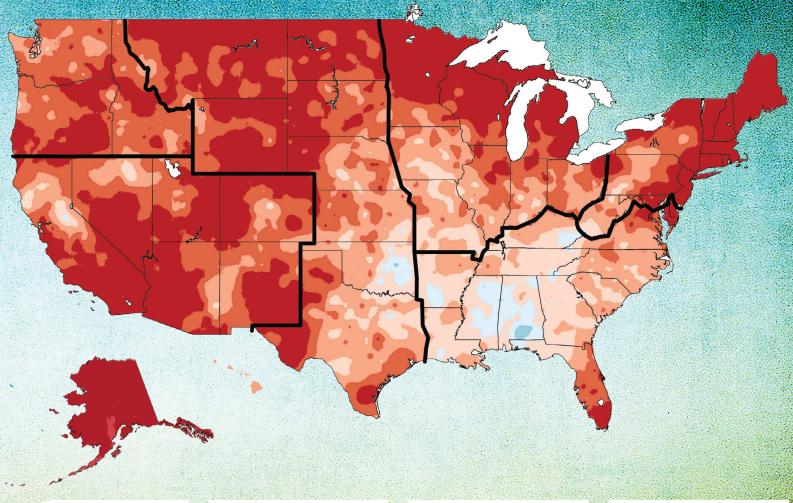
Climate Change Impacts in the United States







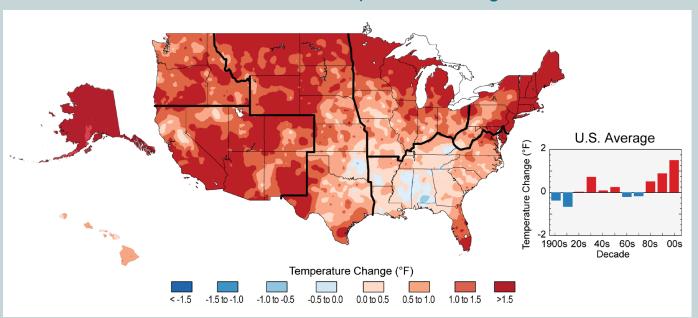




U.S. National Climate Assessment
U.S. Global Change Research Program

Climate Change Impacts in the United States

Observed U.S. Temperature Change



The colors on the map show temperature changes over the past 22 years (1991-2012) compared to the 1901-1960 average for the contiguous U.S., and to the 1951-1980 average for Alaska and Hawaii. The bars on the graph show the average temperature changes for the U.S. by decade for 1901-2012 (relative to the 1901-1960 average). The far right bar (2000s decade) includes 2011 and 2012. The period from 2001 to 2012 was warmer than any previous decade in every region. (Figure source: NOAA NCDC / CICS-NC).



Members of the National Guard lay sandbags to protect against Missouri River flooding.



Energy choices will affect the amount of future climate change.



Climate change is contributing to an increase in wildfires across the U.S. West.



Solar power use is increasing and is part of the solution to climate change.

Online at:

nca2014.globalchange.gov

This report was produced by an advisory committee chartered under the Federal Advisory Committee Act, for the Subcommittee on Global Change Research, and at the request of the U.S. Government. Therefore, the report is in the public domain. Some materials used in the report are copyrighted and permission was granted to the U.S. government for their publication in this report. For subsequent uses that include such copyrighted materials, permission for reproduction must be sought from the copyright holder. In all cases, credit must be given for copyrighted materials.

First published 2014

Printed in the United States of America

ISBN 9780160924026

Recommended Citation

Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2.

Published by the U.S. Government Printing Office Internet: bookstore.gpo.gov; Phone: toll free (866) 512-1800; DC area (202) 512-1800 Fax: (202) 512-2104 Mail: Stop IDCC, Washington, DC 20402-0001





May 2014

Members of Congress:

On behalf of the National Science and Technology Council and the U.S. Global Change Research Program, we are pleased to transmit the report of the Third National Climate Assessment: *Climate Change Impacts in the United States*. As required by the Global Change Research Act of 1990, this report has collected, evaluated, and integrated observations and research on climate change in the United States. It focuses both on changes that are happening now and further changes that we can expect to see throughout this century.

