BCS 100: Introduction to the Circumpolar North
University of the Arctic

MODULE 7 Climate Change (Part 2)

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7.6 Temperature and Precipitation Projections

The Intergovernmental Panel on Climate Change released projections for 21st century climate change in its Fourth Assessment Report (IPCC 2007) (Figure 16). The projections are based on outputs of global climate models (GCMs) that are based on fundamental fluid dynamics (physics) of the atmosphere; those models are used to forecast climates based on scenarios (Special Report on Emissions Scenarios, SRES) for a range of demographic, economic, and technological factors that will determine rates of greenhouse gas emissions. The models forecast a mean global temperature rise of about 0.2^{o}C per decade for the next two decades, and then varying rates of continued warming through the 21st century for the different scenarios. Warming over the 21st century is forecast to range from 0.6^{o}C if atmospheric CO_2 remains at year 2000 levels to 4.0^{o}C for the A1F1 scenario that assumes rapid economic growth, a population that peaks in mid-century, and continued high reliance on fossil fuels.

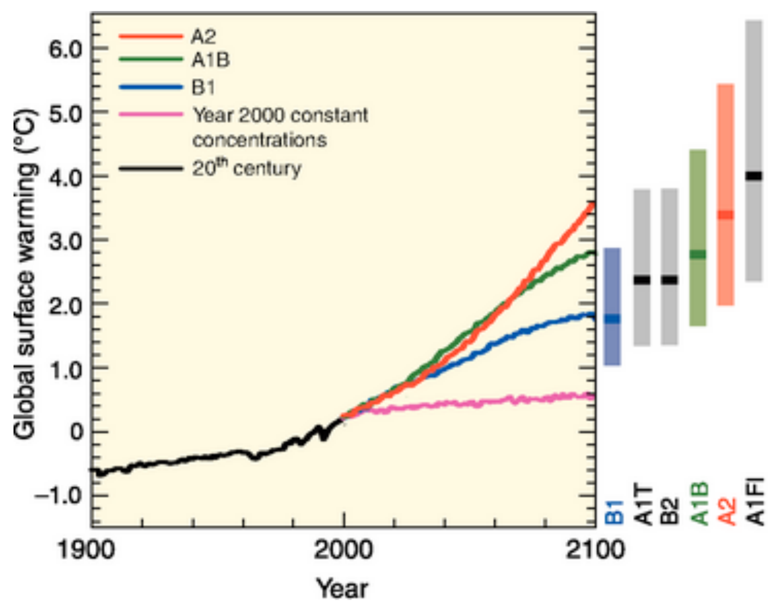


Figure 16 Solid lines are model projections of multi-model global averages (relative to the mean temperature during the 1980–1999 base period) for four of the six scenarios examined by the IPCC (2007). The orange line represents temperature change in the 21st century with atmospheric CO_2 maintained at the Year 2000 level. The bars represent the best estimate and ranges for all six scenarios. The A1 scenarios assume very rapid economic growth, a global population that peaks in mid-century, and rapid introduction of new and more efficient technologies. A1 includes three scenarios for different energy sources for technological change: fossil fuel intensive (A1F1), non-fossil fuel resources (A1T), and a balance of fossil fuels and non-fossil fuels (A1B). The B1 scenario assumes the same global population as A1 but with a conversion towards a service and

information economy. B2 assumes intermediate population and economic growth with local solutions to economic, social, and environmental sustainability. The A2 scenario is for a world with high population growth, slow economic development, and slow technological change. Further information about the scenarios can be found in the IPCC Special Report on Emissions Scenarios (IPCC, 2000).

Source: IPCC. (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Core Writing Team: Pachauri, R.K and Reisinger, A. (eds.). IPCC, Geneva, Switzerland, p. 7. www.ipcc.ch Open Source.

Warming is forecast to be greater over land than over the oceans and greater at high latitudes (Figure 17). Increases in the Arctic for the more conservative A1B scenario (economic growth, population that peaks in mid-century, and a blend of fossil fuel and non-fossil fuel energy sources) range from roughly 4°C to 7.5°C. Notably, actual greenhouse gas emissions for the first decade in the 21st century (2000–2009) have exceeded the projected emissions of the most extreme (A1F1) of the IPCC scenarios.

