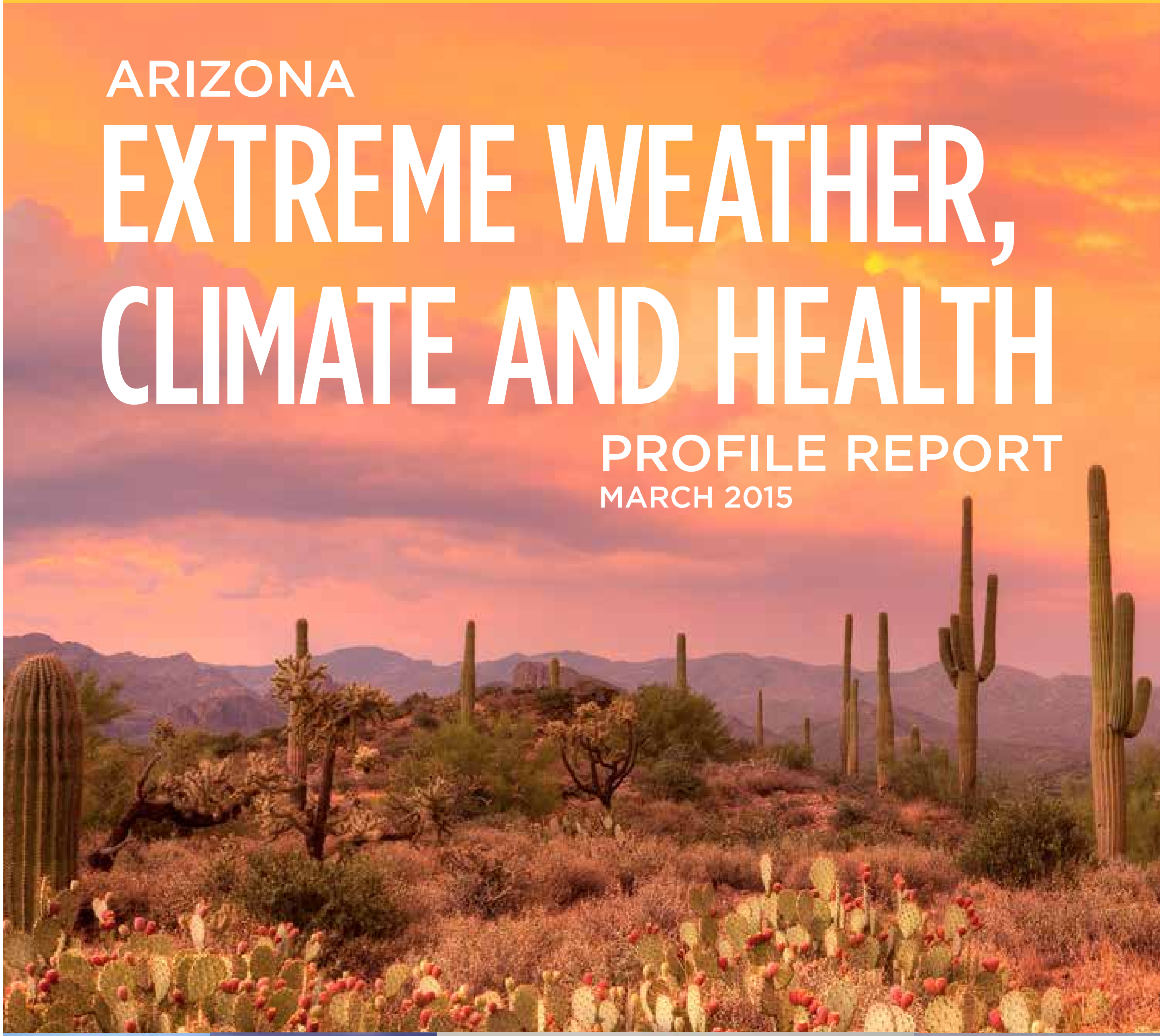
BUILDING RESILIENCE AGAINST CLIMATE EFFECTS

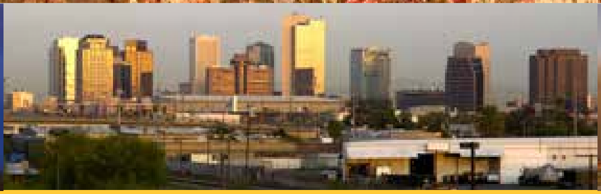
ARIZONA

EXTREME WEATHER, CLIMATE AND HEALTH

PROFILE REPORT

MARCH 2015





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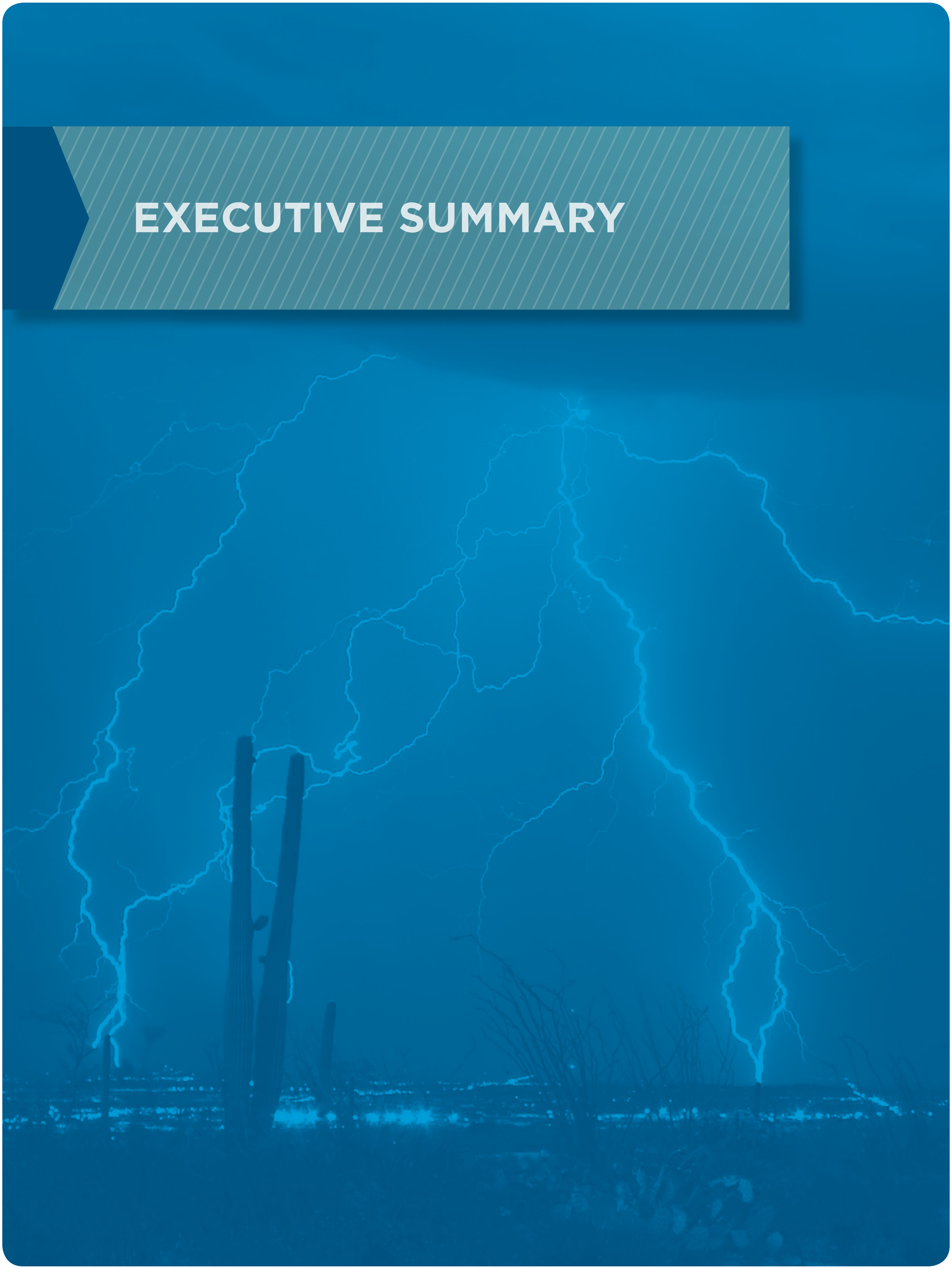

EXECUTIVE SUMMARY

Rationale and objectives

Observed and projected changes to the climate (e.g. more/less precipitation and higher temperatures) can pose significant health risks to the residents of Arizona. As in other locations in the Southwest, across the United States, and around the world, these changes are likely to coincide with an increased frequency of drought, flooding, severe heat events, and wildfires; and disruption of civil infrastructure, including transportation, energy, and water systems. These impacts can lead directly to illness and death and are likely to worsen existing health conditions, such as cardiovascular diseases, asthma, and other respiratory illnesses.

