it has the highest base-to-summit gain in elevation of any mountain on the surface of the earth, roughly 5,500 m. There are 39 mountain ranges found within the state and 17 of the 20 tallest peaks of the United States are found within these mountain ranges.

The climate across the state is also extremely variable; primarily controlled by elevation, latitude, and distance from the coast (Benson et. al., 1983). The northern region of the state experiences the coldest annual temperatures, however, the interior of the state experiences the greatest differences in temperature annually, and the southeastern region of the state receives the most precipitation.

Another characteristic of the state is the cryosphere or that part of the earth's surface that is perennially frozen (van Everdingen, 2005), which is controlled to a large extent by climate. In Alaska, the cryosphere consists

Figure 2. General geography of Alaska showing large rivers, major cities (black) and places mentioned in the text (red) (data source: Alaska Geospatial Data Clearinghouse).

of ice caps, ice sheets, glaciers, sea ice, lake ice, river ice, snow, and perennially frozen ground (permafrost). Two of the primary components of the cryosphere, glaciers and permafrost, have a large and direct influence on the land surface of Alaska. At present, glaciers cover about 75,000 km^2 of the surface of Alaska and account for nearly 5% of the total land surface (Dyurgerov and Meier, 1997). Most of the glaciers are found in the mountain ranges in the southern part of the state (Chugach Range, Wrangell-St. Elias Range, Alaska Range), while a few are located in the northern part of the state in the Brooks Range. About 82% of the land surface of Alaska is underlain by permafrost which is divided into four generalized categories of permafrost: continuous, discontinuous, sporadic, and isolated. Each of these characteristics refers to the lateral continuity of the permafrost in a regional context (Pewe, 1975). A more detailed description of permafrost is presented in the subsequent chapters.

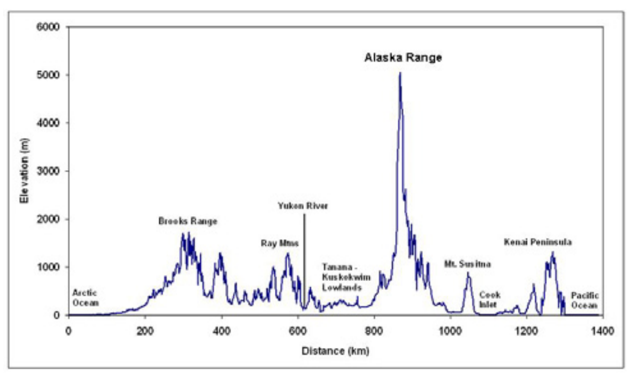


Figure 3. Elevation profile ranging from north to south through Alaska at ~151° W longitude.

Land Ownership

Land ownership within the state has an influence on many of the potential changes that could occur on the land surface and a series of major events have contributed to the current ownership of land in Alaska. The first event occurred in 1867 when the United States government purchased the Alaska Territory from Russia for $70 million. The next major event occurred when Alaska became a state in 1959. At which time, the federal government granted 28% of the land to the state with the caveat that the land was not already designated as federal land, the state chose their sites based on its potential for settlement, potential for resource development, and its potential for recreational land (Alaska Department of Natural Resources, 2000).

In more recent times, two major congressional acts were passed that played a prominent role in the use of land in Alaska – ANSCA and ANILCA. In 1971 Congress passed the Alaska Native Claims Settlement Act (ANSCA). This act granted village and native corporations the rights to 178,000 km^2 and nearly 1 billion dollars in start up funds. These funds were used to establish fixed settlements with modern day amenities; such as, sewage systems, power plants, and runways. The Alaska National Lands Act (ANILCA) was passed in 1980, establishing 220,000 km^2 of national wildlife refuge lands; placed portions of 25 rivers into the national wild and scenic river system; added 13,000 km^2 of national forest land; and 176,000 km^2 of new additions to the national park system. As a consequence, these areas were removed from the pool of land that the state could draw upon.

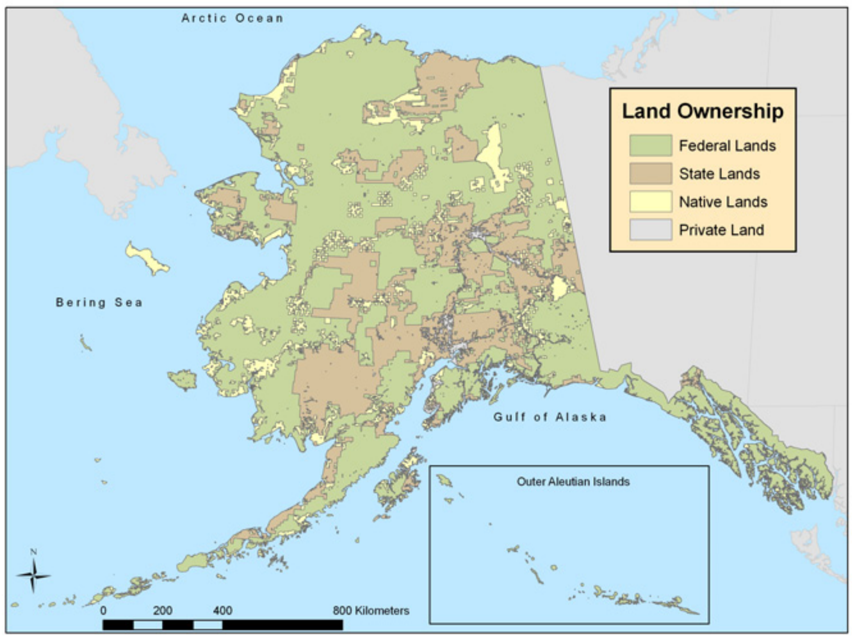


Figure 4. Alaska land status and ownership map. Federal lands constitute the majority of the state, followed by state lands, native lands, and privately owned lands (data source: Alaska Department of Natural Resources).

Overall, the ownership of land within Alaska can be divided into four groups: federal, state, native (private), and other private lands (Figure 4). Through the years following purchase, statehood, and ANILCA, the federal government remains the largest landowner in Alaska at 890,000 km^2 (or 60%). These federal lands include military reservations, national parks, national wildlife refuges, national forests, and the National Petroleum Reserve-Alaska (NPRA). The state owns the second largest proportion of land in Alaska 425,000 km^2 (or 28%), although, to date only about 85% has been allotted (Alaska Department of Natural Resources, 2000). The remainder of the land is considered to be in the private domain consisting of native corporation land (178,000 km^2 or 12%) and all other land owned by individuals (<1%).

Physical Environment

Ecoregions

The sheer vastness of Alaska combined with its latitudinal position, the differences in topography, and its juxtaposition between the frigid Arctic Ocean and the relatively warmer Pacific Ocean has created a landscape that is very diverse. Many of the surficial features change with distance from the coast, altitudinal position, and latitude. These are in a large part driven by variations in abiotic elements, such as the regional climate and the amount of solar insolation that the surface receives. Several different attempts have been made at the division of the state into distinct regions based on variations in climate and ecology (Nowacki et al., 2001; Status and Trends of the Nation's Biological Resources, 1998; Nowacki et al., 1995; Gallant et al., 1995). The most recent attempt by Nowacki et al. (2001) will be referred to in this report which identifies 32 created by using a "tri-archy" based on climate parameters, vegetation response, and disturbance processes (Nowacki et. al., 2001). The ecoregions are combined into three groups at the broadest scale (level 1) and eight groups at the moderate scale (level 2) and establishes a baseline for studying, managing, and understanding the ecosystems of Alaska and their driving processes (Figure 5).

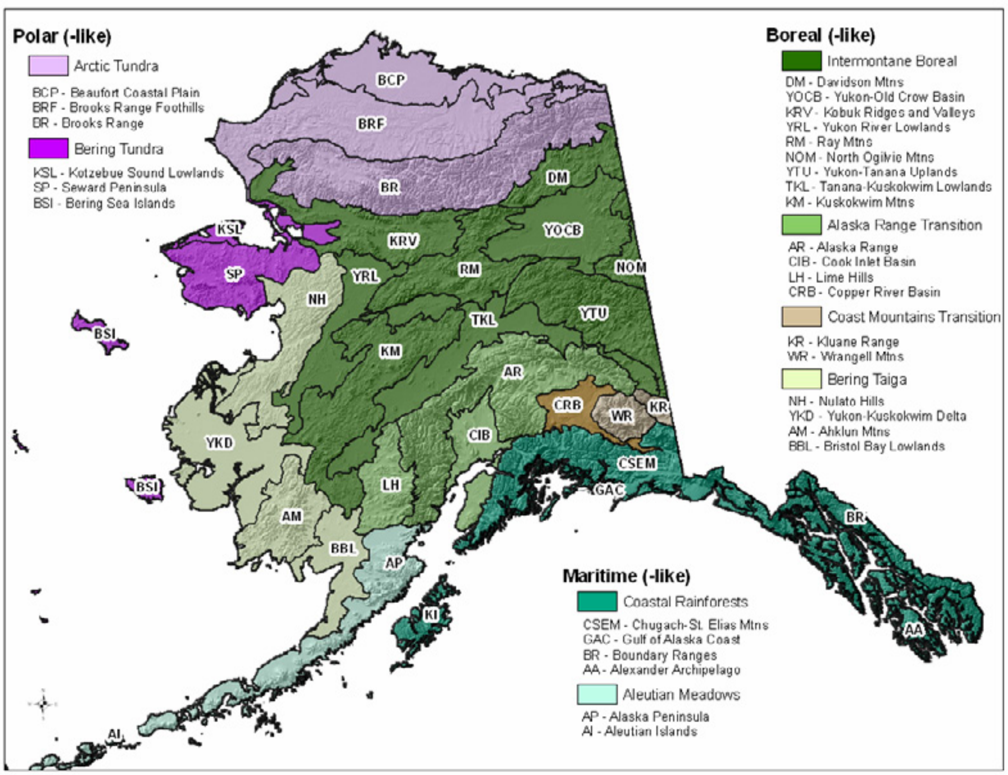


Figure 5. Unified Ecoregions of Alaska (modified from Nowacki et al. 2001; ecoregions have been clipped to Alaska border). Level 1 ecoregions consist of Polar, Boreal, and Maritime like. Level 2 ecoregions are distinguished by color and Level 3 ecoregions are abbreviated on the map and their meaning is conveyed in the legend.

The Level 1 ecoregions consist of Polar, Boreal and Maritime. The key features of the Polar level are non-forested terrain with a cold and dry climate and it covers 24.8% of the land area of Alaska. The Polar level includes the Arctic Tundra and Bering Tundra groups in the Level 2 classification. The Boreal level consists of the

Intermontane Boreal, the Bering Taiga, and Alaska Range Transition and is the dominant Level 1 group in that it covers 56.9% of the surface. This level is identified by a forested landscape with a dry climate, a large seasonal variation in temperature and areas prone to forest fires. The third Level 1 group is the Maritime level. It is restricted to the southern portion of the state and it is the smallest of the Level 1 regions. It covers 18.3% of the land area and it includes the Level 2 groups of the Maritime (Coastal Rainforests, the Coastal Mountains Transition, and the Aluetian Meadows). The Maritime groups are characterized by forested landscapes with a warm and wet climate, limited variation in temperature throughout the season, and areas subject to high wind events.

Forests

The distribution and extent of forests in Alaska are driven by geology, elevation, latitude, climate, insects, plant diseases and animal and human activities. The forests in Alaska are primarily restricted to the Boreal and Maritime ecoregions (Figure 6). Both of these areas however, exhibit a different type of forest community and are subject to different disturbance regimes.

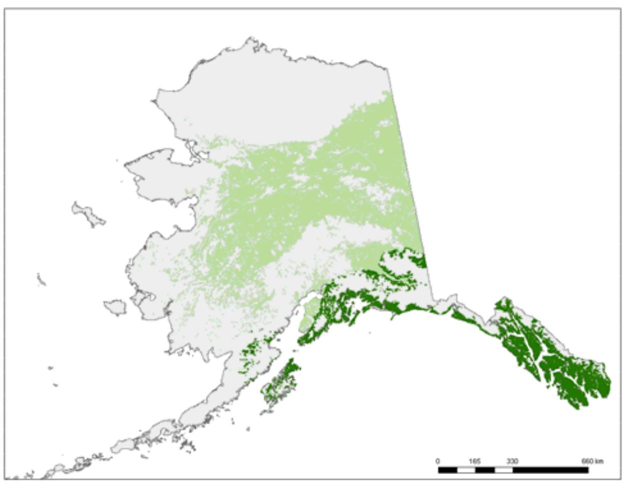


Figure 6. Forested area in Alaska (excluding shrubs). The Boreal Ecoregion contains nearly 85% of the forested area (light green) in the state and the Maritime Ecoregion contains around 13% of the forested area (dark green) (data source: Fleming, 1991; Forest Health Monitoring Clearinghouse).

The boreal forest of the interior of Alaska accounts for nearly 85% of the forested regions in the state. The tree species associated with the ecoregions of the interior are white spruce, black spruce, paper birch, quaking aspen, balsam poplar, and tamarack, with permafrost playing a major role in the presence and distribution of species across the region. Areas underlain by permafrost have cold soils that remain saturated throughout the summer with black spruce and tamarack typically occurring here. White spruce on the other hand is found on warmer soils with adequate drainage, such as slopes with a southern exposure and along rivers. The hardwood trees are primarily the pioneer species and are typically found in recently disturbed areas. The dominant disturbance regime in the boreal forest ecosystem is fire which is predominantly a result of lightening strikes.

The forests associated with the Maritime ecoregion consist of the Coastal Rainforest and the Coastal Mountain Transition. The coastal rainforest region is a continuation of the temperate rain forest that extends northward from Washington and SW Canada. The most predominant tree species in this region is the western hemlock; however, the overall forest composition of this region varies from south to north. The forests in the southern portion of this region are a combination of western hemlock, sitka spruce, pacific silver spruce, and pacific yew. Whereas to the north, western hemlock becomes dominant, pacific silver and pacific yew are no longer present, and there is a greater abundance of western red cedar and Alaska cedar. The forest indicative of the Coastal Mountain Transition is a mixture of the lush temperature rainforests of the southeast and the spruce dominated forests of the interior, although they show more semblances to the boreal forest of the interior. The dominant disturbance regime in the maritime forests is wind throw. Extreme wind events in the region can cause the felling of large stands creating openings in the canopy and allowing soil churning to take place, which in turn provides new habitat for other trees (Forest Health Monitoring, 2004).