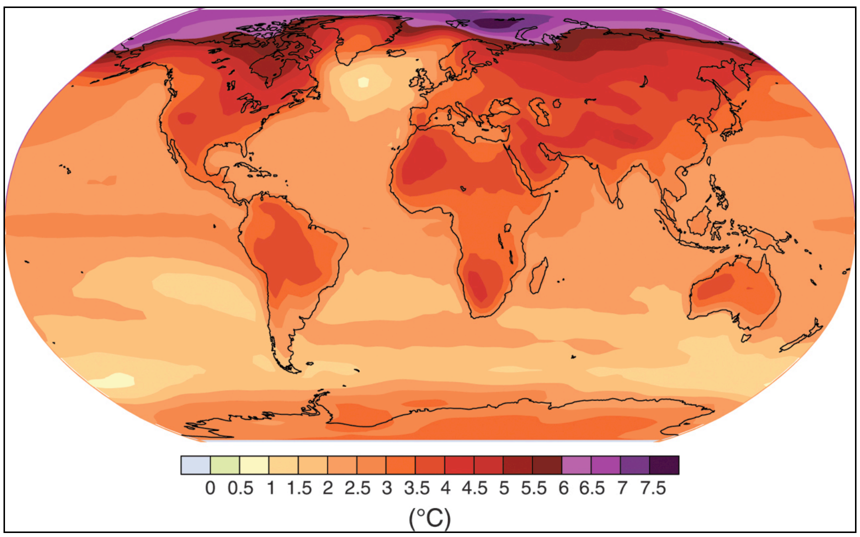


Figure 17 Projected mean surface temperature changes in 2090-2099 for the A1B IPCC scenario.

Source: IPCC. (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Core Writing Team: Pachauri, R.K and Reisinger, A. (eds.). IPCC, Geneva, Switzerland, p. 9. www.ipcc.ch Open Source.

A basic physical principle is that warmer air holds more moisture; eventually that moisture will fall to the ground as precipitation. Accordingly global precipitation will increase with rising temperatures. Global climate models predict a global precipitation increase over the next century with spatial patchiness and differences by latitude (Figure 18). Generally the subtropics are expected to get drier while high latitudes are expected to get wetter. Given the temperature rise, more precipitation will fall as rain. For the mid-range A1B scenario precipitation in the Arctic is forecast to rise as much as 20% by the end of this century compared to 1980–1999.

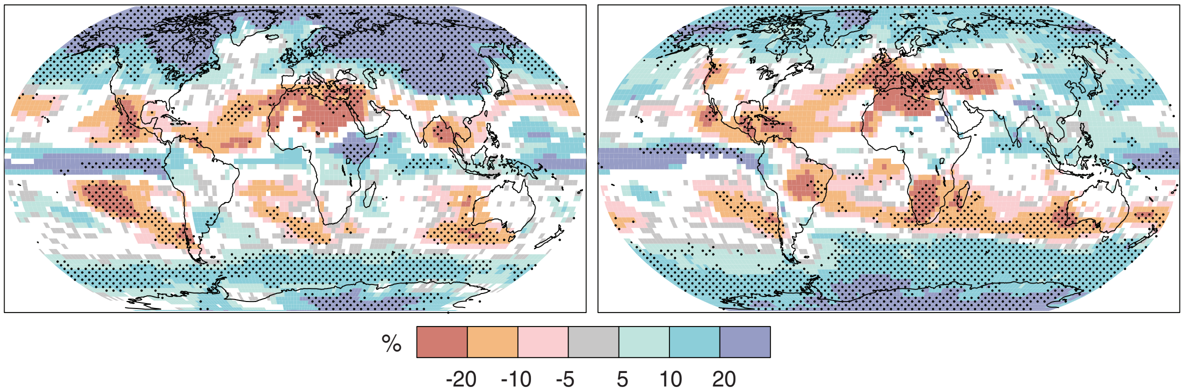


Figure 18: Projected changes in precipitation for 2090–2099 relative to 1980–1999. Values are the means of multiple models based on A1B scenario for December to February (left panel) and June to August (right panel). White represents areas where less than 66% of the models have the same sign (positive or negative) of change, stippling where more than 90% of models give the same sign of change.

