U.S. Climate Change Science Program

Synthesis and Assessment Product 1.3

Reanalysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change

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National Oceanic and Atmospheric Administration

Contributing Agencies:
Department of Energy
National Aeronautics and Space Administration

Note to Reviewers: This report has not yet undergone rigorous copy-editing and will do so prior to layout for publication

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Abstract

This Climate Change Science Program Synthesis and Assessment Program (SAP) Report addresses current capabilities to integrate observations of the climate system into a consistent description of past and current conditions through the method of reanalysis. In addition, it assesses present capabilities to attribute causes for climate variations and trends over North America during the reanalysis period, which extends from the mid-twentieth century to the present.

This Report reviews the strengths and limitations of current atmospheric reanalysis products for documenting and advancing knowledge of the causes and impacts of global-scale and regional-scale climate phenomena. It finds that reanalysis data play a crucial role in a broad range of climate research problems, in particular those addressing the circulation features and physical mechanisms that produce high-impact climate anomalies such as droughts and floods. Reanalysis data also play a critical role in assessing the ability of climate models to simulate the mean climate and its variations, and in identifying fundamental errors in the physical processes that create climate model biases. The Report finds that current reanalyses have a number of deficiencies that limit their usefulness for climate research and applications. In particular, it highlights the limitations imposed by the inhomogeneous nature of the input observations, and the deficiencies in current climate models in simulating various aspects of the hydrological cycle. The Report emphasizes that significant improvements are possible by developing new methods to address observing system inhomogeneities, by developing estimates of the reanalysis uncertainties, by improving our historical observational database, and by

developing integrated Earth system models and analysis systems that incorporate key climate elements not included in atmospheric reanalyses to date.

The Report provides an assessment of current understanding of causes of observed North American climate variability and trends over the period 1951-2006, based on a synthesis of results from research studies, climate model simulations, reanalysis and observational data. For annual- and area-averaged surface temperatures over North America, more than half of the observed surface warming since 1951 is likely the result of increases in anthropogenic greenhouse gas forcing. However, anthropogenic greenhouse gas forcing alone is unlikely to be the main cause for regional and seasonal differences of surface temperature changes, such as the absence of a summertime warming trend over the Great Plains of the United States, and the absence of a warming trend in both winter and summer over portions of the southern United States. The regional and seasonal variations in temperature trends are related to the principal atmospheric flow patterns that affect North American climate and which are well captured in climate re-analyses. It is likely that variations in regional sea surface temperatures have played an important role in forcing these atmospheric flow patterns, although there is evidence that some flow changes are also due to anthropogenic forcing. In contrast to temperature, there is no discernible trend during this period in annual-average North American precipitation, although there is substantial interannual to decadal variability. Part of the observed interannual to decadal variability in precipitation appears to be related to observed regional variations of sea surface temperatures during this period.

Preface

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A primary objective of the U.S. Climate Change Science Program (CCSP) is to provide the best possible scientific information to support public discussion and government and private sector decision making on key climate-related issues. To help meet this objective, the CCSP has identified 21 Synthesis and Assessment Products (SAPs) that address its highest priority research, observational, and decision-support needs. This SAP Report focuses on the topic of "Re-Analysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change."

P.1 OVERVIEW OF REPORT

New climate observations are most informative when they can be put in the context of what has occurred in the past. Are current conditions unusual, or have they been observed frequently before? Are the current conditions part of a long-term trend, or more likely a manifestation of climate variability that may be expected to reverse over months, seasons, or years? Are similar or related changes occurring in other parts of the globe? What are the processes and mechanisms that can explain current conditions, and how are they similar to, or different from, what has occurred in the past?

The scientific methods of climate re-analysis (henceforth, reanalysis) and attribution are central to addressing such questions. In brief, reanalysis is a method for integrating a

diverse array of observations together within a model of the climate system (or of one of its components, such as the atmosphere, ocean, or land surface) to describe past climate conditions over an extended time period, typically multiple decades. An important goal of reanalysis is to provide comprehensive, consistent long-term climate data sets that are reliable on hourly to decadal and longer time scales. Attribution is the process of establishing the most likely cause (or causes) for an observed climate variation or change, and generally involves the use of both observational data and model simulations.

