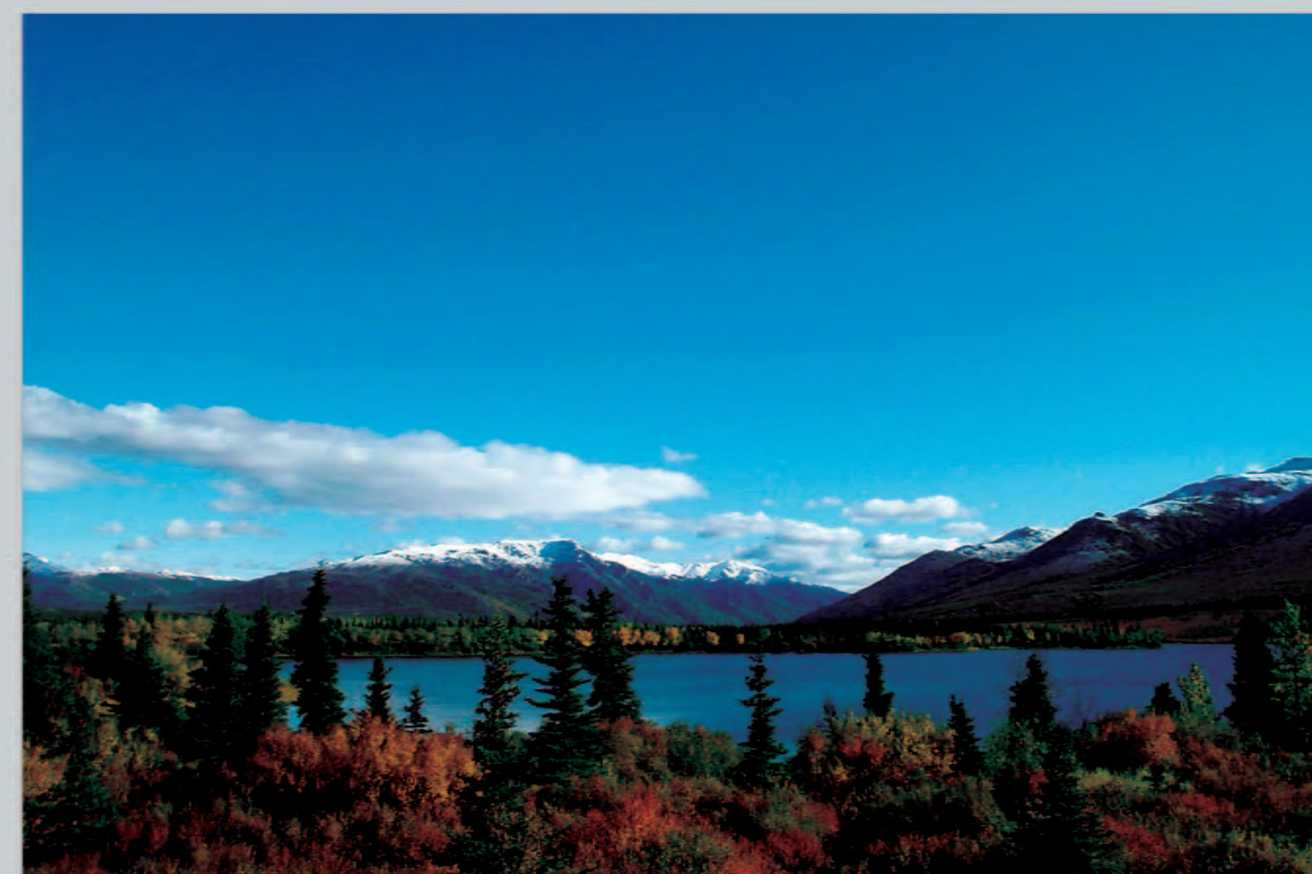
A Workshop Summary Report to

RISA

The Regional Integrated Sciences and Assessments Program

Enhancing Decision-Making Through Integrated Climate Research



Alaska

Summary of an Exploratory Workshop
Anchorage, AK
February 18–19, 2004

UCAR

NOAA's strategic vision is to:
Move NOAA into the 21st century scientifically and operationally, in the same interrelated manner as the environment that we observe and forecast, while recognizing the link between the global economy and the planet's environment.

NOAA's mission is to:
Understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet our nation's economic, social, and environmental needs.

The relevant NOAA strategic goals and priorities for the RISA Program are:
- Protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management.
- Understand climate variability and change to enhance society's ability to plan and respond.
- Serve society's needs for weather and water information.

NOAA's Cross-Cutting Priorities:
- Integrated Global Environmental Observation and Data Management System
- Environmental Literacy, Outreach, and Education
- Sound, Reliable, State-of-the-Art Research
- International Cooperation and Collaboration
- Organizational Excellence: Leadership, Human Capital, Facilities, Information
- Technology, and Administrative Products and Services

Goal 5 of the Climate Change Science Program is also an important reference for the RISA Program.
CCSP Goal 5: Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

Cover Photo: Small lake near Denali National Park, reprinted with permission by Larry Hinzman

RISA

The Regional Integrated Sciences and Assessments Program

Enhancing Decision-Making Through
Integrated Climate Research

A workshop sponsored by:
National Oceanic & Atmospheric Administration, Office of Global Programs

Co-sponsors:
National Weather Service, Alaska Climate Services
United States Geological Survey, Alaska Science Center
National Park Service, Alaska Region

Alaska

Summary of an Exploratory Workshop held in Anchorage, AK
February 18-19, 2004

Prepared
by
Susanne Moser

FOREWORD

Thank you for your interest in the exploratory Regional Integrated Sciences and Assessments (RISA) workshop held in Anchorage, AK on February 18-19, 2004. This document is intended to provide a summary of the discussions and recommendations from the workshop and is not a peer-reviewed publication.

The National Oceanic and Atmospheric Administration (NOAA) is sponsoring workshops, like this meeting, in regions across the United States that currently have no formal link with existing RISA Programs. The workshops serve to educate the RISA program management about opportunities and needs for climate relevant integrated research and available regional capacity. In addition, the meetings are designed to educate regional research and decision-making communities about the RISA program's goals, research philosophy and methodologies.

I would like to personally thank those Alaskans who participated in this workshop, as your insights and concerns, aptly captured in this report by Susanne Moser, will help to guide NOAA's decision support research priorities in the future. The multiple comments we received on the draft document were also extremely useful and served to improve the final report in a meaningful way. I also hope that this document will serve as a useful source of information and tool for new collaborations, both locally in Alaska and beyond.

RISA researchers from the western U.S. also gave much of their time and energy to this meeting, and I'd like to thank them and acknowledge the many opportunities for potential cross-RISA collaboration in Alaska in the future.

And to our meeting co-sponsors: Judy Gottlieb from the National Park Service, Mark Shasby-USGS, and Gary Hufford, NWS, many thanks for your guidance and support of this meeting.

I welcome your comments and suggestions, so please feel free to contact me regarding this report or the RISA program in general.

Sincerely,

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RISA: Program Description

The Regional Integrated Sciences and Assessments (RISA) Program for Climate-Sensitive Decision-Making and Policy Planning

> *"Other than a relatively small program* **[RISA]** *at NOAA, there is currently no structure or process within USGCRP to identify potential users, understand their needs, and connect them to the research agenda….RISA has been called a step in the right direction by some while others view it as a model that could guide larger efforts within USGCRP."*
>
> —Committee on Science U.S. House of Representatives,
> "New Directions for Climate Research and Technology Initiatives," April 17, 2002

Introduction

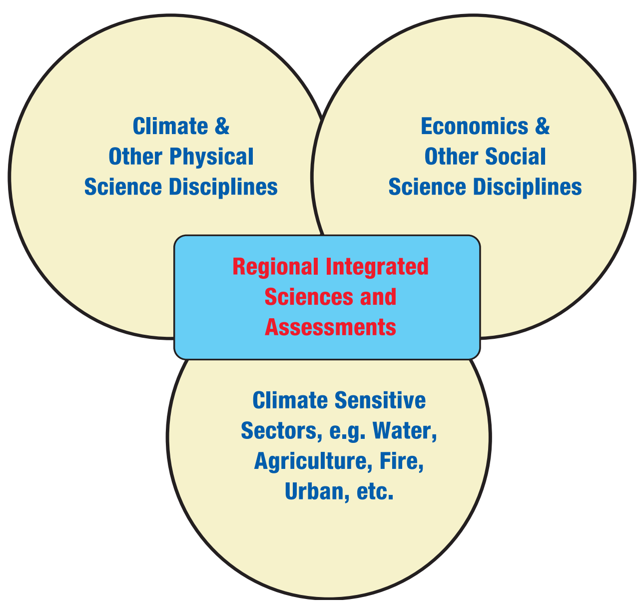
The National Oceanic and Atmospheric Administration (NOAA) has a mandate to provide the U.S. public with high-quality scientific data and climate services. Fulfilling this mandate requires research, partnerships, and patience, as climate services are still embryonic, though maturing quickly. One form of research that is supported by NOAA that contributes to the development of scientifically based climate services is the Regional Integrated Sciences and Assessments (RISA) Program. The program supports integrated research across a range of disciplines to expand decision-makers' options at the regional level. It does this in a manner cognizant of the context in which decision-makers function and of the constraints they face in managing their climate-sensitive resources.

That is why NOAA is supporting a series of workshops on integrated sciences and assessments. It is expected that the workshops will provide interested parties in regions not currently involved in RISA activities an opportunity to acquaint themselves with the program. Also, the results of the workshops will aid in the design of NOAA's national research and climate services policies, structures, and resource allocations, and ensure effective partnering with other federal, state, and local agencies, decision-makers, and the private sector. It is further expected that these workshops will lead to more uniform research proposals should a competitive funding opportunity arise in the future.

Why Is RISA Relevant and How Does It Work?

Normally, most decision-makers and policy planners include only the climatology (the long-term mean and distribution of weather) for a region in their decision processes. Scientific and decision-making communities increasingly recognize the need to include subtler climate trends and variability. This is occurring because advances in knowledge of ocean surface/atmosphere and land surface/atmosphere interactions make climate variability prediction,

Figure 1: The RISA integrated approach

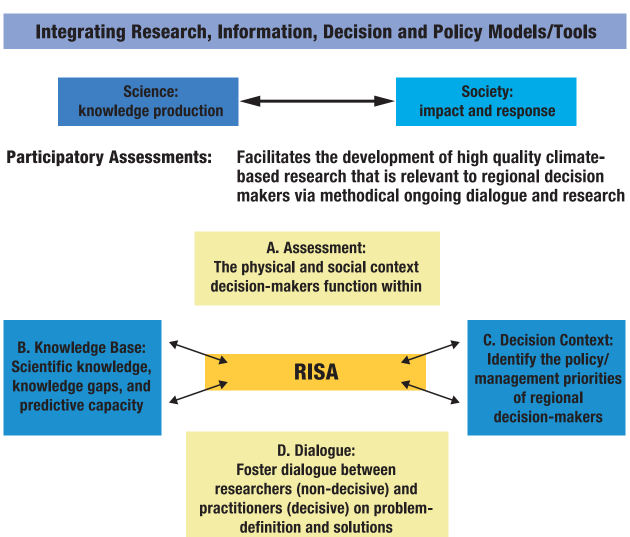


and potentially climate change prediction, feasible. El Niño, for example, is now recognized as causing predictable seasonal climate variability in parts of the United States and the rest of the world. Climate change is now widely accepted as an influence on the physical environment and society. Historically, translating these advances into operationally useful information has been challenging for the following reasons:

1. Scientists often do not appreciate how climate information fits into the institutional, economic, and cultural parameters and factors facing decision-makers (Jacobs 2002).
2. Conversely, decision-makers tend not to actively identify new sources of information or establish contacts with experts who could contribute to making more informed decisions (Ibid).
3. There is a perceived lack of structured processes to identify, assess, and meet national, regional, private and local climate-related needs. This hinders the timely adoption and effective use of climate information and technology throughout the U.S. economy (U.S. Congress 1998; NRC 2003).

The House of Representatives recognizes that RISA is contributing to ameliorating the preceding shortfalls (Jacobs 2002, U.S. House of Representatives 2002).

Figure 2: The RISA process



The process of how RISA integrates research, information needs, decision- and policy-making tools is depicted in Figure 2.

RISA Objectives and Methods

The goals of NOAA's Regional Integrated Sciences and Assessments Program are as follows:

1. Identify the climate, physical, and social context in which decision-makers manage.
2. Identify climate-sensitive constraints facing decision-makers that may be ameliorated by scientific research.
3. Collaborate with decision-makers to expand their options in the face of identified constraints by integrating research from a range of physical and social sciences to develop methodologies, prototypes, and policy-related insights.

The RISA Program is congruent with the mission, strategic vision, and goals of NOAA. The most relevant NOAA strategic goals and priorities for the RISA Program are to: a) protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management; b) understand climate variability and change to enhance society's ability to plan and respond; and c) serve society's needs for weather and water information.

The RISA activities succeed to a great extent because of the partnerships the RISA teams develop across a spectrum of interests (federal, state, local, private, and tribal). These partnerships enable the RISA teams to identify risks, uncertainties, and critical knowledge gaps, make balanced syntheses, and identify needed services on an ongoing basis. The RISA Program has been influenced by documents from the National Research Council, the U.S. Congress, the NOAA Strategic Plan, the U.S. Climate Change Science Program (CCSP) Report (2003), and others. Figure 3 illustrates where current teams are situated and the types of activities in which they are engaged.

In addition to the NOAA strategic goals, the RISA Program contributes to the CCSP's Goal 5 ("Explore uses and identify limits of evolving knowledge to manage risks and opportunities related to climate variability and change"). RISA activities contribute to identifying a) uses and limitations of observations, data, forecasts, and other

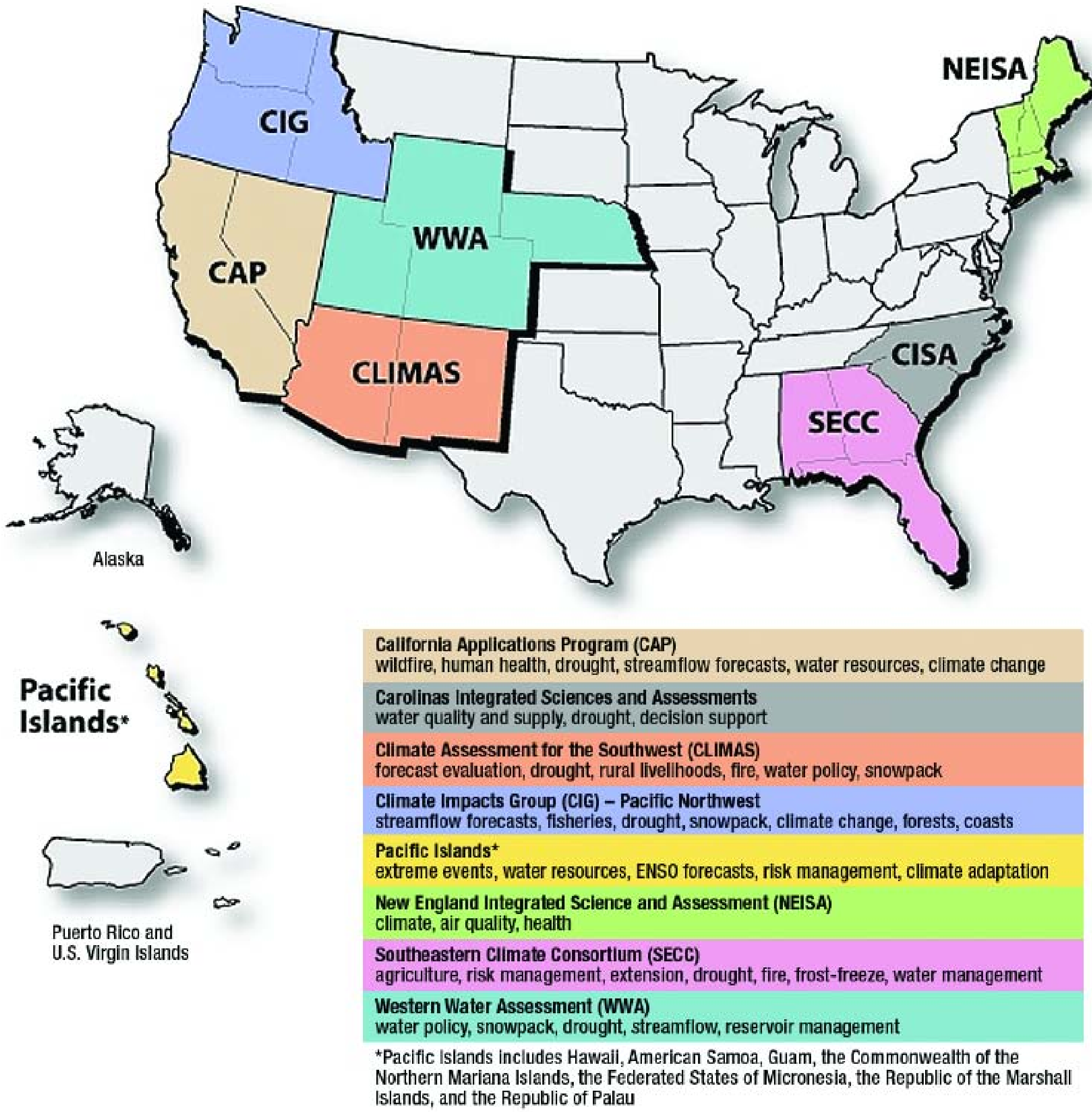


Figure 3: Existing RISA teams and their core integrated science and assessment themes

projections in decision support for selected sectors and regions; b) best-practice approaches to characterize, communicate, and incorporate scientific uncertainty in decision-making; c) decision-support experiments and evaluations using seasonal to inter-annual forecasts and observational data.

The methodologies and policy insights identified by RISA teams are contributing key components of the research foundations for a climate service. These results are yielding prototypes and policy guidance that have high potential or are already being transitioned into operational settings. It is important to note, however, that the RISA Program is not an operational extension service. It conducts research that often leads to prototypical decision-support products. The teams cannot produce sustained operational products.