Source: IPCC. (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Core Writing Team: Pachauri, R.K and Reisinger, A. (eds.). IPCC, Geneva, Switzerland, p. 47. www.ipcc.ch Open Source.

7.7 Biophysical and Societal Impacts of Climate Change

Arctic

The Arctic, because of its amplified warming, is undergoing fundamental changes in multiple systems – physical and biological – that are unprecedented over the past 10,000 years. In some cases, rapid changes (e.g., reduction in the summer extent of the polar ice sheet) have already been observed; in other cases, changes are slower (e.g., alteration of plant and animal species ranges) though they are still observable. Thus far, human societies in the North have shown relatively good resiliency to recent climate change though there are exceptions (e.g., impacts of rising sea levels on coastal native communities in Alaska). Consideration of the full extent of biophysical and social impacts of climate change is beyond the scope of this module. However, following is a brief summary of selected impacts that are important to the function of Arctic systems, culture, and quality of life.

Sea Level

Global sea level (now measured via satellite) rose at an average rate of 1.8 mm yr^{-1} during the period 1961-2003; the rate increased to 3.1 mm yr^{-1} from 1993 to 2003 (Figure 19) (IPCC 2007). The increase is due to thermal expansion of the ocean and the melting of land-based ice. Note that the melting of sea ice in the Arctic does not raise sea level: the water volume displaced by ice is the same as the volume displaced by the melt water. The total sea level increase during the 20th Century is estimated to be 0.17 m (Bindoff et al. 2007). Sea level rise has the potential to be one of the most damaging effects of climate change, and there is already evidence of damage to coastal towns, communities, and some island nations in the Pacific Ocean. In the Arctic, Inuvialuit in the Beaufort Delta area of the Northwest Territories, Canada (Griffiths 2007) and several communities (e.g., Shishmaref and Kivalina) along the northwest coast of Alaska have experienced increasing coastline erosion during storm events over the past few decades, and relocations of the towns inland are being planned. In contrast, shoreline rise (due to rebound resulting from reduction of glacial ice sheets) in many parts of the Arctic may exceed the rate of sea level rise (McBean et al. 2005). Effects of global sea level rise will vary regionally. The potential global sea level rise by 2100, based on the IPCC scenarios, is 0.5-1.4 m above 1990 levels (Rahmstorf 2007).

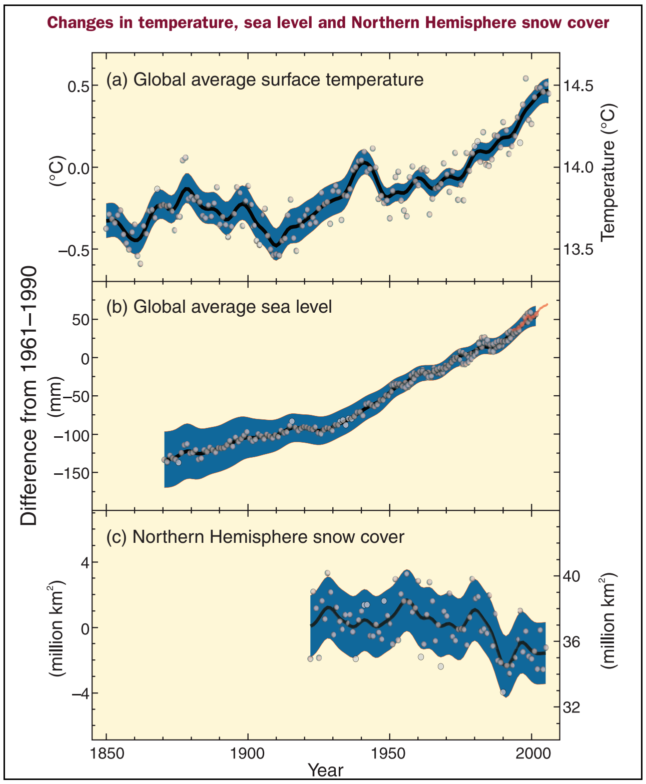


Figure 19: Observed changes in global average surface air temperature (°C), global average sea level (mm), and area of Northern Hemisphere snow cover in March to April relative to mean values for the period 1961-1990. The curves represent decadal averaged values, and white circles are yearly values. The blue shaded areas are uncertainty intervals.

