

# Fifth National Climate Assessment



U.S. Global Change  
Research Program

Full report available online at: [nca2023.globalchange.gov](https://nca2023.globalchange.gov)

**Cover image**

Two volunteers help demonstrate and install solar panels in Highland Park, Michigan, in May 2021. The event was hosted by the local nonprofit Soulardarity, which teaches local residents about solar power, installs solar-powered streetlights that also provide wireless internet access, and helps local communities build a just and equitable energy system. Adopting energy storage with decentralized solutions, such as microgrids or off-grid systems, can promote energy equity in overburdened communities. Photo credit: Nick Hagen.

# Fifth National Climate Assessment



U.S. Global Change  
Research Program

The Fifth National Climate Assessment is the US Government’s preeminent report on climate change impacts, risks, and responses. It is a congressionally mandated interagency effort that provides the scientific foundation to support informed decision-making across the United States.

Full report available online at: [nca2023.globalchange.gov](https://nca2023.globalchange.gov)

## Copyright Information

This report is in the public domain. Some materials used herein are copyrighted, and permission was granted 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. All other materials are free to use with credit to this report. Published November 14, 2023. Revised June 06, 2024—see [errata](#) for details.

## Recommended Citation – Full Report

USGCRP, 2023: *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA. <https://doi.org/10.7930/NCA5.2023>

## Recommended Citation – Front Matter

Avery, C.W., A.R. Crimmins, S. Basile, A.M. Grade, and A.A. Scheetz, 2023: Front matter. In: *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA. <https://doi.org/10.7930/NCA5.2023.FM>

## Startlement

by Ada Limón, 24th Poet Laureate Consultant in Poetry at  
the Library of Congress

It is a forgotten pleasure, the pleasure  
of the unexpected blue-bellied lizard  
skittering off his sun spot rock, the flicker  
of an unknown bird by the bus stop.  
To think, perhaps, we are not distinguishable  
and therefore no loneliness can exist here.  
Species to species in the same blue air, smoke—  
wing flutter buzzing, a car horn coming.  
So many unknown languages, to think we have  
only honored this strange human tongue.  
If you sit by the riverside, you see a culmination  
of all things upstream. We know now,  
we were never at the circle's center, instead  
all around us something is living or trying to live.  
The world says, What we are becoming, we are  
becoming together.  
The world says, One type of dream has ended  
and another has just begun.  
The world says, Once we were separate,  
and now we must move in unison.

*A poem written for the Fifth National Climate Assessment.  
© 2023 Ada Limón. All Rights Reserved.*

## Credits

### Federal Steering Committee for the Fifth National Climate Assessment

**Allison R. Crimmins**, Chair, US Global Change Research Program (USGCRP)  
**Margaret Walsh**, US Department of Agriculture  
**Daniel Barrie**, US Department of Commerce  
**Kurt Preston**, US Department of Defense  
**Tristram O. West**, US Department of Energy  
**Daniel Dodgen**, US Department of Health and Human Services  
**Merissa Zuzulock**, US Department of Homeland Security (from June 2023)  
**Paul Wagner**, US Department of the Interior  
**Sierra Woodruff**, US Department of State  
**Rebecca Beavers**, US Department of Transportation (from May 2023)  
**April Marchese**, US Department of Transportation (through May 2023)  
**Darrell A. Winner**, US Environmental Protection Agency  
**Kathy A. Hibbard**, National Aeronautics and Space Administration  
**Maria Uhle**, National Science Foundation (from July 2022)  
**Jennifer Carroll**, National Science Foundation (through July 2022)  
**Rebecca N. Johnson**, Smithsonian Institution  
**Emily Weeks**, US Agency for International Development

### Subcommittee on Global Change Research

**Wayne Higgins**, Chair, US Department of Commerce  
**J. Michael Kuperberg**, Executive Director, US Global Change Research Program  
**William Hohenstein**, US Department of Agriculture  
**Ben DeAngelo**, US Department of Commerce  
**Ben Petro**, US Department of Defense  
**Gary Geernaert**, US Department of Energy  
**John Balbus**, US Department of Health and Human Services  
**David Bascom**, US Department of Homeland Security  
**Geoff Plumlee**, US Department of the Interior  
**Trigg Talley**, US Department of State  
**Gretchen Goldman**, US Department of Transportation (from May 2023)  
**April Marchese**, US Department of Transportation (through May 2023)  
**Rebecca S. Dodder**, US Environmental Protection Agency (from January 2023)  
**Andy Miller**, US Environmental Protection Agency (through January 2023)  
**Jack Kaye**, National Aeronautics and Space Administration  
**Maria Uhle**, National Science Foundation  
**Kirk Johnson**, Smithsonian Institution  
**Noel P. Gurwick**, US Agency for International Development

### USGCRP National Climate Assessment (NCA) Coordination Office

#### NCA Leadership

**Allison R. Crimmins**, NCA Director  
**Christopher W. Avery**, NCA Chief of Staff  
**J. Michael Kuperberg**, Acting NCA Director (through June 2021)

#### Chapter Points of Contact

**Samantha Basile**, Lead Carbon Cycle Specialist  
**David J. Dokken**, Senior International Assessment Lead  
**Leo Goldsmith**, Climate and Health Specialist  
**Aaron M. Grade**, NCA Staff Scientist  
**Joshua Hernandez**, NCA Staff Specialist  
**Katia Kontar**, International Global Change Science Lead  
**Yishen Li**, Water Cycle Science Coordinator  
**Fredric Lipschultz**, Senior Staff Scientist  
**Allyza R. Lustig**, Senior NCA Staff Manager  
**Austin A. Scheetz**, Social Sciences Specialist  
**Reid A. Sherman**, Climate Adaptation Lead  
**Susan C. Aragon-Long**, Senior Science Coordinator / USGS Liaison to USGCRP (through January 2022)  
**Drew Story**, Global Change Science Lead (through July 2022)

#### Communications

**Bradley Akamine**, Chief Digital Information Officer  
**Laurie Howell**, Engagement and Communications Lead  
**Alexa K. Jay**, Senior Science Writer  
**Stephanie Lopez**, Communications Specialist  
**Katie Reeves**, Engagement and Communications Lead (through April 2023)  
**Charles A. Brodine**, Engagement and Communications Specialist (through August 2022)

#### Operations and Special Projects

**Ciara R. Lemery**, Senior Editorial Specialist and Figure Coordinator  
**Sarah Abdelrahim**, USGCRP Deputy Director (through March 2023)  
**Julie Morris**, Associate Director  
**Nico Adams**, Chief of Operations  
**Mathia Biggs**, Operations Coordinator Lead  
**Alex Da Silva**, Climate Change and Sustainability Analyst, ICF  
**D'Arcy Carlson**, Climate Change and Sustainability Analyst, ICF  
**Alida Monaco**, Climate Change and Sustainability Analyst, ICF  
**Emma Conrad-Rooney**, Intern (through April 2023)

**Peter Schultz**, Vice President, ICF  
**Jamie Genevie**, Senior Associate, ICF  
**Sonia Aronson**, Climate Change and Sustainability Analyst, ICF (through June 2023)  
**Matt Greico**, Climate Resilience Specialist, ICF (through October 2022)  
**Lynn Socha**, Climate Change and Sustainability Analyst, ICF (through July 2022)  
**Nicole Rucker**, Knauss Marine Policy Fellow (through January 2022)

#### Global Change Information System (GCIS)

**Amrutha Elamparathy**, GCIS Lead  
**Zachary G. Landes**, Software Developer  
**Reuben Aniekwu**, Senior Climate Research Specialist  
**Shamel Wilson**, Data Management Intern (from October 2022)

#### NOAA Technical Support Unit

**David R. Easterling**, Technical Support Unit Director, NOAA National Centers for Environmental Information (NCEI)  
**Kenneth E. Kunkel**, Lead Scientist, North Carolina State University  
**Sara W. Veasey**, NCEI Visual Communications Team Lead, NOAA NCEI  
**Brooke C. Stewart**, Managing Editor and Lead Science Editor, North Carolina State University (through July 2023)  
**Thomas K. Maycock**, Senior Science Editor, North Carolina State University  
**Jessicca Allen**, Visual Communications Specialist and Lead Graphic Designer, North Carolina State University  
**Barbara Ambrose**, Visual Communications Specialist, Mississippi State University, Northern Gulf Institute  
**Rocky Bilotta**, Physical Scientist, NOAA NCEI  
**Amy V. Camper**, Visual Communications Specialist, Innovative Consulting and Management Services LLC  
**Linda B. Copley**, Software Engineer, North Carolina State University (through June 2023)  
**Ryan Cox**, Web Developer, North Carolina State University  
**Jacquelyn Crossman**, NOAA NCEI Librarian, MPF-ZAI  
**Mark R. Essig**, Scientific Technical Editor, North Carolina State University  
**Bridgette O. Haley**, Visual Communications Specialist, NOAA NCEI  
**Katharine M. Johnson**, Web Developer and GIS Specialist, North Carolina State University  
**April D. Lamb**, Editor, Visual Communications and Metadata Specialist, North Carolina State University  
**Ciara R. Lemery**, Senior Editorial Specialist and Figure Coordinator, US Global Change Research Program / ICF  
**Angel Li**, Web Developer, North Carolina State University  
**Liz Love-Brotak**, Visual Communications Specialist, NOAA NCEI