Conclusions

Although the RISA Program is a national program there are many regions of the United States that do not have RISA-supported teams. This document is an example of the RISA Program management's intention to methodically identify the needs of regions and educate regional players about the RISA research effort. It is hoped that by conducting workshops now, in the future as resources become available, NOAA shall be able to competitively develop the RISA Program in a manner that best benefits regional and national interests and needs.

RISA teams identify risks, uncertainties, and critical knowledge gaps, make balanced syntheses, and identify needed services on an ongoing basis.

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Alaska: "The Great Land"

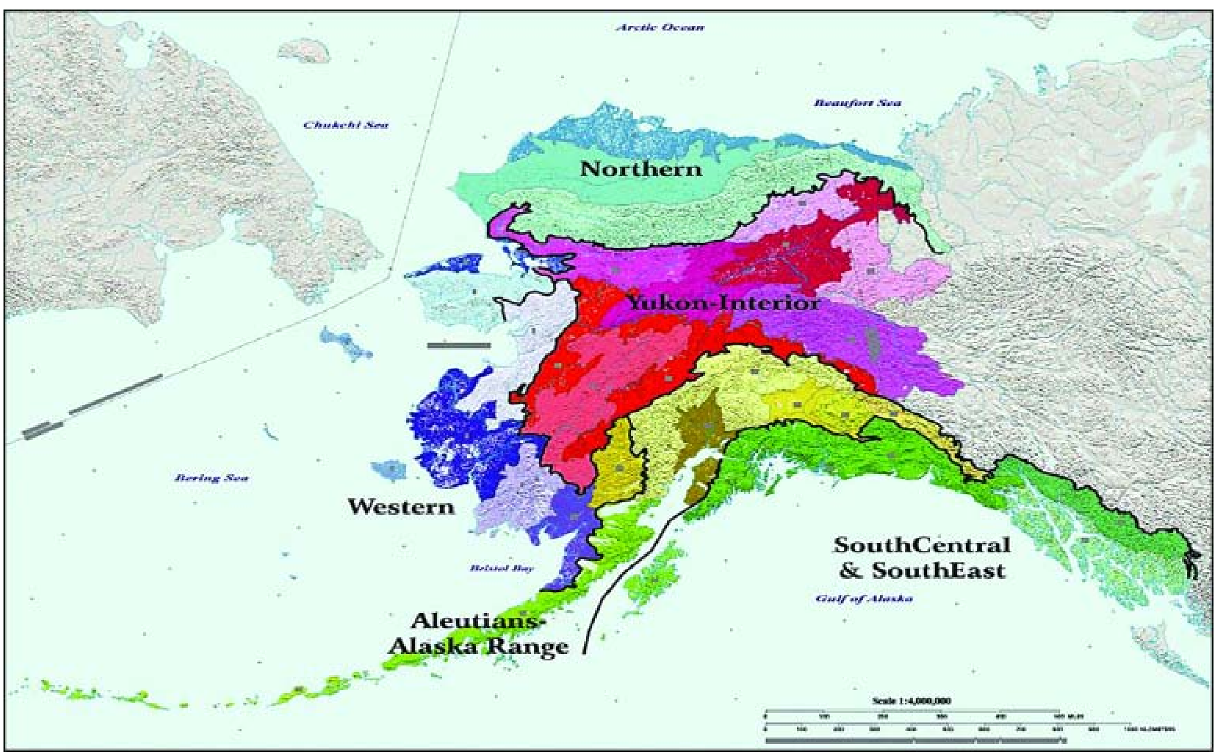
For most, Alaska is a faraway land of immense landscapes, tall mountain ranges, largely untouched wilderness and – above all – great beauty. For the nearly 650,000 people who call the state home, it is the nearby land from whose rich environments and coastal oceans one draws physical and spiritual sustenance; whose harsh realities are dictated by the change between dark and never-dark seasons; whose vastness magnifies the importance and dependence on local community. For all, Alaska – Alakshak[1] – is "the Great Land," an awe-inspiring land increasingly at risk from climate change.

Alaska – "The Great Land" is increasingly at risk from climate change.

A Vast and Diverse Geography

With a land area of 571,951 square miles, the 49th state to enter the union in 1959 is the largest of all U.S. states – twice the size of Texas, and roughly equal to one-fifth of the continental U.S. Bounded in the southwest by the Pacific Ocean, in the west by the Bering Sea, and in the north by the Arctic Ocean, it is the only U.S. state with two international borders (with Russia and Canada). Its many thousand miles of coastline, numerous active volcanoes, 39 majestic mountain ranges containing 17 of the 20 highest peaks in the United States, and diverse ecosystems ranging from temperate rainforest to desert-like Arctic tundra offer a home to some of North America's most remarkable – and threatened – wildlife, provide a plethora of natural resources, and also pose significant geophysical and climatic hazards. Earthquakes, volcanic eruptions, tsunamies, coastal erosion, and climatic hazards such as droughts, floods, wildfires, and severe winter storms are all part of life in this northern state (Figure 4).

Figure 4: Physical-geographical regions of Alaska (Source: United States Geological Survey)



[1]A word derived from the Aleutian language.

Physical Geography

Alaska's geography varies greatly from north to south and from sea level to its highest peak, Mt. McKinley – at 20,320 feet (6,194 m), the highest mountain in all of North America. The state is commonly divided into four major geographic subregions: the Pacific Mountain System, the Central Up- and Lowlands, the Rocky Mountain System of Alaska, and the Arctic Coastal Plain.

Climate

Spanning 20 degrees of latitude and 60 degrees of longitude, Alaska covers large climatic differences. Generally speaking, its climate very much reflects the geographic divisions described in Box 1. Because of the maritime influence, not four, but five different climatic zones are generally distinguished. The first zone is dominantly influenced by the closeness to the ocean and includes all southern, southeastern and southwestern coastal regions along the Pacific. The second zone is a maritime-continental transition zone influenced during summers by the Bering Sea and in winter by the continental air masses of the interior. It includes western portions of Bristol Bay and of the west-central regions. The third climatic region is another maritime-continental transition zone located in the southern Copper River region and includes the Cook Inlet and northern reaches of the south coast region. The Interior Basin and the remainders of the Copper River and west-central region make up the fourth, a more continental climatic zone. Finally, the arctic climatic zone essentially covers the Arctic Coastal Plain region (WRCC no year).

Temperature and precipitation vary across this vast state along south-to-north and west-to-east gradients. Precipitation generally is highest in southern and coastal regions and decreases sharply toward the interior and to near-desert-like amounts in the Arctic region (Figure 5).

Box 1: Alaska's geographic regions

Pacific Mountain System

This region comprises all the mountain ranges in Alaska's south, southeast, and southwest. It is the northern extension of the mountain system running the length of the North American continent on its western side. In Alaska the ranges run along the Pacific coast, from the Aleutian Islands to the narrow Alaskan Panhandle. It includes such well-known ranges as the Saint Elias Range, the Wrangle Mountains, the Chugach Mountains, the Kenai Mountains, the Talkeetna Mountains, the Alaska Range, which includes Mt. McKinley, and in the southwest, the Aleutian Mountain Range – a 1,600 mile-long chain of 14 large and 55 smaller volcanic islands. The region also includes two lowland areas, the Copper River Basin and the Susitna-Cook Inlet lowland. The former is mostly forested, whereas the latter, extending north and east from Anchorage, includes forests and the fertile Matanuska Valley, which is important to local agriculture.

Central Uplands and Lowlands (The Interior)

This region between the Alaska Range to the south and the Brooks Range (or Rocky Mountain System of Alaska) to the north is known as the Central Upland and Lowland region. From east to west it extends from the Canadian border to the Seward Peninsula and the Kuskokwim River area of southwestern Alaska. It is made up of low, rolling hills and swampy river valleys such as those of the Koyukuk, Kuskokwim, and Tanana rivers, as well as Alaska's longest river, the Yukon.

Rocky Mountain System of Alaska

The northernmost mountain range in Alaska is the Brooks Range with its foothills and numerous glaciers and peaks – some of which rise to 9,000 feet above sea level. Generally, there is an elevation gradient from east to west.

Arctic Coastal Plain

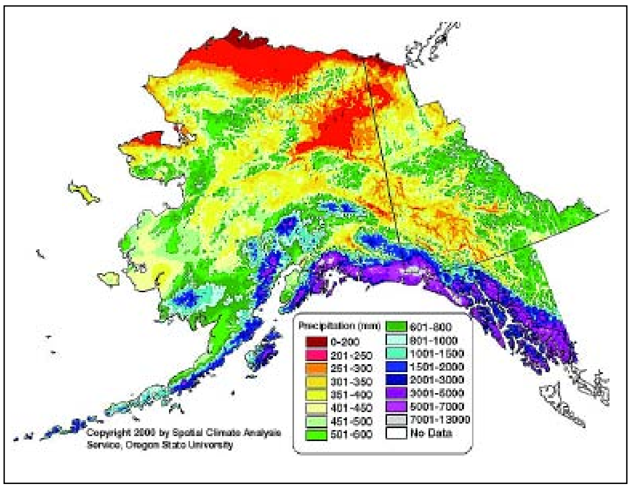
Finally, Alaska's northernmost geographic region is the Arctic Coastal Plain. This region extends north from the Rocky Mountain System, gradually sloping down toward the Arctic Ocean. Characterized by continuous permafrost (permanently frozen ground with only a thin top layer that thaws during the summer months), the dominant vegetation type is tree-less tundra.

Source: Netscape.com 2004

Snowfall, of course, makes up a significant amount of annual precipitation. Most of the storms cross into Alaska on storm tracks along the Aleutian Island chain, the Alaska Peninsula, the coast of the Gulf of Alaska, or come into the state via the Bering Sea or the southern Arctic Ocean. Frequently they bring strong winds that cause hazardous conditions for shipping vessels, or those exposed to the elements in wind-chill temperatures.

The south-to-north and coast-to-inland gradients are also evident in temperatures, with average annual temperatures ranging from the low 40s (Fahrenheit) in southern and coastal areas to the 10s along the Arctic Slope. The seasonal temperature range is largest in the interior, where average summer maxima can be in the 70s and winter average minima in the -20s to -30s, but extremes of +100°F and -80°F have been recorded (Figure 6). The low winter temperatures play an important role in subsistence and other economic activities, as ice on rivers and coastal oceans allows for transportation and gives access to hunting grounds, while permafrost allows for transportation related to natural gas and oil development.

Figure 5: Mean annual precipitation in Alaska (Source: Kelly Redmond, WRCC)



Ecosystems and Natural Resources

Geographic factors such as topography, elevation, the varying degrees of influence from maritime versus continental air masses, the extent of permafrost, and the large differences in the amount of daylight received over the course of the seasons give rise to a variety of soil and vegetation types (Figure 7).

The majority of ecosystem types belong to the polar domain, except for southern Alaska's coastal forests, which are considered humid temperate (Figure 8).

Treeless tundra in northernmost regions is habitat for cottongrass-tussock and other grasses and sedges, providing a rich food source for caribou, numerous smaller mammals, and in the rich coastal areas also for migrating waterfowl and shore birds. On higher ground or where soils are better drained and roots can penetrate soils to greater depth, thickets of birch, willow, alder, and poplar begin to fill in; especially along rivers this provides ideal habitat for

Figure 6: Mean annual temperatures in Alaska. Minimum January temperatures (l), maximum July temperatures (r) (Source: Kelly Redmond, WRCC)

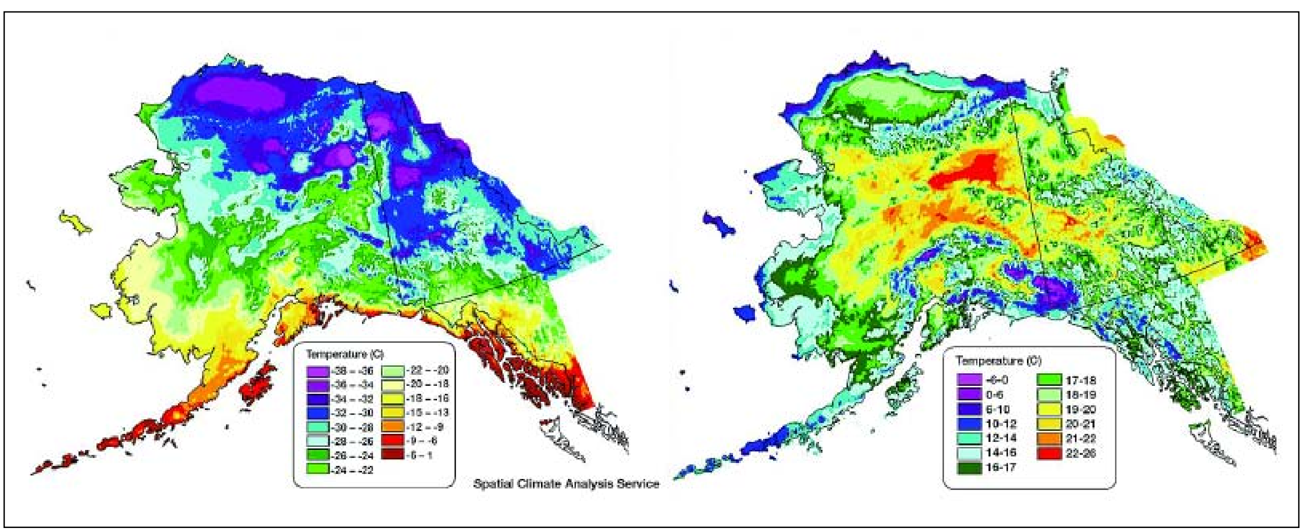


Figure 7: Alaska ecosystems along environmental gradients (Source: USGS 2001)

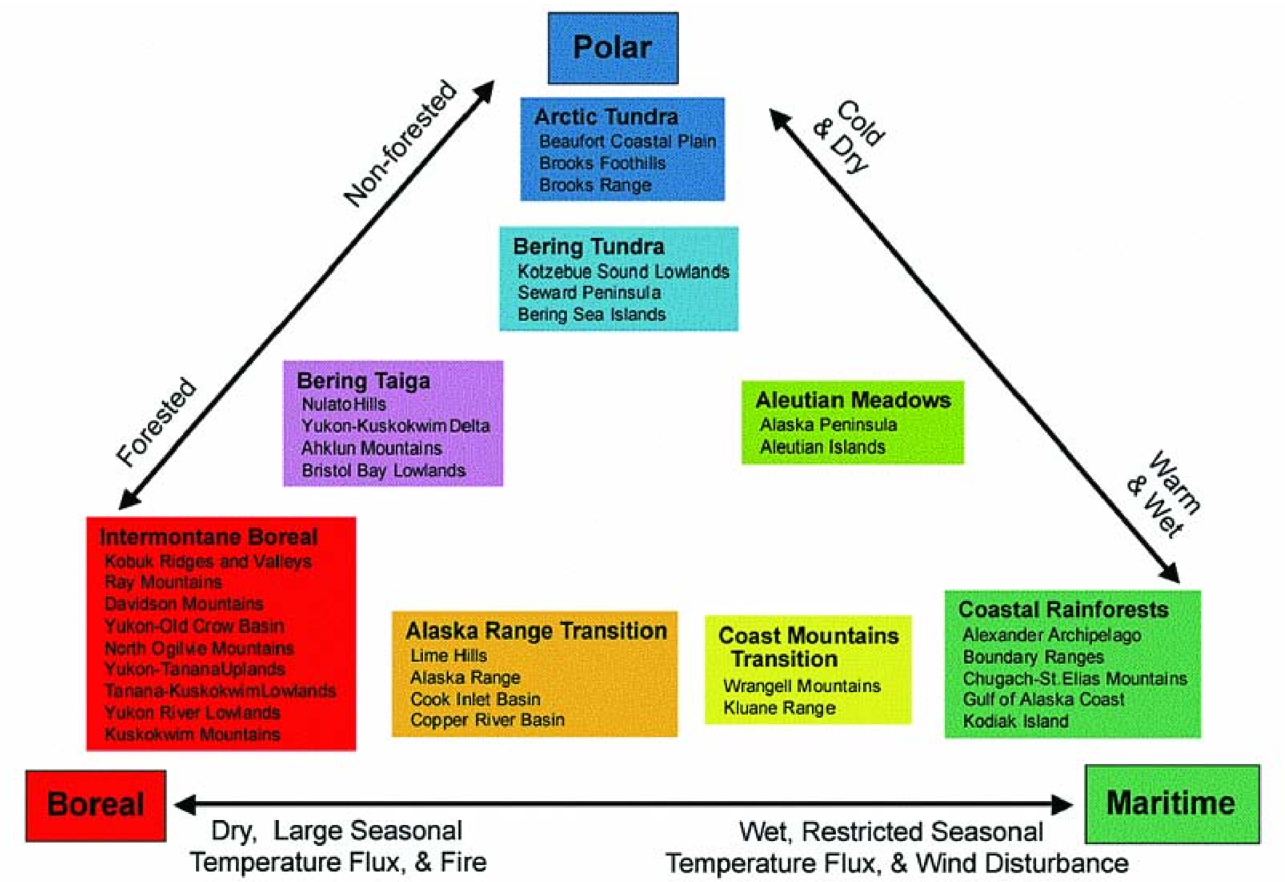
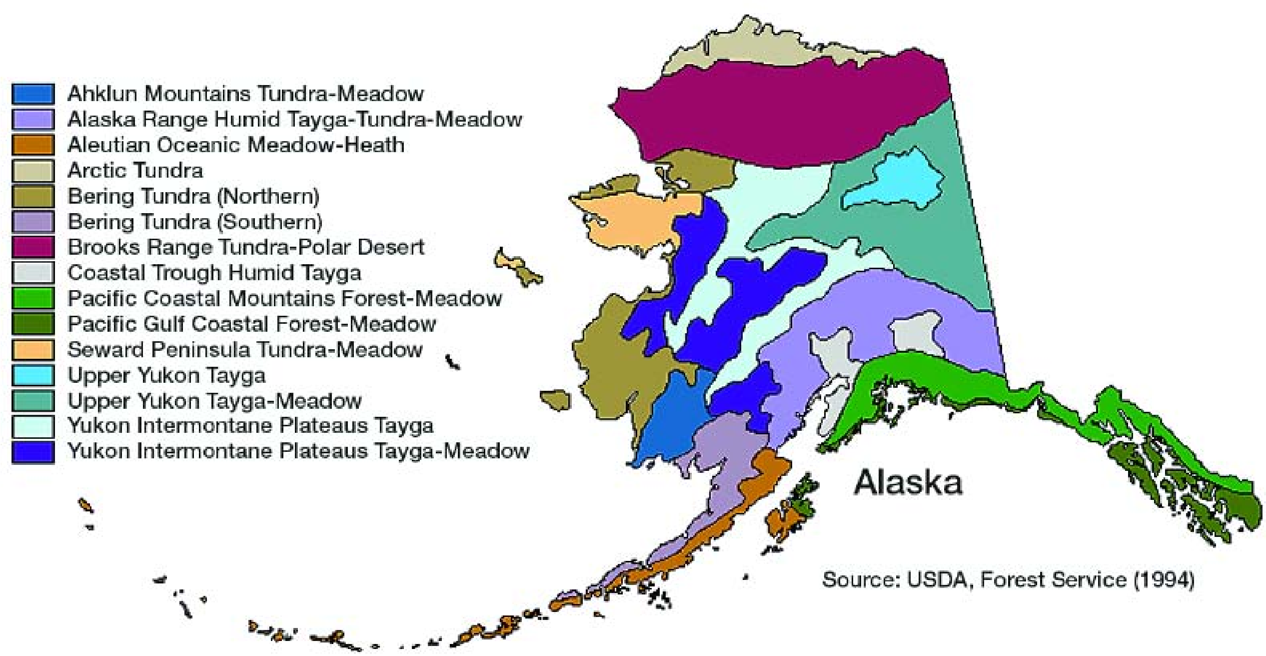


Figure 8: Alaska's ecosystem provinces (Source: USDA Forest Service 1994)



furbearers, game birds, and moose. Along the Arctic Ocean and Bering Sea coasts, polar bears, walrus, artic fox, and millions of migrating waterfowl find their home. Farther south and inland (e.g., around Bristol Bay), brown bears are common, feeding on some of the world's largest sockeye salmon runs. On the Aleutian Islands, climatic conditions resemble those of the Arctic Coastal Plain, except with a stronger maritime influence that does not allow for permafrost. As a result, tundra or heath lands dominate the islands – no trees, but thickets of low willows and a wide range of grasses, ferns, and heath. The islands support land mammals only up to the size of foxes, but marine mammals such as seals, sea lions, and sea otters are abundant.