A number of other factors are expected to compound these health issues. Achieving air quality goals may be more difficult because of changes in the emission rates of ozone precursors including nitrogen oxides (NOx), carbon monoxide (CO), and volatile organic compounds (VOCs), along with changes in meteorological conditions that facilitate high pollutant concentrations. Additionally, the timing and potency of aeroallergens may be hastened and increased. Finally, vector-borne illnesses carried by insects (i.e., mosquitos, mites, and ticks) are likely to become increasingly widespread.

The U.S. Centers for Disease Control and Prevention (CDC) have developed the *Building Resilience Against Climate Effects* (BRACE) framework (Figure A) to provide local health officials with a mechanism for addressing climate-related public health effects and to support the creation of regional public health adaptation and mitigation efforts. The framework uses the principles of adaptive management to achieve these goals. This report addresses Step 1 of the framework, focusing on two climate-related hazards and associated health impacts of major importance to Arizona—extreme heat events and air pollution.

The frequency and intensity of extreme heat events already are increasing in the state and this trend is expected to continue. Likewise, under some future climate scenarios, ozone formation and accumulation are expected to increase (Weaver et al. 2009; Kim et al. 2015). Furthermore, historical monitoring of air pollution, especially ozone and coarse particulate matter (PM_{10}), has identified these pollutants as a problem in the state.

This report describes the link between these hazards and human health outcomes, and identifies the segments of the population that would be at-risk or vulnerable to their effects.

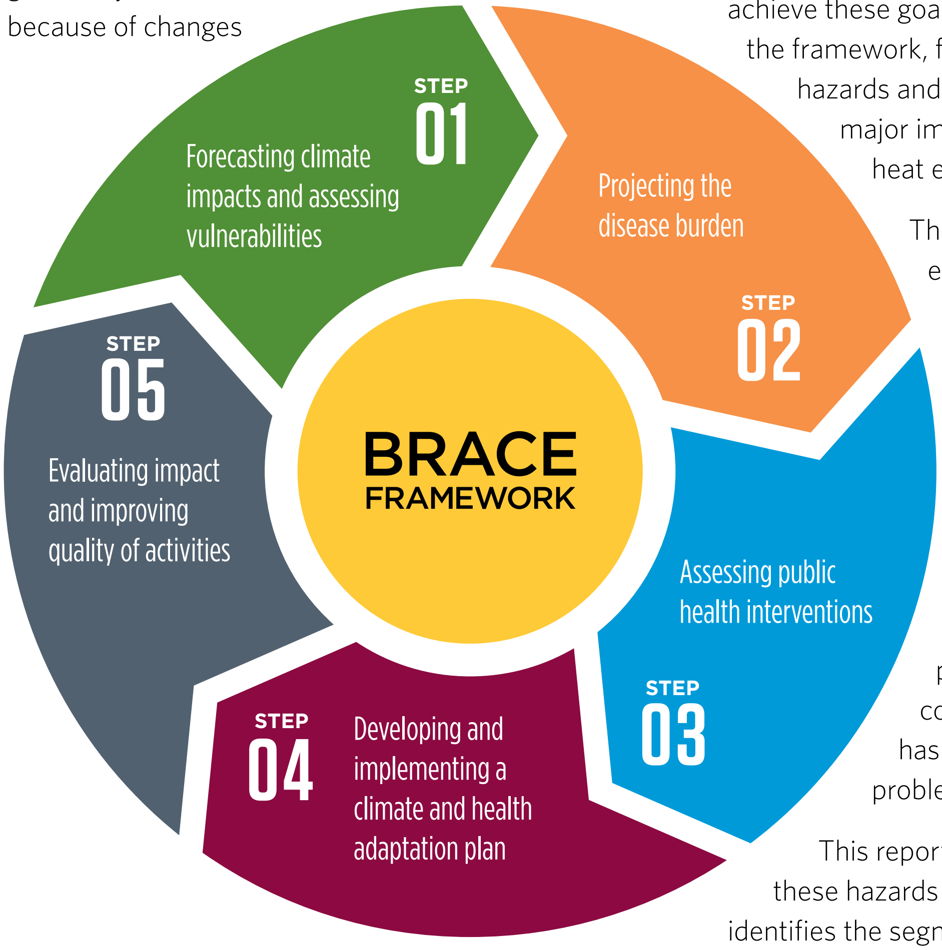

Figure A The five-step BRACE framework. Source: Adapted from Marinucci et al. (2014).

The work involved extracting downscaled climate projections for Arizona and identifying populations vulnerable to extreme heat and poor air quality. Further work will include projecting future public health burdens, identifying mitigating measures, evaluating their cost-effectiveness, and developing an adaptation plan. Flood- and drought-related hazards will also be analyzed. Throughout these activities, Arizona Department of Health Services (ADHS) and the project team will evaluate the framework's effectiveness and revise their efforts, as needed.

Projections summary

Regional and national climate assessments typically provide estimates of future changes at national and regional scales. These are generally too coarse to use for county and sub-county public health impacts. Applying a "downscaled," or layered, projection model is one way to transfer coarse projections to finer geographic scales to aid in adaptation planning and decision making. However, it typically requires a number of different models and "runs," or computational cycles, to obtain the most accurate predictions for multiple impacts. For instance, there were at least 37 downscaled models and more than 200 model runs used in the *Coupled Model Intercomparison Project Phase 5* (CMIP5) of the World Climate Research Program in 2013. Multiple models and runs add significant time and costs to assessments.

As a starting point for the BRACE Step 1 analysis, the interdisciplinary team employed a single model run, the Hadley Centre Global Environmental Model version 2 Earth System configuration (HadGEM2-ES) published by the Met Office Hadley Centre in the United Kingdom. The team chose HadGEM2-ES because its historical simulations have shown low bias (i.e., a low error rate between predictions and actual changes) across North America compared with other models. Since using a single model output does not represent the whole range of future projections, future estimations for this project will incorporate additional downscaled models.

Consistent with the most recent climate science, as embodied in the Intergovernmental Panel on Climate Change's *Fifth Assessment Report*, the project team evaluated future temperature scenarios in Arizona according to the four representative concentration pathways (RCPs). These RCPs included the highest and lowest GHG concentration scenarios between 2000 and 2100 – both with and without climate mitigation scenarios. Thus, RCPs provide a framework that will enable the scientific modeling community to undertake long- and near-term modeling experiments.

Overall, downscaled projections showed that the largest temperature changes are likely to occur in the state's more rural areas. In the medium and high RCP scenarios, the largest temperature increases were observed in northeastern and northern Arizona, including Mohave, Coconino, Navajo, and Apache Counties. The highest projected temperature increase in 2030 was seen in Mohave County under the RCP 2.6 scenario, with a 4.56°F increase from the 2010 baseline. In the year 2060, Navajo and Apache Counties also might experience temperature increases of as much as 3.64°F - 3.75°F.

Climate-sensitive health issues

A wide range of human health issues have been shown to be sensitive to environmental triggers

