A CLIMATE CHANGE VULNERABILITY AND RISK ASSESSMENT FRAMEWORK FOR CULTURAL RESOURCES IN THE NATIONAL PARK SERVICE'S INTERMOUNTAIN REGION VANISHING TREASURES PROGRAM

PHASE I: COMPILATION OF EXISTING DATA AND MODELS

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In conjunction with:
Desert Southwest Cooperative Ecosystem Studies Unit (DS-CESU)
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Cover photo: Summer rainstorm moving toward Tuzigoot National Monument, Arizona. Photo by Laura Burghardt

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PROJECT INFORMATION

This project was carried out between the National Park Service and the University of Arizona through a Joint Ventures Agreement administered by the Desert Southwest Cooperative Ecosystem Studies Unit (DSCESU).

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EXECUTIVE SUMMARY

Future climate scenarios produced by the National Oceanic and Atmospheric Administration (NOAA) suggest that the National Park Service's Intermountain Region is likely to see temperature and precipitation changes during the next century. These changes and associated environmental changes will likely affect park cultural resources within the region, including resources managed by the Vanishing Treasures program.

Climate scenarios suggest that almost all areas in the region can expect changes in temperature and precipitation, both annually and seasonally. Annual temperatures are expected to increase throughout the region, while annual precipitation is expected to increase in some areas and decrease in others. The annual frequency of extreme weather events, including days with very high (above 95°F) and very low (below 10°F) temperatures and consecutive days of high (more than 1 inch) and low (less than 0.1 inch) precipitation, are expected to change in the region.

Buried archaeological resources and historic architectural resources are vulnerable to changes in the environments in which they exist. These cultural resources are especially vulnerable to changes in moisture, which can increase wetting and drying cycles, potentially accelerating deterioration. Earthen architecture is particularly vulnerable to heavy rainfall events, which may increase in some areas of the region. Areas in which climate changes are expected to be the greatest are perhaps the most vulnerable, because the local climate has the potential to be considerably different than the environment in which historic architectural resources were constructed to suit.

Research on the potential effects of climate change on cultural resources is sparse, especially in the United States. This report recommends that future research focus on topics that are important to the Intermountain Region, including the potential effects of soil moisture and soil chemistry changes on buried archaeological resources and historic architectural resources, as well as climate factors contributing to erosion and the potential effects this process has on cultural resources. Additionally, future research should focus on monitoring techniques for assessing the impacts of temperature and moisture changes on cultural resources, both above and below ground. Increased support for research on the potential effects of climate change on cultural resources within the Intermountain Region will allow resource managers to better monitor and maintain these important resources for their long-term preservation.

PART ONE

INTRODUCTION

INTRODUCTION

PROJECT BACKGROUND

The effects of climate change pose a challenge not only to the managers of natural resources, but also to those who manage cultural resources. Extensive research has been conducted regarding the potential impact of climate change on natural resources and this research has been translated into strategic and management risk assessment policy in the National Park Service (NPS). However, no systematic method exists for identifying significant climate change variables and developing predictive management and treatment decisions for NPS cultural resources.

A National Park Service brief published in March 2013 outlined the agency's commitment to addressing the topic of climate change and cultural resources. This brief notes that while cultural resources have always been subject to various environmental forces, observed and projected climate change trends are concerning, as environmental forces intensify, accelerate, and combine in new ways. These trends have the potential to increase the rate of loss of cultural resources. For this reason, the 2013 brief called for the development of an NPS survey of climate-vulnerable areas and the development of appropriate preservation and documentation techniques.

The NPS Vanishing Treasures Program (VT) has determined that a climate change risk assessment for VT resources is a priority. VT resources include both historic and prehistoric archaeological and architectural resources, comprised of earthen materials (including adobe, earthen mortars, and earthen plasters), stone, and wood, in 46 national park units in the Intermountain Region (IMR) and Pacific West Region (PWR). VT resources are considered more vulnerable to severe impacts from climate change because these resources are more intimately tied to their environment than most modern structures.

This report summarizes the results of the first phase of a long-term, multi-phase project to develop a climate change vulnerability and risk assessment framework for identifying cultural resources most at risk within the Intermountain Region's VT Program. In a multi-region, multi-park effort to assess the threats to built heritage in the parks of the arid west, this project will identify the most at-risk sub-regions and resource types, and develop strategies to mitigate impacts. The development of this framework for identifying risks and assessing the impacts of climate change on cultural resources, as well as developing mitigation and adaptation strategies, is essential to the improvement of planning efforts for the survival of these delicate resources.

This long-term project is designed to be conducted in three phases:

1. Scope the key challenges facing IMR cultural resources through the compilation of existing data and models;
2. Develop scenario planning, adaptation, mitigation, and monitoring options based on use of predictive models and prioritization of the most at-risk resources; and
3. Implement baseline assessment and long-term monitoring protocols to evaluate and refine the modeling and management strategies.

This report is the result of the first phase of the project, the compilation of existing literature, data, and climate change models. The project is a collaboration between the Vanishing Treasures Program (Lauren Meyer) and the University of Arizona's Drachman Institute (R. Brooks Jeffery). This phase of the project took place between July 2013 and June 2014 and was completed by University of Arizona graduate student Laura Burghardt.

PROJECT TASKS

The focus of this first phase of the project is to identify key challenges facing IMR cultural resources through the compilation and analysis of existing literature, data, and climate models. The tasks of this first phase of the project are to:

1. Compile existing data (including climate models and predictions) and literature on climate change in the southwest and the degradation of cultural resources by a variety of climate parameters, as well as other relevant materials;
2. Identify climate parameters that are most destructive to the built environment; and
3. Identify climate models and projections that include the above parameters for the Intermountain Region.

METHODS

This phase of the project is intended to provide a comprehensive review of data and literature on climate change and cultural resources. In order to accomplish this task, a search was conducted online and at the University of Arizona library to identify current existing and emerging tools, policies, baseline documents, context studies, vulnerability assessment guides, building materials risk assessments, and resource databases for cultural resource inventory and monitoring, mapping, and scenario planning. These included data and literature from a range of sources, primarily including the National Park Service, the National Oceanic and Atmospheric Administration (NOAA), the North American Regional Climate Change Assessment Program (NARCCAP), the Climate Assessment for the Southwest (CLIMAS) program, and the National Climate Assessment (NCA). Several international sources were also consulted, including: the Noah's Ark project; the United Nations Educational, Scientific, and Cultural Organization (UNESCO); as well as literature prepared by English Heritage. Several National Park Service staff who study climate change were also consulted, including Marcia Rockman, Patrick Gonzalez, Tom Olliff, Pam Benjamin, Cat Hoffman, and John Gross. A partially annotated bibliography at the end of this report documents all relevant sources identified at the time of publication.

CHALLENGES

An analysis of the potential effects of climate change on cultural resources in the Intermountain Region presents several challenges. Ranging from the northern border of the United States with Canada to the southern border of the country with Mexico, and covering eight states, the region is incredibly diverse in ecosystems and resources. Climate change scenarios from NOAA technical reports, summarized in this report, cover broad regions of several states. Scenarios from these reports are not so specific to a location to allow for accurate projections at specific parks. However, Patrick Gonzalez, NPS Climate Scientist, has written and is currently working on several park-specific climate change and impacts reports.

A wide variety of cultural resources exist within the parks of the Intermountain Region. Resources fall into a range of categories, including historic architecture, architectural ruins, buried archaeology, historic roads and engineering features, cultural landscapes, and museum collections.

The focus of this report is the potential effects of climate change on historic architecture and architectural ruins. Despite this relatively limited focus, it is not possible to fully cover the range of material types and conditions of these resources and the potential effects of projected climate changes in each part of the region that these resources exist. This report summarizes the potential effects of climate change on common architectural materials found in the region. Each resource must be assessed individually to understand the climate changes projected for the resource location and the potential effects these climate changes could have on the individual resource.

REPORT ORGANIZATION

This report is organized into four chapters, including this introductory chapter. The second chapter provides an overview of projected climate changes for the Intermountain Region, based on information provided in 2013 NOAA technical reports. This information is the most current future climate change projection data available at the time of writing this report. The summary of climate change scenarios focuses on the changes that are most likely to affect cultural resources. This chapter includes a set of maps, which overlay NOAA 2013 climate scenario maps onto a map of NPS Intermountain Region units, allowing park resource managers to identify climate change scenario data for their management area.

The final section of the second chapter identifies climate risks related to the climate scenarios identified in NOAA technical reports. This section bridges the gap between climate scenarios and the effects these scenarios may have on cultural resources by identifying physical changes that may result from climate changes and will affect resources. A comprehensive matrix at the end of the second chapter relates projected climate changes to climate risks and climate change indicators.

The third chapter describes the potential impacts of climate change to cultural resources, focusing on the potential effects of different climate risks on architectural materials and buried archaeological resources. The term "cultural resources" will be used throughout this report to generally refer to these types of resources. Architectural materials discussed in this chapter include those most commonly found in VT resources. Architectural material vulnerabilities are paired with potential climate impacts to analyze likely methods of deterioration that could result from future climate changes.

The fourth chapter of this report provides concluding remarks, including an analysis of VT resources and areas of the region that are likely most vulnerable to climate change and suggestions for future research. The report concludes with a partially annotated bibliography of literature related to climate change and cultural resources.

This report is meant to be an initial step in addressing the potential impacts of climate change on cultural resources in the Intermountain Region. The compilation and summary of relevant climate scenarios and architectural materials deterioration research in the following chapters explore how changes in the region's climate may detrimentally impact cultural resources. The report is intended for use by cultural resource managers as an introduction to the topic of climate change and cultural resources. Additionally, the report is intended as a reference for future phases of the project, which are designed to explore resource vulnerability, as well as monitoring and management strategies to address the impacts of climate change on cultural resources.

PART TWO

FUTURE CLIMATE CHANGES

FUTURE CLIMATE CHANGES

INTRODUCTION

Climate is extremely variable within the Intermountain Region. Even climates within individual parks are variable, primarily due to variation in elevation. Climate change scenarios are not currently available at a scale small enough to look at the possible effects on individual cultural resources within the region, based on the individual locations of resources. However, looking at general future climate scenarios for the Intermountain Region, and combining this with the knowledge of how cultural resources can be affected by climate parameters, provides a better idea of what to expect in the future.

On the advice of climate scientists with the National Park Service, including Patrick Gonzalez, Tom Olliff, and Cat Hawkins Hoffman, the 2013 National Oceanic and Atmospheric Administration (NOAA) Regional Climate Reports for the National Climate Assessment (NCA) will be used as the primary source of information for climate simulations and scenarios for this report. Although the NOAA report scenarios are divided into large regions, encompassing several states, the climate scientists consulted recommended this as the best scale of scenarios for this Intermountain Region project.

This chapter will first look at climate simulations for the Intermountain Region as described in the NOAA reports. Selected relevant information and maps have been summarized and included so that resource managers may identify climate data applicable for their locations. Maps from the NOAA reports are included in each summary section for reference. Additionally, maps created by the author overlay NOAA report maps onto a map of Intermountain Region parks. These maps should be viewed with an understanding that boundaries marking the degree of projected changes are not as precise as the underlying parks map; as they are based on the more general lines indicated in the NOAA report maps. Despite this, these composite maps provide a useful reference for park managers in defining the general degree and direction of projected climate changes.

The NOAA reports provide very general information on projected future temperature and precipitation changes. Although useful for understanding future climate, this information does not translate well into expected effects on cultural resources. In order to understand how temperature and precipitation changes can affect cultural resources, the second part of this chapter will identify ecosystem effects (i.e., increased erosion, changes in the distribution of pests) that are expected to result from projected climate changes identified in the NOAA reports. The table at the end of this chapter (Table 2.1) identifies climate scenarios and associated ecosystem changes for quick reference.

FUTURE REGIONAL CLIMATE SCENARIOS

NOAA has produced future climate scenarios covering the Intermountain Region in the form of technical reports for the National Climate Assessment (NCA). The most recent National Climate Assessment was published in 2009; the next will be published in 2014. The NOAA technical reports used for this report were published in 2013, and will be used as the primary source of information for the authors of the 2014 NCA. These are the most up-to-date climate assessments from NOAA available at the time of the writing of this report.

The states within the National Park Service's Intermountain Region lie within the NCA's Great Plains and Southwest regions, Parts 4 and 5, respectively, of the Regional Climate Trends and Scenarios for the U.S. National Climate Assessment Technical Report, published January 2013. At this time, these climate scenarios are those most often consulted by climate scientists in the NPS. For the purposes of this project, the NOAA reports provide climate scenarios that are at an appropriate scale for looking at the effects of climate change on cultural resources. Climate scenarios differ from climate projections in that climate scenarios do not have established probabilities for their future realization. The physical climate framework for the NOAA technical reports is based on future climate model simulations using the high (A2) and low (B1) Intergovernmental Panel on Climate Change (IPCC) special report emissions scenarios (SRES) (see NOAA 2013, Part 5:5-6).

Analyses for relevant future climate scenarios are provided in the NOAA reports for the future time period 2041-2070 with changes calculated with respect to an historical climate reference period (1971-2000 or 1980-2000). Although a single reference period would have been ideal, information from a single period was not available for all climate variables. More information about how the

2013 report climate scenarios were developed by NOAA, including information on the emissions scenarios used, can be found in the introduction sections of any one of the 2013 technical reports.

The following sections summarize the future regional climate scenarios published in the NOAA technical reports for the National Climate Assessment for the areas within the Intermountain Region. Of the states within the Intermountain Region, the NCA Great Plains Region includes Montana, Wyoming, Oklahoma, and Texas; the NCA Southwest Region includes Utah, Colorado, Arizona, and New Mexico.

Mean Temperature Changes

All states within the Intermountain Region are simulated to have an increase in mean annual temperatures during the twenty-first century. Mean temperatures are simulated to increase during all seasons in all areas of the region, though seasonal temperature increases vary spatially.

Southwest

In the Southwestern states, NOAA's future weather climate scenarios indicate that mean surface temperatures will continue to increase during the twenty-first century (see Figures 2.1 and 2.3). Simulated mean annual temperature increases are generally uniform for the region and in the range of 4 to 5°F for the period of 2041-2070, using the reference period of 1971-2000. Warming tends to be slightly greater in the north part of the Southwest, including Utah and Colorado (NOAA 2013, Part 5:33-40).

Simulated future seasonal temperature changes for the Southwest indicate that warming will occur in all areas of the region in all seasons. However, seasonal future temperature changes show more spatial variability than annual mean changes. More warming will occur in the summer and fall than in the winter and spring. Winter differences are simulated to range from 2.5 to 4.5°F with the greatest warming occurring in the middle of the region, especially Utah. Springtime temperature increases are within the same range, but with the greatest warming occurring in western New Mexico. Summer shows the greatest temperature increases across the region, in the range of 4 to 6.5°F. The greatest increases for summer are simulated for northern areas of the Southwest region, including parts of Colorado and Utah. Fall temperature increases are in the range of 3.5 and 5.5°F with the greatest increases simulated for the eastern parts of the region, including parts of Colorado and New Mexico (NOAA 2013, Part 5:33-40).

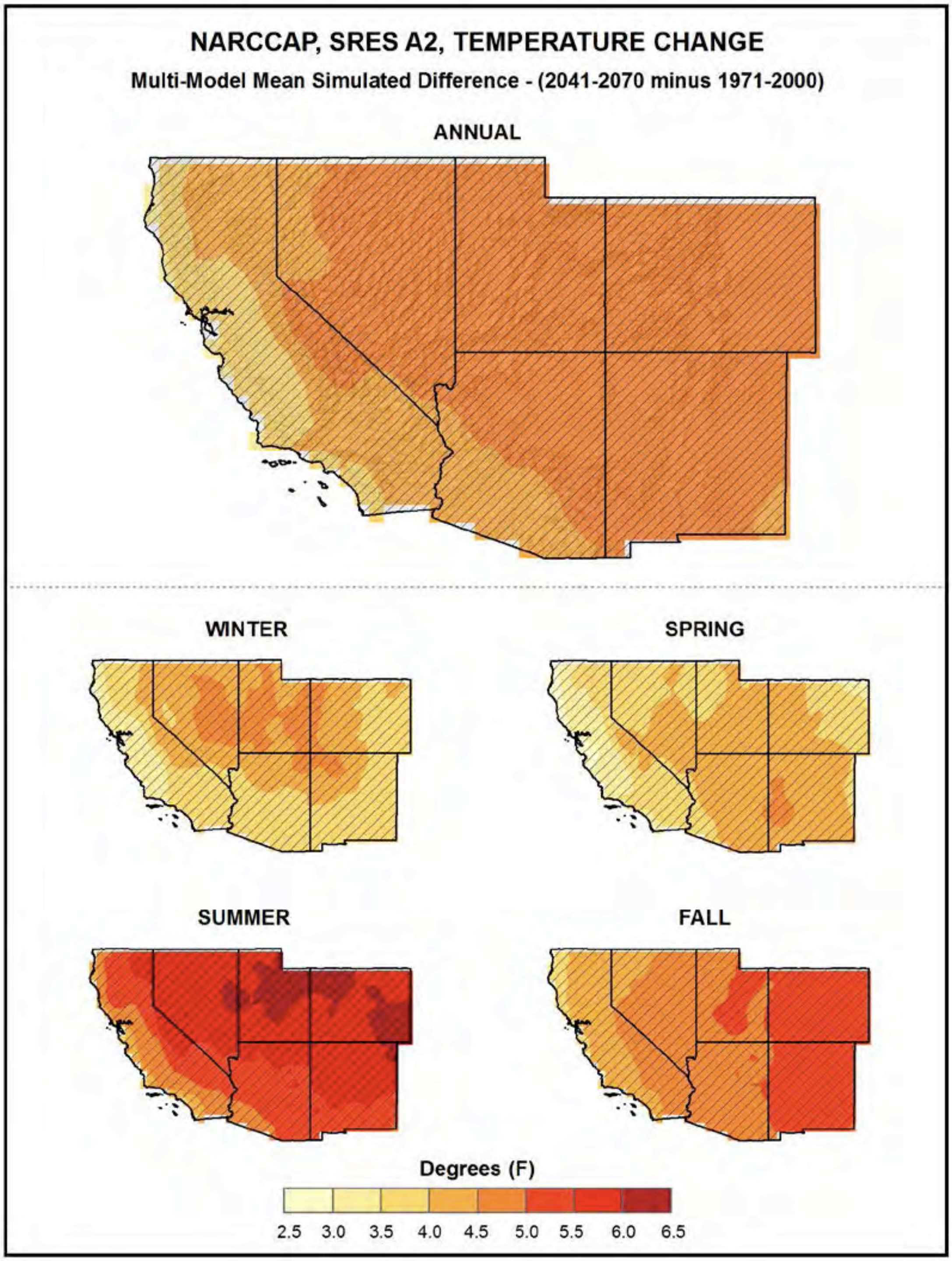


Figure 2.1. Simulated difference in annual and seasonal mean temperature (°F) for the Southwest region, for 2041-2070 with respect to the reference period of 1971-2000. Color with hatching indicates that more than 50% of the models show a statistically significant change in temperature, and more than 67% agree on the sign of the change. (NOAA 2013, Part 5, Figure 15)

Great Plains

In the Great Plains region, both annual and seasonal temperatures have generally been above the 1901-1960 average for the last twenty years. NOAA's simulations indicate that this 20-year warming trend will continue during the twenty-first century. The mean annual average temperature change for 2041-2070, with a reference period of 1971-2000, is simulated to be quite uniform and generally in the range of 4 to 5°F, except coastal Texas, where the warming is smaller (see Figures 2.2 and 2.3). This is roughly the same range of future temperature increase simulated for the Southwest region. (NOAA 2013, Part 4:35-42).

Simulated future temperature changes indicate that temperatures will increase in all seasons throughout the Great Plains. Seasonal temperature changes are simulated to have more spatial variability than mean annual temperature changes. Winter temperatures in the region are simulated to increase in the range of 3 and 6.5°F, with the greatest increases simulated for the northern part of the region, including parts of Montana. Simulated spring temperature changes are generally smaller than other seasons, in the range of 2.5 to 4.5°F, with the greatest warming simulated for southwest Texas. Summer temperature changes are generally larger than those of other season, as was also noted in the Southwest region. Temperature changes for the summer in the Great Plains are in the range of 3.5 to 6.5°F. The largest warming in this part of the Intermountain Region is simulated for Oklahoma panhandle and southern Wyoming. Fall warming ranges from 3.5 to 5.5°F, with the greatest temperature increases simulated for the central part of the Great Plains, including parts of Texas, Oklahoma, and Wyoming (NOAA 2013, Part 4:35-42).