Taiga (or tayga) can mostly be found in the interior uplands and lowlands region where a variety of vegetation types reflect wetter and drier conditions depending on permafrost and topography. On better-drained soils and only intermittent permafrost, taiga supports forests of white spruce, cottonwood, and poplar with thick undergrowth of alder, willow, dogwood, dwarf birches, and berries. Bears, wolves, caribou, and smaller mammals, as well as Dall sheep in the uplands, are plentiful. In wetter marsh areas, black spruce, alder, willow, or peat areas dominate, providing habitat for moose and water-loving small mammals and birds.

Alaska's most southern ecoregions fall into the humid-temperate domain and comprise mostly coastal forests, ranging from sea level up to nearly 20,000 feet. While in the highest elevations ice fields and bare rock or rubble support no or little vegetation, lower elevations host Alaska cedar, western hemlock, mountain hemlock, Sitka spruce, willows, and cottonwood. Wetland vegetation reigns in wet, poorly drained areas. Brown and black bears, mountain goats, and small mammals live in the higher elevation areas, whereas the Sitka black-tailed deer, bears, wolves, moose, and other mammals are common in lower elevations. Fish, salmon, and a wide range of birds are also characteristic.

It is this wealth of ocean and land-based wildlife, Alaska's vast forests and the well-drained, fertile soils in the south-central region, as well as the sheer beauty of the natural environment, that form the basis of the state's major economic sectors as well as of the subsistence economies of Alaska Natives. Fish, salmon, crab, shrimp, and whales, fur-bearing animals from seals to beavers, and minks to bears, as well as lumber and wood products mostly produced in the southeast have historically been mainstays of Alaska's economy. Agriculture – while restricted by the brevity of the frost-free period – bursts into production each year as long days allow for rapid growth. Grass crops, milk production, and vegetable crops are grown near the main population centers in the "Land of the Midnight Sun." Nature-based tourism and hunting is an important and growing sector, and with improved air transportation reaches even into the most remote areas of the state.

The wealth of ocean and land-based wildlife, Alaska's vast forests as well as the sheer beauty of its natural environment form the basis of the state's major economic sectors and the subsistence economies of Native Alaskans.

Finally, extractive industries based on the mineral resources of the state have long been and are becoming evermore important to the state economy. Although this part of Alaska's history began with gold and other precious metals in the middle of the 19th century, the modern "gold" began flowing in 1968 when oil and natural gas reservoirs were discovered in Prudhoe Bay. Oil and gas extraction were made easier with the completion of the Trans-Alaska pipeline in 1977. In addition, coal, uranium, and platinum generate significant revenue for the state.

Population

Alaska was first populated by native peoples crossing the Bering Strait during the last ice age. In more recent times, "The Last Frontier" has been a land for the adventurous and hardy, and thus historically thinly populated. Most recent census data estimate a total population of 643,786 (2002), resulting in a population density of less than 1 per square mile. While population growth in the last few years has been far below historical records, the population has increased by more than 9% over the past decade (U.S. Bureau of Census 2002). Nearly 16% of the population self-identify as American Indian (primarily Athabascan, Tlingit, Tsimshian, and Haida), Eskimo (mainly Inupiat and Yupik), or Aleuts (Figure 9). Honoring their heritage and cultures, many Alaska Natives still live in small communities in remote areas, pursuing essential livelihood activities such as hunting, fishing, and whaling, and are thus directly linked to the natural rhythms of this northern environment.

Only three Alaskan cities are home to more than 30,000 people – the largest city by far, Anchorage, with 260,000 residents, the capital Juneau (with about 31,000), and the main center of the interior, Fairbanks (just over 30,000 people). These population centers are the trading and service centers of Alaska, playing key links between the state, national, and global economies and the economic activities "in the bush."

The Remainder of this Report

The purpose for providing this general background about Alaska upfront is to place the workshop discussions summarized in the following chapters into their appropriate geographical, ecological, and social context. Where deemed necessary, explanatory detail from sources other than workshop participants was added to provide sufficient information for non-local and/or non-experts readers. The next chapter is dedicated to issues of climate variability and change and to how sensitive Alaska's environment is to climate. Subsequent chapters approach this link from the point of view of ecological, social, and economic vulnerability. The regional research and assessment capacity is highlighted before concluding with a needs assessment for further integrated research.

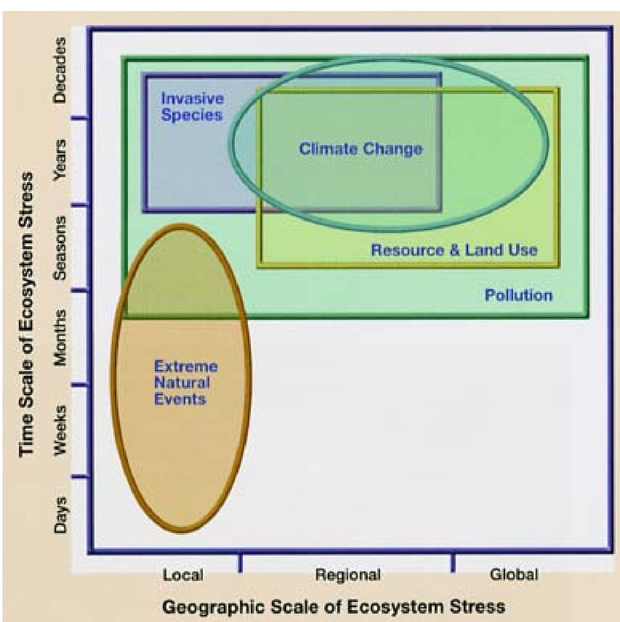
Figure 9: Alaska Natives (Source: Tony Weyiouanna/Kawerak Transportation Program (ice fishing) and Larry Merculieff (father and son, Native women); reprinted with permission)

Climate Variability and Change in Alaska: Today's Challenges, Tomorrow's Unknowns

With Alaska's state and Native economic activities being largely dependent on its natural resource base, it is not surprising how sensitive much of the state is to climate variability and change. Moreover, evidence for a major climate regime shift in the mid-1970s and early warning signs of anthropogenic climate change are more clearly established in the state than in most other lower-latitude regions. Thus, Alaska's state motto – "North to the future" – is almost prophetic. As some scientists suggest, if we want to understand the future implications of climate change, we should look north to Alaska. At the workshop, some suggested that the region is about 10-20 years ahead of other parts of the world in terms of seeing the impacts of global climate change.

Clearly, climate is not the only stress on Alaska's ecosystems and economic activities. Major stresses rooted in a variety of causes interact in space and time (Figure 10).

Figure 10: Major interactive stressors across time and space (Source: James Overland)



This suggests that dealing with the vulnerabilities and stresses on Alaska's environment, economy, and people requires an integrated comprehensive systems approach in order to increase resilience.

> *"I saw some dead fish in Fish Lake.*
> *You know when you see a dead fish in a river you know something is wrong.*
> *Like I was saying, the people have been mining that area since I can remember. What have they been putting into that lake?*
> *It makes you wonder.*
> *The reason a person wants answers to these kinds of questions is because you are concerned about your land and the next generation."*
>
> –John Starr, Native elder, Tanana, Alaska
> (Source: Larry Merculieff)

Thus, while none of the major drivers of change can be neglected in the search for a better understanding of regional problems or for effective solutions, climate – as Native and scientific observers have been documenting in recent decades – is a significant and increasingly important driver of change. As Arctic communities increasingly recognize the important role climate plays in multiple aspects of their lives and in the natural environment, climate change can no longer be ignored.

Climate Variability

A number of presentations at the exploratory RISA workshop highlighted the links between climate and Alaska's environment, natural resources, and the well-being of its people. Year-to-year climate variability has significant consequences on natural resources and the environment. Arctic communities are among the most vulnerable to climate variability and change, especially those in coastal areas or those dependent on subsistence activities. In addition, statewide economic achievements and plans depend on climate-sensitive sectors and resources; they are also linked to the effective functioning of infrastructure, which is, unfortunately, already stressed in many places and much affected by weather and climate. Of critical importance are Alaska's unique ecosystems and rich biodiversity, which are directly and indirectly linked to climate variability and change. Finally, critical water resources are already stressed in some areas and short- as well as long-term changes in weather and climate directly affect their availability and quality.

Among the most important influences on short- and medium-term climate variability in Alaska are the El Niño-Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), the Arctic Oscillation (AO) and North Atlantic Oscillation (NAO) (see Box 2).

These large-scale modes of interannual climate variability (as well as long-term climate change, see below) have direct and indirect impacts on individual species, entire ecosystems, and natural resources. Among the *direct* impacts are changes in the suitability of habitats, e.g., through heat stress or exceedance of thermal tolerance thresholds, drought stress or water abundance, variation in solar radiation, suitability of ocean currents, and so on. Other direct impacts relate to timing shifts as temperatures vary, e.g., breeding of some species occurring later, egg-laying or budding occurring earlier, etc.

Among the *indirect* impacts are those habitat changes that cause changes in the food web (availability of appropriate food, adequacy of food quality), and thus changes in the interactions among predators and prey, or grazers and their primary food sources. Other indirect impacts arise from mismatches in the timing of ecological processes for different species that are somehow interdependent. For example, peaks in plankton availability may not coincide in space or time with the presence of feeding fish populations (see Box 3 for another example).

Impacts of climate variability on species and ecosystems have been documented for marine and forest ecosystems, often revealing complex mixes of more than one mode of climate variability affecting ecosystem dynamics. The degree of influence of climate variability on different species or ecosystems also varies with the directness of the climate–species or climate–habitat link, and thus may be clearly apparent or hidden in a range of observed ecological variabilities.

Early Warning Signs of Climate Change

> *"The Earth is faster now."*
>
> –Mabel Toolie, Alaska Eskimo elder[2]

In addition to shorter-term climate variability on daily, seasonal, annual, interannual, and decadal timescales, there are also longer-term changes in climate over a timescale of decades and centuries. Over the 20th century, Alaska witnessed long-term climatic changes, with a warming in the early decades until about 1940, followed by a cooling, and a return to a strong warming trend since the 1960s. This relatively recent history reflects North American and global patterns. Over the past decade, a strong scientific consensus has emerged that human activities are releasing heat-trapping greenhouse gases to the atmosphere, causing changes in the global energy balance, which in turn lead to long-term changes in the global climate (IPCC 2001).

Because of a variety of positive (reinforcing) feedback mechanisms, high-latitude areas, especially the Arctic, which includes northern Alaska, are expected to respond more rapidly and more severely than other regions of the world to global warming. Impacts of this significant warming are expected to have local, regional, and worldwide consequences for the climate, water cycle, species, habitats, and for socio-economic activities and human cultures. In fact, many of the recently observed changes in these high-latitude regions are consistent with what scientists and models project would occur under climate change. Some of the major observed changes are briefly summarized below, along with the types of impacts such environmental changes involve.

[2]Mabel Toolie, an Alaska Eskimo elder, used this phrase to describe the changes she observed in her environment, thereby providing the title for a book on indigenous observations of Arctic environmental change, edited by Igor Krupnik and Dyanna Jolly in 2002.

Box 2: Major Drivers of Interannual Climate Variability

El Niño-Southern Oscillation (ENSO)

ENSO can be defined as a periodic, but not entirely regular, cycle of warming and cooling of the sea surface temperatures of the tropical Pacific Ocean. The warm phase is known as El Niño, while the opposite phase is called La Niña, with a neutral state in between. During an El Niño, warming extends over much of the tropical Pacific. The fluctuations in ocean temperatures during El Niño and La Niña are accompanied by even larger-scale fluctuations in air pressure known as the Southern Oscillation. The negative phase of the Southern Oscillation occurs during El Niño events (i.e., abnormally high air pressure covers Indonesia and the western tropical Pacific and abnormally low air pressure covers the eastern tropical Pacific). The positive phase of the Southern Oscillation occurs during La Niña episodes (with abnormally low air pressure covering Indonesia and the western tropical Pacific and abnormally high air pressure covering the eastern tropical Pacific). These changes in the Pacific Ocean's temperatures and the atmosphere above it affect the global climate system through atmospheric and oceanic processes that exert influence on other regions across long distances (teleconnections).

Pacific Decadal Oscillation (PDO)

The Pacific Decadal Oscillation, or PDO, is a long-lived pattern of Pacific climate variability. Extremes in the PDO pattern are marked by widespread variations in the climate of the Pacific Basin and over North America. In parallel with the ENSO phenomenon, the extreme phases of the PDO have been classified as either warm or cool, as reflected in ocean temperature anomalies in the northeast and tropical Pacific Ocean. Cool PDO phases or regimes prevailed from 1890-1924 and from 1947-1976, while warm PDO regimes dominated from 1925-1946 and from 1977 through (at least) the mid-1990s. Recent changes in Pacific climate suggest a possible return to a cool PDO phase since 1998.

Two main characteristics distinguish the PDO from ENSO. First, typical PDO "events" have shown remarkable persistence relative to those attributed to ENSO events: while ENSO phases typically last from one to a few years, major PDO events in the 20th century have persisted for 20-30 years. Second, the climatic impacts of the PDO are most apparent over the North Pacific and North America, while secondary fingerprints are witnessed in the tropics. For ENSO, the opposite is true.

Arctic Oscillation (AO) and North Atlantic Oscillation (NAO)

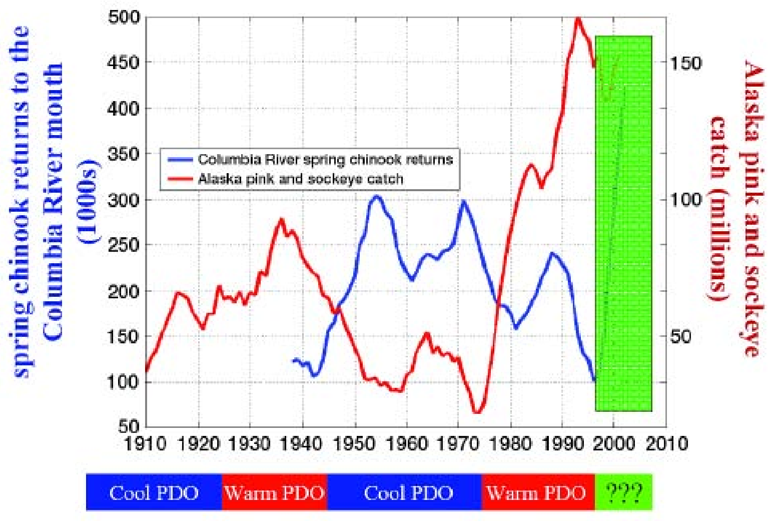
Recognized increasingly as one of the most important influences on northern latitude climates, the Arctic Oscillation (AO) is the dominant pattern of non-seasonal, inter-decadal sea-level pressure (SLP) variation north of 20 degrees latitude. SLP anomalies in the Arctic correspond with SLP anomalies in the opposite direction centered about 37-45N. This SLP see-saw is also known as the Northern Hemispheric annular mode, and varies on timescales ranging from weeks to decades. The oscillation extends through the depth of the lowest part of the atmosphere, the troposphere. During the months of January through March it extends upward into the stratosphere where it modulates in the strength of the westerly circulation (or vortex) that encircles the Arctic polar cap region. The AO is correlated with another northern latitudinal pressure oscillation, the North Atlantic Oscillation, but is distinct from it. The NAO is a SLP oscillation between the Icelandic Low and the Azores High.