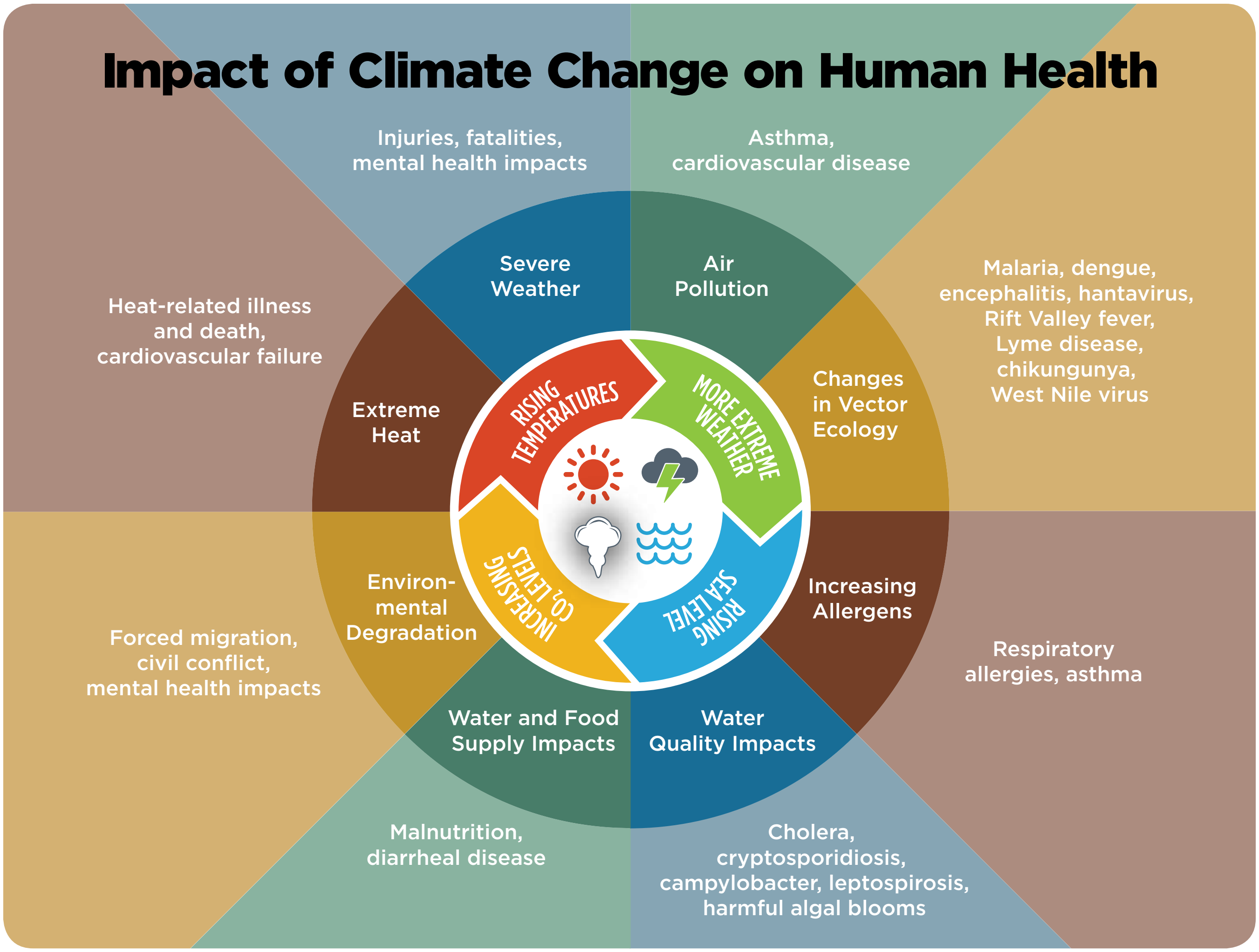

Figure B Conceptual Pathways of Climate and Health. Source: CDC Climate Effects on Health – www.cdc.gov/climateandhealth/effects/

and conditions (Figure B). The prevalence and distribution of these issues are expected to shift with a changing climate and subsequent impacts on aquatic, terrestrial, and atmospheric environments and ecosystems. In fact, national and international research bodies have established numerous conceptual pathways linking climate to human health. These pathways range from those that occur over short time scales (i.e., minutes, days), with direct links between climatic conditions or extreme weather events and health problems to those that occur over decadal (or longer) time scales and involve many intermediary environmental and/or human processes or behaviors.

Short-term, direct pathways are relatively straightforward, as the climate- and weather-related impacts themselves are the direct cause of illness and death. An example of a direct pathway would be a person drowning during a flash flood. Health issues directly related to extreme heat exposure are of particular concern in Arizona because much of the state experiences dangerously hot weather during the warm season. For example, the increased frequency and severity of extreme high-temperature events is very likely to increase the rate and occurrence of heat-related illnesses, including hyperthermia or heat stroke, and heat-related deaths.

Indirect, longer-term pathways connecting climatic and health issues are more difficult to measure and observe, but likely affect a much larger portion of the population due to the variety of mechanisms and extended time periods involved. In Arizona, the increased frequency and severity of extreme temperatures is expected to lead to human health impacts beyond heat stroke and heat-related deaths in a variety of ways. For instance, increases in the number and intensity of higher, less tolerable outdoor temperatures are likely to discourage outdoor exercise and recreation, as well as the use of non-motorized transportation. This, in turn, may increase the likelihood of chronic health conditions associated with sedentary lifestyles.

Increasing incidence of extreme heat can also affect air quality as concentrations of some pollutants, including ozone, are partially dependent on temperature. Poor air quality affects a large portion of Arizona's population living in regions that find it difficult to meet federal air quality standards for particulate matter (PM) and ozone, or that face challenges in maintaining compliance. Epidemiological research has found associations between increasing PM concentrations and total death rates; as well as hospital admissions for asthma, chronic obstructive pulmonary disease (COPD), cardiovascular disease, decreased lung function, and other respiratory symptoms. In children, exposure to PM has been found to hamper lung development.

Short-term ozone exposure can also result in respiratory health issues, including decreased lung function, cough, chest pain, shortness of breath, inflammation, and emergency room visits for respiratory issues. There is suggestive evidence that ozone exposure is associated with cardiovascular disease and total death rates. In addition, criteria air pollutants—those regulated by the U.S. Environmental Protection Agency—and the production and distribution of aeroallergens, including pollens and molds, are also likely to shift with increasing temperatures. Many individuals are sensitive to and suffer allergic reactions from airborne pollens (e.g., tree, weed, and grass) and mold. Thus, common allergic reactions and diseases, including rhinitis, asthma, and eczema, are expected to increase.

Due to the significance of extreme heat, air quality issues, and the host of health impacts that stem from these environmental conditions, this report focuses on heat and air pollution. Future BRACE reports will address two additional environmental drivers that are likely to change in ways that will affect public health—flooding and drought. Additionally, infectious diseases, which are likely to shift with changing environmental conditions, will be discussed in future reports.

Vulnerable demographic groups and geographic areas

Public health vulnerability describes the extent to which a given population is susceptible to death and illness. Scholars have identified three major components that affect a population's or system's degree of vulnerability—exposure, sensitivity, and adaptive capacity. Exposure includes proximity to or direct contact with environmental hazards, such as heat waves, air pollution, extreme weather events, or disease vectors. Sensitivity refers to population characteristics that influence the degree of susceptibility to the hazard—including race, ethnicity, poverty, access to health care, and access to transportation. Finally, adaptive capacity refers to the ability to modify behavior to prepare for the anticipated changes. Using these parameters, the team identified vulnerable demographic groups and geographic areas in Arizona by referencing academic literature and constructing several social vulnerability indicators using census data.

RATIONALE FOR POTENTIAL COLLABORATIONS IDENTIFIED

Successfully completing subsequent steps in the BRACE framework will require incorporating additional collaborators. Future partnerships will build on existing relationships established by ADHS and ASU. Stakeholder engagement is critical throughout all steps of the BRACE framework.

STEP 01 >> Partnerships with agencies and organizations that have access to local climate data and projections, as well as those that can review and summarize literature on related health impacts, have helped inform the climate projections and vulnerability assessments.

STEP 02 >> Engaging organizations that can employ qualitative and quantitative approaches to assess the climate and health data can help with projecting the disease burden.

STEP 03 >> Collaborators will be essential in identifying the range of health interventions available for each health outcome; as well as assessing the capacity to deliver each intervention, and prioritizing health interventions deemed most suitable for Arizona.

STEP 04 >> Collaborators will also be essential to support the dissemination of the Arizona Strategic Climate and Health Adaptation Plan, because those agencies and organizations may play a part in implementing the interventions.

STEP 05 >> Additionally, stakeholder engagement will be crucial for evaluating effective implementation of interventions, assessing whether climate and health are considered in broader public health planning, and establishing whether actions taken improved health outcomes.

Vulnerability to extreme heat events - Human vulnerability to extreme or excessive heat events (EHEs) involves more than physical exposure. It also involves individual and population sensitivity to EHEs and adaptive capacity. Sensitivity depends on the underlying characteristics of a population, such as age and ethnicity, while adaptive capacity reflects the capability of a system, population, or individual to cope with changes. The interdisciplinary team has identified the characteristics that make populations vulnerable to heat, as well as the locations (i.e., the places in which vulnerable populations congregate) where interventions are most needed. Reviews of this work show that low-income groups, African Americans, Latino Americans, Hispanic Americans, Native Americans, people with weak social ties, infants, the elderly, and those without access to air conditioning, are among the groups that usually suffer the effects of heat stress at rates that exceed those found in the general population.

Vulnerability to air pollution - Vulnerability to air pollution-related illnesses and death is known to be worse among the very young and very old, those in poverty, those without a high school diploma, workers with occupational exposures to air pollution, and those living near heavily traveled roadways.

