CCSP Synthesis and Assessment Product 1.2

Past Climate Variability and Change in the Arctic and at High Latitudes

Chapter 3 — Preface: Why and How to Use This Synthesis and Assessment Report

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3.1 Introduction

The U.S. Climate Change Science Program (CCSP), a consortium of Federal agencies that investigate climate, has established a Synthesis and Assessment Program as part of its Strategic Plan. A primary objective of the CCSP is to provide the best science-based knowledge possible to support public discussion and government- and private-sector decisions about the risks and opportunities associated with changes in climate and in related environmental systems (U.S. Climate Change Science Program, 2007). The CCSP has identified an initial set of 21 Synthesis and Assessment Products (SAPs) that address the highest-priority research, observation, and information needed to support decisions about issues related to climate change. This assessment, SAP 1.2, focuses on the evidence for and record of past climate change in the Arctic. This SAP is one of 3 reports that address the climate-variability-and-change research element and Goal 1 of the CCSP Strategic Plan to improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.

The development of an improved understanding of natural, long-term cycles in climate is one of the primary goals of the climate research element and Goal 1 of the CCSP. The Arctic region of Earth, by virtue of its sensitivity to the effects of climate change through strong climate feedback mechanisms, has a particularly informative paleoclimate record. Because mechanisms operating in the Arctic and at high northern latitudes are also linked to global climate mechanisms, an examination of how Arctic climate has changed in the past is also globally informative.

3.2 Motivation for this Report

3.2.1 Why Does the Past Matter?

Paleoclimate records play a key role in our understanding of Earth's past and present climate system and in predicting future climate changes. Paleoclimate data help to elucidate past and present active mechanisms by permitting computer-based models to be tested beyond the short period (less than 250 years) of instrumental records. Paleo-records also provide quantitative estimates of the magnitude of the polar amplification of (more intense response to) climate change. These estimates can also be used to evaluate polar amplification derived from model simulations of past and future climate changes.

This important role of paleoclimate records is recognized, for example, by inclusion of paleoclimate as Chapter 6 of the 11-chapter Fourth Assessment Report of Working Group I (AR4-I) of the Intergovernmental Panel on Climate Change (IPCC), and by the extensive references to paleoclimatic data in climate change reports of the U.S. National Research Council, such as *Climate Change Science: An Analysis of Some Key Questions* (Cicerone et al., 2001).

The pre-instrumental context of Earth's climate system provided by paleodata strengthens the interlocking web of evidence that supports scientific results regarding climate change. For example, in considering whether fossil-fuel burning is an important contributor to the recent rise in atmospheric carbon-dioxide concentrations, researchers must determine and quantify global sources and sinks of carbon in Earth's overall carbon budget. But one can also ask whether the change of atmospheric carbon-dioxide concentrations observed in the instrumental record for the past 100 years falls inside or outside the range of natural variability as revealed in the paleo-record and, if inside, whether the timing of changes in carbon dioxide levels matches any known natural cycles that can explain them. Answers to such questions must come from paleoclimate data, because the instrumental record is much too short to characterize the full range of natural fluctuations.

Testing and validation of climate models requires the use of several techniques, as described in Chapter 8 of IPCC AR4-I (2007) The specific role of paleoclimate information is described there: “Simulations of climate states from the more distant past allow models to be evaluated in regimes that are significantly different from the present. Such tests complement the ‘present climate’ and ‘instrumental period climate’ evaluations, since 20th century climate variations have been small compared with the anticipated future changes under forcing scenarios derived from the IPCC *Special Report on Emission Scenarios* (SRES).”

3.2.2 Why the Arctic?

During the past century the planet has warmed, overall, by 0.74°C (0.56°–0.92°C) (IPCC, 2007). Above land areas in the Arctic, air temperatures have warmed as much as 3°C (exceeding 4°C in winter; Serreze and Francis, 2006) during the same period of time. Instrumental records indicate that in the past 30 years, average temperatures in the Arctic have increased at almost twice the rate of the planet as a whole. Attendant changes include reduced sea ice, reduced glacier extent, increased coastal erosion, changes in vegetation and wildlife habitats, and permafrost degradation. Global climate models incorporating the current trend of increasing greenhouse gases project continued warming in the near future and a continued amplification of global signals in the Arctic. . The sensitivity of the Arctic to changed forcing is due to powerful positive feedbacks in the Arctic climate system. These feedbacks produce large effects on Arctic climate while also having significant impacts on the global climate system.

