Prospectus for Synthesis and Assessment Product 1.2

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

Lead Agency: USGS
Supporting Agencies: NOAA, NASA, DOE, NSF

1. Overview: Description of Topic, Audience, Intended Use and Questions to be Addressed

This prospectus has been prepared according to the *Guidelines for Producing Climate Change Science Program (CCSP) Synthesis and Assessment Products*. The prospectus will be reviewed and approved by the CCSP Interagency Committee. The document describes the focus of this synthesis and assessment product, and the process that will produce it. The document does not express any regulatory policies of the United States or any of its agencies, or make any findings of fact that could serve as predicates for regulatory action.

1.1 Description of Topic

Current documented rapid rates of warming in the Arctic regions of the Earth have focused the attention of multiple social, political, and economic sectors on the potential impacts a sustained Arctic warming trend would have in many segments of human endeavor. The extent to which current changes in the Arctic and at high latitudes can be informed by the record of past climate fluctuations is the topic of this Synthesis and Assessment Product. The record of past changes and an understanding of the mechanisms that caused those changes can help better define the causes and potential impacts of the changes currently underway.

This CCSP synthesis and assessment report will summarize the state of knowledge of the history of Arctic and subarctic climate as it relates to ongoing and future climate. The state of knowledge will be classified into those results that have been clearly demonstrated, those supported with the balance of evidence, and those that are suggested but not demonstrated. Such a classification should be useful to policymakers and stakeholders. Results from outside the Arctic and subarctic that are required to reveal the status of the northern high latitudes will be summarized in the same way.

The four questions detailed in section 1.3 will serve as the overarching framework for the report. These four questions were chosen because they unify the main scientific work that has been ongoing in the Arctic and subarctic, and lead to results that will be of greatest importance to policymakers and stakeholders in the Arctic and worldwide.

1.2 Introduction and Background

Over the past century the planet has shown an overall warming of 0.7^{o}C. Instrumental records indicate that, over the past 30 years, temperatures in the Arctic have exhibited a greater rate of increase than the planet as a whole, although the variability is also greater in the Arctic. 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 predict 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 impacts on Arctic climate while also having significant impacts on the global climate system.

Summaries of recent Arctic environmental change (e.g. Arctic Climate Impact Assessment) are mostly based on observations and instrumental records. This CCSP product will utilize paleoclimate records to provide a longer-term context for recent Arctic warming in order to better anticipate future climate changes. Paleoclimate records enable us to define the range of natural variability in the Arctic and the magnitude of polar amplification, to evaluate the past rates of Arctic climate change – and thereby provide a long-term context for current rates of change, and to identify past Arctic warm states that are potential analogs of future conditions. The paleoclimate record also permits quantification of the impacts of abrupt perturbations and threshold behaviors (e.g. large injections of volcanic ash into the atmosphere), and offers insights into how the Arctic has behaved during past warm times by identifying critical feedbacks and their mechanisms. Understanding threshold behavior in the highly non-linear Arctic system is one of the key areas of uncertainty in predicting future impacts. In addressing the above issues we will seek to characterize the levels of uncertainty associated with paleoclimate data and to define research priorities for ways to reduce these uncertainties.

Large inter-agency programs like SEARCH (Study of Environmental Arctic Change; http://psc.apl.washington.edu/search/index.html) have now been launched to monitor ongoing change and to develop models for predicting its magnitude and direction. An evaluation of periods in the recent geologic past when the Arctic was as warm or warmer than it is today is crucial to evaluating current warming trends in both the Arctic and throughout the world. Paleoenvironmental data provide us with specific examples of naturally-driven circumarctic warming and the impacts of that warming on natural systems in and beyond the Arctic. These examples will be outlined in this report in order to demonstrate the range of consequences of future warming in the coming century, as estimated by Intergovernmental Panel on Climate Change (2003).

1.3 List of Key Questions and their Relevance

The report will be organized around ways that paleoclimatic data can help answer key questions about the present and future changes of relevance to policy makers and stakeholders**.**

- **What does the paleoclimate record tell us about potential changes of the Arctic sea ice cover in the 21st century?**

Observations document significant retreat and thinning of the Arctic sea ice cover over the past several decades, a trend that is expected to continue. A reduction in sea ice will accelerate Arctic warming through the ice-albedo feedback mechanism. Through impacts on the surface-energy budget and heating contrasts, changes in sea ice will influence weather systems both in the Arctic and in middle latitudes. Changes in ice cover and freshwater flux out of the Arctic Ocean may also affect oceanic circulation of the North Atlantic, which has significant control on European and North American climate.