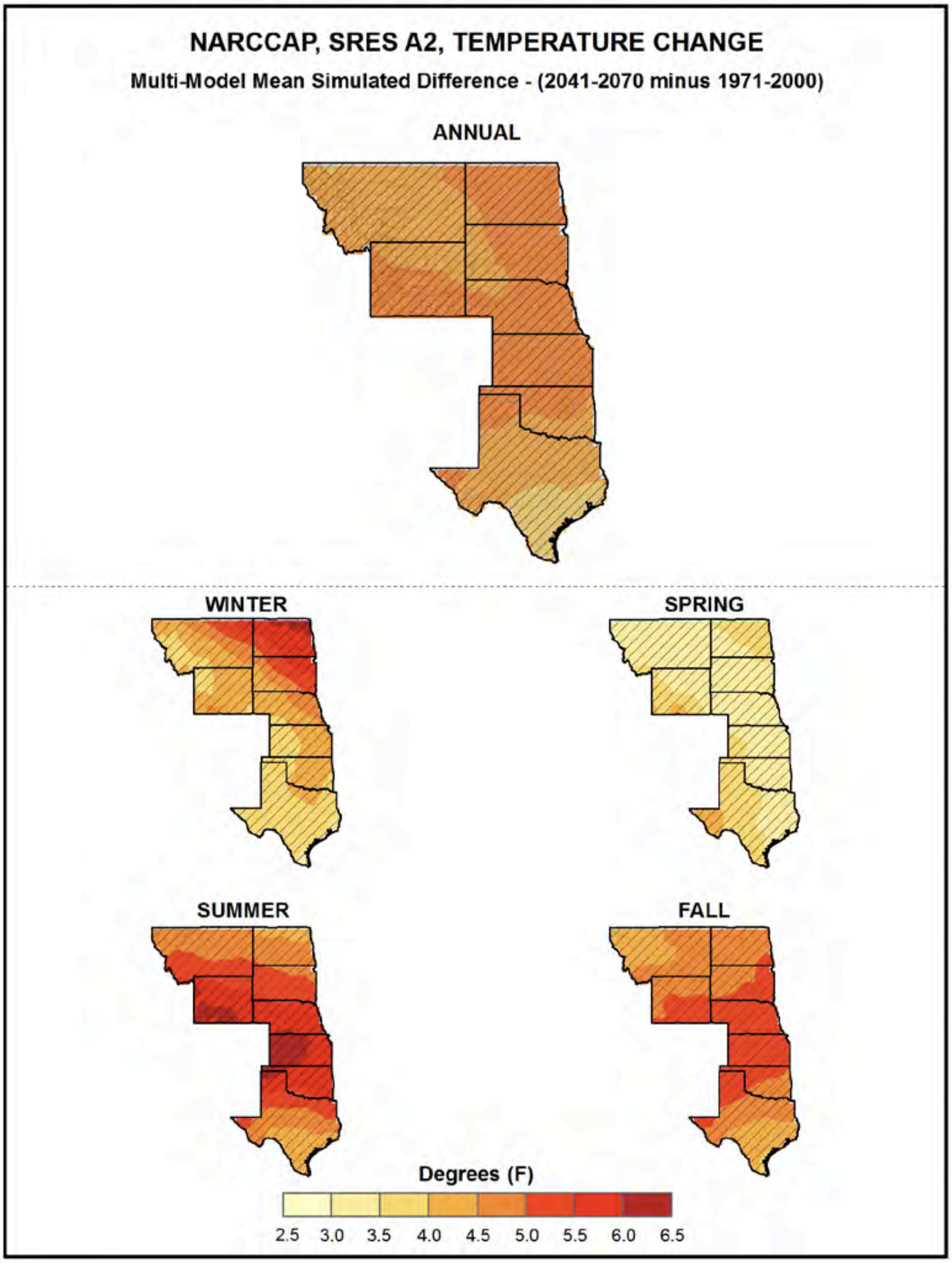
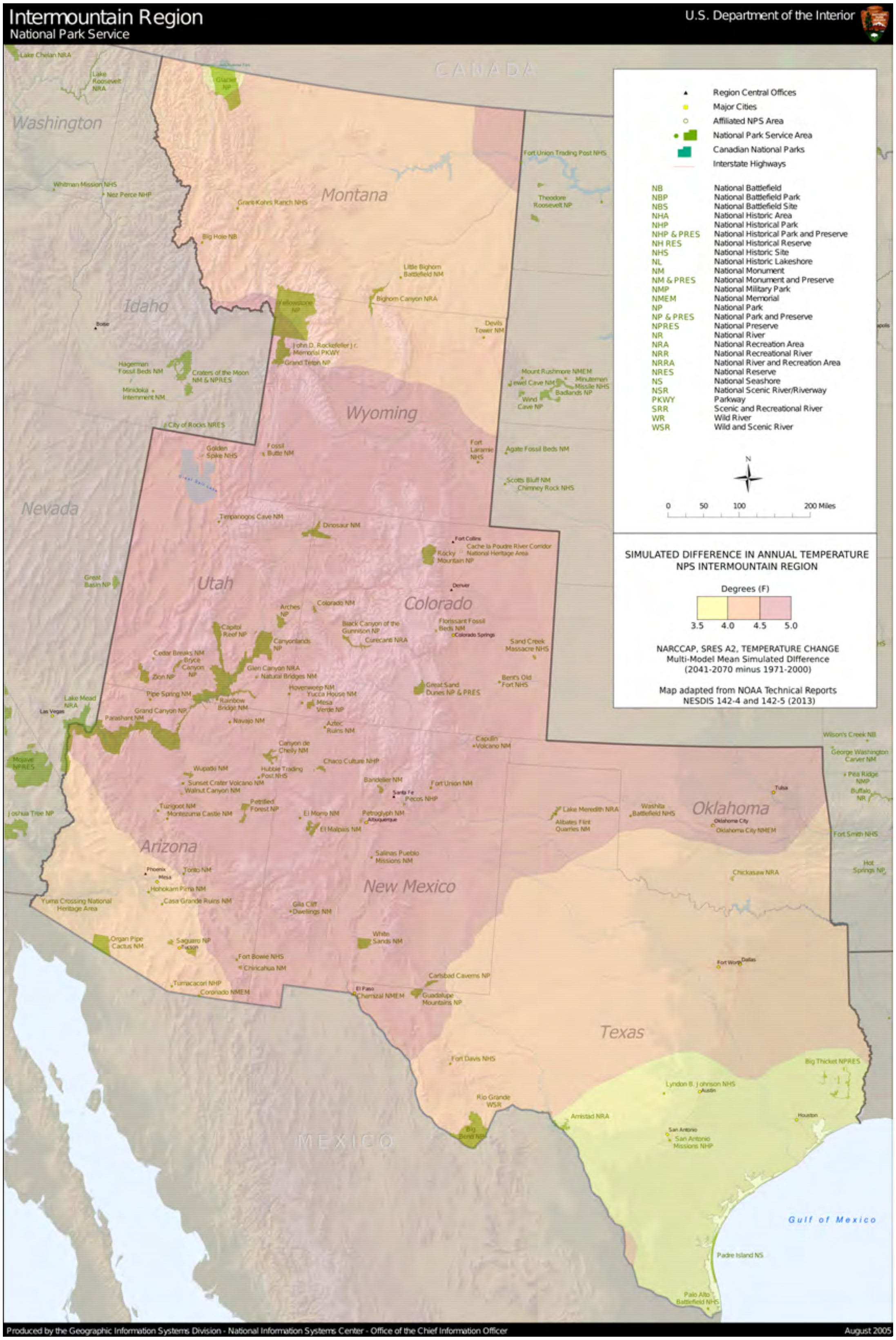


Figure 2.2. Simulated difference in annual and seasonal mean temperature (°F) for the Great Plains region for 2041-2070 with respect to the reference period of 1971-2000. Color with hatching indicates that more than 50% of the models show a statistically significant change in temperature, and more than 67% agree on the sign of the change. (NOAA 2013, Part 4, Figure 14)

Figure 2.3. Simulated difference in annual mean temperature (°F) for the NPS Intermountain Region for 2041-2070 with respect to the reference period of 1971-2000. Overlay of NOAA 2013, Part 5, Figure 15 and NOAA 2013, Part 4, Figure 14 onto NPS map of Intermountain Region parks. Statistical significance indicated on original maps is not shown on this map. Lines separating degree of difference are generally based on overlaid NOAA maps. (Composite map by author)


Intermountain Region
National Park Service
U.S. Department of the Interior
CANADA
MEXICO
Gulf of Mexico
Washington
Montana
Idaho
Wyoming
Nevada
Utah
Colorado
Arizona
New Mexico
Oklahoma
Texas
Region Central Offices
Major Cities
Affiliated NPS Area
National Park Service Area
Canadian National Parks
Interstate Highways
NB National Battlefield
NBP National Battlefield Park
NBS National Battlefield Site
NHA National Historic Area
NHP National Historical Park
NHP & PRES National Historical Park and Preserve
NH RES National Historical Reserve
NHS National Historic Site
NL National Historic Lakeshore
NM National Monument
NM & PRES National Monument and Preserve
NMP National Military Park
NMEM National Memorial
NP National Park
NP & PRES National Park and Preserve
NPRES National Preserve
NR National River
NRA National Recreation Area
NRR National Recreational River
NRRA National River and Recreation Area
NRES National Reserve
NS National Seashore
NSR National Scenic River/Riverway
PKWY Parkway
SRR Scenic and Recreational River
WR Wild River
WSR Wild and Scenic River
N
0
50
100
200 Miles
SIMULATED DIFFERENCE IN ANNUAL TEMPERATURE
NPS INTERMOUNTAIN REGION
Degrees (F)
3.5
4.0
4.5
5.0
NARCCAP, SRES A2, TEMPERATURE CHANGE
Multi-Model Mean Simulated Difference
(2041-2070 minus 1971-2000)
Map adapted from NOAA Technical Reports
NESDIS 142-4 and 142-5 (2013)
Lake Chelan NRA
Lake Roosevelt NRA
Glacier NP
Whitman Mission NHS
Nez Perce NHP
Grant-Kohrs Ranch NHS
Big Hole NB
Fort Union Trading Post NHS
Theodore Roosevelt NP
Little Bighorn Battlefield NM
Bighorn Canyon NRA
Yellowstone NP
Devils Tower NM
John D. Rockefeller Jr. Memorial PKWY
Grand Teton NP
Boise
Hagerman Fossil Beds NM
Craters of the Moon NM & NPRES
Minidoka Internment NM
City of Rocks NRES
Mount Rushmore NMEM
Jewel Cave NM
Minuteman Missile NHS
Badlands NP
Wind Cave NP
Golden Spike NHS
Fossil Butte NM
Fort Laramie NHS
Agate Fossil Beds NM
Scotts Bluff NM
Chimney Rock NHS
Great Salt Lake
Timpanogos Cave NM
Dinosaur NM
Fort Collins
Cache la Poudre River Corridor National Heritage Area
Rocky Mountain NP
Denver
Great Basin NP
Arches NP
Colorado NM
Black Canyon of the Gunnison NP
Curecanti NRA
Florissant Fossil Beds NM
Colorado Springs
Capitol Reef NP
Canyonlands NP
Sand Creek Massacre NHS
Cedar Breaks NM
Bryce Canyon NP
Zion NP
Glen Canyon NRA
Natural Bridges NM
Hovenweep NM
Yucca House NM
Mesa Verde NP
Great Sand Dunes NP & PRES
Bent's Old Fort NHS
Pipe Spring NM
Lake Mead NRA
Las Vegas
Rainbow Bridge NM
Parashant NM
Grand Canyon NP
Navajo NM
Aztec Ruins NM
Capulin Volcano NM
Canyon de Chelly NM
Chaco Culture NHP
Mojave NPRES
Wupatki NM
Hubbell Trading Post NHS
Sunset Crater Volcano NM
Walnut Canyon NM
Bandelier NM
Santa Fe
Fort Union NM
Pecos NHP
Wilson's Creek NB
George Washington Carver NM
Pea Ridge NMP
Buffalo NR
Tulsa
Joshua Tree NP
Tuzigoot NM
Montezuma Castle NM
Petrified Forest NP
El Morro NM
Petroglyph NM
Albuquerque
El Malpais NM
Lake Meredith NRA
Alibates Flint Quarries NM
Washita Battlefield NHS
Oklahoma City
Oklahoma City NMEM
Fort Smith NHS
Salinas Pueblo Missions NM
Phoenix
Mesa
Tonto NM
Hohokam Pima NM
Casa Grande Ruins NM
Yuma Crossing National Heritage Area
Gila Cliff Dwellings NM
Chickasaw NRA
Hot Springs NP
Organ Pipe Cactus NM
Saguaro NP
Tucson
White Sands NM
Fort Bowie NHS
Chiricahua NM
Tumacacori NHP
Coronado NMEM
Carlsbad Caverns NP
El Paso
Chamizal NMEM
Guadalupe Mountains NP
Fort Worth
Dallas
Fort Davis NHS
Big Thicket NPRES
Lyndon B. Johnson NHS
Austin
Rio Grande WSR
Amistad NRA
Houston
Big Bend NP
San Antonio
San Antonio Missions NHP
Padre Island NS
Palo Alto Battlefield NHS
Produced by the Geographic Information Systems Division - National Information Systems Center - Office of the Chief Information Officer
August 2005

Extreme Temperatures

For the purposes of this study, days with extreme temperatures are considered those with a maximum temperature exceeding 95°F or a minimum temperature less than 10°F. Throughout the region, the number of days with extreme heat are expected to increase while the number of days with extreme cold are expected to decrease. Changes in the number of days with extreme temperatures vary greatly across the region, with some areas simulated to experience large increases in the number of extreme temperature days and some areas not showing statistically significant changes.

Southwest

According to future temperature simulations for the Southwest region, heat waves during the summer will be longer and hotter, while cold snaps during the winter will likely become less frequent, but will not necessarily be less severe (Institute of the Environment 2013:5).

The average annual number of days with a maximum temperature exceeding 95°F is simulated to increase throughout the Southwest region (see Figures 2.4, 2.5, and 2.10). NOAA simulations are for the future time period of 2041-2070 with regard to the reference period 1980-2000. Simulations indicate increases of more than 25 days of extreme heat in the southern and eastern areas of the Southwest. These areas of the region already experience the highest number of extreme heat days in the historical period, more than 30 days in some areas of Arizona and New Mexico. The smallest increases in the number of days of extreme heat, less than 5 days, are simulated for the highest elevation areas of the region. In these high elevation areas, the general increase in temperature is not large enough to markedly increase chances for days above 95°F (NOAA 2013, Part 5:40-45).

NOAA's simulated mean change in the average annual number of days with a minimum temperature less than 10°F for the future time period of 2041-2070 with regard to the reference period 1980-2000 indicate that the number of days of extreme cold will decrease throughout the region (see Figures 2.6, 2.7, and 2.11). The interior north, including parts of Colorado and Utah, is simulated to experience a large decrease in the number of extreme cold days, whereas the southern areas of the region will experience little or no change in the annual number of extreme cold days. The largest decreases simulated are for higher elevation areas, some of which will have 25 fewer days of extreme cold. Decreases in the number of extreme cold days are largest in the northeast part of the region and smallest in the south and west parts of the region, a pattern similar to the present-day climatology (NOAA 2013, Part 5:40-45).

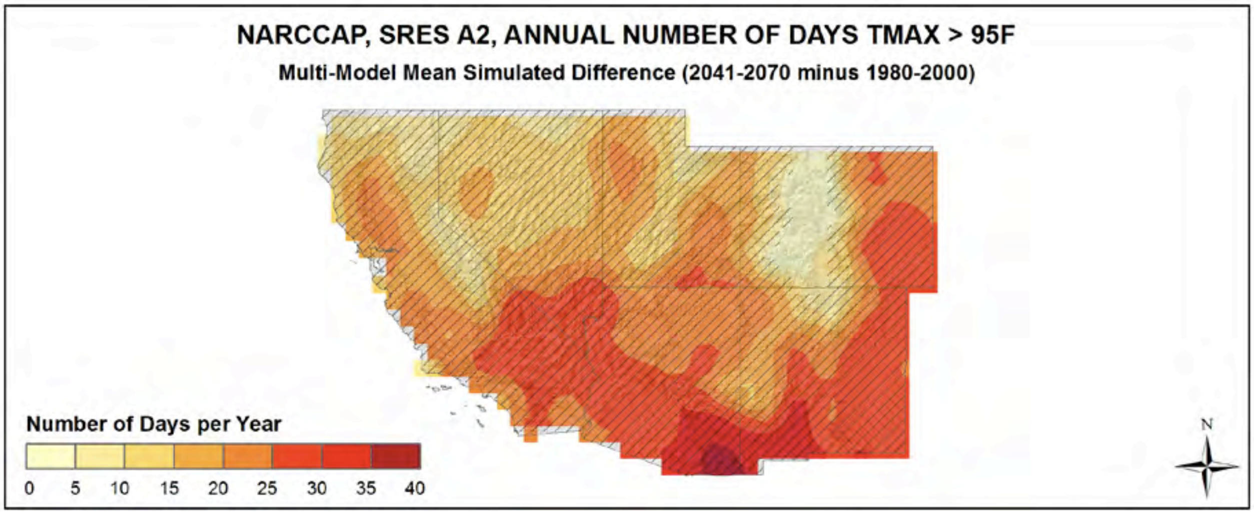


Figure 2.4. Simulated difference in the mean annual number of days with a maximum temperature greater than 95°F for the 2041-2070 time period using the reference period of 1980-2000 in the Southwest region. Color with hatching indicates that more than 50% of the models show a statistically significant change in the number of days, and more than 67% agree on the sign of the change. (NOAA 2013, Part 5, Figure 18)

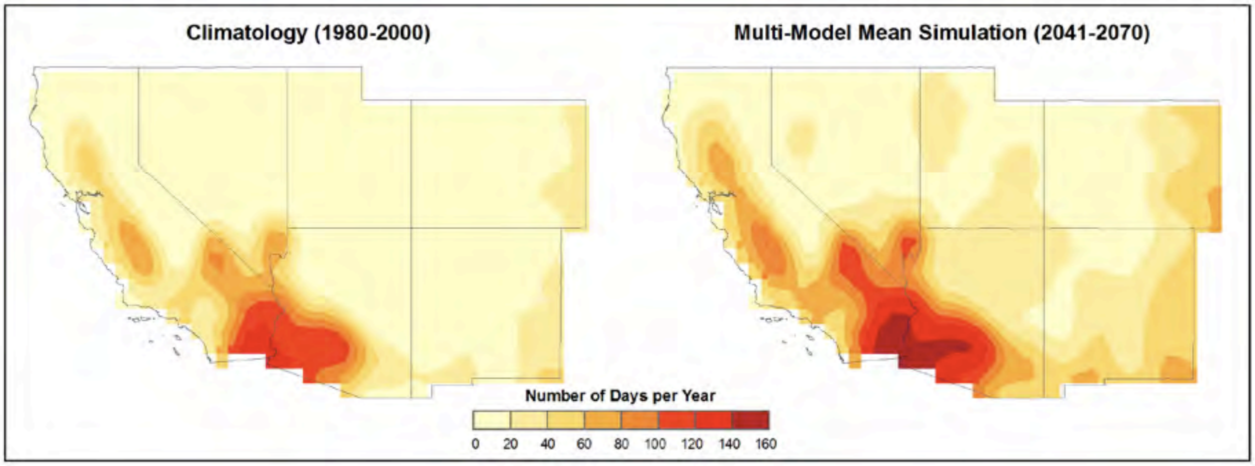


Figure 2.5. Mean annual number of days with a maximum temperature greater than 95°F for the 1980-2000 reference period in the Southwest region (left). Mean annual number of days with a maximum temperature greater than 95°F for the simulated 2041-2070 future time period in the Southwest region (right). (NOAA 2013, Part 5, Figure 18)

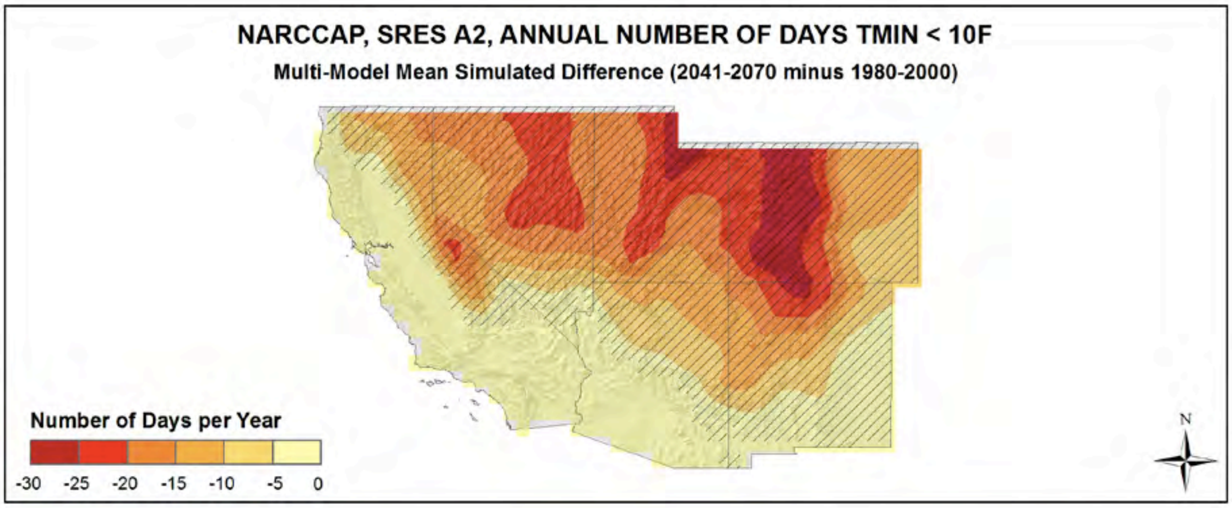


Figure 2.6. Simulated difference in the mean annual number of days with a minimum temperature less than 10°F for the 2041-2070 time period using the reference period of 1980-2000 in the Southwest region. Color with hatching indicates that more than 50% of the models show a statistically significant change in the number of days, and more than 67% agree on the sign of the change. (NOAA 2013, Part 5, Figure 19)

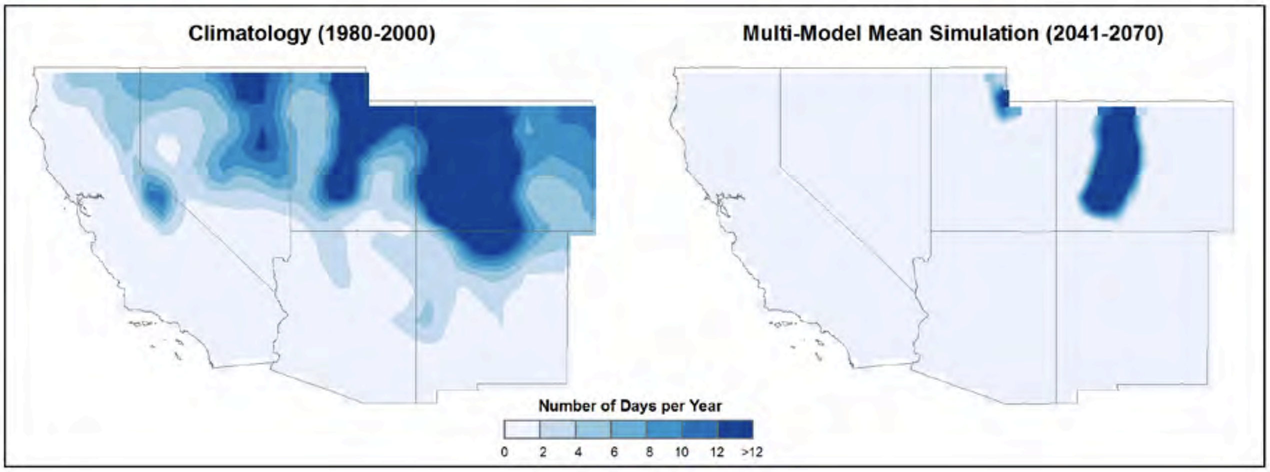


Figure 2.7. Mean annual number of days with a minimum temperature less than 10°F for the 1980-2000 reference period (left). Mean annual number of days with a minimum temperature less than 10°F for the simulated 2041-2070 future time period (right). (NOAA 2013, Part 5, Figure 19)

Great Plains

The Great Plains region is expected to see longer and hotter heat waves, as well as fewer extreme cold days. The average annual number of days with a maximum temperature exceeding 95°F for the future time period of 2041-2070 with regards to the reference period of 1980-2000 is simulated to increase (see Figure 2.8 and 2.10). The largest simulated increases of annual extreme heat days occur in the southwest corner of Texas with increases of more than 30 days. The area from Texas north to southeast Wyoming, including Oklahoma, is simulated to see an increase of more than 20 days. The smallest increases of less than 10 days are simulated for the far north of the Great Plains region, including Wyoming and Montana, and in high elevation areas. For most models, the changes are not statistically significant for a portion of western Wyoming and Montana (NOAA 2013, Part 4:42-47).

The simulated change in the average annual number of days with a minimum temperature of less than 10°F shows a decrease in these extreme cold days in the Great Plains region for the future period 2041-2070 with regards to the reference period of 1980-2000 (see Figure 2.9 and 2.11). The northern half of the region, including Wyoming and Montana, is simulated to experience the largest decrease in extreme cold days. High elevation areas and areas near the Canadian border are simulated to have the greatest changes in the number of extreme cold days, with some areas indicating decreases of 25 days or more. The changes in Oklahoma and Texas are not statistically significant because the number of extreme cold days in the historical period is small.

