*Chapter 1*

# An Introduction to the Arctic Climate Impact Assessment

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## Contents

*I have heard it said by many Russians that their climate also is ameliorating! Will God, then, … give them up even the sky and the breeze of the South? Shall we see Athens in Lapland, Rome at Moscow, the riches of the Thames in the Gulf of Finland, and the history of nations reduced to a question of latitude and longitude?*
Astolphe de Custine, 14 July 1839 de Custine, 2002

## 1.1. Introduction

The *Arctic Climate Impact Assessment* (ACIA) is the first comprehensive, integrated assessment of climate change and ultraviolet (UV) radiation across the entire Arctic region. The assessment had three main objectives:

1. To provide a comprehensive and authoritative scientific synthesis of available information about observed and projected changes in climate and UV radiation and the impacts of those changes on ecosystems and human activities in the Arctic. The synthesis also reviews gaps in knowledge and the research required to fill those gaps. The intended audience is the international scientific community, including researchers and directors of research programs. The *ACIA Scientific Report* fulfills this goal.
2. To provide an accessible summary of the scientific findings, written in plain language but conveying the key points of the scientific synthesis. This summary, the *ACIA Overview Report* (ACIA, 2004a), is for policy makers and the general public.
3. To provide policy guidance to the Arctic Council to help guide the individual and collective responses of the Arctic countries to the challenges posed by climate change and UV radiation. The *ACIA Policy Document* (ACIA, 2004b) accomplishes this task.

An assessment of expected impacts is a difficult and long-term undertaking. The conclusions presented here, while as complete as present information allows, are only a step – although an essential first step – in a continuing process of integrated assessment (e.g., Janssen, 1998). There are many uncertainties, including the occurrence of climate regime shifts, such as possible cooling and extreme events, both of which are difficult if not impossible to predict. New data will continue to be gathered from a wide range of approaches, however, and models will be refined such that a better understanding of the complex processes, interactions, and feedbacks that comprise climate and its impacts will undoubtedly develop over time. As understanding improves it will be possible to predict with increasing confidence what the expected impacts are likely to be in the Arctic.

This assessment uses the definition of the Arctic established by the Arctic Monitoring and Assessment Programme, one of the Arctic Council working groups responsible for the ACIA. Each of the eight arctic countries established the boundary in its own territory, and the international marine boundary was established by consensus. The definition of the arctic landmass used here is wider than that often used but has the advantage of being inclusive of landscapes and vegetation from northern forests to polar deserts, reflecting too the connections between the Arctic and more southerly regions. Physical, biological, and societal conditions vary greatly across the Arctic. Changes in climate and UV radiation are also likely to vary regionally, contributing to different impacts and responses at a variety of spatial scales. To strike a balance between over-generalization and over-specialization, four major regions were identified based on differences in large-scale weather- and climate-shaping factors. Throughout the assessment, differences in climate trends, impacts, and responses were considered across these four regions, to explore the variations anticipated and to illustrate the need for responses targeted to regional and local conditions. The four ACIA regions are shown in Fig. 1.1. There are many definitions of the Arctic, such as the Arctic Circle, treeline, climatic boundaries, and the zone of continuous permafrost on land and sea-ice extent on the ocean. The numerous and complex connections between the Arctic and lower latitudes make any strict definition nearly meaningless, particularly in an assessment covering as many topics and issues as this one. Consequently, there was a deliberate decision not to define the Arctic for the assessment as a whole. Each chapter of this report describes the area that is relevant to its particular subject, implicitly or explicitly determining its own southern boundary.

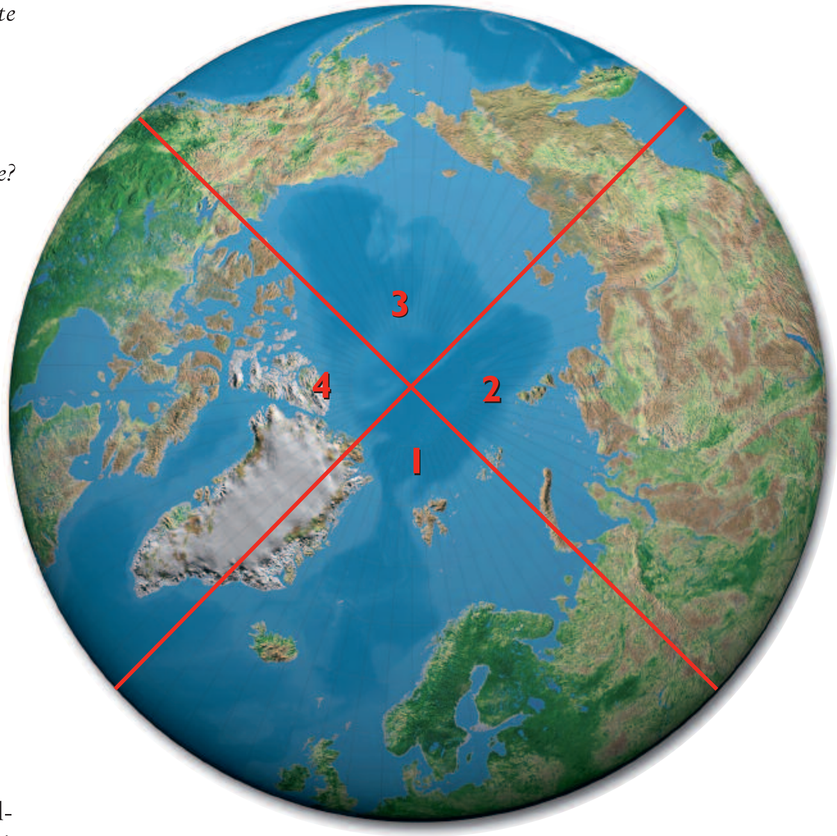


**Fig. 1.1.** The four regions of the Arctic Climate Impact Assessment.

## 1.2. Why assess the impacts of changes in climate and UV radiation in the Arctic?

### 1.2.1. Climate change

There are four compelling reasons to examine arctic climate change. First, the Arctic, together with the Antarctic Peninsula, experienced the greatest regional warming on earth in recent decades, due largely to various feedback processes. Average annual temperatures have risen by about 2 to 3 °C since the 1950s and in winter by up to 4 °C. The warming has been largest over the land areas (Chapman and Walsh, 2003; see also Figs. 1.2 and 1.3). There are also areas of cooling in southern Greenland, Davis Strait, and eastern Canada. The warming has resulted in extensive melting of glaciers (Sapiano et al., 1997), thawing of permafrost (Osterkamp, 1994), and reduction in extent of sea ice in the Arctic Ocean (Rothrock et al., 1999; Vinnikov et al., 1999). The warming has been accompanied by increases in precipitation, but a decrease in the duration of snow cover. These changes have been interpreted to be due at least in part to anthropogenic intensification of the global greenhouse effect, although the El Niño–Southern Oscillation and the inter-decadal Arctic Oscillation also affect the Arctic. The latter can result in warmer and wetter winters in its warm phases, and cooler, drier winters in its cool phases (see Chapter 2).

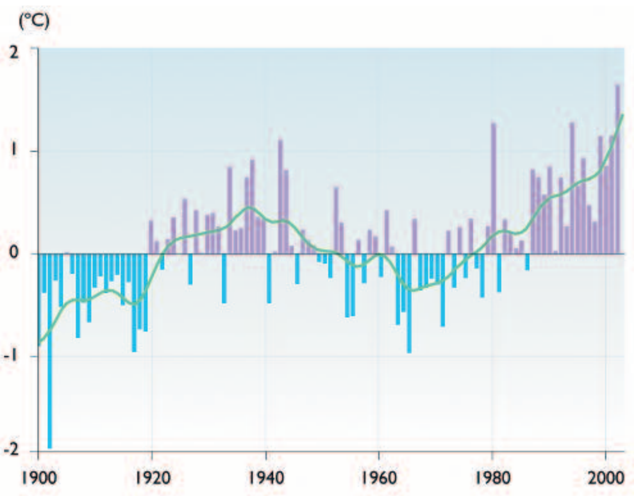



**Fig. 1.2.** Annual average near surface air temperature from stations on land relative to the average for 1961–1990, for the region from 60° to 90° N (updated from Peterson and Vose, 1997).

Second, climate projections suggest a continuation of the strong warming trend of recent decades, with the largest changes coming during winter months (IPCC, 1990, 1996, 2001a,b). For the B2 emissions scenario used by the Intergovernmental Panel on Climate Change (IPCC) and in the ACIA (see section 1.4.2), the five ACIA-designated general circulation models (GCMs; see section 1.4.2) project an additional warming in the annual mean air temperature of approximately 1 °C by 2020, 2 to 3 °C by 2050, and 4 to 5 °C by 2080; the three time intervals considered in this assessment (see Figs. 1.4 and 1.5). Within the Arctic, however, the models do show large seasonal and regional differences; in fact, the differences between individual models are greatest in the polar regions (McAvaney et al., 2001). The reduction in or loss of snow and ice has the effect of increasing the warming trend as reflective snow and ice surfaces are replaced by darker land and water surfaces that absorb more solar radiation. At one extreme, for example, the model of the Canadian Centre for Climate Modelling and Analysis projects near-total melting of arctic sea ice by 2100. Large winter warming in the Arctic is likely to accelerate already evident trends of a shorter snow season, retreat and thinning of sea ice, thawing of permafrost, and accelerated melting of glaciers.