Continued reduction of sea ice will also accelerate coastal erosion. This is due to the longer fetch of winds over open water areas that results in increased wave action. The Arctic Ocean food web will change, at levels from phytoplankton production to top predators. Wildlife, such as polar bears and seals that depend on the ice cover, are likely to be adversely affected. This will affect indigenous human populations that harvest such species. On the other hand, a loss of sea ice will allow for greater commercial exploitation of the Arctic Ocean. Navigability of the northeast and northwest passages will provide expanded opportunities for increased commercial shipping and increased natural resource exploitation. This increased level of activity will result in impacts to the environment (e.g. from contamination, noise, and infringement on natural habitats).

A persistent loss of sea ice cover raises issues of national security for the Arctic countries. There may be greater ship-based access to unprotected and unpopulated coasts, providing increased opportunity for illegal entry. Naval forces may need surface ships and aircraft better able to operate safely in cold environments if an ice-reduced Arctic requires naval action to protect or interdict shipping, or contend with a hostile force. Both navies and coast guards may need to prepare for increased search and rescue activities as shipping and tourism increase in response to diminished Arctic sea ice.

This report will document past periods when Arctic sea ice was reduced and the causes and effects of these reductions. This information will provide a context within which the impacts of the current and future ice-reduced state of Arctic sea ice can be evaluated.

- **What does the paleoclimate record tell us about the status of the Greenland Ice Sheet?**

Changes in glaciers, especially the Greenland ice sheet, may have widespread impacts. Complete ice-sheet loss would raise global sea level by 7 m; even partial melting would cause important coastal changes globally. Fresh water from ice-sheet melting would be delivered to the oceans in sensitive regions, and could contribute to important changes in sea-ice extent, ocean circulation, and climate, with strong regional and possibly global impacts. Dwindling glaciers will contribute to sea level rise and will affect water availability for some municipal, agricultural, and industrial activities. Continued retreat will potentially impact ecotourism as well.

Changes in ice delivery to the oceans could affect iceberg distribution and thus shipping. Paleoclimatic data allow reconstruction of changes in the size of the Greenland ice sheet at various times in the past, and the climatic conditions that produced those changes. This report will summarize available data and identify knowledge gaps and opportunities for filling those gaps.

- **What can paleoclimate records tell us about how much warmer/colder, wetter/drier is it going to get in the next 100 years?**

The range and variability of past climate fluctuations are consistent with modern records, but they appear to be imposed on a general long-term warming trend that is evident in both historical (the past 120 years) and paleoclimate records. Continued warming will have widespread impacts on all aspects of the Arctic system, some with global consequences. More than 85 percent of the Arctic landscape is underlain by permanently frozen ground (permafrost) that is vulnerable to warming. Permafrost thaw induces landscape instability which impacts infrastructure, rivers, and ecosystems. Thawing of permafrost will increase the decomposition of widespread high-latitude peatlands, significantly increasing the rate of CO_2 and methane release to the atmosphere from these areas. Injections of methane could also come from breakdown of clathrates (frozen gas hydrates) known to be widespread beneath the Arctic continental shelves. These changes will have global consequences, increasing greenhouse gas loadings, in turn amplifying warming processes.

Warming will also allow northward migration of agriculture and natural ecosystems. Climate models suggest that the northward migration of the treeline will amplify climate changes through feedback mechanisms. Anticipated increases in precipitation will alter the Arctic's freshwater budget with impacts on sea ice, ecosystems and, potentially, thermohaline circulation.

Historical records such as recovered instrumental observations, seasonal phenologies, and descriptive records can be used to fill in the gap. These records show that the Arctic climate has fluctuated from region to region in the past. Changes were noticed and recorded, and were significant enough to affect agriculture, marine resources and transportation, for example.

This report will document what is known of environmental conditions during earlier warm periods on a variety of time scales using sedimentary, biological and geochemical proxies. Historical records will be used to link modern data and paleoclimate reconstructions. The proxies permit quantification of changes in air, ground and sea surface temperature, precipitation, and attendant ecosystem change for comparison with magnitudes and rates of contemporary change. Past warm periods provide analogs for future change.