Source: IPCC. (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Core Writing Team: Pachauri, R.K and Reisinger, A. (eds.). IPCC, Geneva, Switzerland, p. 31. www.ipcc.ch Open Source.

Arctic Sea Ice

Perhaps one of the most stunning changes in the Arctic during the past decade has been the rapid drop in the extent and thickness of Arctic sea ice (Figure 20). Since satellites began measuring Arctic ice extent in 1979, the minimum sea ice extent (normally reached in mid-September) has declined 8.7% per decade, or by roughly 72,000 km^2 per year (National Snow and Ice Data Center).

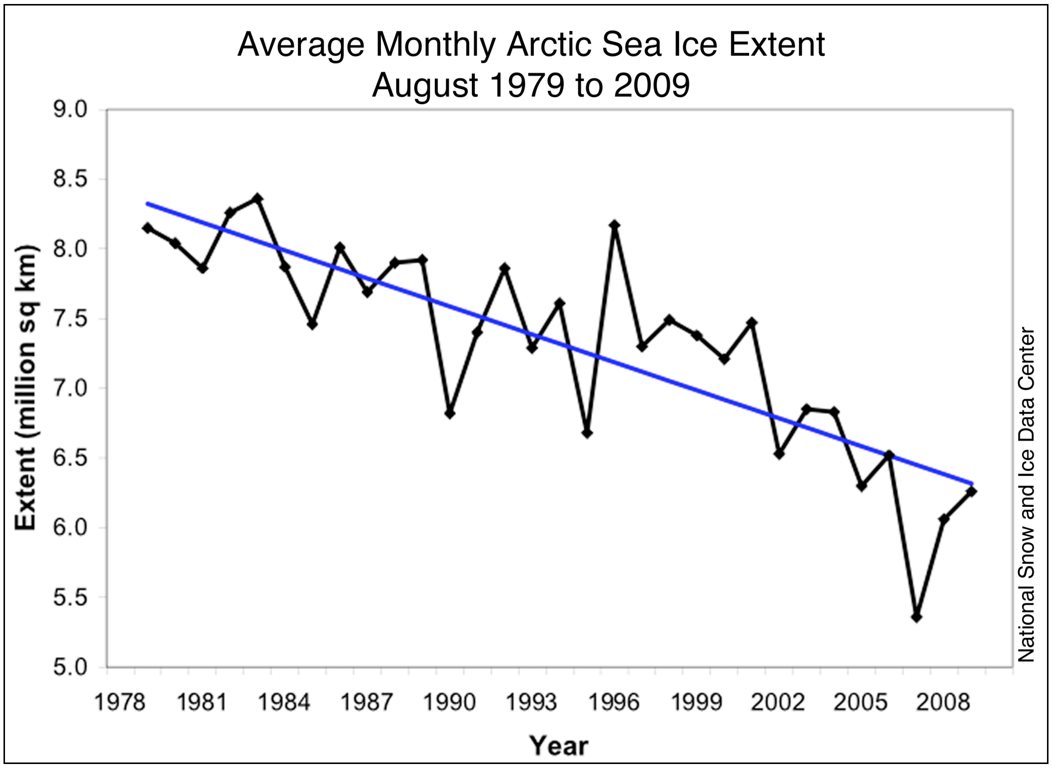


Figure 20: Mean monthly Arctic sea ice extent in August 1979–2009.

Source: National Snow and Ice Data Center http://nsidc.org **Open Source.**

Records to the early 1950s indicate a progressive decline in sea ice from the mid-1960s. Sea ice extent was likely lower in the 1930s and 1940s (the second most warm period in the Arctic in the 20th Century) but not as low as the extent in the past decade (National Snow and Ice Data Center). In addition to the reduction in ice extent, sea ice thickness in the Arctic has declined appreciably in the past 50 years (Kwok and Rothrock 2009). During the 1980-2008 period the mean Arctic winter sea ice thickness declined from 3.64 m to 1.89 m, or by 48%.