**Andrea McCarrick**, Scientific Technical Editor, North Carolina State University  
**Laura Ohlmann**, Communications Specialist, Innovative Consulting and Management Services LLC  
**Deborah B. Riddle**, Visual Communications Specialist, NOAA NCEI  
**Laura E. Stevens**, Research Scientist, North Carolina State University  
**Liqiang Sun**, Research Scientist, North Carolina State University  
**Xia Sun**, Climate Data Analyst, North Carolina State University  
**Xiangdong Zhang**, Senior Scientist, North Carolina State University  
**Sarah M. Champion**, Data Architect and Lead Information Quality Analyst, North Carolina State University (through December 2022)  
**Deborah Misch**, Visual Communications Specialist (through August 2022)

#### UNC Asheville's National Environmental Modeling and Analysis Center

**Karin Rogers**, Director and Research Scientist  
**Matthew Geiger**, Software Developer  
**Ian Johnson**, GIS Analyst and Science Communications Associate  
**Jeff Bliss**, Principal Software Developer  
**Ashlyn Shore**, Science Editor

#### Administrative Lead Agency

Department of Commerce / National Oceanic and Atmospheric Administration

Full report credits available online at: [nca2023.globalchange.gov/credits](https://nca2023.globalchange.gov/credits)

# Table of Contents

<b>About This Report</b> .....	<b>xx</b>
<b>Guide to the Report</b> .....	<b>xxi</b>
<b>Key Advances Since the Fourth National Climate Assessment</b> .....	<b>xxviii</b>
<b>Chapter 1. Overview: Understanding Risks, Impacts, and Responses</b> .....	<b>1-1</b>
How the United States Is Addressing Climate Change .....	1-5
How the United States Is Experiencing Climate Change .....	1-16
Current and Future Climate Risks to the United States .....	1-23
The Choices That Will Determine the Future .....	1-37
How Climate Action Can Create a More Resilient and Just Nation .....	1-42
<b>Chapter 2. Climate Trends</b> .....	<b>2-1</b>
Introduction .....	2-4
Key Message 2.1. Climate Is Changing, and Scientists Understand Why .....	2-5
Key Message 2.2. Extreme Events Are Becoming More Frequent and Severe .....	2-16
Key Message 2.3. How Much the Climate Changes Depends on the Choices Made Now .....	2-21
Traceable Accounts .....	2-34
References .....	2-41
<b>Chapter 3. Earth Systems Processes</b> .....	<b>3-1</b>
Introduction .....	3-5
Key Message 3.1. Human Activities Have Caused the Observed Global Warming .....	3-5
Key Message 3.2. The Estimated Range of Climate Sensitivity Has Narrowed by 50% .....	3-10
Key Message 3.3. New Data and Analysis Methods Have Advanced Climate Science .....	3-13
Key Message 3.4. Humans Are Changing Earth System Processes .....	3-18
Key Message 3.5. Humans Are Changing Weather and Climate Extremes .....	3-30
Traceable Accounts .....	3-34
References .....	3-48

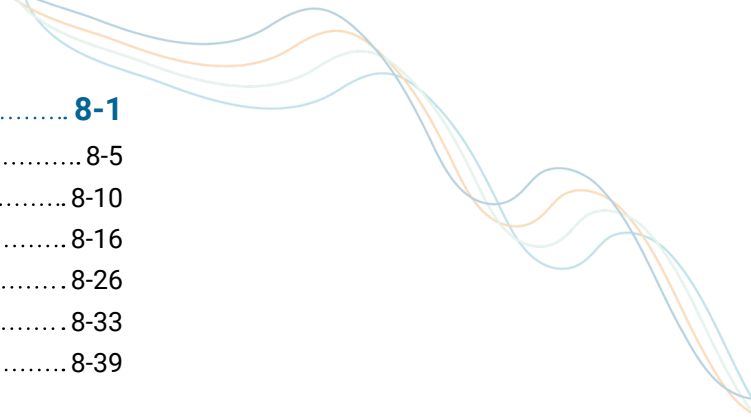


Ellen Anderson

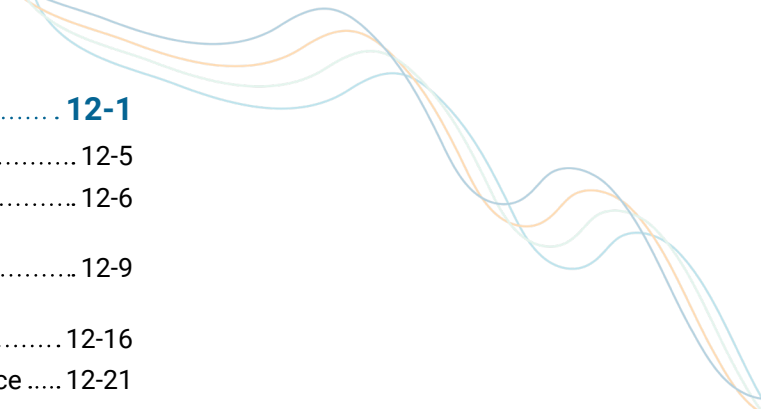


<b>Chapter 4. Water</b> .....	<b>4-1</b>
Introduction .....	4-4
Key Message 4.1. Climate Change Will Continue to Cause Profound Changes in the Water Cycle .....	4-6
Key Message 4.2. Water Cycle Changes Will Affect All Communities, with Disproportionate Impacts for Some .....	4-16
Key Message 4.3. Progress Toward Adaptation Has Been Uneven .....	4-23
Traceable Accounts .....	4-28
References .....	4-34
<b>Chapter 5. Energy Supply, Delivery, and Demand</b> .....	<b>5-1</b>
Introduction .....	5-4
Key Message 5.1. Climate Change Threatens Energy Systems .....	5-4
Key Message 5.2. Compounding Factors Affect Energy-System and Community Vulnerabilities .....	5-9
Key Message 5.3. Efforts to Enhance Energy System Resilience Are Underway .....	5-12
Traceable Accounts .....	5-19
References .....	5-27
<b>Chapter 6. Land Cover and Land-Use Change</b> .....	<b>6-1</b>
Introduction .....	6-5
Key Message 6.1. The Goods and Services Provided by Land Systems Are Threatened by Climate Change .....	6-9
Key Message 6.2. Changes in Climate and Land Use Affect Land-System Resilience .....	6-13
Key Message 6.3. Mitigation and Adaptation Priorities Will Increasingly Constrain Future Land-Use Options .....	6-17
Traceable Accounts .....	6-24
References .....	6-30
<b>Chapter 7. Forests</b> .....	<b>7-1</b>
Introduction .....	7-5
Key Message 7.1. Forests Are Increasingly Affected by Climate Change and Disturbances .....	7-8
Key Message 7.2. Climate Change Affects Ecosystem Services Provided by Forests .....	7-14
Key Message 7.3. Adaptation Actions Are Necessary for Maintaining Resilient Forest Ecosystems .....	7-20
Traceable Accounts .....	7-24
References .....	7-28

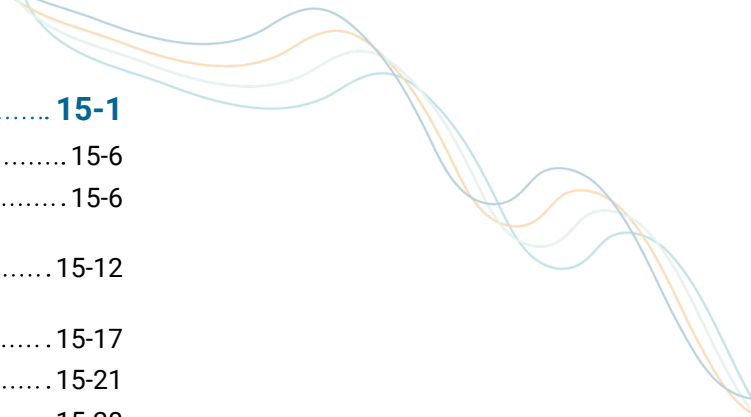
<b>Chapter 8. Ecosystems, Ecosystem Services, and Biodiversity .....</b>	<b>8-1</b>
Introduction .....	8-5
Key Message 8.1. Change Is Driving Rapid Ecosystem Transformations .....	8-10
Key Message 8.2. Species Changes and Biodiversity Loss Are Accelerating .....	8-16
Key Message 8.3. Impacts to Ecosystem Services Create Risks and Opportunities .....	8-26
Traceable Accounts .....	8-33
References .....	8-39
 <b>Chapter 9. Coastal Effects .....</b>	 <b>9-1</b>
Introduction .....	9-4
Key Message 9.1. Coastal Hazards Are Increasing Due to Accelerating Sea Level Rise and Changing Storm Patterns .....	9-5
Key Message 9.2. Coastal Impacts on People and Ecosystems Are Increasing Due to Climate Change ..	9-12
Key Message 9.3. Adaptation Reduces Risk and Provides Additional Benefits for Coastal Communities .....	9-17
Traceable Accounts .....	9-22
References .....	9-29
 <b>Chapter 10. Ocean Ecosystems and Marine Resources .....</b>	 <b>10-1</b>
Introduction .....	10-4
Key Message 10.1. Unprecedented Climate Impacts Threaten Ecosystems and Human Well-Being .....	10-5
Key Message 10.2. Climate Change Is Altering Marine-Related Economic Activities .....	10-10
Key Message 10.3. Our Future Ocean Depends on Decisions Today .....	10-15
Traceable Accounts .....	10-19
References .....	10-25
 <b>Chapter 11. Agriculture, Food Systems, and Rural Communities .....</b>	 <b>11-1</b>
Introduction .....	11-4
Key Message 11.1. Agricultural Adaptation Increases Resilience in an Evolving Landscape .....	11-5
Key Message 11.2. Climate Change Disrupts Our Food Systems in Uneven Ways .....	11-14
Key Message 11.3. Rural Communities Face Unique Challenges and Opportunities .....	11-20
Traceable Accounts .....	11-24
References .....	11-30