- **What have been the past rates of change and what does this tell us about current and future rates of change?**

Current climate models predict that annual temperatures in the Arctic will increase between 4 and 6 degrees Celsius by the end of the 21st century. Significant variations from year to year and between decades are superimposed upon this general trend. These annual and decadal variations can have significant socioeconomic and environmental impacts of importance to policy makers and stakeholders. In addition to a similar variability, the paleoclimate record also indicates that changes of even larger magnitude have occurred more rapidly, although rarely. Climate models do not capture these rare events well. Faster or less-expected changes have larger impacts on natural and human systems. Socioeconomic and infrastructure viability thus depend on rates of change. Conditions more extreme than any experienced in the memory of a system can be especially stressful. Even if such events should prove to be highly unlikely, any nonzero probability motivates interest. For example, a sudden rearrangement of the ocean-atmosphere circulation system conceivably could influence conditions across much of the planet within years, possibly causing socioeconomic dislocations and environmental refugees. Or, thawing of subsea permafrost could trigger a massive undersea landslide from a steep continental shelf, generating a devastating tsunami impacting ocean-basin-wide coasts. More-likely issues, such as interaction of human-forced changes with natural variability to dampen or amplify total climate changes, also matter. This report will summarize paleoclimatic data on variability in the Arctic and subarctic, with special focus on those abrupt changes that have had widespread impacts. Knowledge of key regions where discontinuities may develop will be assessed, as will any possible premonitory events for abrupt changes. The report also will identify knowledge gaps and opportunities for filling those gaps.

1.4 Stakeholders

This CCSP synthesis and assessment report is intended to provide state-of-the-art information based on paleoclimate science to support U.S. government policy and adaptive-management decision making. The information contained within this report is intended for use in national resource assessments and socioeconomic decision support activities. Primary stakeholders include but are not limited to: U.S. government Agencies; U.S. Congress; The Executive Branch; energy and transportation sectors; federal, regional, and local resource and land managers; the human health sector, circum-Arctic populations; and commercial and environmental sectors, scientific researchers and the general public.

1.5 Intended Use

This report is intended to provide a synthesis and assessment of the most reliable paleoclimate information available today and to utilize this record to provide a perspective on contemporary climate change in the Arctic and sub-Arctic region. The report is intended to inform federal, regional, and local policy decisions and land-use and resource management decisions, and to provide the basis for informed adaptive-management decision-making by providing a long-term perspective on current conditions of climate change in the Arctic. The report will also assist funding Agencies to identify areas of future research.

1.6 Data Resources

The report will be based on the publicly available scientific literature. Refereed scientific papers that are published or in press will be the primary data source, supplemented by limited use of books and of abstracts of national and international conferences, which will be noted.

2. Contact Information: E-mail and Telephone for Responsible Individuals at the Lead and Supporting Agencies

U.S. Geological Survey (USGS) – Lead Agency
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3. Lead Authors: Required Expertise of Lead Authors and Biographical Information for Proposed Lead Authors

Lead author nominees below have been identified based on their interest in this product and record of accomplishments in the relevant fields of expertise.

Richard Alley, The Pennsylvania State University
Julie Brigham-Grette, University of Massachusetts, Amherst
Gifford Miller, Institute for Arctic and Alpine Research, University of Colorado
Leonid Polyak, Ohio State University

Brief biographies of the lead authors are provided in Appendix A. It is anticipated that additional contributing authors will be finalized by the lead agency in consultation with the supporting Agencies.

4. Stakeholder Interactions

The process for drafting, receiving comments, and finalizing the document will be open to the public and will comply with the Federal Advisory Committee Act (FACA). The drafting committee will be designated as a FACA committee; thus, all committee meetings will be open to the public. Timely notice of each meeting will be published in the Federal Register, and other types of public notice will be used to insure that all interested persons are notified of the meeting. Interested persons will be encouraged to attend, appear before, or file statements with the committee, subject to such reasonable rules or regulations that may be prescribed. All records of the committee will be available for public inspection and reproduction at a designated location. Requests for public comment will be posted in the Federal Register.

5. Drafting Process (Including Materials to be Used in Preparing the Product)

Under the leadership of a convening lead author for each of the chapters, the group of lead authors and contributors is charged with the preparation of the scientific/technical analysis section of the synthesis report. They will draw upon published, peer-reviewed scientific literature in the drafting process.

The Synthesis and Assessment Product will include an Executive Summary which will present key findings from the report. It will be written by a team consisting of a convening lead author assisted by the convening lead authors from each of the chapters.

The Synthesis and Assessment Product will identify disparate views that have significant scientific or technical support, and will provide confidence levels for key findings, as appropriate.

The Synthesis and Assessment Product will pay special attention to addressing uncertainties and confidence levels in our statements.

6. Review

The lead authors identified above will compile a draft of the synthesis for review by a panel of experts in the field of paleoclimate research with some individuals knowledgeable about Arctic paleoclimates.