This report is the result of a three-year analytical effort by a team of over 300 experts, overseen by a broadly constituted Federal Advisory Committee of 60 members. It was developed from information and analyses gathered in over 70 workshops and listening sessions held across the country. It was subjected to extensive review by the public and by scientific experts in and out of government, including a special panel of the National Research Council of the National Academy of Sciences. This process of unprecedented rigor and transparency was undertaken so that the findings of the National Climate Assessment would rest on the firmest possible base of expert judgment.

We gratefully acknowledge the authors, reviewers, and staff who have helped prepare this Third National Climate Assessment. Their work in assessing the rapid advances in our knowledge of climate science over the past several years has been outstanding. Their findings and key messages not only describe the current state of that science but also the current and future impacts of climate change on major U.S. regions and key sectors of the U.S. economy. This information establishes a strong base that government at all levels of U.S. society can use in responding to the twin challenges of changing our policies to mitigate further climate change and preparing for the consequences of the climate changes that can no longer be avoided. It is also an important scientific resource to empower communities, businesses, citizens, and decision makers with information they need to prepare for and build resilience to the impacts of climate change.

When President Obama launched his Climate Action Plan last year, he made clear that the essential information contained in this report would be used by the Executive Branch to underpin future policies and decisions to better understand and manage the risks of climate change. We strongly and respectfully urge others to do the same.

Sincerely,

Dr. John P. Holdren

Assistant to the President for Science and Technology Director, Office of Science and Technology Policy

Executive Office of the President

John P. Holder

Dr. Kathryn D. Sullivan

Under Secretary for Oceans and Atmosphere

NOAA Administrator

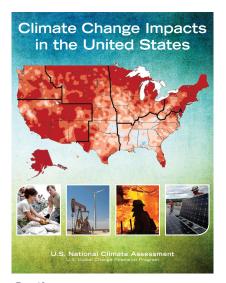
U.S. Department of Commerce

About the NATIONAL CLIMATE ASSESSMENT

The National Climate Assessment assesses the science of climate change and its impacts across the United States, now and throughout this century. It documents climate change related impacts and responses for various sectors and regions, with the goal of better informing public and private decision-making at all levels.

A team of more than 300 experts (see page 98), guided by a 60-member National Climate Assessment and Development Advisory Committee (listed on page vi) produced the full report – the largest and most diverse team to produce a U.S. climate assessment. Stakeholders involved in the development of the assessment included decision-makers from the public and private sectors, resource and environmental managers, researchers, representatives from businesses and non-governmental organizations, and the general public. More than 70 workshops and listening sessions were held, and thousands of public and expert comments on the draft report provided additional input to the process.

The assessment draws from a large body of scientific peer-reviewed research, technical input reports, and other publicly available sources; all sources meet the standards of the Information Quality Act. The report was extensively reviewed by the public and experts, including a panel of the National Academy of Sciences, the 13 Federal agencies of the U.S. Global Change Research Program, and the Federal Committee on Environment, Natural Resources, and Sustainability.



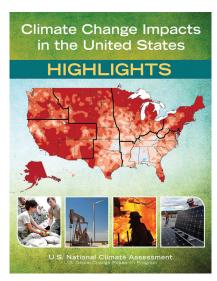
Online at: nca2014.globalchange.gov

About the HIGHLIGHTS

The *Highlights* presents the major findings and selected highlights from *Climate Change Impacts in the United States*, the third National Climate Assessment.

The *Highlights* report is organized around the National Climate Assessment's 12 Report Findings, which take an overarching view of the entire report and its 30 chapters. All material in the *Highlights* report is drawn from the full report. The Key Messages from each of the 30 report chapters appear in boxes throughout this document.

A 20-page *Overview* booklet is available online.