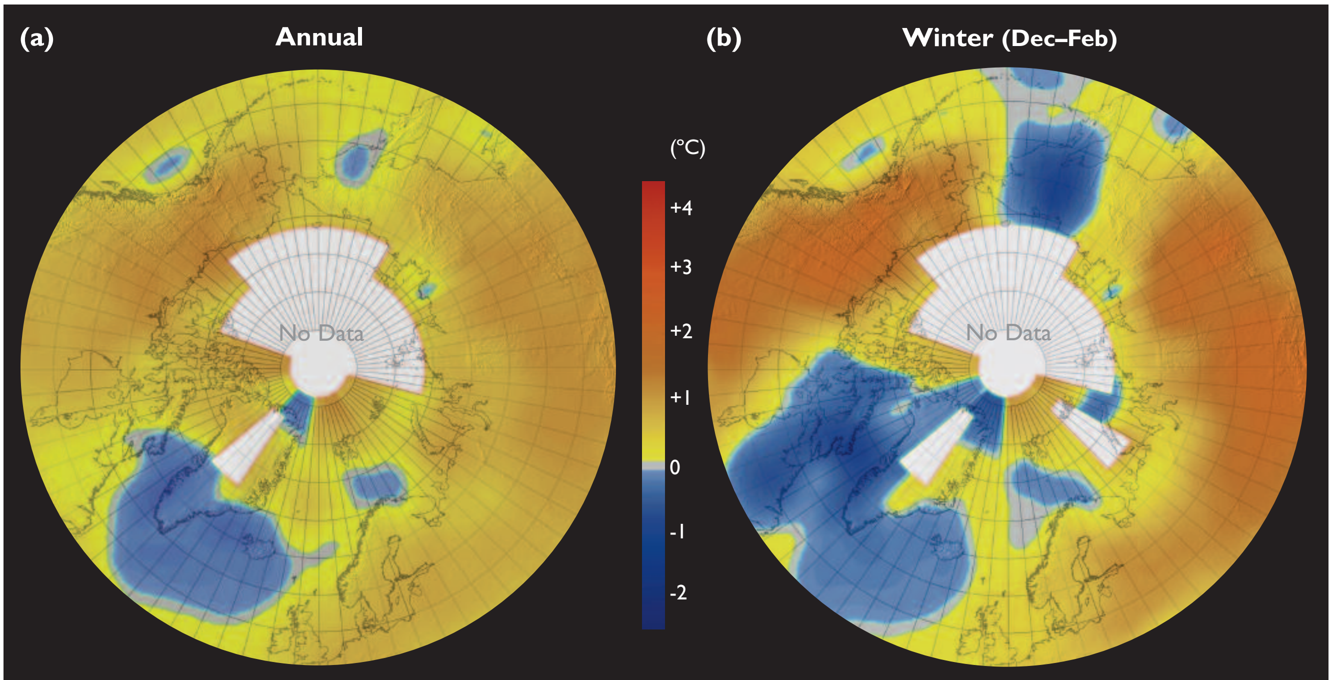



**Fig. 1.3.** Change in observed surface air temperature between 1954 and 2003: (a) annual mean; (b) winter (Chapman and Walsh, 2003, using data from the Climatic Research Unit, University of East Anglia, www.cru.uea.ac.uk/temperature).

Third, the changes seen in the Arctic have already led to major impacts on the environment and on economic activities (e.g., Weller, 1998). If the present climate warming continues as projected, these impacts are likely to increase, greatly affecting ecosystems, cultures, lifestyles, and economies across the Arctic (see Chapters 10 to 17). On land, the ecosystems range from the ecologically more productive boreal forest in the south to the tundra meadows and unproductive barrens in the High Arctic (Fig. 1.6). Reindeer herding and, to a lesser extent, agriculture are among the economic activities in terrestrial areas. Tourism is an increasing activity throughout the region. Some of the world's largest gas, oil, and mineral deposits are found in the Arctic. In the marine environment, the Bering Sea, North Atlantic Ocean, and Barents Sea have some of the most productive fisheries in the world (Weller and Lange, 1999). As this assessment makes clear, all these systems and the activities they support are vulnerable to climate change.

In the Arctic there are few cities and many rural communities. Indigenous communities throughout the Arctic depend on the land, lakes and rivers, and the sea for food and income and especially for the vital social and cultural importance of traditional activities. The cultural diversity of the Arctic is already at risk (Freeman, 2000; Minority Rights Group, 1994), and this may be exacerbated by the additional challenge posed by climate change. The impacts of climate change will occur within the context of the societal changes and pressures that arctic indigenous residents are facing in their rapid transition to the modern world. The imposition of climate change from outside the region can also be seen as an ethical issue, in which people in one area suffer the consequences of actions beyond their control and in which beneficial opportunities may accrue to those outside the region rather than those within.

Fourth, climate change in the Arctic does not occur in isolation. The Arctic is an important part of the global climate system; it both affects and is affected by global climate change. Changes in climate in the Arctic, and in the environmental parameters such

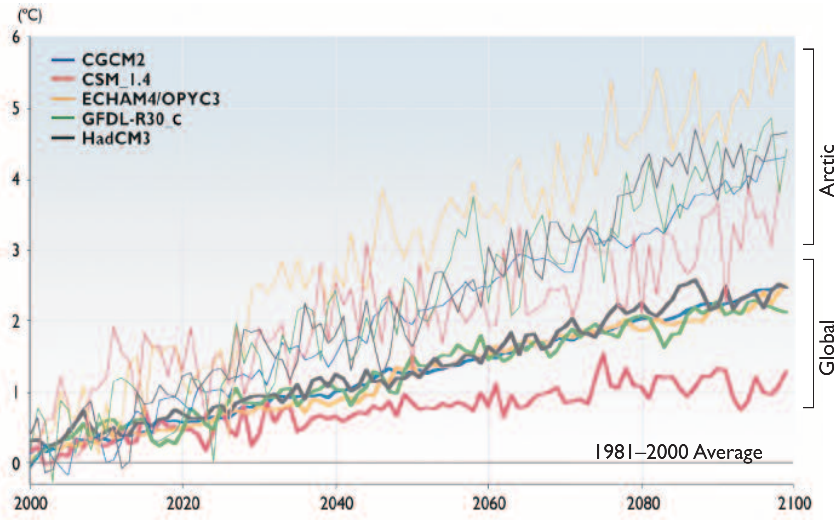



**Fig. 1.4.** Average surface air temperatures projected by the five ACIA-designated climate models for the B2 emissions scenario (see Chapter 4 for further details). The heavy lines are projected average *global* temperature increases and the thinner lines the projected average *arctic* temperature increases.

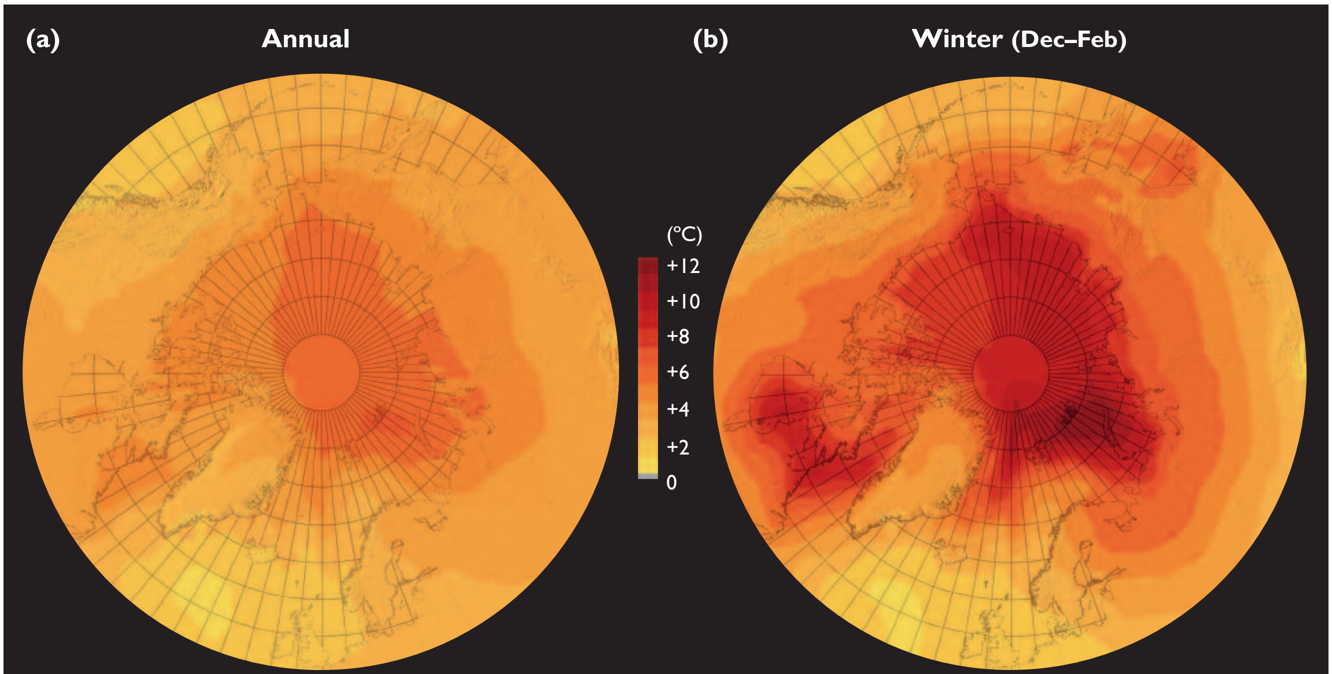



**Fig. 1.5.** (a) Projected annual surface air temperature change from the 1990s to the 2090s, based on the average change projected by the five ACIA-designated climate models using the B2 emissions scenario. (b) Projected surface air temperature change in winter from the 1990s to the 2090s, based on the average change projected by the five ACIA-designated climate models using the B2 emissions scenario.

