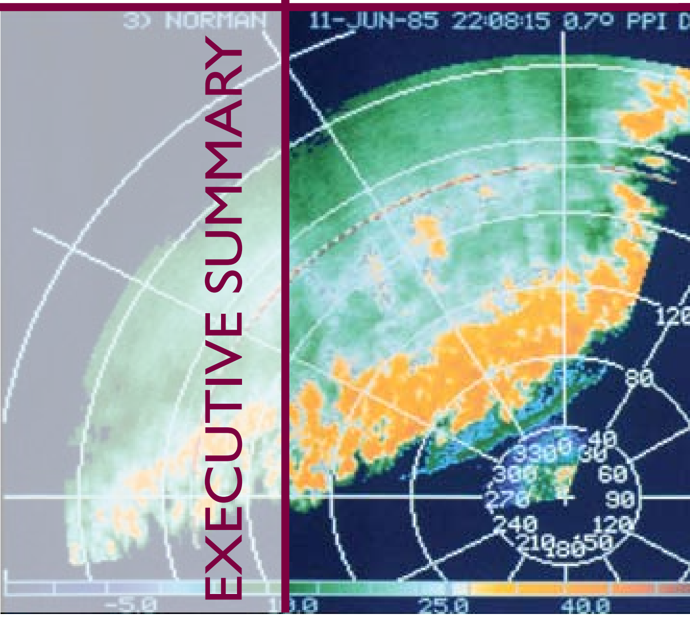
EXECUTIVE SUMMARY



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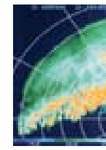
Among the most common questions that climate scientists are asked to address are: What are current climate conditions? How do these conditions compare with the past? What are the causes for current conditions, and are the causes similar to or different from those of the past? This Climate Change Science Program (CCSP) Synthesis and Assessment Product considers such questions, focusing on advances in scientific understanding obtained through the methods of reanalysis and attribution.



In climate science, a *reanalysis* is a method for constructing a high-quality climate record that combines a diverse array of past observations together within a model to derive a best estimate of how the climate system has evolved over time. 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. The atmospheric reanalyses assessed in this Product provide a continuous, detailed record of how the atmosphere has evolved every 6 to 12 hours over periods spanning multiple decades. The Product addresses the strengths and limitations of current reanalyses in advancing scientific knowledge of the climate system. It then assesses current scientific 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. The Product concludes with recommendations to improve national capabilities in reanalysis and attribution in order to increase the value of future products for research, applications and decision making.

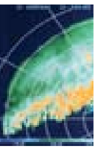
This Product represents a significant extension beyond the recently completed Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (*Climate Change 2007: The Physical Science Basis*). While the IPCC Report mainly emphasized climate change at global to continental scales, this Product focuses on North America, including regional climate variations and trends that are of substantial interest to the U.S. general public, decision makers, and policy makers.

ES.1 PRIMARY RESULTS AND FINDINGS

ES.1.1 Strengths and Limitations of Current Reanalysis Datasets for Representing Key Atmospheric Features

KEY FINDINGS (from Chapter 2)

- Reanalysis plays a crucial integrating role within a global climate observing system by producing comprehensive, long-term, objective, and consistent records of climate system components, including the atmosphere, oceans and land surface.
- Reanalysis data play a fundamental and unique role in studies that address the nature, causes, and impacts of global-scale and regional-scale climate phenomena.
- Reanalysis datasets are of great value in studies of the physical processes that produce high-impact weather and climate events such as droughts and floods, as well as other key atmospheric features that affect the United States, including climate variations associated with major modes of climate variability, such as the El Niño-Southern Oscillation.



- Global and regional surface temperature trends in reanalysis datasets are broadly consistent with those obtained from temperature datasets constructed from surface observations not included in the reanalyses, particularly since the late 1970s. However, in some regions (*e.g.*, Australia) the reanalysis trends show major differences with observations.

- Reanalysis precipitation trends are less consistent with those calculated from observational datasets. The differences are likely due principally to limitations in the initial reanalysis models and the methods used for integrating diverse datasets within models.

- Current reanalysis data are extremely valuable for a host of scientific and practical applications; however, the overall quality of reanalysis products varies with latitude, altitude, time period, location and time scale, and variable of interest, such as temperature, winds or precipitation.

- Current global reanalysis data are most reliable in Northern Hemisphere midlatitudes, in the middle to upper troposphere (about three to twelve miles above Earth's surface), and for regional and larger areas. They are also most reliable for time periods ranging from one day up to several years, making reanalysis data well suited for studies of midlatitude storms and short-term climate variability.

- Present reanalyses are more limited in their value for detecting long-term climate trends, although there are cases where reanalyses have been usefully applied for this purpose. Important factors constraining the value of reanalyses for trend detection include changes in observing systems over time; deficiencies in observational data quality and spatial coverage; model limitations in representing interactions across the land-atmosphere and ocean-atmosphere interfaces, which affect the quality of surface and near-surface weather and climate variables; and inadequate representation of the water cycle.

- At the present time, datasets constructed for an individual variable, for example, surface temperature or precipitation, are generally superior for climate change detection. However, the integrated and comprehensive nature of reanalysis data provides a quantitative foundation for improving understanding of the processes that produce changes. These qualities make reanalysis data more useful than individual variable data sets for attributing the causes of climate variations and change.