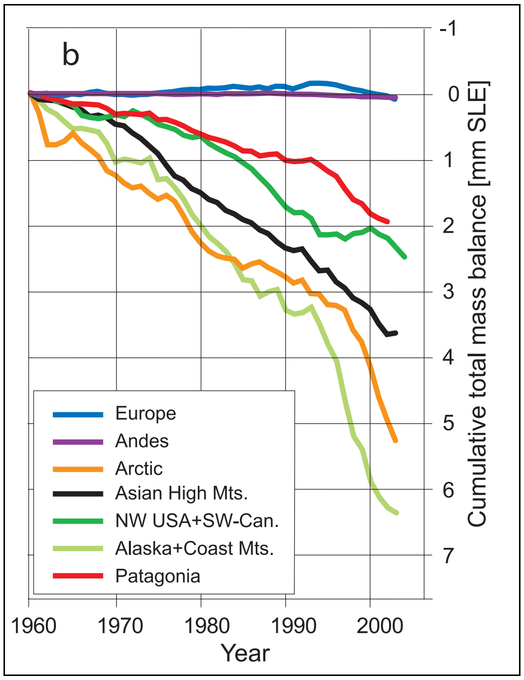
What has caused the decline in extent and thickness? Changes in atmospheric oscillation patterns (Arctic Oscillation and the North Atlantic Oscillation) were likely the strongest factors during most of the 20th Century. More recently, however, it is highly likely that rising Arctic temperatures from greenhouse gases are also a dominant factor as the Arctic and North Atlantic Oscillations have been in generally neutral phases since 1997. There are also indications that pulses of increasingly warm water from the North Atlantic are entering the Arctic Ocean. Additionally, warmer Pacific waters are entering the Beaufort Sea as have been tracked by Fisheries and Oceans, Canada. The decline in sea ice extent represents a positive feedback loop that should intensify climate change. As sea ice extent decreases, Arctic waters will absorb more heat and promote more ice melting. Scientists now forecast that the summer Arctic Ocean will likely be ice-free within the next 25-30 years (Kerr 2009b).

Positive and negative consequences are associated with the loss of sea ice. A positive effect is the opening of the fabled Northwest Passage (Canadian coast mainly) and the Northern Sea Route (NSR) or Northeast Passage (Russian coast) to commercial shipping; the routes will shorten the time and cost to ship goods from Asia to Europe and eastern North America. In the summer of 2009, for example, two German ships completed what is likely the first commercial shipping transit of the entire NSR from Asia to Europe (Kramer and Revkin, 2009). Negative effects of ice reduction include (1) loss of habitat for polar bears and marine mammals that depend on ice for breeding, refuge, and feeding, and (2) increasing difficulties for indigenous hunters who depend on ice for access to marine prey species. Potential consequences for the cultures of Arctic indigenous peoples that depend on sea ice are severe (Krupnik and Jolly 2002).

Glaciers, Snow Cover, and Permafrost

The extent and volume of glaciers are influenced by many factors including both snowfall and temperature. Glaciers may shrink because of reduced precipitation, higher temperatures, or both. Glaciers may grow if increased precipitation more than offsets loss due to melting. There are still considerable unknowns about the controls on glacier growth and shrinkage and the factors that determine rates of change. There are only roughly a dozen Arctic glaciers for which there is a record of glacier ice volume extending back more than 20 years (Walsh et al. 2005). While data on glaciers must be considered carefully, recent evidence indicates that most glaciers worldwide are getting smaller.

Mountain glaciers (with few exceptions) are retreating at all latitudes, with highest mass losses in Alaska, the northwest USA, Patagonia, and southwest Alaska (Figure 21) (Lemke et al. 2007). Forecasts indicate that those at tropical and mid-latitudes will be gone by 2050 (Pew Center on Global Climate Change 2009). The Greenland ice sheet, which makes up >80% of glacier ice volume in the Arctic, has been increasingly dynamic in the past few decades. Although glacier ice in central Greenland may have thickened, the total ice sheet volume has decreased due to higher rates of outlet glacier flow, iceberg calving, and summer melt (Lemke et al. 2007; Walsh et al. 2005). In Antarctica it appears that ice accumulation in the eastern part of the continent has been more than offset by mass losses of the West Antarctic ice sheets (Lemke et al. 2007). The Greenland and Antarctic ice sheets have high potential to raise sea level because (as predominantly land-based ice) they displace no ocean water.