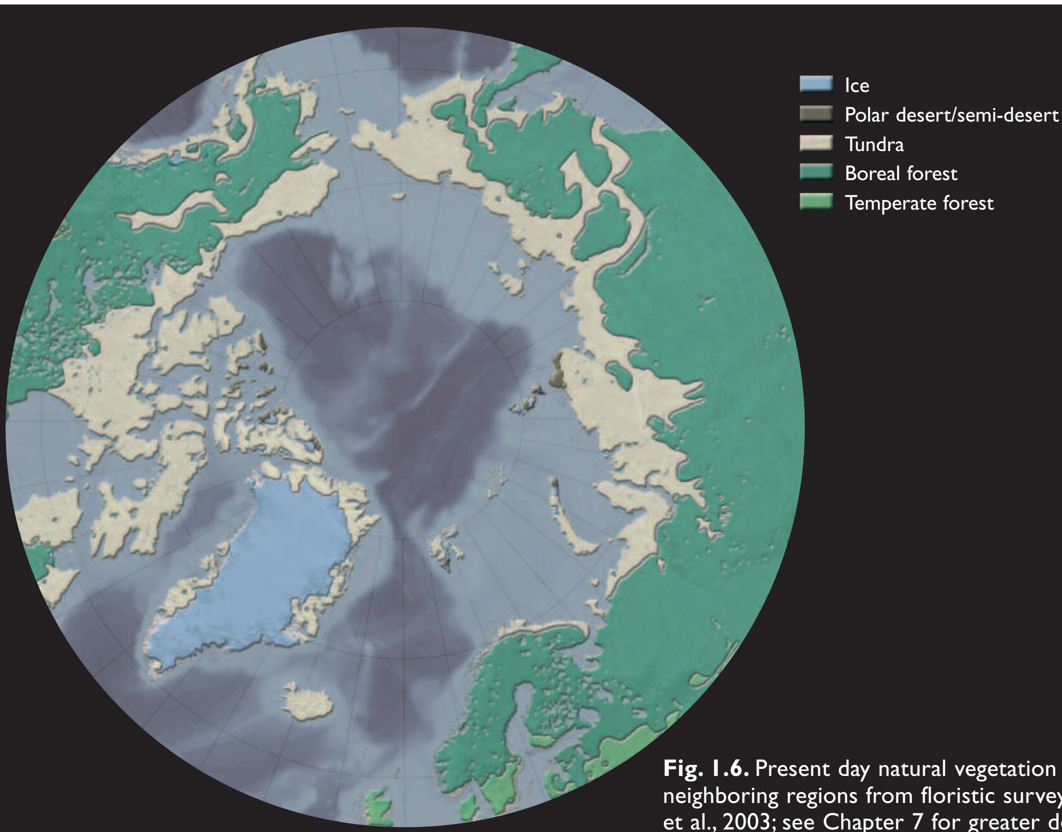



**Fig. 1.6.** Present day natural vegetation of the Arctic and neighboring regions from floristic surveys (based on Kaplan et al., 2003; see Chapter 7 for greater detail).

as snow cover and sea ice that affect the earth's energy balance and the circulation of the oceans and the atmosphere, may have profound impacts on regional and global climates. Understanding the role of the Arctic and the implications of projected changes and their feedbacks, regionally and globally, is critical to assessing global climate change and its impacts. Furthermore, migratory species provide a direct biological link between the Arctic and lower latitudes, while arctic resources such as fish and oil play an economic role of global significance. Impacts on any of these may have global implications.

### 1.2.2. UV radiation

The case for assessing UV radiation is similarly compelling. Stratospheric ozone depletion events of up to 45% below normal have been recorded recently in the Arctic (Fioletov et al., 1997). Dramatic change in the thickness of the stratospheric ozone layer and corresponding changes in the intensity of solar UV radiation were first observed in Antarctica in the mid-1980s. The depletions of ozone were later found to be the result of anthropogenic chemicals such as chlorofluorocarbons reaching the stratosphere and destroying ozone. Ozone depletion has also been observed in the Arctic in most years since 1992. Owing to global circulation patterns, the arctic stratosphere is typically warmer and experiences more mixing than the antarctic stratosphere. The ozone decline is therefore more variable in the Arctic. For example, severe arctic ozone depletions were observed in most of the last ten springs, but not in 2002 owing to early warming of the stratosphere.

Although depletion of stratospheric ozone was expected to lead to increased UV radiation at the earth's surface, actual correlations have become possible only recently because the period of instrumental UV measurement is short. Goggles found in archaeological remains in the Arctic indicate that UV radiation has been a fact of human life in the Arctic for millennia. In recent years, however, UV radiation effects, including sunburn and increased snow blindness, have been reported in regions where they were not observed previously.

Future increases in UV-B radiation of 20 to 90% have been predicted for April for the period 2010 to 2020 (Taalas et al., 2000). Ultraviolet radiation can have a variety of harmful impacts on human beings, on plants and animals, and on materials such as paints, cloths, and plastics (Andrady et al., 2002). Ultraviolet radiation also affects many photochemical reactions, such as the formation of ozone in the lower atmosphere. In the Arctic, human beings and ecosystems have both adapted to the very low intensity of the solar UV radiation compared with that experienced at lower latitudes. The low intensity of UV radiation in the Arctic is a consequence of the sun never reaching high in the sky as well as the presence of the world's thickest ozone layer. The Arctic as a whole may therefore be particularly susceptible to increases in UV radiation.

Other factors that affect the intensity of UV radiation include cloudiness and the amount of light reflected by the surface. Climate change is likely to affect atmospheric circulation as well as cloudiness and the extent and duration of snow and ice cover, which in turn will

affect UV radiation. Thus, UV radiation is both a topic of concern in itself and also in relation to climate change (UNEP, 2003).

## 1.3. The Arctic Climate Impact Assessment

### 1.3.1. Origins of the assessment

The idea to conduct an assessment of climate and UV radiation in the Arctic grew from several initiatives in the 1990s. The International Arctic Science Committee (IASC) had been engaged in climate studies since it was founded in 1991, and conducted regional arctic impact studies throughout the 1990s. The Arctic Monitoring and Assessment Programme (AMAP) also conducted a preliminary assessment of climate and UV impacts in the Arctic, which was published in 1998. The need for a comprehensive and circum-Arctic climate impact study had been discussed by IASC for some time, and IASC invited AMAP and CAFF (Conservation of Arctic Flora and Fauna) to participate in a joint venture. A joint meeting between the three groups was held in April 1999 and the IASC proposal was used as the basis for discussion. A revised version of the proposal was then submitted to the Arctic Council and the IASC Council for approval. A joint project between the Arctic Council and IASC – the Arctic Climate Impact Assessment – was formally approved by the Arctic Council at its meeting in October 2000.

In addition to the work of the groups responsible for its production, the ACIA builds on several regional and global climate change assessments. The IPCC has made the most comprehensive and best-known assessment of climate change on a global basis (e.g., IPCC, 2001a,b), and has provided many valuable lessons for the ACIA. In addition, regional studies have examined, among other areas, Canada (Maxwell, 1997), the Mackenzie Basin (Cohen 1997a,b), the Barents Sea (Lange and the BASIS Consortium, 2003; Lange et al., 1999), and Alaska (Weller et al., 1999). (The results of these regional studies are summarized in Chapter 18.) Ozone depletion and UV radiation have also been assessed globally by the World Meteorological Organization (WMO, 2003) and the United Nations Environment Programme (UNEP, 2003). These assessments, and the research that they comprise, provide a baseline against which the findings of the ACIA can be considered.

### 1.3.2. Organization

The ACIA started in October 2000 and was completed by autumn 2004. Together, AMAP, CAFF, and IASC set up the organization for the ACIA, starting with an Assessment Steering Committee (ASC) to oversee the assessment. The members of the ASC included a chair, vice-chair, and executive director, all the lead authors for the ACIA chapters, several scientists appointed by the three sponsoring organizations, and three individuals appointed by the indigenous organizations in the Arctic Council. A subset of the ASC, the Assessment Integration Team, was created to coordinate the material in the various chapters and documents produced by the ACIA. The Arctic Council, including its Senior Arctic Officials, provided oversight through progress reports and documentation at all the Arctic Council meetings.