Online at: nca2014.globalchange.gov/highlights

Federal National Climate Assessment and Development Advisory Committee (NCADAC)

Chair

Jerry Melillo, Marine Biological Laboratory

Vice-Chairs

Terese (T.C.) Richmond, Van Ness Feldman, LLP Gary Yohe, Wesleyan University

Committee Members

Daniel Abbasi, GameChange Capital, LLC

E. Virginia Armbrust, University of Washington

Timothy (Bull) Bennett, Kiksapa Consulting, LLC

Rosina Bierbaum, University of Michigan and PCAST

Maria Blair, Independent

James Buizer, University of Arizona

Lynne M. Carter, Louisiana State University

F. Stuart Chapin III, University of Alaska

Camille Coley, Florida Atlantic University

Jan Dell, ConocoPhillips

Placido dos Santos, WestLand Resources, Inc.

Paul Fleming, Seattle Public Utilities

Guido Franco, California Energy Commission

Mary Gade, Gade Environmental Group

Aris Georgakakos, Georgia Institute of Technology

David Gustafson, Monsanto Company

David Hales, Second Nature

Sharon Hays, Computer Sciences Corporation

Mark Howden, CSIRO

Anthony Janetos, Boston University

Peter Kareiva, The Nature Conservancy

Rattan Lal, Ohio State University

Arthur Lee, Chevron Corporation

Jo-Ann Leong, Hawai'i Institute of Marine Biology

Diana Liverman, University of Arizona and Oxford University

Rezaul Mahmood, Western Kentucky University

Edward Maibach, George Mason University

Michael McGeehin, RTI International

Susanne C. Moser, Susanne Moser Research & Consulting and

Stanford University

Richard Moss, University of Maryland and PNNL

Philip Mote, Oregon State University

Jayantha Obeysekera, South Florida Water Management District

Marie O'Neill, University of Michigan

Lindene Patton, Zurich Financial Services

John Posey, East-West Gateway Council of Governments

Sara Pryor, Indiana University

Andrew Rosenberg, University of New Hampshire and Union of

Concerned Scientists

Richard Schmalensee, Massachusetts Institute of Technology

Henry Schwartz, HGS Consultants, LLC

Joel Smith, Stratus Consulting

Donald Wuebbles, University of Illinois

Ex Officio Committee Members

Ko Barrett, U.S. Department of Commerce

Katharine Batten, U.S. Agency for International Development

Virginia Burkett, U.S. Department of the Interior

Patricia Cogswell, U.S. Department of Homeland Security

Gerald Geernaert, U.S. Department of Energy

John Hall, U.S. Department of Defense

Leonard Hirsch, Smithsonian Institution

William Hohenstein, U.S. Department of Agriculture

Patricia Jacobberger-Jellison, National Aeronautics and Space

Administration

Thomas R. Karl, Subcommittee on Global Change Research, U.S.

Department of Commerce

George Luber, U.S. Department of Health and Human Services

C. Andrew Miller, U.S. Environmental Protection Agency

Robert O'Connor, National Science Foundation

Susan Ruffo, White House Council on Environmental Quality

Arthur Rypinski, U.S. Department of Transportation

Trigg Talley, U.S. Department of State

Designated Federal Officers

Cynthia J. Decker, NOAA

Kandis Y. Wyatt, NOAA

Federal Executive Team

John Holdren, Assistant to the President for Science and Technology and Director, White House Office of Science and Technology Policy

Katharine Jacobs, Director, National Climate Assessment, White House Office of Science and Technology Policy (through December 2013)

Thomas Armstrong, Director, U.S. Global Change Research Program National Coordination Office, White House Office of Science and Technology Policy

Thomas R. Karl, Chair, Subcommittee on Global Change Research, U.S. Department of Commerce

Tamara Dickinson, Principal Assistant Director for Environment and Energy, White House Office of Science and Technology Policy

Fabien Laurier, Director, Third National Climate Assessment, White House Office of Science and Technology Policy