<b>Chapter 12. Built Environment, Urban Systems, and Cities</b> .....	<b>12-1</b>
Introduction .....	12-5
Key Message 12.1. Urban Areas Are Major Drivers of Climate Change .....	12-6
Key Message 12.2. Attributes of the Built Environment Exacerbate Climate Impacts, Risks, and Vulnerabilities .....	12-9
Key Message 12.3. Urban Environments Create Opportunities for Climate Mitigation and Adaptation .....	12-16
Key Message 12.4. Community-Led Actions Signal a Shift Toward Equitable Climate Governance .....	12-21
Traceable Accounts .....	12-23
References .....	12-30
<b>Chapter 13. Transportation</b> .....	<b>13-1</b>
Introduction .....	13-5
Key Message 13.1. Limiting Transportation Sector Emissions and Integrating Climate Projections Can Reduce Risks .....	13-6
Key Message 13.2. Climate Change Combined with Other Disruptors Requires New Frameworks and Competencies .....	13-10
Key Message 13.3. Sustainable Transportation Would Produce Societal Benefits .....	13-12
Key Message 13.4. Equitable Distribution of Transportation Trade-Offs and Benefits Requires Community Involvement .....	13-14
Traceable Accounts .....	13-18
References .....	13-24
<b>Chapter 14. Air Quality</b> .....	<b>14-1</b>
Introduction .....	14-5
Key Message 14.1. Climate Change Will Hamper Efforts to Improve US Air Quality .....	14-5
Key Message 14.2. Increasing Wildfire Smoke Is Harming Human Health and Catalyzing New Protection Strategies .....	14-9
Key Message 14.3. Air Pollution Is Often Worse in Communities of Color and Low-Income Communities .....	14-11
Key Message 14.4. Climate Change Is Worsening Pollen Exposures and Adversely Impacting Health .....	14-14
Key Message 14.5. Policies Can Reduce Greenhouse Gas Emissions and Improve Air Quality Simultaneously .....	14-16
Traceable Accounts .....	14-20
References .....	14-28

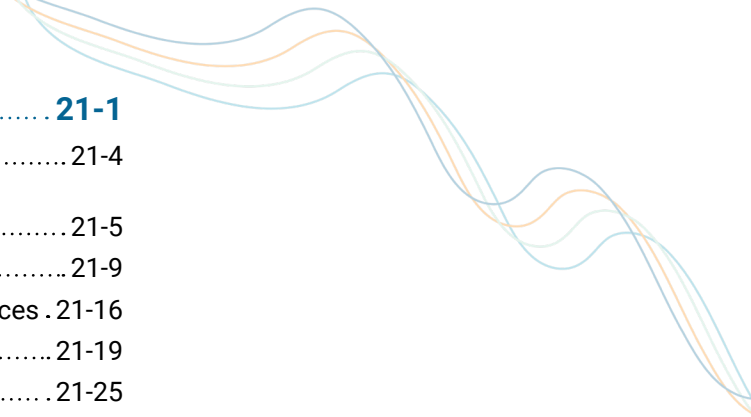


<b>Chapter 15. Human Health</b> .....	<b>15-1</b>
Introduction .....	15-6
Key Message 15.1. Climate Change Is Harming Human Health .....	15-6
Key Message 15.2. Systemic Racism and Discrimination Exacerbate Climate Impacts on Human Health .....	15-12
Key Message 15.3. Timely, Effective, and Culturally Appropriate Adaptation and Mitigation Actions Protect Human Health .....	15-17
Traceable Accounts .....	15-21
References .....	15-28
<b>Chapter 16. Tribes and Indigenous Peoples</b> .....	<b>16-1</b>
Introduction .....	16-4
Key Message 16.1. Indigenous Peoples Face Risks to Well-Being and Livelihoods from Climate Change and Barriers to Energy Sovereignty .....	16-8
Key Message 16.2. Self-Determination Is Key to Indigenous Peoples' Resilience to Climate Change ..	16-14
Key Message 16.3. Indigenous Leadership Guides Climate Change Response .....	16-16
Traceable Accounts .....	16-23
References .....	16-27
<b>Chapter 17. Climate Effects on US International Interests</b> .....	<b>17-1</b>
Introduction .....	17-4
Key Message 17.1. Interdependent, Systemic Climate-Related Risks Increasingly Affect US Interests ..	17-5
Key Message 17.2. Climate Change Exacerbates Risks to National Security .....	17-8
Key Message 17.3. Climate Change Presents Risks and Opportunities for US Economics, Trade, and Investments .....	17-12
Key Message 17.4. Climate Change Undermines Sustainable Development .....	17-16
Traceable Accounts .....	17-20
References .....	17-25

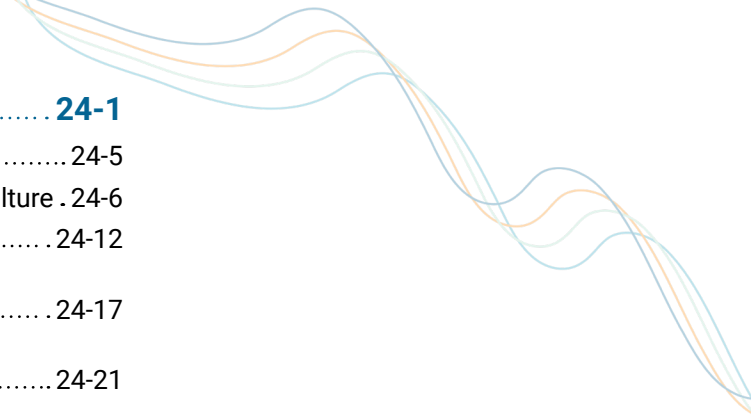


<b>Chapter 18. Sector Interactions, Multiple Stressors, and Complex Systems .....</b>	<b>18-1</b>
Introduction .....	18-5
Key Message 18.1. Human–Nature Interconnections Create Unexpected Climate Risks and Opportunities .....	18-6
Key Message 18.2. Complex Climate Impacts and Responses Further Burden Frontline Communities .....	18-9
Key Message 18.3. Collaborations Among Diverse Knowledge Holders Improve Responses to Complex Climate Challenges .....	18-11
Key Message 18.4. New Governance Approaches Are Emerging, but Gaps in Practice and Evidence Persist .....	18-16
Traceable Accounts .....	18-20
References .....	18-25
<b>Chapter 19. Economics .....</b>	<b>19-1</b>
Introduction .....	19-5
Key Message 19.1. Climate Change Affects the Economy Directly .....	19-5
Key Message 19.2. Markets and Budgets Respond to Climate Change .....	19-13
Key Message 19.3. Economic Opportunities for Households, Businesses, and Institutions Will Change .....	19-17
Traceable Accounts .....	19-20
References .....	19-25
<b>Chapter 20. Social Systems and Justice .....</b>	<b>20-1</b>
Introduction .....	20-4
Key Message 20.1. Social Systems Are Changing the Climate and Distributing Its Impacts Inequitably .....	20-6
Key Message 20.2. Social Systems Structure How People Know and Communicate About Climate Change .....	20-9
Key Message 20.3. Climate Justice Is Possible If Processes like Migration and Energy Transitions Are Equitable .....	20-14
Traceable Accounts .....	20-19
References .....	20-26