Learning Activity 2: Interdisciplinary Study
Interview elders/people who have lived in your area for 20 years or more and ask them to describe if they have observed any changes in climate. Ask them if they are concerned about the effects of climate change.

Figure 21: Total mass balance (expressed as mm Sea Level Equivalent) for glaciers and ice caps. Lemke et al. 2007 (adapted from Dyurgeov and Meier 2005).

Source: IPCC. (2007). Lemke, P., J. Ren, R.B. Alley, I. Allison, J. Carrasco, G. Flato, Y. Fujii, G. Kaser, P. Mote, R.H. Thomas and T. Zhang, 2007: Observations: Changes in Snow, Ice and Frozen Ground. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.). Cambridge University Press, Cambridge, UK, p. 359. www.ipcc.ch Open Source.

Trends in snow cover extent and permafrost temperatures also are consistent with warming effects. Snow cover in the Northern Hemisphere from 1966–2005 has decreased in most regions as measured by satellite (Figure 19); snow cover in the Southern Hemisphere has either decreased or shown no change in the past 40 years or more (Lemke 2007). Permafrost, soil that remains frozen (<0^{o}C) for more than two years, is found extensively in the Arctic. Though the record of direct measurements is limited, permafrost temperatures in the Arctic have increased appreciably during the past 50 years (Walsh et al. 2005). Thawing permafrost has the potential to release methane (a greenhouse gas), damage roads and buildings, and alter terrestrial hydrology.

Biological Systems – Natural and Managed

Ecosystems have changed in the past as regional and global climates have changed. This is the first time, however, that there has been such rapid climate change on a global scale since humans emerged from the Paleolithic period. The degree to which people in the Arctic are affected will depend on how climate change affects local food supply (managed and wild), timber, transportation, development, and culture. Arctic plant and animal species are well adapted to harsh conditions and are likely to be poor competitors with the temperate-zone (lower latitude) species that move northward as the climate warms (Anisimov et al. 2007). Climate change is likely to have strongly negative effects on polar bears, walruses, seals, and other ice-dependent species (stressed by shrinking summer ice); generally positive effects on agriculture (longer growing seasons and northward shift of agricultural zones); and variable effects on fisheries, timber production, and wildlife. Tree lines and more temperate plant species will continue moving north, and the tundra biome (north to south) will be compressed. In some cases increased drought associated with warming will have a stronger effect on plant species distributions than higher temperatures. Climate-change impacts will include both negative and positive ones; how they compare will vary regionally and in magnitude, depending on the specific resource, cultural values, and economics. Climate change effects must also be placed in the context of other ecological stressors (e.g. land-use changes, resource extraction, and development). In any analysis it is important that climate change effects (positive or negative) are not exaggerated but also that they are not underestimated.

See **Appendix A** for sources of high quality information on climate change / how to evaluate the quality of climate change information.

People

As with physical and biological systems the impacts of climate change on peoples of the North will vary markedly by region and will include negative, neutral, and positive effects. Although impacts in some regions (e.g., coastal towns and villages at risk of rising sea level in western Alaska and in the Canadian Northwest Territories; changes in caribou migration patterns) will be severe, native peoples in other regions may adapt to climate changes (versus climate change) that in some cases may be positive (e.g. longer subsistence fishing seasons). Notably indigenous peoples today are usually more focused on job training, housing, health care, education, economic health, and cultural survival than on climate change (Simon 2007 and Griffiths 2007). There is wide variation in how people in the circumpolar North view climate change. Some Arctic natives regard climate change as a threat to their culture and ways of life, whereas others see a mixture of benefits and drawbacks (Gregoire, 2008; Krupnik and Jolly, 2002) or observe no change. Non-natives in the north and "southerners" also have mixed views of climate change though they generally have greater concern about negative consequences. We must not drift into what Griffiths (2007) calls a "crisis narrative," nor fail to prepare for the damaging aspects of climate change that will impair quality of life. Indeed, climate change will be one of the dominant issues (if not *the* dominant issue) influencing the Arctic and its peoples through the 21st century.