Glaciers

Glaciers exist in several different forms in Alaska: ice fields, ice domes, mountain glaciers, valley glaciers, piedmont glaciers, cirque glaciers, hanging glaciers, and tidewater glaciers. Glaciers are primarily found in the south-central and south-eastern portion of the state, while a few are located in the Brooks Range to the north (Figure 7). Glaciers cover about 70,000 km^2 of the land surface of Alaska, which accounts for roughly 5% of the total area. Arendt et al. (2002) identified 67 glaciers in Alaska and the surrounding Canadian Territories and separated them into seven geographic regions: Alaska Range, Brooks Range, Coast Range, Kenai Mountains, St. Elias Mountains, Western Chugach Range, and the Wrangell Mountains. Using this classification, there are 55 glaciers located solely in Alaska; 11 glaciers that cross the border between Alaska and Canada; and one glacier is located entirely within the Yukon Territory. If all of the glaciers in Alaska and the neighboring territories of Canada were considered, they would cover 90,000 km^2 and account for nearly 13% of the mountain glacier area worldwide (Dyurgerov and Meier, 2000; Meier, 1984).

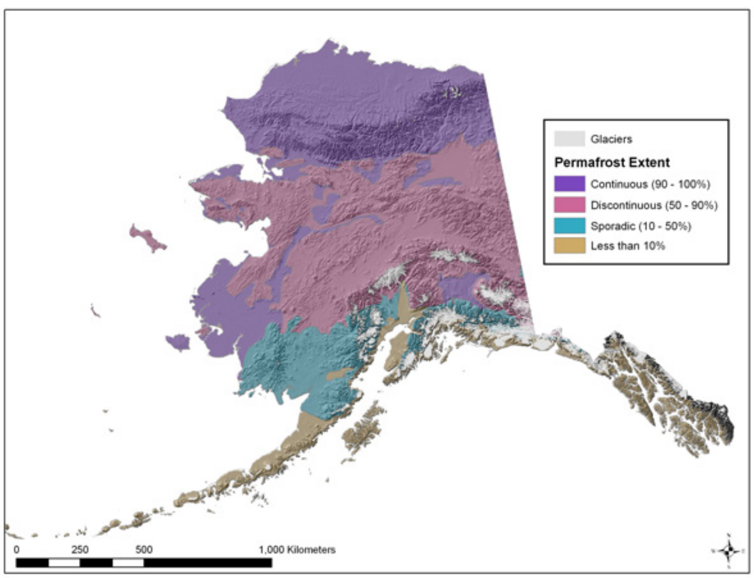


Figure 7. Two components of the cryosphere in Alaska: glaciers and permafrost. Glaciers cover roughly 5% of the land surface of Alaska. Continuous permafrost accounts for 33%, discontinuous 39%, and the sporadic permafrost zone 12% (data source: Brown et al., 1998).

Permafrost

As defined by Muller (1947) permafrost is any thickness of soil or other surficial deposit which has been colder than 0˚C for 2 years or more. In Alaska, permafrost varies in its depth, continuity, and ice content. There are four generalized categories of zones of permafrost: continuous (90 to 100% aerial extent), discontinuous (50 to 90%), sporadic (10 to 50%), and isolated (less than 10%).

About 85% of the land surface of Alaska is underlain by permafrost (Figure 7). Continuous permafrost is found beneath 33% of the land surface, discontinuous permafrost underlies 39%, and sporadic permafrost accounts for 12%. Continuous permafrost is mostly found in northern and western portions of the state. Discontinuous and sporadic permafrost are typically found in the interior and southern portion of the state north of the Maritime ecoregion.

Volcanoes

There are more volcanoes in Alaska than in the rest of the United States. Cameron (2005) provided the latitudes and longitudes of 127 volcanic centers in Alaska believed to be less than 2 million years old (Figure 8). Of these, more than 40 have been reported as having been a historically active volcano; that is having experienced a volcanic eruption, other than low level steam and gas venting, in historical time (Miller et. al., 1998; Cameron, 2005). The historic period in Alaska generally refers to the period since 1760, during which written records have been kept. At least 265 eruptions have occurred at the 29 most active volcanoes in historic times and seven volcanoes (Veniaminof, Pavlof, Shishaldin, Akutun, Makushin, Okmok, and Bogoslof Island) have accounted for 60% of the 265 eruptions. As a minimum estimate, there have been 1.1 to 1.3 eruptions per year since 1760; however, because much of Alaska remains to be sparsely populated, many eruptions may have gone unreported. A better estimate of eruptions began in 1945 as this marks the beginning of widespread air travel in the state. Since then, 90 eruptions have been reported from 23 different volcanoes. This results in a frequency of 1.8 eruptions per year (Miller et. al., 1998).

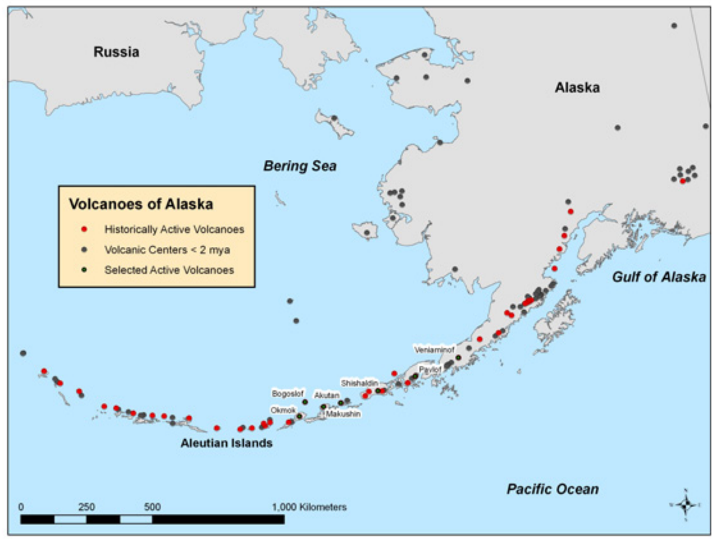


Figure 8. The volcanoes of Alaska. The volcanoes indicated in red are considered to be historically active volcanoes. The seven volcanes highlighted account for 60% of the eruptions over the historical period (data source: Cameron, 2005).

Earthquakes

Alaska is located in a very seismically active area that is primarily the result of the collision between the Pacific Plate and the North American Plate. The denser Pacific Plate is moving northwestward towards southern Alaska, the Alaskan Peninsula, and the Aleutian Islands; where the two plates meet, the Pacific Plate plunges below the North American Plate creating a subduction zone. Much like the active volcano pattern, a great deal of the earthquake activity follows the Aleutian Arc, although there are also significant earthquakes that occur inland.

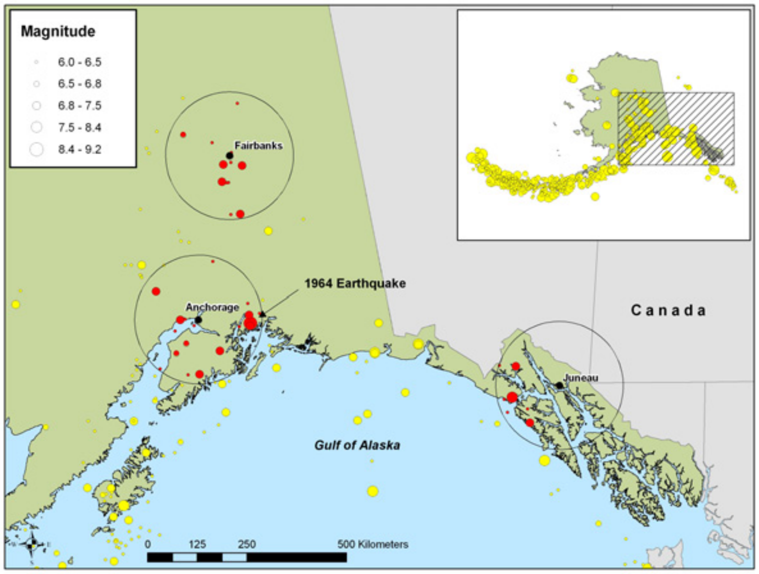


Figure 9. Earthquakes in Alaska with a magnitude greater than or equal to 6.0. The inset image in the corner shows all of the 6.0 or larger earthquakes. The zoomed image shows the earthquakes relative to prominent cities in Alaska (yellow indicates an earthquake of at least 6.0 magnitude and red indicates an earthquake of that severity within 160 km (100 miles) of either Anchorage, Fairbanks, or Juneau (data source: AEIC earthquake database).

Since 1898 there have been nearly 600 earthquakes with a magnitude larger than 6.0 reported in and around Alaska and 5 earthquakes with a magnitude larger than 8.0 (Figure 9) (AEIC Earthquake Database, 2005). Within 160 km of Anchorage, there have been 18 earthquakes with a magnitude larger than 6.0 since 1898, the largest being the 9.2 magnitude quake in 1964. Within 160 km of Fairbanks, 12 earthquakes greater than 6.0 have occurred over the same time period. Of these, four have had a magnitude greater than 7.0. Conversely, there have only been 7 earthquakes, greater than 6.0, within 160 km of Juneau from 1898 to 31 May 2005.

Socio-Economic Conditions

General Population

The United States purchased Alaska from Russia in 1867 and since that time the trends in the settlement patterns and the growth of population throughout the state have been guided by boom and bust cycles (**Error! Reference source not found.**). The first such boom, the Klondike gold rush, occurred at the turn of the 20th Century. During the gold rush, the population doubled from roughly 32,000 people to 64,000 people, with peak gold production occurring in 1906.

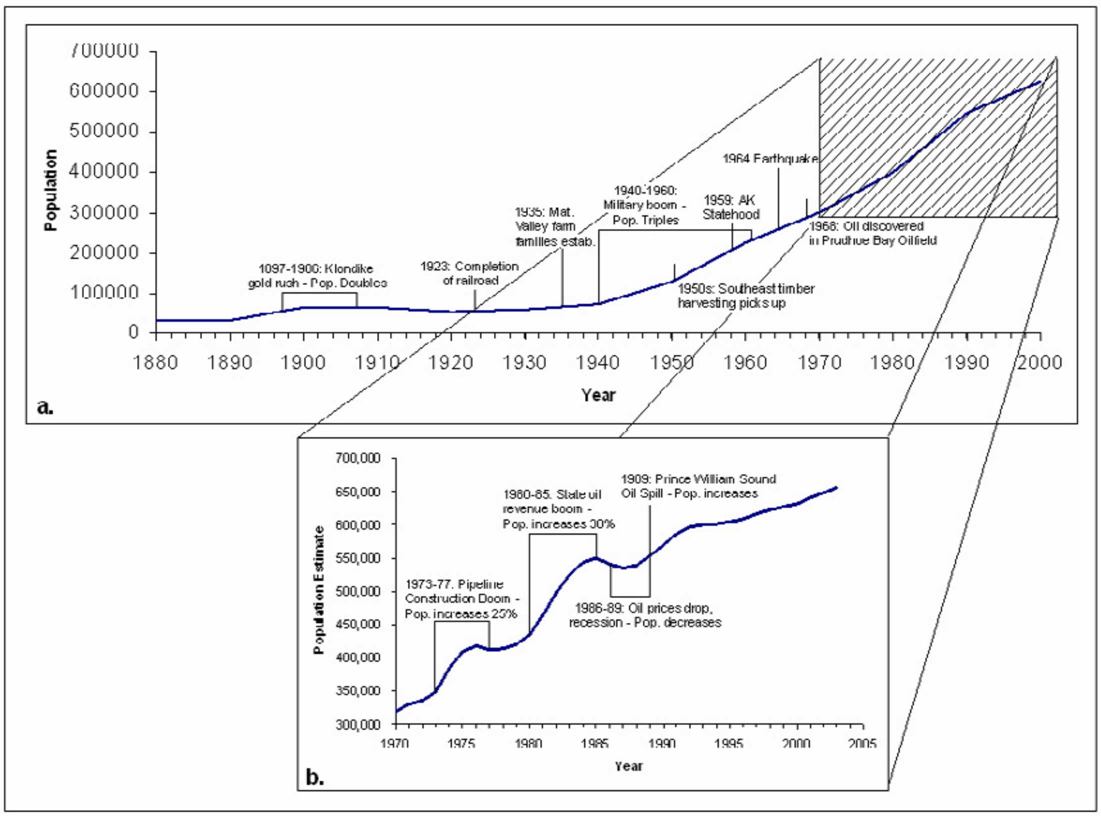


Figure 10. Alaska population, 1880 to 2004. (a) U.S Census Bureau population data from 1880 to 2000. The inset box (b) represents Alaska population estimates from 1970 to 2004. Estimates based on economic forces (data sources: Alaska Department of Labor and Workforce Analysis; Leask, 2001; and U.S. Census Bureau).

In 1912 Alaska was organized as a territory, however, following the Klondike gold rush the population of Alaska declined between 1910 and 1920. The 1920 Census reported the lowest population figure of the 20th Century at 55,000, but then gradually increased during the 1920's and 1930's. Some significant events that occurred during this time period consisted of the opening of the first pulp mill in Southeast Alaska (1922), the completion of the Alaska railroad (1923), and the establishment of farming families in the Matanuska Valley (1935).

Alaska's population began to increase rapidly in the 1940's coinciding with the establishment of the Fort Richardson Army Base and the Elmendorf Air Force Base. In the 20 years following their establishment the population had tripled from 72,500 to 226,000. Two other important events occurred over this 20 year period. During the 1950's, timber harvesting and processing boomed in Southeast Alaska. As a result, the first plywood mill opened in Juneau in 1953 followed by another pulp mill in Sitka in 1958. The end of this decade was marked by the proclamation of Alaskan statehood on January 3, 1959.