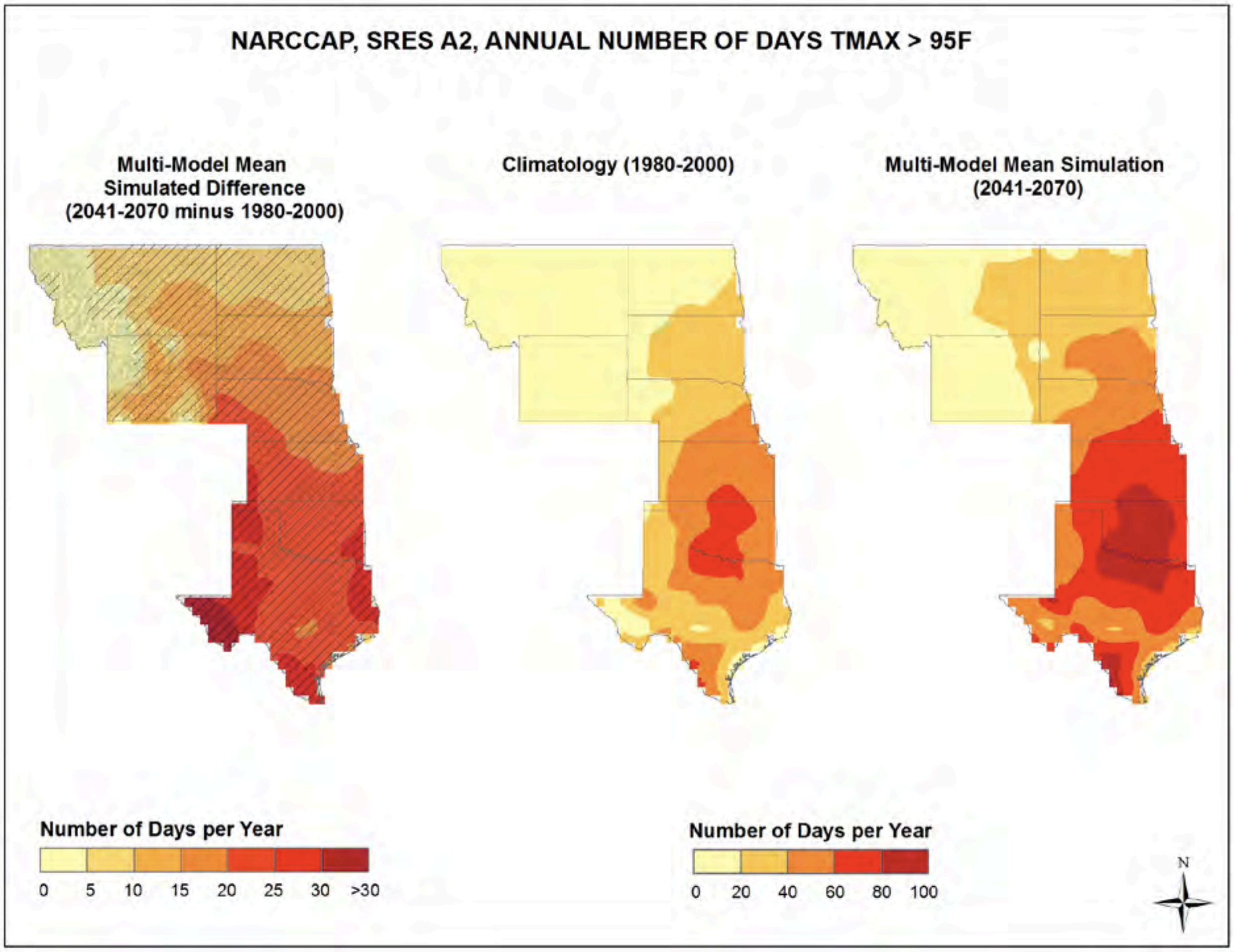


Figure 2.8. Simulated difference in the mean annual number of days with a maximum temperature greater than 95°F for the 2041-2070 future time period using the reference period of 1980-2000 in the Great Plains region (left). Color with hatching indicates that more than 50% of the models show a statistically significant change in the number of days, and more than 67% agree on the sign of the change. Mean annual number of days with a maximum temperature greater than 95°F for the 1980-2000 reference period (center). Mean annual number of days with a maximum temperature greater than 95°F for the simulated 2041-2070 future time period (right). Note that the color scale for the left map is different than that for the center and right. (NOAA 2013, Part 4, Figure 17)

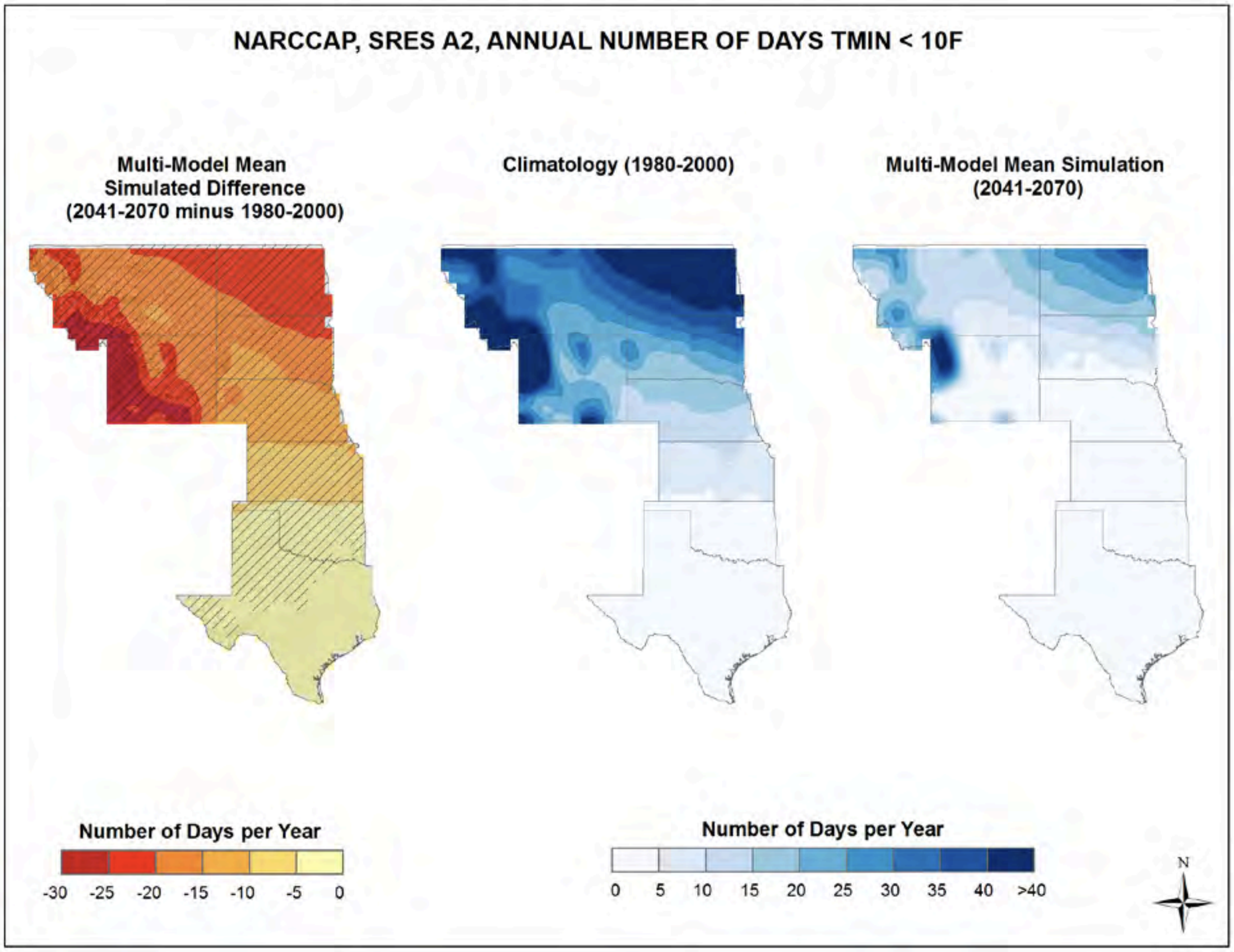
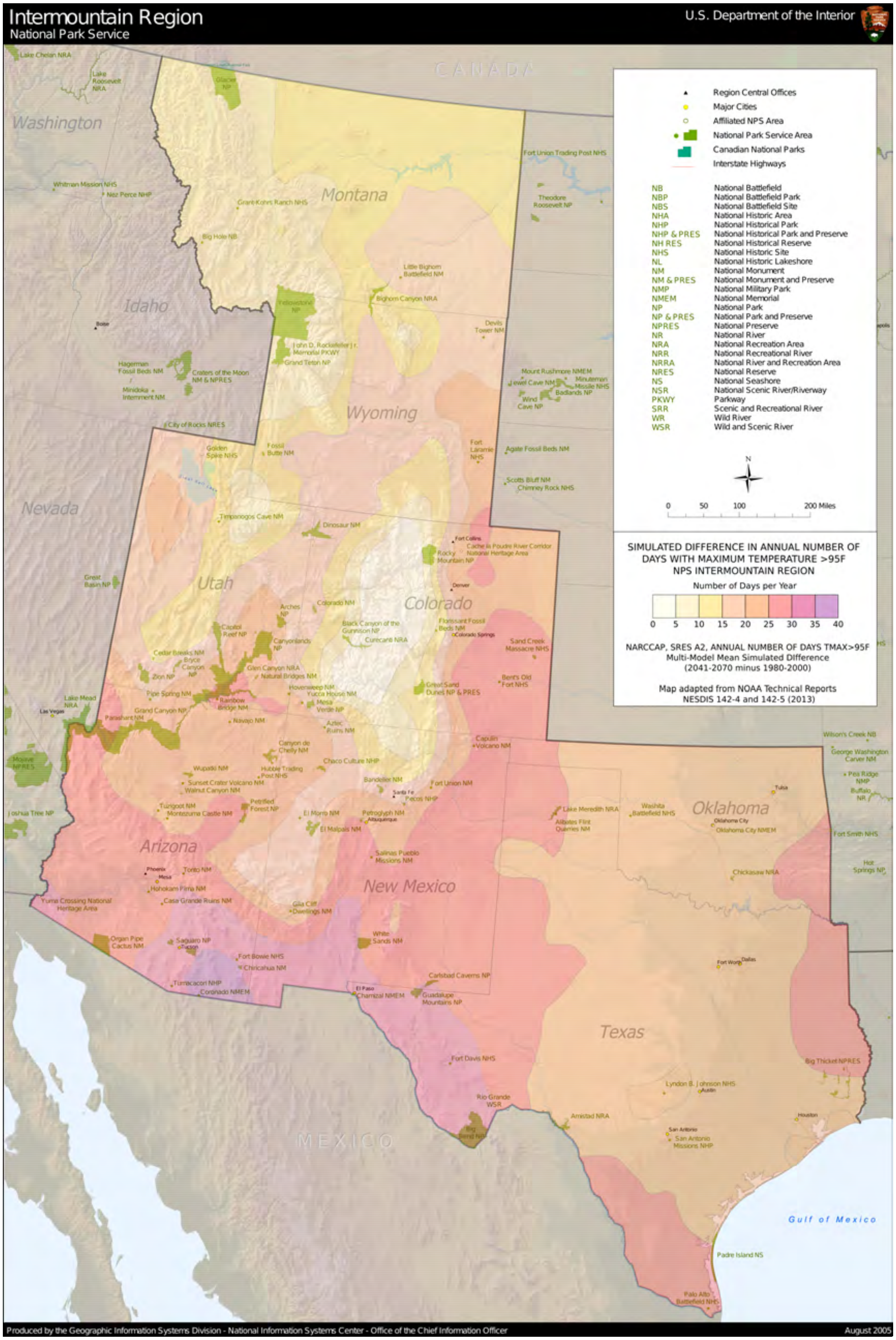


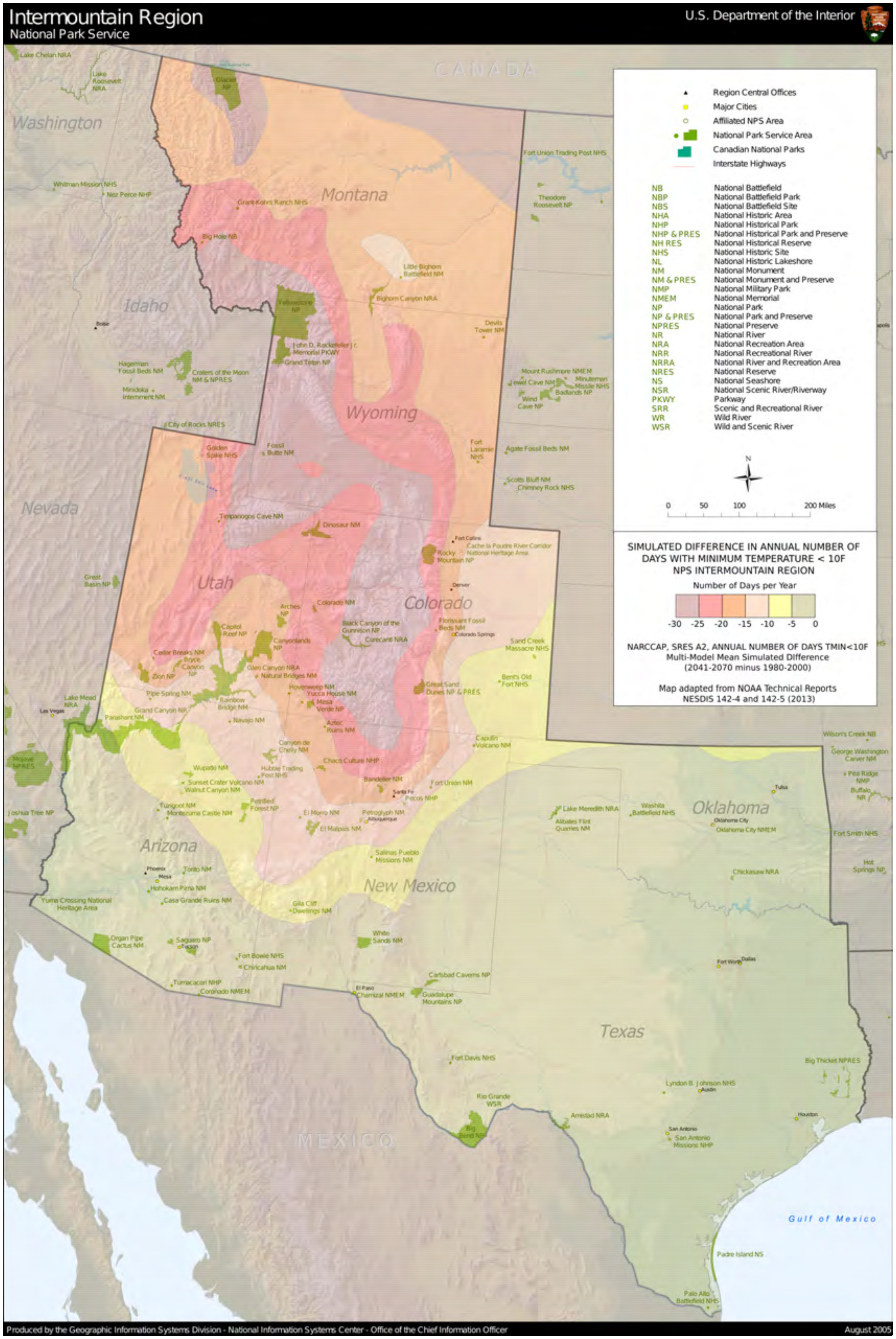
Figure 2.9. Simulated difference in the mean annual number of days with a minimum temperature less than 10°F for the 2041-2070 time period using the reference period of 1980-2000 in the Great Plains region. Color with hatching indicates that more than 50% of the models show a statistically significant change in the number of days, and more than 67% agree on the sign of the change (left). Mean annual number of days with a minimum temperature less than 10°F for the 1980-2000 reference period (center). Mean annual number of days with a minimum temperature less than 10°F for the simulated 2041-2070 future time period (right). Note that the color scale for the left map is different than that for the center and right. (NOAA 2013, Part 4, Figure 18)

Figure 2.10. Simulated mean annual number of days with a maximum temperature greater than 95°F for the 2041-2070 future time period using the reference period of 1980-2000 for the NPS Intermountain Region. Overlay of NOAA 2013, Part 5, Figure 18 and NOAA 2013, Part 4, Figure 17 onto NPS map of Intermountain Region parks. Statistical significance indicated on original maps is not shown on this map. Lines separating degree of difference are not precise, but generally based on overlaid NOAA maps. (Composite map by author)



A Climate Change Vulnerability And Risk Assessment Framework For Cultural Resources in the National Park Service's Intermountain Region Vanishing Treasures Program
Phase I: Compilation of Existing Data and Models

Figure 2.11. Simulated difference in the mean annual number of days with a minimum temperature less than 10°F for the 2041-2070 time period using the reference period of 1980-2000 for the NPS Intermountain Region. Overlay of NOAA 2013, Part 5, Figure 19 and NOAA 2013, Part 4, Figure 18 onto NPS map of Intermountain Region parks. Statistical significance indicated on original maps is not shown on this map. Lines separating degree of difference are not precise, but generally based on overlaid NOAA maps. (Composite map by author)



A Climate Change Vulnerability And Risk Assessment Framework For Cultural Resources in the National Park Service's Intermountain Region Vanishing Treasures Program Phase I: Compilation of Existing Data and Models

Changes In Mean Precipitation

NOAA simulations indicate that precipitation changes will vary spatially across the Intermountain Region, with some areas expected to see increases in precipitation, some expected to see decreases, and some expected to see no change. Models for changes in precipitation are generally not as statistically significant as those for changes in mean temperature.

Southwest

Climate scientists project that the average annual precipitation will decrease in the southern Southwest and perhaps increase in the northern Southwest (Institute of the Environment 2013:6).

According to the NOAA report simulations, generally, there is a north-south gradient in the region in respect to precipitation change for the future time period 2041-2070 with respect to the reference period 1971-2000. (see Figures 2.12 and 2.14). The largest decreases in annual precipitation are projected for the Sierra Nevada and southern parts of Arizona and New Mexico. Parts of Nevada and Utah are simulated to see a slight increase of up to 6 percent in annual precipitation. Winter, the wettest season in the Southwest, has the smallest variability in precipitation change, ranging from -10 to greater than 15 percent. Spring is expected to be drier in most of the region, with the largest decreases simulated in parts of Arizona and New Mexico. The largest variability in precipitation change occurs in summer, ranging from decreases of more than 15 percent in parts of Utah, Arizona, and New Mexico, to increases of more than 15 percent in part of northern Utah. Fall changes in precipitation are mostly downward. Annually, and for all seasons, simulated changes in precipitation are not statistically significant for most models of the majority of the region (NOAA, Part 5:51-57).

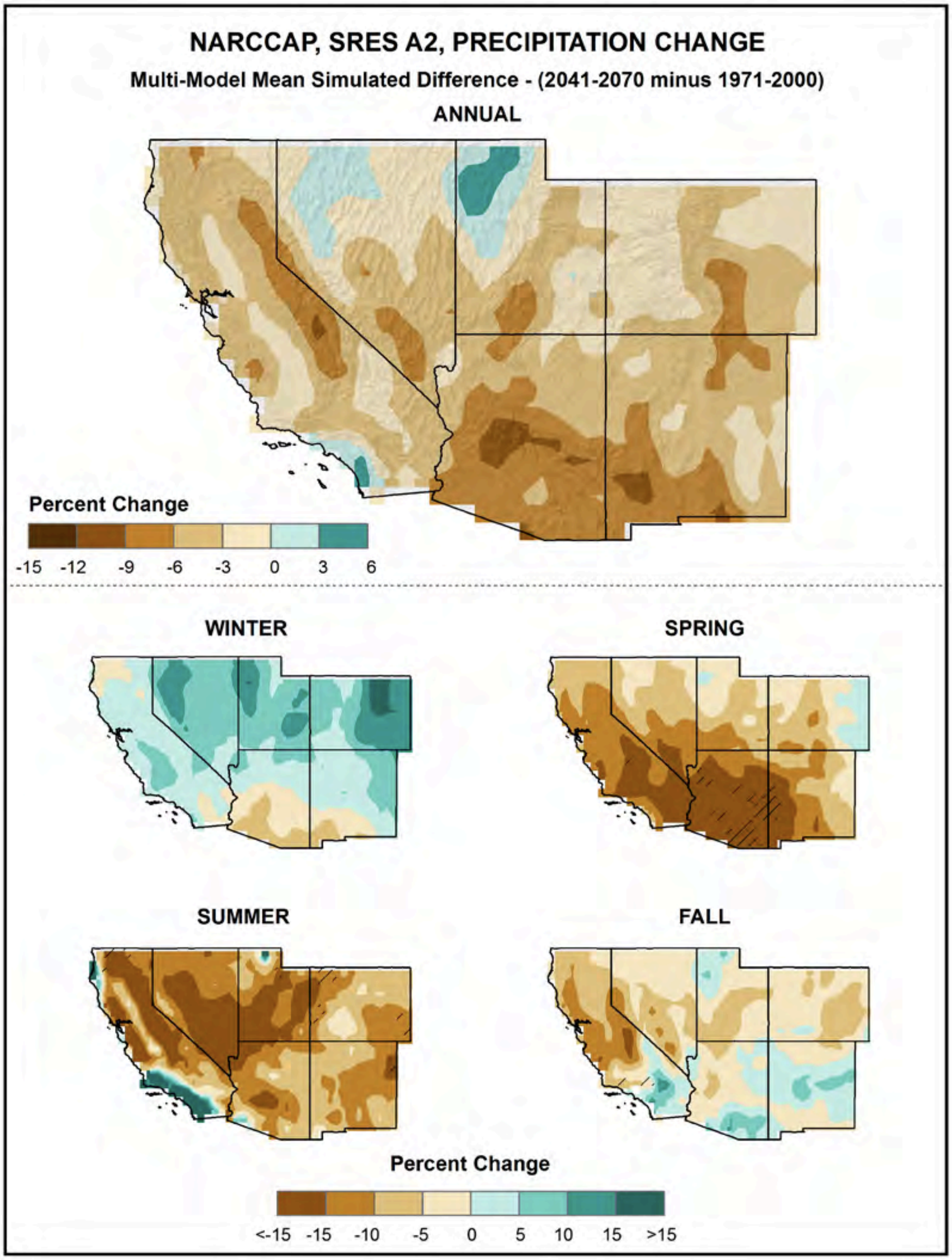


Figure 2.12. Simulated difference in annual and seasonal mean precipitation (%) for the Southwest region for the future time period 2041-2070 with respect to the reference period of 1971-2000. Color with hatching indicates that more than 50% of the models show a statistically significant change in precipitation, and more than 67% agree on the sign of the change. Note that the top and bottom color scales are different. (NOAA 2013, Part 5, Figure 26).

Great Plains

NOAA simulations indicate that mean annual precipitation change in the Great Plains region is upward in the northeast of the region and downward in the southwest, with large areas of little to no change across the central part of the region (see Figures 2.13 and 2.14). The largest annual precipitation increases for the future time period 2041-2070 with respect to the reference period 1971-2000, are simulated for the northeast part of the region, including Montana. Large increases are also simulated for coastal Texas. Most areas in the southern part of the Great Plains region, including west Texas, indicate decreases of more than 6 percent in annual mean precipitation. Changes in winter precipitation are mostly positive. Winter precipitation change ranges from almost no change in central Texas to more than a 15 percent increase across Wyoming and Montana. Changes in spring and fall are simulated to be mostly positive. Summer shows the most spatial variability in precipitation change, ranging from 15 percent increases to 20 percent decreases. Summer precipitation changes are greatly variable within the state of Texas. Annually, and for all seasons, simulated changes in precipitation are not statistically significant for most models over the majority of the region (NOAA, Part 4:53-58).