<b>Chapter 21. Northeast</b> .....	<b>21-1</b>
Introduction .....	21-4
Key Message 21.1. Chronic Impacts of Extreme Weather Are Shaping Adaptation and Mitigation Efforts .....	21-5
Key Message 21.2. Ocean and Coastal Impacts Are Driving Adaptation to Climate Change .....	21-9
Key Message 21.3. Disproportionate Impacts Highlight the Importance of Equitable Policy Choices .....	21-16
Key Message 21.4. Climate Action Plans Are Now Being Implemented .....	21-19
Key Message 21.5. Implementation of Climate Plans Depends on Adequate Financing .....	21-25
Traceable Accounts .....	21-30
References .....	21-35
<b>Chapter 22. Southeast</b> .....	<b>22-1</b>
Introduction .....	22-6
Key Message 22.1. Regional Growth Increases Climate Risks .....	22-7
Key Message 22.2. Climate Change Worsens Human Health and Widens Health Inequities .....	22-17
Key Message 22.3. Climate Change Disproportionately Damages Southeastern Jobs, Households, and Economic Security .....	22-23
Key Message 22.4. Agriculture Faces Growing Threats, but Innovations Offer Help .....	22-31
Traceable Accounts .....	22-36
References .....	22-42
<b>Chapter 23. US Caribbean</b> .....	<b>23-1</b>
Introduction .....	23-6
Key Message 23.1. Climate-Driven Extreme Events Exacerbate Inequities and Impact Human Health and Well-Being .....	23-12
Key Message 23.2. Ecology and Biodiversity Are Unique and Vulnerable .....	23-18
Key Message 23.3. Climate Change Threatens Water and Food Security .....	23-22
Key Message 23.4. Infrastructure and Energy Are Vulnerable, but Decentralization Could Improve Resilience .....	23-27
Key Message 23.5. Adaptation Effectiveness Increases When Coupled with Strategic Governance and Planning .....	23-30
Traceable Accounts .....	23-33
References .....	23-39



<b>Chapter 24. Midwest</b> .....	<b>24-1</b>
Introduction .....	24-5
Key Message 24.1. Climate-Smart Practices May Offset Complex Climate Interactions in Agriculture .....	24-6
Key Message 24.2. Adaptation May Ease Disruptions to Ecosystems and Their Services .....	24-12
Key Message 24.3. Climate Adaptation and Mitigation Strategies Improve Individual and Community Health .....	24-17
Key Message 24.4. Green Infrastructure and Investment Solutions Can Address Costly Climate Change Impacts .....	24-21
Key Message 24.5. Managing Extremes Is Necessary to Minimize Impacts on Water Quality and Quantity .....	24-26
Traceable Accounts .....	24-33
References .....	24-41
<b>Chapter 25. Northern Great Plains</b> .....	<b>25-1</b>
Introduction .....	25-6
Key Message 25.1. Climate Change Is Compounding the Impacts of Extreme Events .....	25-8
Key Message 25.2. Human and Ecological Health Face Rising Threats from Climate-Related Hazards .....	25-14
Key Message 25.3. Resource- and Land-Based Livelihoods Are at Risk .....	25-17
Key Message 25.4. Climate Response Involves Navigating Complex Trade-Offs and Tensions .....	25-21
Key Message 25.5. Communities Are Building the Capacity to Adapt and Transform .....	25-24
Traceable Accounts .....	25-33
References .....	25-41
<b>Chapter 26. Southern Great Plains</b> .....	<b>26-1</b>
Introduction .....	26-5
Key Message 26.1. How We Live: Climate Change Is Degrading Lands, Waters, Culture, and Health .....	26-7
Key Message 26.2. How We Work: Climate Changes Are Creating Economic Challenges and Opportunities .....	26-11
Key Message 26.3. How We Play: Climate Extremes Are Endangering Sports, Recreation, and Leisure .....	26-19
Key Message 26.4. How We Heal: Climate Change Is Exacerbating Existing Social and Environmental Disparities .....	26-26
Key Message 26.5. How We Serve: Climate Change Is Straining Public Infrastructure and Services .....	26-31
Traceable Accounts .....	26-38
References .....	26-47



<b>Chapter 27. Northwest</b> .....	<b>27-1</b>
Introduction .....	27-5
Key Message 27.1. Frontline Communities Are Overburdened, and Prioritizing Social Equity Advances Regional Resilience .....	27-8
Key Message 27.2. Ecosystems Are Transitioning in Response to Extreme Events and Human Activity .....	27-11
Key Message 27.3. Impacts to Regional Economies Have Cascading Effects on Livelihoods and Well-Being .....	27-17
Key Message 27.4. Infrastructure Systems Are Stressed by Climate Change but Can Enable Mitigation and Adaptation .....	27-21
Key Message 27.5. Climate Change Amplifies Health Inequities .....	27-26
Key Message 27.6. Climate Change Affects Heritage and Sense of Place .....	27-30
Traceable Accounts .....	27-35
References .....	27-44

<b>Chapter 28. Southwest</b> .....	<b>28-1</b>
Introduction .....	28-6
Key Message 28.1. Drought and Increasing Aridity Threaten Water Resources .....	28-9
Key Message 28.2. Adaptation Efforts Increase to Address Accelerating Impacts to the Region's Coast and Ocean .....	28-13
Key Message 28.3. Increasing Challenges Confront Food and Fiber Production in the Southwest .....	28-18
Key Message 28.4. Climate Change Compromises Human Health and Reshapes Demographics .....	28-22
Key Message 28.5. Changes in Wildfire Patterns Pose Challenges for Southwest Residents and Ecosystems .....	28-26
Traceable Accounts .....	28-31
References .....	28-40



<b>Chapter 29. Alaska</b> .....	<b>29-1</b>
Introduction .....	29-5
Key Message 29.1. Our Health and Healthcare Are at Risk .....	29-10
Key Message 29.2. Our Communities Are Navigating Compounding Stressors .....	29-15
Key Message 29.3. Our Livelihoods Are Vulnerable Without Diversification .....	29-19
Key Message 29.4. Our Built Environment Will Become More Costly .....	29-23
Key Message 29.5. Our Natural Environment Is Transforming Rapidly .....	29-26
Key Message 29.6. Our Security Faces Greater Threats .....	29-30
Key Message 29.7. Our Just and Prosperous Future Starts with Adaptation .....	29-34
Traceable Accounts .....	29-39
References .....	29-46

<b>Chapter 30. Hawai'i and US-Affiliated Pacific Islands</b> .....	<b>30-1</b>
Introduction .....	30-6
Key Message 30.1. Climate Change Impairs Access to Healthy Food and Water .....	30-17
Key Message 30.2. Climate Change Undermines Human Health, but Community Strength Boosts Resilience .....	30-21
Key Message 30.3. Rising Sea Levels Threaten Infrastructure and Local Economies and Exacerbate Existing Inequities .....	30-25
Key Message 30.4. Responses to Rising Threats May Help Safeguard Tropical Ecosystems and Biodiversity .....	30-30
Key Message 30.5. Indigenous Knowledge Systems Strengthen Island Resilience .....	30-35
Traceable Accounts .....	30-38
References .....	30-46

<b>Chapter 31. Adaptation</b> .....	<b>31-1</b>
Introduction .....	31-5
Key Message 31.1. Adaptation Is Occurring but Is Insufficient in Relation to the Pace of Climate Change .....	31-7
Key Message 31.2. Effective Adaptation Requires Centering Equity .....	31-11
Key Message 31.3. Transformative Adaptation Will Be Needed to Adequately Address Climate-Related Risks .....	31-14
Key Message 31.4. Effective Adaptation Governance Empowers Multiple Voices to Navigate Competing Goals .....	31-18
Key Message 31.5. Adaptation Requires More Than Scientific Information and Understanding .....	31-21
Key Message 31.6. Adaptation Investments and Financing Are Difficult to Track and May Be Inadequate .....	31-24
Traceable Accounts .....	31-30
References .....	31-39
 <b>Chapter 32. Mitigation</b> .....	 <b>32-1</b>
Introduction .....	32-6
Key Message 32.1. Successful Mitigation Means Reaching Net-Zero Emissions .....	32-6
Key Message 32.2. We Know How to Drastically Reduce Emissions .....	32-13
Key Message 32.3. To Reach Net-Zero Emissions, Additional Mitigation Options Need to Be Explored .....	32-21
Key Message 32.4. Mitigation Can Be Sustainable, Healthy, and Fair .....	32-26
Key Message 32.5. Governments, Organizations, and Individuals Can Act to Reduce Emissions .....	32-35
Traceable Accounts .....	32-42
References .....	32-46
 <b>Focus on Compound Events</b> .....	 <b>F1-1</b>
Focus on Compound Events .....	F1-3
Traceable Accounts .....	F1-7
References .....	F1-8
 <b>Focus on Western Wildfires</b> .....	 <b>F2-1</b>
Focus on Western Wildfires .....	F2-3
Traceable Accounts .....	F2-7
References .....	F2-8