Sources: Trenberth 1997; Mantua n.y.; Mantua 2000; Mitchell 2003; NWS 2004; NSIDC 2004

- **Temperatures are rising faster in these high-latitude regions than anywhere else in the world**. Extensive land areas in the Arctic have witnessed greater-than-global average temperature increases over the 20th century. In Alaska, average annual temperatures have increased up to 1.5°F (1°C) per decade over the last three decades, with the largest warming occurring in the interior, in arctic regions, and during winters (Weller, Anderson and Wang 1999). Since the 1960s, Alaska has warmed an average 5°F (3°C) and 8°F (4.5°C) in winter (Figure 11). As a result, the growing season has gotten longer.
- **Precipitation has increased.** While less homogenous a change across the region and less certain scientifically, increases in precipitation have been observed in some areas of Alaska. Except over the Alaska panhandle (i.e., west of 141 degrees longitude), the state's precipitation has increased by about 30% (Weller, Anderson and Wang 1999).
- **Glaciers and sea ice are melting.** Mountain glaciers are retreating in much of Alaska (Figure 12). The resulting meltwater has contributed 0.14 +/- 0.04 mm/year to global sea-level rise from the mid-1950s to mid-1990s, and 0.27+/- 0.10 mm/year SLE, during the past decade (Arendt et al., 2002). Moreover, the extent of arctic sea ice has decreased by nearly 3% per decade over the latter part of the 20th century (winter ice extent is decreasing 2% per decade, summer ice 7% per decade); sea ice has thinned leading to an ice volume decrease of 40% over the past five decades; sea ice drift patterns are changing; and there are more melt days during the summer now than previously (Figure 13).

Observed changes in high-latitude regions are consistent with what scientists and models project would occur under climate change.

Box 3: A North-South See-Saw in Salmon Production



What links climate and salmon? Our current scientific understanding of the causal link between climate variability and the production of different species of salmon suggests a chain of interactions relating atmospheric circulation to primary productivity in the oceans and the waxing and waning of salmon populations with the available food sources. For much of the 20th century, warm decades in Alaska were associated with warm phases of the Pacific Decadal Oscillation (PDO). The warm PDO periods also bring warm ocean temperatures to the nearshore ocean off the west coast. These warm ocean temperatures appear to benefit the ocean food web and ocean survival rates for many species of Alaska salmon, while reducing food-web productivity in the California Current and ocean survival for many salmon species along the Washington-Oregon-California coast. The recent period of high salmon production in both Alaska and the Pacific Northwest (WA-OR-CA) has seen warm nearshore ocean temperatures in Alaska, but cooler nearshore ocean temperatures in the California Current, a set of conditions not related to the PDO, but another configuration of climate over the Pacific ocean. (Source: Nate Mantua)

Figure 11: Observed surface air temperature change: 1973–2002 (Source: Updated from Walsh and Chapman 1993)

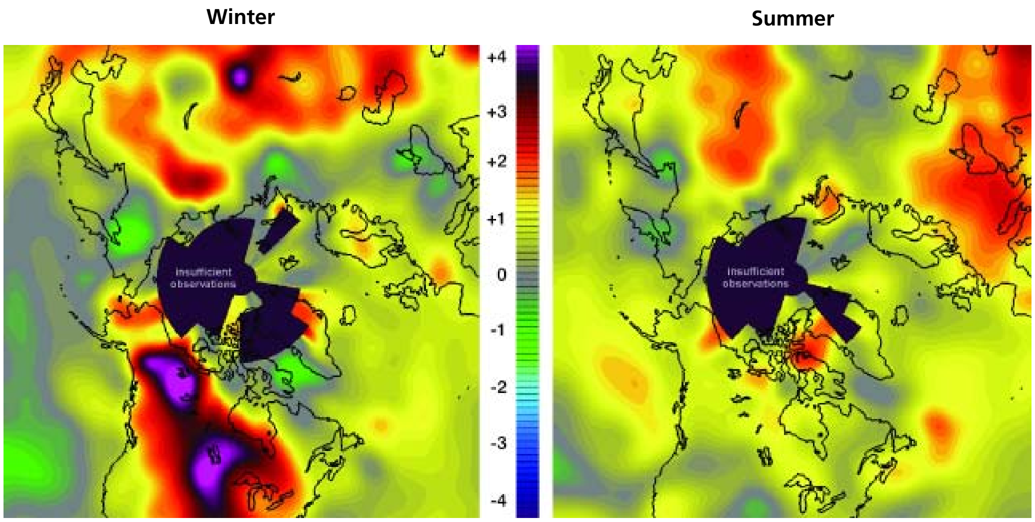


Figure 12: MacGall Glacier Terminus Photographed in 1953 and 2003 (Source: Matt Nolan, University of Alaska–Fairbanks)

Figure 13: Sea ice is declining in extent and thickness (Source: George Divoky; reprinted with permission)

- **Permafrost regions have decreased in extent and ground temperatures are warming**. Exact observations vary regionally, but the pattern is common across Alaska and the Arctic region (IPCC 2001; Weller, Anderson, and Wang 1999). As a result, shrubs and trees have been able to slowly move into permafrost/tundra regions.
- **Less snow in spring, earlier snowmelt and river ice break-up**. Scientists largely confirm Alaska Natives' observations that some regions receive less snow in the spring as more precipitation comes as rain, snowmelt occurs earlier, and rivers break up sooner than they did in previous years (Figure 14).
- **Oceans are changing**: Sea levels along Alaskan coasts are rising; warmer Atlantic waters are penetrating farther into the Arctic Ocean; and ocean circulation and wave heights are changing, while atmospheric pressures at sea level are declining.

These climatic and related oceanic changes already have hydrological, ecological, socio-economic, and cultural impacts on northern communities. At the exploratory workshop, several researchers and Native observers reported on a range of species shifts – halibut stocks moving farther north in the Bering Sea, crab migrations changing – and other changes in species behavior and reproductive success (see Box 4). Alaska Natives are also observing changes in other animal and especially insect patterns. Mosquitoes are now appearing in areas where they never occurred before.

Vegetation changes are also widely observed in response to warming in the Arctic. For example, tundra is being lost at the expense of shrubs and trees gradually moving into the grassland areas. The tree line is moving northward and higher in elevation.

Figure 14: Snowmelt trends in Barrow, AK (Source: Stone 2004)

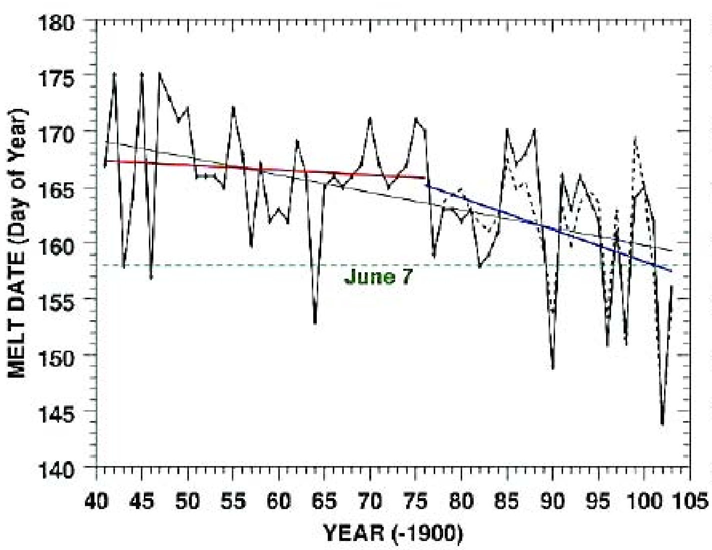
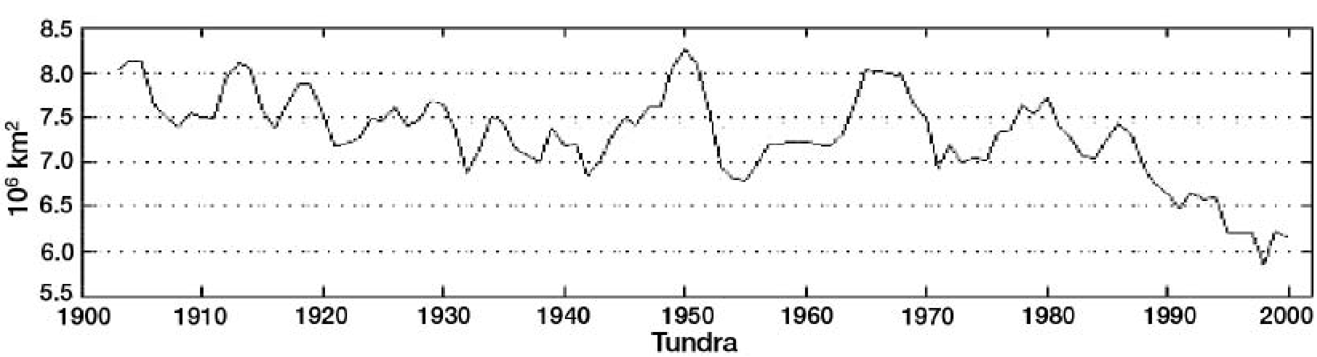


Figure 15: Loss of arctic tundra 1900-2000 – 15% loss since 1980 (Source: James Overland)



Box 4: The Black Guillemot as an Indicator of Climate Change in the Arctic

The black guillemot (Cepphus grylle, also known in the Canadian Arctic by the Inuktitut name Pitsiulaaq) is a small alcid, a member of the Auk family, which also includes puffins, razorbills, and murres. It migrates little and is generally found close to ice year-round. During the winter months adult birds winter in or near pack ice. The bird nests in small scattered colonies on sea cliffs and rock piles, in holes, clefts, and cracks on islands free of land predators. The black guillemot nests in loose colonies where seasonal snow cover can be found, and generally lays one to two eggs. The total breeding period is more than 80 days. The young leave the nest at about five weeks.

Black guillemots are generalists that can respond rapidly to changes in resource availability; typically they feed on fish and zooplankton associated with ice. Parents are provisioning their young, flying back and forth between the nest and the edge of the pack ice. At fledging, the young move to the pack-ice edge to feed by themselves.

Clearly, the birds' close association with ice makes them sensitive indicators of changes in climate and ice. Changes in ice extent, thickness, and location can all affect survival at sea and breeding success. In a long-term study, George Divoky (University of Alaska–Fairbanks) has documented a complex story reflecting the bird's tight relationship to climate.

From 1965 to 1990, snowmelt came earlier and earlier. This allowed black guillemots to begin breeding earlier in northern Alaska. The proximity of pack ice facilitated colony growth by increasing productivity and in-migration. By the 1990s, climate had warmed so significantly that snowmelt advanced the date of egg-laying. Changes in pack ice location, coverage and thickness decreased the extent and quality of foraging habitat. As a result, reproductive success began to decline (see table).

Reproductive Success of Cooper Island Black Guillemots

	1975-1990	2003
Hatching Success	72%	71%
Fledging Success	72%	12%
Breeding Success	53%	9%
Fledging Weight	309g	283g
Two-Chick Broods	60%	0%

What is the outlook for black guillemots over the 21st century? Clearly, snow is no longer a regular constraint on breeding, but with the retreat of pack ice from shore decreased access to ice-associated prey is reducing breeding success. Additionally an increase in wind speed has decreased the ability of parents to find food for their young. Climate-driven changes in the occurrence of nest predators and competitors have also reduced colony productivity. In short, in forty years, northern Alaska has gone from being too cold to almost too warm for guillemots. As the arctic becomes subarctic, guillemots – being an arctic seabird – will become less sensitive indicators of regional climate change. In the next ten years the continuing regional warming could result in major changes in the type of prey provided to chicks; in extirpation (local extinction) of the colony due to lack of breeding success; or in occupation of the colony by subarctic seabird species expanding their range northward.

(Source: Data and black guillemot chick photograph by George Divoky, reprinted with permission; photograph of two black guillemots by Joe McNally; reprinted with permission)

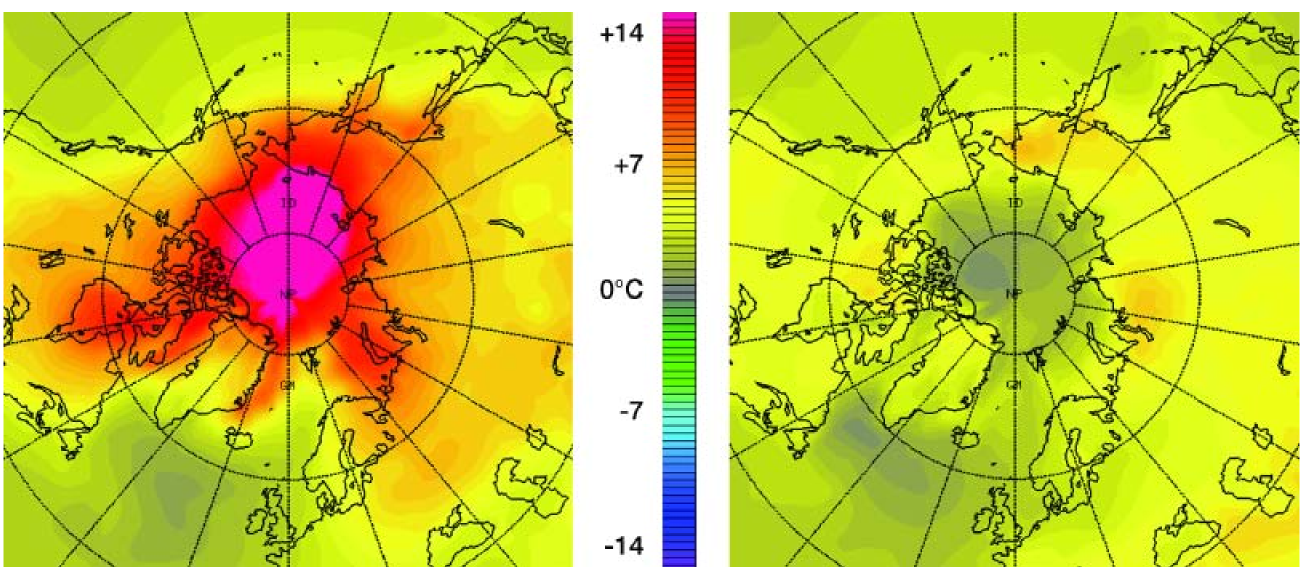
(Note: The 30-year study of the seabird colony on Cooper Island will be ending in 2005 due to a lack of funding for the collection, analysis and archiving of data. For further information contact George Divorky at divorky@cooperisland.org.)

Figure 16: Alaskan tundra and lakes – hydrological changes induced by climatic change are already becoming apparent (Source: Torre Jorgenson (photo on left); James Jacobson (photo on right); reprinted with permission)

Where permafrost is melting, water can infiltrate the soils more easily. This may explain the decreased lake levels observed in some areas (Figure 16). One apparent impact on waterfowl is that puddle ducks are then more than previously exposed to predators.

According to workshop participants, clearly, some of these changes are synergistic consequences of land use (e.g., deforestation) and climatic change, as well as other stresses mentioned above. It is also not entirely clear whether the climate-related changes are the result of the climate regime shift that occurred in the mid-to-late 1970s, or of anthropogenic climate change, or both. As the Intergovernmental Panel on Climate Change concluded in its 2001 assessment, however, "In summary, many observations of environmental change in the Arctic show a trend that is consistent with warming and similar to that predicted by general circulation models" (IPCC 2001, p.803).

Figure 17: Composite projections: IPCC/DDC models: temperature change (°C) from (1961-1990) to (2060-2089), based on the IPCC's B2 SRES Scenario (Source: Walsh et al. 2002; also used in the Arctic Climate Impacts Assessment (ACIA))



Future Projections of Climate Change

Climate scientists use global climate models to project potential climate futures under a range of assumptions about global demographic, technological, and economic developments (for one example, see Figure 17). The combination of running various emissions pathways on a number of global climate models results in a range of possible climate futures for northern-latitude regions like Alaska. The best approach is to look at a range of plausible future scenarios and assess potential impacts for the state. Clearly, major uncertainties exist about socio-economic development, the amount of future heat-trapping emissions, and about the sensitivity with which the climate will respond to this forcing. What scientists agree on, however, is that the Arctic is among the most vulnerable of all regions to climate change. Many view the high latitudes as "canaries in the mine."

Presentations by researchers at the meeting highlighted potential climate changes and future impacts on Alaska (discussed further in the next chapter), including:

- further dramatic temperature increases
- as-yet uncertain changes (i.e., increases or decreases) in precipitation
- further decreases of sea-ice extent and thickness with a seasonal opening of sea routes previously unavailable and wider spread of pollutants
- with loss of sea ice, an increased vulnerability to coastal storms and coastal erosion, and forced relocation in populated coastal areas
- further thawing of permafrost, with severe implications for buildings, infrastructure, and industrial activities currently dependent on frozen ground (Figure 18)
- major shifts in to forest ecosystems and challenges to forest health
- increased runoff into the Arctic Ocean
- deep changes in the marine food web, and further north- and upward shifts of species along with an increased threat to, or even loss of, some polar species (e.g., seals, walrus, polar bears), while others may expand and thrive (e.g., some fish species) (Figure 19)

Figure 18: Melting permafrost severely impacts buildings (Source: Larry Hinzman; reprinted with permission)

Figure 19: Mammals threatened by climate change and the Impact on sea ice (Sources: Mark Shashby/USGS (polar bear, Gary Hufford (walrus); reprinted with permission)

- new and unpredictable changes for native peoples will result from the combined impacts of climate change and globalization, including changes in subsistence activities such as fishing, hunting, and gathering of food and medicinal plants as flora and fauna shift; relocation from hazardous areas; increased health threats; loss of cultural activities; unreliability of traditional knowledge and wisdom under changing environmental conditions, with subsequent changes in social relations
- significant challenges to health of all Alaskans

The following chapter explores in more detail the vulnerabilities of Alaska's environment, economic sectors, and people to climate change. It highlights some of the sectors and environments that are most sensitive to climate variability and change.

Vulnerability: Climate, Sensitive People, Sectors, and Environments

Coastal Land and Ocean Areas

As sea level rises and sea ice retreats, leaving coastal areas open and unprotected for longer portions of the year, coastal storms can have greater impact on these areas and communities. Coastal communities such as Shishmaref (Figure 20) already suffer the direct impact of increased coastal erosion, particularly where homes and critical infrastructure for marine economic activities such as fishing take the full onslaught of wind and waves.

Important coastal habitats, such as estuaries, which are critical for some life stages of fish and shellfish, may also be impacted by sea-level rise, coastal erosion, and the increased salinity in coastal waters. According to workshop attendees, this in turn will affect the economically significant fisheries of Alaska (e.g., salmon, herring, shellfish), as well as the local fisheries of Alaska Natives.