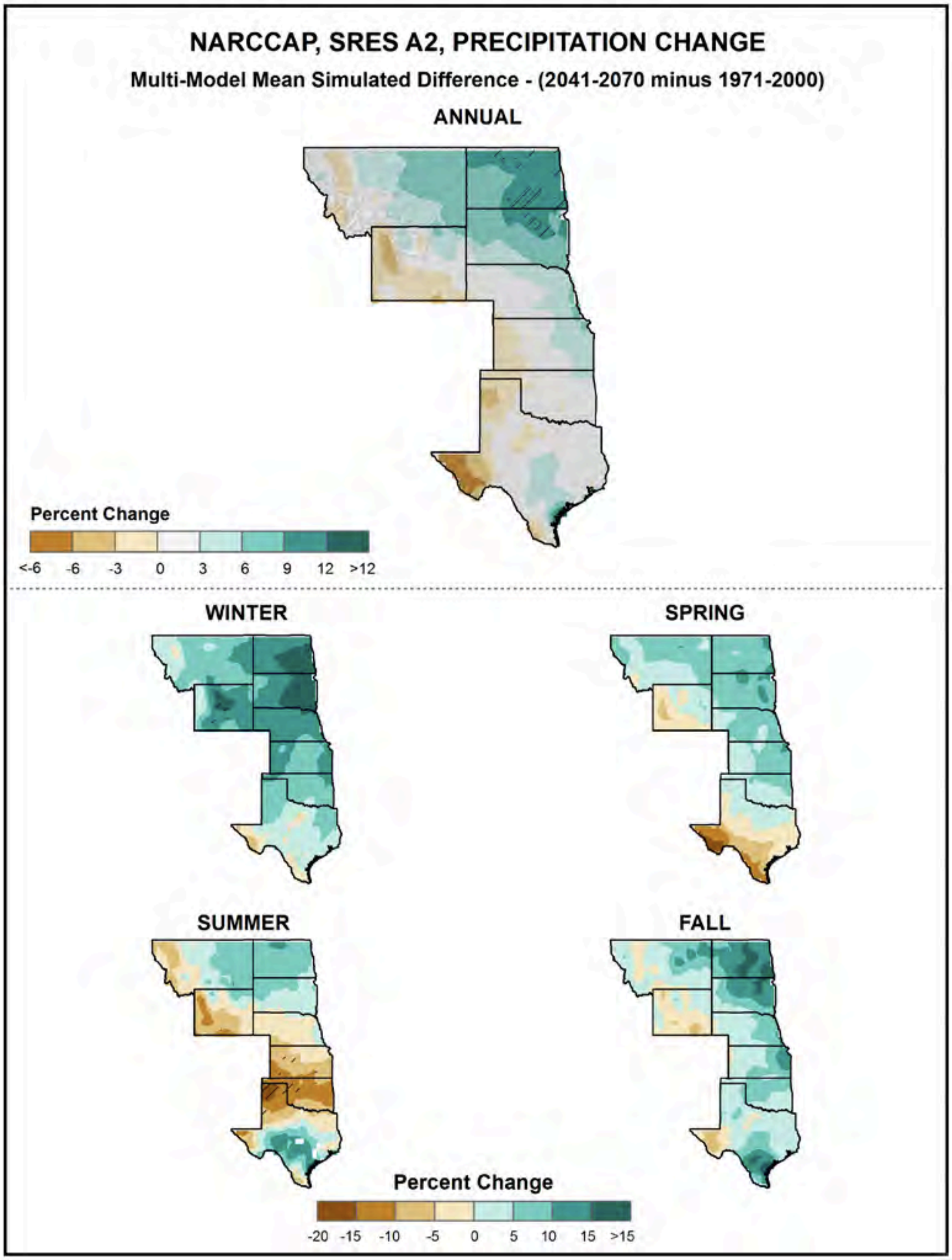
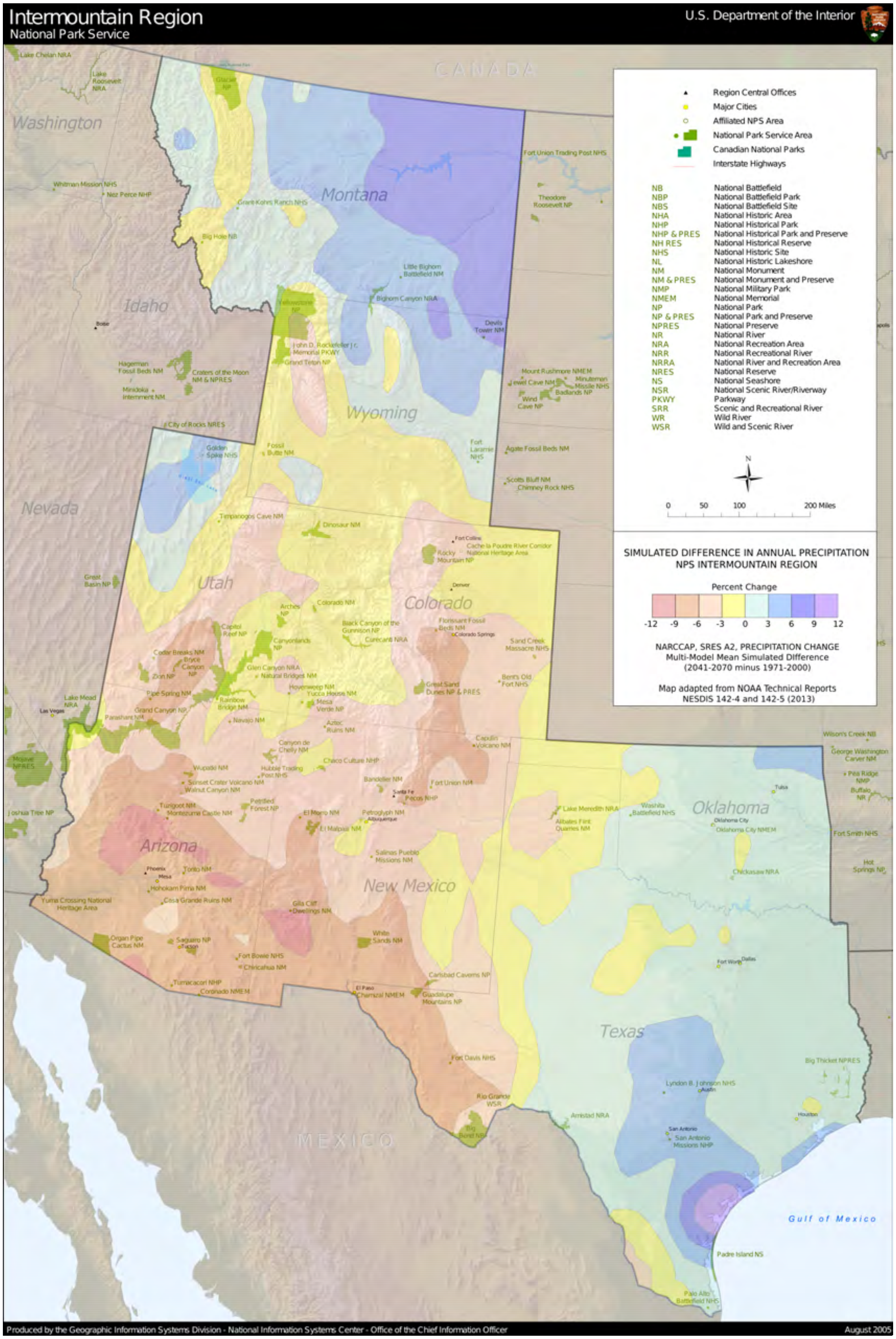


Figure 2.13. Simulated difference in annual and seasonal mean precipitation (%) for the Great Plains region for the future time period 2041-2070 with respect to the reference period of 1971-2000. Color with hatching indicates that more than 50% of the models show a statistically significant change in precipitation, and more than 67% agree on the sign of the change. Note that the top and bottom color scales are different. (NOAA 2013, Part 4, Figure 25)

Figure 2.14. Simulated difference in annual mean precipitation (%) for the NPS Intermountain Region for the future time period 2041-2070 with respect to the reference period of 1971-2000. Overlay of NOAA 2013, Part 5, Figure 26 and NOAA 2013, Part 4, Figure 25 onto NPS map of Intermountain Region parks. Statistical significance indicated on original maps is not shown on this map. Lines separating degree of difference are generally based on overlaid NOAA maps. (Composite map by author)


Intermountain Region
National Park Service
U.S. Department of the Interior
CANADA
Washington
Idaho
Montana
Wyoming
Nevada
Utah
Colorado
Arizona
New Mexico
Oklahoma
Texas
MEXICO
Gulf of Mexico
Lake Chelan NRA
Lake Roosevelt NRA
Glacier NP
Whitman Mission NHS
Nez Perce NHP
Grant-Kohrs Ranch NHS
Big Hole NB
Fort Union Trading Post NHS
Theodore Roosevelt NP
Little Bighorn Battlefield NM
Bighorn Canyon NRA
Yellowstone NP
Devils Tower NM
John D. Rockefeller Jr. Memorial PKWY
Grand Teton NP
Boise
Hagerman Fossil Beds NM
Craters of the Moon NM & NPRES
Minidoka Internment NM
City of Rocks NRES
Mount Rushmore NMEM
Jewel Cave NM
Minuteman Missile NHS
Badlands NP
Wind Cave NP
Fort Laramie NHS
Agate Fossil Beds NM
Scotts Bluff NM
Chimney Rock NHS
Golden Spike NHS
Fossil Butte NM
Timpanogos Cave NM
Dinosaur NM
Fort Collins
Cache la Poudre River Corridor National Heritage Area
Rocky Mountain NP
Great Basin NP
Denver
Arches NP
Colorado NM
Black Canyon of the Gunnison NP
Curecanti NRA
Florissant Fossil Beds NM
Colorado Springs
Sand Creek Massacre NHS
Capitol Reef NP
Canyonlands NP
Cedar Breaks NM
Bryce Canyon NP
Zion NP
Glen Canyon NRA
Natural Bridges NM
Hovenweep NM
Yucca House NM
Mesa Verde NP
Great Sand Dunes NP & PRES
Bent's Old Fort NHS
Lake Mead NRA
Las Vegas
Pipe Spring NM
Rainbow Bridge NM
Grand Canyon NP
Parashant NM
Navajo NM
Aztec Ruins NM
Canyon de Chelly NM
Chaco Culture NHP
Capulin Volcano NM
Mojave NPRES
Wupatki NM
Sunset Crater Volcano NM
Walnut Canyon NM
Hubbell Trading Post NHS
Bandelier NM
Santa Fe
Pecos NHP
Fort Union NM
Joshua Tree NP
Tuzigoot NM
Montezuma Castle NM
Petrified Forest NP
El Morro NM
El Malpais NM
Petroglyph NM
Albuquerque
Lake Meredith NRA
Alibates Flint Quarries NM
Washita Battlefield NHS
Oklahoma City
Oklahoma City NMEM
Tulsa
Phoenix
Mesa
Tonto NM
Hohokam Pima NM
Casa Grande Ruins NM
Salinas Pueblo Missions NM
Chickasaw NRA
Yuma Crossing National Heritage Area
Gila Cliff Dwellings NM
Organ Pipe Cactus NM
Saguaro NP
Tucson
White Sands NM
Fort Bowie NHS
Chiricahua NM
Tumacacori NHP
Coronado NMEM
El Paso
Chamizal NMEM
Guadalupe Mountains NP
Carlsbad Caverns NP
Fort Worth
Dallas
Wilson's Creek NB
George Washington Carver NM
Pea Ridge NMP
Buffalo NR
Fort Smith NHS
Hot Springs NP
Fort Davis NHS
Rio Grande WSR
Big Bend NP
Amistad NRA
Lyndon B. Johnson NHS
Austin
San Antonio
San Antonio Missions NHP
Big Thicket NPRES
Houston
Padre Island NS
Palo Alto Battlefield NHS
Region Central Offices
Major Cities
Affiliated NPS Area
National Park Service Area
Canadian National Parks
Interstate Highways
NB National Battlefield
NBP National Battlefield Park
NBS National Battlefield Site
NHA National Historic Area
NHP National Historical Park
NHP & PRES National Historical Park and Preserve
NH RES National Historical Reserve
NHS National Historic Site
NL National Historic Lakeshore
NM National Monument
NM & PRES National Monument and Preserve
NMP National Military Park
NMEM National Memorial
NP National Park
NP & PRES National Park and Preserve
NPRES National Preserve
NR National River
NRA National Recreation Area
NRR National Recreational River
NRRA National River and Recreation Area
NRES National Reserve
NS National Seashore
NSR National Scenic River/Riverway
PKWY Parkway
SRR Scenic and Recreational River
WR Wild River
WSR Wild and Scenic River
N
0
50
100
200 Miles
SIMULATED DIFFERENCE IN ANNUAL PRECIPITATION
NPS INTERMOUNTAIN REGION
Percent Change
-12
-9
-6
-3
0
3
6
9
12
NARCCAP, SRES A2, PRECIPITATION CHANGE
Multi-Model Mean Simulated Difference
(2041-2070 minus 1971-2000)
Map adapted from NOAA Technical Reports
NESDIS 142-4 and 142-5 (2013)
Produced by the Geographic Information Systems Division - National Information Systems Center - Office of the Chief Information Officer
August 2005

Extreme Precipitation

For the purposes of the NOAA technical reports, extreme precipitation is considered days with precipitation exceeding one inch. Future changes in the number of days with extreme precipitation vary spatially across the region, with some areas expected to see increases, some expected to see decreases, and some no change. However, changes in the number of days with extreme precipitation are not statistically significant for most models over the majority of the Intermountain Region.

Lack of precipitation is also simulated in the NOAA technical reports. The average annual number of consecutive days with precipitation less than 0.1 inch is expected to increase in some areas and decrease in others.

Southwest

Most areas within the Southwest region are simulated to have an increase in the number of days of extreme precipitation for the future time period 2041-2070 with respect to the reference period 1980-2000 (see Figures 2.15 and 2.19). The largest increases are simulated for parts of Utah and Colorado, where changes of up to 130 percent are simulated. Some areas are simulated to see decreases, including eastern Colorado, Arizona, and the Sierra Nevada. Changes in the number of days are not statistically significant for most models (NOAA, Part 5:57-61).

The change in the average annual consecutive number of days with less than 0.1 inches of precipitation is statistically significant for most models of the Southwest region for the future period 2041-2070 with respect to reference period 1980-2000 (see Figures 2.16 and 2.20). Models indicate increases over the majority of the region, with the greatest changes in the southern part of the region. Areas of the region that are already prone to little precipitation are simulated to see an increase in the number of days with little or no precipitation, up to 25 days per year in parts of Arizona. Most other areas in the Intermountain Region included in the NCA Southwest region are simulated to see an increase of up to 15 days. Some areas of Colorado are simulated to see a decrease in the number of days with little or no precipitation, but these values are small (NOAA, Part 5:57-61).

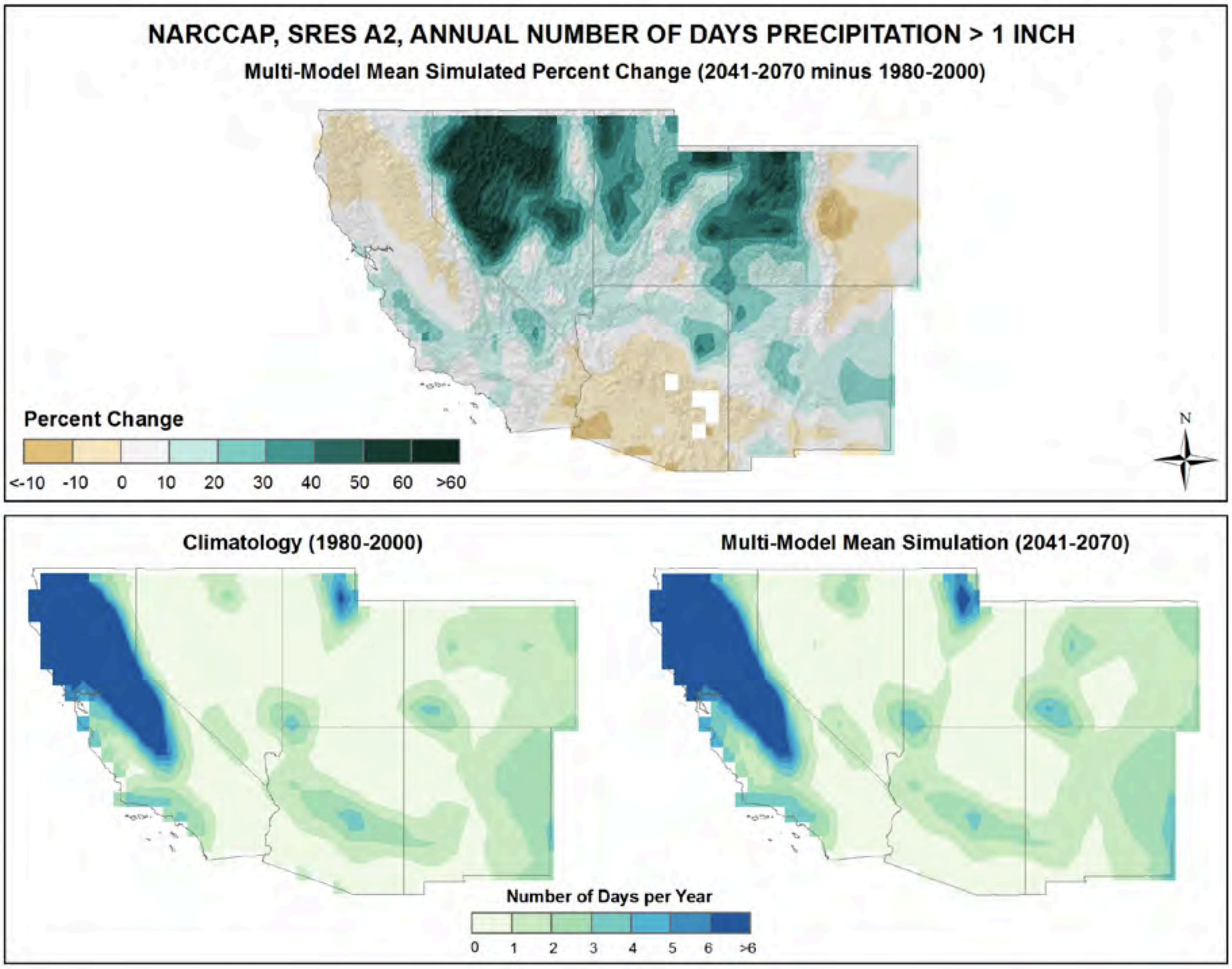


Figure 2.15. Simulated difference (%) in the mean annual number of days with precipitation greater than one inch for the Southwest region, for the 2041-2070 time period with respect to the reference period of 1980-2000 (top). Color with hatching indicates that more than 50% of the models show a statistically significant change in the number of days, and more than 67% agree on the sign of the change. Whited out areas indicate that more than 50% of the models show a statistically significant change in the number of days, but less than 67% agree of the sign of the change. Mean annual number of days with precipitation of greater than one inch for the 1980-2000 reference period (bottom left). Simulated mean annual number of days with precipitation of greater than one inch for the 2041-2070 future time period (bottom right). Note that the top and bottom color scales are different. (NOAA 2013, Part 5, Figure 29)

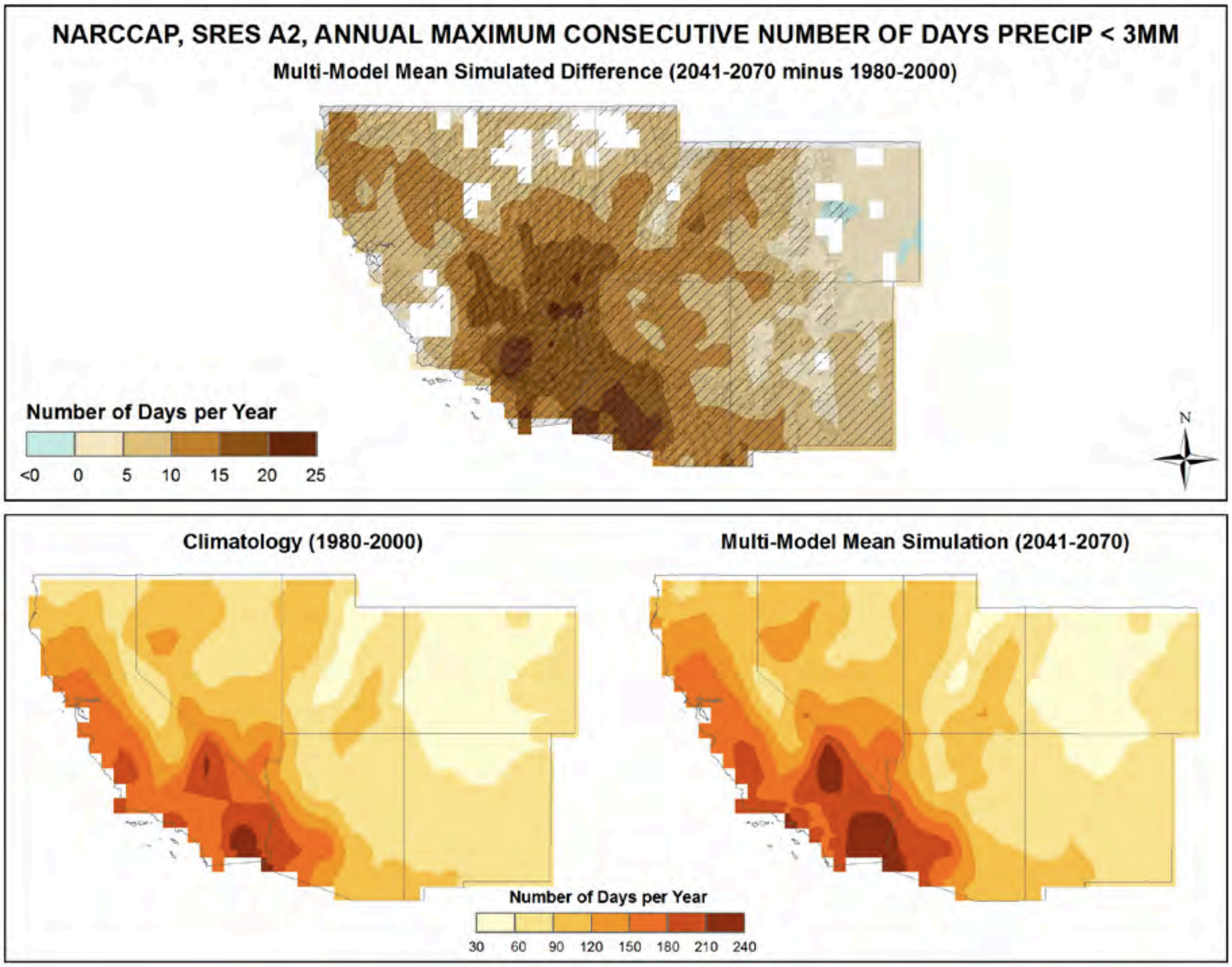


Figure 2.16. Simulated difference in the mean annual maximum number of consecutive days with precipitation less than 0.1 inch for the Southwest region, for the 2041-2070 future time period with respect to the reference period of 1980-2000 (top). Color with hatching indicates that more than 50% of the models show a statistically significant change in the number of consecutive days, and more than 67% agree on the sign of the change. Whited out areas indicate that more than 50 percent of the models show a significant change in the number of days, but less than 67% agree on the sign of the change. Mean annual maximum number of consecutive days with precipitation of less than 0.1 inch for the 1980-2000 reference period (bottom left). Simulated mean annual maximum number of consecutive days with precipitation of less than 0.1 inch for the 2041-2070 future time period (bottom right). Note that the top and bottom color scales are different. (NOAA 2013, Part 5, Figure 30)

Great Plains

NOAA's report shows simulated increases in average annual number of days with precipitation exceeding one inch for the future period of 2041-2070 with respect to the reference period 1980-2000 (see Figures 2.17 and 2.21). Increases of up to 30 percent are noted in the northern parts of the Great Plains region, including parts of Wyoming and Montana. Decreases in extreme precipitation are simulated for parts of west Texas. However changes in the number of days exceeding 1 inch in precipitation are not statistically significant for most models over the majority of the region (NOAA, Part 4:58-63).