<b>Focus on COVID-19 and Climate Change</b> .....	<b>F3-1</b>
Focus on COVID-19 and Climate Change .....	F3-3
Traceable Accounts .....	F3-7
References .....	F3-8
<b>Focus on Risks to Supply Chains</b> .....	<b>F4-1</b>
Focus on Risks to Supply Chains .....	F4-3
Traceable Accounts .....	F4-6
References .....	F4-7
<b>Focus on Blue Carbon</b> .....	<b>F5-1</b>
Focus on Blue Carbon .....	F5-3
Traceable Accounts .....	F5-6
References .....	F5-7
<b>Appendix 1 Assessment Development Process</b> .....	<b>A1-1</b>
A1.1. The US Global Change Research Program .....	A1-3
A1.2. Roles and Participants in NCA5 .....	A1-3
A1.3. Creating the NCA5 Report .....	A1-4
References .....	A1-8
<b>Appendix 2 Information Quality</b> .....	<b>A2-1</b>
A.2.1. Introduction .....	A2-3
A2.2. Source Materials .....	A2-3
A2.3. Data and Metadata Standards .....	A2-4
References .....	A2-5
<b>Appendix 3 Scenarios and Datasets</b> .....	<b>A3-1</b>
A3.1. Scenarios and Climate Model Output .....	A3-3
A3.2. Projected Climate Variables .....	A3-4
A3.3. Sea Level Rise .....	A3-6
A3.4. Tools and Applications .....	A3-7
References .....	A3-8

<b>Appendix 4 Indicators</b> .....	<b>A4-1</b>
A4.1. The Importance of Indicators .....	A4-5
A4.2. Atmospheric Indicators .....	A4-12
A4.3. Ice, Snow, and Water Indicators .....	A4-16
A4.4. Ocean and Coastal Indicators .....	A4-19
A4.5. Land and Ecosystems Indicators .....	A4-24
A4.6. Health Indicators .....	A4-29
A4.7. Adaptation and Mitigation Indicators .....	A4-31
A4.8. Knowledge Gaps and New Approaches .....	A4-32
References .....	A4-33

<b>Appendix 5 Glossary of Terms</b> .....	<b>A5-1</b>
About the Glossary of Terms .....	A5-3
Note on Glossary Development Process .....	A5-3
Glossary .....	A5-4
References .....	A5-31



Margaret Plumley

# About This Report

The Global Change Research Act of 1990<sup>1</sup> mandates that the US Global Change Research Program (USGCRP) deliver a report to Congress and the President not less frequently than every four years that “integrates, evaluates, and interprets the findings of the Program and discusses the scientific uncertainties associated with such findings; analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity; and analyzes current trends in global change, both human-induced and natural, and projects major trends for the subsequent 25 to 100 years.”

The Fifth National Climate Assessment (NCA5) fulfills that mandate by delivery of this Assessment and provides the scientific foundation to support informed decision-making across the United States. By design, much of the development of NCA5 built upon the approaches and processes used to create the Fourth National Climate Assessment (NCA4),<sup>2</sup> with a goal of continuously advancing an inclusive, diverse, and sustained process for assessing and communicating scientific knowledge on the impacts, risks, and vulnerabilities associated with a changing global climate (App. 1).

The findings in this report are based on a comprehensive review and assessment of information sources determined to meet the standards and documentation required under the Information Quality Act and the Foundations for Evidence-Based Policymaking Act of 2018 (App. 2), including peer-reviewed literature, other literature, Indigenous Knowledge, other expert and local knowledge, and climate data processed and prepared for authors by NOAA’s Technical Support Unit (TSU; see Guide to the Report section below and App. 3).

NCA5 was thoroughly reviewed by Federal Government experts, external experts, and the public multiple times throughout the report development process. An expert external review was performed by an ad hoc committee of the National Academies of Sciences, Engineering, and Medicine.<sup>3</sup> Additional information on the development of this Assessment can be found in Appendix 1: Assessment Development Process.

# Guide to the Report

## Intended Audience

The products of the US Global Change Research Program are designed to assist the Nation and the world in understanding, assessing, predicting, and responding to human-induced and natural processes of global change. National Climate Assessments synthesize scientific information and evaluate the state of the science on climate change to inform a broad audience of decision-makers across the country. These decision-makers include national, state, local, and Tribal governments, city planners, public health officials, adaptation specialists, nurses, farmers, business owners, community organizers, researchers, water utilities, ecosystem managers, educators, students, the media, and concerned individuals who need to make timely decisions about the climate impacts they are facing. National Climate Assessments make policy-neutral and policy-relevant information accessible and actionable by relying on the expert judgment of the report authors to determine what topics are included in each chapter, to describe what we know and where uncertainties remain, and to clearly communicate the risks, responses, and opportunities associated with climate change.

## Categories of Chapters and Their Scope

### Overview

The Overview chapter presents the major findings of the report alongside highlights drawn from across NCA5. This chapter provides a synthesis of material from the underlying report chapters.

### Physical Science Chapters

The Climate Trends and Earth Systems Processes chapters (Chs. 2, 3) assess how climate change affects physical Earth systems, with a focus on the United States, including observations and projections of climate change and discussion of how methods to understand changes in Earth systems have advanced since NCA4, which was released in November 2018.

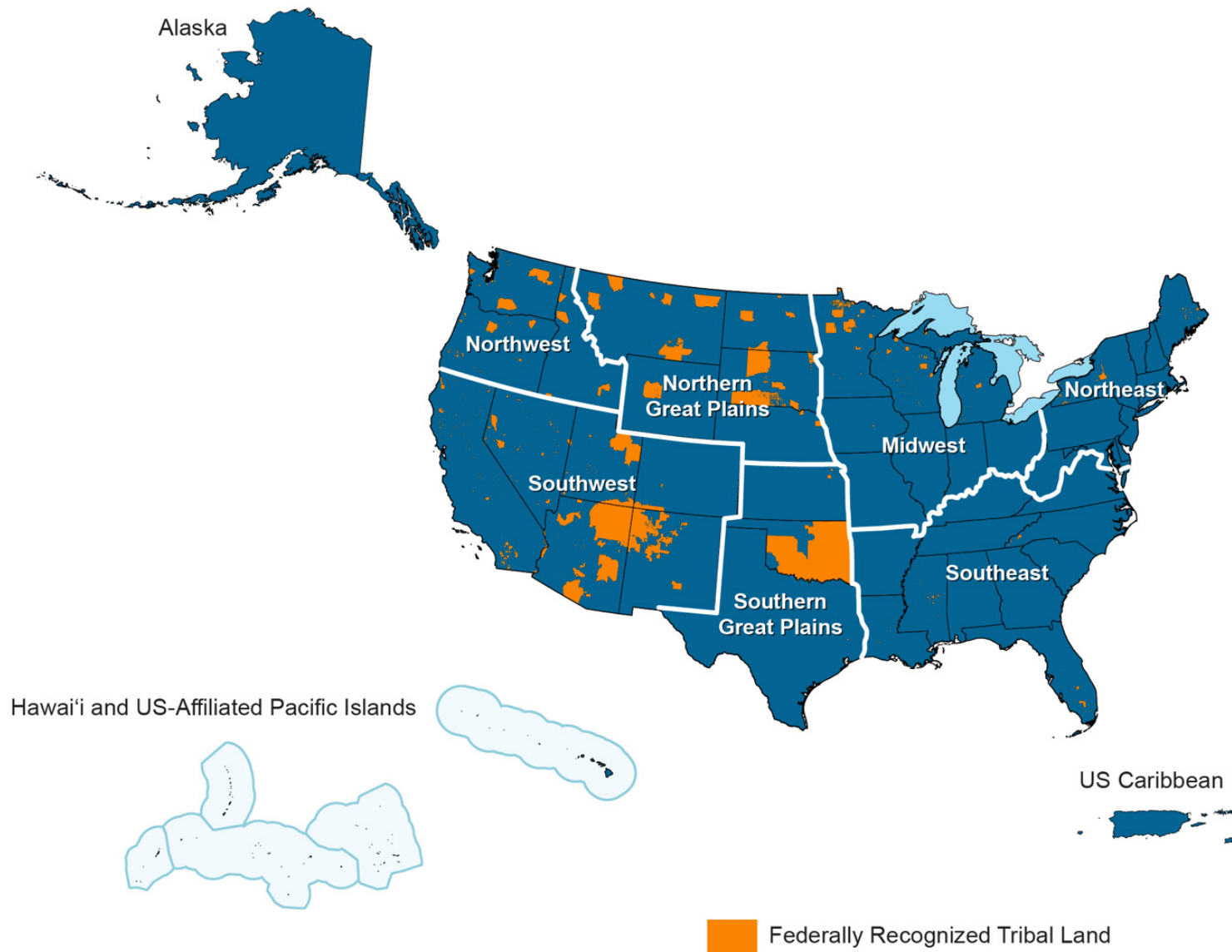
### National Topic Chapters

The national topic chapters (Chs. 4–20) summarize current and future risks related to climate change and what can be done to reduce those risks for a variety of societal and economic sectors of the United States. This Assessment builds on the range of topics covered in NCA4 by adding two new chapters: Economics (Ch. 19) and Social Systems and Justice (Ch. 20).