Study Questions

1. The British Isles and the East coast of the United States experienced one of the most severe winters in recent memory in late 2009/early 2010. Some American politicians cited this as compelling evidence that global warming is not occurring. Discuss this phenomenon in the context of climate and weather.

2. Explain the importance of oceans to global and regional climate change.

3. Compare the changes in global temperature differences during the period 1940–1970 with those in the more distant past.

4. Describe why it is difficult to generalize [Explain the challenges of the impacts of climate change in the Arctic.

5. Project the biophysical and societal effects of climate change in your area over the next 100 years.

Glossary

Aerosols: A gaseous suspension of fine solid or liquid particles.

Albedo: The degree to which a surface reflects light.

Climate: The meteorological conditions, including temperature, precipitation, and wind, that characteristically prevail in a particular region.

Earth's orbital cycles: Variations in the Earth's tilt, the pattern that the Earth circumscribes around the Sun, and the direction of the Earth's north-south axis that influence the distribution of solar radiation by latitude.

Energy balance: The arithmetic balancing of energy inputs versus outputs for an object, reactor, or other processing.

Feedback loops: A system that allows for feedback and self-correction and that adjusts its operation according to differences.

Greenhouse gases: Atmospheric gases that trap long wave radiation (heat) released from the Earth's surface, occur naturally and are released due to human activity.

Proxy data: Data such as tree rings and isotope concentrations in ice cores that are used to infer temperatures for periods that pre-date the period when thermometer measurements were made.

Radiative forcing factor: A factor that promotes climate warming or cooling.

Reflectivity: the fraction of radiant energy that is reflected from a surface.

Residence time: the duration of persistence of a mass or substance in a medium or place (such as the atmosphere).

Specific heat: The heat required to raise the temperature of one gram of a substance one degree centigrade.

Weather: The state of the atmosphere at a given time and place, with respect to variables such as temperature, moisture, wind velocity, and barometric pressure.

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APPENDIX A. SOURCES FOR HIGH QUALITY INFORMATION ON CLIMATE CHANGE/HOW TO EVALUATE THE QUALITY OF CLIMATE CHANGE INFORMATION.

Long-term climate change (over a decade or more) can be a difficult topic to understand and evaluate. Climate change is now a daily topic in the popular media (e.g., web sites, television, radio, blogs, and newspapers). The media often report stories that raise the level of controversy surrounding a topic (e.g., is global warming caused by humans?) without providing an informed analysis of the scientific evidence. Keeping up with the nuances of scientific disagreements about climate change is beyond the capability or interest of most laypeople. In most cases people decide what to "believe" or to side with one expert or another based on their assessment of the expert's credibility and whether information appears to be sound. An irony is that a non-scientist needs to trust that a scientific source provides accurate information, while the process of science encourages objective skepticism.

How can the non-scientist decide what information and sources are trustworthy? Here are some recommendations about different sources of information:

- **The media:** Information from the media can be suspect because the goal of journalists and reporters, with some exceptions, is not to "get the science right" but to publish a story that is newsworthy. When reading a media article consider the background and institutional affiliations of any scientists who are quoted. Information about the professional credentials and research background of any scientist should be available via a web search. Especially relevant is whether a quoted scientist actually conducts climate science research.

- **Books:** The reliability of information about climate science in books depends in part on whether the books are for a popular or academic audience. Popular books often take a point of view rather than a dispassionate objective examination of scientific facts and principles. Academic books should be quite accurate, but may not be easily understood without a background in the discipline. Some recent academic books (e.g., Asher and Rahmstorf, 2010) provide a superb grounding in climate change science and can be readily understood by a non-scientist. For either type of book (popular or academic) consider the publication date. The field of climate science is changing quickly. The basics of climate science haven't changed for decades, but knowledge about climate change (given the various factors that cause it and are affected by it) is growing and changing rapidly. Keep in mind that authors are paid by publishers, whose goal is to sell books.