During the 1960's Alaska's population continued to gradually increase. At the end of the decade the Prudhoe Bay oil reserves, located in northern Alaska, were discovered and in 1969, a $900 million North Slope oil lease sale took place. This promise of new jobs resulted in a population boom during the mid-1970's and has been responsible for a great deal of social and economic changes since that time because a large share of the oil profits have gone into the state's economy (Leask et al., 2001). In 1973, construction began on the Trans-Alaska Pipeline and continued through 1977, during which time the population increased roughly 25%, from 348,000 to 412,000. Following the completion of the pipeline the population leveled off over the next three years.

The beginning of the 1980s marked some important events in Alaskan state history. In 1980, the Alaska legislature repealed the state income tax law and the legislature also established the Permanent Fund, setting aside one-fourth of all royalty oil revenue for future generations. Thus, the stagnant growth at the end of the 1970's was then followed by a major increase (30%) in state population in the early 1980's. This coincided with a peak in state oil revenues. The Alaska National Interest Lands Conservation Act (ANILCA) passed in 1980 also added to the influx of people to Alaska at this time. ANILCA converted vast tracts of land in Alaska to national wildlife refuge lands, national wild and scenic river lands, the national forest lands, and national park lands which consequently led to an increase in the number of federal employees entering the state to undertake management responsibilities for these lands. Overall, the increase in population primarily occurred as a result of massive state spending; however, this boom ended in 1986 with the worldwide collapse in oil prices and Alaska experienced a recession and a decreasing population throughout the remainder of the 1980's (Leask et al., 2001).

Alaska's economy slowly recovered by 1990 and the state population had begun to grow again. Some of the growth that began to occur at the end of the 1980s and beginning of the 1990s was a result of the Exxon/Valdez oil spill, partially due to the massive workforce that was needed to cleanup the spill in Prince William Sound. The growth that has occurred since the early 1990s has been slow compared to that of the mid-1970s and the early to mid-1980s. The slower growth in population could be linked to the decline in North Slope oil production since the peak of the 1980's (Figure 10), which, in turn has corresponded to smaller state revenues (Leask et al., 2001). Currently, much of the growth is being driven by a population that has become more stable and one that shows a longer residence time than in previous decades. The number of residents staying in the state longer than 5 years grew by 20% from 1970 to 1990 (Leask et al., 2001).

The population of Alaska in 2004 was estimated to be 655,435 (US Census Bureau, 2005). According to the State of Alaska, Division of Community Advocacy the population is dispersed throughout 358 communities, with Anchorage being the largest urban setting with a population of 272,687 in 2004 (US Census Bureau, 2004). The state population is expected to gradually increase throughout the 21st Century as areas outside of Anchorage continue to be developed.

Native Population

The Alaska Native and American Indian population accounts for more almost 20% of Alaska's statewide population (US Census Bureau, 2005). The native population has experienced many changes since the turn of the 20th Century. The native population declined dramatically following the arrival of Russian Explorers and Americans in the late 1700s and 1800s, respectively, and continued through 1910. During this time several epidemics, such as, smallpox, measles, influenza, diphtheria, and tuberculosis devastated many of the native villages. After 1910 the native population gradually increased and during the 1950s public health in rural communities improved and the population began to increase, since 1960 the native population has almost tripled statewide and it is believed that the population reached the "pre-contact" level in the early 1970s. Much of this growth is attributed to a reduction in infant mortality which have declined by more than a third since the early 1990s. An improvement in health care for adults allowing life expectancy to increase also accounts for the increase in population. The average life expectancy among Alaskan natives was roughly 47 years in 1950, this increased to 64.4 in 1980, by 1990 it was 68.8, and in 1997 it was 69.5 (Goldsmith et al., 2004). There has also been a shift by Alaskan Natives from rural, subsistence lifestyles to urban living. From 1970 to 2000, the percentage of Alaska Natives living in urban areas increased from 17 to 32 percent (Leask et al., 2001).

Jobs

As of 2004, there were 304,000 jobs statewide. This year marks the first time that the number of jobs in Alaska has reached the 300,000 mark. Historically, the number of jobs in Alaska surpassed 100,000 in 1972 and 200,000 jobs in 1982 (Erskine, 2005). Thus, it is evident the number of jobs in Alaska increased much more dramatically in the 1970s and early 1980s than it does today. Still, the historical increase in jobs statewide is impressive. Since 1961, there are five times as many jobs statewide and the state has posted an increase in jobs every year since 1988. Since 1960, state and trade industries created about half of the new jobs, state and local governments created about 20 percent, and resource and infrastructure industries added about one-third (Leask et al., 2001).

As mentioned before, job growth slowed in the 1990s and several of the industries in Alaska actually lost jobs from 1990 to 1999 (Figure 11). Since 1990, tourism has added more jobs than any of the other basic industries, while the biggest decline in jobs were from the military sector, the timber industry, and the petroleum industry.

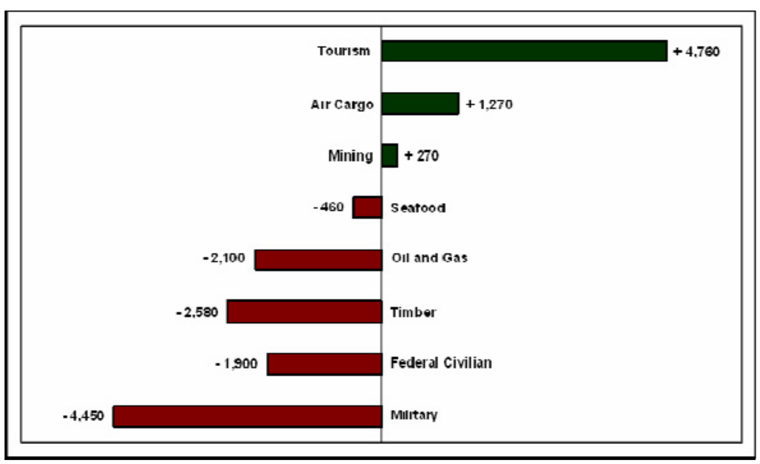


Figure 11. Graphic showing the gains (green) and losses (maroon) of basic industry jobs in Alaska from 1990-1999 (modified from Leask et al., 2001).

Commodities

Commodities refer to tangible items that can be bought or sold. In Alaska, there are three major commodities that contribute to the economy: seafood, petroleum, and minerals. In 1965, seafood was the most valuable commodity; however, over the next 20 years this changed as oil and gas production surpassed seafood as the leading commodity, primarily a result of the development of resources on the North Slope. In 2000, seafood had dropped to the third most valuable commodity behind oil and gas and minerals. Minerals had become the second most valuable commodity in the state as the production of zinc increased, a result of the development of Red Dog Mine in northwestern Alaska, as well as a decrease in salmon prices worldwide due to pressure from foreign farmed salmon (Leask et al., 2001). Agriculture is also another commodity that contributes to Alaska's economy, however, it continues to remain small.

Military

The United States Military holds a large presence in Alaska, both in terms of population and economics and has been this way since World War II. The state population tripled during the military boom between 1940 and 1960 coinciding with the establishment of the Fort Richardson Army Base and the Elmendorf Air Force Base in Anchorage. The number of military personnel in Alaska in 1960 was 33,000 making it the largest single employer statewide. In recent times however, the military population has declined and by 2000 the population had dropped to 18,000 individuals. Military activities within the state however, still contribute about $7 of every $100 of gross state product (Leask et al., 2001).

Tourism

Tourism has been one of the fastest growing contributors to the state's economy since the 1990s with annual visits increasing from roughly 1.1 million in 1994 to over 1.7 million in 2004 (Northern Economics, Inc., 2004). The increase in the number of tourists statewide is reflected in the number of jobs created in the tourism industry which added more jobs than any other basic industry through the 1990s (Leask et al., 2001).

A report prepared by Global Insight (2004), for the Alaska Department of Commerce provides an account of the importance of tourism to the state's economy. The report highlights the challenges of measuring travel and tourism, signifying that tourism is a part of many different industries and not one industry entirely. The report provided three different levels of measuring the contribution of travel and tourism: total sales, total economic contribution, and core industry. The latter measure of the travel and tourism industry provides the narrowest definition of the contribution of the tourism industry because it measures "only the direct impact of end-providers of goods and services to travelers" (Global insight). Therefore, this is the best measure to use for comparison with other industries. Thus, using core industry, in 2002, travel and tourism accounted for 3% of Alaska's gross state product, provided 26,159 jobs (4th overall and 9.1% of total employment), and provided $579 million in core labor income (benefits and salaries) to Alaska.

Factors Affecting Land Surface Features in Alaska

The current status and trends of the land surface of Alaska is an amalgamation of many different factors. These factors can be broken down into two categories; natural forcing and anthropogenic forcing. Natural disturbances, such as forest fires, insect infestation, and coastal erosion can leave a marked impression on the land surface. In addition, a changing climate can lead to widespread changes in glaciers, permafrost and forests. Anthropogenic forces such as, changes in socio-economic conditions can also lead to localized as well as widespread surficial changes; exploration, urban development, and resource extraction can cause several noticeable changes in the land surface. Thus, in order to get an idea of the factors affecting land surface features in Alaska each of these features must be considered.

Natural Drivers

The effects of a changing climate are presumed to be most rapid and dramatic in high-latitude areas (Serreze et al., 2000); thus, Alaska may be an important place to monitor these changes. Numerous studies have taken place within Alaska that have focused on changes in temperature and precipitation; frequency and severity of forest fires; the impact of insect infestation on the forests of Alaska; the size and extent glaciers; changes in permafrost; and changes in the coastline due to erosion. The effects of a changing climate have been well documented in Alaska and this section will serve as a synthesis of the basic trends that are apparent as a result of a changing climate.

Temperature and Precipitation

Changes in climate occur at different spatial and temporal scales, therefore it is important to use caution when analyzing short and long term trends in climate data because they do not occur in a linear fashion; rather, they could occur as a result of a sudden shift in synoptic conditions (Hartmann and Wendler, 2005). Nevertheless, analyzing trends in climate data are an important factor to take into consideration when looking at changes in the land surface of a particular area.

Temperature and precipitation data were collected from 20 of the 21 first-order weather stations in Alaska from the period 1954 to 2004; Valdez was omitted because the record only dated back to the 1970s (Alaska Climate Research Center). The mean monthly temperature and precipitation

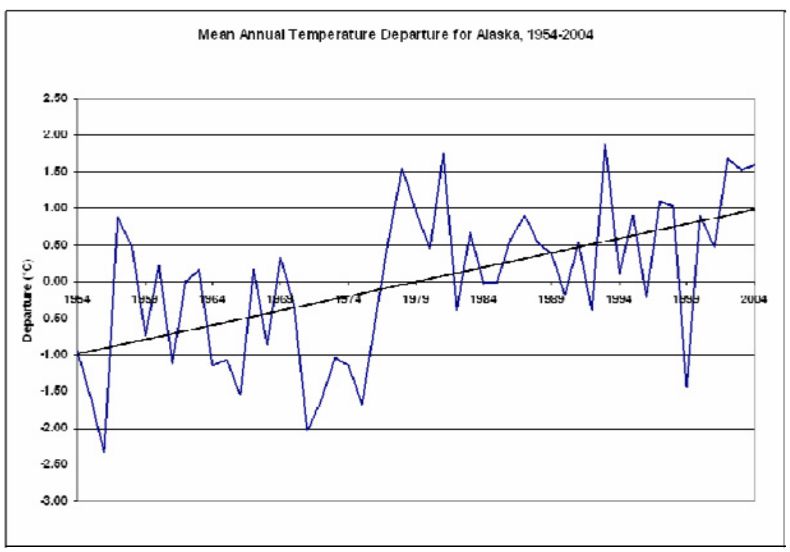


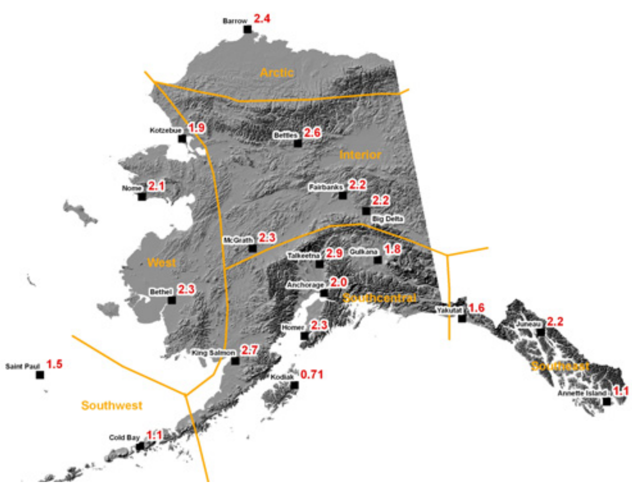
Figure 12. Graph showing the statewide mean annual temperature departure from 1954 to 2004; mean annual climate data has been plotted on the graph and a linear trend was run through the data to gauge the total change over the 50 year period (data source: Alaska Climate Research Center).

Table 1. Seasonal temperature change from 1954 to 2004; 0 to 1in green, 1 to 2 in yellow, 2 to 3 in orange, and more than 4 degree increase in red. At several of the climate stations the warming has occurred during the winter and spring months. The seasons correspond to 3 month blocks; Spring = March, April, and May…(data source: Alaska Climate Research Center).