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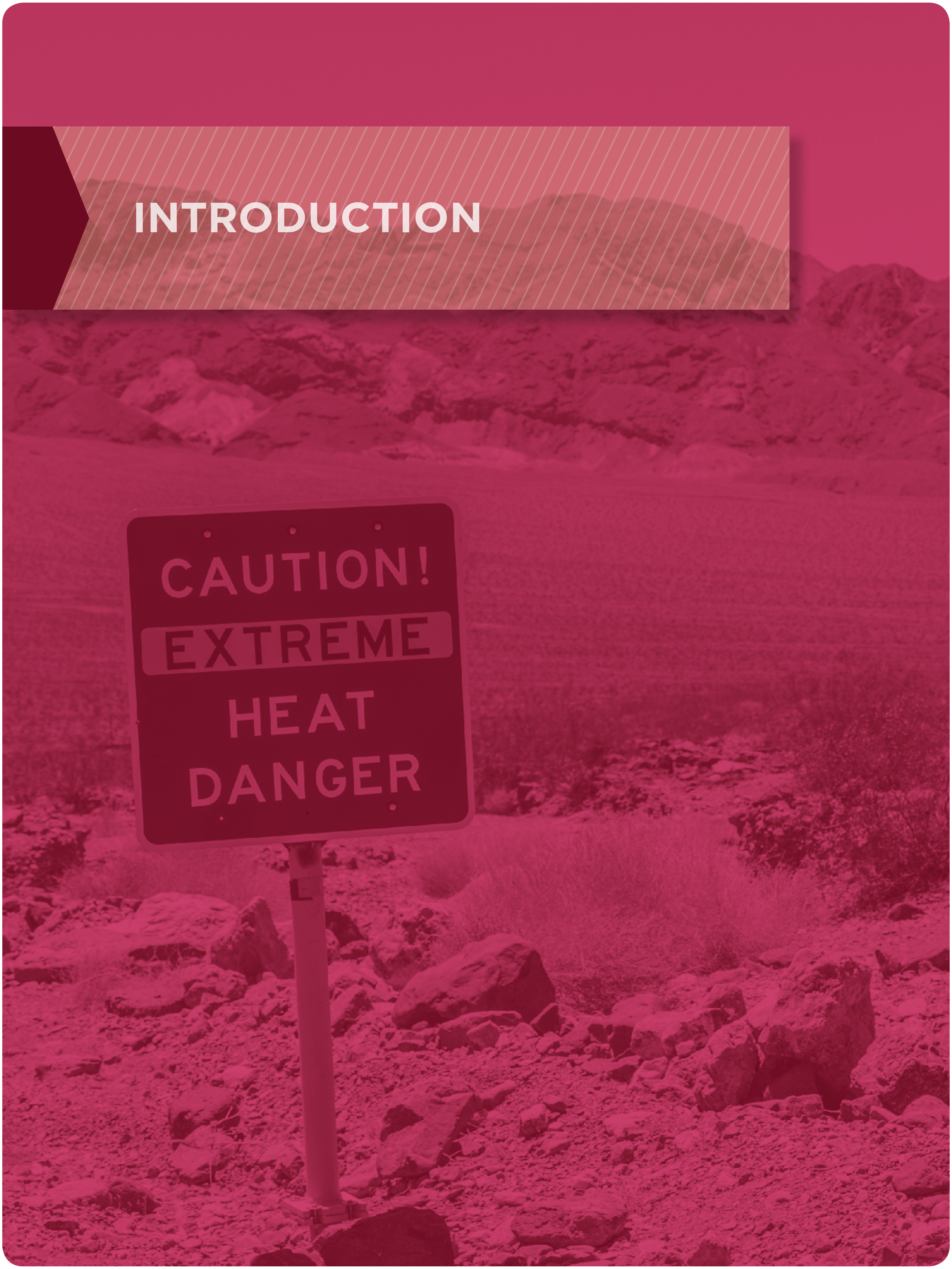
LIST OF ACRONYMS/ABBREVIATIONS

ADHS	Arizona Department of Health Services
AQI	Air Quality Index
ASTHO	Association of State and Territorial Health Officials
ASU	Arizona State University
BRACE	Building Resilience Against Climate Effects
CDC	U.S. Centers for Disease Control and Prevention
CDPH	California Department of Public Health
CEHTP	California Department of Public Health's Environmental Health Tracking Program
CICS-NC	Cooperative Institute for Climate and Satellites – North Carolina
CMIP	Coupled Model Intercomparison Project
CMIP5	Coupled Model Intercomparison Project 5
CO	Carbon monoxide
CO_2	Carbon dioxide
COPD	Chronic obstructive pulmonary disease
CRSCI	Climate-Ready States and Cities Initiative
CSTE	Council of State & Territorial Epidemiologists
EHEs	Extreme heat events
EPA	Environmental Protection Agency
EPHT	Environmental Public Health Tracking
GHGs	Greenhouse gases
GCMs	Global climate models
HadGEM2-ES	Hadley Global Environment Model 2 - Earth System
HiMax	High maximum temperature
HiMin	High minimum temperature
IAM	Integrated assessment modeling
IPCC	Intergovernmental Panel on Climate Change
LoMin	Low minimum temperature
m/s	Miles per second
MAG	Maricopa Association of Governments
MCAQD	Maricopa County Air Quality Department
NAAQS	National Ambient Air Quality Standards
NCDC	National Climatic Data Center
NIEHS	National Institute of Environmental Health Sciences
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NO	Nitric oxide
NOx	Nitrogen oxides
O_3	Ozone
PM	Particulate matter
$PM_{2.5}$	Fine particulate matter
PM_{10}	Coarse particulate matter
PPM	Parts per million
RCPs	Representative concentration pathways
SIP	State Implementation Plan
SO_2	Sulfur dioxide
SoVI	Social Vulnerability Index
SRES	Special Report on Emissions Scenarios
Tmax	Maximum temperature
Tmin	Minimum temperature
UA	University of Arizona
UHI	Urban heat island
USGCRP	U. S. Global Change Research Program
VOCs	Volatile organic compounds
W/m^2	Watts per square meter

INTRODUCTION



INTRODUCTION

Observed and projected changes in climate may affect the health of Arizonans. The temperature projections summarized in this report predict that, by 2060, some Arizona counties may experience summer temperature increases of up to 4.5°F above current conditions. As in other locations in the Southwest, across the United States, and around the world, these increases in temperature may coincide with increased frequency of drought, flooding, extreme heat events, wildfires; and disruption of civil infrastructure, including transportation, energy, and water systems (Garfin et al. 2013; Melillo et al. 2014; Revi et al. 2014). In addition to illness and death caused directly by severe weather, a shift in Arizona's climate may exacerbate existing health conditions.

Changes in emission rates of ozone precursors (nitrogen oxides, carbon monoxide, and volatile organic compounds) and greenhouse gases may make the achievement of air quality goals more difficult. Those changes also may hasten and increase the force of aeroallergens (e.g., pollen, mold, and indoor allergens). Arizona may experience these aeroallergens earlier in the season and with increasing force, potentially increasing respiratory illness and death. Vector-borne illnesses are also likely to become more widespread. Importantly, these impacts may not be distributed equitably across the population, as lower socioeconomic status has been shown to increase vulnerability to the range of climate-related human health impacts (Harlan et al. 2012).

The goal of this report is to improve knowledge on how climatic hazards may impact the health of Arizonans. Furthermore, this information is vital to understanding effective ways to adapt to Arizona's projected climate and mitigate any potential negative effects that may arise in the future.

The Arizona Department of Health Services (ADHS) retained an interdisciplinary team at Arizona State University (ASU) to investigate expected climate-related impacts in the state and their likely effects on vulnerable populations. The U.S. Centers for Disease Control and Prevention's (CDC) *Climate-Ready States and Cities Initiative* supported this work. As of late 2014, this work was being undertaken in 16 states and two cities (Centers for Disease Control and Prevention 2014). To guide these efforts and provide regionally specific measures, the CDC has developed the *Building Resilience Against Climate Effects* (BRACE) framework to assist public health agencies in planning for potential health effects (Manangan et al. 2014; Marinucci et al. 2014).

This ADHS/ASU report begins to develop data sources and the intellectual infrastructure needed to apply the BRACE framework in Arizona. The project team applied downscaled climate projections for the state, and estimated and identified populations that are vulnerable to extreme heat events and air pollution. Ongoing work will expand the analysis to include the impacts of infectious diseases, as well as flood- and drought-related hazards.

Rationale

Although the general health-related impacts of projected changes in climate are well known, there will be substantial spatial and demographic variation in their magnitude and frequency in the United States and around the globe (Longstreth 1999; Patz et al. 2005; Haines et al. 2006; Luber and Hess 2007; Smith et al. 2014). The U.S. population is expected to fare well (Patz et al. 2000; Luber and Hess 2007); however, there will be regional and demographic variations in both the kind and severity of impacts (Frumkin et al. 2008). Targeting specific interventions to specific states and regions should promote the most effective use of resources and maximize the benefits of measures implemented at the state, regional, and local levels.

The CDC designed the BRACE framework to assist state and local policymakers in gathering and analyzing the information needed for managing the greatest location-specific public health threats posed by changes in climate. The framework uses modeling to understand and project health impacts related to long-term temperature shifts. The framework also uses evidenced-based strategies to assess interventions and management strategies aimed at protecting vulnerable populations.

It uses adaptive management principles, recognizing that:

1) The relationship between climate and public health is not fully understood;

2) New information is likely to emerge that may make previous decisions appear suboptimal;

3) Interventions can have unexpected or unintended effects on system performance; and

4) Interventions will need to be updated as stakeholders learn more about climate-public health interactions (Marinucci et al. 2014).

Figure 1 The five-step BRACE framework. Source: Adapted from Marinucci et al. (2014).

According to Huang et al. (2011), uncertainty regarding future climatic and socioeconomic conditions, technology constraints, possible adaptive actions, and their associated costs and benefits, among other factors, constrains the public health response to climate and health issues. BRACE seeks to address many of these limitations explicitly through the completion of five iterative steps (Figure 1).