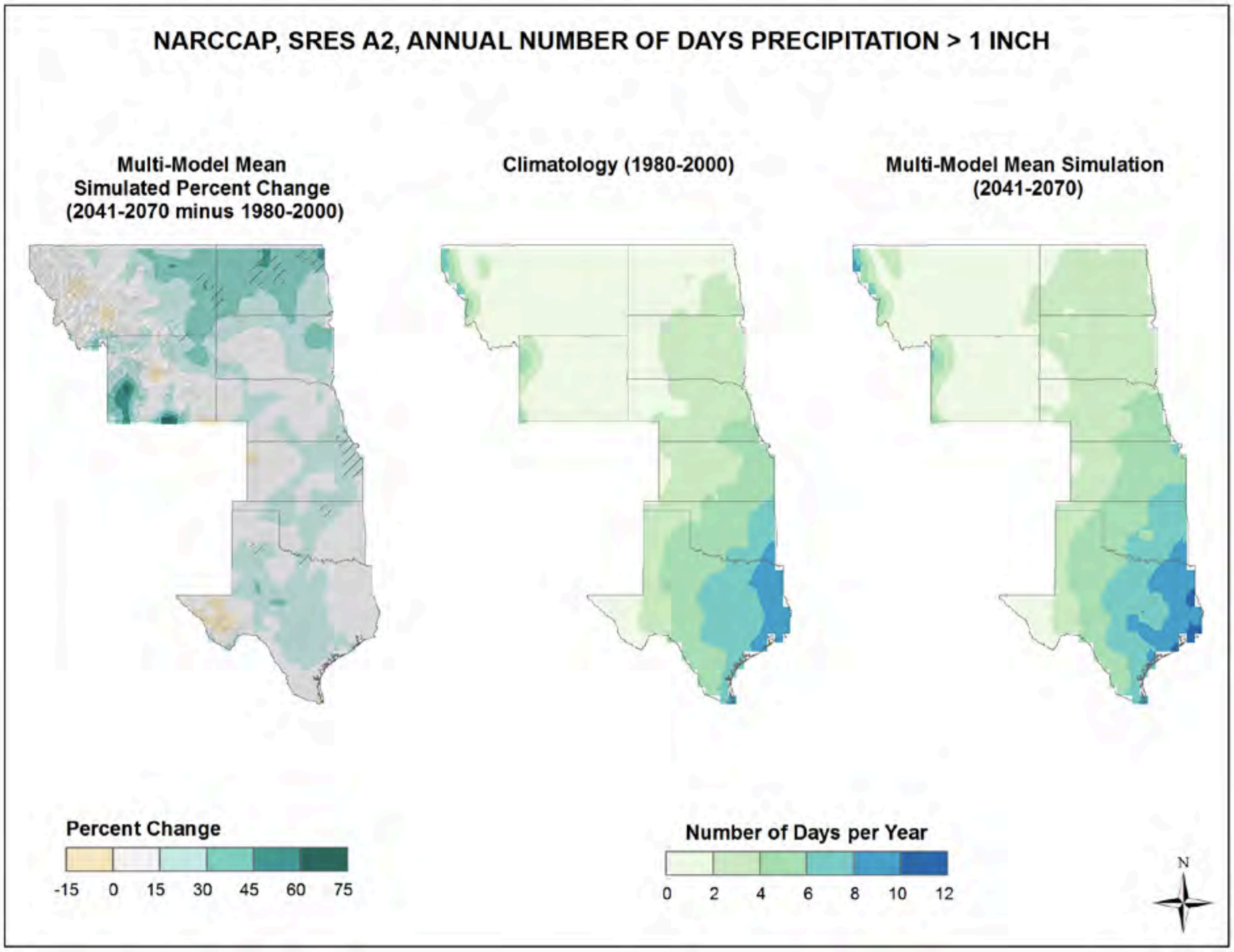


Figure 2.17. Simulated difference (%) in the mean annual number of days with precipitation greater than one inch for the Great Plains region, for the 2041-2070 time period with respect to the reference period of 1980-2000 (left). Color with hatching indicates that more than 50% of the models show a statistically significant change in the number of days, and more than 67% agree on the sign of the change. Mean annual number of days with precipitation of greater than one inch for the 1980-2000 reference period (center). Simulated mean annual number of days with precipitation of greater than one inch for the 2041-2070 future time period (right). Note that the left map color scale is different than that of the center and right. (NOAA 2013, Part 4, Figure 28)

Consecutive days with little or no precipitation, less than 0.1 inch, for the future time period 2041-2070 with respect to the reference period 1980-2000, are expected to increase over most of the region, with slight decreases in the north (see Figures 2.18 and 2.22). The largest increases up to 13 days with little or no precipitation are simulated for the south part of the Great Plains region. The largest decreases are simulated for part of the north, including Wyoming and Montana with decreases of up to eight days per year. Changes in the number of days with little or no precipitation are not statistically significant for most models over the majority of the region (NOAA, Part 4:58-63).

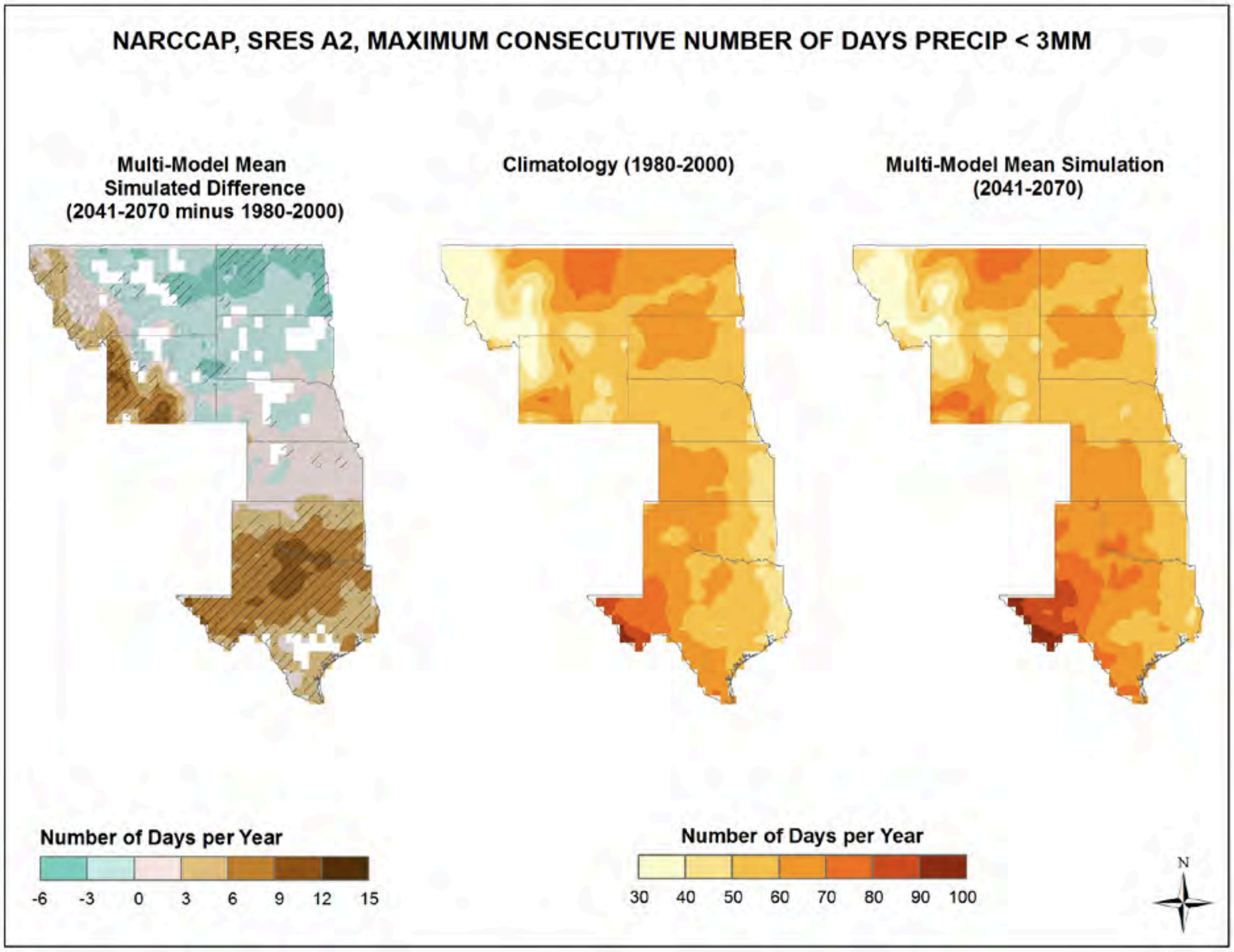


Figure 2.18. Simulated difference in the mean annual maximum number of consecutive days with precipitation less than 0.1 inch for the Great Plains region, for the 2041-2070 future time period with respect to the reference period of 1980-2000 (left). Color with hatching indicates that more than 50% of the models show a statistically significant change in the number of consecutive days, and more than 67% agree on the sign of the change. Whited out areas indicate that more than 50 percent of the models show a significant change in the number of days, but less than 67% agree on the sign of the change. Mean annual maximum number of consecutive days with precipitation of less than 0.1 inch for the 1980-2000 reference period (center). Simulated mean annual maximum number of consecutive days with precipitation of less than 0.1 inch for the 2041-2070 future time period (right). Note that the left map color scale is different than that of the center and right. (NOAA 2013, Part 4, Figure 29)

Figure 2.19. Simulated difference (%) in the mean annual number of days with precipitation greater than one inch for the Southwest part of the NPS Intermountain Region (UT, CO, AZ, NM) for the 2041-2070 time period with respect to the reference period of 1980-2000. Overlay of NOAA 2013, Part 5, Figure 29 onto NPS map of Intermountain Region parks. Statistical significance indicated on original maps is not shown on this map. Lines separating degree of difference are generally based on overlaid NOAA maps. Whited out areas indicate that more than 50 percent of the models show a significant change in the number of days, but less than 67 percent agree on the sign of the change. The NOAA Southwest Region and Great Plains Region extreme precipitation maps could not be overlaid onto a single map of the NPS Intermountain Region, because the maps were drawn with different reference scales. (Composite map by author)

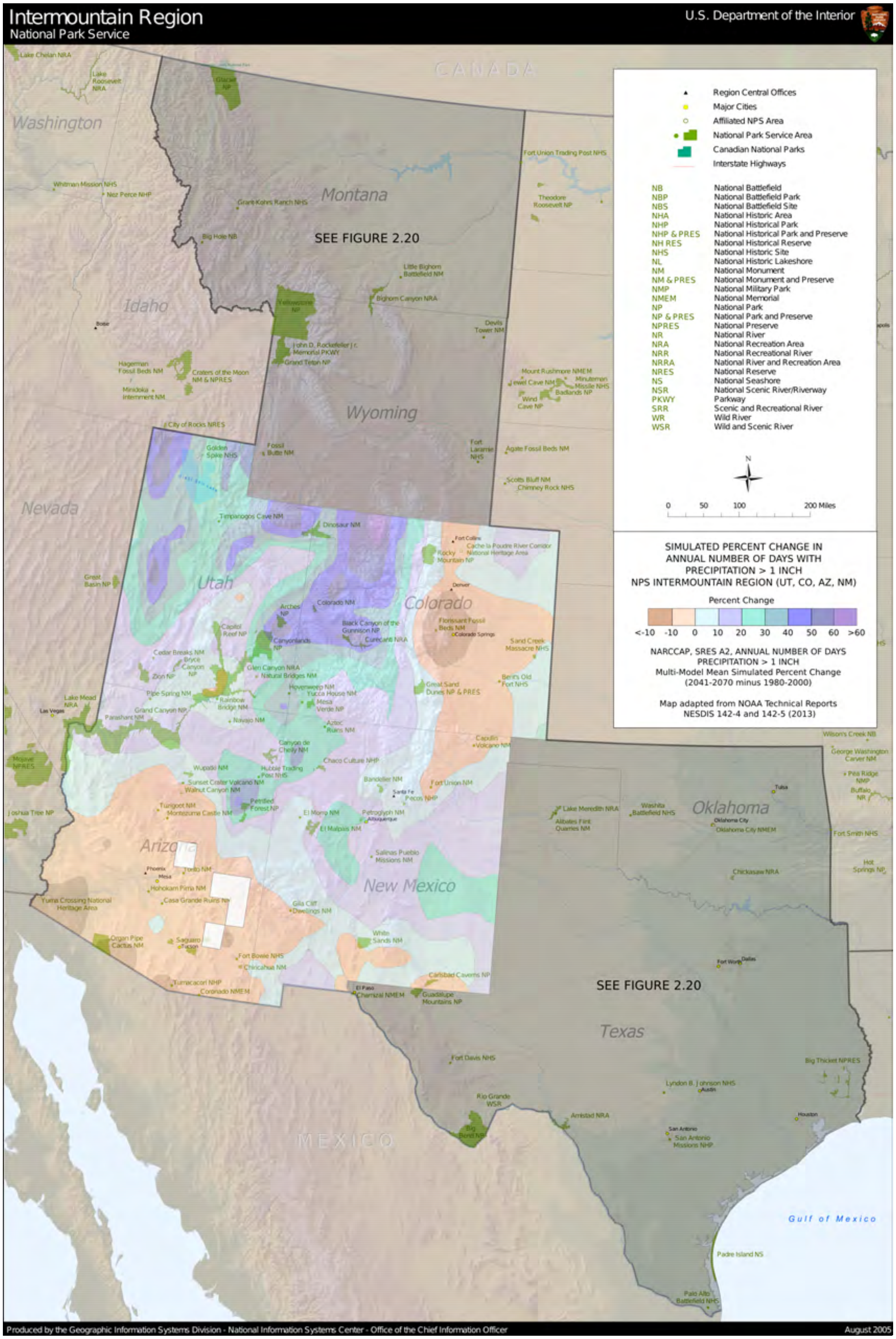
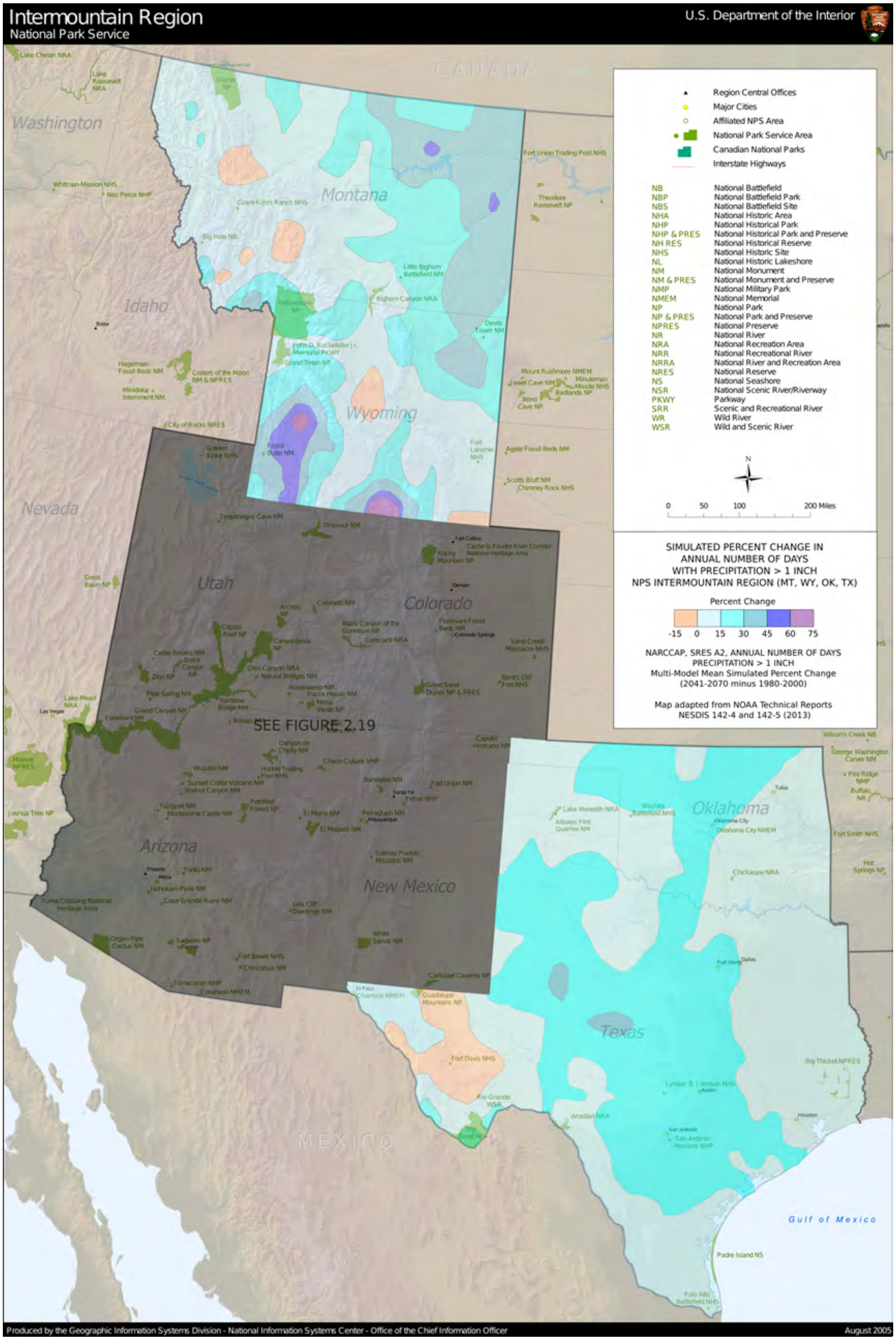

Intermountain Region
National Park Service
U.S. Department of the Interior
Region Central Offices
Major Cities
Affiliated NPS Area
National Park Service Area
Canadian National Parks
Interstate Highways
NB National Battlefield
NBP National Battlefield Park
NBS National Battlefield Site
NHA National Historic Area
NHP National Historical Park
NHP & PRES National Historical Park and Preserve
NH RES National Historical Reserve
NHS National Historic Site
NL National Historic Lakeshore
NM National Monument
NM & PRES National Monument and Preserve
NMP National Military Park
NMEM National Memorial
NP National Park
NP & PRES National Park and Preserve
NPRES National Preserve
NR National River
NRA National Recreation Area
NRR National Recreational River
NRRA National River and Recreation Area
NRES National Reserve
NS National Seashore
NSR National Scenic River/Riverway
PKWY Parkway
SRR Scenic and Recreational River
WR Wild River
WSR Wild and Scenic River
N
0 50 100 200 Miles
SIMULATED PERCENT CHANGE IN ANNUAL NUMBER OF DAYS WITH PRECIPITATION > 1 INCH
NPS INTERMOUNTAIN REGION (UT, CO, AZ, NM)
Percent Change
<-10 -10 0 10 20 30 40 50 60 >60
NARCCAP, SRES A2, ANNUAL NUMBER OF DAYS PRECIPITATION > 1 INCH
Multi-Model Mean Simulated Percent Change
(2041-2070 minus 1980-2000)
Map adapted from NOAA Technical Reports NESDIS 142-4 and 142-5 (2013)
CANADA
Washington
Montana
Idaho
Wyoming
Nevada
Utah
Colorado
Arizona
New Mexico
Oklahoma
Texas
MEXICO
Gulf of Mexico
SEE FIGURE 2.20
SEE FIGURE 2.20
Lake Chelan NRA
Lake Roosevelt NRA
Glacier NP
Whitman Mission NHS
Nez Perce NHP
Grant-Kohrs Ranch NHS
Big Hole NB
Fort Union Trading Post NHS
Theodore Roosevelt NP
Little Bighorn Battlefield NM
Bighorn Canyon NRA
Yellowstone NP
John D. Rockefeller Jr. Memorial PKWY
Grand Teton NP
Devils Tower NM
Boise
Hagerman Fossil Beds NM
Craters of the Moon NM & NPRES
Minidoka Internment NM
Mount Rushmore NMEM
Jewel Cave NM
Minuteman Missile NHS
Badlands NP
Wind Cave NP
City of Rocks NRES
Golden Spike NHS
Fossil Butte NM
Fort Laramie NHS
Agate Fossil Beds NM
Scotts Bluff NM
Chimney Rock NHS
Timpanogos Cave NM
Dinosaur NM
Fort Collins
Cache la Poudre River Corridor National Heritage Area
Rocky Mountain NP
Great Basin NP
Denver
Arches NP
Colorado NM
Black Canyon of the Gunnison NP
Curecanti NRA
Florissant Fossil Beds NM
Colorado Springs
Sand Creek Massacre NHS
Capitol Reef NP
Canyonlands NP
Cedar Breaks NM
Bryce Canyon NP
Zion NP
Glen Canyon NRA
Natural Bridges NM
Hovenweep NM
Yucca House NM
Mesa Verde NP
Great Sand Dunes NP & PRES
Bent's Old Fort NHS
Lake Mead NRA
Las Vegas
Pipe Spring NM
Rainbow Bridge NM
Grand Canyon NP
Parashant NM
Navajo NM
Aztec Ruins NM
Capulin Volcano NM
Canyon de Chelly NM
Chaco Culture NHP
Mojave NPRES
Wupatki NM
Hubbell Trading Post NHS
Sunset Crater Volcano NM
Walnut Canyon NM
Bandelier NM
Santa Fe
Pecos NHP
Fort Union NM
Joshua Tree NP
Tuzigoot NM
Montezuma Castle NM
Petrified Forest NP
El Morro NM
El Malpais NM
Petroglyph NM
Albuquerque
Salinas Pueblo Missions NM
Phoenix
Mesa
Tonto NM
Hohokam Pima NM
Casa Grande Ruins NM
Gila Cliff Dwellings NM
Yuma Crossing National Heritage Area
Organ Pipe Cactus NM
Saguaro NP
Tucson
White Sands NM
Fort Bowie NHS
Chiricahua NM
Tumacacori NHP
Coronado NMEM
Carlsbad Caverns NP
El Paso
Chamizal NMEM
Guadalupe Mountains NP
Lake Meredith NRA
Alibates Flint Quarries NM
Washita Battlefield NHS
Tulsa
Oklahoma City
Oklahoma City NMEM
Chickasaw NRA
Wilson's Creek NB
George Washington Carver NM
Pea Ridge NMP
Buffalo NR
Fort Smith NHS
Hot Springs NP
Fort Worth
Dallas
Fort Davis NHS
Lyndon B. Johnson NHS
Austin
Big Thicket NPRES
Houston
Rio Grande WSR
Amistad NRA
San Antonio
San Antonio Missions NHP
Big Bend NP
Padre Island NS
Palo Alto Battlefield NHS
Produced by the Geographic Information Systems Division - National Information Systems Center - Office of the Chief Information Officer
August 2005

