

1 **CCSP Synthesis and Assessment Product 1.2**
2 **Past Climate Variability and Change in the Arctic and at High Latitudes**

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4 **Chapter 2 — Preface: Why and How to Use This Synthesis and Assessment**
5 **Report**

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16 **2.1 Introduction**

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

31

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

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40 **2.2 Motivation for this Report**

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42 **2.2.1 Why Does the Past Matter?**

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

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

55 The pre-instrumental context of Earth’s climate system provided by paleodata strengthens
56 the interlocking web of evidence that supports scientific results regarding climate change. For
57 example, in considering whether fossil-fuel burning is an important contributor to the recent rise
58 in atmospheric carbon-dioxide concentrations, researchers must determine and quantify global
59 sources and sinks of carbon in Earth’s overall carbon budget. But one can also ask whether the
60 change of atmospheric carbon-dioxide concentrations observed in the instrumental record for the
61 past 100 years falls inside or outside the range of natural variability as revealed in the paleo-

62 record and, if inside, whether the timing of changes in carbon dioxide levels matches any known
63 natural cycles that can explain them. Answers to such questions must come from paleoclimate
64 data, because the instrumental record is much too short to characterize the full range of natural
65 fluctuations.

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

73

74 **2.2.2 Why the Arctic?**

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

84 due to powerful positive feedbacks in the Arctic climate system. These feedbacks produce large
85 effects on Arctic climate while also having significant impacts on the global climate system.

86 This high degree of sensitivity makes the paleoclimate history of the Arctic especially
87 informative when one considers the issue of modern climate change. Summaries of recent

88 changes in the Arctic environment (e.g., ACIA, 2005; Richter-Menge et al., 2006) are based
89 primarily on observations and instrumental records. This report uses paleoclimate records to

90 provide a longer-term context for recent Arctic warming; that context allows us to better
91 understand the potential for future climate changes. Paleoclimate records provide a way to

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

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102 **2.3 Focus and Scope of this Synthesis Report (Geographic and Temporal)**

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104 The content of this report follows from the prospectus developed early in its planning
105 (this prospectus is available at the CCSP website, <http://www.climatescience.gov>), and it is
106 focused on four topical areas in which the paleo-record can most strongly inform discussions of

107 climate change. These topics, each addressed in a separate chapter of this synthesis report, are:

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

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

119

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

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

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

130 Bradley, 1999). (See Chapter 3 for a discussion of proxies.) Some of the many proxies routinely
131 used are :

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

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

140 The proxy records document large changes in the Arctic. As described in Chapter 4,
141 comparison of Arctic paleoclimatic data with records from lower latitude sites for the same time
142 period shows that temperature changes in the Arctic were greater than temperature changes
143 elsewhere (changes were “amplified”). This Arctic amplification occurred for climate changes
144 with different causes. Physical understanding shows that this amplification is a natural
145 consequence of features of the Arctic climate system.

146

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

150 The climate record of Earth shows changes that operate on many time scales—tens of
151 millions of years for continents to rearrange themselves, to weeks during which particles from a
152 major volcanic eruption spread in the stratosphere and block the sun. This report summarizes

153 paleoclimate data on past rates of change in the Arctic and subarctic on all relevant time scales,
154 and it characterizes in particular detail the records of past abrupt changes that have had
155 widespread effects. This section of the report has been coordinated with CCSP Synthesis and
156 Assessment Product 3.4, the complete focus of which is on global aspects of abrupt climate
157 change.

158 The data used to assess rates of change in Chapter 5 are primarily the same as those used
159 to assess the magnitudes of change in Chapter 4. However, as discussed in Chapter 4, the
160 existence of high-time-resolution records that cannot always be synchronized exactly to other
161 records, and additional features of the paleoclimatic record, motivate separate treatment of these
162 closely related features of Arctic climate history.

163 Faster or less expected changes have larger effects on natural and human systems than do
164 slower, better anticipated changes (e.g., National Research Council, 2002). Comparison of
165 projected rates of change for the future (IPCC, 2007) with those experienced in the past can thus
166 provide insights to the level of impacts that may occur.. Chapter 5 summarizes rates of Arctic
167 change in the past, compares these with recent Arctic changes and to non-Arctic changes, and
168 assesses processes that contribute to the rapidity of some Arctic changes.

169

170 ***3) What does the paleoclimate record tell us about the past size of the Greenland Ice Sheet and***
171 ***its implications for sea level changes?***

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

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

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

196

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

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

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

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213 **2.4 Report and Chapter Structure**

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215 This report is organized into five primary technical chapters. The first of these (Chapter
216 3) provides a conceptual framework for the information presented in the succeeding chapters,
217 each of which focuses on one of the topics described above. Chapter 3 also contains information
218 on the standardized use of time scales and geological terminology in this report.

219 Each of the topical chapters (Chapters 4 through 7) answers, in this order, the questions
220 “Why, how, what, and so what?” The “Why” or opening introductory segment for each chapter
221 outlines the relevance of the topic to the issue of modern climate change. The “How” segment

222 discusses the sources and types of data compiled to build the paleoclimate record and the
223 strengths and weaknesses of the information. The ““What”” segment is the paleo-record
224 information itself, presented in chronological order, oldest to most recent. The final “So what”
225 segment discusses the significance of the material contained in the chapter and its relevance to
226 current climate change. Each technical chapter is preceded by an abstract that outlines the
227 principal conclusions contained in the body of the chapter itself. Bolded words in the text
228 indicate entries in the technical glossary at the end of this report. Italicized locations in the text
229 can be found on the index map. This map includes locations referred to in the text that are
230 located above 64° north latitude.

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232 **2.5 The Synthesis and Assessment Product Team**

233

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

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