	Spring (°C)	Summer (°C)	Fall (°C)	Winter (°C)		Annual (°C)
Anchorage	1.97	1.10	1.06	4.02		2.04
Annette	1.29	0.90	0.34	1.86		1.10
Barrow	2.69	1.74	2.44	2.91		2.45
Bethel	3.29	1.35	0.90	3.88		2.35
Bettles	2.30	1.16	1.21	4.75		2.36
Big Delta	2.29	0.76	0.99	4.76		2.20
Cold Bay	1.49	1.22	0.69	0.98		1.10
Fairbanks	2.55	1.17	0.79	4.16		2.16
Gulkana	1.45	0.57	0.44	4.13		1.65
Homer	2.20	1.93	1.45	3.52		2.27
Juneau	1.90	1.55	1.08	3.18		1.93
King Salmon	3.35	1.47	1.05	4.93		2.70
Kodiak	1.27	0.94	0.34	0.69		0.81
Kotzebue	1.51	1.30	1.82	3.41		2.01
McGrath	2.84	1.61	1.29	3.76		2.37
Nome	2.73	1.37	1.40	2.99		2.12
St Paul	2.11	1.76	1.01	1.13		1.50
Talkeetna	3.02	1.86	1.89	4.61		2.84
Yakutat	1.87	1.05	0.56	2.61		1.52
Statewide Change	2.22	1.31	1.09	3.28		1.97

data were used to determine mean annual temperature and precipitation values as well as seasonal values. The weather station data indicate a mean temperature increase of 1.97°C from 1954 to 2004 (Figure 12). Using climatic regions similar to Shulski et al. (2005), regional patterns of temperature change emerge (Figure 13). The Arctic, Interior, West, and Southcentral regions have all experienced warming greater than 2.0°C,whereas the warming in the Southwest and Southeast regions has been less pronounced, 1.30°C and 1.52°C, respectively.

Overall the majority of the warming has occurred in the fall and the winter (Table 1). Examining the graph closer it is evident that the changes in temperature over this 50 year period have not occurred in a linear fashion. Around 1976, there was a shift in the Pacific Decadal Oscillation (PDO) from a negative phase to a positive phase (Mantua, 2001). The PDO primarily affects the North Pacific and has been described as a long-lived El Nino-like pattern of Pacific climate variability; while PDO phases are believed to persist for 20 to 30 years (Mantua, 2001). This is represented by the spike in mean annual temperature around the middle of the graph. Since 1976, there has actually been little warming statewide, thus the majority of the warming that has taken place can be accounted for by this shift to a positive phase of the PDO. Hartmann and Wendler (2005) have reported that mean annual and seasonal temperatures have been as much as 3.1°C higher during this positive phase of the PDO when compared to the negative phase. The authors also reported a deepening of the Aleutian low in winter and spring which has lead to increased advection of relatively warm and moist air from the south; therefore, this could explain why much of the warming has taken place during the winter and spring.



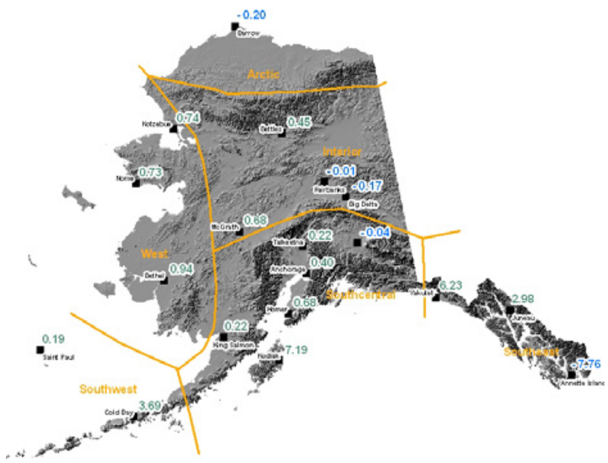


Figure 13 (left). Climate divisions in Alaska based upon Shulski et al. (2005). The greatest changes in temperature have occurred in the arctic and interior regions, while the least amount of change has occurred in the southeast and southwest regions. Figure 14 (right). Mean annual precipitation change in Alaska, 1954 to 2004; blue indicates decreasing values and green indicates increasing values. Climate divisions based on Shulski et al. (2005).

Analyzing the precipitation data shows that there has been an increase in precipitation of about 1 cm throughout most of the state. The precipitation data however, do not show the strong seasonal pattern that is evident in the temperature record, nor does it show a strong relationship with the shift in the PDO in 1976. The only region to show a decrease in precipitation is the Arctic region (but this is only represented by one site) (Figure 14). Curtis et al. (1998) also found that the Arctic region has experienced a decrease in precipitation. The authors determined that some causes of this decrease could be a result of wind direction changes, decreasing variability in surface pressure, and decreasing cloudiness. Overall, the precipitation data is believed to be somewhat problematic due to precipitation catchment problems and differing observation techniques (Shulski et al., 2005). Other recent studies that have analyzed temperature and precipitation data for the state of Alaska have come to similar conclusions indicating that both temperature and precipitation have increased statewide over the last half of the 20th Century (Stafford et al., 2000; Shulski et al., 2005).

Fires

Forest fires are a major part of the ecosystem processes in Alaska and are responsible for wide scale changes in the land surface. On average, up to ten times more forest area is burned on an annual basis in Alaska when compared to the rest of the United States (Court and Griffith, 1992). This is largely a function of the size of Alaska, its immense boreal forest region, and low population densities which translate into allowing more fires to burn unimpeded. During the 2005 fire season, there were 624 fires throughout the state that burned an area of 18,650 km^2. This was the second highest total of area burned from the period 1990 to present and the third highest total since 1950.

The largest fire season on record in Alaska was the 2004 fire season, surpassing the 20,230 km^2 burned in 1957 with a total acreage burned of 27,200 km^2. In 2004, there were 706 fires across the state and of these 706 fires, 424 were caused by humans and 259 were caused by lightning strikes. The record breaking fire season of 2004 was initially predicted to be an “average” fire season. The winter snow pack throughout the state was 70% to 120% of the normal average, during the late spring/early summer intense convection and record-breaking rainfall occurred in interior Alaska, and there was only 103 km^2 burned by the middle of June (Alaska Fire Service, 2004). However, conditions began to shift during the middle of June and the resultant fire season can be attributed to the following factors. Following the record rain fall totals for the interior during the early summer, drought conditions set in. For the month of June, precipitation for the region was 25 to 50 % of normal and the temperatures were 6°F to 10°F above normal. During July, the temperatures were only slightly above normal and in August the same drought conditions returned to the interior. Fairbanks experienced the least amount of precipitation in the month of August in over 100 years of records. Thus, the persistent drought conditions throughout the interior during the summer of 2004, the above normal temperatures from May to August, the below normal precipitation from June to August, and the abundance of lightning strikes from the end of May to the middle of July contributed to the extreme fire season of 2004 (Richmond and Shy, 2005).

Fire reporting datasets date back to the 1950's. The BLM – Alaska Fire Service has compiled datasets for the time period 1950 to 2004. The data are available as a shapefile which allow for limited spatial analysis because of the coarseness of the data and probability of unrecorded fires. The originators of the data warn that there are at least 300 missing fires in the dataset and that this will impact the results of its use; however, some basic acreage burned estimates and other measures can be made. Fires recorded from the period 1950 to 1987 exceeded 4 km^2 in area burned and fires recorded from 1988 to 2004 consisted of fires greater than 0.4 km^2. Thus, it appears that more fires have been reported since 1988 simply based on the change in fire reporting status. Nonetheless, from 1950 to 2004, there have been 1,950 fires reported which account for a burn area of 188,900 km^2 across the state of Alaska. Of the 1,950 fires, about 25% are between 0.4 km^2 and 4 km^2 indicating that they were post-1987; however, these smaller fires only account for an addition of roughly 0.4% of the area burned between 1950 and 2004. Of, the majority of the fires that have occurred in the interior region of the state, roughly 93% of the fires burned have occurred in the Intermontane Boreal region (Figure 15).

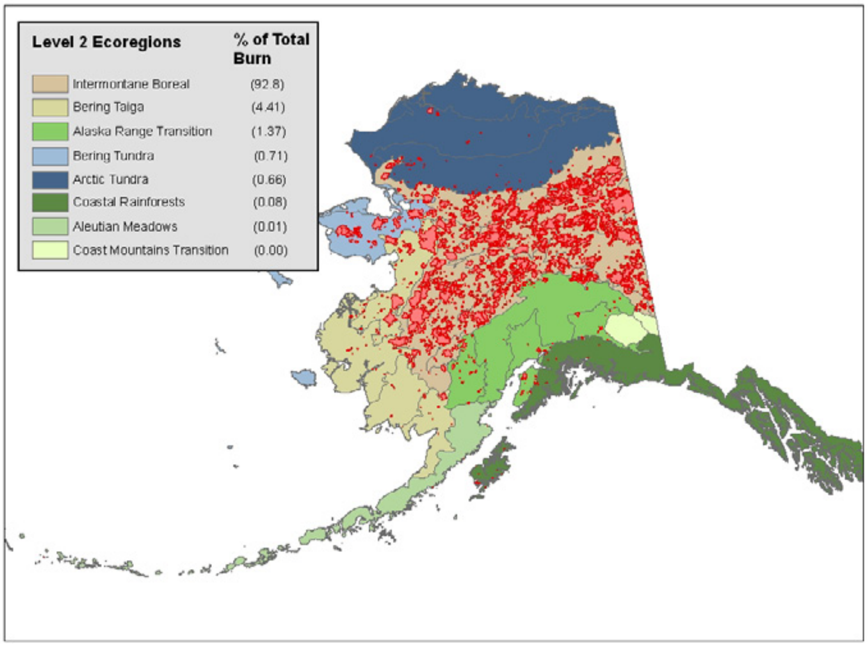


Figure 15. Fires in Alaska from 1950 to 2004. The majority (92.8%) of the fires have occurred in the Intermontane Boreal region (data source: BLM – Alaska Fire Service, Nowacki et al., 2001).

More detailed statewide fire statistics have been compiled by the Alaska DNR and the Bureau of Land Management since 1990 (Figure 16). These data indicate that since 1990, there have been 9,343 fires observed and 100,100 km^2 burned throughout the state. The 16 year average (90-05) for the state is 585 fires per year with a total of roughly 6,300 km^2 burned. The last two fire seasons, 2004 and 2005, have been the most active fire seasons during this time period. They have exceeded the 16 year average by a factor of nearly 4.5 and 3, respectively.

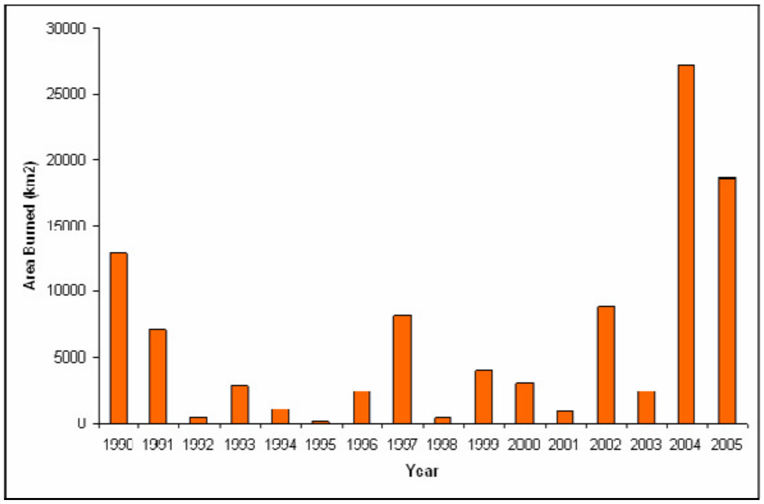


Figure 16. Total forest area burned (km2) in Alaska from 1990 to 2005 (data source: BLM – Alaska Fire Service).

Lightning and Fire

The BLM has operated a cloud-to-ground lightning strike automated network since 1976, with 9 stations in Alaska and 3 in the Yukon Territory. The location of a lightning strike is estimated by triangulation, thus there has to be at least two sensors that detect the strike. The location of a detected lightning strike is assumed to have a positional accuracy of roughly 2-4 km and a detection efficiency of 60% - 80%, however, a study to test the detection efficiency and positional accuracy have not been conducted in Alaska (see Dissing and Verbyla, 2003).

Utilizing the lightning strike datasets from the Bureau of Land Management – Alaska Fire Service, recent studies have been conducted on the relationship between cloud-to-ground lightning strikes and wildfires in Alaska (McGuiney et al., 2005; Dissing and Verbyla, 2003). Dissing and Verbyla (2003) compared the spatial patterns of lightning strikes in the interior and their relationship with elevation and vegetation between 1986 and 1999. The McGuiney et al. (2005) study looked at the relationship between lightning strikes and fires as a whole between 1986 and 2002 and focused on distinguishing between human caused fires and lightning caused fires.

Dissing and Verbyla (2003) used the lightning strike dataset to determine where lightning strikes preferentially occurred. At the regional scale (interior Alaska), the authors found that the number of lightning strikes were driven by elevation and percent cover of boreal forest and location. These factors combined to explain 66% of the variation in lightning strike densities in the interior. Thus, lightning strikes appear to preferentially occur in continental locations between 1000 m and 1200 m in areas with around 50% to 70% boreal forest coverage.

McGuiney et al. (2005) utilized the lightning strike dataset in order to relate lightning climatology and wildfires in the state over the period 1986 to 2002. Over this time period, there has been an average of 32,400 lightning strikes per year and approximately 90 days per year in which lightning occurs. This study reported that almost 100% of the lightning strikes occur over the months May through August and nearly 91% of the lightning strikes occur in June and July and were a result of thunderstorm activity and hypothesized to be driven by synoptic conditions or convective lifting. The authors reported that the majority of the lightning strikes in the state were a result of convective lifting because there is a lag in the maximum stroke count of about 3 hours following solar noon. The authors also found a correlation between daily maximum temperature and the number of lightning strikes in this region of Alaska. For thunderstorm activity to take place, the temperature must be higher than 10°C, and for a thunderstorm associated with an extreme lightning event (>2000 strikes) the temperature must be greater than 21°C (McGuiney et. al. 2005).

Although humans have been the cause of more than two-thirds of the forest fires since 1986, lightning strikes are responsible for the majority of the area burned in the state. Lightning strike fires have accounted for almost 93% of the burned area each year from 1986 to 2002. McGuiney et al. (2005) found a positive correlation between lightning strikes and wildfire starts between 2000 and 2002 ($R^2 = 0.45$), a negative correlation between precipitation and wildfire starts between 2000 and 2002 ($R^2 = 0.21$) (McGuiney et. al., 2005). Thus, with potentially warmer conditions occurring in Alaska, the number of lightning strikes may increase as a result of increased convective lifting.