### Regional Chapters

The regional chapters (Chs. 21–30) assess current and future risks posed by climate change to each of the 10 NCA5 regions (Figure 1). These chapters provide detailed discussions of region-specific challenges, opportunities, and success stories for managing risks and impacts.

## Fifth National Climate Assessment Regions



The Fifth National Climate Assessment explores subnational climate change risks, impacts, and responses in each of the 10 regions shown.

Figure 1. The map shows the 10 US regions that correspond to the 10 regional chapters of the report (Chs. 21–30). The same regional boundaries are used in text and figures throughout the Assessment to provide regional-scale information where appropriate. Adapted from USGCRP 2018.<sup>2</sup>

## Response Chapters

The response chapters (Ch. 31: Adaptation and Ch. 32: Mitigation) assess the science of adapting to a changing climate, emissions reductions, and other efforts that together describe the US's existing and potential response to climate change, including benefits, trade-offs, targets, limitations, and best practices. The National Climate Assessment does not evaluate or recommend specific adaptation or mitigation policies.

## Focus on... Features

To better address critical and timely topics with themes that span the Assessment chapters, NCA5 pioneered a new feature: a set of five “Focus on...” boxes on important cross-cutting issues. High-priority topics were nominated by authors during early development of the report; final topics were approved for inclusion by the Federal Steering Committee. Authors from multiple NCA5 chapters assessed literature, coordinated cross-report discussions, and contributed text and figures to these features.

## Appendices

The first three appendices outline the development process, legal standards of scientific quality for assessing scientific information, and the climate scenarios and datasets used to support author assessment. Appendix 4 explores indicators of observed climate-related changes that support findings across NCA5. Appendix 5 is a glossary defining select terms in the context of how they are typically used across the Assessment.

## Glossary of Terms

Throughout the online version of the report, definitions of terms in the glossary (App. 5) are accessible via an interactive hover-over feature where text appears with a dotted underline. Any usage of a term that differs from the glossary definition is explicitly defined within chapter text.

## Artwork and Gallery

The NCA5 Art × Climate gallery showcases the work of visual artists across the country. These artworks and their accompanying descriptions speak to the causes and impacts of climate change, as well as the ways that people are responding. Submissions of visual art were collected through a public call, and finalists were selected by a jury panel of experts (App. 1). Artworks that appear throughout the PDF version of the report are denoted by a teal border. The artworks and associated artists' statements are not Assessment products and do not necessarily represent the views of the authors or USGCRP.



## Structure and Format of Chapter Content

### Key Messages

Chapters are centered around Key Messages, which are conclusions based on authors' expert judgment and synthesis of the assessed information sources. Many Key Messages present findings in the context of risks to natural and/or human systems. The text supporting each Key Message provides evidence, discusses implications, identifies intersections between systems or hazards, and presents examples of paths to greater resilience.

### Confidence and Likelihood

Evaluating confidence and likelihood is a key part of the assessment process. As in previous Assessments, NCA5 uses specific terms to convey information about scientific confidence and certainty associated with important findings, observations, and projections. Chapter authors use a range of calibrated terms adopted from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report<sup>4</sup> to describe the levels of **confidence** and, where appropriate, the assessment of **likelihood** associated with the statements in their Key Messages (Tables 1, 2).

- **Confidence** in a finding is based on the type, amount, quality, strength, and consistency of evidence; the skill, range, and consistency of methods to detect, evaluate, attribute, and interpret climate trends; and the degree of agreement across scientific information sources.
- **Likelihood** of a finding is based on measures of certainty expressed probabilistically; in other words, based on statistical analysis of observed or projected results or on the authors' expert judgment based on their assessment across scientific information sources.

These calibrated terms are presented in parentheses and set in *italics* after relevant phrases or sentences in the Key Messages. Statements in Key Messages that do not include either likelihood or confidence terms are intended as statements of fact. In some cases, calibrated likelihood assessments are also included in *italics* in the narrative text supporting Key Messages.

Table 1. Calibrated Language for Confidence Assessment

The NCA5 calibrated uncertainty language listed here and in Table 2 follows standards developed for the Intergovernmental Panel on Climate Change Fifth Assessment Report. The confidence levels listed below are used to reflect the quantity, quality, and degree of agreement across the evidence base underpinning an assessment finding. Source: Mastrandrea et al. 2011<sup>4</sup>

Confidence Level	Definition
Very high	<ul style="list-style-type: none"> <li>• Strong evidence (established theory, multiple sources, well-documented and accepted methods, etc.)</li> <li>• High consensus</li> </ul>
High	<ul style="list-style-type: none"> <li>• Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.)</li> <li>• Medium consensus</li> </ul>
Medium	<ul style="list-style-type: none"> <li>• Suggestive evidence (a few sources, limited consistency, methods emerging, etc.)</li> <li>• Competing schools of thought</li> </ul>
Low	<ul style="list-style-type: none"> <li>• Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.)</li> <li>• Disagreement or lack of opinions among experts</li> </ul>

Table 2. Calibrated Language for Likelihood Assessment

The calibrated uncertainty terms below are used to express a probabilistic assessment across the evidence base of the likelihood of observed or projected results. Source: Mastrandrea et al. 2011.<sup>4</sup>

Likelihood Assessment	Numeric Probability of Outcome
Virtually certain	99%–100%
Very likely	90%–100%
Likely	66%–100%
As likely as not	33%–66%
Unlikely	0%–33%
Very unlikely	0%–10%
Exceptionally unlikely	0%–1%

## Traceable Accounts

Each chapter concludes with a section entitled Traceable Accounts, which provides information on the overall process used to develop the chapter as well as a separate Traceable Account section for each Key Message. These Traceable Accounts describe the supporting evidence behind each Key Message, the process and rationale authors used in reaching their conclusions, and the author team's expert assessment of the confidence in and, where applicable, likelihood of these conclusions. As such, Traceable Accounts provide information about the state of the science, document sources of uncertainty, identify research gaps, and allow traceability to data and resources.






Additional information on Key Messages and Traceable Accounts can be found in the Front Matter for NCA4.<sup>2</sup>

## Figures and Tables

Each figure in the report includes a figure number and title, a figure intent, and a caption. The figure title (embedded at the top of the figure) briefly describes what is shown in the figure, the figure intent (shown below the figure) provides a key takeaway message of the figure, and the caption (shown below the figure intent) provides additional information on how to interpret the elements of the figure. Where original figures have

been developed for the Assessment, the figure credit listed at the end of the caption notes the affiliation of the NCA5 authors or contributors responsible for the development of the figure.

Each figure and some tables are accompanied by a metadata survey, which can be accessed in the online version of the report by clicking on the eyeball icon above the figure or table (see the table below for explanations of additional icons used throughout the report). The metadata survey describes data sources, figure or table development methods, copyright information, and other important documentation. All figures that appear in the online version of the report are also accompanied by alternative text for screen readers.

Icon	Description
	Share a chapter, chapter section, figure, table, box, or other content element
	Access metadata for a table or figure
	Download a figure
	Access additional information about a figure, table, or box in the Climate Resilience Toolkit
	Access additional information about a figure, table, or box in the NCA5 Atlas

## Metrics and Definitions Used Across the Report

### Economic Estimates

Unless otherwise noted, economic estimates in this report have been converted to 2022 US dollars using the US Bureau of Economic Analysis's Implicit Price Deflators for Gross Domestic Product, Table 1.1.9.<sup>12</sup> Where documented in the underlying literature, discount rates in specific estimates in this Assessment are noted next to those projections.

### Use of Scenarios

Climate modeling experts develop global climate projections for a range of realistic futures. These projections capture variables such as the relationship between human behavior, greenhouse gas (GHG) emissions, the Earth system processes and responses to changes in concentration of GHGs in our atmosphere and oceans, and resulting impacts, including temperature change and sea level rise. Because there are

uncertainties inherent in all of these factors—especially human behavior and the choices that determine emissions levels—the resulting range of projections are not predictions but instead reflect multiple potential pathways for our collective future (Ch. 2). The scenarios do not have relative likelihoods assigned and are all plausible futures.

NCA5 authors were advised to assess the full range of scenarios available. While use of specific scenarios was not mandated across the report, authors were encouraged to report impacts under more than one scenario in order to describe a range of possible outcomes. Few climate projections extend past 2100, limiting the information available for authors to evaluate trends 100 years into the future (Box A3.1).

To help communicate author findings effectively, the naming convention with simplified summary descriptions shown in Table 3 is used across the report to describe the Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs) used in Phases 5 and 6 of the Coupled Model Intercomparison Project (CMIP5 and CMIP6), respectively. Scenarios other than those described in Table 3 are referred to by name.