In Step 1, downscaled global climate models (GCMs) are used to project locally relevant climate conditions and link them to specific health issues of interest. Populations thought to be most at risk for these health issues and their locations are subsequently identified. Step 2 undertakes a qualitative and/or quantitative assessment of expected changes in disease burden using these data. Step 3 assesses different public health interventions that may mitigate the most important threats. Here, cost-effectiveness and suitability of interventions to the local setting are also assessed, including factors such as logistics and political acceptability. In Step 4, an overall adaptation plan is developed and implemented. Step 5 reassesses the performance of the plan and the process begins anew, to address further projections and unforeseen consequences.

This report addresses Step 1, focusing on two climate-related hazards and associated health impacts of major importance to Arizona—extreme heat events and air pollution. The frequency and intensity of extreme heat events are already increasing in the state and this trend is expected to continue. Likewise, under some future climate scenarios, ozone formation and accumulation are expected to increase (Weaver et al. 2009; Kim et al. 2015). Furthermore, air pollution, especially as a result of increases in ozone and coarse particulate matter (PM_{10}), has presented recurrent challenges to the state's ability to meet the National Ambient Air Quality Standards (NAAQS). This report describes the link between these hazards and human health issues, and the identification of especially vulnerable populations.

Continuing efforts under Step 1 include addressing three additional climate-related hazards—drought, flooding, and infectious diseases—and related public health vulnerabilities. ASU and the University of Arizona (UA) will collaborate with ADHS to link the disease burdens associated with these climate hazards with weather patterns (Step 2). Once these relationships are established, the project team and collaborators will develop future projections of climate-related health impacts for the state, which will facilitate completion of the remaining three steps of the BRACE framework. As additional climate data are made available and as public health knowledge of climate impacts improves, steps in the process will be revisited and data reassessed to understand the impacts of public health interventions on reducing the severity of projected climate- and weather-related health effects.

In this first step, the ADHS Extreme Weather and Public Health Program and the ASU team have identified several knowledge gaps that will be explored through upcoming analysis projects with existing partners and community stakeholders. While the Arizona Extreme Weather and Public Health Program staff will participate as facilitators, project managers, and developers of the protocols to complete the projects, much of the actual data collection, identification of existing datasets, statistical analysis, geo-spatial conversions, and results interpretation to fill these gaps will be completed with the assistance and expertise of contractual partners.

Steps 1 and 2 of the BRACE framework are expected to be completed by summer 2015. Step 3 is expected to be completed by fall 2015. The completion of a strategic adaptation plan for health issues related to climate (Step 4) and an evaluation (Step 5) of the BRACE framework is expected by fall 2016.

History of engagement with climate- and weather-related health issues

Arizona has long recognized the need to build public health resilience against the impacts of climatic and extreme weather events. To facilitate these efforts, ADHS undertook several initiatives and activities to prepare Arizonans before participating in the CDC's *Climate-Ready States and Cities Initiative* (CRSCI) and during an initial three-year grant period (2010-2013). The following highlights some of the major prevention efforts undertaken thus far.

Engagement prior to 2010

Emergency response plans - Arizona has had a history of severe weather-related events, which ADHS has addressed by creating emergency response plans to aid in coordinating state and local public health department responsibilities during emergencies. To date, plans have been developed for flooding, wildfire, and extreme heat.

ADHS also has participated in a multiagency task force led by the Arizona Department of Water Resources. The task force developed a state drought preparedness plan. ADHS helped to ensure that the public health effects of drought were considered within that plan.

Outreach - ADHS outreach efforts have included online dissemination of information and printable brochures regarding safety and health effects of wildfires, air quality, and extreme heat.

Arizona's early participation in CDC's Climate-Ready States and Cities Initiative (2010-2013)

In 2010, ADHS received its first three-year grant under the CDC's CRSCI to help address the current and future risk of severe heat in Arizona. The initiative helped grantees create dedicated programs to address the adverse health effects resulting from extreme weather by using climate science to inform public health decision making. Arizona's grant focused on assessing the ability of the state's public health agencies to respond to expected increases in heat wave frequency.

The objectives of, and strategies for, the extreme heat grant included determining a knowledge baseline and identifying perceived program needs and data gaps; enhancing current surveillance activities by linking health outcomes and weather data; promoting awareness of heat-related impacts on public health; creating and implementing adaptation strategies; and exploring ways to adapt the BRACE framework within existing strategies.

Project activities included:

- Development of the "Extreme Weather & Public Health" program by the Office of Environmental Health and hiring of dedicated staff for project;
- Execution of a *State Health Agency Needs Assessment Survey on Extreme Weather & Public Health;*
- Implementation of a *Local Health Department Needs Assessment Survey on Extreme Weather & Public Health;*
- Completion of an *Extreme Heat Vulnerability Assessment;*
- Scheduling of meetings, workshops, and webinars on heat safety;
- Attendance and presentations at climate and health-related conferences;
- Epidemiological analysis of climate risk factors and health issues; and
- Improvements to public health collaboration with climate scientists

A number of products were developed from this work, including a set of heat vulnerability maps focusing on social vulnerability, urban heat island effect, cooling center accessibility, weather-related variables, and heat-related mortality. In addition, the grant supported preparation of updated response plans at the state and local level, and an ADHS Extreme Heat Communication Plan that employs effective evidence-based messaging strategies.

Public education through the Extreme Weather & Public Health Program's website has scaled up over the past few years with 1,376 visitors reported in 2011; 1,515 in 2012; and 7,364 in 2013. In addition, the CDC's Extreme Heat Media Toolkit and outreach material have been distributed at more than a dozen health fairs; social media messages have been sent out on the topics of severe heat prevention, recognition, and treatment during the summer months; and 16 presentations on the health effects of severe heat in Arizona have been delivered to concerned citizen groups, public health professionals, and employers.

Successes from Arizona's Climate-Ready States and Cities Initiative

State heat preparedness workgroup

In spring 2013, ADHS held its first Statewide Heat Preparedness meeting. The gathering facilitated information exchange on prevention activities, surveillance, and treatment for heat-related illnesses. Development of this workgroup arose out of interest from local health departments. Participants included decision-makers from agencies at the local, state, and federal levels, as well as representatives from nonprofit organizations and universities.

A subcommittee of the State Heat Preparedness Workgroup–which comprised members of the Arizona Department of Health Services Extreme Weather & Public Health program; as well as representatives from National Weather Service offices in Arizona, Maricopa County Department of Public Health, ASU, and other local government entities –worked together to revise and coordinate the health messaging released during heat warnings. The subcommittee used evidenced-based information from public health data and the scientific literature to identify specific health messages and strategies to protect Arizonans. The language drafted was used in the National Weather Service heat warning alerts during summer 2014.

State and local health department extreme weather capacity and gaps assessment

In 2013, ADHS conducted an internal, agency-wide survey to assess the state's baseline capacity to monitor public health effects resulting from extreme weather and to identify gaps in public health surveillance efforts. A similar survey also was distributed to local health departments. The results helped ADHS to understand the type of extreme weather events that were of most concern to local jurisdictions. Both the internal and local agency surveys covered effects of extreme heat, flooding, air quality, and wildfires. After a review of both assessments, ADHS summarized state and local health department capacity to implement climate and health interventions in an internal report for program planning purposes.

Enhanced heat surveillance

In collaboration with the Council of State and Territorial Epidemiologists (CSTE) and the Association of State and Territorial Health Officials (ASTHO), ADHS has been exploring appropriate methods for tracking heat-related deaths and illnesses. In spring 2013, the ADHS CRSCI and the Minnesota Department of Health collaborated to co-lead a workgroup of nearly 60 participants representing North American state and local public health jurisdictions. The workgroup is targeted at exploring the use of syndromic surveillance–or the sharing of population-based public health data between providers and decision-makers–to link climate with health effects. Syndromic surveillance enables real-time electronic reporting of chief complaints in hospitals to public health officials. These data aid in driving timely public health action during severe weather. The workgroup has held four successful webinars highlighting syndromic surveillance systems currently in use to track heat-related illnesses nationwide. It also has developed a workshop and related summary report that have garnered international interest.

Heat safety toolkits
ADHS has developed Heat & Outdoor Worker Heat Safety Toolkits targeted at three populations susceptible to heat illness (older adults, children, and outdoor workers) in partnership with the Arizona Division of Occupational Safety and Health. A Heat & Older Adult Heat Safety Toolkit also has been developed in partnership with the Arizona Governor's Office on Aging; and a Heat & School-Age Children Safety Toolkit has been created in partnership with Safe Kids Arizona.[1]

ASTHO Public Health Tracking (EPHT) fellowship
In 2011, ADHS participated in ASTHO's EPHT Peer-to-Peer Fellowship Program. The fellowship aimed to enhance capacity in non-EPHT grantee states to conduct environmental public health tracking-related activities. The ADHS project specifically dealt with heat-related illness. The project helped fill a data gap related to recent heat-related hospital inpatient admissions and emergency department visits. Arizona became part of the national tracking conversation and propelled ADHS to build a peer network across state agencies.