Coastal waters and habitats will also be affected by warming coastal waters and increasing runoff from rivers, which may change the freshwater influx, the size of freshwater pulses, as well as the input of pollutants carried by riverine waters. Thus, coastal areas will face multiple stresses. Long-term trends as well as extreme events such as storms will be of critical importance.

Fisheries

As James Overland (NOAA/PMEL) told workshop participants, the Gulf of Alaska and the Bering Sea are among the most productive marine regions of the world, supporting extensive commercial fisheries and diverse populations of plankton, fishes, marine mammals, and birds (Figure 21). The ocean-atmosphere system fluctuates on many different time scales related to El Niño, the Arctic Oscillation, and the Pacific Decadal Oscillation (see above). These decadal oscillations, sometimes called regime shifts, cause natural perturbations of ecosystem productivity and community structure affecting populations of zooplankton, jellyfish, salmon, shrimp, and others. Long-term climate change could cause shifts in a species' range or abundance, and impact – positively or negatively – reproductive success.

Water Resources and Waterways

Over the past few decades, temperatures have increased across the state, precipitation increased in some regions, snowmelt has come earlier during the year, permafrost has begun melting, most mountain glaciers are retreating, and evaporation is changing due to shifts in vegetation. These climate-driven changes cause deep changes in the

Figure 20: Coastal storm on October 8, 2002 – coastal road in Shishmaref (located on Sarichef Island, Chukchi Sea), at around 12:30pm (l) and 2:30pm (r). (Source: Tony Weyiouanna/Kawerak Transportation Program; reprinted with permission)

Figure 21: Commercial and subsistence fisheries vary with climate variability and may be threatened by long-term climate change (Source: John Field (left) and Tony Weyiouanna/Kawerak Transportation Program (below); reprinted with permission)

hydrological cycle. Some of these changes are already apparent in parts of Alaska, while future changes are difficult to predict as climate models do not agree on the direction and/or amount of precipitation changes. Moreover, how these complex changes will play out regionally and locally will also be affected by land use and other factors.

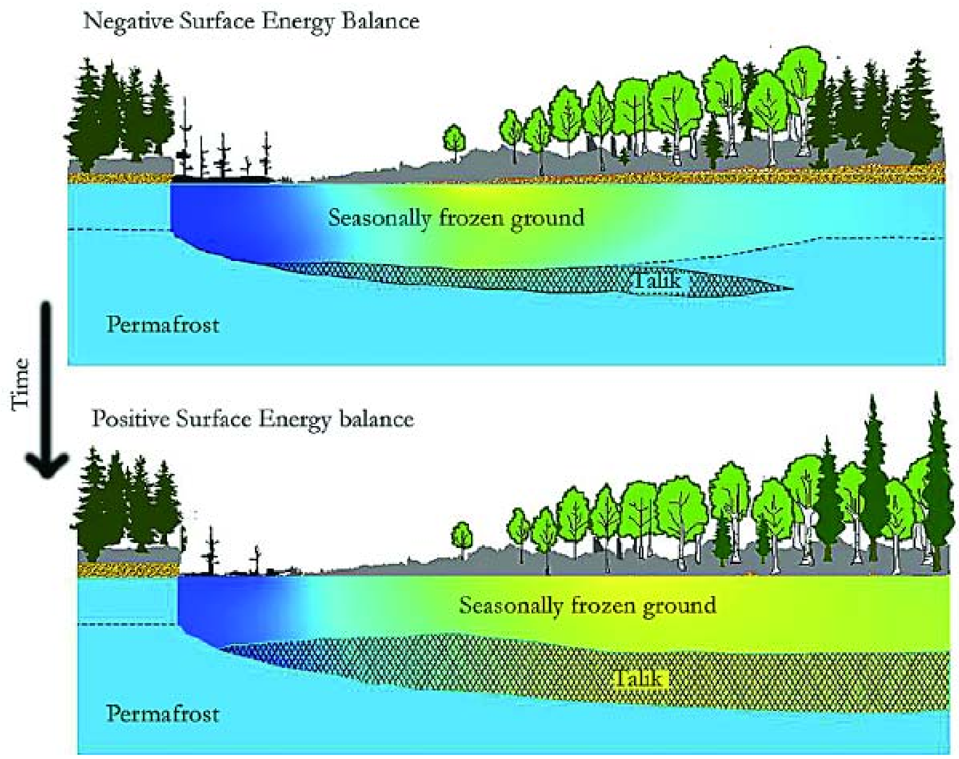
One of the already observed changes in the hydrological cycle is variable – but overall increasing – river discharges, reflecting both connections with the North Atlantic Oscillation and a long-term trend consistent with increased temperature and precipitation. Recognizing scientific uncertainties about this connection, Larry Hinzman (University of Alaska—Fairbanks) suggested at the workshop that melting mountain glaciers and permafrost may also play a role in this upward trend. These runoff changes have numerous implications, including a changing flooding risk (with floods occurring earlier and possibly being bigger), greater river bank and river bed erosion, impacts on fish species living in rivers, and on other riparian species whose breeding habits and habitat may be affected by earlier or increased flooding. Increased and earlier runoff will also impact ecosystems in coastal waters where runoff pulses affect the mixing of fresh water and ocean waters. River ice break-up also affects transportation of goods as well as hunting and fishing, as natives depend on certain frozen river passages during the winter season for hunting (see potential impacts on subsistence activities below).

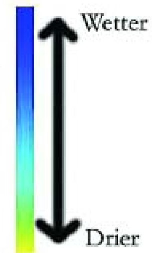
Other possible implications of the changing hydrology relate to the thawing of permafrost areas. Unfrozen ground can infiltrate water more deeply, while also allowing for deeper-rooting vegetation, such as shrubs and trees, to establish itself. This can result in wetlands drying out and lake levels dropping, with the subsurface runoff adding to the increasing river discharge. As Figure 22 shows, better drained soils change the energy balance of a landscape, thus producing reinforcing feedbacks to the warming climate.

Forests and the Forestry Sector

Climate variability and long-term changes in climate involve different impacts on Alaska's forests and its forestry sector. Among the most important are drought years, fires, and the potential increase in growth of vegetation under higher carbon dioxide (CO_2) concentrations.

Forest growth could potentially be spurred by climate change as warmer temperatures allow trees to grow further north and at higher altitudes. In addition, a longer growing season and higher concentrations of CO_2 in the atmosphere enhance tree growth and allow plants to use water more efficiently unless other nutrients limit such improved CO_2 uptake.





Permafrost = Zone of permanently frozen ground (incl. water, soil, and rock) found in high latitude soils and sediments. Permafrost can be continuous, discontinuous, sporadic, in alpine areas, or under the sea.

Talik = An unfrozen section of ground found above, below, or within a layer of discontinuous permafrost. These layers can also be found beneath water bodies in a layer of continuous permafrost.

Figure 22: Landscape changes associated with thawing of permafrost (Source: Larry Hinzman)

Interannual climate variability affects forest dynamics but can also have impacts on forest growth. One or several successive dry years can cause drought conditions that reduce tree growth and make wildfires more likely (Figure 23), especially in the Alaskan interior where historically most fires have occurred. According to experts at the meeting, the wet Alaska panhandle is unlikely to see major increases in fire occurrence. Insect infestations – especially outbreaks of spruce bark beetle – are also common problems during dry years, making forests even more vulnerable to fires. Outbreaks of spruce bark beetle and their links to wildfire have been studied for over ten years, for example, at the Kenai National Wildlife Refuge (Morton, personal communication to J. Neill). Wetter years increase growth of trees and understory brush, thereby also increasing the fuel load that could feed larger fires in subsequent years.

Figure 23: Wildfire in Alaska (Source: La'ona DeWilde; reprinted with permission)

With long-term warming, the fire season is likely to start earlier and last longer, thus potentially affecting larger forest areas and placing increasing demands on fire-fighting capacities across the state. Already human encroachment into the bush has created more problems with fires. The extended fire season of 2002 was a good example, when an unusually large number of fires – more the 250 small and several large ones – burned across the state.

Early-season fires, frequently caused by people, tend to sweep across a landscape when the ground is still frozen. They predominantly kill the vegetation on top, resulting in permanent loss of spruce, but only temporary curtailment of hardwoods like willow, alder, and birch. Summer and late-season fires, by contrast, are more often started by lightning strikes and burn hotter and deeper. In fact, they can not only burn above-ground vegetation, but even reach into organic soil layers, leaving nothing but mineral soil. While more damaging, such fires also help in the rejuvenation of forest ecosystems, allowing a variety of seeds to sprout in the newly opened soil.

If precipitation declines in the future, or successive dry years become more common occurrences, the risk of forest fires is likely to increase. This would also imply another positive feedback to the climate in that forest fires release vast amounts of carbon stored in trees and the organic layers of soils. On the socio-economic side, more wildfires reduce timber harvest, cause greater risks to timber harvesting crews, and add to air pollution and related health impacts (see below). These fires can also place greater demands on the mostly volunteer fire-fighting teams as they focus on containing fires that threaten homes, villages, and personal property.

Transportation, Infrastructure and Related Industries

Transportation in Alaska has a number of unique characteristics and hence faces challenges that are uncommon to most other parts of the United States. The state's road system is less dense and far less developed than in more densely populated states. A greater proportion of transportation is by air, even if unfavorable flying weather is frequently a major impediment, planes are small, and airports often nothing more than unpaved landing strips in the bush. Alaskans also depend on ice and frozen ground not only for back-country subsistence activities, but even for major industrial activities. Finally, transportation by sea is also constrained for significant portions of the year due to sea ice.

These unique characteristics of Alaska's transportation system make it extremely vulnerable to climate variability and long-term change. More extreme events (storms and floods) can hamper road and air transportation; more fog would reduce flying times or flight safety; thawing of permafrost will severely impact paved and unpaved roads and landing strips; and shorter sea and river ice seasons reduce the on-ice hunting season and make such activities more dangerous. Travel over frozen tundra – the only time to move heavy equipment over this vulnerable ecosystem, e.g., for purposes of petroleum extraction – will also become only possible for shorter and shorter periods.

Closely related to the highly climate-sensitive transportation and infrastructure challenges are impacts on extractive and construction industries. The key climate-sensitive factor again is ice and frozen ground. In permafrost regions, buildings and infrastructure were built on the assumption of a deeply and/or permanently frozen building surface. This, of course, now turns out to be changing. The impacts of thawing are already becoming apparent (see, e.g., Figure 18 above), with buildings sinking, roads buckling, deep potholes cracking open, telephone poles toppling, coastal cliffs eroding more readily, and pilings of critical infrastructure becoming less reliable. The latter is particularly dangerous – in terms of human safety, environmental impact, and economic loss – in the case of the 800-mile-long Trans-Alaska pipeline, as the risk of the pipe breaking in places grows unpredictably. For about half of its length, the Prudhoe Bay to Port Valdez pipeline is buried underground, for the remaining miles, it sits on pilings.

Among the few, but significant positive impacts of global warming on the transportation sector and related communities and industries is the likely impact on sea ice. Workshop attendees stated that as sea ice extent declines further, previously unavailable sea routes may open up, at least for the summer season, shortening travel routes, and facilitating commerce in ways that were impossible before. New northern harbors may emerge, involving economic opportunities in regions where a steady income is hard to find. Development would need to be carefully conducted to avoid ecological harm in fragile environments.

Tourism and Recreation

Alaska's beautiful and wild landscapes – both at land and at sea – attract visitors from all over the world and offer practically unlimited recreational opportunities for residents. Hunting, fishing, boating, canoeing, sea-kayaking, bird-, whale- and other wildlife watching, hiking, skiing, and glacier, cruise, and volcano tourism are just the most common and obvious activities locals and visitors enjoy (Figure 24). The recreation and tourism sector is growing in importance in the state's economy with over $1.2 billion in sales in 1997 and nearly 30,000 related jobs (average annual in 2003), 10 percent of the wage and salary workforce (Alaska DOLWD 2004; Fried and Windisch-Cole 2004). A recent assessment of trends in the leisure and tourism sector proclaimed it as "a billion-dollar industry that employs many Alaskans, entertains the rest, and is the hub of the visitor industry."

Clearly, with Alaska tourism being largely nature-based, its sensitivity to weather, climate variability, and climate change is obvious. What is far less clear is whether the economic bottom line will be positive or negative.

The potential positive consequences of climate warming mention by workshop attendees include:

- a longer summer tourism season
- if winter precipitation (as snow) increases, a growing potential for the skiing industry
- shift of ecosystems and individual wildlife species to new locations previously undeveloped for tourism (potential new opportunities)

Among the potential negative impacts of climate change for tourism mentioned are:

- shift or even loss of important ecosystems and associated bird, fish, and wildlife species (e.g., polar bears, migratory birds), particularly out of currently protected areas such as parks and reserves
- loss of glaciers
- expansion of mosquito range, along with potentially increasing risks from vector-borne diseases
- increased risk from wildfires
- increased health risks from UV radiation and air pollution
- less predictable and more dangerous mountaineering conditions (e.g., due to rapid weather changes, growing avalanche risks, or less reliable ice conditions), with resulting impacts on allocation of scarce resources in public parks

Wilderness tourism itself is likely to have some negative impacts on the environment through increased traffic, vegetation trampling, careless handling of open fire, noise, and other pressures on wildlife. These human impacts will aggravate those from climate change. At the same time, visitors to Alaska will – perhaps for the first time – witness first-hand the impacts of climate change on the environment. This experience may lessen the uncertainty about the reality of global warming among these individuals.

Figure 24: Salmon fishing (Fried and Windisch-Cole 2004). (Source: Mark Shashby; reprinted with permission)

Human Health

One of the most important and complex areas of concern relative to climate change and other drivers of global and local change in Alaska is human health. Humans may be affected by climatic and other changes through direct and indirect pathways (Figure 25), any one of which can affect people's *exposure* to disease or health risks, their *sensitivity* or, differently put, their ability to protect themselves against disease, and their *resilience*, i.e., their ability to cope with diseases and recover.

Assessing potential future impacts of climate change on human health critically depends on developing a comprehensive picture of the current health status and demographic characteristics of the population, and of the health-related challenges Alaskans already face today. These pre-conditions have a strong influence on future vulnerability and coping capacity. On that basis, one can assess potential health impacts from climate change.

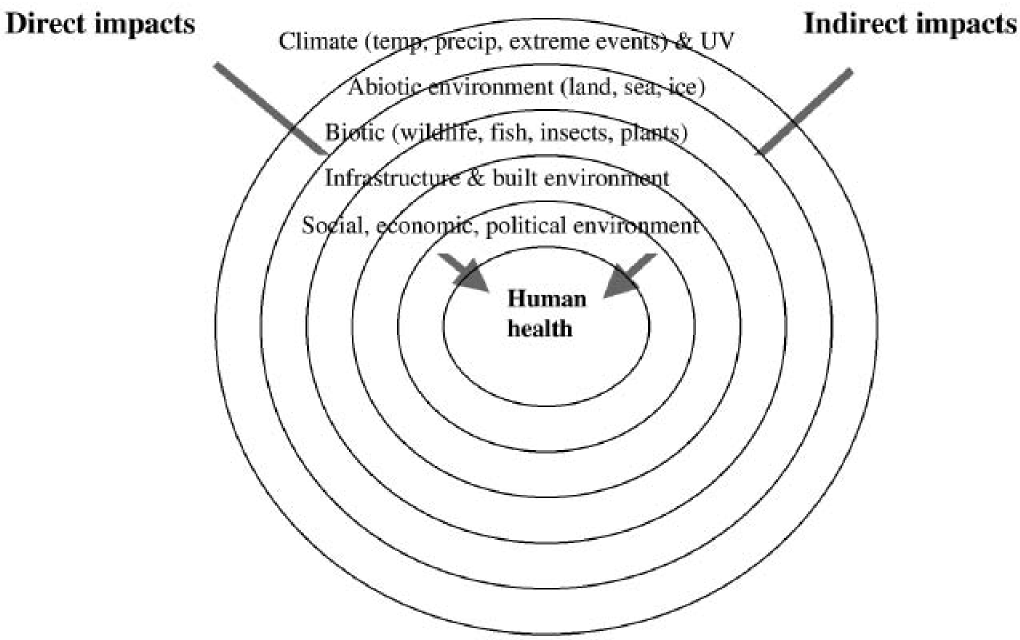


Figure 25: Direct and indirect influences on human health (Source: James Berner)

The health-related challenges Alaskans already face today are the pre-conditions that influence their future vulnerability and coping capacity.

Among the direct health impacts mentioned by the experts at the meeting are those that result from direct interaction between people and their environment. The environment is changing as a result of climate change, i.e., as a result of interaction with physical characteristics of the environment, such as air, water, ice, and the land. Examples mentioned include:

- difficulties resulting from increasing heat stress
- alleviation of cold stress as winters warm
- dangers associated with travels over less reliable sea, lake and river ice or other activities on land under unpredictable weather patterns
- increased risks from more frequent extreme events and/or wildfires
- effects on health as a result of changing air quality (local and long-range influx of air pollutants)
- incidence of sun burn, rashes, and skin cancers due to increased exposure to and higher levels of UV radiation

Indirect health impacts are all those that result from indirect interaction with aspects of the environment that are changing as a result of climate change, such as changes in ecosystems, natural cycles, available plants and animals for food, and so on. Examples mentioned at the meeting include:

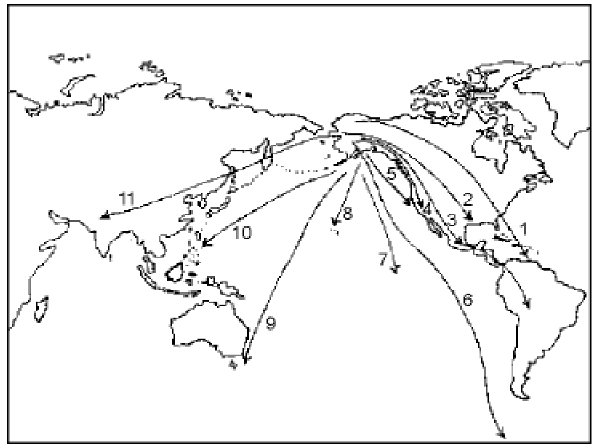
- changes in the diet due to changing access to or sufficient availability of culturally-important food species
- effects on health as a result of changed access to good quality drinking water
- effects on health due to spread of new/different infectious diseases or disease vectors (extension of range, new migratory pathways, mixing of species, and other stresses on populations) (see Box 5 below)
- effects on health as a result of climate impacts on infrastructure (e.g., sanitation or road infrastructure)
- various forms of social and mental stress related to changes in the environment, lifestyle resulting from climate change

Human's susceptibility to the direct and indirect impacts from climate, as well as their ability to protect themselves and cope with health impacts will be crucial in determining the actual incidence of disease and accidents. Indirect impacts, in particular, are typically mediated by human behavior or other components of the environment. For example, the availability and functioning of sanitation

Box 5: Not A Question of "If" But "When": Waiting for the Arrival of West Nile Virus in Alaska

West Nile Virus is a disease of birds spread by mosquitoes. Human and other animals can also be infected. The disease was first recognized in 1999 on the East Coast of the continental United States. By November 2003, it was documented in 46 of the lower 48 states and in 7 of 13 Canadian provinces. Nearly 9,000 human cases were reported and over 200 people died in 2003.