Funding was provided to the ACIA through direct and indirect support by each of the eight arctic nations. As the lead country for the ACIA, the United States provided financial support through the National Science Foundation and the National Oceanic and Atmospheric Administration, which allowed the establishment of an ACIA Secretariat at the University of Alaska Fairbanks. Contributions from the other arctic countries, as well as from the United Kingdom, supported the involvement of their citizens and provided in-kind support, such as hosting meetings and workshops.

Much of the credibility associated with an assessment comes from the reputation of the authors, who are well-recognized experts in their fields of study. Broad participation of experts from many different disciplines and countries in the writing of the ACIA documents was established through an extensive nomination process. From these nominations, the ASC selected lead and contributing authors for each chapter of the assessment. The chapters were drafted by around 180 lead and co-lead authors, contributing authors, and consulting authors from 12 countries, including all the arctic countries. The ultimate standard in any scientific publication is peer review. The scientific chapters of the ACIA were subject to a rigorous and comprehensive peer review process, which included around 200 reviewers from 15 countries.

### 1.3.3. Terminology of likelihood

Discussion of future events and conditions must take into account the likelihood that these events or conditions will occur. Often, assessments of likelihood are qualitative or cover a range of probabilities. To avoid confusion and to promote consistent usage, the ACIA has adapted a lexicon of terms from the US National Assessment Team (NAST, 2000) describing the likelihood of expected change. The stated likelihood of particular impacts occurring is based on expert evaluation of results from multiple lines of evidence including field and laboratory experiments, observed trends, theoretical analyses, and model simulations. Judgments of likelihood are indicated using a five-tier lexicon (see Fig. 1.7) consistent with everyday usage. These terms are similar to those used by the IPCC, though somewhat simplified, and are used throughout the ACIA.


**Fig. 1.7.** Five-tier lexicon describing the likelihood of expected change.

## 1.4. The assessment process

### 1.4.1. The nature of science assessment

The ACIA is a "science assessment" in the tradition of other major international assessments of current environmental issues. For example, the IPCC, the international body mandated to assess the relevant information for understanding the risk of human-induced climate change, recently released its Third Assessment Report (IPCC, 2001a,b). The WMO and UNEP jointly released their latest assessments of the issue of stratospheric ozone depletion (WMO, 2003; UNEP, 2003). Two Arctic Council working groups, AMAP and CAFF, have also recently completed science assessments of, respectively, pollution and biodiversity in the circumpolar Arctic (AMAP, 2002, 2003a,b, 2004a,b,c; CAFF, 2001). All of these, and indeed all other assessments, have in common the purpose of providing scientific advice to decision makers who need to develop strategies regarding their respective areas of responsibility. The ACIA responds directly to the request of the Arctic Council for an assessment that can provide the scientific basis for policies and actions.

The essence of a science assessment is to analyze critically and judge definitively the state of understanding on an issue that is inherently scientific in nature. It is a point-in-time evaluation of the existing knowledge base, highlighting both areas of confidence and consensus and areas of uncertainty and disagreement in the science. Another aim of an assessment is to stimulate research into filling emerging knowledge gaps and solving unresolved issues. A science assessment thus draws primarily on the available literature, rather than on new research. To be used within an assessment, a study must have been published according to standards of scientific excellence. (With regard to the incorporation of indigenous knowledge, see the discussion in section 1.4.3.) Publications in the open, peer-reviewed scientific literature meet this standard. Other resources, such as technical publications by government agencies, may be included if they have undergone review and are publicly available.

### 1.4.2. Concepts and tools in climate assessment

The arctic climate system is complex. The processes of climate and the ways in which various phenomena affect one another – the feedbacks in the system – are still not fully understood. Specific feedbacks are introduced by the cryosphere and, in particular, by sea ice with its complex dynamics and thermodynamics. Other complex features include the internal dynamics of the polar atmosphere, stratification of both the lower troposphere and the ocean, and phenomena such as the dryness of the air and multiple cloud layers. All these add to the challenge of developing effective three-dimensional models and constructing climate scenarios based on the outcome of such models (Randall et al., 1998; Stocker et al., 2001).

"Climate scenario" means a plausible representation of the future climate that is consistent with assumptions about future emissions of greenhouse gases and other pollutants (emissions scenarios) and with the current understanding of the effects that increased atmospheric concentrations of these components have on climate (IPCC-TGCIA, 1999). Correspondingly, a "climate-change scenario" is the difference between conditions under a future climate scenario and those of today's climate. Being dependent on a number of assumptions about future human activities and their impact on the composition of the atmosphere, climate and climate-change scenarios are not predictions, but plausible descriptions of possible future climates.

Selection of climate scenarios for impact assessments is always controversial and vulnerable to criticism (Smith et al., 1998). The following criteria are suggested (Mearns et al., 2001) for climate scenarios to be most useful to impact assessors and policy makers: (1) consistency with global warming projections over the period 1990 to 2100 ranging from 1.4 to 5.8 °C (IPCC, 2001a); (2) physical plausibility; (3) applicability in impact assessments, providing a sufficient number of variables across relevant temporal and spatial scales; (4) representativeness, reflecting the potential range of future regional climate change; and (5) accessibility. It is preferable for impact researchers to use several climate scenarios, generated by different models where possible, in order to evaluate a greater range of possible futures. Practical limitations, however, typically mean researchers can only work with a small number of climate scenarios.

One starting point for developing a climate change scenario is to select an emissions scenario, which provides a plausible projection of future emissions of substances such as greenhouse gases and aerosols. The most recent IPCC emissions scenarios used in model simulations are those published in the Special Report on Emissions Scenarios (SRES, Nakićenović et al., 2000). The SRES emissions scenarios were built around four basic paths of development that the world may take in the 21st century. It should be noted that no probabilities were assigned to the various SRES emissions scenarios.

During the initial stage of the ACIA process, to stay coordinated with current IPCC efforts, it was agreed that the ACIA should work from IPCC SRES emissions scenarios (Källén et al., 2001). At that time, most of the available or soon-to-be-available simulations that allowed their own uncertainties to be assessed used the A2 and B2 emissions scenarios (Cubasch et al., 2001):

- The *A2 emissions scenario* assumes an emphasis on economic development rather than conservation. Population is projected to increase continuously.
- The *B2 emissions scenario* differs in having a greater emphasis on environmental concerns than economic concerns. It has intermediate levels of economic growth and a population that, although continuously increasing, grows at a slower rate than that in the A2 emissions scenario.

Both A2 and B2 can be considered intermediate scenarios. For reasons of schedule and limitations of data storage, ACIA had to choose one as the central emissions scenario. B2 was chosen because at the time it had been more widely used to generate scenarios, with A2 as a plausible alternative as its use increased.

Once an emissions scenario is selected, it must be used in a climate model (atmosphere–ocean general circulation model, or AOGCM; those used in this assessment are coupled atmosphere-land-ice-ocean models) to produce a climate scenario. Considering the large and increasing number of models available, selecting the models and model outputs for the assessment was not a trivial matter. The IPCC (McAvaney et al., 2001) concluded that no single model can be considered "best" and that it is important to utilize results from a range of coupled models.

Initially, a set of the most recent and comprehensive AOGCMs whose outputs were available from the IPCC Data Distribution Centre were chosen. Later, this set was reduced to five AOGCMs (two European and three North-American) for practical reasons. The treatment of land surfaces and sea ice is included in all these models, but with varying degrees of complexity. The five ACIA-designated models and the institutes that run them are:

- CGCM2 (Canadian Centre for Climate Modelling and Analysis)
- CSM_1.4 (National Center for Atmospheric Research, USA)
- ECHAM4/OPYC3 (Max-Planck Institute for Meteorology, Germany)
- GFDL-R30_c (Geophysical Fluid Dynamics Laboratory, USA)
- HadCM3 (Hadley Centre for Climate Prediction and Research, UK).

In the initial phase of the ACIA, at least one simulation using the B2 emissions scenario and extending to 2100 was accomplished with each of the five ACIA-designated models. For climate change scenarios, the ACIA climate baseline is 1981–2000. Any differences from the more familiar IPCC baseline of 1961–1990 were small. Three 20-year time slices are the foci of the ACIA for the 21st century: 2011–2030, 2041–2060, and 2071–2090, corresponding to near-term, mid-term, and longer-term outlooks for climate change. A complete description and discussion of the modeling work under ACIA, as well as its limitations, are provided in Chapter 4.