ES.1.2 Attribution of the Causes of Climate Variations and Trends over North America during the Modern Reanalysis Period

KEY FINDINGS (from Chapter 3)

- Significant advances have occurred over the past decade in capabilities to attribute causes for observed climate variations and change.

- Methods now exist for establishing attribution for the causes of North American climate variations and trends due to internal climate variations and/or changes in external climate forcing.

Annual, area-average change for the period 1951 to 2006 across North America shows the following:

- Seven of the warmest ten years for annual surface temperatures from 1951 to 2006 have occurred between 1997 and 2006.

- The 56-year linear trend (1951 to 2006) of annual surface temperature is +0.90°C ±0.1°C (1.6°F ± 0.2°F).

- Virtually all of the warming since 1951 has occurred after 1970.

- More than half of this warming is *likely* the result of human-caused greenhouse gas forcing of climate change.

- Changes in ocean temperatures *likely* explain a substantial fraction of the human-caused warming of North America.

- There is no discernible trend in average precipitation since 1951, in contrast to trends observed in extreme precipitation events.

Spatial variations in annual average change for the period from 1951 to 2006 across North America show the following:

- Observed surface temperature change has been largest over northern and western North America, with up to +2°C (3.6°F) warming in 56 years over Alaska, the Yukon Territories, Alberta, and Saskatchewan.

- Observed surface temperature change has been smallest over the southern United States and eastern Canada, where no significant trends have occurred.

- There is *very high* confidence that changes in atmospheric wind patterns have occurred, based upon reanalysis data, and that these wind pattern changes are *likely* the physical basis for much of the spatial variations in surface temperature change over North America, especially during winter.

- The spatial variations in surface temperature change over North America are *unlikely* to be the result of anthropogenic forcing alone.

- The spatial variations in surface temperature change over North America are *very likely* influenced by changes in regional patterns of sea surface temperatures through the effects of sea surface temperatures on atmospheric wind patterns, especially during winter.

Spatial variations of seasonal average change for the period 1951 to 2006 across the United States show that:

- Six of the warmest ten summers and winters for the contiguous United States average surface temperatures from 1951 to 2006 occurred recently (1997 to 2006).

- During summer, surface temperatures warmed most over western states, with insignificant change between the Rocky and Appalachian Mountains. During winter, surface temperatures warmed most over northern and western states, with insignificant changes over Maine and the central Gulf of Mexico.

- The spatial variations in summertime surface temperature change are *unlikely* to be the result of anthropogenic forcing alone.

- The spatial variations and seasonal differences in precipitation change are *unlikely* to be the result of anthropogenic greenhouse gas forcing alone.

- Some of the spatial variations and seasonal differences in precipitation change and variations are *likely* the result of regional variations in sea surface temperatures.

An assessment to identify and attribute the causes of abrupt climate change over North America for the period 1951 to 2006 finds that:

- There are limitations for detecting rapid climate shifts and distinguishing these shifts from quasi-cyclical variations because current reanalysis data only extends back until to the mid-twentieth century. Reanalysis over a longer time period is needed to distinguish between these possibilities with scientific confidence.

An assessment to determine trends and attribute causes for droughts for the period 1951 to 2006 shows that:

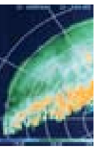
- It is *unlikely* that a systematic change has occurred in either the frequency or area coverage of severe drought over the contiguous United States from the mid-twentieth century to the present.

- It is *very likely* that short-term (monthly-to-seasonal) severe droughts that have impacted North America during the past half-century are mostly due to atmospheric variability, in some cases amplified by local soil moisture conditions.

- It is *likely* that sea surface temperature variations have been important in forcing long-term (multi-year) severe droughts that have impacted North America during the past half-century.

- It is *likely* that anthropogenic warming has increased drought impacts over North America in recent decades through increased water stresses associated with warmer conditions, but the magnitude of the effect is uncertain.

ES.2 RECOMMENDATIONS



The following six recommendations are aimed at improving the scientific and practical value of future reanalyses of the climate system.

- To better detect changes in the climate system, improve the quality and consistency of the observational data and reduce effects of observing system changes.

- Develop analysis methods that are optimized for climate research and applications. These methods should include uncertainty estimates for all reanalysis products.

- To improve the description and understanding of major climate variations that occurred prior to the mid-twentieth century, develop the longest possible consistent record of past climate conditions.

- To improve decision support, develop future climate reanalysis products at finer space scales (*e.g.*, resolutions of 10 miles rather than 100 miles) and emphasize products that are most relevant for applications, such as surface temperatures, winds, cloudiness, and precipitation.

- Develop new national capabilities in analysis and reanalysis that focus on variables that are of high relevance to policy and decision support. Such variables include those required to monitor changes in the carbon cycle and to understand interactions among Earth system components (atmosphere, ocean, land, cryosphere, and biosphere) that may lead to accelerated or diminished rates of climate change.

- Develop a more coordinated, effective, and sustained national capability in analysis and reanalysis to support climate research and applications.

The following priorities are recommended for reducing uncertainties in climate attribution and realizing the benefits of this information for decision support:

- Develop a national capability in climate attribution to provide regular and reliable explanations of evolving climate conditions relevant to decision making.

- Focus research to better explain causes of climate conditions at regional and local levels, including the roles of changes in land cover, land use, atmospheric aerosols, greenhouse gases, sea surface temperatures, and other factors that contribute to climate change.

- Explore a range of methods to better quantify and communicate findings from attribution research.