Mosquitoes and birds that carry the virus are already found in the Arctic. So far, temperature may be the only limiting factor in how far north the disease will spread. Warming trends in Northern Canada/Alaska may promote northern expansion of the disease. If, or more appropriately, when it reaches Alaska and Northern Canada, West Nile Virus may jump to Asia via migratory birds and become a health threat to the more than two billion people of China and Southern Asia.



Migratory Pathways of Alaskan Birds

Similar climate change-related threats from zoonotic (animal-carried) diseases that can be spread to humans abound and are of growing concern to medical researchers. Avian influenza, a flu carried by birds among others, is of particular concern as birds can serve as genetic reservoirs for new strains of influenza, a disease that kills thousands of people every year.

(Sources: Mike Bradley; Alaska Native Knowledge Network (map produced by Donna Miller MacAlpine, Iditarod Area School District); reprinted with permission)

infrastructure (including water collection, treatment, distribution, and disposal) will strongly affect the degree of water-related health threats such as giardiasis, cryptosporidiosis or hepatitis A and B. Similarly, crowded housing facilitates the spread of communicable diseases such as bronchitis. And access to health care services via a functional transportation infrastructure enhances people's coping capacity.

Native Economy, Livelihood, and Culture

The climatic and environmental changes, and social vulnerabilities mentioned above combine in synergistic ways to pose unique and critical challenges, particularly to Alaska's native peoples who continue to depend on the land and its natural resources for their food, shelter, well-being, and cultural survival. The quote to the right from Alaska Native Science Commissioner Larry Merculieff pinpoints the close interdependence between Natives, the climate, ocean and land, as well as animals and plants that live there.

> *"As species decline and terrestrial and marine systems change, little attention is given to the socio-economic-cultural changes that result in response. For example, no one has seen what Aleuts have seen when sea lions declined in terms of loss of cultural ways and the littoral loss of young men due to suicides, incarceration for felony crimes, etc."*
>
> Larry Merculieff,
> Alaska Native Science Commission

Among the threats to Alaska Natives' subsistence mentioned at the workshop are the following:

- loss of subsistence resources and activities, including availability and or access to animal and plant species important to native people's diet, medicinal practices, and cultural rituals (see Box 6)
- threats from less predictable and more variable weather patterns, extreme events and chronic hazards, such as sea-level rise and coastal erosion, to people, communities, and their infrastructure
- growing accident risk from earlier breakup and loss of sea and river ice, and transportation problems due to changing snow and ice conditions
- impacts on hydrology and water resources as precipitation changes and permafrost melts
- impacts on buildings and infrastructure as permafrost melts
- threats from new, emerging, and infectious diseases as low temperatures no longer restrict their spreading into Alaska
- mental and social stress resulting from changes in the environment, diet, and lifestyles
- loss of social recognition and status of community members as traditional knowledge and wisdom become less reliable in the rapidly changing environment

Box 6: Bowhead Whale Hunting in Barrow, AK

Bowhead whale hunting has been part of Alaska Native livelihood and culture as long as people can remember. Its success hinges on two main questions: Are the animals *available* (present in the vicinity and in sufficient numbers)? And if they are available, are they also *accessible* to the hunters? Can the hunter find them, reach them, catch them, and bring the catch home safely without anyone being killed or seriously injured?

Enter the issue of climate change. In what ways does climate affect either availability or accessibility, and hence the success of whale hunting? And what is the link to human health, to diet, to culture?

Cutting Jake Adams' whale, October 8, 2003

Historically, the main bowhead hunting season has been between the beginning of September and the beginning of November, with the largest animals arriving earlier and the smaller animals arriving later in the season. Thus, there is great incentive to go out and hunt whales early on. At the same time, hunters require safe platforms to butcher their catch – something traditionally done out on the ice and away from the village to avoid attracting polar bears. With ice now forming later and later in the fall, finding safe ice on which to do the cutting is becoming increasingly difficult. Moreover, a well-documented increase in fall storms hitting the North Slope coastline makes butchering out on the ice or bringing the whales in onto the beach more dangerous.

These environmental changes illustrate how the issue of accessibility endangers hunting success and the safety of native hunters. Moreover, losing whale meat as one of the mainstays of the traditional diet creates additional new challenges for people's health. The cultural implications, however, run far deeper. Whale hunting is done in groups, and while the man catching a whale is recognized, the hunted food is shared among family and community members, and sometimes across long distances. However modern the tools of hunting have become, these traditional patterns of reciprocity remain essential to the Inupiaq way of life.

(Source: Anne Jensen; photograph reprinted with permission)

> *"The community is highly dependent on its cultural and traditional heritage. Subsisting off the land and sea is a vital component to the daily consumption of natural foods harvested in Shishmaref and passed on from generation to generation, which is continued today. The preservation of our unique culture is vital to the continued existence of our community as one family."*
>
> Tony Weyiouanna Sr. and Luci Eningowuk,
> Shishmaref, AK

In all these potential impacts from climate change, the remoteness of many Alaska Native villages, lack of access to health and other services, very limited opportunities for alternative income, as well as marginal water, transportation, and communication infrastructure critically determine people's ability to adapt to a rapidly changing environment. Environmental, socio-cultural, and economic pressures combine to not only make "coping" a difficult challenge, but maybe more importantly, pose ever-greater challenges to sustaining native ways of life.

Land and Ecosystem Management

Land and ecosystem management in Alaska faces multiple stresses: rapid climate change, increasing UV radiation, air pollution via long-range transportation from far-away pollution sources, invasive species, and a variety of land use pressures from extractive industries and tourism are among the most important.

Interestingly, both in absolute and relative terms, Alaska has more land in public ownership, and more land protected than any other U.S. state. Fifty-eight percent of Alaska is federal land managed by the Department of the Interior (Fish and Wildlife Service, National Park Service and Bureau of Land Management; see Figures 26a, b, c below). The National Park Service alone manages 54 million acres as parks (17 units), preserves, and monuments, including 20,000 protected river miles.

One of the key challenges in managing protected land areas and the species and ecosystems within them is that plants and animals do not respect, and are not constrained

(a) BLM land (yellow)

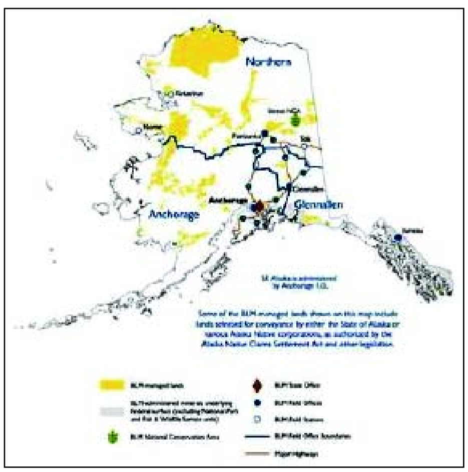
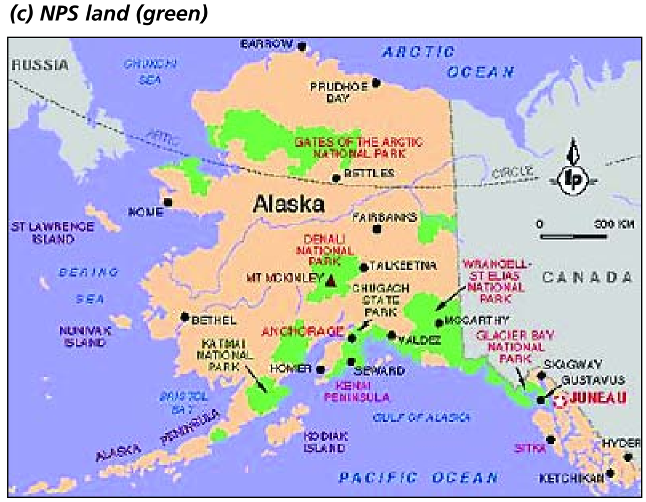


Figure 26: Public land holdings (DOI) in Alaska (Source: Department of the Interior, Bureau of Land Management, Fish and Wildlife Service and National Park Service)

(b) FWS land

(c) NPS land (green)



by human-made boundaries. Thus, as climate warming pressures species to adapt and move – if they can – northward and upward to areas with more adequate climatic conditions, the species that are currently sheltered inside parks and preserves will move outside the bounds of protection. While this is a challenge in other regions of the U.S. and around the world, it is particularly pressing in the fast-changing high latitudes.

Workshop participants argued that—both philosophically and practically—climate change forces public and private land owners to critically examine and confront the question: What is to be protected? Species will react individually, not in unison, to climate forcing. This means that ecosystems in their current assemblage will most likely not be sustainable into the future. As a result, species interactions will change. Predator and prey relationships may get out of synch; symbiotic or parasitic relationships may shift; the physical components of ecosystems may no longer suit the biotic needs of species and so on. Moreover, ecosystem functions and the goods and services that ecosystems provide will also shift. Some will be lost, others gained.

Figure 27: Seals threatened by the loss of sea ice (Source: National Marine Mammal Laboratory, NOAA)

Species will react individually, not in unison, to climate forcing. Thus, ecosystems in their current assemblage will most likely not be sustainable into the future.

In some instances, species will simply run out of suitable space to move to as land areas are limited to the north by the Arctic Ocean, or in high altitudes when there is nowhere else to go beyond the mountain top. Sea ice – important habitat for some species – will melt away at least for critical periods of the year, thus eliminating hunting, resting, or breeding grounds for mammals and birds (Figure 27).

Summary

More than anywhere else in the world, high-latitude regions like Alaska face the prospect that their flora and fauna may not be able to adapt given the observed and projected rate of environmental change associated with global warming. Even potential benefits of warming for people, land, and ecological resources will have to be managed in order to be realized. Effective management of a moving target, however, requires vigilant monitoring and ambitious research. Alaska's capacity to do both is described in the next section.

Effective management of a moving target requires vigilant monitoring and ambitious research.

Regional Research and Assessment Capacity

The workshop demonstrated that Alaska already has a strong research and assessment capacity, albeit one that is stretched thin in the face of the many changes occurring in the Arctic that require analysis. The challenge is aggravated by the sheer size of the state, where vast publicly-owned areas have not been inventoried and are not being monitored. Some remain largely untouched by humans. Both governmental and university-based research programs and researchers are deeply involved in local, regional, and wider Arctic climate- and impacts-related research. At the same time, workshop participants highlighted many opportunities for better communication and information exchange, greater coordination and integration of research efforts, the challenging merging of traditional and western scientific knowledge and insights, as well as improved science–stakeholder interactions.

The following examples provide only snapshots of research capacities and efforts underway at present. These were represented at the workshop. A broader, mostly university-based research community, ranging from the natural (e.g., climatology, geophysics, and ecology) to the social sciences (e.g., economics, anthropology, geography, sociology, and psychology), and into the humanities, complements the capacities described below.

Climate and Ecosystem Process Monitoring

One of the most critical tasks highlighted by workshop participants in trying to understand Arctic environmental change is to conduct inventories of environmental resources and closely and consistently monitor all aspects of environmental change:

- extend existing historical records into the past and the future
- develop historical data sets for variables not yet studied
- enlarge the geographic network and/or increase its density in areas previously unobserved.

Such monitoring activity is currently conducted by government agencies, universities, by private companies for certain variables, and by Alaska Natives living day in, day out close to the changing land and sea.

One of the most critical tasks in trying to understand Arctic environmental change is to closely and consistently monitor it.

Locally, specific monitoring (e.g., of river discharge, temperature changes, or species interactions) can give detailed information, but is sometimes difficult to extrapolate beyond the monitoring site. By contrast, aerial or satellite-based observation (e.g., of large-scale vegetation changes, snow cover, or sea-ice extent) give a far broader picture, but sometimes with limited spatial resolution. In addition, this type of monitoring often does not go back in time more than 20-30 years. Thus, both types of monitoring are essential and need to be combined in sophisticated ways to generate a full understanding of climate and landscape changes.

Climate monitoring stations are maintained by a number of agencies and institutions. Maybe the most comprehensive climate data clearinghouse for Alaska is the Western Regional Climate Center at the Desert Research Institute in Reno, Nevada.[3] Other common sources include NOAA's National Weather Service and NASA.

Ecological monitoring is conducted in the context of academic or government research or ecosystem management involving researchers from the University of Alaska system and government agencies. For example, at many publicly owned lands such monitoring is carried out by federal agency staff, such as the U.S. Geological Survey, National Park Service, National Fish and Wildlife Service, Bureau of Land Management, and others. Alaska also is home to one long-term ecological research (LTER) and monitoring site on the North Slope.

[3]Contact information for all agencies, research centers, and programs are given in Appendix C: Key Research Programs in or on Alaska and the Arctic.

Ecological Research on Land and Ocean Systems

Research on ecological processes in Alaska's terrestrial, aquatic, and marine ecosystems is ongoing in many university departments both in and beyond Alaska. Much of that research is the essential foundation for specific research on the impacts from climate variability and change (Figure 28).

Understanding biochemical changes in the atmosphere and the environment, species interactions, migratory patterns of birds and fish, food requirements of certain species, sensitivity of plants to climate variability, or critical thresholds beyond which species can no longer maintain their populations are just some of the interests researchers pursue.

Again, long-term observations and analysis, especially of terrestrial species, are essential to understand the full complexity of species–environment interactions over time. Rapid environmental change driven by climate warming make such research both extremely interesting and challenging, especially in light of the multiple stresses driving environmental change in Alaska.

Human Dimensions Monitoring and Research

The importance of social-science research in the context of global change is clearly recognized in Alaska. Climate change, other large-scale environmental changes, and globalizing economic forces create opportunities as well as hardship for both Alaska Natives and other state residents. Potential impacts on key economic sectors, human health as well as on native peoples and cultures have been described above. Research in these areas is both ongoing and needed in the future.

Recognizing the opportunities and challenges humans face in times of rapid change, the University of Alaska—Fairbanks, for example, created a research and education program focused specifically on resilience and adaptation. The National Science Foundation and other U.S. and international funding and research programs have begun supporting human-dimensions research explicitly. Monitoring of social, economic, health, and cultural indicators is vital and needed immediately to help establish baselines, to assess capacities, and to better understand vulnerabilities among Natives and other Alaskans to environmental change. Both native and scientific efforts are underway to collect this much-needed information.

Figure 28: Examining the impact of climate on fish size: smaller Arctic Cod (**Boreogadus saida**) would negatively affect Black Guillemots (Source: George Divoky; reprinted with permission)

A special line of research highlighted by meeting attendees must address the integration of Native/traditional knowledge and wisdom with western scientific approaches. Both types of observations of environmental change in the Arctic largely confirm each other. Yet mutual respect, recognition, and understanding of the underlying worldviews and approaches continue to be difficult to achieve and require addressing of tough ethical and methodological questions.

Climate Impact Assessments

> *"…Interaction between local experts and academic scholars will require other patterns of collaboration than between, let's say, physical and social scientists. Familiar ways of doing research – scanning earlier data, disputing other people's concepts, and borrowing references across disciplines – will be inadequate for this new unfolding collaboration. We rather have to learn to act through sharing, listening, and accommodation to others' ways of observing and 'knowing'."*
>
> –Igor Krupnik and Dyanna Jolly (2002, p.1)

Maybe the greatest challenge climate impact assessments face is the integration of insights from a range of physical, ecological, and social sciences, as well as from indigenous observations to produce a comprehensive, relevant, and credible synthesis.

In the context of the First U.S. National Assessment of the Potential Consequences of Climate Variability and Change, Alaska undertook a first regional assessment of its vulnerability to climate change (Weller, Anderson, and Wang 1999). Now five years old, this preliminary assessment forms a critical foundation for further climate impacts research and assessments on Alaska.

One example of such an integrated assessment, though not solely focused on Alaska, but on the entire circumpolar region, is the Arctic Climate Impact Assessment (ACIA), conducted from 2000-2004 under the auspices of the Arctic Council and the International Arctic Sciences Committee. Many Alaskans are involved in this international effort, both confirming previous observations of change and advancing the scientific understanding of complex interactions between environmental and social systems under the pressures of rapid climate change and increasing UV radiation. One of the assessment's most intriguing contributions is the considerable effort that was made to link indigenous and western-scientific knowledge and understanding. The final scientific reports from the Assessment will be released at an *ACIA International Scientific Symposium on Climate Change in the Arctic* to be held in Reykjavik, Iceland, 9-12 November, 2004.

Another ongoing research and assessment effort is the Study of Environmental Arctic Change (SEARCH), funded by NOAA and seven other federal agencies. This comprehensive research effort focuses on atmospheric and climatic changes, ocean and sea ice changes, terrestrial and physical changes in the environment, chemical, biological, and ecosystem changes, and on the human dimensions. To date, however, this effort has been weak in directly interacting with stakeholders and responding to their specific information and decision needs.

From this cursory review of ongoing research efforts in and on Alaska, it becomes quickly apparent that Alaska has substantial research and assessment capacity. It is precisely this large number of research activities that implies a significant challenge as well: namely, that of coordination and integration of different research and monitoring efforts.

Alaska's research community faces the great challenge of coordinating and integrating its many different research and monitoring efforts.