Following expert review, the lead authors will revise the draft product by incorporating comments and suggestions from the reviewers, as the lead authors deem appropriate.

Following this revision, the draft product will be released for public comment. The public comment period will be 45 days and will take place in Winter 2008.

The lead authors will prepare a third draft of the product, taking into consideration the comments submitted during the public comment period. The scientific judgment of the lead authors will determine responses to the comments.

Once the revisions are complete, the lead agency will submit the synthesis and assessment product to the CCSP Interagency Committee for approval. If the CCSP Interagency Committee determines that further revision is necessary, their comments will be sent to the lead agency for consideration and resolution by lead authors. If needed, the National Research Council will be asked to provide additional scientific analysis to bound scientific uncertainty associated with specific issues.

If the CCSP Interagency Committee review determines that no further revisions are needed and that the product has been prepared in conformance with the *Guidelines for Producing CCSP Synthesis and Assessment Products* and the Data Quality Act (including ensuring objectivity, utility, and integrity as defined in 67 FR 8452), they will submit the product to the National Science and Technology Council (NSTC) for clearance. Clearance will require the concurrence of all members of the Committee on Environment and Natural Resources. Comments generated during the NSTC review will be addressed by the CCSP Interagency Committee in consultation with the lead and supporting agencies and the lead authors.

7. Related Activities, Including Other National and International Assessment Processes

The international science community is preparing to undertake the International Polar Year during 2007-2009. There will be opportunities for further analysis of past instrumental data and paleo-data, although many of these analyses may conclude after publication of this assessment report. For example, NOAA and Roshydromet are engaged in a new analysis of radiosonde data from the Russian Arctic that will improve our understanding of Arctic climate variability and change from the early 20th century. The National Science Foundation will provide new support for the Study of Environmental Arctic Change (SEARCH) that may include support for Arctic paleo-studies. The International Study of Arctic Change (ISAC), the international parent of SEARCH, may also conduct similar studies. The Arctic Council is considering what it should do as a follow-up to the Arctic Climate Impact Assessment; additional studies of past climate change are a possibility.

8. Communications: Proposed Method of Publication and Dissemination of the Product

USGS, as the lead agency, will produce and release the completed product using a standard format for all CCSP synthesis and assessment products. The final product and the comments received during the expert review and the public comment period will be posted, without attribution (unless specific reviewers agree to attribution), on the CCSP web site.

The lead authors will also be encouraged to publish their findings in the scientific literature.

9. Proposed Timeline

Task	**Completion Date**
Prospectus	
Draft prospectus delivered to CCSP	August 2006
Review of draft prospectus by CCSP	September/October 2006
Comment period (30 days)	November 2006
Revision of draft prospectus	December 2006
Prospectus Published	January 2007
Report (timeline dependent upon FACA process)	
First Lead Authors Meeting	January 2007
Zero order draft complete	August 2007
Second Lead Authors Meeting	August 2007
Expert Review (First) draft complete	October 2007
Expert review	November 2007
Third Lead Authors Meeting	December 2007
Public Comment (Second) Draft complete	January 2008
Public comment period	March 2008
Final draft complete	April 2008
Submission to CCSP	May/June 2008

Appendix A. Biographical Information for Authors

Richard B. Alley: Dr. Richard B. Alley is Evan Pugh Professor of Geosciences and Associate of the EMS Environment Institute at The Pennsylvania State University, University Park, PA. There he teaches and conducts research on the paleoclimatic records, dynamics, and sedimentary deposits of large ice sheets, as a means of understanding the climate system and its history, and projecting future changes in climate and sea level. Dr. Alley has spent three field seasons in Antarctica and five in Greenland. He is a Fellow of the American Geophysical Union, and has been awarded a Packard Fellowship, a Presidential Young Investigator Award, the Horton Award of the American Geophysical Union Hydrology Section, the Wilson Teaching Award of the College of Earth and Mineral Sciences and the Faculty Scholar Medal of the Pennsylvania State University. His book on abrupt climate change, The Two-Mile Time Machine, was the national Phi Beta Kappa Science Award winner for 2001. Dr. Alley recently chaired a National Research Council study on Abrupt Climate Change, and serves, or has served, on many other advisory panels and steering committees, such as the Polar Research Board of the National Research Council, the Intergovernmental Panel on Climate Change, the Antarctic External Review Panel (the "Augustine Commission"), and the board of directors of the Arctic Research Consortium of the United States. He has authored or coauthored more than 120 refereed publications, and his publications have been cited more than 4000 times in the refereed literature. He received his Ph.D. in Geology, with a minor in Materials Science, from the University of Wisconsin-Madison in 1987, and earned an MSc degree (1983) and BSc degree (1980) in Geology from the Ohio State University in Columbus, Ohio.