Current reanalysis products provide a foundation for a broad range of weather and climate research. As one measure of their extraordinary research impact, the initial overview paper describing one of the first-generation reanalyses produced in the United States, Kalnay *et al.* (1996), has received 5,300 literature citations as of early 2008, making it the most widely cited paper in the geophysical sciences (ISI Web of Knowledge). A follow-up paper five years later that included a small set of products derived from the same reanalysis (Kistler *et al.*, 2001) has already received nearly 750 citations. Beyond their research applications, reanalysis data are used in an increasing range of commercial and business applications. Some examples include energy (supply/demand analysis), assessing locations for wind power generation, agriculture, water resource management, insurance and reinsurance (*e.g.*, Parry *et al.*, 2007, Chapter 17).

This Report addresses the strengths and limitations of current reanalysis products in documenting, integrating, and advancing knowledge of the climate system. It also

assesses our ability to attribute causes for weather and climate variations and trends over North America during the reanalysis period, and discusses the uses, limits and opportunities of improvement of reanalysis data applied for this purpose. The Report is intended to be of value to policymakers in assessing the present state of knowledge with respect to our ability to describe and attribute causes of climate variations and change; for users of reanalysis products in better understanding the strengths and limitations of these products; and for science program managers in developing priorities for future observing, modeling, and analysis systems required to advance national and international capabilities in climate reanalysis and attribution.

Consistent with guidance provided by the Climate Change Science Program, this Report is written primarily for the informed lay reader. For subject matter experts, more detailed discussions are available through the original references cited herein. Because some terms used in this Report will be new to non-specialists, a glossary and list of acronyms is included at the end of this Report.

P.2 PRIMARY REPORT FOCI

This Report considers two general issues of broad interest, within which specific questions are addressed. These are i) the reanalysis of historical climate data for key atmospheric features, in particular, for past climate variations and trends, and ii) attribution of the causes of climate variations and trends over North America during the period from the mid-20th century to present. These topics are described in more detail below.

P.2.1 Reanalysis of Historical Climate Data for Key Atmospheric Features

The availability and usefulness of reanalysis data has led to many important scientific advances, as well as a broad range of new applications. However, limitations of past and current observations, models, and reanalysis methods have also contributed to uncertainties in describing climate system behavior. Chapter 2 of the Report focuses on the strengths and limitations of current reanalysis data for identifying and describing past climate variations and trends. The "first-generation" climate reanalyses developed over the past decade focused on reconstructing past atmospheric conditions from the second half of the twentieth century to the present. Because of the greater maturity and more extensive use of these atmospheric reanalyses, they constitute the primary focus of this Report. However, efforts are now underway to create reanalyses for the ocean and land surface, and so emerging capabilities in these areas will also be briefly discussed.

The specific questions addressed in this Chapter are:

- What is a climate reanalysis, and what role does reanalysis play within a comprehensive climate observing system?
- What can reanalysis tell us about climate forcing and the veracity of climate models?
- What is the capacity of current reanalyses to help us identify and understand major seasonal-to-decadal climate variations, including changes in the frequency and intensity of climate extremes such as droughts?

- To what extent is there agreement or disagreement between climate trends in surface temperature and precipitation derived from reanalyses and those derived from independent data?
- What steps would be most useful in reducing spurious trends and other major uncertainties in describing the past behavior of the climate system through reanalysis methods? Specifically, what contributions could be made through improvements in data recovery or quality control, modeling, or data assimilation techniques?

This part of the Report should prove useful for science program managers in developing priorities to reduce uncertainties and improve capabilities to describe past and ongoing climate variability and change through reanalysis methods. The assessment of capabilities and limitations of current reanalysis products should also be of value to users of reanalysis products.