Insect Infestation

The impact of insect infestations on Alaskan forests as a disturbance agent is believed to be linked to a warming climate (Juday et al., 1998). A climate shift in which there are higher temperatures and less precipitation allows insect reproductive rates to increase, as well as, weakening the strength of the forest by inducing stress from drought (Forest Health Monitoring, 2004). The primary insects that have contributed to disturbances throughout Alaska can be divided into two categories: bark beetles and defoliators. Bark beetles are considered to be more of a threat to Alaska's forests than the defoliators because the bark beetles cause a greater incidence of tree mortality (Forest Health Monitoring, 2004). Defoliators attack the leaves and needles of trees which lead to increased stress but not necessarily tree mortality (USFS-Forest Health Conditions in Alaska, 2004).

The dominant species of bark beetle that has lead to widespread disturbance is the Spruce bark beetle (*Dendroctonus rufipennis* Kirby), while the Western Balsam Bark Beetle (*Dryocoetes confuses* Swaine), the Eastern Larch Beetle (*Dendroctonus simplex* LeC.), and the Engravers (*Ips perturbatus* Eichhoff) have also contributed to forest disturbance. Many of the disturbances caused by bark beetles lead to changes in the structure and composition of the forest ecosystem as well as alter the socioeconomic benefits of the forest. Some examples are loss of harvestable timber, long-term stand conversion, changing wildlife habitats and behavior, impacts on aesthetic value, increases in fire hazard conditions, and impacts on fisheries and watersheds (Forest Health Monitoring, 2004).

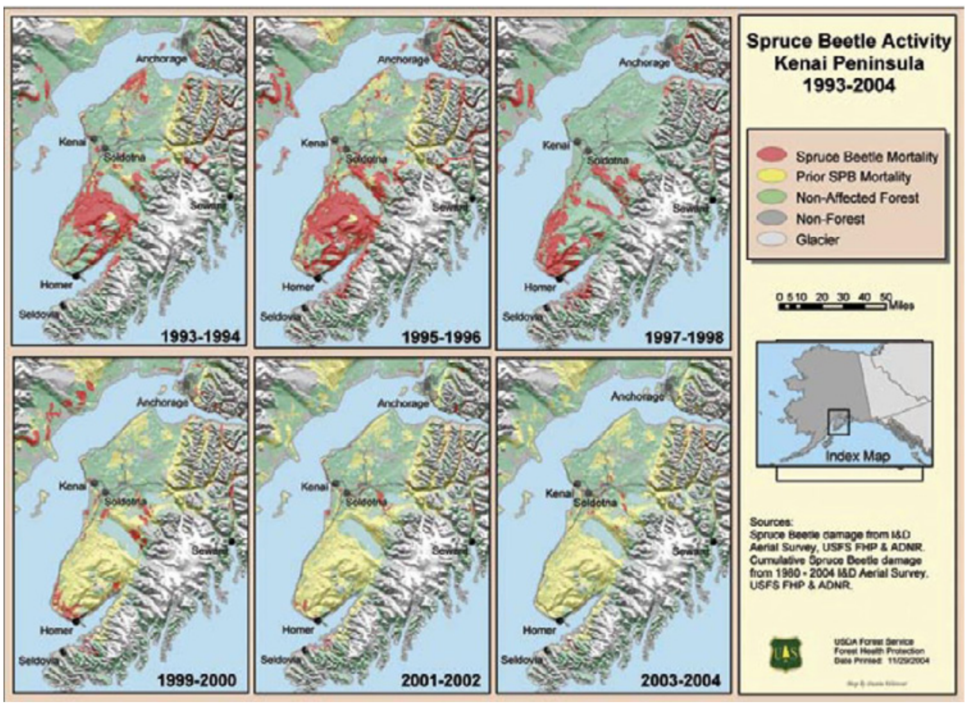


Figure 17. Spruce bark beetle impacts on the Kenai Peninsula from 1993 – 2004. The outbreak peaked in 1996, yet there are still newly impacted areas each year (Source: Forest Health Conditions in Alaska – 2004).

A predominant spruce bark beetle attack began in the late 1980s throughout the state with some areas having been impacted more than others (USFS-Forest Health Conditions in Alaska, 2004). The beetles bore into the bark of the spruce trees and feed on the thin phloem layer between the bark and the wood. This essentially starves the tree through lack of nutrients and causes mortality. Since 1989 there have been 13,000 km^2 of the forest impacted statewide. The two areas that have received the largest disturbance from the spruce bark beetles have been the Kenai Peninsula and the Copper River region.

The outbreak on the Kenai Peninsula began in 1989 and since that time over 5,600 km^2 of forest has been lost to spruce bark beetle infestations. This has been the largest case of tree mortality due to a single insect outbreak in all of North America (Werner, 1996). The affected tree species consisted of white spruce ((*Picea glauca* (Moench) Voss) and Lutz Spruce (*Picea xlutzii* Little) The peak of the outbreak occurred in 1996 and in recent years the impacts of the spruce bark beetles on the Kenai Peninsula has waned primarily because the bark beetles have destroyed the majority of their food source (Figure 17).

The Copper River Basin has also been heavily impacted by the spruce bark beetle with roughly 2,000 km^2 of forest lost to the infestation from 1989 to 1998 (USFS-Alaska State and Private Forestry Aerial Insect and Disease Surveys, 1989-1998). Wesser et al. (2001) found that within the Wrangell-St. Elias Natioal Park and Preserve region of the Copper River Basin over 800 km^2 had been impacted over the same time period (**Error! Reference source not found.**8). The spruce bark beetle infestation primarily occurred in white spruce (*Picea glauca* (Moench) Voss) forests within the park.

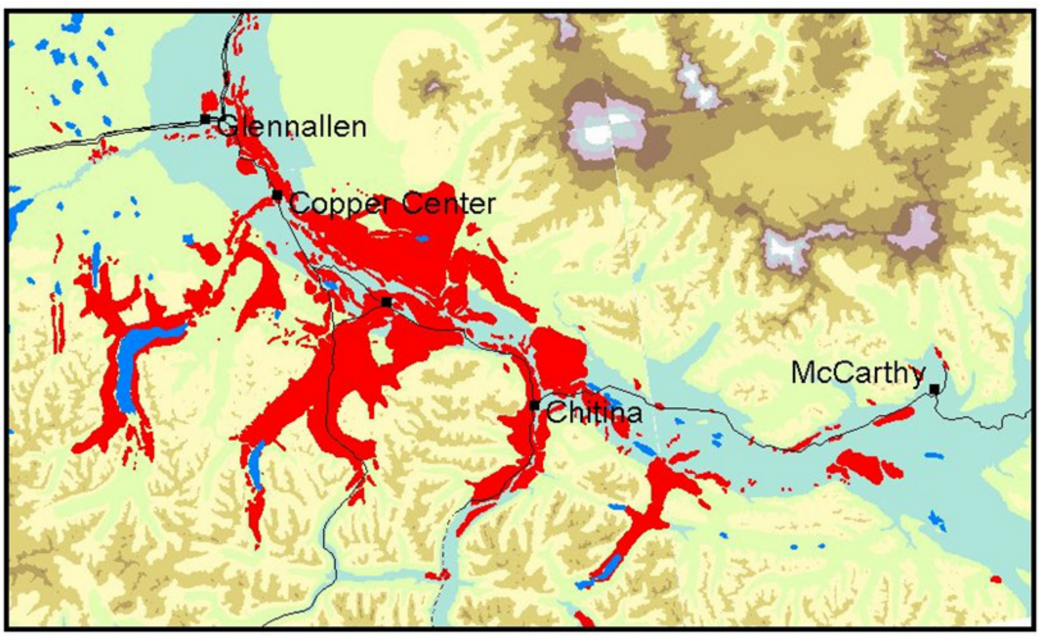


Figure 18. Areas within the Copper River region that have been impacted by the spruce bark beetle (red) since 1989 (Source: Wesser and Allen, 2001)

In addition to bark beetle kills, the defoliators found within Alaska are a major concern and consist of the spruce aphid (*Elatobium abietinum* Walker), spruce budworm (*Choristoneura fumiferana* Clemens), western black-headed budworm (*Acleris gloverana* Walsingham), yellow-headed spruce sawfly (*Pikonema alaskensis* Rohwer), hemlock sawfly (*Neodiprion tsugae* Middleton), larch sawfly (*Pristiphora erichsonii* Hartig), aspen leaf miner (*Phyllocnistis populiella* Chambers), birch leaf roller (*Epinotia solandriana* L.), willow leaf blotch miner (Micrurapteryx salicifolliela *Chambers*), and the noctuid defoliator (*Sunira verberata* Smith) (Forest Health Monitoring, 2004). The defoliator outbreaks tend to be cyclic in nature and related closely to climatic conditions (USFS-Forest Health Conditions in Alaska, 2004). Higher temperatures generally increase the adult emergence and survival rate and milder winter temperatures aid in the over wintering survival of adults. Of these species, the spruce aphids, spruce budworms, western black-headed budworms, larch sawflies, and aspen leaf miner have had the most impact on Alaskan forests (USFS-Forest Health Conditions in Alaska, 2004). Even though defoliators are found in all forests of Alaska, there effect on the maritime forests of Alaska appears to be more widespread over space and time (USFS-Forest Health Conditions in Alaska, 2004). The impacts of a defoliator outbreak can effect the feeding behavior of wildlife in the effected forest by altering the nutrient cycling of the ecosystem. This in turn may stunt the growth of trees, consequently decreasing economic returns, as well as altering the aesthetic value of the forest (Forest Health Monitoring, 2004).

Changes in Glaciers

The glaciers of Alaska are believed to be changing rather rapidly in response to modern regional climate changes. Roughly 5% of the land surface of Alaska is covered by glaciers. The USGS has been monitoring two glaciers in Alaska, Gulkana and Wolverine, to analyze changes in climate, glacier geometry, glacier mass balance, glacier motion and stream runoff, since the 1960's. Gulkana Glacier (63°14'N) is located in the Alaskan Range and Wolverine Glacier (60°23'N) is located in the Coastal Mountain Range in the Gulf of Alaska. Both glaciers have shown a drastic reduction in cumulative net balance since the late-1980's (Figure 19) and are indicative of changes taking place in the glaciers throughout the state and the neighboring Canadian territories (Arendt et. al., 2002). Arendt et al. (2002) used airborne laser altimetry to study the volume changes of 67 glaciers in Alaska and Canada from the mid-1950s to the mid-1990s representing roughly 20% of the 90,000 km^2 glaciated area. The overall results show a dramatic increase in glacier thinning however, from the mid-1990's to 2001 the rate of thinning was -1.8 m/year, while the rate of thinning was only -0.7 m/yr from the mid-1950s to the mid-1990s. Thus, the 5 to 7 year recent period has exhibited a rate of glacier thinning more than twice as fast as the 40 year early period. Extrapolating the results to include all of the glaciers in Alaska and neighboring Canada, the estimated annual change in volume is -52 +/- 15 km^3/yr.

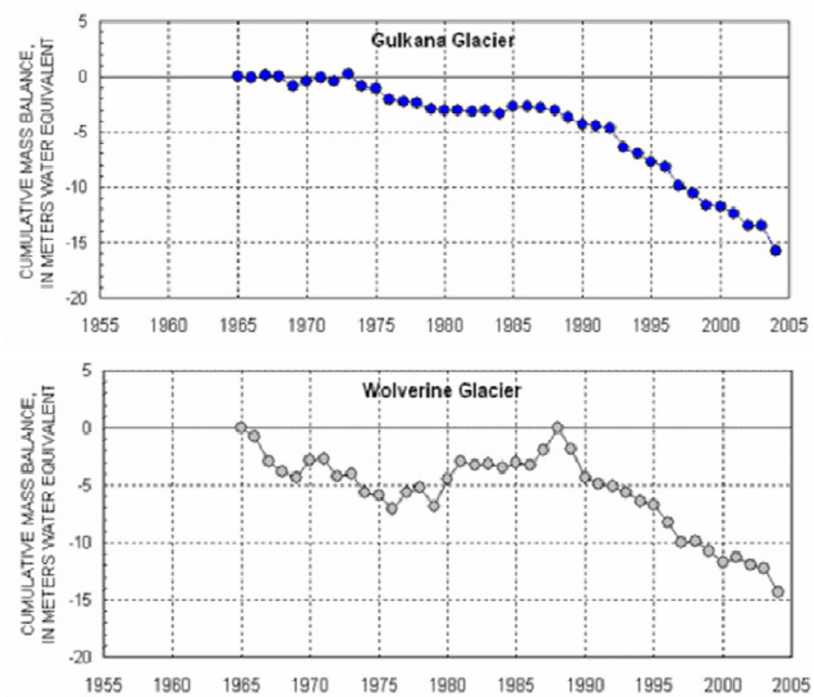


Figure 19. Changes in cumulative mass balance for Gulkana (Alaska Range) and Wolverine glaciers (Coastal Mountain Range) from 1965 to 2004 (Source: USGS, Benchmark Glaciers).

Arendt et al. (2002) believe that this loss of volume has contributed to rising sea levels and that the loss of glacier area in Alaska's mountain glaciers have contributed to roughly 9% increase in sea level over the past 50 years. Thus, over the past 50 years it is believed that Alaska's melting glaciers have made the largest glacial contribution to rising sea levels worldwide. Even though the authors suggest that the rates of thinning could be related to a warming climate, they indicate that in some cases, the rapid thickness changes of surge-type glaciers probably occur independently of climate fluctuations (Arendt et. al., 2002).

Other Examples of Glacier Change

Overall, land terminating valley and mountain glaciers are behaving differently than their tidewater counterparts (Arendt et. al., 2002). There are 8 calving glaciers in the state that are advancing and gaining mass. Each of these tidewater glaciers is believed to be linked more to the interaction between fjord depth, ice thickness, and calving rate, while climate change plays a secondary role (Meier and Post, 1987). Thus, changes in glaciers occurring as a result of a changing climate are better reflected in non-tidewater ice masses.