Julie Brigham-Grette: Dr. Julie Brigham-Grette is a professor in the Department of Geosciences at the University of Massachusetts, Amherst. Dr. Brigham-Grette received her Ph.D. from the University of Colorado's Institute for Arctic and Alpine Research. After post-doctoral research at the University of Bergen, Norway, and the University of Alberta, Canada with the Canadian Geological Survey, she joined the faculty at the University of Massachusetts in the fall of 1987. Dr. Brigham-Grette has been conducting research in the Arctic for nearly 24 years, including eight field seasons in remote parts of northeast Russia since 1991, participating in both the science program as well as dealing with difficult logistics. Her research interests and experience span a broad spectrum dealing with arctic paleoclimate records and the Late Cenozoic evolution of the Arctic climate both on land and off shore, especially in the Bering Strait region. She has published over 65 articles and refereed papers in her area of research expertise. She served as member of the Arctic Logistics Task Force for the NSF OPP 1996-1999 and 2000-2003, chaired the US Scientific Delegation to Svalbard for Shared Norwegian/U.S. Scientific Collaborations and Logistical Platforms in 1999, and was member of the OPP Office Advisory Council 2002-2004. Brigham-Grette is currently Chairman of the International Geosphere/Biosphere Program's Science Steering Committee on Past Global Change (PAGES) with an international program office in Bern, Switzerland, President of the American Quaternary Association, and a member of a National Academy of Sciences committee studying the role and future uses the US Icebreaker fleet. She also serves as one of two US representatives to the International Continental Drilling Program.

Leonid Polyak: Dr. Leonid Polyak has been a Research Scientist at the Byrd Polar Research Center of The Ohio State University and the Curator of the BPRC Sediment Core Facility since 1993. He received his M.S. degree in Biology and Ph.D. in Geology from the Leningrad Mining Institute in 1980 and 1985, respectively. He is widely published in the fields of systematics and ecology of benthic foraminifera, Quaternary stratigraphy of the central Arctic Ocean, paleoceanography of the Arctic Ocean and marginal Arctic seas, the history of Pleistocene glaciation in the Arctic, and modern Arctic marine environments and the impacts of contaminants and climate change on these environments. He has participated in numerous Arctic field projects and field expeditions including the SCICEX geophysical investigation of the Arctic Ocean floor and the Trans-Arctic HOTRAX 2005 deep seismic profiling mission which involved collaboration with research groups from the United States, Russia, Canada, Norway, and Sweden. Utilizing sonar images of the Arctic Ocean floor during the SCICEX mission he has been able to demonstrate the existence of ancient massive floating ice sheets in the Arctic during the Pleistocene. Dr. Polyak's unique experience and expertise in Arctic sea ice history represent a key component in building a comprehensive Arctic paleoclimate history for this synthesis and assessment product.

Gifford H. Miller: Dr**.** Gifford Miller is a professor in the Department of Geological Sciences and the Director of the Center for Geochronological Research at the University of Colorado, Boulder. He received his B.A. in 1970 and Ph.D. in 1975 from the University of Colorado at Boulder and was a Postdoctoral Fellow at the Geophysical Laboratory of the Carnegie Institute from 1974-1976 and a visiting Professor at the University of Bergen, Norway in 1997 – 1980. He is currently a visiting fellow at the Research School of Earth Sciences at Australian National University in Canberra, Australia. He has served on the editorial boards of *Geology* (1992-1994), *Quaternary Science Rev*iew (1988-), *Journal of Quaternary*. *Science* (1987-), *Quaternary Geochronology* (1993-), and Jøkull (2003-).

His research has focused on glaciation, paleoenvironments and paleoclimate of the Eastern Canadian Arctic, Svalbard and the Russian Arctic, and monsoonal variations, faunal extinctions and human-landscape interactions in the Australian Arid Zone. His current research includes the timing and mechanism of ice-sheet growth and decay in Arctic Canada and the European Arctic, and the interactions between ice sheets, oceans, and the atmosphere during the last deglaciation; developing new or improved applications of protein diagenesis in carbonate fossils to date geological and archaeological events; climate-forcing of wet/dry cycles in monsoonal Australia, the earliest immigration of humans to the continent, and their impact on climate, regional vegetation and megafauna extinction; and high-resolution records of environmental change for the Arctic over for the past 20,000 yr based on the record preserved in lake sediments.