Glynis C. Lough, NCA Chief of Staff, U.S. Global Change Research Program

David Easterling, NCA Technical Support Unit Director, NOAA NCDC

NATIONAL CLIMATE ASSESSMENT STAFF

USGCRP National Climate Assessment Coordination Office

Katharine Jacobs, Director, National Climate Assessment, White House Office of Science and Technology Policy (OSTP) (through December 2013) / University of Arizona

Fabien Laurier, Director, Third National Climate Assessment, White House OSTP (previously Deputy Director, USGCRP) (from December 2013)

Glynis Lough, NCA Chief of Staff, USGCRP / UCAR (from June 2012)

Sheila O'Brien, NCA Chief of Staff, USGCRP / UCAR (through May 2012)

Susan Aragon-Long, NCA Senior Scientist and Sector Coordinator, U.S. Geological Survey

Ralph Cantral, NCA Senior Scientist and Sector Coordinator, NOAA (through November 2012)

Tess Carter, Student Assistant, Brown University

Emily Therese Cloyd, NCA Public Participation and Engagement Coordinator, USGCRP / UCAR

Chelsea Combest-Friedman, NCA International Coordinator, Knauss Marine Policy Fellow, NOAA (February 2011-February 2012)

Alison Delgado, NCA Scientist and Sector Coordinator, Pacific Northwest National Laboratory, Joint Global Change Research Institute, University of Maryland (from October 2012)

William Emanuel, NCA Senior Scientist and Sector Coordinator, Pacific Northwest National Laboratory, Joint Global Change Research Institute, University of Maryland (June 2011-September 2012)

Matt Erickson, Student Assistant, Washington State University (July-October 2012)

Ilya Fischhoff, NCA Program Coordinator, USGCRP / UCAR

Elizabeth Fly, NCA Coastal Coordinator, Knauss Marine Policy Fellow, NOAA (February 2013-January 2014)

Chelcy Ford, NCA Sector Coordinator, USFS (August-November 2011)

Wyatt Freeman, Student Assistant, George Mason University / UCAR (May-September 2012)

Bryce Golden-Chen, NCA Program Coordinator, USGCRP / UCAR

Nancy Grimm, NCA Senior Scientist and Sector Coordinator, NSF / Arizona State University (July 2011-September 2012)

Tess Hart, NCA Communications Assistant, USGCRP / UCAR (June-July 2011)

 $\label{lem:mellissa} \mbox{Melissa Kenney, NCA Indicators Coordinator, NOAA / University of Maryland}$

Fredric Lipschultz, NCA Senior Scientist and Regional Coordinator, NASA / Bermuda Institute of Ocean Sciences

Stuart Luther, Student Assistant, Arizona State University / UCAR (June-August 2011)

Julie Maldonado, NCA Engagement Assistant and Tribal Coordinator, USGCRP / UCAR

Krista Mantsch, Student Assistant, Indiana University / UCAR (May-September 2013)

Rebecca Martin, Student Assistant, Washington State University (June-August 2012)

Paul Schramm, NCA Sector Coordinator, Centers for Disease Control and Prevention (June-November 2010)

Technical Support Unit, National Climatic Data Center, NOAA/NESDIS

David Easterling, NCA Technical Support Unit Director, NOAA National Climatic Data Center (from March 2013)

Anne Waple, NCA Technical Support Unit Director, NOAA NCDC / UCAR (through February 2013)

Susan Joy Hassol, Senior Science Writer, Climate Communication, LLC /
Cooperative Institute for Climate and Satellites, North Carolina State University
(CICS-NC)

Paula Ann Hennon, NCA Technical Support Unit Deputy Director, CICS-NC Kenneth Kunkel, Chief Scientist, CICS-NC

Sara W. Veasey, Creative Director, NOAA NCDC

Andrew Buddenberg, Software Engineer/Scientific Programmer, CICS-NC

Fred Burnett, Administrative Assistant, Jamison Professional Services, Inc.