Glaciers in Central and Southcentral Alaska

Portage Glacier is one of Alaska's most visited tourist attractions, located about an hour's drive south of Anchorage. The Begich – Boggs Visitor Center was constructed in 1986 and at that time the snout of the glacier was visible from the visitor center. Since that time however, the glacier has retreated and by 1993 it could no longer be seen from the visitor center (Figure 20). Much of the retreat taking place at Portage Glacier has been attributed to erosion from the warming of the proglacial lake (Blanchet, 2002). Exit Glacier is another one of Alaska's most visited glaciers. It emanates from the Harding Icefield and is a land terminating glacier located near Seward, Alaska. This glacier is also showing a pattern of retreat. Cusick (2001) determined that Exit Glacier reached its most recent maximum extent in 1815. Since that time the glacier has been receding in a series of waves, with some years of intensive retreat followed by years of slow to moderate retreat.

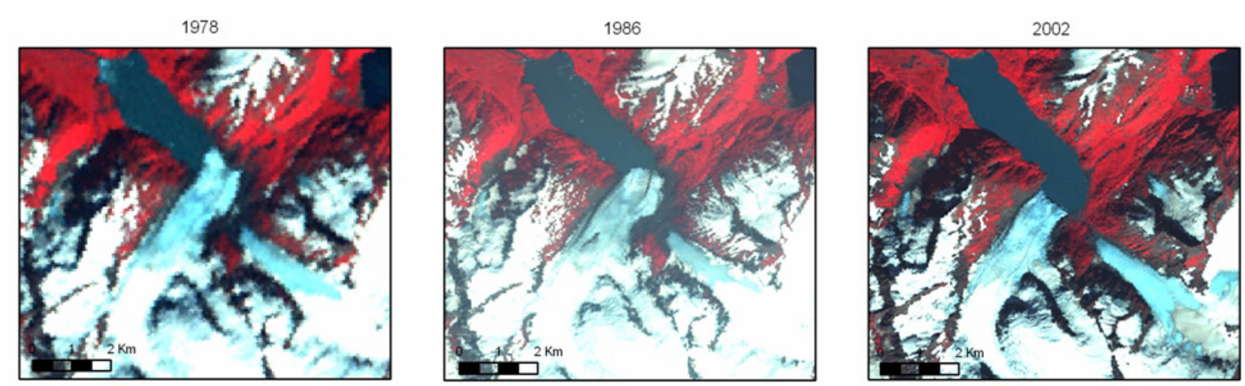


Figure 20. Portage glacier is located in center of each of these frames. The first frame shows the glacier in 1978. The next two frames show the glacier in 1986 (the year that the visitor center was constructed) and 2002, respectively. Over this time period the glacier has receded by such an extent that it can no longer be seen from the visitor center.

Glaciers in the Brooks Range

The McCall Glacier is a land terminating glacier located in the Brooks Range inside the Arctic National Wildlife Refuge. It is believed that this glacier began its retreat towards the end of the 1800s with monitoring beginning in the late-1950s; photos taken in 1958 and 2003 by Post and Nolan, respectively, offer a comparison of the glacier between the two time periods (Figure 21). However, due to the remoteness of the glaciers in the Brooks Range, this region remains understudied.

Figure 21. Historic and recent oblique photographs of McCall Glacier, Brooks Range, Alaska. The photo on the left was taken in 1958 and the photo on the right was taken at the same spot in 2003 (Source: Nolan, M., UAF).

Glaciers in Southeast Alaska and Prince William Sound

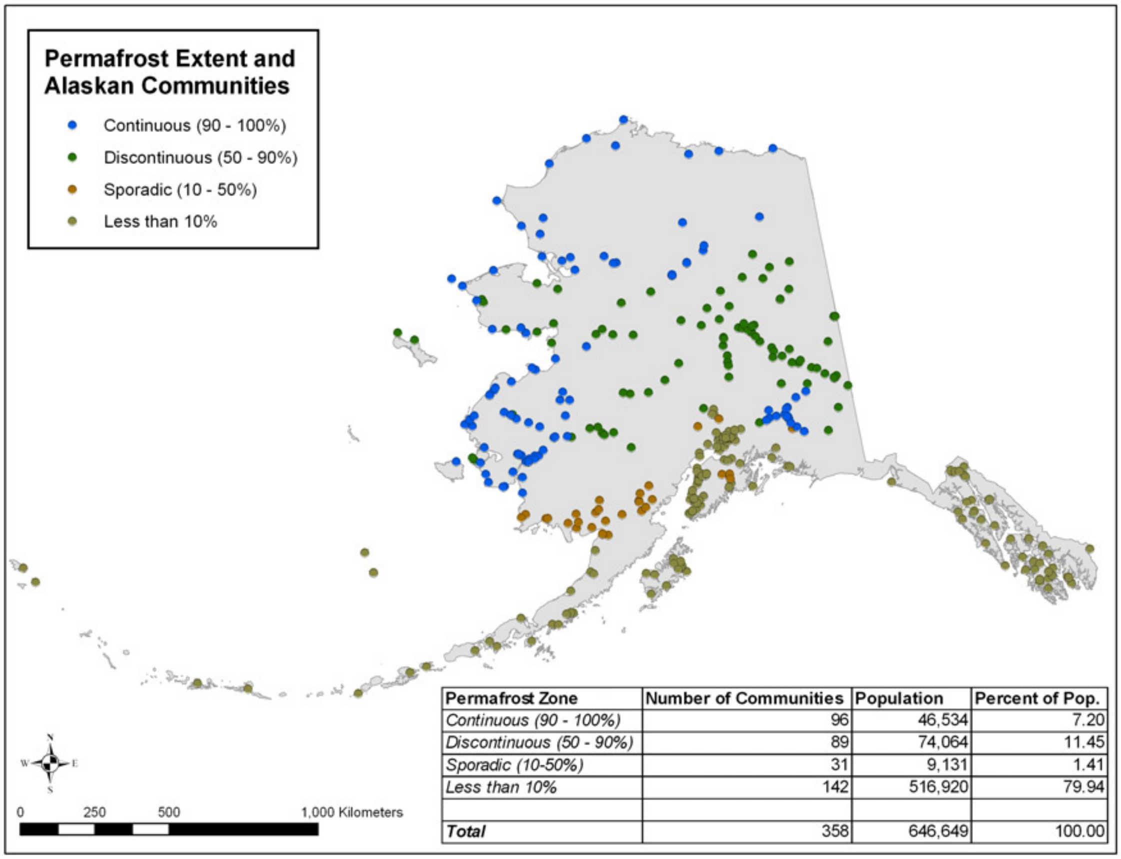
Glacier Bay, Alaska has only formed in recent times (the last 200 years) following a rapid retreat of glaciers in the region and is currently composed of both tidewater and non-tidewater glaciers (Seramur et al., 1996). For the most part these glaciers have been retreating. The Muir Glacier, a tidewater glacier, has been in a fairly steady state of retreat since the late 1970s. Landsat derived measurements have revealed that the glacier retreated 0.73 km per year between 1973 and 1982, and 0.04 km per year between 1982 to 1992 (Hall, 2005). Six other glaciers within the bay have retreated more than 1 km from 1966 to1986, while some have advanced slightly, and one, the Carroll Glacier, a tidewater glacier, has advanced more than 5 km (Hall et al., 1995).

The Shoup Glacier is a tidewater glacier located in northeast Prince William Sound that began its documented retreat in 1750 and around 1850, the glacier became somewhat stable on a bedrock shoal, which was followed by minor advances and retreats for about 100 years. In 1957, the glacier receded off of the shoal into deeper water and since that time the retreat is believed to be controlled by water depth (Brown et al., 1982). Between 1957 and 1990 the glacier retreated about 2.0 km exposing a deep tidal basin (Post and Viens, 1994).

Other examples of tidewater glaciers in Alaska are the Hubbard Glacier, near Russell Fjord, and the Harvard and Yale Glaciers of College Fjord, northwest Prince William Sound. The Hubbard Glacier has advanced about 24 meters per year from 1895 to 2001 and in 1986 and again in 2002 actually blocked Russell Fjord creating the two largest glacial-lake outburst floods in historical time (USGS fact sheet 001-03). The Harvard and Yale Glaciers are the two largest tidewater glaciers in College Fjord. The Harvard Glacier has been advancing since at least 1905 and since 1931 it has advanced approximately 20 meters per year (Sturm et al., 1991). The Yale Glacier on the other hand has retreated about 50 meters per year over the same time period (Sturm et al., 1991). The behavior of these two adjacent glaciers suggests that their terminus behavior is being controlled more by the complex interaction of factors in the tidewater environment than by climate change (Sturm et al., 1991).

Changes in Permafrost

For the most part, air temperature controls the existence and condition of permafrost but other factors such as substrate and groundwater contribute as well. A warming climate could potentially create widespread changes in permafrost across Alaska. As mentioned previously, roughly 85% of the state is underlain by permafrost and degradation of permafrost throughout the state could impact the socioeconomic conditions statewide because much of the current infrastructure resides atop areas underlain by permafrost (Figure 22). In addition, almost 130,000 people (~20%) live in areas that could be adversely affected by permafrost degradation and significant stretches of roadways traverse these populated regions.



Permafrost Zone	Number of Communities	Population	Percent of Pop.
Continuous (90 - 100%)	96	46,534	7.20
Discontinuous (50 - 90%)	89	74,064	11.45
Sporadic (10-50%)	31	9,131	1.41
Less than 10%	142	516,920	79.94
Total	358	646,649	100.00

Figure 22. The communities in Alaska as they relate to the permafrost zones found within Alaska. More than 20% of the population in state live in areas with more than 10% coverage by permafrost (data sources: Alaska Community Database; Brown et al., 1997,1998).

There have been recent studies that have alluded to the warming of surface permafrost temperatures across Alaska (Osterkamp and Romanovsky, 1999; Jorgenson et al., 2001). Since the 1940's the USGS has monitored permafrost temperatures in northern Alaska suggesting that the temperature of the upper permafrost has warmed by 2-4°C through the mid-1980's (Lachenbruch and Marshall, 1986). Other data suggest that the permafrost surface began to warm extensively around the end of the 1980's (Clow, pers. comm.). A study by the USGS on the Arctic Coast Plain near Teshekpuk Lake has found that there has been a 3.6°C increase in surface temperatures since 1989. Other studies have also noted similar increases in near surface permafrost temperatures near Prudhoe Bay and the Arctic Ocean on the order of 3-4°C, a warming of about 2°C over the rest of Arctic Coastal Plain, and typically 0.5°C-1.5°C in the zone of discontinuous permafrost has also been found (Nelson et al., 2003). Osterkamp and Romanovsky (1999) reported that the temperature of the permafrost had warmed at all of their study sites along a north – south transect from Prudhoe Bay to Glennallen through 1980's and 1990's

Widespread warming of the upper permafrost can have a large impact on the communities and infrastructure of Alaska. This is primarily due to the ice content of the permafrost. It is the thawing of the permafrost under ice-rich conditions that has the largest potential impact on society. Thermokarst (ground subsidence) will develop under such conditions which can affect buildings and roads as well as natural habitats.

Coastal Erosion

Nearly 85% of the population of Alaska lives in an area considered to be a part of the coastal zone (Bernd-Cohen and Gordon, 1999). In a study conducted by a state task force in 1984, 62 communities were identified with known erosion problems (State of the Beach, 2005). The coastline of Alaska is also an important economic component of the state. A large proportion of the profitable industry (commercial fishing, oil and gas development, logging, and tourism) has its roots along the coasts of Alaska. Assuming an estimated 76,000 km long coastline, roughly 70% (55,000 km) is considered tidal shoreline, and only about 1% of the coastline of Alaska is considered to be critically eroding. (Bernd-Cohen and Gordon, 1999).

Coastal erosion is driven by the composition of bluff sediments in the coastline and their interaction with rising sea levels, storm events, and in some locations earthquakes and tsunamis. Coastal erosion has less of an impact in areas with rocky shorelines than in those areas with unconsolidated sediments and permafrost. Rising sea levels and storm surges have affected large areas of coastline in the Bering, Arctic, and Cook Inlet regions whereas, earthquakes have had more of an impact in the regions along the Gulf of Alaska and southeast.

Mason et al. (1997) identified coastal communities in which bluff erosion was a major hazard and all of the communities occurred in the Arctic, Bering, or Cook Inlet region (**Error! Reference source not found.**). Much of the coastline of the Bering and Arctic regions consist of ice-laden, unconsolidated sediments that are vulnerable to coastal flooding and bluff erosion and collapse, whereas, much of the sediments in the Cook Inlet region are composed of glacial outwash composed of sands and gravels. In contrast, the coastline of the Aleutian Chain, Gulf of Alaska, and southeast Alaska consists of bedrock bluff or cliffs which are resistant to erosion over the same time span. The driver of coastal erosion in this region is typically a result of earthquake activity and block collapse. Earthquakes can also cause massive uplift of the land surface which can aid in the protection of the shorelines in this region although, associated tsunamis may have a large potential for shoreline destruction.