Figure 2.20. Simulated difference (%) in the mean annual number of days with precipitation greater than one inch for Great Plains part of the NPS Intermountain Region (MT, WY, OK, TX) for the 2041-2070 time period with respect to the reference period of 1980-2000. Overlay of NOAA 2013, Part 5, Figure 28 onto NPS map of Intermountain Region parks. Statistical significance indicated on original maps is not shown on this map. Lines separating degree of difference are generally based on overlaid NOAA maps. Whited out areas indicate that more than 50 percent of the models show a significant change in the number of days, but less than 67 percent agree on the sign of the change. The NOAA Southwest Region and Great Plains Region extreme precipitation maps could not be overlaid onto a single map of the NPS Intermountain Region, because the maps were drawn with different reference scales. (Composite map by author)


Intermountain Region
National Park Service
U.S. Department of the Interior
Region Central Offices
Major Cities
Affiliated NPS Area
National Park Service Area
Canadian National Parks
Interstate Highways
NB National Battlefield
NBP National Battlefield Park
NBS National Battlefield Site
NHA National Historic Area
NHP National Historical Park
NHP & PRES National Historical Park and Preserve
NH RES National Historical Reserve
NHS National Historic Site
NL National Historic Lakeshore
NM National Monument
NM & PRES National Monument and Preserve
NMP National Military Park
NMEM National Memorial
NP National Park
NP & PRES National Park and Preserve
NPRES National Preserve
NR National River
NRA National Recreation Area
NRR National Recreational River
NRRA National River and Recreation Area
NRES National Reserve
NS National Seashore
NSR National Scenic River/Riverway
PKWY Parkway
SRR Scenic and Recreational River
WR Wild River
WSR Wild and Scenic River
N
0 50 100 200 Miles
SIMULATED PERCENT CHANGE IN
ANNUAL NUMBER OF DAYS
WITH PRECIPITATION > 1 INCH
NPS INTERMOUNTAIN REGION (MT, WY, OK, TX)
Percent Change
-15 0 15 30 45 60 75
NARCCAP, SRES A2, ANNUAL NUMBER OF DAYS
PRECIPITATION > 1 INCH
Multi-Model Mean Simulated Percent Change
(2041-2070 minus 1980-2000)
Map adapted from NOAA Technical Reports
NESDIS 142-4 and 142-5 (2013)
CANADA
Washington
Montana
Idaho
Wyoming
Nevada
Utah
Colorado
Arizona
New Mexico
Oklahoma
Texas
MEXICO
Gulf of Mexico
SEE FIGURE 2.19
Glacier NP
Grant-Kohrs Ranch NHS
Big Hole NB
Little Bighorn Battlefield NM
Bighorn Canyon NRA
Yellowstone NP
John D. Rockefeller Jr. Memorial PKWY
Grand Teton NP
Devils Tower NM
Fossil Butte NM
Fort Laramie NHS
Fort Union Trading Post NHS
Theodore Roosevelt NP
Mount Rushmore NMEM
Jewel Cave NM
Wind Cave NP
Minuteman Missile NHS
Badlands NP
Agate Fossil Beds NM
Scotts Bluff NM
Chimney Rock NHS
Whitman Mission NHS
Nez Perce NHP
Lake Chelan NRA
Lake Roosevelt NRA
Hagerman Fossil Beds NM
Craters of the Moon NM & NPRES
Minidoka Internment NM
City of Rocks NRES
Golden Spike NHS
Timpanogos Cave NM
Dinosaur NM
Great Basin NP
Rocky Mountain NP
Cache la Poudre River Corridor National Heritage Area
Colorado NM
Arches NP
Black Canyon of the Gunnison NP
Curecanti NRA
Florissant Fossil Beds NM
Sand Creek Massacre NHS
Great Sand Dunes NP & PRES
Bent's Old Fort NHS
Capitol Reef NP
Canyonlands NP
Cedar Breaks NM
Bryce Canyon NP
Zion NP
Pipe Spring NM
Glen Canyon NRA
Natural Bridges NM
Hovenweep NM
Yucca House NM
Mesa Verde NP
Rainbow Bridge NM
Navajo NM
Grand Canyon NP
Lake Mead NRA
Parashant NM
Canyon de Chelly NM
Chaco Culture NHP
Hubbell Trading Post NHS
Wupatki NM
Sunset Crater Volcano NM
Walnut Canyon NM
Petrified Forest NP
Tuzigoot NM
Montezuma Castle NM
El Morro NM
El Malpais NM
Bandelier NM
Pecos NHP
Petroglyph NM
Fort Union NM
Capulin Volcano NM
Salinas Pueblo Missions NM
Tonto NM
Hohokam Pima NM
Casa Grande Ruins NM
Yuma Crossing National Heritage Area
Organ Pipe Cactus NM
Saguaro NP
Gila Cliff Dwellings NM
White Sands NM
Fort Bowie NHS
Chiricahua NM
Tumacacori NHP
Coronado NMEM
Carlsbad Caverns NP
Guadalupe Mountains NP
Chamizal NMEM
Fort Davis NHS
Rio Grande WSR
Big Bend NP
Amistad NRA
Lake Meredith NRA
Alibates Flint Quarries NM
Washita Battlefield NHS
Oklahoma City NMEM
Chickasaw NRA
Lyndon B. Johnson NHS
San Antonio Missions NHP
Big Thicket NPRES
Padre Island NS
Palo Alto Battlefield NHS
Wilson's Creek NB
George Washington Carver NM
Pea Ridge NMP
Buffalo NR
Fort Smith NHS
Hot Springs NP
Mojave NPRES
Joshua Tree NP
Boise
Las Vegas
Phoenix
Mesa
Denver
Fort Collins
Colorado Springs
Santa Fe
Albuquerque
El Paso
Tulsa
Oklahoma City
Fort Worth
Dallas
Austin
San Antonio
Houston
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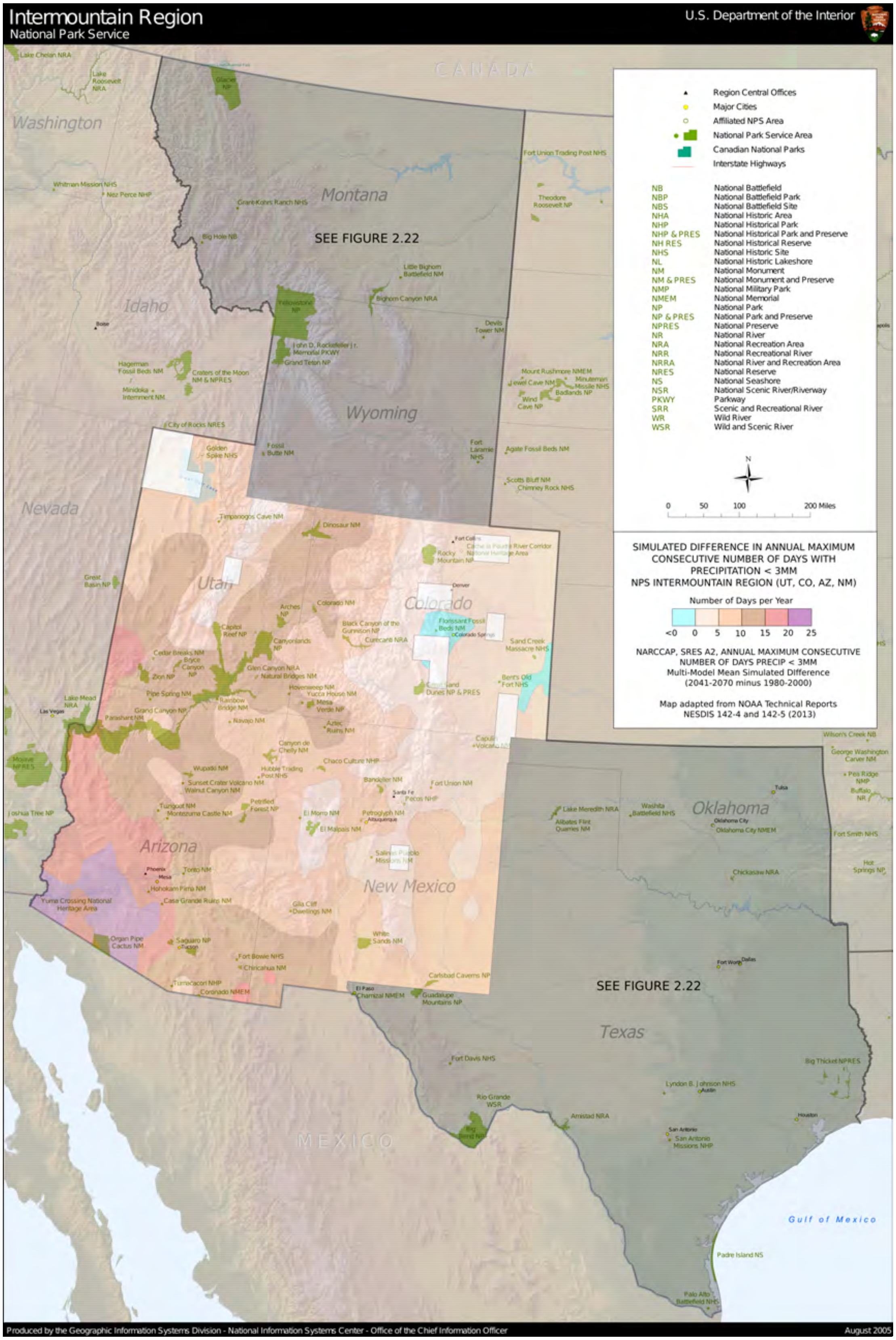
August 2005

Figure 2.21. Simulated difference in the mean annual maximum number of consecutive days with precipitation less than 0.1 inch for the Southwest part of the NPS Intermountain Region (UT, CO, AZ, NM) for the 2041-2070 future time period with respect to the reference period of 1980-2000. Overlay of NOAA 2013, Part 5, Figure 30 onto NPS map of Intermountain Region parks. Statistical significance indicated on original maps is not shown on this map. Lines separating degree of difference are generally based on overlaid NOAA maps. Whited out areas indicate that more than 50 percent of the models show a significant change in the number of days, but less than 67 percent agree on the sign of the change. The NOAA Southwest Region and Great Plains Region extreme precipitation maps could not be overlaid onto a single map of the NPS Intermountain Region, because the maps were drawn with different reference scales. (Composite map by author)


Intermountain Region
National Park Service
U.S. Department of the Interior
CANADA
Washington
Montana
Idaho
Wyoming
Nevada
Utah
Colorado
Arizona
New Mexico
Oklahoma
Texas
MEXICO
Gulf of Mexico
SEE FIGURE 2.22
SEE FIGURE 2.22
Region Central Offices
Major Cities
Affiliated NPS Area
National Park Service Area
Canadian National Parks
Interstate Highways
NB National Battlefield
NBP National Battlefield Park
NBS National Battlefield Site
NHA National Historic Area
NHP National Historical Park
NHP & PRES National Historical Park and Preserve
NH RES National Historical Reserve
NHS National Historic Site
NL National Historic Lakeshore
NM National Monument
NM & PRES National Monument and Preserve
NMP National Military Park
NMEM National Memorial
NP National Park
NP & PRES National Park and Preserve
NPRES National Preserve
NR National River
NRA National Recreation Area
NRR National Recreational River
NRRA National River and Recreation Area
NRES National Reserve
NS National Seashore
NSR National Scenic River/Riverway
PKWY Parkway
SRR Scenic and Recreational River
WR Wild River
WSR Wild and Scenic River
N
0 50 100 200 Miles
SIMULATED DIFFERENCE IN ANNUAL MAXIMUM CONSECUTIVE NUMBER OF DAYS WITH PRECIPITATION < 3MM
NPS INTERMOUNTAIN REGION (UT, CO, AZ, NM)
Number of Days per Year
<0 0 5 10 15 20 25
NARCCAP, SRES A2, ANNUAL MAXIMUM CONSECUTIVE NUMBER OF DAYS PRECIP < 3MM
Multi-Model Mean Simulated Difference
(2041-2070 minus 1980-2000)
Map adapted from NOAA Technical Reports
NESDIS 142-4 and 142-5 (2013)
Yellowstone NP
Grand Teton NP
Glacier NP
Rocky Mountain NP
Grand Canyon NP
Mesa Verde NP
Arches NP
Canyonlands NP
Zion NP
Bryce Canyon NP
Capitol Reef NP
Petrified Forest NP
Carlsbad Caverns NP
Big Bend NP
Padre Island NS
Phoenix
Denver
Las Vegas
Santa Fe
Albuquerque
El Paso
Dallas
Houston
San Antonio
Austin
Oklahoma City
Tulsa
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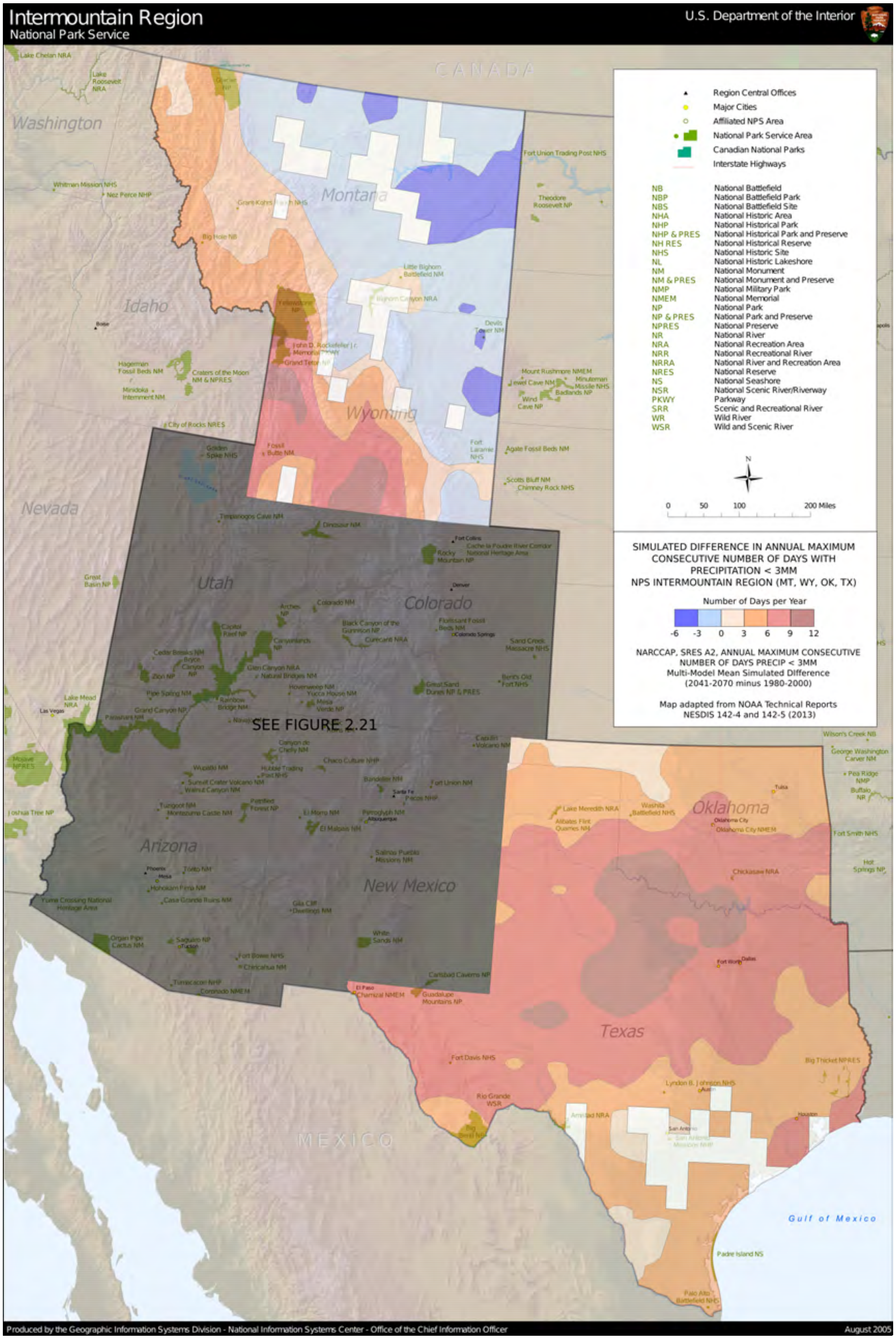
August 2005

Figure 2.22. Simulated difference in the mean annual maximum number of consecutive days with precipitation less than 0.1 inch for the Great Plains part of the NPS Intermountain Region (MT, WY, OK, TX), for the 2041-2070 future time period with respect to the reference period of 1980-2000. Overlay of NOAA 2013, Part 4, Figure 29 onto NPS map of Intermountain Region parks. Statistical significance indicated on original maps is not shown on this map. Lines separating degree of difference are generally based on overlaid NOAA maps. Whited out areas indicate that more than 50 percent of the models show a significant change in the number of days, but less than 67 percent agree on the sign of the change. The NOAA Southwest Region and Great Plains Region extreme precipitation maps could not be overlaid onto a single map of the NPS Intermountain Region, because the maps were drawn with different reference scales. (Composite map by author)


Intermountain Region
National Park Service
U.S. Department of the Interior
CANADA
Washington
Montana
Idaho
Wyoming
Nevada
Utah
Colorado
Arizona
New Mexico
Oklahoma
Texas
MEXICO
Gulf of Mexico
SEE FIGURE 2.21
Region Central Offices
Major Cities
Affiliated NPS Area
National Park Service Area
Canadian National Parks
Interstate Highways
NB National Battlefield
NBP National Battlefield Park
NBS National Battlefield Site
NHA National Historic Area
NHP National Historical Park
NHP & PRES National Historical Park and Preserve
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NM National Monument
NM & PRES National Monument and Preserve
NMP National Military Park
NMEM National Memorial
NP National Park
NP & PRES National Park and Preserve
NPRES National Preserve
NR National River
NRA National Recreation Area
NRR National Recreational River
NRRA National River and Recreation Area
NRES National Reserve
NS National Seashore
NSR National Scenic River/Riverway
PKWY Parkway
SRR Scenic and Recreational River
WR Wild River
WSR Wild and Scenic River
N
0 50 100 200 Miles
SIMULATED DIFFERENCE IN ANNUAL MAXIMUM CONSECUTIVE NUMBER OF DAYS WITH PRECIPITATION < 3MM
NPS INTERMOUNTAIN REGION (MT, WY, OK, TX)
Number of Days per Year
-6 -3 0 3 6 9 12
NARCCAP, SRES A2, ANNUAL MAXIMUM CONSECUTIVE NUMBER OF DAYS PRECIP < 3MM
Multi-Model Mean Simulated Difference
(2041-2070 minus 1980-2000)
Map adapted from NOAA Technical Reports NESDIS 142-4 and 142-5 (2013)
Lake Chelan NRA
Lake Roosevelt NRA
Glacier NP
Whitman Mission NHS
Nez Perce NHP
Grant-Kohrs Ranch NHS
Big Hole NB
Fort Union Trading Post NHS
Theodore Roosevelt NP
Little Bighorn Battlefield NM
Bighorn Canyon NRA
Yellowstone NP
John D. Rockefeller Jr. Memorial Pkwy
Grand Teton NP
Devils Tower NM
Boise
Hagerman Fossil Beds NM
Craters of the Moon NM & NPRES
Minidoka Internment NM
City of Rocks NRES
Mount Rushmore NMEM
Jewel Cave NM
Wind Cave NP
Minuteman Missile NHS
Badlands NP
Golden Spike NHS
Fossil Butte NM
Fort Laramie NHS
Agate Fossil Beds NM
Scotts Bluff NM
Chimney Rock NHS
Timpanogos Cave NM
Dinosaur NM
Fort Collins
Cache la Poudre River Corridor National Heritage Area
Rocky Mountain NP
Denver
Great Basin NP
Arches NP
Colorado NM
Black Canyon of the Gunnison NP
Curecanti NRA
Florissant Fossil Beds NM
Colorado Springs
Sand Creek Massacre NHS
Capitol Reef NP
Canyonlands NP
Cedar Breaks NM
Bryce Canyon NP
Zion NP
Glen Canyon NRA
Natural Bridges NM
Hovenweep NM
Yucca House NM
Mesa Verde NP
Great Sand Dunes NP & PRES
Bents Old Fort NHS
Lake Mead NRA
Las Vegas
Pipe Spring NM
Grand Canyon NP
Rainbow Bridge NM
Navajo NM
Parashant NM
Capulin Volcano NM
Canyon de Chelly NM
Hubbell Trading Post NHS
Chaco Culture NHP
Bandelier NM
Santa Fe
Pecos NHP
Fort Union NM
Mojave NPRES
Wupatki NM
Sunset Crater Volcano NM
Walnut Canyon NM
Petrified Forest NP
Tuzigoot NM
Montezuma Castle NM
El Morro NM
El Malpais NM
Petroglyph NM
Albuquerque
Joshua Tree NP
Salinas Pueblo Missions NM
Phoenix
Mesa
Tonto NM
Hohokam Pima NM
Casa Grande Ruins NM
Gila Cliff Dwellings NM
Yuma Crossing National Heritage Area
Organ Pipe Cactus NM
Saguaro NP
Tucson
Fort Bowie NHS
Chiricahua NM
White Sands NM
Tumacacori NHP
Coronado NMEM
Carlsbad Caverns NP
El Paso
Chamizal NMEM
Guadalupe Mountains NP
Lake Meredith NRA
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Oklahoma City NMEM
Tulsa
Chickasaw NRA
Wilson's Creek NB
George Washington Carver NM
Pea Ridge NMP
Buffalo NR
Fort Smith NHS
Hot Springs NP
Fort Worth
Dallas
Fort Davis NHS
Rio Grande WSR
Big Bend NP
Amistad NRA
Lyndon B. Johnson NHP
Austin
San Antonio
San Antonio Missions NHP
Houston
Big Thicket NPRES
Padre Island NS
Palo Alto Battlefield NHS
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August 2005

EXPECTED CLIMATE CHANGES AND ECOSYSTEM EFFECTS

NOAA technical reports for the National Climate Assessment provide scenarios for changes in regional climate, including changes in precipitation and temperature, as well as extreme events (see NOAA 2013, Parts 4 and 5). These changes will impact cultural resources directly, but the effects these temperature and precipitation changes have on local ecosystems will also impact cultural resources. This section will explore the ecosystem changes that are expected to occur as a direct result of the climate scenarios described in the previous section.