This high degree of sensitivity makes the paleoclimate history of the Arctic especially informative when one considers the issue of modern climate change. Summaries of recent changes in the Arctic environment (e.g., Correll, 2004; Richter-Menge et al., 2006) are based primarily on observations and instrumental records. This report uses paleoclimate records to provide a longer-term context for recent Arctic warming; that context allows us to better understand the potential for future climate changes. Paleoclimate records provide a way to

- define the range of past natural variability in the Arctic and the magnitude of polar amplification,
- evaluate the past rates of Arctic climate change (and thereby provide a long-term context for current rates of change),
- identify past Arctic warm states that are potential analogs of future conditions,
- quantify the effects of abrupt perturbations (such as large injections of volcanic ash into the atmosphere) and threshold behaviors, and
- gain insights into how the Arctic has behaved during past warm times by identifying critical feedbacks and their mechanisms.

3.3 Focus and Scope of this Synthesis Report (Geographic and Temporal)

The content of this report follows from the prospectus developed early in its planning (this prospectus is available at the CCSP website, http://www.climatescience.gov), and it is focused on four topical areas in which the paleo-record can most strongly inform discussions of climate change. These topics, each addressed in a separate chapter of this synthesis report, are:

- The history of past changes in Arctic temperature and precipitation,
- Past rates of change in the Arctic,
- The paleo-history of the Greenland Ice Sheet, and
- The paleo-history of sea ice in the Arctic.

In general, the temporal scope of this report covers the past 65 million years (m.y.) from the early Cenozoic (65 Ma, million years ago) to the recent Holocene (today). Each chapter presents information in chronological sequence from oldest to youngest. The degree of detail in the report generally increases as one moves forward in time because the amount and detail of the available information increases as one approaches the present. The geographic scope of this report, although focused on the Arctic, includes some sub-Arctic areas especially in and near the North Atlantic Ocean in order to make use of many relevant paleo-records from these regions.

The specific questions posed in the report are as listed below:

1) How have temperature and precipitation changed in the Arctic in the past? What does this tell us about Arctic climate that can inform projections of future changes?

This report documents what is known of high-latitude temperature and precipitation during the past 65 million years at a variety of time scales, using sedimentary, biological, and geochemical **proxies**—indirect recorders—obtained largely from ice cores, lake sediment, and marine sediment but also from sediment found in river and coastal bluffs and elsewhere. Sedimentary deposits do not record climate data in the same way that a modern scientific observer does, but climatic conditions control characteristics of many sediments, so these sedimentary characteristics can serve as proxies for the climate that produced them (e.g., Bradley, 1999). (See Chapter 4 for a discussion of proxies.) Some of the many proxies routinely used are :

- the character of organic matter,
- the isotopic geochemistry of minerals or ice,
- the abundance and types of macrofossils and microfossils, and
- the occurrence and character of specific chemicals (biomarkers) that record the presence or absence of certain species and of the conditions under which those species grew.

Historical records taken from diaries, notebooks, and logbooks are also commonly used to link modern data with paleoclimate reconstructions.

The proxy records document large changes in the Arctic. As described in Chapter 5, comparison of Arctic paleoclimatic data with records from lower latitude sites for the same time period shows that temperature changes in the Arctic were greater than temperature changes elsewhere (changes were "amplified"). This Arctic amplification occurred for climate changes with different causes. Physical understanding shows that this amplification is a natural consequence of features of the Arctic climate system.

2) How rapidly have temperature and precipitation changed in the Arctic in the past? What do these past rates of change tell us about Arctic climate that can inform projections of future changes?

The climate record of Earth shows changes that operate on many time scales—tens of millions of years for continents to rearrange themselves, to weeks during which particles from a major volcanic eruption spread in the stratosphere and block the sun. This report summarizes paleoclimate data on past rates of change in the Arctic and subarctic on all relevant time scales, and it characterizes in particular detail the records of past abrupt changes that have had widespread effects. This section of the report has been coordinated with CCSP Synthesis and Assessment Product 3.4, the complete focus of which is on global aspects of abrupt climate change.

The data used to assess rates of change in chapter 6 are primarily the same as those used to assess the magnitudes of change in chapter 5. However, as discussed in chapter 5, the existence of high-time-resolution records that cannot always be synchronized exactly to other records, and additional features of the paleoclimatic record, motivate separate treatment of these closely related features of Arctic climate history.

Faster or less expected changes have larger effects on natural and human systems than do slower, better anticipated changes (e.g., National Research Council, 2002). Comparison of projected rates of change for the future (IPCC, 2007) with those experienced in the past can thus provide insights to the level of impacts that may occur.. Chapter 6 summarizes rates of Arctic change in the past, compares these with recent Arctic changes and to non-Arctic changes, and assesses processes that contribute to the rapidity of some Arctic changes.

3) What does the paleoclimate record tell us about the past size of the Greenland ice sheet and its implications for sea level changes?