Sarah Champion, Scientific Data Curator and Process Analyst, CICS-NC

Doreen DiCarlo, Program Coordinator, CICS-NC (August 2011-April 2012)

Daniel Glick, Editor, CICS-NC

Jessicca Griffin, Lead Graphic Designer, CICS-NC

John Keck, Web Consultant, LMI, Inc. (August 2010 - September 2011)

Angel Li, Web Developer, CICS-NC

Clark Lind, Administrative Assistant, The Baldwin Group, Inc.

(January-September 2012)

Liz Love-Brotak, Graphic Designer, NOAA NCDC

Tom Maycock, Technical Editor, CICS-NC

Janice Mills, Business Manager, CICS-NC

Deb Misch, Graphic Designer, Jamison Professional Services, Inc.

Julie Moore, Administrative Assistant, The Baldwin Group, Inc.

(June 2010-January 2012)

Ana Pinheiro-Privette, Data Coordinator, CICS-NC (January 2012-July 2013)

Deborah B. Riddle, Graphic Designer, NOAA NCDC

April Sides, Web Developer, ERT, Inc.

Laura E. Stevens, Research Scientist, CICS-NC

Scott Stevens, Support Scientist, CICS-NC

Brooke Stewart, Science Editor/Production Coordinator, CICS-NC

Liqiang Sun, Research Scientist/Modeling Support, CICS-NC

Robert Taylor, Student Assistant, UNC Asheville, CICS-NC

Devin Thomas, Metadata Specialist, ERT, Inc.

Teresa Young, Print Specialist, Team ERT/STG, Inc.

Review Editors

Joseph Arvai, University of Calgary

Peter Backlund, University Corporation for Atmospheric Research

Lawrence Band, University of North Carolina

Jill S. Baron, U.S. Geological Survey / Colorado State University

Michelle L. Bell, Yale University

Donald Boesch, University of Maryland

Joel R. Brown, New Mexico State University

Ingrid C. (Indy) Burke, University of Wyoming

Gina Campoli, Vermont Agency of Transportation

Mary Anne Carroll, University of Michigan

Scott L. Collins, University of New Mexico

John Daigle, University of Maine

Ruth DeFries, Columbia University

Lisa Dilling, University of Colorado

Otto C. Doering III, Purdue University

Hadi Dowlatabadi, University of British Columbia

Charles T. Driscoll, Syracuse University

Hallie C. Eakin, Arizona State University

John Farrington, Woods Hole Oceanographic Institution

Chris E. Forest, Pennsylvania State University

Efi Foufoula-Georgiou, University of Minnesota

Adam Freed, The Nature Conservancy

Robert Fri, Resources for the Future

Stephen T. Gray, U.S. Geological Survey

Jay Gulledge, Oak Ridge National Laboratory

Terrie Klinger, University of Washington

Ian Kraucunas, Pacific Northwest National Laboratory

Larissa Larsen, University of Michigan

William J. Massman, U.S. Forest Service

Michael D. Mastrandrea, Stanford University

Pamela Matson, Stanford University

Ronald G. Prinn, Massachusetts Institute of Technology

J.C. Randolph, Indiana University

G. Philip Robertson, Michigan State University

David Robinson, Rutgers University

Dork Sahagian, Lehigh University

Christopher A. Scott, University of Arizona

Peter Vitousek, Stanford University

Andrew C. Wood, NOAA

United States Global Change Research Program

Thomas Armstrong (OSTP), Executive Director, USGCRP
Chris Weaver (OSTP / EPA), Deputy Executive Director, USGCRP

Subcommittee on Global Change Research Chair

Thomas Karl, U.S. Department of Commerce

Vice Chairs

Ann Bartuska, U.S. Department of Agriculture, Vice Chair, Adaptation Science Gerald Geernaert, U.S. Department of Energy, Vice Chair, Integrated Modeling Mike Freilich, National Aeronautics and Space Administration, Vice Chair, Integrated Observations