In summary, CRSCI activities undertaken during 2010-2013 have:

1) Improved technical expertise at ADHS in the areas of climate and health;

2) Enhanced ADHS's ability to anticipate climate-related public health impacts; and

3) Increased the knowledge base of climate and health impacts in Arizona.

At the end of the grant period, ADHS had established a more solid foundation to address the health impacts associated with extreme heat in Arizona. However, there was still a pressing need to develop and provide vulnerability data to communities for adaptation planning related to other climatic effects. ADHS recognized that, in order to protect current and future Arizonans, health policy and planning efforts must include a more detailed analysis of climate risks and disease burdens, along with proven strategies for community adaptation and decision-making.

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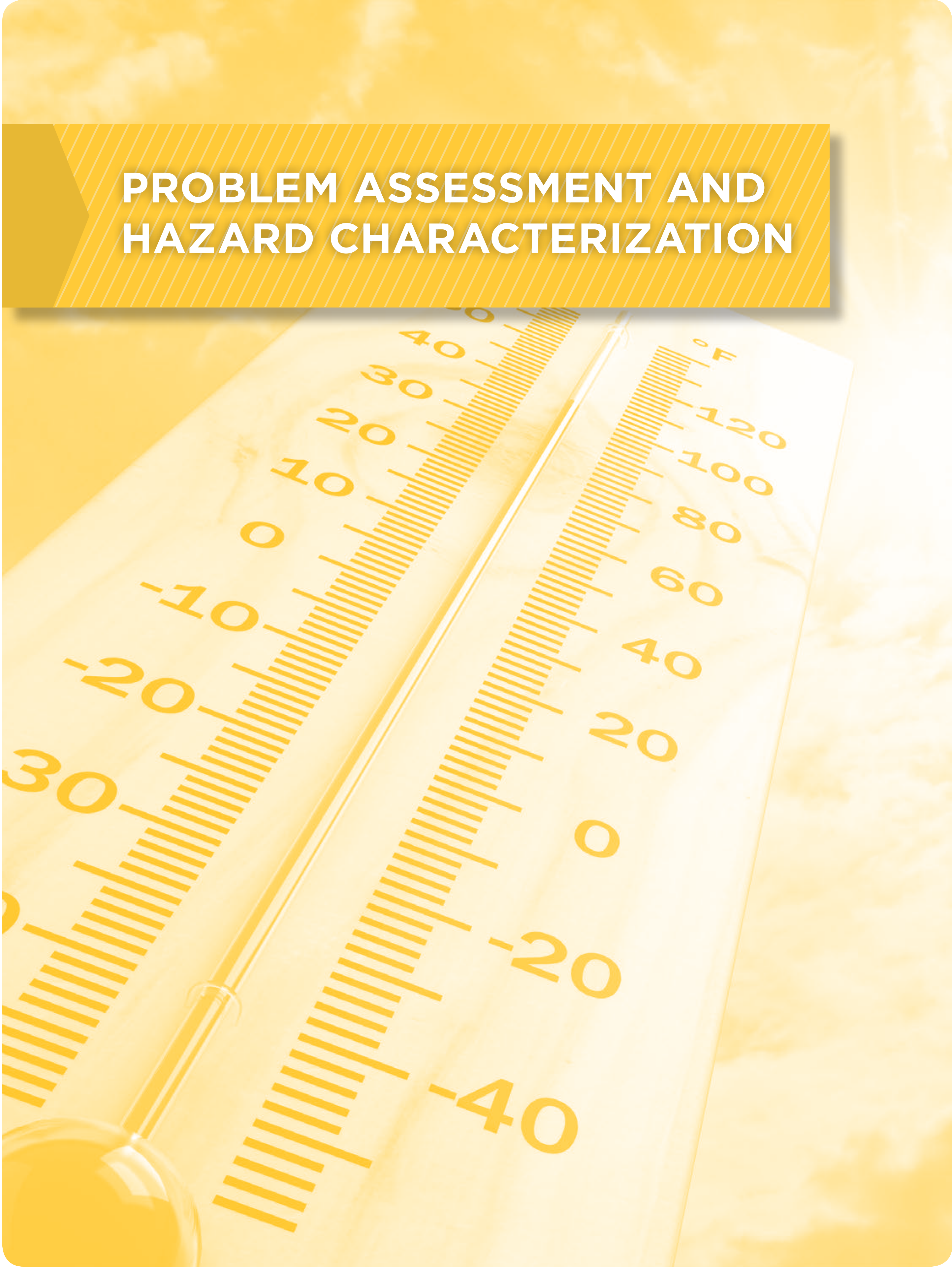
[1] These toolkits are available through at http://www.azdhs.gov/phs/oeh/extreme/index.php

PROBLEM ASSESSMENT AND HAZARD CHARACTERIZATION



PROBLEM ASSESSMENT AND HAZARD CHARACTERIZATION

Baseline climatic description

Summary of Arizona's physiographic regions

The geographic scope for this problem assessment is the state of Arizona—the sixth-largest state in land area, 15th largest in population, and 37th highest in population density. It comprises three physiographic regions that designate distinct climatic zones (Figure 2).

The northeastern Colorado Plateau (Apache, Coconino, Navajo, and portions of adjacent counties) is a high-elevation arid region (5,000-foot-plus high desert) that averages 10 inches or less of annual precipitation. It experiences both hot summers with daytime temperatures between 80°F (27°C) and 95°F (35°C), and cold winters with sub-freezing temperatures and occasional snow cover.

The southwestern desert and lower Colorado River valley, known as the Basin and Range Region (Pima, Santa Cruz, Cochise, La Paz, Yuma, Maricopa, Pinal, and southern Graham and Greenlee counties), also receives less than 10 inches of annual precipitation, with the driest areas nearer to 3 inches of annual rainfall. Temperatures in the southwestern desert regularly exceed 105°F (41°C) in the summer and can drop below freezing at night in the winter.

Between these two dry extremes lies the transitional region of the Central Highlands, (Gila and northern Graham and Greenlee counties) which includes the Mogollon Rim (4,000 -12,000 feet in elevation). Here, annual precipitation ranges from 17 to 45 inches in the lower and higher elevations, respectively. Much of the precipitation in the higher elevations falls as snow during the winter. Daytime temperatures at the higher elevations rarely exceed 80°F (27°C), but nighttime temperatures frequently fall below freezing.

Description of Arizona climatology

All of Arizona is classified as arid or semi-arid, because evaporation in the state far exceeds precipitation. Like all dry climates, Arizona exhibits extreme variability in both temperature and precipitation. Its large daily and annual temperature shifts and ranges result from low humidity, due to a predominantly westerly airflow that precludes frequent precipitation events. The state's low latitude and topography typically create clear sky conditions, attributed to a semi-permanent high-pressure ridge and the rain shadow effect of the Santa Ana and San Jacinto mountains to the west.[2] The rain shadow effect suppresses cloud formation as air sinks from the general high pressure and air movement down the leeward side of the mountains.

Figure 2 Arizona's physiographic regions. Source: Arizona Department of Water Resources (2009)

In the summer, the monsoon is characterized by southerly or southeasterly airflow, which brings subtropical moisture from the Gulf of California

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[2] A rain shadow is created on the lee side of a mountain range. Moisture laden air rising up the windward side is forced to drop its moisture as it cools, resulting in relatively heavier precipitation on the windward than the leeward side.

or the Gulf of Mexico. The surface heating and instability caused by the warm, moist air trigger convective thunderstorms, resulting in extremely heavy, localized precipitation that often leads to flash flooding.

Spring and fall are relatively dry seasons. Occasionally, tropical storms or the remnants of eastern Pacific hurricanes move north along the Mexican or Baja California coast in September, bringing intense rainfall to the southern one-third of the state.

While temperatures have been slowly increasing since the mid-1970s, there has been substantial year-to-year variability in the period of record, and the past 14 years have seen a slight decrease in the statewide average temperature (Figure 3).[3] After a relatively wet period spanning the late 1970s through the mid-1990s, Arizona has been in a prolonged period of drought (Figure 4). The drought has been characterized by a decrease in cold winter storms and associated higher winter temperatures across the state.

Major seasons of the year

Arizona experiences two wet seasons and two dry seasons annually. Spring and fall are mild, with westerly winds bringing dry air and predominantly cloudless skies. Days are generally warm with temperatures in the mid-70s (°F) to low-90s and nights are cool with temperatures in the mid-50s (°F) to mid-60s.

Occasionally, high summer temperatures extend into October, but the last 100°F (38°C) day is typically in late September. Early summer onset is also possible, with the first 100°F day generally in mid-May, although the earliest on record was late March in 1988.