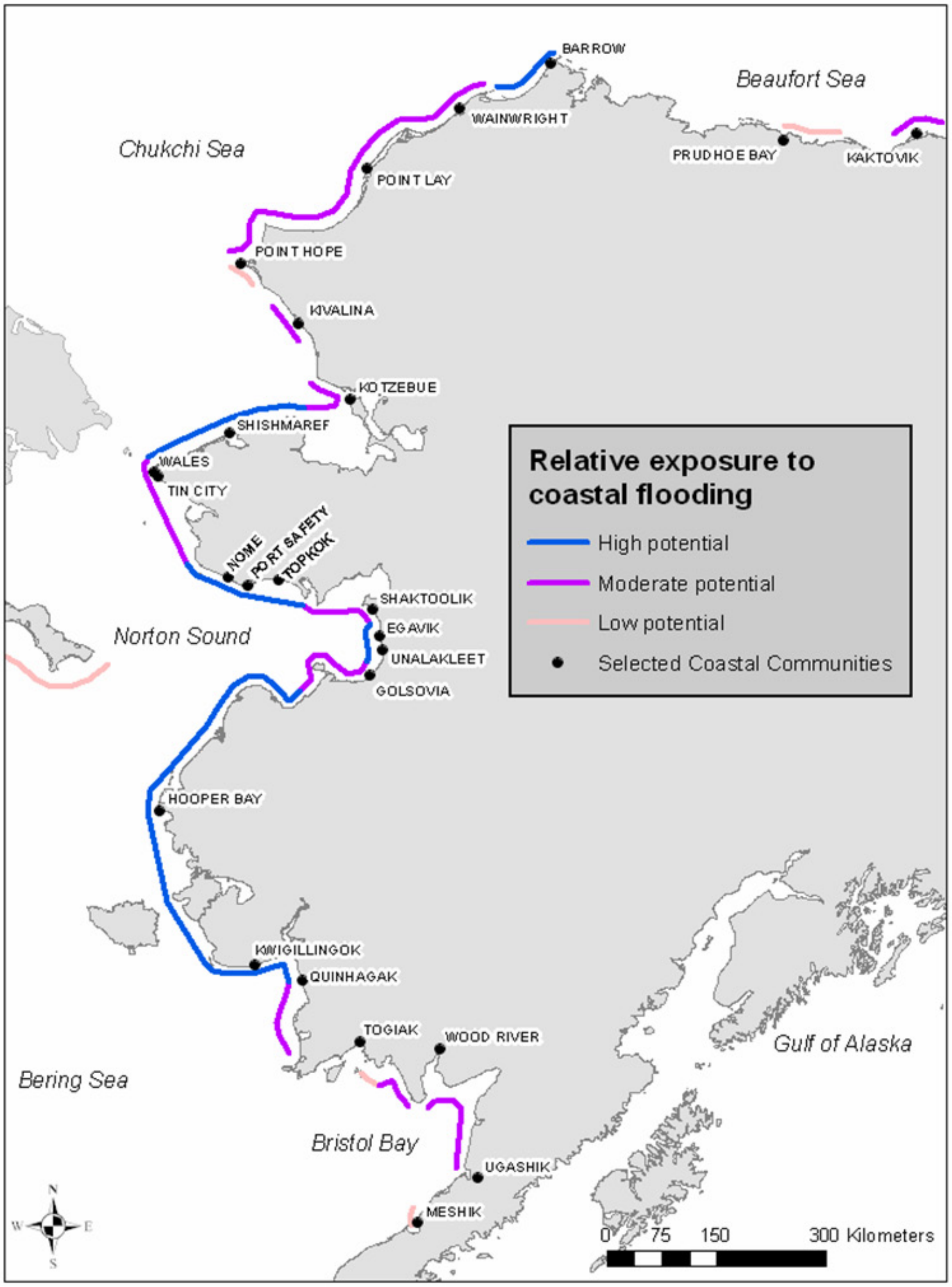


Figure 23. Map showing susceptibility to flooding during coastal storms. Low: flooding not common, Moderate: flooding every 3 to 5 years, sufficient to cause beach erosion, High: significant coastal erosion at least every 2 years (modified from Mason et al., 1997).

As an example of the effect of earthquakes on coastal stability, the magnitude 9.2 earthquake of 1964 that impacted southern Alaska caused the land surface within the vicinity of Prince William Sound to tilt, trending from the southern end of Kodiak Island northeastward to Prince William Sound overall uplift of the land occurred. On the southwestern end of Montague Island in Prince William Sound a vertical displacement of about 13-15 meters occurred. Conversely, over much of the Kenai Peninsula and the north and west portion of Prince William Sound the land surface subsided, resulting in an increase in coastal erosion along the western Kenai Peninsula (Stover and Coffman, 1993).

In Kachemak Bay in 2003 a beach monitoring camera station that observes coastal processes was installed by the USGS on the north side of the bay in Homer. Two of the primary objectives of this project are to monitor coastal erosion and loss of near shore habitat. In an area adjacent to the camera, Bishop's Beach, coastal erosion averages 0.5 – 1.0 meter per year. Bluff erosion on the north side of Kachemak Bay is primarily the result of storms that come from the southwest at high tide. Many structures have been lost to date and erosion has actually enhanced as some shoreline armor has been constructed. The construction of shoreline armor reduces erosion at the particular spot where it is constructed, however, it increases erosion in adjacent areas (Mason et. al., 1997).

Example of Coastal Erosion: Chukchi Sea Coast and Elson Lagoon

Barrow is the largest town on the North Slope and the largest town that far north in the world with a population in 2000 just over 4500 people. It is well within the zone of continuous permafrost located at the point of a peninsula marking the northern reaches of the state. The Chukchi Sea lies to the west and the Beaufort seas to the east. The bluffs along the west coast of the peninsula are considerable higher than those on the east. The west coast bluffs are composed of interbedded sands and gravels mixed with ground ice, while the bluffs to the east along Elson Lagoon are considerably lower and are dominated by ice-rich, silts and sands. Manley (2004) determined erosion rates along the peninsula over a fifty year time period. It was determined that 91% of the coastline of the peninsula had undergone erosion over this time period and that the average rate of coastal erosion was 0.91 m/yr with an average horizontal displacement of 42.5 m. Lower rates of erosion were found along the higher bluffs on the Chukchi coast (0.3 m/yr) while much higher rates were found along the Elson Lagoon coast (up to 5 m/yr). Along the portion of coastline adjacent to the town of Barrow, the shoreline eroded 0.2 to 0.8 m/yr. Overall the peninsula decreased in area by 11.8 km^2. The rates of erosion in Barrow have had some impact on the structures in the community, however, there are other communities in this region experiencing far greater problems as a result of coastal erosion.

Point Lay a community located about 300 km southwest of Barrow was forced to relocate in the 1970s. Prior to this, the village had established itself on a barrier island just off the coast of the mainland. Barrier islands are extremely susceptible to storm surges and they have a natural tendency to migrate landward as the sediments are removed from the ocean side and redeposited on the mainland side.

Point Hope is another village that has had to face consequences of coastal erosion and relocation. Point Hope was located near the tip of a spit about 200 km southwest of Point Lay. This portion of the coastline experienced a great deal of erosion during the 20^{th} Century and by the 1960s nearly two-thirds of the village was lost (Mason et. al., 1997). In the mid-1970s the remainder of the town was relocated several miles eastward along the spit.

Kivalina, a town located on a barrier island southeast of Point Hope lies only 1 to 2 feet above normal high-tide line. The island is believed to be eroding on both sides, ocean and mainland, at estimated rates in excess of 1 to 1.3 meters per year (Mason et. al., 1997). A large storm struck the town in October of 2004 and the idea of relocation has risen to the forefront.

Shishmaref, another town located on a barrier island (Sarichef Island) about 275 km southwest of Kivalina, on the other side of the bay, is also experiencing extreme erosion problems. Over the last 10-20 years, locals believe that around 9 meters of erosion has occurred on the dune scarp in town and the island has lost nearly 35 meters of beach front in the past 40 years (Mason et. al., 1997). In a recent report by the Army Corps of Engineers there are four alternatives that the village of Shishmaref faces, either stay on Sarichef Island, relocate to a new mainland site, collocate to Nome, or collocate to Kotzebue. The cost of each of these alternatives would be $110 million, $180 million, $95 million, and $140 million, respectively.

Following current climate conditions many of the islands and stretches of coastline in this region could experience higher rates of erosion resulting from an increased summer fetch due to more open ocean conditions. This combined with enhanced permafrost degradation could further the negative impacts occurring in these arctic villages. As these communities have become fixed settlements the costs associated with their relocation, both financially and culturally have drastically increased.

Anthropogenic Drivers

The anthropogenic drivers contributing most directly to landscape changes are a result of resource exploration, urban development, and logging. Primary drivers in this context are discussed below.

Oil and Gas Exploration and Development

The idea that Alaska was rich in oil and gas reserves has existed for quite sometime. The first wells drilled for oil extraction occurred at the end of the 1800s on the lower Kenai Peninsula and the first commercial discovery of oil came in the mid-1950s at the Swanson River oil field on the northern region of the Kenai Peninsula. This was followed by discoveries on the Kenai Peninsula and in Cook Inlet. The Cook Inlet region provided the first major quantity of profitable oil extraction and a mini-boom in population occurred on the Kenai Peninsula in the late 1950s/early 1960s. The largest oil field in North America was discovered on the North Slope in 1968. To transport the reserves southward from the North Slope the Trans-Alaska Pipeline System (TAPS) was completed in 1977 and since that time the modern economy of the state has been closely tied to the oil and gas prices worldwide. With the North Slope crude oil production peaking in late 1980s (**Error! Reference source not found.**), there is a mounting interest to develop the natural gas reserves within Alaska in the near future.

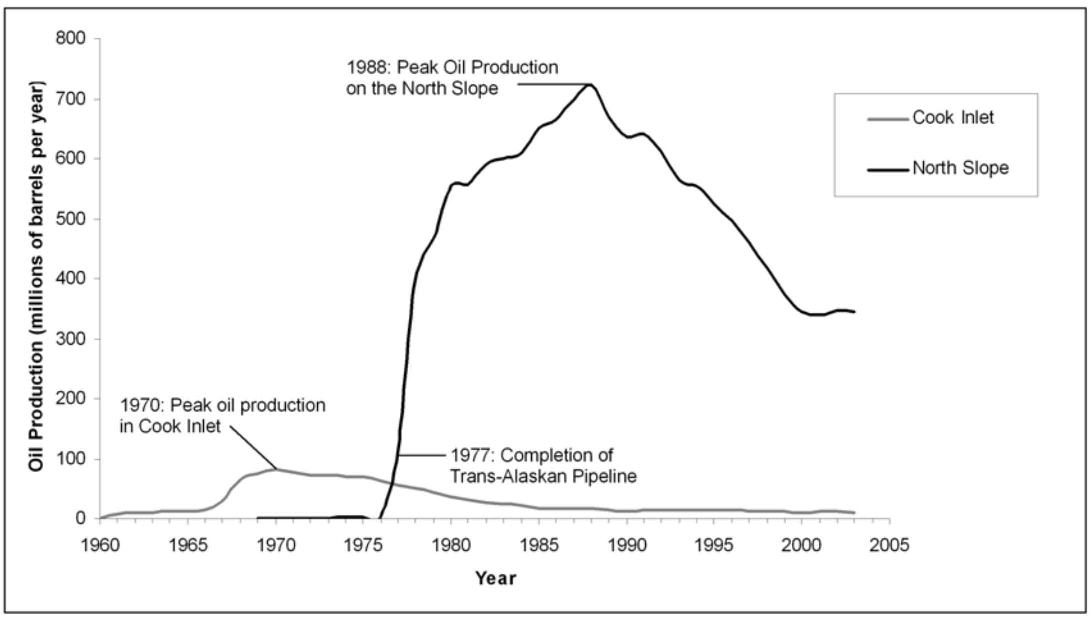


Figure 24. Graphs of oil production (millions of barrels per year) for the state. Cook Inlet production years range from 1960s to 2003. North Slope oil production ranges from 1969 to 2003 (data source: Alaska Department of Natural Resources).

Urban Development

Urban centers and large towns are not typical of Alaskan communities. There is one sizeable population center in Alaska, the Municipality of Anchorage (MOA) which represents 43% (277,498 people) of the state's population and consists of Anchorage, Eagle River-Chugiak, and Girdwood (AK Community Database, 2005).

Juneau, the state capital, represents the second largest population center in the state with a population around 31,000, while Fairbanks has the third largest population at 30,000. The only other town in Alaska with a population greater than 10,000 people is College which is essentially an integral part of Fairbanks. In contrast, there are 25 towns in Alaska with a population between 3,000 people and 10,000 people.

Selected Communities

Anchorage

Much of the growth that has occurred in the Anchorage area began in the 1940s and has been driven by the boom and bust cycles that have dominated population trends statewide (Figure 10). For example, the population of Anchorage increased more than 40% during state oil revenue boom of the 1980s (Goldsmith et al., 2005).

A recent study conducted by Markon (2003) revealed that the Greater Anchorage Bowl, an area of approximately 300 km^2 consisted of approximately 24% urban area in the early 1970s. By the year 2000 the percentage of urban lands increased to 45%, almost a factor of 2. Much of the development had occurred in areas that proved to be relatively easy surfaces in which to construct upon (i.e. flat, relatively dry ground). For Anchorage, the majority of the urban growth took place between the late 1970s and the early 1980s, accounting for 15% of the 21% change over the thirty year period.

Fairbanks

The population of Fairbanks has grown dramatically over the past century as well. In 1950, the population was slightly higher than 5,000 people and by 2000 the population was over 30,000 people, an increase of 600% (U.S. Census Bureau, 2000). To date, a detailed study has not been conducted on the change in urban areas within the Fairbanks region; however, there has been a study on the development of an urban heat island effect in Fairbanks over the time period 1949 to 1997 (Magee et al., 1999). The urban heat island effect describes the effects of an urban area (development and human activity) on temperatures and it can serve as a proxy of the urbanization of an area. In the study by Magee et al. (1999), the mean annual heat island effect observed at Fairbanks grew by 0.4°C from 1949 to 1997, with the winter experiencing an increase of 1.0°C.

The Matanuska-Susitna Valley

The Mat-Su Valley has become an area of rapid urbanization as it is essentially an exurb of the Municipality of Anchorage. The Mat-Su area is also the primary agricultural region in the state. Thus, the valley has been experiencing the conversion of agricultural lands to residential and other urban areas since the early 1980s (Alaska Department of Commerce, 2005). In the 1960s the Mat-Su Borough population was around 5,000 people and by 2005 it has grown to over 74,000 people, an increase of nearly 1500% over the 45 year time period (Alaska Department of Commerce, 2005).

Mining

Mining has recently become the second most valuable commodity in the state with the most important economic minerals mined in the state, in order of importance, are zinc, gold, lead, coal, sand and gravel, building stone, silver, copper, and jade. Since 1981, the total value of the mineral industry has increased from $290 million to $1.4 billion in 2004, with the industry exceeding $1 billion per year since 1996 (Figure 25). In 2004, 21 mines across the state accounted for 97% of the money spent on mineral exploration, and 59% of the money spent on exploration occurred in southwestern Alaska.