P.2.2 Attribution of the Causes of Climate Variations and Trends Over North America

Chapter 3 discusses progress and limits in our understanding of the causes of climate variations and trends over the North American region from the mid-twentieth century to the present, the time period encompassed by current atmospheric reanalysis products. It also addresses strengths and limitations of reanalysis products in supporting research to attribute the causes of climate variations and trends over North America during this time period. The specific questions considered in this Section are:

- What is climate attribution, and what are the scientific methods used for establishing attribution?
- What is the present understanding of the causes for North American climate trends in annual temperature and precipitation during the reanalysis record?
- What is the present understanding of causes for seasonal and regional variations in United States temperature and precipitation trends over the reanalysis record?
- What is the nature and cause of apparent rapid climate shifts, having material relevance to North America, over the reanalysis record?
- What is our present understanding of the causes for high-impact drought events over North America over the reanalysis record?

The primary audience for this Section is policymakers, who will have an improved basis for ascertaining the present state-of-knowledge and key remaining uncertainties in attributing the causes of major climate variations and trends over North America and the United States during the past half-century. Resource managers and other decision makers, as well as the general public, may also benefit from a report assessing our present understanding of the causes of past climate variations and trends, especially those events that have high societal, economic, or environmental impacts, such as major droughts.

The concluding Chapter of this Report (Chapter 4) discusses steps needed to improve national capabilities in reanalysis and attribution in order to better address key issues in climate science and to increase the value of such products for applications and decision making. This Chapter may be of particular interest to scientists and research program

managers who are engaged in efforts to advance national and international capabilities in climate reanalysis and attribution.

P.3 TREATMENT OF UNCERTAINTY

In this Report, terms used to indicate the assessed likelihood of an outcome are consistent with those used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) (IPCC, 2007). This terminology is summarized in Table P.1:

Table P.1 IPCC AR4 terminology - likelihood of outcome.

Likelihood Terminology	Likelihood of occurrence/outcome
Virtually Certain	> 99% probability
Extremely Likely	> 95% probability
Very Likely	> 90% probability
Likely	> 66% probability
More Likely than Not	> 50% probability
About as Likely as Not	33% to 66% probability
Unlikely	< 33% probability
Very Unlikely	< 10% probability
Extremely Unlikely	< 5% probability
Exceptionally Unlikely	< 1% probability

Terms denoting levels of confidence on findings are also consistent with AR4 usage, as specified in Table P.2:

Table P.2 IPCC AR4 terminology - degree of confidence.

Terminology	Degree of confidence in being correct
Very High Confidence	At least 9 out of 10 change of being correct
High Confidence	About 8 out of 10 chance
Medium Confidence	About 5 out of 10 chance
Low Confidence	About 2 out of 10 chance
Very Low Confidence	Less than 1 out of 10 chance

P.4 SCOPE AND LIMITATIONS OF THIS REPORT

The time period considered in this Report for describing and attributing the causes of climate variations and trends is limited to that of present-day reanalysis records, which

extend from approximately 1950 to the present. As discussed in the concluding Chapter, an effort is now underway to extend reanalysis data back to at least the latter part of the 19th century. While initial results appear promising, this extended reanalysis project is not yet completed and so it is premature to assess results of this effort within this Report.

As with any report of this type, the findings described here provide a snapshot of the state-of-science at a given time; in this case, as of mid-2007. The fields of climate analysis, reanalysis, and attribution are cutting edge areas of climate research, with new results being obtained every month. Hence, within the next few years new results are likely to appear that will supersede some of this Report's findings; for example, with respect to the quality, types and lengths of reanalysis records that are available.

Finally, in preparing this Report, its scope was considered in light of other ongoing assessments, especially the recently completed IPCC AR4 report and other synthesis and assessment reports being developed within the Climate Change Science Program. While it is inevitable, and perhaps even desirable, that there be some overlap with these other assessments, we have attempted to minimize duplication and to focus on issues of special relevance to the intended audience. Thus, while the IPCC AR4 Working Group I report (Solomon *et al.*, 2007) devotes a chapter to understanding and attributing climate change (Hegerl *et al.*, 2007), that report primarily emphasizes changes at global to continental scales, whereas in this Report the focus is on the United States/North American sector and considers regional climate variations and trends of specific interest to the United States public and decision makers.

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