Winter is the primary wet season for northern and eastern Arizona, during which snow falls at mid- to high elevations (4,500 feet and above). Lower elevations generally experience rain, although extremely cold winter storms occasionally bring snowfall down to 3,000 feet. Winter temperatures in northern and eastern Arizona average in the mid-20s (°F) to the upper 30s during the day, and

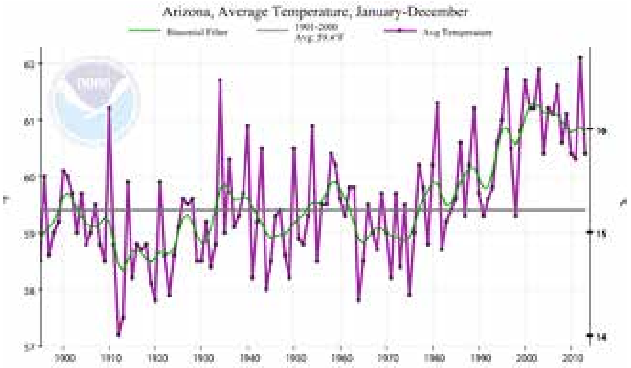

Figure 3 Arizona average annual temperature. The "binomial filter" represents a weighted average of the central point and four surrounding points on each side. Points that are further away receive less weight. The National Climatic Data Center's (NCDC's) trend lines are not included, as they depict a single trend for the entire period of record, while the data show brief periods of warming and cooling, many of which coincide with dry and wet periods. The trend of warming during the past 45 years appears more significant than the long-term trend of warming since 1895, which would be shown by NCDCs trend line. Source: NCDC Climate at a Glance (http://www.ncdc.noaa.gov/cag/time-series/us)

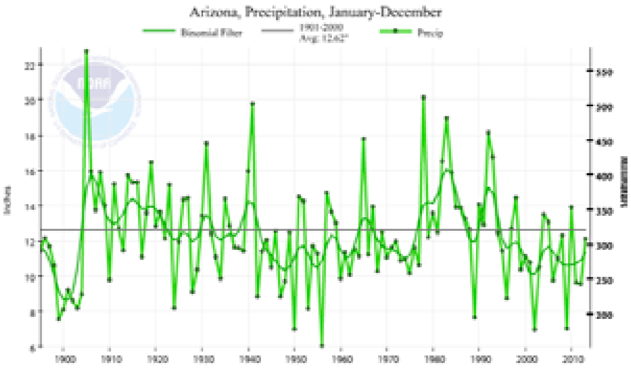

Figure 4 Arizona average annual precipitation. The "binomial filter" represents a weighted average of the central point and four surrounding points on each side. Points that are further away receive less weight. Source: NCDC Climate at a Glance (http://www.ncdc.noaa.gov/cag/time-series/us)

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[3] Data for all temperature and precipitation figures in this section of the report originate from NOAA's Cooperative Observer Network containing at least two stations in each climate division. Climate divisions are areas within a state with relatively similar climate characteristics. Climate divisions can cross county boundaries. In Arizona, there are roughly 170 current Cooperative Weather stations reporting daily temperature and precipitation data. The climate-division data record begins in 1895, though there were very few stations in the first 35 years of data collection, making the early part of the record less robust than the latter part, due to a higher proportion of missing data and low station density.

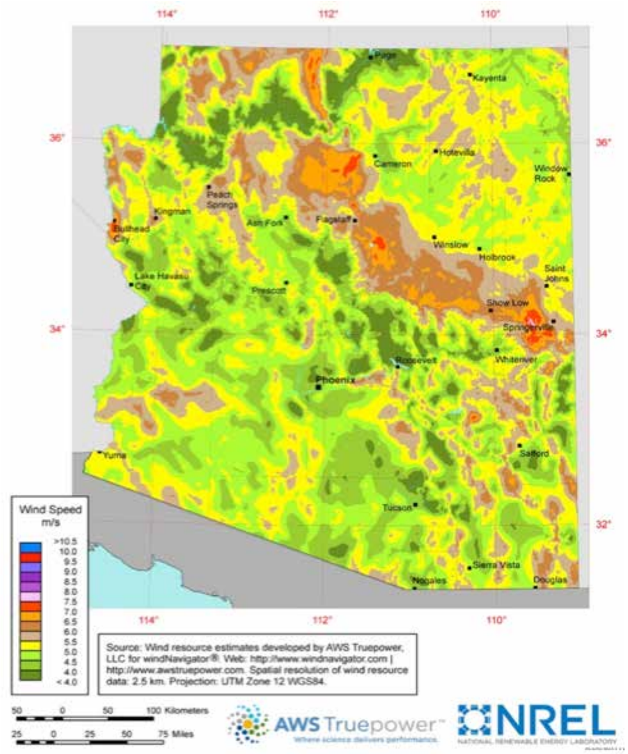
well below freezing at night. Every year, there are several days with nighttime temperatures near or below 0 °F (-18°C), although many high-elevation areas, including Flagstaff, can reach temperatures well below -15 °F (-26°C).

In southern Arizona, winter is generally dry, with mild daytime temperatures in the deserts and low temperatures at the higher elevations. Nighttime temperatures are cold at all elevations, with occasional freezing temperatures on the desert floor and frequent sub-freezing temperatures at the higher elevations. Winter daytime temperatures in southern Arizona average from the mid-30s (°F) to the mid-60s, with higher temperatures at the lower elevations.

Winter precipitation comprises a smaller percentage of annual precipitation in the southern counties. However, each winter, at least one cold storm pushes south toward the Mexico border –bringing significant precipitation and very cold temperatures. In the southwest corner of the state, this single event often provides nearly two-thirds of the area's total annual rainfall.

Summer is the primary wet season for southern Arizona– particularly, for southeastern Arizona. Beginning in early June, thunderstorms form over southern and central Mexico, gradually moving northward (Douglas et al. 1993). By late June or early July, the region's high-pressure system, which has kept moisture out of Arizona, shifts to New Mexico or Colorado. This generates a clockwise circulation that pulls the moisture from Mexico northeast into Arizona. The southerly winds and influx of moisture trigger widespread thunderstorm activity, known as the North American monsoon (Douglas et al. 1993). More than half the annual precipitation in southern Arizona falls as rain during this period.

Monsoon activity is not continuous, but has wet and dry cycles called "burst" and "break" periods, respectively (Carleton 1986). Bursts are periods of increased moisture and high thunderstorm activity lasting from one week to three weeks. Breaks, which generally are shorter, represent periods of dry westerly airflow lasting from two to seven days. Nighttime temperatures remain higher during the bursts, but daytime temperatures may decrease due to cloud cover and cooling rainfall. During breaks, daytime temperatures rise toward 110°F (43°C) in the southwest deserts and nighttime temperatures drop slightly.



Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: UTM Zone 12 WGS84.

Figure 5 Arizona 80 m wind map. Source: U. S. Department of Energy (http://apps2.eere.energy.gov/wind/windexchange/wind_resource_maps.asp?stateab=az)

In central Arizona, winter brings about 50% of the total annual precipitation, as many of the winter storms sweep across the region before exiting the state to the northeast. Frequent snowfall occurs in the higher elevations, but the snow generally does not remain on the ground for more than one week. The Phoenix area, at 1,100 feet in elevation, has a snowfall event about every 10-20 years, although it melts quickly. Daytime temperatures range from the mid-40s (°F) to the mid-70s, while nighttime temperatures frequently drop into the low-50s (°F) and high-40s. The lower deserts of central and southern Arizona occasionally see nighttime lows below freezing – but usually no lower than 20°F (-7°C). The other half of central Arizona's annual precipitation occurs as rain during the summer.

Winds

Arizona tends to experience relatively light winds. In most areas of the state, the local winds are topographically driven. The general flow across the state is west to east, and at 80 m–the height of the typical wind turbine hub–wind speed in most areas is between 4 and 7.5 m/s (miles per second) (Figure 5).

The highest wind speeds in the state occur along the Mogollon Rim in the transitional zone and at the highest elevations of the northern and southern rim of the Grand Canyon.

The highest localized winds occur during the monsoon season, when outflows from thunderstorms rush down to the ground; then, out in a gust front that frequently picks up dust, generating large dust storms. These dust storms can travel over 100 miles and can extend upward over 5,000 feet. They are fast moving and dangerous. They decrease visibility on the roadways and stir up particulate matter that degrades air quality.

Historical Arizona climate observations

Description of historical weather data

In the mid-1990s, Arizona began a transition to extremely dry conditions, resulting in an extended drought. At the same time, statewide annual temperatures leveled off to about 1.5°F (0.8°C) above the 20th century average, where it has remained as of late 2014. In some areas of the state, the warming in the latter half of the 20th century also brought an increase in the number of maximum temperature records set or tied. Table 1 shows the number of daily high maximum, high minimum, and low minimum temperature records set or tied in various periods since recordkeeping began in Flagstaff, Phoenix, and Tucson.

In Flagstaff, about 30% of the high maximum records were set both before 1951 and after 1989. About 35% were set between 1951 and 1989, with a similar distribution of high minimum temperature records (Table 1). Fewer low minimum temperature records (43 or 12%) have been set since 1990.