- **Scientific articles:** These are generally the most reliable sources of information on climate change, though they are generally too advanced for someone without a science background or even for scientists outside the climate science discipline. Some journals (e.g., Science and Nature) provide in each issue a short profile, written in less technical language, of scientific articles in the issue that are regarded as having highest scientific impact.

- **Web sites:** Web sites not surprisingly can be problematic. The quality varies greatly and depends on who or what organization produces the site. Some, particularly web sites from government agencies (e.g., NASA, World Meteorological Organization, Environment Canada, United Nations Environment Program) are excellent. Other web sites contain erroneous and sometimes biased information (intentional or not). In all cases consider if a web site appears objective or politically motivated and if information sources are fully referenced.

Although judgment is always required in assessing the reliability of information, the preceding guidelines should help.

What are the best sources of information about climate change? The following are two of the most comprehensive and reliable sources that have gone through critical peer review and represent the consensus view of the most outstanding scientists across the globe:

- **Intergovernmental Panel on Climate Change (IPCC):** The IPCC developed from the World Meteorological Organization has released regular assessments on climate change and its impacts since 1990. The IPCC released its Fourth Assessment Report in 2007 and is now working on its Fifth Assessment. IPCC reports represent the most current, vetted state of knowledge and include extensive citations from the peer-reviewed literature. A notable feature of the more recent IPCC reports is that they provide the degree of uncertainty (virtually certain to exceptionally unlikely) about findings and forecasts. All IPCC reports (including figures) are freely available and can be downloaded from the IPCC web site (www.ipcc.ch). Importantly the IPCC does not conduct research, but instead evaluates and summarizes the scientific literature. The working group that summarized the physical basis for climate change (Working Group 1, WG1) in the most recent IPCC Assessment report (the fourth, abbreviated as AR4) included over 450 lead authors, 800 contributing authors, and over 2,500 reviewers from 130 countries; the authors and reviewers are international leaders in climate change science and include some that identify themselves as climate change “skeptics” (Trenberth 2010 www.cgd.ucar.edu/cas/trenbert.html). All comments from reviewers of the AR4 WG1 report, the Technical Summary, and the Summary for Policy Makers are archived at Harvard University and publically available (Trenberth 2010 www.cgd.ucar.edu/cas/trenbert.html). This author finds that the IPCC remains the most reliable source for the highest quality information on climate change.

- **Arctic Climate Impact Assessment (ACIA):** The ACIA report, published in 2005, is the first comprehensive and multi-disciplinary assessment of climate change and its impacts in the Arctic. The report includes not only the record of climate change but also effects on natural resources (fisheries, forestry, wildlife) and indigenous peoples. The ACIA report is freely downloadable from the ACIA web site (www.acia.uaf.edu).

Another excellent and recent report, though not going through the rigorous IPCC review process, is the Climate Change Science Compendium 2009 authored by the United Nations Environment Program (www.unep.org/compendium2009/). The report summarizes roughly 400 reports from the peer-reviewed scientific literature and research institutions published since the deadline of research reports considered for the IPCC Fourth Assessment. In addition to the IPCC, ACIA, and UNEP resources there are many government and university websites (including nations across the circumpolar north) with excellent information on climate change and its impacts. A sampling of recommended sites is shown in the following table:

Organization	Link
GRID – Arendale, Norway, United Nations Environment Program (UNEP)	www.grida.no
United Nations Environment Program	www.unep.org/compendium2009/
Met Office, Hadley Centre, UK National Weather Service	www.metoffice.gov.uk/
U.S. Global Change Research Program, U.S. Agencies (e.g., NASA and NOAA)	www.globalchange.gov/
Environment Canada	www.ec.gc.ca/default.asp?lang=En&n=2967C31D-1
Potsdam Institute for Climate Impact Research, Germany	www.pik-potsdam.de/
International Geosphere-Biosphere Program (funded by Swiss and U.S. National Science Foundations and the U.S. National Oceanic and Atmospheric Administration)	www.pages.unibe.ch/
The Yale Forum on Climate Change and the Media, Yale University	www.yaleclimatemediaforum.org/index.php

Media sources with well informed and objective articles on climate change include

- the BBC http://news.bbc.co.uk/
- the Guardian www.guardian.co.uk
- The Economist www.economist.co m
- The New York Times www.nytimes.com