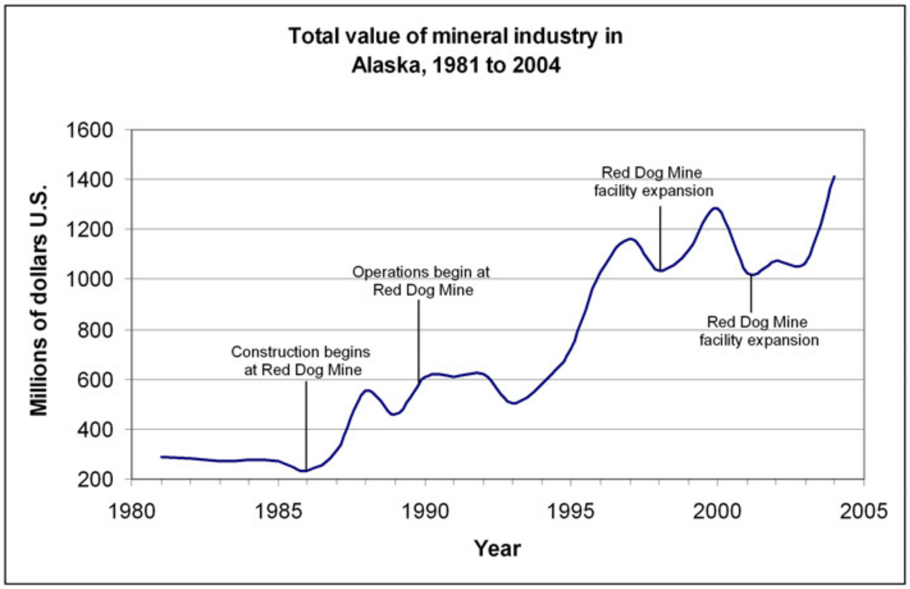


Figure 25. The total value of the mineral industry (non-petroleum) in Alaska from 1981 to 2004. The Red Dog Mine operation (largest zinc producer in the world) began in 1990 and much of the growth in this industry is presumed to be a result of this mine (data source: Division of Geological and Geophysical Surveys).

Logging

There are two National Forests in Alaska; the Tongass and the Chugach. The Tongass National Forest is 67,200 km^2, of which 40,000 km^2 are forested and 14,500 km^2 are deemed harvestable and available to commercial activities with the target species being Sitka spruce, western hemlock, western red cedar, and yellow cedar. The Chugach National Forest spans 24,000 km^2. Of this area only 6% is considered to be harvestable forest and the target species are Sitka spruce and white spruce (USDA – Forest Service).

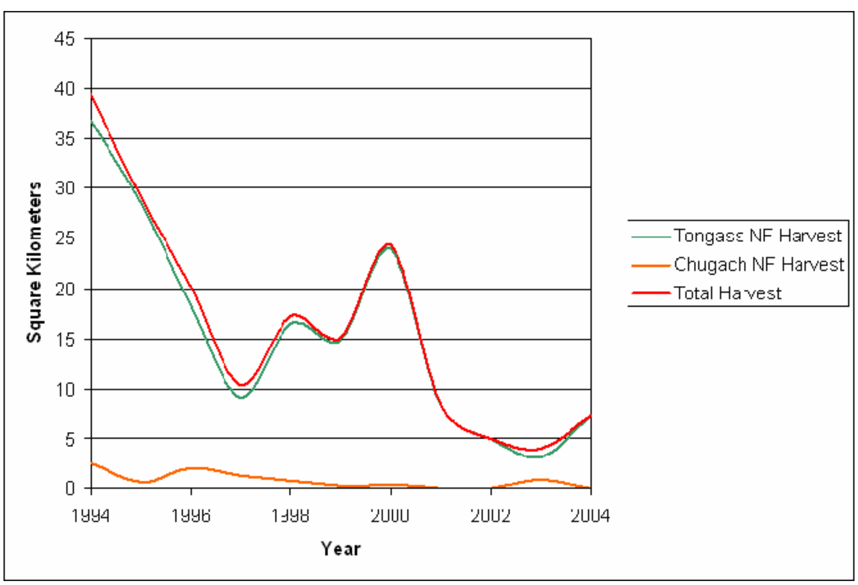


Figure 26. Area of forest harvested in the two national forests in Alaska from 1994 to 2004. The Tongass National Forest represents the majority of the logging taking place in the NF in Alaska (data source: US Forest Service).

Commercial logging began in southeast Alaska during the 1920s and it boomed in the Tongass National Forest during the 1950s where the industry dominated. Historically, the timber industry grew through the 1980s, butby the late 1990s, the reduced harvests led to closure of pulp mills which caused a fifty percent reduction of the work force (Leask et al., 2001). Figure 26 shows the trend in area harvested in the Tongass National Forest and the Chugach National Forest from 1994 to 2004.

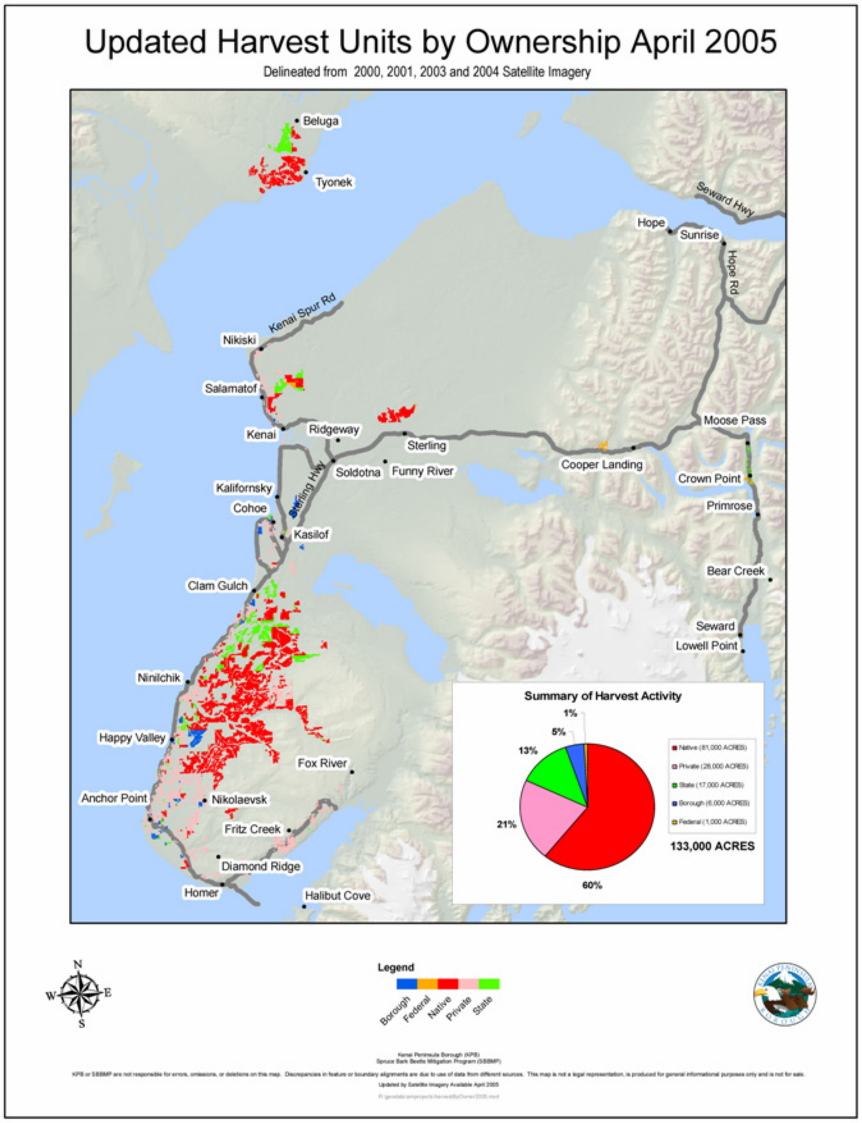


Figure 27. Harvested forest land on the Kenai Peninsula as a response to the spruce bark beetle activity, as of April 2005. The map does not display exact years of forest harvest, and thus, some of the harvested forest could have occurred pre-2000 (Source: Kenai Peninsula Borough)

Logging has also occurred on the Kenai Peninsula as a response to the spruce bark beetle outbreak that ravaged the forests in the mid-1990s. The spruce bark beetle infestation on the Kenai Peninsula is considered to be the most devastating insect infestation to occur in North America. Since 1989 the U.S. Forest Service and the

Alaska Division of Forestry have mapped over 5,600 km^2 of beetle infected forests on the Kenai Peninsula. The infestation of the 1990s accelerated in 1992 and peaked in 1996, however, new stands still continue to be infested each year. The Kenai Peninsula Borough (KPB), Spruce Bark Beetle Mitigation Program (SBBMP) identified 133,000 acres of harvested forest on the Kenai by using satellite imagery from 2000 to 2005 (Figure 27**Error! Reference source not found.**). The boreal forests of the interior have been logged to a much lesser degree, but there is increased interest in harvesting the resources there. The target species in the boreal forest are white spruce, quaking aspen, and paper birch.

Discussion and Conclusions

The land surface of Alaska is sparsely populated and the impacts from humans are far less extensive when compared to the contiguous United States. The changes in the population and the economy of Alaska have historically been driven by boom and bust cycles, primarily from mineral discoveries, logging, military expansion, and oil and gas development; however, the changes as a result of these factors have occurred in relatively small, localized areas. The economy of Alaska changed drastically after the discovery of the North Slope oil fields. This was followed by an increase in population partially because of TAPS construction, but also because of an increase in state spending of oil revenue in the 1980s (Goldsmith et al., 2005; Markon, 2003). The majority of the state's revenues still come from this resource; however, at the present time, much of the growth occurring in the state is a result of tourism and a more stable population, one which exhibits a longer residence time (Leask et al., 2000). Many of the statewide changes taking place in the land surface however, are a result of natural or climate driven processes as opposed to direct anthropogenic activities.

The widespread statewide changes appear to be occurring in relation to changing climatic conditions. The mean annual air temperature has warmed by about 2.0°C since the middle of the 20^{th} Century. Some parts of the state have experienced more warming than others but the general trend is apparent statewide. Many areas have also experienced more mean annual precipitation over that time period with the exception of the Arctic. The weather related phenomena over the past ~ 50 years are believed to be the cause of many of the changes taking place across the state today, such as more intense fire seasons, lightning and thunderstorms, insect infestation outbreaks, glacier retreat, permafrost degradation, and enhanced coastal erosion (Juday 1998; Osterkamp and Romanovsky, 1999).

During 2004 and 2005 Alaska has experienced the first and third largest fire seasons on record and these have been attributed to summer drought conditions and an increase in lightning activity (McGuiney et al., 2005; Richmond and Shy, 2005). The majority of the fires have occurred in the interior of the state. However, if the current warming scenario continues the expansion of forest fires to the coastal forest zones could become more prevalent.

The impact of insect infestation outbreaks is another component of land surface change occurring in Alaska in recent times. The recent spruce bark beetle attack (late 1980s to 1998) has had the largest impact on the integrity of Alaska's forests on the Kenai Peninsula and the Copper River region. The beetles leave behind a forest filled with dead spruce timber, potentially creating an instant fuel source for forest fires. As a consequence logging has become more proactive on the Kenai since the peak in the bark beetle outbreak of the mid-1990s as a means of timber salvage and hazard remediation. In 2004, spruce bark beetle infestations were reported on the Seward Peninsula, east of Nome, in western Alaska and if current climate trends continue the beetles range could expand northward. (USFS-Forest Health Monitoring, 2005).

Glacier retreat and permafrost degradation are expected to continue in the near future. The land terminating glaciers appear to be more closely linked to changing climate conditions than the tidewater glaciers and they serve as a proxy of how rapid changes can occur. For example, two of the most visited tourist attractions in the state, Portage Glacier and Exit Glacier, have been in a continual state of retreat in recent times. Permafrost degradation is expected to have the biggest impact in the interior region of the state were it is more susceptible to changing climatic conditions because the permafrost is less extensive and thinner than in continuous zones, which should result in basal thawing (Osterkamp and Romanovsky, 1999).

Coastal erosion is expected to increase along Alaska's western and northern coastlines following current climate trends. These coastlines consist primarily of unconsolidated sediments in permafrost, thus, they are susceptible to erosion. An increase in fetch and storm activity is expected because the pack ice extent is decreasing in the Bering Sea and Arctic Ocean. In recent times, the pack ice has resided farther from land and for a longer part of the year.

Coastal erosion along these coastlines has received a lot of press in recent times due to effect on local communities. The people of this region used to live a lifestyle in which mobility and relocation allowed them to cope with the changing conditions of the coastline. Today, however, modern amenities such as plumbing, fixed structures, and power plants have decreased their mobility significantly. Several communities along these coastlines have already had to deal with the loss of land due to coastal erosion and several more will probably face this consequence in the future.

The anthropogenic changes that have occurred in Alaska have remained localized in nature and relatively small in scale. The largest anthropogenic impacts on land cover change have come from resource exploration/extraction and urbanization. The development of the North Slope oil reserves has had the largest impact on the state's economy and in the near future an adjacent gas pipeline is planned for development along side the Trans-Alaskan Pipeline, thus harboring the potential for another boom in Alaska. The mining (non-petroleum) industry has recently become the second most valuable commodity in the state behind oil and gas and the potential for future development is likely as exploration is underway in areas of the Brooks Range as well as areas in Southwestern Alaska. The utilization of forest resources in Alaska was highest during the logging boom of the 1950s in southeastern Alaska however, this boom began to wane in the late 1980s. Urbanization will probably continue to have an effect on land-cover change as the population of Alaska is expected to grow throughout the 21st Century (Campbell, 1996). The Municipality of Anchorage is the largest urban area in the state, however much of the developable lands in Anchorage have already been developed, as a result new growth in the Cook Inlet Region is expected to continue to occur in the Matanuska-Susitna Valley.

It is apparent that several changes are occurring in the land surface of Alaska. However, all of the information and data available covers a relatively short time period, roughly the 1950s onward. It will be important to extend the monitoring of these changes into the future to compare rates of change from the latter half of the 20th Century, into the 21st Century.

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