Other types of scenario were also used by chapter authors or by the studies on which the chapters of the assessment are based. These include analogue scenarios of a future climate, based on past (instrumentally recorded) or paleo (geologically recorded) warm climates (i.e., temporal analogue scenarios) or current climates in warmer regions (i.e., spatial analogue scenarios). Although instrumental records provide relatively poor coverage for most of the Arctic, their use avoids uncertainties associated with interpreting other indicators, providing a significant advantage over other approaches. Overall, analogue scenarios were used widely in the ACIA, supplementing the scenarios produced by numerical models. No single impact model was used in the impacts chapters of the assessment; each chapter made use of its own approaches. Further work in this area might consider the need and ability to develop impact models that can be used to address the diversity of topics addressed in this assessment. Another need is for models and scenarios that are able to show more detailed regional and sub-regional variations and that can be used for local impact assessments.

### 1.4.3. Approaches for assessing impacts of climate and UV radiation

The study of climate and UV radiation involves detailed measurements of physical parameters and the subsequent analysis of results to detect patterns and trends and to create quantitative models of these trends and their interactions. As Chapters 2, 4, 5, and 6 show, this is not a trivial undertaking. The next step, using measurements and models to assess the likely impacts of changes in climate and UV radiation, is even more complex and uncertain. Ecosystems and societies are changing in ways great and small and are driven by many co-occurring factors regardless of variability in climate and UV radiation. Determining how changes in climate and UV radiation may affect dynamic systems relies on several sources of data and several approaches to analysis (see further discussion in Chapter 7).

Most experimental and empirical data can reveal how climate and UV radiation affect plants, animals, and human communities. Observational studies and monitoring can document changes in climate and UV radiation over time together with associated changes in the physical, biological, and social environment. The drawback to observational studies is that they are opportunistic and require that the correct parameters are tracked in a system in which change actually occurs. Establishing causal connections is harder, but can be done through studies of the physical and ecological processes that link environmental components. Experimental studies involve manipulations of small components of the environment, such as vegetation plots or streams. In these cases, the researcher determines the simulated climate or UV radiation change or changes, so there is great control over the conditions being studied. The drawback is that the range of climate and UV radiation conditions may not match that anticipated by various scenarios used for regional assessments, limiting the applicability of the experimental data to the assumptions of the particular assessment.

The use of analogues, as described at the end of the previous section, can help identify potential consequences of climate change. Looking at past climates and climate change events can help identify characteristic biota and how they change. Spatial analogues can be used to compare ecosystems that exist now with the ecosystems where similar climate conditions are anticipated in the future. A strength of analogues is that they enable an examination of actual changes over an ecosystem, rather than hypothetical changes or changes to small experimental sites. Their weakness is that perfect analogues cannot be found, making interpretation difficult because of the variety of factors that cannot be controlled.

For assessing impacts on societies, a variety of social and economic models and approaches can be used. Examining resilience, adaptation, and vulnerability (see further discussion in Chapter 17) offers a powerful means of understanding at least some of the dynamics and complexity associated with human responses to environmental and other changes. As with changes to the natural environment, examining societal dynamics can be achieved through models, observations, and the use of analogues.

These scientific approaches can be complemented by another source of information; indigenous and local knowledge[1]. This assessment makes use of such knowledge to an unprecedented degree in an exercise of this kind. Some extra attention to the topic is therefore warranted here. Indigenous residents of the Arctic have for millennia relied on their knowledge of the environment in order to provide food and other materials and to survive its harsh conditions. More recent arrivals, too, may have a wealth of local knowledge about their area and its environment. The high interannual variability in the Arctic has forced its residents to be adaptable to a range of conditions in climate and the abundance and distribution of animals. Although indigenous and local knowledge is not typically gathered for the specific purpose of documenting climate and UV radiation changes, it is nonetheless a valuable source of insight into environmental change over long periods and in great local detail, often covering areas and seasons in which little scientific research has been conducted. The review of documented information by the communities concerned is a crucial step in establishing whether the information contained in reports about indigenous and local knowledge reliably reflects community perspectives. This step of community review offers a similar degree of confidence to that provided by the peer-review process for scientific literature.

Determining how best to use indigenous knowledge in environmental assessments, including assessments of the impacts of climate and UV radiation, is a matter of debate (Howard and Widdowson, 1997; Stevenson, 1997), but the quality of information generated in careful studies has been established for many aspects of environmental research and management (e.g., Berkes, 1999; Huntington, 2000; Johannes, 1981). In making use of indigenous knowledge, several of its characteristics should be kept in mind. It is typically qualitative rather than quantitative, does not explicitly address uncertainty, and is more likely to be based on observations over a long period than on comparisons of observations taken at the same time in different locations. Identifying mechanisms of change can be particularly

[1]Many terms are used to refer to the type of knowledge referred to in this assessment as "indigenous knowledge". Among the terms in use in the literature are traditional knowledge, traditional ecological knowledge, local knowledge (often applied to the knowledge of non-indigenous persons), traditional knowledge and wisdom, and a variety of specific terms for different peoples, such as Saami knowledge or Inuit Qaujimajatuqangit. Within the context of this assessment, "indigenous knowledge" should be taken broadly, to include observations, interpretations, concerns, and responses of indigenous peoples. For further discussion see Chapter 3.

difficult. It is also important to note that indigenous knowledge refers to the variety of knowledge systems in the various cultures of the Arctic and is not merely another discipline or method for studying arctic climate.

Using more than one approach wherever possible can reduce the uncertainties inherent in each of these approaches. The ACIA has drawn on all available information, noting the limitations of each source, to compile a comprehensive picture of climate change and its impacts in the Arctic. Existing climate models project a wide range of conditions in future decades. Not all have been or can be studied empirically, nor can field studies examine enough sites to be fully representative of the range of changes across the Arctic. Instead, using data from existing studies to assess impacts from regional scenarios and models requires some extrapolation and judgment. In this assessment, the chapters addressing impacts may not be able to assess the precise conditions projected in the scenarios upon which the overall assessment is based. Instead, where necessary they will describe what is known and examine how that knowledge relates to the conditions anticipated by the scenarios.

## 1.5. The Arctic: geography, climate, ecology, and people

This section is intended for readers who are unfamiliar with the Arctic. Summaries and introductions to specific aspects of the Arctic can be found in reports published by AMAP (1997, 1998, 2002) and CAFF (2001), as well as the *Arctic Atlas* (State Committee of the USSR on Hydrometeorology and Controlled Natural Environments, 1985) published by the Arctic and Antarctic Research Institute in Russia. *The Arctic: Environment, People, Policy* (Nuttall and Callaghan, 2000) is an excellent summary of the present state of the Arctic, edited by two ACIA lead authors and with contributions from contributing ACIA authors.

### 1.5.1. Geography

The Arctic is a single, highly integrated system comprised of a deep, ice covered, and nearly isolated ocean surrounded by the land masses of Eurasia and North America, except for breaches at the Bering Strait and in the North Atlantic. It encompasses a range of land- and seascapes, from mountains and glaciers to flat plains, from coastal shallows to deep ocean basins, from polar deserts to sodden wetlands, from large rivers to isolated ponds. They, and the life they support, are all shaped to some degree by cold and by the processes of freezing and thawing. Sea ice, permafrost, glaciers, ice sheets, and river and lake ice are all characteristic parts of the Arctic's physical geography.

The Arctic Ocean covers about 14 million square kilometers. Continental shelves around the deep central basin occupy slightly more than half of the ocean's area – a significantly larger proportion than in any other ocean. The landforms surrounding the Arctic Ocean are of three major types: (1) rugged uplands, many of which were overrun by continental ice sheets that left scoured rock surfaces and spectacular fjords; (2) flat-bedded plains and plateaus, largely covered by deep glacial, alluvial, and marine deposits; and (3) folded mountains, ranging from the high peaks of the Canadian Rockies to the older, rounded slopes of the Ural Mountains. The climate of the Arctic, rather than its geological history, is the principal factor that gives the arctic terrain its distinctive nature (CIA, 1978).

### 1.5.2. Climate

The Arctic encompasses extreme climatic differences, which vary greatly by location and season. Mean annual surface temperatures range from 4 °C at Reykjavik, Iceland (64° N) and 0 °C at Murmansk, Russia (69° N) through -12.2 °C at Point Barrow, Alaska (71.3° N), -16.2 °C at Resolute, Canada (74.7° N), -18 °C over the central Arctic Ocean, to -28.1 °C at the crest of the Greenland Ice Sheet (about 71° N and over 3000 m elevation). Parts of the Arctic are comparable in precipitation to arid regions elsewhere, with average annual precipitation of 100 mm or less. The North Atlantic area, by contrast, has much greater average precipitation than elsewhere in the Arctic.

Arctic weather and climate can vary greatly from year to year and place to place. Some of these differences are due to the poleward intrusion of warm ocean currents such as the Gulf Stream and the southward extension of cold air masses. "Arctic" temperature conditions can occur at relatively low latitudes (52° N in eastern Canada), whereas forestry and agriculture can be practiced well north of the Arctic Circle at 69° N in Fennoscandia. Cyclic patterns also shape climate patterns, such as the North Atlantic Oscillation (Hurrell, 1995), which strongly influences winter weather patterns across a vast region from Greenland to Central Asia, and the Pacific Decadal Oscillation, which has a similar influence in the North Pacific and Bering Sea. Both may be related to the Arctic Oscillation (see Chapter 2).