Roger Wakimoto, National Science Foundation, Vice-Chair

Principals

John Balbus, U.S. Department of Health and Human Services

Katharine Batten, U.S. Agency for International Development

Joel Clement, U.S. Department of the Interior

Robert Detrick, U.S. Department of Commerce

Scott L. Harper, U.S. Department of Defense

Leonard Hirsch, Smithsonian Institution

William Hohenstein, U.S. Department of Agriculture

Jack Kaye, National Aeronautics and Space Administration

Michael Kuperberg, U.S. Department of Energy

C. Andrew Miller, U.S. Environmental Protection Agency

Arthur Rypinski, U.S. Department of Transportation

Joann Roskoski, National Science Foundation

Trigg Talley, U.S. Department of State

Interagency National Climate Assessment Working Group

Chair

Katharine Jacobs, White House Office of Science and Technology Policy (through December 2013)

Fabien Laurier, White House Office of Science and Technology Policy (from December 2013)

Vice-Chair

Virginia Burkett, U.S. Department of the Interior – U.S. Geological Survey (from March 2013)

Anne Waple, NOAA NCDC / UCAR (through February 2013)

National Aeronautics and Space Administration

Allison Leidner, Earth Science Division / Universities Space Research Association

National Science Foundation

Anjuli Bamzai, Directorate for Geosciences (through May 2011)

Eve Gruntfest, Directorate for Geosciences (January-November 2013)

Rita Teutonico, Directorate for Social, Behavioral, and Economic Sciences (through January 2011)

Smithsonian Institution

Leonard Hirsch, Office of the Undersecretary for Science

U.S. Department of Agriculture

Linda Langner, U.S. Forest Service (through January 2011)

Carolyn Olson, Office of the Chief Economist

Toral Patel-Weynand, U.S. Forest Service

Louie Tupas, National Institute of Food and Agriculture

Margaret Walsh, Office of the Chief Economist

U.S. Department of Commerce

Ko Barrett, National Oceanic and Atmospheric Administration (from February 2013)

David Easterling, National Oceanic and Atmospheric Administration – National Climatic Data Center (from March 2013)

Nancy McNabb, National Institute of Standards and Technology (from February 2013)

Adam Parris, National Oceanic and Atmospheric Administration Anne Waple, NOAA NCDC / UCAR (through February 2013)

U.S. Department of Defense

William Goran, U.S. Army Corps of Engineers

John Hall, Office of the Secretary of Defense

Katherine Nixon, Navy Task Force Climate Change (from May 2013)

Courtney St. John, Navy Task Force Climate Change (through August 2012)

U.S. Department of Energy

Robert Vallario, Office of Science

U.S. Department of Health and Human Services

John Balbus, National Institutes of Health

Paul Schramm, Centers for Disease Control and Prevention (through July 2011)

U.S. Department of Homeland Security

Mike Kangior, Office of Policy (from November 2011)

John Laws, National Protection and Programs Directorate (from May 2013)

U.S. Department of the Interior

Susan Aragon-Long, U.S. Geological Survey

Virginia Burkett, U.S. Geological Survey

Leigh Welling, National Park Service (through May 2011)

U.S. Department of State

David Reidmiller, Bureau of Oceans and International Environmental

& Scientific Affairs

Kenli Kim, Bureau of Oceans and International Environmental

& Scientific Affairs (from February 2013)

U.S. Department of Transportation

Arthur Rypinski, Office of the Secretary

Mike Savonis, Federal Highway Administration (through March 2011)

AJ Singletary, Office of the Secretary (through August 2010)

U.S. Environmental Protection Agency

Rona Birnbaum, Office of Air and Radiation

Anne Grambsch, Office of Research and Development

Lesley Jantarasami, Office of Air and Radiation

White House Council on Environmental Quality

Jeff Peterson (through July 2013)

Jamie Pool (from February 2013)

White House Office of Management and Budget

Stuart Levenbach (through May 2012)

White House Office of Science and Technology Policy

Katharine Jacobs, Environment and Energy Division (through December 2013)

Fabien Laurier, Environment and Energy Division (from December 2013)

With special thanks to former NOAA Administrator, Jane Lubchenco and former Associate Director of the Office of Science and Technology Policy, Shere Abbott