While some of the most pressing and interesting research questions may be found at the interface of different disciplines, the coordination, integration, and cross-disciplinary synthesis is one of the biggest challenges facing the Alaskan research community today. It involves overcoming conceptual and institutional barriers, and creating ongoing communication and face-to-face interaction to build the necessary rapport and trust. Indeed, this is no small challenge in times of limited staff and financial resources.

Involving Regional Stakeholders and Governmental Partners

To fully realize the potential usefulness of research and assessments in Alaska and the Arctic, building ongoing relationships between the research community and regional stakeholders is essential. Stakeholders – broadly defined – are all those individuals, agencies, and non-governmental entities whose interests and decisions are potentially affected by weather, climate, and short- and long-term changes therein.

Undoubtedly, the range of stakeholders is huge. With virtually all of Alaska's economic sectors affected by weather and climate, decision-makers in the private sector have great stakes in better understanding their vulnerabilities. Similarly, decision-makers concerned with public safety, public health, economic and social welfare, environmental protection, and the provision and maintenance of adequate and safely functional infrastructure require climate information and a better understanding of the complex interactions between climate, the environment, and society. Alaska Natives have unique needs and interests given the many challenges they face in sustaining their subsistence livelihoods, cultural heritage, and traditional ways of life.

The flip side of these stakeholders' interest in research findings is that they also have tremendous resources, information, insights, and wisdom to offer to the research community. Yet the fit between research and stakeholder needs and offerings is neither natural nor optimal on its own. It requires frequent interaction, continuing communication, and – perhaps most vitally – open minds to be *made* optimal.

Only through such close collaboration can both sides appropriately prioritize research needs, and find the ever-shifting balance between the needs of the scientific community to produce credible science, the needs of decision-makers for timely and relevant information input into the decision-making process, and the needs of all stakeholders involved to be engaged in a legitimate process of conducting joint assessments.

The research and assessment needs identified at the workshop are described in the following section.

The fit between research and stakeholder needs and offerings is neither natural nor optimal on its own. It requires frequent interaction, continuing communication, and – perhaps most vitally – open minds to be made optimal.

Regional Integrated Science and Assessment Needs

At the exploratory RISA workshop in Anchorage participants identified numerous research and assessment needs. Basic and applied scientific research questions overlapped more or less with identified decision-support needs. The realm in which they overlap may be called "use-inspired" research. Generally, such policy- or decision-relevant research would have to be *integrated* and *interdisciplinary* to aid and expand decision-makers options, *cognizant of the context* decision-makers function within and *of the constraints* they face in managing their climate-sensitive resources. Thus, before describing the specifics, it is useful to begin by describing effective decision support.

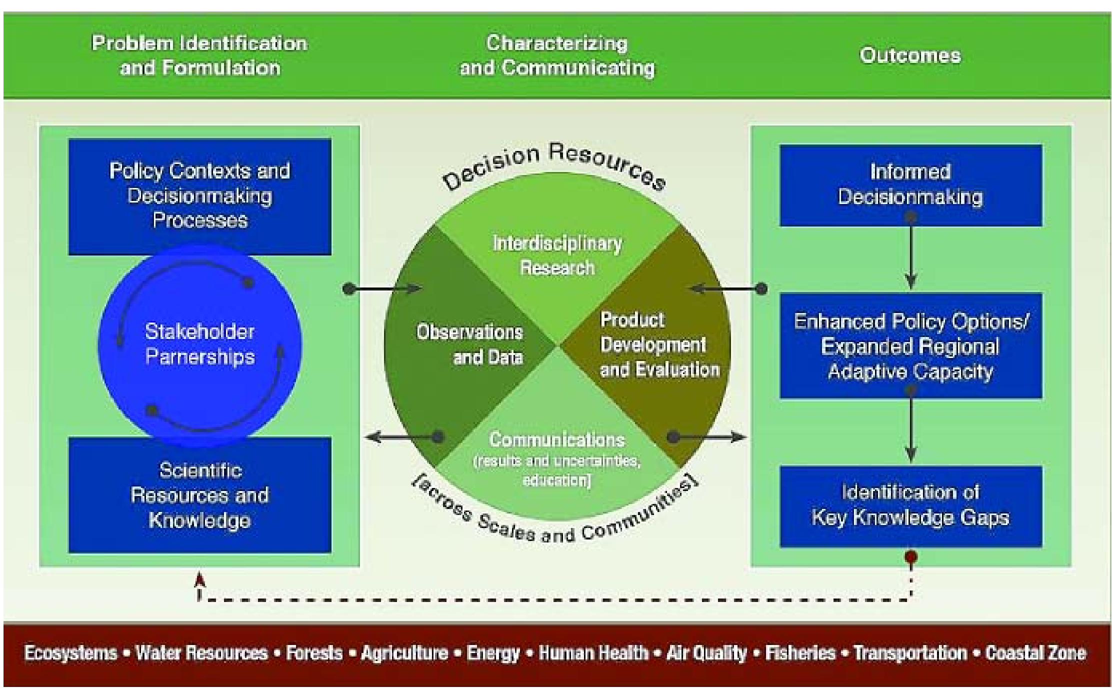
What is Effective Decision Support?

Useful decision support from the scientific community has a number of characteristics, including:

- information focuses on a critical societal issue, providing more than a state-of-the-knowledge assessment
- information answers specific questions identified by stakeholders
- information is provided in a timely fashion, fitting into the timeframe of the decision-maker
- information is directly relevant in form and content to the decision at hand, reflecting an understanding of the decision context
- information is communicated in accessible language and formats
- information includes an evaluation of the degree of uncertainty, limitations in scientific understanding, and the confidence in the results provided
- research products are the result of close science-stakeholder interaction (Figure 29)

As Susan Avery (Director of CIRES, University of Colorado) suggested at the workshop, developing effective partnerships to provide effective decision support requires effort, including a significant investment of time, a

Figure 29: Decision-support framework (Source: U.S. Climate Change Science Program 2003)



commitment to sustained communication and follow-up to meet user expectations. Moreover, careful planning is needed to allow for the transition from research to operational products useful to educated users. Frequently, partnerships between researchers and the user community also benefit from independent information brokers. Such information brokering can be critical because it allows researchers and decision-makers to continue doing what each does best. It can leave all partners in the collaboration with satisfied expectations, new scientific insights, useful information, enhanced institutional capacity, and ultimately reduced vulnerability, greater preparedness, enhanced opportunities, and a greater chance at sustainable management of resources.

If such science-stakeholder collaborations are understood as continuing processes of shared learning and joint problem solving, frequent evaluation and adjustment of the process become indispensable elements of the process.

Which Decisions and Goals Need Support?

> *"To build and sustain a successful science–stakeholder partnership we must ensure credibility, build trust, and be responsive with ever-improving communication, ever-improving science, and tangible products and tools."*
>
> –Jonathan Overpeck, University of Arizona, CLIMAS

If the goal of such integrated, interdisciplinary, and iterative research is effective decision support, then one might ask: which decisions need support? Focusing on key Alaskan vulnerabilities, participants identified the following as critical concerns in Alaska:

- the relationship between native communities, land, and resources
- human health maintenance and management
- long-term planning in living and non-living resource sectors, communities, and infrastructure
- subregional (place-based) and shorter-term (seasonal) decisions requiring high-resolution specificity (impacts of climate variability and extremes on travel or fire management, etc.)
- climate-driven ecosystem changes and the impacts of land and ecosystem management decisions on habitat and species populations in light of climate variability and change

Each is described in more detail below. Workshop participants emphasized that the key objectives in each of these cases would be to:

- better ***understand and reduce exposure and sensitivity*** to impacts from climate variability, climate change, and other changes
- ***enhance preparedness, public awareness, and understanding***
- ***maintain or enhance flexibility and adaptive capacity, and hence resilience*** in the face of change
- ***share resources*** where possible to meet common goals or solve common problems
- ***develop appropriate response options,*** that are mindful of resource constraints, cognizant of environmental and socio-economic impacts, and respectful of cultural heritage
- ***create opportunities*** where possible to take advantage of the changes, and
- ***build long-term institutional and individual capacity*** through dialogue, education, training, and critical partnerships.

Importantly, as representatives from other RISA regional teams reported (e.g., Overpeck, Whitely-Binder, Garfin, Webb, and Shea), many decisions are not solely climate-related, but rather have to respond to multiple stresses in which climate sometimes is a direct but often only a marginal factor. Thus decision-relevant research – even if focused on climate – must recognize these multiple stresses and assess the relative importance of climate accordingly.

Use-Inspired, Integrative Research Foci

> *"We heard Orville [Huntington] speak of combining knowledge with wisdom. That's a great concept, but as scientists, we don't really know how to do this. If this future RISA only does knowledge, we don't need it. If it brings wisdom, it will be a good thing."*
>
> –Gunter Weller, University of Alaska—Fairbanks

Native Subsistence

As described in the chapter on vulnerabilities above, the challenges to native livelihoods and cultures from multiple stresses and environmental change pose an integrative focus for future research and assessment in Alaska. In some instances, fundamental research is required to understand the drivers and impacts of environmental change. More often, however, the question will be how to cope with and effectively and sensitively adapt to rapid change. Ways of life, people's physical and mental health, cultural heritage, a sense of community and intergenerational connection, as well as the ecological integrity in and around native communities are at stake.

In the past, Alaska Natives adapted to environmental changes primarily by moving to more adequate environments. Housing was more mobile, and family and kinship ties provided a communal context for food and resource sharing that afforded significant flexibility and resilience. The deep environmental knowledge of elders provided physical survival and social stability. Today, fixed houses and dependence on physical infrastructure provide both benefits and reduced flexibility in adapting to environmental change. The knowledge of elders is becoming less dependable in such rapidly changing times, potentially creating tension and uncertainty in native communities. Changes in weather patterns are harder to interpret; in coastal locations, erosion is increasing and threatening the location of entire communities; permafrost is causing major problems; and species shift and populations are declining. All these affect subsistence activities and diet. At the same time, the younger generation is torn between traditional lifestyles, cultural heritage, and intimate knowledge of the environment on the one hand, and the allure of western amenities and lifestyles on the other. These intertwined trends in Alaska Native communities create enormous stresses on the social fabric at the same time that the changing environment demands ready adaptation.

Workshop participants identified key focus areas of concern to native communities. Among them were

- human health
- permafrost and infrastructure
- changes in marine and aquatic ecosystems
- changes in sea ice
- coastal hazards (storms, erosion)
- relationship between hunting and fishing success and social indicators of community well-being
- changes in water availability, temperature, and quality
- current and future change in species shifts, distribution, and abundance
- legal and regulatory issues concerning the continuation of native activities and lifestyles

Frequently, this highly contextual research will also include very practical assistance for native communities in dealing with emergency situations, technical problem solving, accessing resources, and generating public and private champions and support to implement appropriate responses. Federal or state regulations in some instances impede assistance to native communities. For example, federal cost-benefit ratio requirements may eliminate small native communities from receiving federal funds for coastal protection or relocation. Other regulations may prevent federal or state agencies from appropriately addressing the diverse needs of small native villages. Such regulations and standards need to reviewed, adapted, or alternative assistance mechanisms found.

Human Health Maintenance, Improvement, and Management

Human health was identified as another highly context-specific, geographically differentiated issue for further research and assessment attention. While research on health issues is ongoing in university and governmental departments, related education and outreach components, as well as integration with actual health management needs frequently fall short of satisfying user needs. A strong institutionalized focus on health issues through a RISA like program could provide essential issue advocacy and visibility, and provide leverage by better organizing and coordinating disparate efforts.

Important foci would include:

- infectious disease surveillance, e.g., surface water contamination, spread of disease vectors
- establishment of early warning systems
- air and water pollution from local and remote sources and their interconnection with climate
- monitoring of ecological changes that have direct and indirect health implications (e.g., changes in fire regimes, species shifts, changes in species availability and accessibility, edibility of plants and animals, changes in ice conditions)
- examination of changes in diet (driven by environmental and other factors)
- monitoring of people's mental health (as affected, for example, by exodus from communities, loss of homes, loss of subsistence)

Such monitoring and research activity could tap into and extend existing health data and tracking systems, involve the Indian General Assistance Program (IGAP), and draw on wide public support in local communities and non-governmental organizations. Circumpolar collaboration via the Arctic Council could also be beneficial in light of the cross-boundary spread of air pollution and infectious diseases. Resources would be required to build and sustain health-related infrastructure, physical infrastructure, and the monitoring systems.

Long-Term Planning in Resource Sectors, Communities, and Infrastructure

Management challenges and decisions with longer time horizons are separated here from those with shorter time horizons, though the same resources sectors or geographic locations could benefit from future integrative research and assessments (see below). The types of decisions here involve timeframes of one to several decades, and will most likely be made in sectors where resources and/or infrastructure do not change rapidly in response to climate conditions. This timeframe also places special attention on the scientific community's ability to separate out long-term climate change from multi-decadal climate regimes and shifts therein. Examples of management challenges and hence needed research attention include:

- construction and location of water-related infrastructure (sewage treatment plants, wells, etc.)
- road building and repair
- installation of coastal protective structures (seawalls, bulkheads, etc.)
- construction and location of buildings, especially large ones that are difficult to relocate
- placement of infrastructure required for oil and natural gas extraction and transportation
- choice of forest species for timber production
- boundaries around protected natural areas, creation of buffer zones or migration pathways
- long-term fisheries management decisions regarding stock rebuilding plans, gear or permit investments, international treaties, etc.

Adequate long-term planning requires place- and/or region-specific, long-term climate projections, including projections of impacts on relevant environmental components, with a clear articulation of uncertainties and levels of scientific confidence. These long-term environmental projections must be integrated with – equally uncertain – socio-economic forecasts and translated into concrete management decisions. Frequently, this will require comparative assessment of numerous management alternatives, engineering genius, and wise (precautionary) foresight to implement. The overarching goal would be to better understand the conditions that create stability in a system, or that would enhance a system's resilience.

Subregional and Shorter-Term Decisions in Various Resource Sectors

Management at shorter time scales – from days to weeks, to months, to seasons, to several years – frequently requires high(er) specificity in spatial resolution. Such decisions are most common in living-resource sectors, hazard and emergency situations, as well as human health where resources and conditions can change rapidly in response to weather and climate. These shorter timescales require special attention from the climate community in terms of improving seasonal forecasting capabilities as well as regional downscaling from global circulation models. Workshop participants raised the following examples of salient climate-sensitive management challenges:

- fisheries harvesting decisions cognizant of climate variability (e.g., fish allocation to different fishermen, fish disease management, minimizing the risk of big surprises such as fish population crashes)
- harvesting decisions regarding mammal populations as their abundance varies with climate
- agricultural production in light of seasonal and interannual climate variability
- fire and forest insect pest management under varying seasonal and multi-year climatic conditions
- decisions regarding travel by air, by sea, over ice, or on land (e.g., wet season impeding travel over certain land areas)
- determination of local sea-level rise and coastal erosion rates for emergencies and longer-term coastal and sediment management decisions
- water resource allocations and the balancing of flood protection and water storage needs
- on-ice hunting and fishing activities and related safety concerns affected by sea ice conditions
- seasonal and annual preparedness relative to changing environmental conditions affecting human health (e.g., spread of infectious disease vectors)

Such shorter-term management issues arise in the context of decision-making that must meet multiple objectives and the diverse needs of several affected stakeholder groups. Moreover, the need to be location-specific requires difficult cross-scale challenges – down-scaling from global and regional climate models, as well as up-scaling from local conditions to the broader regional context. Associated with these challenges are data integration and quality challenges, and as-yet unsolved problems in cross-scale model integration since the underlying physics and relationships between variables are insufficiently understood.

Climate-Driven Ecosystem Changes

Workshop participants singled out ecosystem management as another important integrative focus for future research, particularly in the face of the multiple stresses that drive environmental change. Such research can be approached from the climate side, from any of the other pressures (such as pollution, land use change, introduction and spread of invasive species), or from the management perspective concerned with ecosystem goods and services.[4] The former perspective would ask how climate and other driving forces affect ecosystem health, while the latter would be concerned with the impacts of land and ecosystem management decisions on habitat and species populations in light of climate variability and change.

Among the key research foci suggested by workshop participants were the following:

- future distribution and abundance of species
- future ecosystem assemblages and the goods and services future ecosystems may/can provide
- prospects of already threatened or endangered species
- management of moving species populations and rapidly changing ecosystems
- growing threat from invasive species, or maybe more to the point, management of landscapes where virtually all species begin to move and are introducing themselves into previously unoccupied regions

Workshop participants hoped for progress by better coordination between monitoring and research activities conducted by federal agency staff and the academic research community; greater cross-disciplinary integration; and improved cooperation between agencies and research programs to build capacity, leverage strengths, data and knowledge, and financial and technical resources. Turf issues and limited resources as well as narrow missions can impede such cooperation.

Overarching Needs and Cross-Cutting Challenges

No matter what the specific research questions, workshop participants emphasized the over-arching and cross-cutting needs and challenges that any future RISA-like activity would have to address.

Observation and monitoring is a persistent need in all areas – climate, ecology, economic activities, and human communities. Workshop participants reiterated the need for increasing the density of observational networks,

[4]For one example of an effort that assesses cumulative impacts on the environment, see the multi-partner Kenai Watershed Forum (http://www.kenaiwatershed.org/effectsmodel.html).

particularly for terrestrial observations, and maintaining or modernizing existing monitoring stations. In addition, they stressed the need for extending observational records into the past and the future, assuring data quality, and producing useful aggregates and interpretative materials to turn "data" into "useful information." Much could be gained by analyzing existing data, and increasing our understanding of past patterns of variability and change.

> *"It's like having a baby – you can't just deliver the [observation] system, you have to maintain and grow it."*
>
> –Kelly Redmond, Western Regional Climate Center

The ***integration of traditional knowledge and wisdom with western science*** remains a special challenge requiring attention in all research areas. As Larry Merculieff (Alaska Native Science Commission) stated, "We are concerned about using only the western, Cartesian-based paradigms to understand what is happening to ecosystems because western science tries to understand the whole by taking apart its pieces…." Western science can greatly benefit from the observations and worldview of natives, while natives can benefit from information gathered by scientists (e.g., from remote sensing platforms) to augment their own observations. While integration of information derived by different methods is one important challenge even in instances where one set of information essentially confirms the other, there are other instances where observations apparently contradict each other. These have to be resolved on a case-by-case basis.