Paleoclimate data allow us to reconstruct the size of the Greenland ice sheet at various times in the past, and they provide insight to the climatic conditions that produced those changes. This report summarizes those paleoclimate data and what they suggest about the mechanisms that caused past changes and might contribute to future changes.

An ice sheet leaves tracks—evidence of its passage—on land and in the ocean; those tracks show how far it extended and when it reached that extent, (e.g., Denton et al., 2005). On land, moraines (primarily rock material), which were deposited in contact with the edges of the ice, document past ice extents especially well. Beaches now raised out of the ocean following retreat of ice that previously depressed the land surface, and other geomorphic indicators, also preserve important information. Moraines and other ice-contact deposits in the ocean record evidence of extended ice; isotopic ratios of shells that grew in the ocean may reveal input of meltwater, and iceberg-rafted debris identified in sediment cores can be traced to source regions supplying the icebergs (e.g., Hemming, 2004). The history of ice thickness can be traced by use of moraines or other features on rock that projected above the level of the ice sheet, by the history of land rebound following removal of ice weight, and by indications (especially total gas content) in ice cores (Raynaud et al., 1997). Models can also be used to assimilate data from coastal sites and help constrain inland conditions. This report integrates these and other sources of information that describe past changes in the Greenland ice sheet.

Changes in glaciers and ice sheets, especially the Greenland ice sheet, have global repercussions. Complete melting of the Greenland ice sheet would raise global sea level by 7 meters (m); even partial melting would flood the world's coasts (Lemke et al., 2007). Freshwater from melting ice-sheets delivered to the oceans in sensitive regions—the North Atlantic Ocean, for example—could contribute to changes in extent of sea ice, ocean circulation, and climate and could produce strong regional and possibly global effects (Meehl et al., 2007).

4) What does the paleoclimate record tell us about past changes in Arctic sea ice cover, and what implications does this have for consideration of recent and potential future changes?

This report documents past periods when the extent of Arctic sea ice was reduced, and evaluates the scope, causes, and effects of these reductions (e.g., CAPE, 2006). The extent of past sea ice and patterns of sea-ice drift are recorded in sediments preserved on the sea floor. Sea-ice extent can also be reconstructed from fossil assemblages preserved in ancient beach deposits along many Arctic coasts (Brigham-Grette and Hopkins, 1995; Dyke et al., 1996).

Recent advances in tapping the Arctic paleoceanographic archives, notably the first deep-sea drilling in the central Arctic Ocean (Shipboard Scientific Party, 2005) and the 2005 Trans-Arctic Expedition (Darby et al., 2005), have provided new, high-quality material with which to identify and characterize warm, reduced-ice events of the past, which may serve as analogs for possible future conditions (e.g., Holland *et al*., 2006). Sea ice fundamentally affects the climate and oceanography of the Arctic (e.g., Seager et al., 2002), the ecosystems, and human use. The implications of reduced sea ice extend throughout the Arctic and beyond, and they bear on such issues as national security and search-and-rescue (National Research Council, 2007).

3.4 Report and Chapter Structure

This report is organized into five primary technical chapters. The first of these (Chapter 4) provides a conceptual framework for the information presented in the succeeding chapters, each of which focuses on one of the topics described above. Chapter 4 also contains information on the standardized use of time scales and geological terminology in this report.

Each of the topical chapters (Chapters 5 through 8) answers, in this order, the questions "Why, how, what, and so what?" The "Why" or opening introductory segment for each chapter outlines the relevance of the topic to the issue of modern climate change. The "How"' segment discusses the sources and types of data compiled to build the paleoclimate record and the strengths and weaknesses of the information. The "'What'" segment is the paleo-record information itself, presented in chronological order, oldest to most recent. The final "So what" segment discusses the significance of the material contained in the chapter and its relevance to current climate change. Each technical chapter is preceded by an abstract that outlines the principal conclusions contained in the body of the chapter itself. Bolded words in the text indicate entries in the technical glossary at the end of this report.

3.5 The Synthesis and Assessment Product Team

Four of the Lead Authors of this report were constituted as a Federal Advisory Committee (FAC) that was charged with advising the U.S. Geological Survey and the CCSP on the scientific and technical content related to the topic of the paleoclimate history of the Arctic as described in the SAP 1.2 prospectus. (See Public Law 92-463 for more information on the Federal Advisory Committee Act; see the GSA website http://fido.gov/facadatabase/ for specific information related to the SAP 1.2 Federal Advisory Committee.) The FAC for SAP 1.2 acquired input from more than 30 contributing authors in five countries. These authors provided substantial content to the report, but they did not participate in the Federal Advisory Committee deliberations upon which this SAP was developed.

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