**Table 3. Descriptive Terms for Common Climate Scenarios Used in NCA5**

This table summarizes the terms used to describe scenarios from Phases 5 and 6 of the Coupled Model Intercomparison Project (CMIP5 and CMIP6). This standardized terminology is used throughout the report when discussing scenarios to facilitate easier comparison by readers. Sources: Arias et al. 2021; Gidden et al. 2019; Meinshausen et al. 2020; O’Neil et al. 2017; Riahi et al. 2017; van Vuuren et al. 2011<sup>5,6,7,8,9,10</sup>

Climate Scenario Descriptor	CMIP5	CMIP6	Summary
Very High Scenario	RCP8.5	SSP5-8.5	Among the scenarios described here, these reflect the highest range of carbon dioxide (CO <sub>2</sub> ) emissions and no mitigation. Total annual global CO <sub>2</sub> emissions in 2100 are quadruple emissions in 2000 (RCP8.5 and SSP5-8.5). Population growth in 2100 doubles from 2000 in RCP8.5, but the SSP5-8.5 population remains relatively stable, with approximately 13% growth in 2100 from 2005. Both scenarios include fossil fuel development, but SSP5-8.5 has higher economic growth than RCP8.5.
High Scenario	RCP6.0	SSP3-7.0	These scenarios reflect high CO <sub>2</sub> emissions with limited (RCP6.0) or no (SSP3-7.0) mitigation. Total annual CO <sub>2</sub> emissions in 2100 are more than 75% higher than in 2000 in RCP6.0, and triple that of 2000 emissions in SSP3-7.0. Compared to 2000, both scenarios include expanded fossil fuel development and population growth but slow economic growth.
Intermediate Scenario	RCP4.5	SSP2-4.5	These scenarios reflect reductions in CO <sub>2</sub> emissions from current levels. Total annual CO <sub>2</sub> emissions in 2100 are 46% (RCP4.5) and 67% (SSP2-4.5) less than the year 2000. Mitigation efforts include low-carbon technology (SSP2-4.5) and expanded renewable energy compared to 2000 (RCP 4.5).
Low Scenario	RCP2.6	SSP1-2.6	These scenarios reflect rapidly declining and net-negative CO <sub>2</sub> emissions (with CO <sub>2</sub> removal from the atmosphere exceeding human-caused emissions) by 2100. Mitigation efforts include increased renewable energy. Adaptive capacity reflects effective governance institutions, reduced inequality, and international cooperation (SSP1-2.6).
Very Low Scenario	n/a	SSP1-1.9	Among the scenarios described here, SSP1-1.9 reflects the greatest reduction in global greenhouse gas emissions and substantial CO <sub>2</sub> removal from the atmosphere. Total annual CO <sub>2</sub> emissions have a steeper decline than SSP1-2.6, dropping by more than 145% by 2100 compared to 2000. Mitigation efforts include a shift to nuclear and renewable energy and sustainable land use. Adaptive capacity benefits from international cooperation and sharing of technology.

## Box 1. Global Warming Levels Measure How Much the Planet Has Warmed

In this report, the term “global warming level” is used to describe the level of global temperature increase relative to preindustrial temperatures conditions (the 1850–1900 average). A given global warming level is reached when global annual warming, defined by the average temperature over multiple decades, exceeds a specified level. Although this Assessment primarily reports temperatures in Fahrenheit, global warming levels are usually reported and more widely known in degrees Celsius. For example, the [Paris Agreement](#) set a goal of holding the increase in global average temperature to “well below” 2°C (3.6°F) and pursuing efforts to limit the temperature increase to 1.5°C (2.7°F) above preindustrial levels. Thus, global warming levels are typically defined in this report with their Celsius value first and their Fahrenheit value in parentheses.

Internal variability in the climate system means that even as the world rapidly warms, some years will be hotter and some years will be cooler than the multidecadal average. This annual variability means that even if a single year occurs in which Earth is 1.5°C (2.7°F) hotter than the preindustrial average, the 1.5°C global warming level has not necessarily been reached. Conversely, such variability also means that climate impacts projected to occur at a given global warming level may occur earlier than expected, before that level is reached in terms of multidecadal average temperatures. In addition, temperatures in some parts of the world are warmer or cooler than the global average. For example, a global warming level of 2°C (3.6°F) would result in regional temperatures in parts of the United States that are more than 2°C above preindustrial levels (Figure 1.14).

Global warming levels are not thresholds; they do not represent “safe” levels of warming, nor does exceeding a particular global warming level mean that it is too late to slow or halt many of the impacts of climate change by reducing greenhouse gas emissions. Continued action to reduce emissions can avoid the worst impacts of climate change and provide valuable benefits to society and ecosystems no matter what global warming level is reached or exceeded. At regional or local scales, climate impacts, such as increased risks of extreme weather, depend on changes to underlying drivers like local temperatures and rainfall. These changes in turn depend on the level of global warming. The level of global warming depends on future emissions, which depend on human actions. This means that future projections are conditional: when or if Earth reaches a particular level of warming is largely dependent on human choices.

To support decision-making related to future sea level risks, a set of five specific trajectories were selected to cover a range of plausible future global mean sea level conditions. Table 4 displays the naming convention used by NCA5 authors to describe the range of possible rise in global and US sea levels. Although the sea level rise scenarios in Table 4 were developed using global warming levels derived from the Shared Socioeconomic Pathways and there are similarities in the naming conventions (e.g., low, intermediate, high), they have distinct definitions and are used in different ways from the climate scenarios shown in Table 3 (App. 3).<sup>11</sup>

Additional information on scenarios can be found in the Overview and in Appendix 3.

**Table 4. Descriptive Terms for Common Sea Level Rise Scenarios Used in NCA5**

Future global mean sea level rise and sea level rise along United States coastline are shown for five scenarios in feet (and meters), relative to a 2000 baseline. The US values shown in the right half of the table are averaged across the US coastal regions, including the contiguous US, Alaska, Hawai'i and the US-Affiliated Pacific Islands, and the US Caribbean. The national values shown in the table differ substantially from regional values. For example, sea level rise is higher in the Gulf Coast and lower or even negative in some parts of Alaska. In the next 30 years (2020–2050), sea level along the contiguous US coasts is expected to rise 0.92 feet (0.28 m), the same amount of sea level rise observed over the last 100 years (1920–2020). See Chapter 9 for regional sea level information. Adapted from Sweet et al. 2022.<sup>11</sup>

Sea Level Rise Scenario Descriptor	Global Mean Sea Level			United States		
	2050	2100	2150	2050	2100	2150
Year	2050	2100	2150	2050	2100	2150
Low	0.49 (0.15)	0.98 (0.3)	1.31 (0.4)	0.59 (0.18)	0.98 (0.3)	1.64 (0.5)
Intermediate-Low	0.66 (0.20)	1.64 (0.5)	2.62 (0.8)	0.75 (0.23)	1.64 (0.5)	2.95 (0.9)
Intermediate	0.92 (0.28)	3.28 (1.0)	6.23 (1.9)	0.89 (0.27)	3.28 (1.0)	6.89 (2.1)
Intermediate-High	1.21 (0.37)	4.92 (1.5)	8.86 (2.7)	1.12 (0.34)	4.92 (1.5)	8.86 (2.7)
High	1.41 (0.43)	6.56 (2.0)	12.14 (3.7)	1.38 (0.42)	6.56 (2.0)	12.46 (3.8)

# Key Advances Since the Fourth National Climate Assessment

Advances since the publication of the Fourth National Climate Assessment (2017–2018) have led to new understanding of the changing climate system, the resulting impacts on society, and approaches to reduce risks. See Appendix 1 for advances in the development process of NCA5.

## Physical Climate Science

**Reduced uncertainty:** New observations combined with improved modeling provide multiple lines of evidence supporting advances in understanding and projections of climate change. Improved understanding has significantly narrowed the estimated range of global warming expected from a doubling of CO<sub>2</sub> in the atmosphere to 4.5°–7.2°F (2.5°–4.0°C). (KMs 3.2, 3.3)

**Improved attribution:** Advances have increased confidence in the linkages between many weather disasters and climate change, and scientists can now estimate the role of climate change in some types of extreme events in real time. For example, climate change was estimated to have increased the rainfall of Hurricane Harvey in 2017 by about 15% to 20%. (Ch. 2; Introduction; KMs 2.2, 3.3)

**Incorporating socioeconomics:** New model projections are based on policy-relevant scenarios that span plausible future social and economic development pathways (Table 3). These scenarios allow for a deeper exploration of the interactions between development and emissions pathways, as well as technology pathways to reach net-zero emissions goals. (KMs 2.3, 3.2, 6.3, 32.2; App. 3)

**New models:** The latest generation of Earth system models incorporates more detailed simulations of the physical climate system and provides improved understanding of how regional-scale processes will change with warming. (KM 3.3)

## Risks and Impacts

**Connecting justice:** More information is available on disproportionate climate change impacts on overburdened communities, including a better understanding of how climate impacts exacerbate, and are exacerbated by, social inequities. (KMs 4.2, 9.2, 11.2, 12.2, 14.3, 15.2, 16.1, 19.1, 21.3, 26.4, 27.1, 31.2; Introductions in Chs. 16, 17, 20)