Atmospheric Moisture Changes

The annual amount of precipitation is expected to decrease throughout most of the Intermountain Region. However, the National Climate Assessment indicates that heavy rainfall events will become more common in many areas. The known environmental effects of heavy rainfall events include erosion of soils and flooding. These effects will be especially damaging in environments with conditions most vulnerable to these effects. In addition, changing annual precipitation amounts, combined with increased heavy rainfall events and increased periods of drought will result in increased wetting and drying extremes, changes in soil chemistry, and possible increased fire frequency. These ecosystem changes all have the potential to affect cultural resources.

Increased Wetting And Drying Extremes

Future climate scenarios indicate that there will likely be an increase in extreme precipitation events throughout most of the Intermountain Region. Both days of heavy precipitation (more than one inch) and consecutive days of little or no precipitation (less than 0.1 inches) are expected to increase, indicating there will be more wetting and drying extremes in the future. Wetting and drying events increase the risk of ground subsidence. Cracking and heaving of soils can result in the loss of soil stratigraphy (English Heritage 57:8).

Erosion Of Soils

Arroyo creation and widening has become a significant issue in the arid southwest over the last 200 years. Several factors likely contribute to arroyo formation, including heavy rainfall, grazing of arid lands, and a natural cycle of erosion and deposition (Vogt 1997). With more frequent heavy rainfall events, the landscape has less time to recover and less time for plants to grow with root systems to help prevent erosion. Areas expected to receive increased heavy rainfall can expect to see increased erosion.

Flooding

Warmer temperatures and increased extreme precipitation events mean an increased risk of flooding for much of the Intermountain Region. Flooding is projected to become more frequent and intense in some seasons and in some parts of the region, but less frequent and less intense in other seasons and areas (Institute of the Environment 2013:6). Winter precipitation in Arizona, for example, has become more variable, with both more frequent extremely dry and extremely wet winters. Land transformation in the Southwest, including vegetation die-off and wildfire, reduce flood buffering. In addition, decreased snow cover on the lower slopes of high mountains and an increased fraction of winter precipitation falling as rain, due to higher temperatures, results in more rapid run-off and increased flooding (NCA 2009, Southwest).

A special report by the Federal Emergency Management Administration (FEMA) in 2013 predicts that areas at risk of flooding in the United States will increase 45 percent by 2100, largely due to climate change (AECOM 2013). Areas within the Intermountain Region that are predicted to see the greatest increase in flood risk include parts of Colorado, Utah, Wyoming and Arizona (see Figure 2.23).

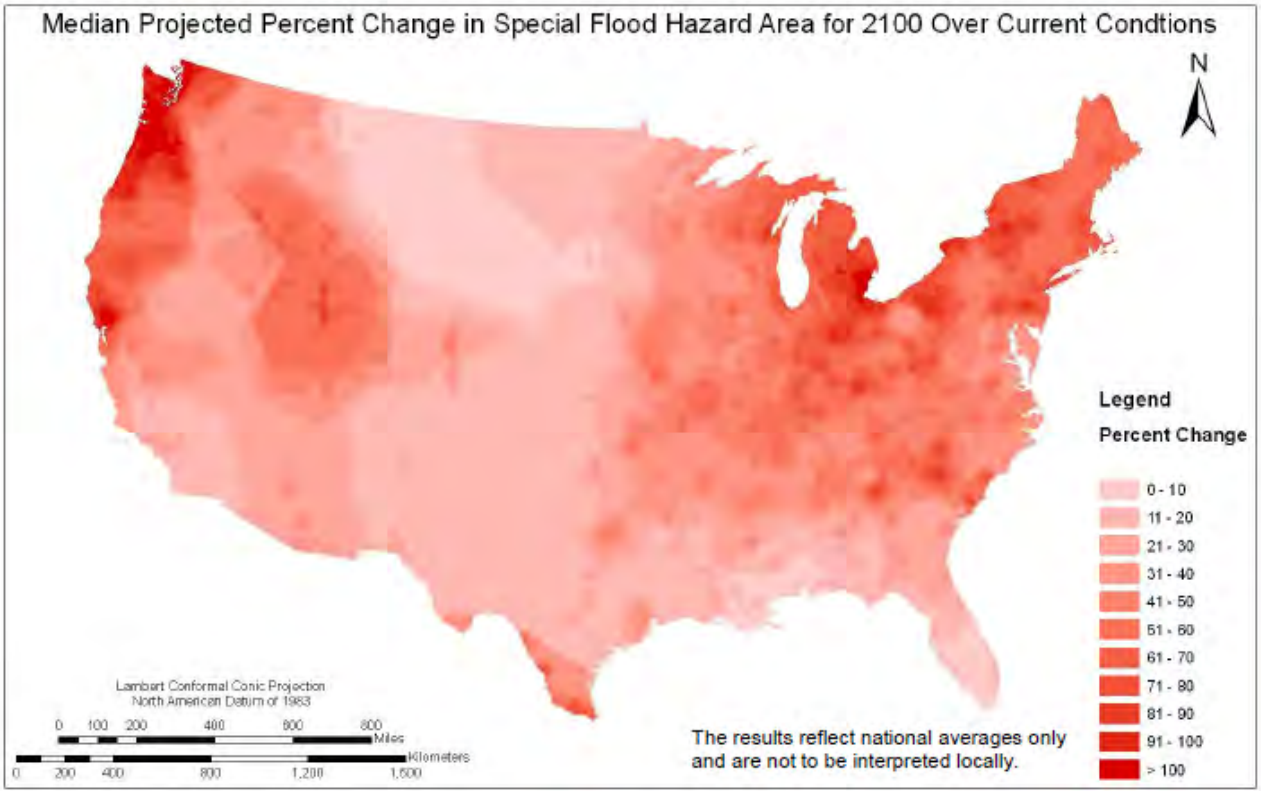

Figure 2.23. Median projected percent change in the Special Flood Hazard Area for 2100 over current conditions. Special Flood Hazard Areas are defined as those that have a 1-percent annual chance of flood, also referred to as the 100-year flood zone. (AECOM 2013, Figure 4-10)

Changes In Soil Chemistry

Changes in groundwater levels and air moisture, combined with changes in vegetation patterns, can result in changes in soil chemistry. Of particular concern to cultural resources are changes in soil pH (English Heritage 57:8).

Increased Fire Frequency

Forest fires are an important part of the cycle of forest vegetation and soil chemistry. However, fire is a significant danger for historic resources. Fire intensity and frequency are highly dependent on weather and climate. According to paleoecological records, forest fire frequency has varied continually over the last several millennia (Gavin et al. 2007) Some studies, including the 1996 Intergovernmental Panel on Climate Change (IPCC), suggest universal increases in fire frequency as a result of a warming climate. However, others question the universality of these results, because individual fires are the result of a complex set of interactions including ignition agents, fuel conditions, topography and weather including temperature, relative humidity, wind velocity, and the amount and frequency of precipitation. Increasing temperatures alone do not necessarily guarantee an increase in fire frequency (Flannigan 2000).

Local Ecosystem Changes

Changes in local ecosystems will occur and have already been noted within the last two centuries due to changing climate. Changes in temperature and precipitation, both over time and seasonally, can significantly affect the composition and diversity of native species through altering water and food supply and habitat availability. The success of some species and the loss of others can occur as the result of small changes in local climate. Ecosystem changes that will have the greatest impact on cultural resources include changes in the distribution of pests and changes in vegetation patterns.

Changes In Distribution Of Pests

Pests that can have detrimental effects on historic resources will thrive in different geographical locations as local climates change. Some of the pests that are most destructive to cultural resources include termites, carpenter ants, wood-boring beetles, and rodents. Populations of some pests that are known to thrive in warmer climates are projected to increase in the Intermountain Region (NCA 2009, Great Plains). Rodent reproductive potential is known to increase during warmer months, and is likely to increase with warming climate (Chartered Institute of Environmental Health 2008:4).

Changes In Vegetation Patterns

Vegetation can have significant effects on cultural resources, both positive and negative. Vegetation that grows on standing resources, including fungi and moss can degrade building materials and ruins. Larger vegetation, such as trees, growing in the walls of ruins or archaeological sites can damage these resources. However, vegetation can also be important for maintaining the stability of soils that would otherwise be vulnerable to erosion. Changes will occur in the distribution of plant species as a result of the changing climate. The loss of vegetation and the increase of vegetation, depending on the effects this vegetation has on cultural resources, can be detrimental.

Climate And Pollution

The effects of changing climate combined with the effects of pollution cause unique environmental effects that can take a toll on cultural resources. Changing precipitation rates and extreme precipitation events, combined with high levels of pollution, will cause a change in the pH levels of precipitation, as well as changes in the deposition of pollutants across the landscape and over time.

When considering future climate scenarios and projections, it is important to remember that future levels of greenhouse gas emissions are a significant variable in the level of change. High emissions scenarios show more significant changes in climate during the twenty-first century than low emissions scenarios. However, all scenarios show an increase in greenhouse gas emissions, and all show future climate changes. It is important to consider the effects these changes will have on cultural resources. Chapter 3 will detail the effects climate and ecosystem changes are likely to have on cultural resources.

Climate Parameters	**Climate Change Risk**	**Impacts to Historical Environment**
Atmospheric moisture change	Flooding	pH changes to buried archaeological sites
	Intense rainfall	Loss of stratigraphic integrity of archaeological sites resulting from cracking caused by changes in soil moisture
	Changes in water table level	Eutrophication accelerating microbial decomposition of organics in structures and archaeological sites
	Changes in soil chemistry	Physical decay of porous building materials and finishes due to rising damp
	Ground water changes	Damage due to faulty or inadequate water disposal systems (drains, gutters)
	Changes in humidity cycle	Crystallization and dissolution of salts caused by wetting and drying affecting standing structures, archaeology, wall paintings, frescoes and other decorated surfaces
	Increase in time of wetness	Erosion of inorganic and organic materials due to flood waters
	Changes in seasonal rainfall amounts	Biological attack of organic materials by insects, molds, fungi, invasive species (such as termites)
		Subsoil instability, ground heave and subsidence
		Relative humidity cycle/shock causing splitting, cracking, and delamination of materials and surfaces
		Corrosion of metals
Wind	Wind-driven rain	Penetrative moisture into cultural materials
	Wind-transported soil	Static and dynamic loading of structures
	Wind-driven sand	Structural damage and collapse
	Wind gusts and changes in direction	Deterioration of surfaces due to erosion

Climate Parameters (cont'd)	**Climate Change Risk (cont'd)**	**Impacts to Historical Environment (cont'd)**
Temperature change	Diurnal, seasonal, extreme events (heat waves, snow loading)	Deterioration of facades due to thermal stress
	Changes in freeze-thaw and ice storms, increase in wet frost	Freeze-thaw/frost damage
		Damage inside brick, stone, ceramics, that get wet and freeze before drying
		Biochemical deterioration
Desertification	Drought	Erosion
	Heat waves	Salt weathering
	Fall in water table	Abandonment and collapse
Climate and pollution acting together	pH precipitation	Stone recession by dissolution of carbonates
	Changes in deposition of pollutants	Blackening of materials
		Corrosion of metals
		Influence of bio-colonization
Climate and biological effects	Proliferation of invasive species	Collapse of structural timber and timber finishes
	Spread of existing and new species of insects	Reduction in availability of native species for repair and maintenance of buildings
	Increase in mold growth	Changes in the natural values of sites
	Changes to lichen colonies on buildings	Changes in appearance of landscapes
	Decline of original plant materials	

Table 2.1. Climate Parameters, Associated Climate Change Risks, and Associated Impacts to the Historical Environment (adapted from English Heritage 2008, Table 1)

PART THREE

EFFECTS OF CLIMATE CHANGE ON CULTURAL RESOURCES

EFFECTS OF CLIMATE CHANGE ON CULTURAL RESOURCES

INTRODUCTION

As the previous chapter described, climate changes will have varying effects on local ecosystems within the Intermountain Region. This chapter focuses on the possible effects climate changes and local ecosystem changes are likely to have on cultural resources. Not all resources will be affected by climate changes in the same way or at the same magnitude. Each resource within the Intermountain Region is unique in many respects, including environment, composition, preservation history, and vulnerability to climate changes. This chapter primarily covers the potential effects of climate change on architectural resources, divided by material type. The potential effects to buried archaeological resources are also briefly addressed.

BURIED ARCHAEOLOGY

Buried archaeological resources are primarily preserved due to the condition of the soil in which they are buried, which slows the rate of deterioration and maintains these resources in situ. When these equilibrium conditions are changed, deterioration can occur more rapidly. Changes in soil moisture and soil chemistry can accelerate the deterioration of archaeological materials, especially organics. Conditions that cause movement in the soil, such as erosion and changes in vegetation cover, can cause irreversible damage to these resources, destroying stratigraphic integrity (Cassar 2005:26). Climate changes, including temperature and precipitation changes, present direct and indirect threats to buried archaeological resources, because these changes have the potential to alter the condition of soils that are protecting and preserving buried archaeological resources.

Issues relating to buried archaeology and climate change impacts are only discussed in a few research articles. Reports by Cassar (2005) and Daly (2011) note that the preservation of buried archaeology and the impacts of environmental changes on this process are poorly understood. There is a gap in knowledge in the effects of chemical changes on preservation of buried archaeology. Challenges in predicting the potential impacts of climate change on buried archaeology are compounded by a lack of funding for research on in situ preservation. Researchers have not yet determined the best way to deal with a risk that is largely unquantifiable due to the many unknown sites that are potentially threatened.

ARCHITECTURAL RESOURCES

Historic architectural resources in the national parks are often the most visible cultural resources. Whether in the form of standing structures or ruins, visitors can relate to these resources and develop a better understanding of the individuals who built them and the time periods and circumstances in which they were built. It is important that these architectural resources are preserved as interpretive elements of NPS sites.

Though there are exceptions, most historic architecture was built to be suited to the local climate during the period in which it was built. Certain elements of these structures may not be suited for the new conditions of their local environments as climates change. The sections below discuss known causes of deterioration and visible indications of deterioration that may increase in some regions as climates change.

Earthen Architecture (Adobe)

Earthen architecture is prominent throughout the arid southwest, primarily Arizona, New Mexico, and west Texas. These structures and ruins within the NPS Intermountain Region are primarily of adobe brick. Traditionally, adobe bricks were sun-baked, never kiln fired. These bricks consist of a mix of sand, clay, water, sometimes gravel, and often straw or grass. These elements were often mixed by hand and formed in wooden molds, then laid out to dry in the sun. Mortar was typically of mud, exhibiting similar deterioration properties as the bricks. Walls were covered with traditional surface coating, including mud plaster, lime plaster, whitewash, and stucco, as a preventative maintenance measure (National Park Service 1978). It is important to understand how changes in climate can affect these often-fragile building materials.

It is widely recognized that moisture greatly affects earthen building materials, which is the primary reason these materials were commonly built in arid environments and survive in these environments. According to future climate projections, changes in air and surface moisture can be expected in the future. The most important factor in the performance of earthen structures is excessive moisture, including heavy rainfall, standing water, snow, and high and continual relative humidity.

Excessive moisture affects earthen building materials, as well as building systems. Other factors that can lead to degradation of earthen building materials and buildings systems include excessive winds, physical abrasion by animals and humans, human intervention, and ground motion (Crosby, Condition Assessment 2011:1). When looking at the possible effects of climate change, excessive moisture is the primary deterioration factor to consider, with excessive winds and human intervention being of secondary concern.

Moisture

Traditional adobe bricks are not fired in a kiln, and therefore do not permanently harden. Bricks remain unstable and shrink and swell with moisture content changes. Adobe strength fluctuates with moisture content; higher moisture content results in less strength (National Park Service 1978). Climate scenarios suggest changes in precipitation patterns, resulting in changes in air and ground moisture levels in the future (see Chapter 2). These changes fall into three related categories affecting earthen architecture: increased heavy rainfall events, increased frequency of wetting-drying cycles, and increased frequency of changes in soil moisture.

<u>Heavy Rainfall Events</u>. Climate scenarios indicate that heavy rain events will increase in the future in parts of the Intermountain Region. These events can cause significant deterioration of earthen architecture. Heavy rainfall erodes earthen surfaces. As adobe becomes saturated with rain it loses its cohesive strength and erodes, causing corners and parapets to round. If rainwater damage is left unattended, it can eventually destroy adobe walls and roofs, ultimately leading to collapse. Accumulating standing water at the foundation level of earthen buildings and splashing from heavy rain or drainage systems can cause the hollowing of walls just above grade level, a process called coving (National Park Service 1978).

In 2010, the Franciscan church at Tumacácori National Historical Park experienced damage in the form of partial wall collapse following multiple heavy rain events (Figure 3.1 and see Moss 2010). Although this specific event cannot be directly attributed to climate change, such forms of damage to earthen architecture can be expected to occur more often if heavy rainfall events become more common, as indicated by regional climate scenarios.

Roofing systems and drainage systems are intended to protect structures from precipitation, and the failure of these systems can be catastrophic for earthen buildings. Flat roofs are widely used on earthen structures, greatly contributing to the architectural character. However, the combination of earthen walls and flat roofs creates a maintenance challenge (Iowa 2005:92). Heavy rainfall can put stress on roofs and drainage systems. Collapsing roofs can lead to bulging walls and devastating cracking. Damage to drainage systems can have detrimental effects on earthen walls, leading to rapid deterioration (National Park Service 1978).

Figure 3.1. The sacristy north wall exterior of the Tumacácori Mission church (Tumacácori National Historical Park) collapsed in 2010 after a series of heavy rainfall events. (Moss 2010:12)

Wetting-Drying Cycles. In addition to the direct effects of excessive moisture on earthen building materials, moisture also creates an environment for other processes of decay to occur. Increased moisture content during and immediately after rainfall events and the subsequent drying out of wall surfaces can cause cracks and pitted surfaces to form.

Soluble salts are not harmful to earthen building materials on their own. However, the process of hydration and dehydration of earthen materials causes soluble salts normally found in earthen buildings to crystallize and grow. The crystallization process puts pressure on the pores of the materials, causing the material to break apart or spall. In addition, salts within earthen materials can retain moisture, leading to the decay of other materials that it comes in contact with, for example metal reinforcing (Crosby, Condition Assessment 2011:1).

Ground Moisture Fluctuations. Historically, adobe brick walls were commonly constructed on a foundation of round or flat stones laid in a shallow trench. This foundation inhibited the capillary action of groundwater into the adobe wall. In other cases, however, adobe walls were laid with no footing, though very few of these survive. Changes in the water table due to natural or man-made causes can undermine adobe walls, even those that are stable (Iowa 2005:95). Increased soil moisture due to changes in precipitation patterns can cause increased sustained moisture in the lower sections of earthen walls, as a result of capillary action or rising damp. Continued saturation of earthen materials can result in the erosion of walls, similar to the effects of heavy rainfall. Erosion of the lower courses of adobe walls is particularly dangerous, as it reduces the structural stability of the wall. Eroded lower courses will eventually be unable to support the weight of the wall and roof above it.

Temperature

Temperature does not directly affect earthen building materials, however, it can have an indirect effect in several ways. When combined with excessive moisture, freezing and thawing of water retained in the pores of earthen building materials can put pressure on the material, causing it to break apart (Crosby, Condition Assessment 2011:2). The number of extreme cold days in the Intermountain Region is projected to decrease in the future (see Chapter 2), likely resulting in fewer freeze-thaw cycles. However, a projected increase in rainfall during the winter months in part of the region could mean an increase in freeze-thaw damage as a result of increased moisture retained in earthen materials during the colder months.

Pests

Vegetation and pests can accelerate the deterioration of earthen building materials. Animals, birds, and insects are often found living in earthen structures, sometimes creating burrows or nests in walls and foundations. Increased moisture in earthen materials, which may occur more often in the future as a result of increased heavy rainfall events, can attract insects and animals that otherwise would not be attracted to these structures (Crosby, Condition Assessment 2011:1). Seeds deposited by wind and animals can grow in adobe walls, just as they would in soil. This effect, coupled with the expectation that the geographic distribution of pests will change as regional climates change, could result in increased pest and vegetation activity in earthen structures. Pest and vegetation activity can undermine the structural integrity of earthen buildings (National Park Service 1978).

In summary, earthen architecture is a fragile material that is highly vulnerable to moisture fluctuations, temperature fluctuations, and pests. As climates change, monitoring of earthen structures for signs of deterioration and maintenance of structures to lessen the effects of deterioration will be essential in the preservation of earthen architecture.

Masonry (Brick And Stone)

Brick and stone masonry structures exist throughout the National Park Service's Intermountain Region. This category of structures represents the widest range of variety, ranging from prehistoric cliff dwellings to twentieth century park facilities. Materials used in masonry, including handmade bricks, manufactured bricks, and a variety of stone types, are different in their properties and rates of deterioration. However, masonry materials share several general properties, allowing for a discussion of the possible effects climate change in the region will have on masonry structures. The possible effects on mortar, plaster, and stucco are discussed on page in the Cementitious Materials section below.

Moisture

Although annual rainfall amounts are expected to decrease in most of the Intermountain Region, heavy rainfall events are expected to occur more often in the future, according to climate scenarios. Additionally, rainfall amounts during the winter are expected to increase throughout most of the region. These changes in precipitation patterns will influence moisture-related deterioration in historic masonry structures.

Wetting-Drying Cycles. Increased intense wetting and drying of masonry materials, due to increased heavy rain events projected in the future, could result in increased masonry deterioration. Weathering through projected increased heavy rainfall events could result in deterioration of masonry through efflorescence, delamination, and spalling. Wetting can become a greater problem with faulty rain disposal systems, including leaking gutters or pipes (Weaver 1997:105).

Efflorescence is a major issue associated with wetting and drying. Capillary action during wet periods can pull soluble salts from the ground into masonry, including chlorides from street and sidewalk salting during winter and nitrates from fertilizers. A white haze, referred to as efflorescence, forms as salts are pulled out to the masonry surface during drying periods. This salt layer is not only unsightly, but can be a sign that other damage may soon occur. Salts inside masonry and just behind the surface (subefflorescence) can put pressure on materials, causing them to crack and spall (Grimmer 1984:11).

The layered composition of sedimentary stones, including sandstone and limestone, makes these stones prone to delamination. Weathering can result in delamination, a condition in which the outer layer or layers split off of the stone face. Stones with clay-rich layers are more vulnerable to this type of deterioration (Grimmer 1984:9). Delamination is common in building stones that are improperly laid with their natural bedding planes laid vertically instead of horizontally, a flaw known as face bedding (Weaver 1997:63). Stone ruins without cover may be more vulnerable to delamination, as natural bedding planes are more exposed. Projected increased heavy rain events in the future may result in increased delamination of stones.

Spalling, unlike delamination, is not a deterioration issue for just natural stone, but also brick and other fabricated masonry materials, including terra cotta and concrete blocks. Spalling is a condition in which the outer layers of masonry unevenly break away in parallel layers from the masonry surface. This form of deterioration can be caused by salts in the pores of masonry materials, which put pressure on the material during wetting and drying cycles, forcing outer layers to break away (Grimmer 1984:20).