## 1.5.3. Ecosystems and ecology

Although the Arctic is considered a single system, it is often convenient to identify specific ecosystems within that system. Such classifications are not meant to imply clear separations between these ecosystems. In fact, the transition zones between terrestrial, freshwater, and marine areas are often dynamic, sensitive, and biologically productive. Nonetheless, much scientific research, and indeed subsequent chapters in this assessment, use these three basic categories.

### 1.5.3.1. Terrestrial ecosystems

Species diversity appears to be low in the Arctic, and on land decreases markedly from the boreal forests to the polar deserts of the extreme north. Only about 3% (5900 species) of the world's plant species occur in the Arctic north of the treeline. However, primitive plant species of mosses and lichens are relatively abundant (Matveyeva and Chernov, 2000). Arctic plant diversity appears to be sensitive to climate. The temperature gradient that has such a strong influence on species diversity occurs over much shorter distances in the Arctic than in other biomes. North of the treeline in Siberia, for example, mean July temperature decreases from 12 to 2 ºC over 900 km. In the boreal zone, a similar change in temperature occurs over 2000 km. From the southern boreal zone to the equator, the entire change is less than 10 ºC (Chernov, 1995).

The diversity of arctic animals north of the treeline (about 6000 species) is similar to that of plants (Chernov, 1995). As with plants, the arctic fauna account for about 3% of the global total, and evolutionarily primitive species are better represented than advanced species. In general, the decline in animal species with increasing latitude is more pronounced than that of plants. An important consequence of this is an increase in dominance. "Super-dominant" species, such as lemmings, occupy a wide range of habitats and generally have large effects on ecosystem processes.

Many of the adaptations of arctic species to their current environments limit their responses to climate warming and other environmental changes. Many adaptations have evolved to cope with the harsh climate, and these make arctic species more susceptible to biological invasions at their southern ranges while species at their northern range limit are particularly sensitive to warming. During environmental changes in the past, arctic species have changed their distributions rather than evolving significantly. In the future, changes in the conditions in arctic ecosystems may affect the release of greenhouse gases to the atmosphere, providing a possibly significant feedback to climate warming although both the direction and magnitude of the feedback are currently very uncertain. Furthermore, vegetation type profoundly influences the water and energy exchange of arctic ecosystems, and so future changes in vegetation driven by climate change could profoundly alter regional climates.

### 1.5.3.2. Freshwater ecosystems

Arctic freshwater ecosystems are extremely numerous, occupying a substantial area of the arctic landmass. Even in areas of the Arctic that have low precipitation, freshwater ecosystems are common and the term "polar deserts" refers more to the impoverishment of vegetation cover than to a lack of groundwater. Arctic freshwater ecosystems include three main types: flowing water (rivers and streams), permanent standing water (lakes and ponds), and wetlands such as peatlands and bogs (Vincent and Hobbie, 2000). All provide a multitude of goods and services to humans and the biota that use them.

Flowing water systems range from the large, north-flowing rivers that connect the interiors of continents with the Arctic Ocean, through steep mountain rivers, to slow-flowing tundra streams that may contain water during spring snowmelt. The large rivers transport heat, water, nutrients, contaminants, sediment, and biota into the Arctic and together have a major effect on regional environments. The larger rivers flow throughout the year, but small rivers and streams freeze in winter. The biota of flowing waters are extremely variable: rivers fed mainly by glaciers are particularly low in nutrients and have low productivity. Spring-fed streams can provide stable, year-round habitats with a greater diversity of primary producers and insects.

Permanent standing waters vary from very large water bodies to small and shallow tundra ponds that freeze to the bottom in winter. By the time the ice melts in summer, the incoming solar radiation is already past its peak, so that the warming of lakes is limited. Primary production, by algae and aquatic mosses, decreases from the subarctic to the high Arctic. Zooplankton species are limited or even absent in arctic lakes because of low temperatures and low nutrient availability. Species abundance and diversity increase with the trophic status of the lake (Hobbie, 1984). Fish species are generally not diverse, ranging from 3 to 20 species, although species such as Arctic char (*Salvelinus alpinus*) and salmon (*Salmo salar*) are an important resource.

Wetlands are among the most abundant and productive aquatic ecosystems in the Arctic. They are ubiquitous and characteristic features throughout the Arctic and almost all are created by the retention of water above the permafrost. They are more extensive in the southern Arctic than the high Arctic, but overall, cover vast areas – up to 3.5 million $km^2$ or 11% of the land surface. Several types of wetlands are found in the Arctic, with specific characteristics related to productivity and climate. Bogs, for example, are nutrient poor and have low productivity but high carbon storage, whereas fens are nutrient rich and have high productivity. Arctic wetlands have greater biological diversity than other arctic freshwater ecosystems, primarily in the form of mosses and sedges. Together with lakes and ponds, arctic wetlands are summer home to hundreds of millions of migratory birds.

Arctic freshwater ecosystems are particularly sensitive to climate change because the very nature of their habitats results from interactions between temperature, precipitation, and permafrost. Also, species limited by temperature and nutrient availability are likely to respond to temperature changes and effects of UV radiation on dead organic material in the water column.

### 1.5.3.3. Marine ecosystems

Approximately two-thirds of the Arctic as defined by the ACIA comprises ocean, including the Arctic Ocean and its shelf seas plus the Nordic, Labrador, and Bering Seas. These areas are important components of the global climate system, primarily because of their contributions to deepwater formation that influences global ocean circulation. Arctic marine ecosystems are unique in having a very high proportion of shallow water and coastal shelves. In common with terrestrial and freshwater ecosystems in the Arctic, they experience strong seasonality in sunlight and low temperatures. They are also influenced by freshwaters delivered mainly by the large rivers of the Arctic. Ice cover is a particularly important physical characteristic, affecting heat exchange between water and atmosphere, light penetration to organisms in the water below, and providing a biological habitat above (for example, for seals and polar bears (*Ursus maritimus*)), within, and beneath the ice. The marginal ice zone, at the edge of the pack ice, is particularly important for plankton production and plankton-feeding fish.

Some of these factors are highly variable from year to year and, together with the relatively young age of arctic marine ecosystems, have imposed constraints on the development of ecosystems that parallel those of arctic lands and freshwaters. Thus, in general, arctic marine ecosystems are relatively simple, productivity and biodiversity are low, and species are long-lived and slow-growing. Some arctic marine areas, however, have very high seasonal productivity (Sakshaug and Walsh, 2000) and the sub-polar seas have the highest marine productivity in the world. The Bering and Chukchi Seas, for example, include nutrient-rich upwelling areas that support large concentrations of migratory seabirds as well as diverse communities of marine mammals. The Bering and Barents Seas support some of the world's richest fisheries.

The marine ecosystems of the Arctic provide a range of ecosystem services that are of fundamental importance for the sustenance of inhabitants of arctic coastal areas. Over 150 species of fish occur in arctic and subarctic waters, and nine of these are common, almost all of which are important fishery species such as cod. Arctic marine mammals escaped the mass extinctions of the ice ages that dramatically reduced the numbers of arctic terrestrial mammal species, but many are harvested. They include predators such as the toothed whales, seals, walrus, sea otters, and the Arctic's top predator, the polar bear. Over 60 species of migratory and resident seabirds occur in the Arctic and form some of the largest seabird populations in the world. At least one species, the great auk (*Pinguinus impennis*), is now extinct because of overexploitation.

The simplicity of arctic marine ecosystems, together with the specialization of many of its species, make them potentially sensitive to environmental changes such as climatic change, exposure to higher levels of UV radiation, and increased levels of contaminants. Concomitant with these pressures is potential overexploitation of some marine resources.

## 1.5.4. Humans

Some two to four million people live in the Arctic today, although the precise number depends on where the boundary is drawn. These people include indigenous peoples (Fig. 1.8) and recent arrivals, herders and hunters living on the land, and city dwellers with desk jobs.

Humans have occupied large parts of the Arctic since at least the last ice age. Archeological remains have been found in northern Fennoscandia, Russia, and Alaska dating back more than 12 000 years (e.g., Anderson, 1988; Dixon, 2001; Thommessen, 1996). In the eastern European Arctic, Paleolithic settlements have been recorded from as early as 40 000 years ago (Pavlov et al., 2001). In Eurasia and across the North Atlantic, groups of humans have moved northward over the past several centuries, colonizing new lands such as the Faroe Islands and Iceland, and encountering those already present in northern Fennoscandia and Russia and in western Greenland (Bravo and Sorlin, 2002; Huntington et al., 1998).

In the 20th century, immigration to the Arctic has increased dramatically, to the point where non-indigenous persons outnumber indigenous ones in many regions. The new immigrants have been drawn by the prospect of developing natural resources, from fishing to gold to oil (CAFF, 2001), as well as by the search for new opportunities and escape from the perceived and real constraints of their home areas. Social, economic, and cultural conflicts have arisen as a consequence of competition for land and resources (Freeman, 2000; Minority Rights Group, 1994; Slezkine, 1994) and the incompatibility of some aspects of traditional and modern ways of life (e.g., Huntington, 1992; Nuttall, 2000). In North America, indigenous claims to land and resources have been addressed to some


**Fig. 1.8.** Locations of indigenous peoples in the Arctic, showing affiliation to the Permanent Participants, the indigenous peoples' organizations that participate in the Arctic Council.

extent in land claim agreements, the creation of largely self-governed regions such as Nunavut and Greenland within nation states, and other political and economic actions. In Eurasia, by contrast, indigenous claims and rights have only recently begun to be addressed as matters of national policy (Freeman, 2000).