**Untangling interconnections:** Observations and enhanced modeling highlight the compounding and cascading effects of climate change on interconnected food, energy, and water systems. Understanding of how climate change affects national security, sustainable and equitable development, and disaster risk reduction and recovery has improved. (Chs. 17, 18; KMs 4.2, 5.2, 6.1, 6.2, 12.2, 19.3)

**Damages by degrees:** Improved understanding of the risks human and environmental systems face under each additional increment of global warming has helped scientists quantify potential damages to health, ecosystems, livelihoods, and the economy (see Box 1). (Ch. 8, Introduction; KM 19.1)

## Responses

**Sophisticated support:** Improved tools, data, and climate projections needed to support adaptation, mitigation, and resilience measures are becoming more widely available, including advancements in quantifying the economic, health, and environmental benefits from climate actions and better documentation of how the benefits and burdens of investments are distributed. (Ch. 4, Introduction; KMs 5.3, 7.3, 11.3, 12.2, 13.2, 31.5, 32.4; Box 17.1)

**Understanding people:** The social sciences are providing new insights into how people experience climate change and how climate actions are understood, communicated, and implemented. Increased documentation of institutional changes, partnerships, knowledge sharing, and sustainable financing options are supporting climate action at multiple levels of government. (KMs 12.3, 31.4, 31.6; Ch. 20)

**Indigenous Knowledge:** Growing efforts to integrate Indigenous Knowledge in community adaptation actions build on accumulated knowledge that has enabled Indigenous Peoples to adapt to environmental change for millennia. (KMs 16.3, 25.5, 27.6, 28.2, 29.5, 30.5; Box 27.2)

**Real-world examples:** More examples of adaptation in practice, such as green infrastructure, nature-based solutions, and changes in governance and financing, are now available. Cities and states that have implemented adaptation actions are sharing best practices and aiding cooperation, and many communities are learning from climate change responses led by Tribal and Indigenous Peoples. (KMs 12.3, 16.3; Ch. 31)

## Reporting Suspected Errata

In case of a suspected error in this report, please send an email containing the following information to [nca-errata-group@usgcrp.gov](mailto:nca-errata-group@usgcrp.gov):

Your full name

Your organization (if applicable)

Chapter and section (e.g., chapter title, Key Message number, or figure number)

An explanation of your concern

# References

1. Global Change Research Act of 1990. 101st Congress, Pub. L. No. 101-606, 104 Stat. 3096–3104, November 16, 1990. <https://www.congress.gov/bill/101st-congress/senate-bill/169/text>
2. USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart, Eds. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. <https://doi.org/10.7930/nca4.2018>
3. National Academies of Sciences, Engineering, and Medicine, 2023: *Review of the Draft Fifth National Climate Assessment*. The National Academies Press, Washington, DC, 346 pp. <https://doi.org/10.17226/26757>
4. Mastrandrea, M.D., K.J. Mach, G.-K. Plattner, O. Edenhofer, T.F. Stocker, C.B. Field, K.L. Ebi, and P.R. Matschoss, 2011: The IPCC AR5 guidance note on consistent treatment of uncertainties: A common approach across the working groups. *Climatic Change*, **108** (4), 675. <https://doi.org/10.1007/s10584-011-0178-6>
5. Arias, P.A., N. Bellouin, E. Coppola, R.G. Jones, G. Krinner, J. Marotzke, V. Naik, M.D. Palmer, G.-K. Plattner, J. Rogelj, M. Rojas, J. Sillmann, T. Storelvmo, P.W. Thorne, B. Trewin, K. Achuta Rao, B. Adhikary, R.P. Allan, K. Armour, G. Bala, R. Barimalala, S. Berger, J.G. Canadell, C. Cassou, A. Cherchi, W. Collins, W.D. Collins, S.L. Connors, S. Corti, F. Cruz, F.J. Dentener, C. Dereczynski, A. Di Luca, A. Diongue Niang, F.J. Doblas-Reyes, A. Dosio, H. Douville, F. Engelbrecht, V. Eyring, E. Fischer, P. Forster, B. Fox-Kemper, J.S. Fuglestedt, J.C. Fyfe, N.P. Gillett, L. Goldfarb, I. Gorodetskaya, J.M. Gutierrez, R. Hamdi, E. Hawkins, H.T. Hewitt, P. Hope, A.S. Islam, C. Jones, D.S. Kaufman, R.E. Kopp, Y. Kosaka, J. Kossin, S. Krakovska, J.-Y. Lee, J. Li, T. Mauritsen, T.K. Maycock, M. Meinshausen, S.-K. Min, P.M.S. Monteiro, T. Ngo-Duc, F. Otto, I. Pinto, A. Pirani, K. Raghavan, R. Ranasinghe, A.C. Ruane, L. Ruiz, J.-B. Sallée, B.H. Samset, S. Sathyendranath, S.I. Seneviratne, A.A. Sörensson, S. Szopa, I. Takayabu, A.-M. Tréguier, B. van den Hurk, R. Vautard, K. von Schuckmann, S. Zaehle, X. Zhang, and K. Zickfeld, 2021: Technical summary. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou, Eds. Cambridge University Press, Cambridge, UK and New York, NY, USA, 33–144. <https://doi.org/10.1017/9781009157896.002>
6. Gidden, M.J., K. Riahi, S.J. Smith, S. Fujimori, G. Luderer, E. Kriegler, D.P. van Vuuren, M. van den Berg, L. Feng, D. Klein, K. Calvin, J.C. Doelman, S. Frank, O. Fricko, M. Harmsen, T. Hasegawa, P. Havlik, J. Hilaire, R. Hoesly, J. Horing, A. Popp, E. Stehfest, and K. Takahashi, 2019: Global emissions pathways under different socioeconomic scenarios for use in CMIP6: A dataset of harmonized emissions trajectories through the end of the century. *Geoscientific Model Development*, **12** (4), 1443–1475. <https://doi.org/10.5194/gmd-12-1443-2019>
7. Meinshausen, M., Z.R.J. Nicholls, J. Lewis, M.J. Gidden, E. Vogel, M. Freund, U. Beyerle, C. Gessner, A. Nauels, N. Bauer, J.G. Canadell, J.S. Daniel, A. John, P.B. Krummel, G. Luderer, N. Meinshausen, S.A. Montzka, P.J. Rayner, S. Reimann, S.J. Smith, M. van den Berg, G.J.M. Velders, M.K. Vollmer, and R.H.J. Wang, 2020: The Shared Socio-economic Pathway (SSP) greenhouse gas concentrations and their extensions to 2500. *Geoscientific Model Development*, **13** (8), 3571–3605. <https://doi.org/10.5194/gmd-13-3571-2020>

8. O'Neill, B.C., E. Kriegler, K.L. Ebi, E. Kemp-Benedict, K. Riahi, D.S. Rothman, B.J. van Ruijven, D.P. van Vuuren, J. Birkmann, K. Kok, M. Levy, and W. Solecki, 2017: The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change*, **42**, 169–180. <https://doi.org/10.1016/j.gloenvcha.2015.01.004>
9. Riahi, K., D.P. van Vuuren, E. Kriegler, J. Edmonds, B.C. O'Neill, S. Fujimori, N. Bauer, K. Calvin, R. Dellink, O. Fricko, W. Lutz, A. Popp, J.C. Cuaresma, S. Kc, M. Leimbach, L. Jiang, T. Kram, S. Rao, J. Emmerling, K. Ebi, T. Hasegawa, P. Havlik, F. Humpenöder, L.A. Da Silva, S. Smith, E. Stehfest, V. Bosetti, J. Eom, D. Gernaat, T. Masui, J. Rogelj, J. Strefler, L. Drouet, V. Krey, G. Luderer, M. Harmsen, K. Takahashi, L. Baumstark, J.C. Doelman, M. Kainuma, Z. Klimont, G. Marangoni, H. Lotze-Campen, M. Obersteiner, A. Tabeau, and M. Tavoni, 2017: The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change*, **42**, 153–168. <https://doi.org/10.1016/j.gloenvcha.2016.05.009>
10. van Vuuren, D.P., J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard, G.C. Hurtt, T. Kram, V. Krey, J.-F. Lamarque, T. Masui, M. Meinshausen, N. Nakicenovic, S.J. Smith, and S.K. Rose, 2011: The Representative Concentration Pathways: An overview. *Climatic Change*, **109** (1), 5. <https://doi.org/10.1007/s10584-011-0148-z>
11. Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A.S. Genz, J.P. Krasting, E. Larour, D. Marcy, J.J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K.D. White, and C. Zuzak, 2022: Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp. <https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report-sections.html>
12. BEA. 2023: Table 1.1.9. Implicit Price Deflators for Gross Domestic Product. U.S. Department of Commerce, Bureau of Economic Analysis. <https://apps.bea.gov/iTable/?reqid=19&step=3&isuri=1&1921=survey&1903=13>