Wetting and drying cycles, exaggerated by projected increased heavy rainfall events in the region, could produce more deterioration issues in masonry structures and ruins, including spalling, delamination, and efflorescence. These deterioration issues already occur in the current climate, but could be increased with projected climate changes.

Ground Moisture. Projected changes in precipitation patterns in the region, both seasonally and annually, could have an effect on water table levels and soil moisture levels near the surface. Building conditions can be greatly affected by ground moisture, especially buildings that were not constructed with a foundation to restrict moisture from entering the walls through the ground.

Masonry structures are particularly vulnerable to rising damp, as moisture is pulled up into the pores of masonry walls through capillary action. More porous materials, including soft stones and bricks, experience increased rising damp. This process can leave masonry wet for extended periods of time, leading to deterioration issues, including blistering, efflorescence, delamination, and exfoliation. Additionally, a wet stain or tidemark can appear on the masonry surface as a result of rising damp (Grimmer 1984:18).

Changes in ground moisture can also result in settling ground surfaces, causing structural damage to the building. Structural settling often leads to cracking in masonry walls (Grimmer 1984:6).

Temperature

Projected increased winter rainfall throughout the region could result in increased freeze-thaw cycles. These cycles can have damaging effects on brick and stone masonry, as a result of moisture retained in the capillary structure of these materials. Water soaked bricks exposed to freezing and thawing cycles can eventually shatter (Weaver 1997:105).

Biogrowth is a significant aesthetic problem for masonry structures, and changes in climate could increase biogrowth activity in some parts of the region. Biogrowth is an indication that moisture is being retained in masonry. Major biogrowth can cause material deterioration as fungi and larger plants root in masonry units and adjacent mortar, putting pressure on materials. Heavy accumulations of moist decaying organic debris can cause material deterioration, through retaining moisture (Weaver 1997:121).

Pollution

The combined effects of pollution and changing climate could result in increased damage to historic masonry structures. Some stone types, including limestone and marble, are soluble in acids. Acid rain can quickly cause deterioration of these stones, especially if a mortar joint opens, providing prolonged exposure (Weaver 1997:64).

Efflorescence caused by contaminant salts associated with acid precipitation and air pollution, including sulfates, chlorides, and nitrates, can infiltrate the pores of masonry units and form crusts on masonry surfaces. As with efflorescence from salts in ground water, the force of salt crystals forming in masonry pores can cause layers of masonry to break free from the surface. Pollution can also cause the buildup of soiling on masonry surfaces, which is not only an aesthetic issue, but could also lead to material damage (Weaver 1997:105).

In summary, the porous nature of masonry materials makes these structures prone to many of the same causes of deterioration as earthen structures, including moisture fluctuations and temperature fluctuations. Additionally, certain materials used in masonry are particularly vulnerable to reactions with air and water pollution. Monitoring of moisture levels and visible symptoms of deterioration can aid in preservation of masonry structures.

Wooden Structures And Elements

Historic and wooden structures, including log cabins and wood frame buildings, as well as wooden building elements, exist throughout the Intermountain Region. Architectural wood is resilient and strong, but is vulnerable to certain conditions, including extended periods of dampness, intense exposure to sunlight and high temperatures, and pests. In some parts of the region, projected climate changes could lead to increased deterioration of architectural wood.

Moisture

Oversaturation of architectural wood is typically the key to wood preservation problems. Projected increases in heavy rainfall events in some parts of the Intermountain Region, as well as increases in annual rainfall in some areas, could result in increased prolonged saturation of architectural wood. This is especially true of structures with inadequate rain disposal systems and those with inadequate foundations (Bomberger 1991:9).

High moisture content causes a loss in wood strength. Bending strength is reduced 2 percent for every 1 percent increase in moisture content and compression strength parallel to the grain is reduced 6 percent for every 1 percent increase in moisture content. Wood fibers also can fail under load or stress caused by excessive or too rapid shrinkage as wood dries (Weaver 1997:20). Wood, like masonry, is also vulnerable to damage caused by soluble salts dissolving and crystallizing during wetting and drying cycles (Ibid.: 21).

Wood is particularly vulnerable to biodeterioration. Increased periods of prolonged moistures in wooden architectural elements can lead to an increase in biodeterioration of wood in historic structures of the region. Bacteria, fungi, and mold are all attracted to moist wood (Weaver 1997:23-26). Rot caused by these organisms can occur quickly or slowly over time, depending on the local climate and building conditions.

Some climate scenarios indicate that wildfire activity could increase in parts of the Intermountain Region. Wood structures are particularly vulnerable to fire, and increased dry periods could increase the likelihood of this threat.

Temperature

Temperatures in some of the hottest parts of the Intermountain Region are projected to continue to rise in the future. This change could result in increased deterioration of wooden architectural elements through thermal degradation and photodegradation.

Thermal degradation of wood can occur during extensive periods of high temperatures. Increased ambient temperatures in the future indicate that temperatures inside enclosed buildings and temperatures within walls could be even greater. Wood is vulnerable to thermal degradation when exposed to prolonged periods of elevated temperatures. At 131 to 149 °F depolymerization of the cellulose and hemicellulose in wood begins (Weaver 1997:21). Thermal degradation can cause strength losses in wood.

Exposure to sunlight and ultraviolet radiation can cause photodegredation. Surface layers of wood can be damaged by ultraviolet radiation a few micrometers at a time. Ultraviolet light exposure degrades lignin in the wood, which is water-soluble and can leach out. As lignin is removed, loosened fibers are left behind with a silver-grey appearance (Weaver 1997:20). Areas where temperatures are projected to increase and precipitation are expected to decrease, including the far southwest of the region, can expect to see increased wood deterioration issues.

Pests

Pests are particularly drawn to wooden building elements. Projected climate changes could increase pest activity in some areas and decrease pest activity in other areas. Insect pests that can cause damage to wood include beetles, termites, ants, bees, and wasp. Animal pests, including woodpeckers and rodents, can also cause significant damage (Weaver 1997:26-36).

Wood architectural materials must remain as dry as possible, without being exposed to extreme heat or sunlight, in order to maintain strength and keep from attracting pests. Monitoring of wood for the signs of deterioration, which may become more prevalent in some areas as climates change, can lead to quick action in order to preserve these structures and architectural elements.

Cementitious Materials

Cementitious materials are defined as building materials that may be mixed with liquids, such as water, to form a plastic paste, and to which an aggregate may be added. Cementitious materials in historic contexts include cements, limes, and mortars, which are typically elements of masonry buildings, but can be elements of other types of buildings, including chinking on log structures. Lime-based cementitious materials are often porous and intentionally sacrificial, meant to degrade more quickly than masonry units, and are often periodically repaired and replaced. Being porous, these materials are particularly vulnerable to moisture and pollutants that can be absorbed into the material through moisture. Deterioration of these materials and lack of repair or use of improper repair materials can increase deterioration of the materials they were intended to protect.

Moisture

Prolonged exposure to large quantities of rainwater or snowmelt water can deteriorate lime-based cementitious materials, especially if this water is acidic. Acid in the water removes carbonates from the lime, reducing these materials to wet sand and fragments of deteriorated mortar with little adhesive and cohesive strength (Weaver 1997:137). This overexposure can occur during heavy rainfall events and after large snows, especially if rain disposal systems are inadequate or faulty.

Long periods of wetting can also cause cementitious materials to crumble as clay minerals included in the mix expand. Crumbling can also occur as a result of the presence and growth of masses of crystals of anionic salts, including chlorides, sulfates, and nitrates. These salts can be present as part of the original mix or introduced later due to contamination by polluted water or soils with high natural sulfate contents. Wetting and drying cycles make these salts to grow and expand, causing cementitious materials to crumble (Weaver 1997:137).

Pollution

Acid precipitation and air pollution can dissolve lime or calcium carbonate from mortars, accelerating the deterioration of brickwork (Weaver 1997:105). Prolonged saturation of cementitious materials by polluted rainwater can lead to growth of crystal masses of anionic salts, which can cause mortar to crumble (Ibid.:137).

Cementitious materials, though often intended for regular repair and replacement, may deteriorate more quickly in the future in some areas, due to changing climates. It is important to monitor these materials for signs of deterioration, as deterioration of these materials will lead to quicker deterioration of adjacent materials, including masonry units.

Metalwork

Structural and decorative metal elements of historic buildings can be affected by moisture and heavy rainfall events. Prolonged wetting of metal elements can not only lead to the degradation of the metal elements, but also adjacent architectural materials. Projected increased pollution levels and increased moisture during some parts of the year in some parts of the region, may cause increased levels of metal deterioration.

Most metals corrode, undergoing chemical degradation processes or reactions with water, oxygen, and other substances (Weaver 1997:175). As metals corrode they form films and crusts. Sometimes these crusts are stable, protecting the metal from further corrosion. When a crust is unevenly distributed, it can cause pitting (Ibid.: 181). Iron and iron alloys corrode quickly when exposed to moisture and air if unprotected, especially if exposed to air pollution or acid precipitation. Corrosion can be initiated at 65 percent humidity, but if pollution is present, much lower humidity levels, as low as 20 percent, can cause corrosion. As iron corrodes, it can fall apart in layers, eventually developing holes and losing significant strength (Ibid.:183).

Corrosion of metal not only lessens the strength of the metal, but also can accelerate deterioration of adjacent materials. Corrosion of iron and steel can greatly increase the volume of these materials.

When metal is imbedded in materials, such as masonry, corrosion can cause adjacent materials to shatter (Weaver 1997:185).

Moisture can greatly affect the condition of architectural metal. The deterioration of metal not only affects the metal itself, but can also affect adjacent materials and, in some cases, the structural integrity of a building. Projected climate changes may result in increased deterioration of architectural metal in some areas of the region. Monitoring of visible signs of deterioration is essential for the preservation of metalwork and structures that have metal elements.

SUMMARY

It is important to remember that climate change does not cause the deterioration of architectural materials. Deterioration of building materials is a natural process that is constantly occurring. Changes in climate could lead to an intensification of deterioration processes over time. Deterioration will be physically visible in changes in the condition of the building. These symptoms may include such things as delamination of masonry, rotting of wood, or crumbling of mortar. An investigation of conditions can lead to the identification of causes of deterioration. Causes may include exposure to high levels of pollution, faulty rain disposal systems, or puddling of water near the building foundation. These causes of deterioration may be related to projected climate changes, including increased heavy rainfall events or higher temperatures.

By identifying how projected climate changes may affect historic resources, it may be possible to identify likely future causes of deterioration and expected resulting visible conditions. Monitoring of structures for these expected conditions and addressing of these potential causes of deterioration ahead of time might reduce the negative impacts of projected future climate changes on historic resources.

PART FOUR

CONCLUSIONS

CONCLUSIONS

SUMMARY

The principal objective of this report is to provide an overview of climate change scenarios for the Intermountain Region, and an introduction to the potential effects these changes may have on cultural resources, focusing on VT resources. The collection of this information in the form of this report is intended to serve as a reference for NPS cultural resource managers. Planned future phases of this project will address the vulnerability of resources and sub-regions in the Intermountain Region, as well as monitoring and maintenance strategies for addressing this vulnerability.

Research on the potential effects of climate change on cultural resources has not, to date, been a priority in the United States. Several factors have likely contributed to this lack of research, including a shortage of evidence directly attributing the deterioration of cultural resources to long-term climate change. Many factors contribute to the deterioration of cultural resources, especially architectural resources, including maintenance schedules, previous incompatible repairs, material properties, and structure use. Extreme weather events frequently have the most visible detrimental effects on historic architectural resources, but it is not often possible to directly attribute these events to long-term climate change. The complicated nature of linking long-term climate change with the deterioration of cultural resources has likely limited the research focus on this important issue.

Prehistoric and historic architectural resources were, for the most part, designed to suit the environments in which they were built, at the time in which they were built; and these resources were not built to last forever. Even small changes in the environment can have significant effects on these cultural resources.

The significance of the effect of climate change on cultural resources is not necessarily in the degree of change expected. Climate change models often differ in the degree of change projected, which can be discouraging to resource managers as they develop plans to preserve cultural resources. However, considering the nature of historic architectural materials, perhaps the degree of change projected is not as significant as the fact which climate scientists can agree upon – climates are changing. Local climates will be different than the climates in which park historic architectural resources were constructed to suit, and likely different than what resources managers are currently maintaining them to survive. It is important to consider the potential effects of climate change on cultural resources, even if the degree of change is not exactly known. Simply stated, changes in climate, at any degree, can have significant effects on cultural resources.

Perhaps the most well-known climate change projection is the predicted increase in annual temperatures. This change is expected in differing degrees across the region. Despite this common example being unidirectional, not all climate changes are unidirectional, especially in the precipitation category, and especially across seasons. Future changes in precipitation indicate that some areas will experience increased annual precipitation, while others will experience decreased precipitation. These changes also differ seasonally. It is important for resource managers to note if their resources are in areas that will expect an increase or decrease in precipitation, as this information is significant in considering how future climate changes may affect material deterioration.

PRELIMINARY ANALYSIS OF VULNERABLE AREAS AND RESOURCES

A secondary objective of this report, aside from compiling existing information on climate change and cultural resources, is to identify climate parameters most destructive to the built environment and to identify areas and resources in the region that are perhaps most vulnerable to the effects of climate change. This analysis is not the focus of this report and is therefore brief and not comprehensive, but does provide a preliminary look at what resources and areas may be deserving of additional attention and study in regards to the effects of climate change on cultural resources. An assessment of the vulnerability of cultural resources in the region is planned to be the focus of the second phase of this VT project.

Chapter 3 identified the potential effects of climate change on historic architectural materials. As this chapter explained, architectural materials, especially porous materials, are particularly susceptible to moisture. Abrupt changes in moisture, such as that caused by heavy rainfall events, and long-term changes in moisture – such as that caused by changes in annual precipitation, sustained heavy rainfall events, and drought events – affect architectural materials. Additionally, seasonal changes in precipitation have the potential to detrimentally affect the built environment. Projected increase in winter rainfall in some areas, could contribute to an increase in the negative effects that freeze-thaw events have on historic building materials in these areas.

Moisture changes are perhaps the most easily recognizable climate parameters that are destructive to the built environment. However, indirect changes attributed to precipitation and temperature changes also have the potential to significantly impact cultural resources.

Vulnerable Areas Within The Region

The climate scenarios used for this report (2013 NOAA Reports) indicate areas of the Intermountain Region that are expected to see more extreme climate changes than other parts of the region. In terms of extreme high temperatures, areas of southern Arizona and southern New Mexico are simulated to see the biggest changes, with increases of up to 40 days more per year with maximum temperatures higher than 95°F (see Figure 2.10). This increase in extreme heat could affect architecture materials vulnerable to deterioration by sunlight. Southwestern Montana, western and southern Wyoming, and western and central Colorado are simulated to see the largest decreases in extreme cold temperature days (see Figure 2.11). This change could increase damage to porous building materials during freeze-thaw cycles.

Parts of central Arizona and southwest New Mexico are simulated to see decreases in annual precipitation of more than nine percent, while part of northwest Utah is simulated to see up to a six percent increase in annual precipitation (see Figure 2.14). Changes in annual precipitation could affect soil moisture and soil chemistry, impacting historic architectural resources and buried cultural resources. While most areas in the region are expected to see decreases in annual precipitation, a majority of the region is expected to see an increase in winter precipitation. Central Wyoming and eastern Colorado are simulated to have large increases in winter precipitation, greater than 15 percent (see Figures 2.12 and 2.13). This increase in winter precipitation could result in increased freeze-thaw damage to resources in these areas.

Areas where the most extreme changes are simulated are not only vulnerable because the climate is expected to change to a level that is significantly different than that in which historic architectural resources were designed to suit, but also because the climate is expected to change to a level that is significantly different than that in which resource managers are currently maintaining these resources for preservation. Seasonal changes in temperature and precipitation have the potential to significantly impact current maintenance schedules.

Vulnerable Resources Within The Region

Resources that are most vulnerable to the effects of climate change are perhaps not significantly different than those that are currently most vulnerable to deterioration. These resources include those that are difficult to maintain, especially those constructed of materials that were not meant to last long-term and those that are in the form of ruins.

Earthen architectural materials, including adobe, are particularly vulnerable to moisture changes. Heavy rainfall events can be particularly damaging to earthen architecture due to quick increases in moisture content and the physical force of heavy rainfall. For this reason, earthen architectural resources in areas where heavy rainfall events are expected to occur more frequently in the future are particularly vulnerable.

Architectural ruins are especially vulnerable to the effects of climate change, as these resources typically have low levels of protection from weather, including sunlight and precipitation. These resources already are vulnerable to extreme weather events and potentially face increased vulnerability as extreme weather events increase in some areas. As climates potentially change to be less favorable for exposed architectural materials, especially with increased sun exposure and increased rates of moisture change, resources in the form of ruins are potentially some of the most vulnerable.

Buried archaeological resources are some of the most vulnerable to the effects of climate change. The potential effects to these resources are not the primary focus of this report and are not discussed in detail, because very little research is known that addresses these effects. These resources are considered vulnerable because the potential effects are not known and these effects are not easily monitored. Known potential effects to buried archaeology are the effects of changes in soil moisture and soil chemistry, as well as the documented negative effects of post-fire erosion where buried archaeological resources exist.

FUTURE RESEARCH NEEDS

Available research specific to climate change and cultural resources is not abundant. While climate change research related to the potential effects on natural resources has become common in the United States, research related to cultural resources has not. Possible reasons for this disparity are discussed at the beginning of this chapter. For whatever reason, very little research has been conducted thus far on climate change and cultural resources in the United States. International sources, such as reports by Noah's Ark and English Heritage, focus specifically on the effects of climate change on cultural resources. While much of this research is useful in creating a general understanding of the potential effects, this international research is focused specifically on the climate change scenarios and cultural resources of the specific countries and regions for which the research was conducted. The United States, particularly the southwest United States, is unique in its environments and cultural resources. Further research specific to the topic of climate change and cultural resources in the NPS Intermountain Region is necessary, with specific attention paid to the unique cultural resources and conditions of this region.

Translating the potential effects of climate change on architectural resources, as done in this report, can in many ways be accomplished through an examination of literature on architectural materials deterioration and combining this knowledge with the potential climate changes. This, however, is easier to accomplish when exploring visible, aboveground forms of deterioration. The effects of less visible changes, such as changes in ground moisture and soil chemistry, are not well studied. These changes have the potential to impact both standing architecture and buried archaeological resources, but very little research could be found on this topic. Additionally, it is known that wildfires, in addition to causing damage to resources by fire, also have the potential to accelerate erosion, placing historic architectural resources and buried archaeological resources at risk. These topics related to changes in soil moisture and soil chemistry both are important future research topics.

An important step for resource managers in dealing with the effects of climate change and cultural resources is monitoring of these resources. However, very little research could be found that addresses monitoring techniques and strategies for architectural and archaeological resources. This is an important topic for future research and is planned to be a focus of future phases of this project.

Monitoring of historic architecture is useful in noting trends in material conditions, but it is important to have known building material deterioration thresholds in order to determine at what point action should be taken to prevent further deterioration. While some research exists on this topic and has been included in the bibliography for this report, this research is by no means comprehensive. Additional research on material thresholds will be essential for developing a successful monitoring and maintenance program for cultural resources in response to climate change.

The United States is in the early stages of research on the effects of climate change on cultural resources. As the National Park Service and other agencies and organizations continue to increase support for research on this topic, resource managers and other individuals responsible for cultural resources will continue to gain access to better information, allowing better preparation for future climate changes and better monitoring and maintenance practices for the continued preservation of cultural resources.

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Part 5. Climate of the Southwest U.S. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. NOAA Technical Report NESDIS 142-5. Washington, D.C.

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LITERATURE ON CLIMATE CHANGE AND CULTURAL RESOURCES

NPS Policies on Climate Change

National Park Service

2008 "A Framework for a Regional Strategic Response to Global Climate Change and Cultural Resource Management," National Park Service, Pacific West Region, Cultural Resources Advisory Committee, May 2008 revised outline.

2010 National Park Service Climate Change Response Strategy. National Park Service Climate Change Response Program, Fort Collins, Colorado.

2012 Applying National Park Service Management Policies in the Context of Climate Change. Memorandum from Director Jonathan Jarvis to Park Superintendants, 6 March 2012. Available at http://www.nps.gov/policy/MPandCC.pdf.

2012 Climate Change Action Plan 2012-2014. Available at www.nps.gov/orgs/ccrp/upload/NPS_CCActionPlan.pdf.

2013 Cultural Resources and Climate Change. Climate Change Response Program Cultural Resources Brief, March 2013. Available at http://www.nps.gov/subjects/climatechange/upload/CulturalResourceBriefMar2013.pdf.

2014 Climate Change and Stewardship of Cultural Resources. Policy Memorandum 14-02 from Director Jonathan Jarvis to All Employees, 10 February 2014. Available at http://www.nps.gov/policy/PolMemos/PM-14-02.htm.

This recent memorandum provides guidance and direction to NPS employees on the topic of climate change and cultural resources. Subjects covered include climate change adaptation for cultural resources, cultural resources decision-making, and communicating about climate change science and impacts. The section on decision-making is especially useful as it addresses cultural resource managers' responsibilities under the National Historic Preservation Act, the importance of integrating resource vulnerability and significance into the prioritization of funding and management actions, and the responsibility of resource managers to recognize the potential for loss.

Climate Change Guidance for Cultural Resource Managers

Adger, Neil, et al.

2009 "Are there social limits to adaptation to climate change?" *Climate Change* 93:335-354.

Caffrey, Maria, and Rebecca Beavers

2008 "Protecting Cultural Resources in Coastal U.S. National Parks from Climate Change." *The George Wright Forum* 25(2):86-97.

Daly, Cathy
2011 “Climate Change and the Conservation of Archaeological Sites: a Review of Impacts Theory.” *Conservation and Management of Archaeological Sites* 13(4):293-310. Available at http://arrow.dit.ie/beschrecart/8/.

Daly, a doctoral student at the Dublin Institute of Technology, discusses the current state of knowledge in the literature on the potential impacts of climate change on archaeological sites. The author applies knowledge from the literature to a case study in Ireland, highlighting the strengths and weaknesses of the current body of research.

English Heritage
2008 “Adapting to a Changing Climate.” *Conservation Bulletin* 57. English Heritage, Bristol. Available at http://www.english-heritage.org.uk/publications/conservation-bulletin-57/conbull57pp111.pdf.

Though this report was published several years ago, it remains one of the most useful in the discussion of climate change and cultural resources. The report focuses on future climate changes projected for the UK, but the review of threats to the historic environment is applicable to other regions worldwide. Table 2.1 of this report is based on Table I of this English Heritage report.

2008 “Climate Change and the Historic Environment.” English Heritage, London. Available at http://www.climatechangeandyourhome.org.uk/live/content_pdfs/29.pdf.

Flaming, R. Jay
2012. Uncertainty, Systems and Information Behavior in Climate Change Adaptation: Protecting Cultural Resources in our National Parks (Draft).

This draft document expresses the need for action in protecting cultural resources from the effects of climate change and addresses the uncertainty associated with climate change, noting ways resource managers can cope with and reduce this uncertainty. This document may be particularly useful to resource managers and decision groups in the first stages of addressing the effects of climate change and cultural resources.

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