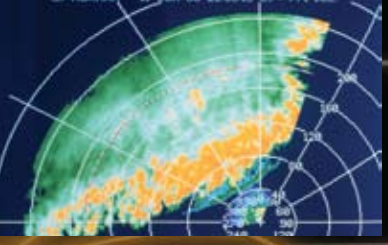

Reanalysis of Historical Climate Data for Key Atmospheric Features:

Implications for Attribution of Causes of Observed Change

U.S. Climate Change Science Program

Synthesis and Assessment Product 1.3

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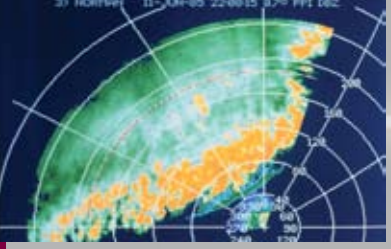
This Synthesis and Assessment Product described in the U.S. Climate Change Science Program (CCSP) Strategic Plan, was prepared in accordance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and the information quality act guidelines issued by the Department of Commerce and NOAA pursuant to Section 515 <http://www.noaanews.noaa.gov/stories/iq.htm>. The CCSP Interagency Committee relies on Department of Commerce and NOAA certifications regarding compliance with Section 515 and Department guidelines as the basis for determining that this product conforms with Section 515. For purposes of compliance with Section 515, this CCSP Synthesis and Assessment Product is an "interpreted product" as that term is used in NOAA guidelines and is classified as "highly influential". This document does not express any regulatory policies of the United States or any of its agencies, or provide recommendations for regulatory action.



Reanalysis of Historical Climate Data for Key Atmospheric Features:

Implications for Attribution of Causes of Observed Change

Synthesis and Assessment Product 1.3
Report by the U.S. Climate Change Science Program
and the Subcommittee on Global Change Research

EDITED BY:
Randall M. Dole

December, 2008

Members of Congress:

On behalf of the National Science and Technology Council, the U.S. Climate Change Science Program (CCSP) is pleased to transmit to the President and the Congress this Synthesis and Assessment Product (SAP) *Reanalysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change*. This is part of a series of 21 SAPs produced by the CCSP aimed at providing current assessments of climate change science to inform public debate, policy, and operational decisions. These reports are also intended to help the CCSP develop future program research priorities.

The CCSP's guiding vision is to provide the Nation and the global community with the science-based knowledge needed to manage the risks and capture the opportunities associated with climate and related environmental changes. The SAPs are important steps toward achieving that vision and help to translate the CCSP's extensive observational and research database into informational tools that directly address key questions being asked of the research community.

This SAP 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, this report 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. It was developed with broad scientific input and in accordance with the Guidelines for Producing CCSP SAPs, the Information Quality Act (Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 [Public Law 106-554]), and the guidelines issued by the Department of Commerce and the National Oceanic and Atmospheric Administration pursuant to Section 515.

We commend the report's authors for both the thorough nature of their work and their adherence to an inclusive review process.

Sincerely,

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Chair, Committee on Climate Change Science and Technology Integration

Samuel W. Bodman
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Vice Chair, Committee on Climate Change Science and Technology Integration

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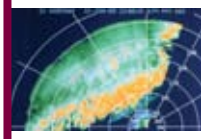

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CCSP Synthesis and Assessment Product 1.3 (SAP 1.3) was developed with the benefit of a scientifically rigorous, first draft peer review conducted by a committee appointed by the National Research Council (NRC). Prior to their delivery to the SAP 1.3 Author Team, the NRC review comments, in turn, were reviewed in draft form by a second group of highly qualified experts to ensure that the review met NRC standards. The resultant NRC Review Report was instrumental in shaping the final version of SAP 1.3, and in improving its completeness, sharpening its focus, communicating its conclusions and recommendations, and improving its general readability.

We wish to thank the members of the NRC Review Committee: David H. Bromwich (Chair), The Ohio State University; Aiguo Dai, National Center for Atmospheric Research; Ioana M. Dima, AIR Worldwide Corporation; John W. Nielsen-Gammon, Texas A&M University; Benjamin Kirtman, University of Miami; Robert N. Miller, Oregon State University; and Andrew W. Robertson, International Research Institute for Climate and Society. The authors also thank the NRC Staff members who coordinated the process: Chris Elfring, Director, Board on Atmospheric Sciences and Climate; Maria Uhle, Study Director; Rachael Shiflett, Senior Program Assistant; and Shuba Banskota, Financial Associate.