One of the greatest needs identified that a RISA-like program in Alaska could support is the development of a ***one-stop clearinghouse for climate and environmental information***. To the degree that such a clearinghouse function could also improve cross-agency, cross-research, and cross-disciplinary integration, networking, and even some degree of coordination, Alaskans could greatly leverage ongoing research and assessment activities.

Closely related to the establishment of an information clearinghouse is the oft-repeated call for ***improved communication*** – across disciplines, across academic/practitioner boundaries, across generational/cultural boundaries, between the scientific community, the media, educators and the larger public, and finally, across barriers that separate old, opposing economic/environmental interests.

Recognizing the need for continuity of resources (in personnel, money, and technical assistance) and the way that low population density and geographic remoteness from centers of power can easily lead to neglect, workshop participants made pragmatic suggestions for how to ***leverage existing resources and bringing in additional ones***. They suggested that research focus on tractable problems (where data and research strengths are available, and the problem is salient to many); focus on research that yields results useful at a range of timescales and to a range of stakeholders; focus on reducing and/or characterizing uncertainty more clearly; motivate stakeholders to become partners in the research effort; and leverage and coordinate existing activities and resources.

Finally, workshop participants alerted other attendees to the ***logistical challenges*** that need to be addressed creatively in a state as large as Alaska, with a highly dispersed population, difficult access to remote areas, and obstacles to communication and interaction where Internet connectivity is not yet common, face-to-face meetings frequently require flights, and tight interdependence of seasonal rhythms with basic livelihood activities determine people's availability to meet.

Final Thoughts

Recognizing both the daunting challenges and the tremendous opportunities embedded in them, public land managers and Alaska Natives emphasized the need to interpret climate change for visitors to the state. The consensus among meeting participants suggests that Alaska is already the poster child for the impacts of global warming, thus presenting clear opportunities for education and awareness-raising. It could also become the poster child for adaptive management. Whether Alaska will lead the nation by positive or negative example will greatly depend on the degree of regional cooperation between scientists and stakeholders, and on support from afar.

Whether Alaska will lead the nation in adaptive management by positive or negative example will greatly depend on the degree of regional cooperation and on support from afar.

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Appendix A: Workshop Agenda

Enhancing Decision-Making Through Integrated Climate Research: Alaska Exploratory Workshop

Sponsored by:

Regional Integrated Sciences and Assessments (RISA) Program
NOAA/Office of Global Programs (OGP), Silver Spring, MD
Captain Cook Hotel, Anchorage, Alaska
February 18-19, 2004

Sponsor: National Oceanic and Atmospheric Administration
Co-Sponsors: National Weather Service-Alaska Region, USGS-Alaska Science Center & National Park Service-Alaska Region

Wednesday, February 18, 2004

7:30-8:30 Registration and Continental Breakfast, *Aft Deck*

Morning Chair: Patricia Anderson, Cooperative Institute for Atmospheric Research (CIFAR)

Introduction and Program Context

8:30-8:40 **Welcome & introduction,** Juniper Neill, Program Officer, NOAA/OGP

8:40-8:55 **Guest presentation: Community at Risk, Shishmaref, AK**. Tony Weyiouanna Sr., Village Transportation Planner & Luci Eningowuk, Erosion and Relocation Coalition

8:55-9:00 **Workshop rationale and goals,** Harvey Hill, RISA Program Coordinator, OGP/UCAR

9:00-9:20 **Decision support research: priorities from the U.S. Climate Change Science Program,** Susan Avery, Director of the Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Western Water Assessment (WWA)-RISA

9:20-9:40 **RISA Program overview,** Jonathan Overpeck, Director, Climate Assessment of the Southwest (CLIMAS)-RISA

The Alaskan Context

9:40-10:15 **Co-sponsor panel: priorities for climate information** - Research, Service, and Management – Mark Shasby, USGS-AK Science Center; Gary Hufford, NWS-Climate Services, AK; Judy Gottlieb, NPS, Alaska Region

10:15-10:45 **The Alaskan context: climate change and variability in the arctic and sub-arctic regions; risks, vulnerabilities, and opportunities,** Gunter Weller, U. of AK, Fairbanks, CIFAR

10:45-11:00 **Break**

11:00-1:00 **Research case studies—the climate connection?**

11:00-11:20 **Ann Jensen, Ukpeagvik Iñupiat Corp. Science Division**

Climate and Arctic Subsistence: Bowheads in Barrow & Bearded Seals in Greenland

11:20-11:40 **George Divoky, UAF, Institute of Arctic Biology**

The response of a seabird to three decades of warming in the Western Arctic: a biotic proxy responds to meteorological and oceanographic change

11:40-12:00 **Larry Hinzman, UAF, Water & Environment Research Center**

Impacts of climate change on hydrological processes in Arctic and Subarctic regions

12:00-12:20 **Terry Chapin, UAF, Institute of Arctic Biology**

Climate-fire-human interactions: Consequences of climate change for rural communities and fire managers

12:20-1:25 **Buffet lunch,** *Quarter Deck (please note guest speaker moved to after lunch)*

Wednesday, February 18, 2004 (continued)

Afternoon Chair: Gunter Weller, CIFAR

Arctic Climate Impact Assessment (ACIA)

1:25-2:05 **Overview of the ACIA and future directions,** Bob Corell, Senior Fellow, Atmospheric Policy Program, American Meteorological Society

2:05-2:30 **Climate and Human Health Connections: Insights from the ACIA and implications for Alaska**, James Berner, M.D., Director-Community Health Services, Alaska Native Tribal Health Consortium

Breakout Sessions

2:30-2:40 **Climate information needs/adaptation response opportunities: framing for breakout sessions,** Eileen Shea, East-West Center, U. of HI, Pacific RISA

2:40-4:10 ***Concurrent Breakout Sessions: Identification of "tractable" areas for integrated research***

Session 1: Climate and Human Health Risks – Facilitator: Suzanne Marcy, U.S. EPA

Session 2: Climate Links to Regime Shifts: Aquatic and Terrestrial Ecosystems – Facilitator: James Overland, NOAA/PMEL

Session 3: Climate Influences on Rural/ Native Subsistence – Facilitator: Judy Gottlieb, NPS-Alaska Region

Session 4: Transportation, Infrastructure & Safety: Climate Adaptation Concerns/ Strategies – Facilitator: James Partain, NWS-AK

Session 5: Observations & Data Management/Integration: Critical Links to Decision-making – Facilitator: Molly McCammon, AK Ocean Observing System

Guiding questions: current research gaps and capacity requirements; stakeholder climate information drivers. *Breakout rooms: Club Room II, Quadrant, Resolution, Easter Island, Voyager*

4:10-4:20 **Break**

4:20-5:20 **Reports back to plenary (10 minutes each),** *Aft Deck*

5:20-5:30 **Summary wrap-up**

5:30-7:30 **Reception,** *Quarter Deck*

Thursday, February 19, 2004

7:30-8:30 **Breakfast Buffet,** *Adventure Room*

Morning Chair: Philip Mote, U. of WA, Climate Impacts Group (CIG)- RISA

8:30-8:40 **Goals for Day 2,** *Endeavor Room*

Rural Alaskan Concerns

8:40-9:20 **Panel: Issues for Alaskan Stakeholders.** Larry Merculieff, AK Native Science Commission; Orville Huntington, U.S. Fish & Wildlife Service, *Aft Deck*

RISA Research: Sharing Methodology in the Alaskan Context

9:20-9:40 **Feedback on breakout results and discussion: implications for integrated, multi-disciplinary decision-support research,** Philip Mote, CIG

9:40-11:10 **Panel & discussion, RISA in the western US:** Gregg Garfin, CLIMAS, U. of AZ; Lara Whitely Binder, CIG, U. of WA; Robert Webb, Western Water Assessment (WWA), U. of CO; (team composition, stakeholder involvement, key science results and applications)

11:10-11:25 **Break**

11:25-12:00 **Climate and Alaska Fisheries: the impacts of the Pacific Decadal Oscillation and implications for fisheries management,** Nate Mantua, Climate Impacts Group, U. of WA, RISA

12:00-1:15 **Lunch** (on your own)

Thursday, February 19, 2004 (continued)

1:15-1:45 **Climate variability & change impacts on coastal communities: mitigation and adaptation,** Eileen Shea, East-West Center, U. of HI, Pacific RISA

Afternoon Chair: Jonathan Overpeck, Climate Assessment of the Southwest (CLIMAS) RISA

Climate Information Resources

1:45-2:05 **NOAA/NWS Climate Services-Alaska,** Gary Hufford

2:05-2:25 **Western Regional Climate Center, Reno, NV,** Kelly Redmond

Arctic Research and Policy Implications

2:25-2:50 **Study of Environmental Arctic Change (SEARCH) and opportunities for collaboration with ongoing research,** John Calder, NOAA's Office of Arctic Research, Silver Spring, MD

2:50-3:15 **Pan-Arctic to the Village: How can the Arctic Climate Impact Assessment contribute to local policy and decision-making?** John Walsh, International Arctic Research Center, U. of AK Fairbanks

3:15-3:30 **Break**

Feedback to the RISA Program

3:30-4:10 **Open discussion: Regional adaptive capacity…prioritize key climate sensitive sectors and areas for the use of climate information by decision-makers**

4:10-4:50 **Open discussion: Drivers for stakeholder relevant climate research…current capacity and identified gaps**

4:50-5:00 **Implications for NOAA/OGP program planning,** Claudia Nierenberg, NOAA/OGP/Climate & Societal Interactions Division Director

5:00-5:10 **Closing remarks & follow-up plans**

Appendix B: Workshop Organizing Committee

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Appendix D: Key Research Programs in or on Alaska and the Arctic

Alaskan Universities

University of Alaska—Anchorage
Alaska Natural Heritage Program
http://enri.uaa.alaska.edu/aknhp/index.html

University of Alaska—Anchorage
Department of Anthropology
http://anthro.uaa.alaska.edu/

University of Alaska—Anchorage
Department of Biological Sciences
http://biohome.uaa.alaska.edu/biology.html

University of Alaska—Anchorage
Institute for Circumpolar Health Studies
http://www.ichs.uaa.alaska.edu/ichs/

University of Alaska—Anchorage
Institute of Social and Economic Research
http://www.iser.uaa.alaska.edu/

University of Alaska—Fairbanks
Alaska Climate Research Center
http://climate.gi.alaska.edu/

University of Alaska—Fairbanks
Alaska GLOBE Program
http://www.cgc.uaf.edu/Globe/akglobe.html

University of Alaska—Fairbanks
Center for Global Change and Arctic System Research
http://www.cgc.uaf.edu/

University of Alaska—Fairbanks
Cooperative Institute for Arctic Research
http://www.cifar.uaf.edu/

University of Alaska—Fairbanks
Department of Anthropology
http://www.uaf.edu/anthro/

University of Alaska—Fairbanks
Forest Sciences Department
http://nrm.salrm.uaf.edu/~jfox/ForestSci.html

University of Alaska—Fairbanks
Geophysical Institute
http://www.gi.alaska.edu/resrchfacils.html

University of Alaska—Fairbanks
Institute of Arctic Biology
http://mercury.bio.uaf.edu/iab/index.html

University of Alaska—Fairbanks
International Arctic Research Center (incl. Frontier Research System for Global Change)
http://www.iarc.uaf.edu/

University of Alaska
Regional Resilience and Adaptation Program
http://www.rap.uaf.edu/

University of Alaska—Fairbanks
School of Fisheries and Ocean Sciences
http://www.sfos.uaf.edu/

University of Alaska—Toolik Field Station
Arctic Long-Term Ecological Research (ARC LTER)
http://ecosystems.mbl.edu/arc/

Arctic Region Supercomputing Center
Fairbanks
http://www.arsc.edu/

Other Universities/Institutions Involved in Alaska and Arctic Research

Michigan State University
Arctic Ecology Laboratory
http://www.cevl.msu.edu/ael/

National Center for Atmospheric Research
Institute for the Study of Society and the Environment
http://www.isse.ucar.edu

Ohio State University
Byrd Polar Research Center
http://www-bprc.mps.ohio-state.edu/

Scripps Institution of Oceanography
Arctic and Antarctic Research Center
http://arcane.ucsd.edu/

University of Colorado
Institute of Arctic and Alpine Research (INSTAAR)
http://instaar.colorado.edu

University of Colorado
National Snow and Ice Data Center (NSIDC)
http://nsidc.org

University of Illinois—Urbana-Champaign
Polar Research Group
Arctic Climate Impacts Assessment Project
http://zubov.atmos.uiuc.edu/ACIA/

University of Washington—Seattle (with eight federal agencies contributing)
Polar Science Center
Study of Environmental Arctic Change (SEARCH)
http://psc.apl.washington.edu/search/

Western Regional Climate Center
Desert Research Institute
Reno, Nevada
http://www.wrcc.dri.edu/

Selected Non-Governmental Research and Monitoring Organizations

National Parks Conservation Association – Alaska Region
http://www.npca.org/across_the_nation/npca_in_the_field/alaska/default.asp

National Wildlife Federation
www.nwf.org

Alaska Conservation Foundation
http://www.akcf.org/

Key State Agencies

Alaska Department of Community & Economic Development
http://www.dced.state.ak.us/

Alaska Department of Environmental Conservation
http://www.state.ak.us/dec/

Alaska Department of Health & Social Services
http://www.hss.state.ak.us/

Alaska Department of Fish and Game
http://www.adfg.state.ak.us/

Alaska Department of Natural Resources (incl. agriculture, forestry, mining, land and water, oil and gas, and parks and outdoor recreation)
http://www.dnr.state.ak.us/

Alaska Department of Transportation and Public Facilities
http://www.dot.state.ak.us/

Key Federal Agencies, Funding, and Research Programs

Alaska Ocean Observing System (jointly funded and conducted with state agencies)
http://www.aoos.org/

Arctic Research Consortium of the United States (ARCUS) & Arctic Logistics Information and Support (ALIAS)
Headquarters: Fairbanks
http://www.arcus.org/

Note: ARCUS manages a "Polar Education" discussion list. See: http://www.arcus.org/education/educationlist/index.html

U.S. Army Corps of Engineers
Cold Regions Research and Engineering Laboratory
Alaskan Projects Office
http://www.crrel.usace.army.mil/alaska-office/

U.S. Department of Agriculture
Natural Resources Conservation Service – Alaska Data Collection Office
http://www.ak.nrcs.usda.gov/

U.S. Department of Agriculture
Forest Service – Alaska Office
http://www.fs.fed.us/r10/

U.S. Department of Commerce
National Oceanic and Atmospheric Administration (NOAA)
Arctic Research Office
http://www.arctic.noaa.gov/aro/

U.S. Department of Commerce
NOAA
Office of Global Programs
http://www.ogp.noaa.gov/

U.S. Department of Commerce
NOAA
Pacific Marine Environmental Laboratory
http://www.pmel.noaa.gov/

U.S. Department of Commerce
NOAA
Study of Environmental Arctic Change (SEARCH)
http://www.arctic.noaa.gov/search/
http://psc.apl.washington.edu/search/

U.S. Department of Commerce
NOAA
National Weather Service – Fairbanks Office
http://pafg.arh.noaa.gov/

U.S. Department of the Interior
Bureau of Indian Affairs – Alaska Region
http://www.the13thregion.com/bia.htm

U.S. Department of the Interior
U.S. Geological Survey – Alaska Science Center
http://mapping-ak.wr.usgs.gov/index.html

U.S. Department of the Interior
U.S. Geological Survey – Geospatial Data Clearinghouse
http://agdc.usgs.gov/

U.S. Department of the Interior
U.S. Geological Survey
Water Resources of Alaska – Glacier & Snow Program
http://ak.water.usgs.gov/glaciology/index.html

U.S. Department of the Interior
National Park Service – Alaska Region
http://www.nps.gov/akso/

U.S. Department of the Interior
Fish and Wildlife Service – Alaska Region
(with access to National Wildlife Refuges across Alaska)
http://alaska.fws.gov/

U.S. Department of the Interior
Bureau of Land Management – Alaska Region
http://www.ak.blm.gov/

U.S. Environmental Protection Agency
Arctic Programs, Region10
http://www.epa.gov/region10/

NASA
Alaska Science Center
http://www.alaskapacific.edu/Science/

National Science Foundation
Arctic Social Science Program
http://www.nsf.gov/od/opp/arctic/social.htm

National Science Foundation
Arctic System Science
http://www.nsf.gov/od/opp/arctic/system.htm

National Science Foundation
Human Dimensions of Arctic Systems (HARC)
http://www.arcus.org/harc/

National Science Foundation
Land-Atmosphere-Ice Interaction Program
http://www.laii.uaf.edu/

National Science Foundation
Office of Polar Programs
http://www.nsf.gov/od/opp/start.htm

U.S. Global Change Research Program
U.S. National Assessment – Alaska Regional Assessment
http://www.usgcrp.gov/usgcrp/Library/nationalassessment/overviewalaska.htm

Selected International Research, Monitoring, and Assessment Efforts

Arctic Climate Impact Assessment
Arctic Council & International Arctic Science Committee
http://www.acia.uaf.edu/

Arctic Coastal Dynamics (ACD)
Alfred Wegener Institute for Polar and Marine Research
http://www.awi-potsdam.de/www-pot/geo/acd.html

Arctic Monitoring and Assessment Program (AMAP)
http://www.amap.no/

United Nations Environment Program
Arctic Net
http://arctic.unep.net/

Alaska Natives' Organizations and Networks

Alaska Federation of Natives (AFN)
http://www.nativefederation.org/flash.html

Alaska Native Knowledge Network
http://www.ankn.uaf.edu/

Alaska Native Science Commission
http://www.nativescience.org/index.html

Alaska Native Tribal Health Consortium
http://www.anthc.org/

Alaska Traditional Knowledge and Native Foods Database
http://www.nativeknowledge.org/login.asp

Inuit Circumpolar Conference (ICC)
http://www.inuitcircumpolar.com

Maniilaq Association
Tribal Government/Native Services/Tribal Environmental Protection
http://www.maniilaq.org/home.html

Additional Links

For further information and numerous additional relevant programs and efforts, go to the links pages of any of the aforementioned programs and institutions.