Many aspects of demography are also changing. Over the past decade, total population has increased rapidly in only three areas: Alaska, Iceland, and the Faroe Islands. Rapid declines in population have occurred across most of northern Russia, with lesser declines or modest increases in other parts of the North (see Table 1.1). Life expectancy has increased greatly across most of the Arctic in recent decades, but declined sharply in Russia in the 1990s. The prevalence of indigenous language use has decreased in most areas, with several languages in danger of disappearing from use. In some respects, the disparities between northern and southern communities in terms of living standards, income, and education are shrinking, although the gaps remain large in most cases (Huntington et al., 1998). Traditional economies based on local production, sharing, and barter, are giving way to mixed economies in which money plays a greater role (e.g., Caulfield, 2000).

Despite this assimilation on many levels, or perhaps in response to it, many indigenous peoples are reasserting their cultural identity (e.g., Fienup-Riordan et al., 2000; Gaski, 1997). With this activism comes political calls for rights, recognition, and self-determination. The response of arctic indigenous groups to the presence of long-range pollutants in their traditional foods is a useful illustration of their growing engagement with the world community. In Canada particularly, indigenous groups led the effort to establish a national program to study

**Table 1.1.** Country population data (data sources as in table notes).

| Country | Region | Total population | Indigenous population | Year of census/ estimate | Previous figure[a] | Previous indigenous figure[a] | Year of previous estimate |
|---|---|---|---|---|---|---|---|
| ALL | Arctic | 3494107 | | | 3885798 | | |
| USA | Alaska (excluding Southeast) | 553850 | 103000[b] | 2000 | 481054 | 73235 | 1990 |
| Canada | Total | 105131 | 59685 | 2001 | 106705 | | 1996 |
| | Yukon Territory | 28520 | 6540 | 2001 | 30766 | 6175 | 1996 |
| | Northwest Territories | 37100 | 18730 | 2001 | 39672 | 19000 | 1996 |
| | Nunavut | 26665 | 22720 | 2001 | 24730 | 20690 | 1996 |
| | Nunavik, Quebec | 9632 | 8750 | 2001 | 8715 | 7780 | 1996 |
| | Northern Labrador[c] | 3214 | 2945 | 2001 | 2822 | | 1996 |
| Denmark | Greenland | 56542 | 49813[d] | 2002 | 55419 | 48029[d] | 1994 |
| | Faroe Islands | 47300 | 0 | 2002 | 43700 | 0 | 1995 |
| Iceland | | 286275 | 0 | 2001 | 266783 | | 1994 |
| Norway | Finnmark, Troms, Nordland | 462908 | | 2002 | 468691 | | 1990 |
| | North of the Arctic Circle | | | | 379461 | 35000[e] | 1990 |
| Sweden | Norrbotten | 254733 | 10000[ef] | 2001 | 263735 | 6000[e] | 1990 |
| | North of the Arctic Circle | 62000[g] | | | 64000[g] | | 1990 |
| Finland | Lapland | 191768 | 4083[ei] | 2000 | 200000[h] | 4000[ei] | 1995 |
| Russia | Total | 1535600 | | 2002 | 1999711 | 67164[j] | 1989 |
| | Murmansk Oblast | 893300 | | 2002 | 1164586 | 1899[j] | 1989 |
| | Nenets Autonomous Okrug | 41500 | | 2002 | 53912 | 6468[j] | 1989 |
| | Yamalo-Nenets Autonomous Okrug | 507400 | | 2002 | 494844 | 30111[j] | 1989 |
| | Taimyr (Dolgano-Nenets) A.O. | 39800 | | 2002 | 55803 | 8728[j] | 1989 |
| | Sakha Republic (Arctic area) | [k] | | 2002 | 66632 | 3982[j] | 1989 |
| | Chukotka Autonomous Okrug | 53600 | | 2002 | 163934 | 15976[j] | 1989 |

Data sources: AMAP, 1998; US Census Bureau, 2002 (www.census.gov); Statistics Canada, 2002 (www12.statcan.ca); Statistics Greenland, 2002 (www.statgreen.gl); Faroe Islands Statistics, 2002 (www.hagstova.fo); Statistics Iceland, 2002 (www.statice.is); Statistics Norway, 2002 (www.ssb.no); Statistics Sweden, 2002 (www.scb.se); Statistics Finland, 2002 (www.stat.fi); State Committee for Statistics, 2003 (www.eastview.com/all_russian_population_census.asp).

[a]Data from AMAP, 1998; [b]estimated by adding the number of Alaska Natives to a proportion of those listed as "mixed race" (calculated using the statewide figure for those of mixed race who are in part Alaska Native); [c]includes Davis Inlet, Hopedale, Makkovik, Nain, Postville, and Rigolet; [d]"indigenous" refers to people born in Greenland, regardless of ethnicity; [e]indigenous population is an estimate only; [f]estimate by the Saami Parliament for 1998 – the difference relative to the 1990 value probably reflects a difference in the method of estimate rather than an actual population increase; [g]estimate only, using the same percentage of the Norrbotten population in each case, rounded to the nearest thousand; [h]year of previous census/estimate unclear – population of Lapland reported as "slightly more than 200000"; [i]this value for the Saami population is for the four northernmost counties of Lapland (the "Saami Area"). There are an additional 3400 Saami elsewhere in Finland; [j]Indigenous figures refer only to the numerically-small peoples, i.e., not the Yakut, Komi, et al.; [k]for the districts of Anabarsk, Allaykhovsk, Bulun, Ust-Yansk, and Nizhnekolymsk.

contaminants, the results of which were used by those groups to advocate and negotiate international conventions to control persistent organic pollutants (Downie and Fenge, 2003). The arguments were often framed in terms of the rights of these distinct peoples to live without interference from afar. The use of international fora to make this case emphasizes the degree to which the indigenous groups think of themselves as participants in global, in addition to national, affairs.

At the same time that indigenous peoples are reaching outward, traditional hunting, fishing, herding, and gathering practices remain highly important. Traditional foods have high nutritional value, particularly for those adapted to diets high in fat and protein rather than carbohydrates (Hansen et al., 1998). Sharing and other forms of distributing foods within and between communities are highly valued, and indeed create a highly resilient adaptation to uncertain food supplies while strengthening social bonds (e.g., Magdanz et al., 2002). The ability to perpetuate traditional practices is a visible and effective way for many indigenous people to exert control over the pace and extent of modernization, and to retain the powerful spiritual tie between people and their environment (e.g., Fienup-Riordan et al., 2000; Ziker, 2002).

It is within this context of change and persistence in the Arctic today that climate change and increased UV radiation act as yet more external forces on the environment that arctic residents rely upon and know well. Depending on how these new forces interact with existing forces in each arctic society and each geographical region, the impacts and opportunities associated with climate change and UV radiation may be minimized or magnified (e.g., Hamilton et al., 2003). The degree to which people are resilient or vulnerable to climate change depends in part on the cumulative stresses to which they are subject through social, political, and economic changes in other aspects of their lives. It also depends in part on the sensitivity of social systems and their capacity for adaptation (see Chapter 17). The human impacts of climate change should be interpreted not in sweeping generalizations about the entire region, but as another influence on the already shifting mosaic that comprises each arctic community.

## 1.5.5. Natural resources and economics

In economic terms, the Arctic is best known as a source of natural resources. This has been true since the first explorers discovered whales, seals, birds, and fish that could be sold in more southerly markets (CAFF, 2001). In the 20th century, arctic minerals were also discovered and exploited, the size of some deposits of oil, gas, and metal ores more than compensating for the costs of operating in remote, cold regions (AMAP, 1998; Bernes, 1996). Military bases and other facilities were also constructed across much of the Arctic, providing employment but also affecting population distribution and local environments (e.g., Jenness, 1962). In recent decades, tourism has added another sector to the economies of many communities and regions of the Arctic (Humphries et al., 1998). The public sector, including government services and transfer payments, is also a major part of the economy in nearly all areas of the Arctic, responsible in some cases for over half the available jobs (Huntington et al., 1998). In addition to the cash economy of the Arctic, the traditional subsistence and barter economies are major contributors to the overall well-being of the region, producing significant value that is not recorded in official statistics that reflect only cash transactions (e.g., Schroeder et al., 1987; Weihs et al., 1993).

The three most important economic resources of the Arctic are oil and gas, fish, and minerals.