We also thank the individuals who reviewed the NRC Report in its draft form: Mary Anne Carroll, University of Michigan; Peter R. Leavitt, Weather Information Company; Elizabeth L. Malone, Joint Global Change Research Institute; Joellen L. Russell, University of Arizona; and Andrew R. Solow, Woods Hole Oceanographic Institution.

The review process for SAP 1.3 also included a public review of the Second Draft, and we thank the individuals who participated in this important step. The Author Team carefully considered all comments, and the subsequent revisions resulted in further improvements in the quality and clarity of the report. Note that the respective review bodies were not asked to endorse the final version of SAP 1.3, as this is the responsibility of the National Science and Technology Council.

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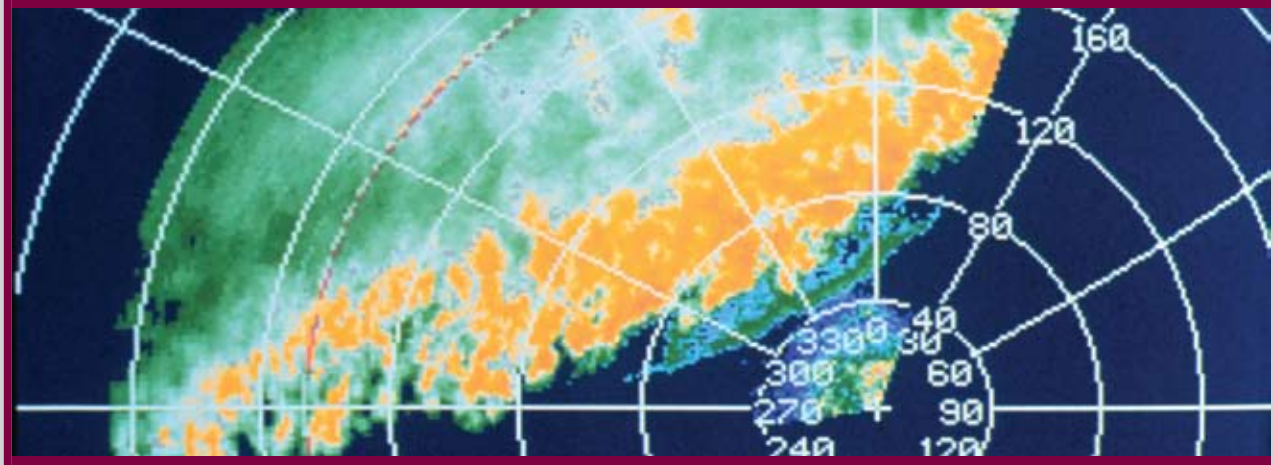
ABSTRACT



This Climate Change Science Program Synthesis and Assessment Product 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, the Product 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 Product reviews the strengths and limitations of current atmospheric reanalysis products. It finds that reanalysis data play a crucial role in helping to identify, describe, and understand atmospheric features associated with weather and climate variability, including high-impact events such as major droughts and floods. Reanalysis data play an important role in assessing the ability of climate models to simulate the average climate and its variations. The data also help in identifying deficiencies in representations of physical processes that produce climate model errors.

The Product emphasizes that significant improvements are possible that would substantially increase the value of reanalyses for climate research, applications, and decision support. Advances are likely through developing new methods to address changes in observing systems over time, improving the historical observational database, and developing integrated Earth system models and analysis systems that include key climate elements for decision support that were not contained in initial atmospheric reanalyses, such as a carbon cycle, aerosols and other important atmospheric constituents.

The Product also assesses current understanding of the causes of observed North American climate variability and trends from 1951 to 2006. This assessment is based on results from research studies, climate model simulations, and reanalysis and observational data. For annual, area-average surface temperatures over North America, more than half of the observed surface warming since 1951 is likely due to anthropogenic forcing associated with greenhouse gas forcing. However, warming due to anthropogenic greenhouse gas emissions 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 wind patterns that affect North American climate, which are well represented in climate reanalyses. It is likely that variations in regional sea surface temperatures have played an important role in forcing these atmospheric wind patterns, although there is evidence that some wind 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 variability in precipitation appears to be related to regional variations of sea surface temperatures during this period.

RECOMMENDED CITATIONS

Entire Report:

CCSP, 2008: *Reanalysis of Historical Climate Data for Key Atmospheric Features: Implications for Attribution of Causes of Observed Change.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [Randall Dole, Martin Hoerling, and Siegfried Schubert (eds.)]. National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, 156 pp.

Preface:

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Executive Summary:

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Chapter 1:

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Chapter 2:

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Chapter 3:

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Chapter 4:

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Appendix A:

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Appendix B:

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PREFACE

Report Motivation and Guidance for Using this Synthesis/Assessment Product

Convening Lead Author: Randall Dole, NOAA/ESRL

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 Product, CCSP SAP 1.3, is one of three products developed to address the first goal of the CCSP Strategic Plan: 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. This Product assesses present capabilities to describe key features of climate from the mid-twentieth century to the present through the scientific method of reanalysis. It also assesses current understanding of the causes of observed climate variability and changes over the North American region during this same period.

P.1 OVERVIEW OF PRODUCT

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 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 reanalysis and attribution are central to addressing such questions. In brief, reanalysis is a method for constructing a high-quality record of past climate conditions. Attribution is the process of establishing the most likely cause (or causes) for an observed climate variation or change.

An important goal of the reanalysis efforts assessed in this Product is to provide comprehensive, consistent, and reliable long-term datasets of temperatures, precipitation, winds, and numerous other variables that characterize the state of the climate system. Because these datasets provide continuous time records, typically at six-hour intervals over several decades, they play an important role in documenting how weather and climate conditions are changing over time. The comprehensive nature of climate reanalyses also makes such datasets of great value in helping scientists to better understand the often complex relationships among variables, for example, how changes in temperatures may be connected to changes in winds, and how these in turn may be related to changes in cloudiness and precipitation.

Reanalysis datasets provide a foundation for a broad range of weather and climate research. As one measure of their extraordinary research impact, an overview paper describing one of the initial reanalyses produced in the United States is now the most widely cited paper in the geophysical sciences. Beyond their research applications, products derived from reanalysis data are used in an increasing range of commercial and business applications in sectors such as energy, agriculture, water resources, and insurance. Some commonly used products include maps showing monthly and seasonal averages, variability and trends in temperatures, winds, precipitation and storminess.

Increasingly, climate scientists are also being asked to go beyond descriptions of *what* are the current climate conditions and how they compare with the past to also explain *why* climate is evolving as observed; that is, to provide attribution for the causes of observed climate variations and change. The capability to attribute causes for past and current climate conditions is an important factor in developing public confidence in scientific understanding of mechanisms that produce climate variability and change. Attribution also provides a scientific underpinning for predicting future climate as well as information useful for evaluating needs and options for adaptation and/or mitigation.

This Product addresses the strengths and limitations of current reanalysis products in documenting, integrating, and advancing knowledge of the climate system. It also assesses present scientific capabilities to attribute causes for weather and climate variations and trends over North America during the reanalysis period (from the mid-twentieth century to the present), including the uses, limitations, and opportunities for improvement of reanalysis data applied for this purpose.

The Product is intended to be of value to the following users:

- policymakers in assessing current scientific capabilities to attribute causes of climate variations and change over the North American region;
- scientists and other users of reanalysis data through the assessment of strengths and limitations of current reanalyses; and
- 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.

Following guidance provided by the Climate Change Science Program, this Product 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 will be new to non-specialists, a glossary and a list of acronyms and abbreviations are included at the end of this Product.

P.2 PRIMARY FOCUS OF THE PRODUCT

Chapter 1 provides a brief, non-technical discussion of the fundamental concepts of reanalysis and attribution. Two issues of broad interest follow, within which specific questions are addressed: (1) the reanalysis of historical climate data for key atmospheric features, in particular, for past climate variations and trends over the reanalysis period from the mid-twentieth century to the present, and (2) attribution of the causes of climate variations and trends over North America during the same period. 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 have 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 each contributed to uncertainties in describing climate system behavior. Chapter 2 focuses on the strengths and limitations of current reanalysis data for identifying and describing past climate variations and trends.