### 1.5.5.1. Oil and gas

The Arctic has huge oil and gas reserves. Most are located in Russia: oil in the Pechora Basin, gas in the lower Ob Basin, and other potential oil and gas fields along the Siberian coast. Canadian oil and gas fields are concentrated in two main basins in the Mackenzie Delta/Beaufort Sea region and in the Arctic Islands. In Alaska, Prudhoe Bay is the largest oil field in North America

and other fields have been discovered or remain to be discovered along the Beaufort Sea coast. Oil and gas fields also exist on Greenland's west coast and in Norway's arctic territories.

#### 1.5.5.2. Fish

Arctic seas contain some of the world's oldest and richest commercial fishing grounds. In the Bering Sea and Aleutian Islands, Barents Sea, and Norwegian Sea annual fish harvests in the past have exceeded two million tonnes, although many of these fisheries have declined (in 2001 fish catches in the Bering Sea totaled 1.6 million tonnes). Important fisheries also exist around Iceland, Svalbard, Greenland, and Canada. Fisheries are important to many arctic countries, as well as to the world as a whole. For example, Norway is the world's biggest fish exporter with exports worth four billion US dollars in 2001.

#### 1.5.5.3. Minerals

The Arctic has large mineral reserves, ranging from gemstones to fertilizers. Russia extracts the greatest quantities of these minerals, including nickel, copper, platinum, apatite, tin, diamonds, and gold, mostly on the Kola Peninsula but also in Siberia. Canadian mining in the Yukon and Northwest Territories and Nunavut is for lead, zinc, copper, diamonds, and gold. In Alaska lead and zinc deposits in the Red Dog Mine, which contains two-thirds of US zinc resources, are mined, and gold mining continues. The mining activities in the Arctic are an important contributor of raw materials to the world economy.



## 1.6. An outline of the assessment

This assessment contains eighteen chapters. The seventeen chapters that follow this introduction are organized into four sections: climate change and UV radiation change in the Arctic, impacts on the physical and biological systems of the Arctic, impacts on humans in the Arctic, and future steps and a synthesis of the ACIA.

### 1.6.1. Climate change and UV radiation change in the Arctic

The arctic climate is an integral part of the global climate, and cannot be understood in isolation. Chapter 2 describes the arctic climate system, its history, and its connections to the global system. This description lays the foundation for the rest of the treatment of climate in this assessment. Chapter 3 lays another essential foundation for the assessment by describing how climate change appears from the perspective of arctic indigenous peoples, a topic also included in other chapters. Chapter 4 describes future climate projections, developed through use of emissions scenarios of greenhouse gases, and climate modeling. Several modeling simulations of future climates were developed specifically for this assessment, and these are described in detail. Chapter 5 provides the counterpart to Chapters 2 and 4 on observations and future projections of UV radiation and ozone, and their effects. The causes and characteristics of ozone depletion are discussed, together with models for the further depletion and eventual recovery of the ozone layer following international action.

### 1.6.2. Impacts on the physical and biological systems of the Arctic

The primary impacts of climate change and increased UV radiation in the Arctic will be to its physical and biological systems. Chapter 6 describes the changes that have already been observed, and the impacts that are expected to occur in the frozen regions of the Arctic, including sea ice, permafrost, glaciers, and snow cover. River discharge and river and lake ice break-up and freeze-up are also discussed. Chapter 7 discusses impacts on the terrestrial ecosystems of the Arctic, drawing on extensive research, experimental data, observations, and indigenous knowledge. Biodiversity, risks to species, including displacements due to climate change, UV radiation effects, and feedback processes as the vegetation and the hydrological regime change are discussed. Chapter 8 examines freshwater ecosystems in a similar fashion, including a discussion of freshwater fisheries in the Arctic. Chapter 9 covers the marine systems of the

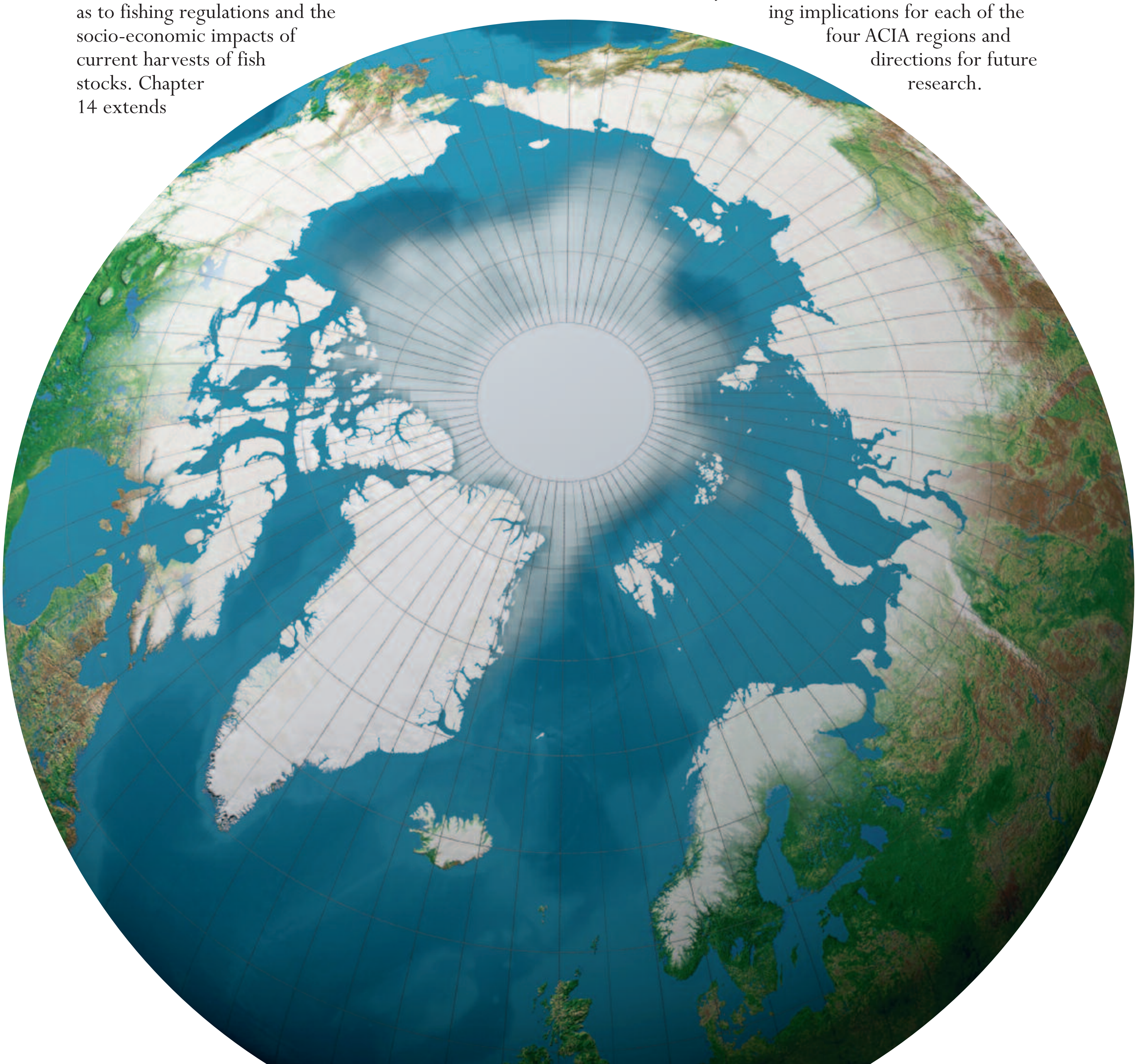
Arctic, and includes topics from the physical ocean regime, including the thermohaline circulation, to sea ice, coastal issues, fisheries, and ecosystem changes.

### 1.6.3. Impacts on humans in the Arctic

The implications of climate change and changes in UV radiation for humans are many and complex, both direct and indirect. Chapter 10 addresses the challenges to biodiversity conservation posed by climate change, especially given the relative paucity of data and the lack of circumpolar monitoring at present. Chapter 11 outlines the implications of climate change for wildlife conservation and management, a major concern in light of the substantial changes that are expected to impact upon ecosystems. Chapter 12 looks at traditional practices of hunting, herding, fishing, and gathering, which are also likely to be affected by ecosystem changes, as well as by changes in policies and society. Chapter 13 describes the commercial fisheries of the arctic seas, including seals and whales, with reference to climate as well as to fishing regulations and the socio-economic impacts of current harvests of fish stocks. Chapter 14 extends the geographic scope of the assessment to the northern boreal forest, examining both that ecosystem and the implications of climate change for agriculture and forestry. Chapter 15 discusses the implications of climate and UV radiation on human health, both for individuals and for communities in terms of public health and cultural vitality. Chapter 16 explores the ways in which climate may affect man-made infrastructure in the Arctic, both in terms of threats to existing facilities such as houses, roads, pipelines, and other industrial facilities, and of future needs resulting from a changing climate.

### 1.6.4. Future steps and a synthesis of the ACIA

Chapter 17 presents an innovative way of examining societal vulnerability to climate change. It gives some initial results from current research but primarily illustrates prospects for applying this approach more broadly in the future. Chapter 18 contains a synthesis and summary of the main results of the ACIA, including implications for each of the four ACIA regions and directions for future research.



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