The first global atmospheric reanalyses were developed a little over a decade ago by NASA, NOAA (together with the National Center for Atmospheric Research [NCAR]), and the European Centre for Medium Range Weather Forecasts. These initial reanalyses were constructed by combining observations from diverse data sources within sophisticated models used for weather predictions through a process called data assimilation. Because of the origins in the use of weather models, the initial reanalyses and the majority of those conducted since that time have focused on reconstructing past atmospheric conditions. The longest reanalysis, conducted by NOAA and NCAR, extends back to 1948. Because of their maturity and extensive use, atmospheric reanalyses constitute the primary focus of this Product. However, efforts are now underway to create reanalyses for other components of the Earth's climate system, such as the ocean and land surface; emerging capabilities in these areas will also be briefly discussed.

The key questions addressed in Chapter 2 are:

- What is a climate reanalysis? What role does reanalysis play within a comprehensive climate observing system?
- What can reanalysis tell us about climate processes and their representation in models used for climate predictions and climate change projections?
- What is the capacity of current reanalyses to help 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; that is, from data that are not included in constructing the reanalysis?
- What steps would be most useful in reducing false jumps and trends in climate time series (those that may be due to changes in observing systems or other non-physical causes) and other uncertainties in past climate conditions? Specifically, what contributions could be made

through advances in data recovery or quality control, modeling, and/or data assimilation techniques?

The assessment of capabilities and limitations of current reanalysis datasets for various purposes will be of value for determining best uses of current reanalysis products for scientific and practical purposes. This Chapter will also be useful for science program managers in developing priorities for improving the scientific and practical value of future climate reanalyses.

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

Chapter 3 discusses current understandings of the causes of climate variations and trends over North America 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 key questions are:

- What is climate attribution? 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 U.S. temperature and precipitation trends over the reanalysis record?
- What are the nature and causes of apparent rapid climate shifts relevant to North America over the reanalysis record?
- What is the present understanding of the causes for high-impact drought events over North America during the reanalysis record?

This Chapter will provide policy makers with an assessment of current scientific understanding and remaining uncertainties regarding the causes of major climate variations and trends over North America since the mid-twentieth century. Resource managers and other decision makers, as well as the general public, will also benefit from this assessment.

Finally, Chapter 4 discusses steps needed to improve national capabilities in reanalysis and attribution to better address key questions in climate science and to increase the value of future reanalysis and attribution products for applications and decision making. This Chapter will be of value 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

Terms used in this Product to indicate the assessed likelihood of an outcome are consistent with those used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (*Climate Change 2007: The Physical Science Basis*) and summarized in Table P.1.

Terms denoting levels of confidence in findings are also consistent with the IPCC Fourth Assessment Report usage, as specified in Table P.2.

Table P.1 Terminology regarding likelihood of outcome according to IPCC AR4.

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

Table P.2 Terminology regarding degree of confidence according to IPCC AR4.

Terminology	Degree of confidence in being correct
Very High Confidence	At least nine out of ten chance of being correct
High Confidence	About eight out of ten chance
Medium Confidence	About five out of ten chance
Low Confidence	About two out of ten chance
Very Low Confidence	Less than one out of ten chance

P.4 SCOPE AND LIMITATIONS OF THIS PRODUCT

The time period considered in this Product is limited to that of present-day reanalysis datasets, which extend from 1948 to the present. As discussed in Chapter 4, an effort is now underway to extend reanalysis data back to at least the latter part of the nineteenth century. While initial results appear promising, this extended reanalysis project is not yet complete; therefore, it is not possible to assess the preliminary results in this Product.

The findings presented in this Product provide a snapshot of the current state of knowledge 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. Within the next few years new results are likely to appear that will supersede some of the key findings discussed in this Product; for example, with respect to the quality, types, and lengths of reanalysis records now available.

The scope of this Product was considered in light of other ongoing assessments, in particular the IPCC Fourth Assessment Report and other synthesis and assessment reports being developed within the Climate Change Science Program. The IPCC Report emphasizes climate change at global to continental scales. This Product focuses on the United States/North American sector and considers regional climate variations and trends of specific interest to U.S. resource managers, decision makers, and the general public.