Tucson set 33% of its high maximum records before 1950, 25% in the middle period, and 42% since 1990. High minimum temperature records in Tucson have been evenly spread across the three periods, but the vast majority of low minimum temperature records (301, or 82%) were set in the early period, before 1950.

Period	Flagstaff			Phoenix			Tucson		
	HiMax	HiMin	LoMin	HiMax	HiMin	LoMin	HiMax	HiMin	LoMin
1895-1950	106	135	151	69	5	202	119	102	301
1951-1989	151	120	172	134	110		92	105	53
1990-2014	109	111	43	163	251	2	155	159	12
2001-2014	60	73	20	108	175	1	72	109	10

Table 1 Number of daily temperature records set or tied by period for Flagstaff, Phoenix, and Tucson. Data were compiled from the Western Region Climate Center Period of Record Daily Summary Statistics http://www.wrcc.dri.edu/summary/Climsmaz.html.

Tucson has had many fewer record-setting cold nights since 1950 than either Flagstaff or Phoenix (Table 1). Only 69 of the high maximum records (or 19%) that were set before 1950 still stand in Phoenix. Phoenix has set many more high daytime and nighttime temperature records since 1950 than the other two locations.

The continual setting of new high daytime temperature records since 1950 and 1990 in all three of the state's major cities indicates regional warming (since the Flagstaff temperature record is not within the urban area).

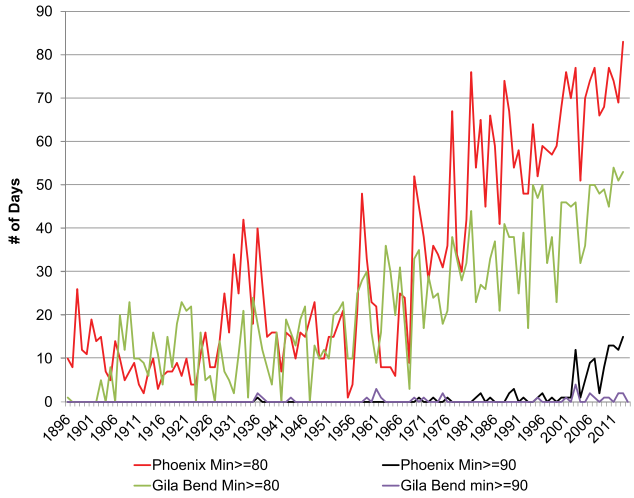


Figure 6 Nighttime low temperatures: Phoenix and Gila Bend. Number of days each year in Phoenix with nighttime low temperatures at or above 90°F (32°C) (black), nighttime low temperatures at or above 80°F (27°C) (red); and Gila Bend nighttime low temperatures at or above 80°F (green), at or above 90°F (purple). Source: National Climatic Data Center.

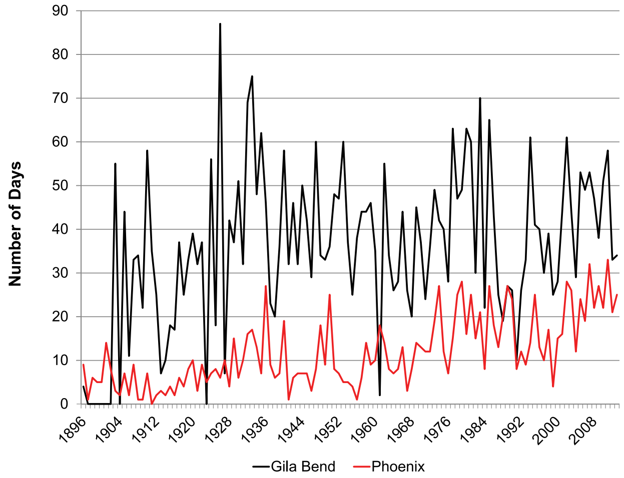


Figure 7 Daytime high temperatures: Phoenix and Gila Bend. Number of days each year in Phoenix (red) and Gila Bend (black) with high temperatures at or above 110°F (43°C). Source: National Climatic Data Center.

Only five of the high nighttime temperature records (or 1%) that were set before 1950 still stand in Phoenix. The Phoenix metropolitan area's growth since 1950 has led to a significant increase in nighttime minimum temperatures, due to the urban heat island (UHI) effect. This UHI effect has also resulted in only two (0.5%) low minimum records set since 1990 (Table 1).

The highest nighttime low temperature record stands at 96°F (36°C), which was set in 2003. Since then, there has been a substantial rise in the number of nights with minimum temperatures at or above 90°F (32°C) (black line in Figure 6).

By comparison, Gila Bend, a rural site in central Arizona, has one or two nighttime minimum temperatures per year as warm as 90°F. Phoenix has seen a steady rise in the number of days with nighttime temperatures at or above 80°F since the early 1960s, as development has increased (red

Figure 8 Arizona Counties Source: http://geoalliance.asu.edu/azga

line in Figure 6); while Gila Bend is on a similar trajectory, but with fewer warm nights (green line in Figure 6).

Urbanization effects contribute less directly to daytime maximum temperatures. At present, the urbanization effect on daytime temperatures is essentially negligible—or associated with minor cooling—in Arizona's major urban corridor (Georgescu et al. 2011). Thus, urbanization effects are not yet a significant contributor to long-term variability in daytime maximum temperatures, or to the number of days with maximum temperatures exceeding high thresholds.

Figure 7 shows the increase in the number of days each year with extremely high daytime temperatures during the summer months for Phoenix and Gila Bend. Phoenix has seen an increase from about 18 days of high temperatures in the 1980s to 25 days or more in the last decade. Gila Bend has seen no trend for the past 70 years. However, the interannual variability, occurring between two or more years, in both these records far exceeds any trends. The highest daytime temperatures tend to be found in the deserts (Lake Havasu and Gila Bend), as the heat gained from the sun remains very near the surface of natural materials like sand and dirt. This heats the overlying air much more than urban materials, which store heat deep in the material. While there has been an increase in the number of extreme heat days in Phoenix, it is not steady, and the variability makes it challenging to project the number of extreme heat events that may occur each year based on the historical record. However, there will continue to be extreme heat events every year in Arizona due to the nature of the desert climate.

Temperature and precipitation conditions and trends: 1895 - 2014

Colorado Plateau (Apache, Coconino, Navajo, and portions of adjacent counties)

Maximum temperatures on the Colorado Plateau (Figure 9), which falls into Arizona's climate division two, show a moderate downward trend from the 1950s until about 1985; then a significant warming trend through 2000. This warming trend was accompanied by an increase in variability, similar to that seen in the early 1900s and 1930s. Beginning in 2000, a lull with slight cooling is apparent, but the variability in the warming trend is the more significant feature for Arizona's future climate.

Minimum temperatures on the Colorado Plateau (Figure 10) show a significant downward trend from the mid-1930s until about 1975; then, a significant warming trend through 2000. In contrast to the

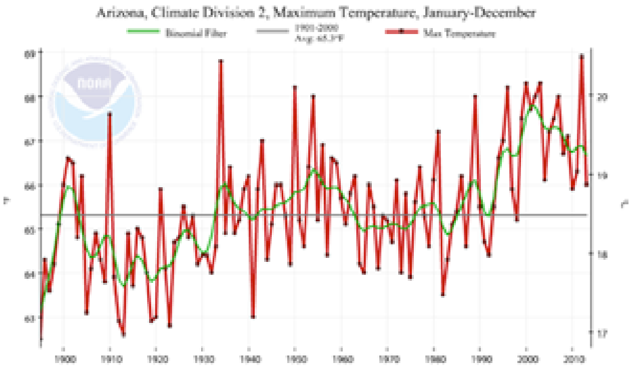


Figure 9 Maximum temperatures on the Colorado Plateau (Apache, Coconino, Navajo, and portions of adjacent counties). The "binomial filter" represents a weighted average of the central point and four surrounding points on each side. Points that are further away receive less weight. Source: NCDC Climate at a Glance (http://www.ncdc.noaa.gov/cag/time-series/us)

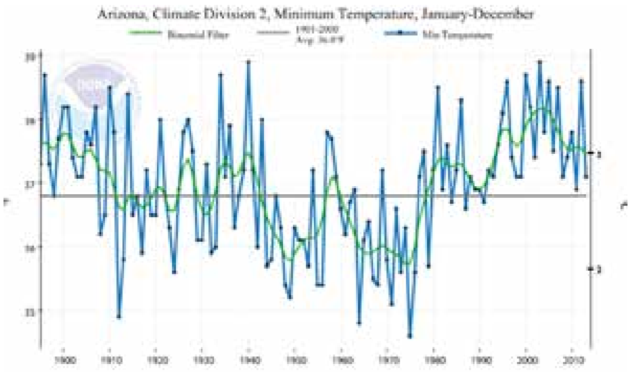


Figure 10 Minimum temperatures on the Colorado Plateau (Apache, Coconino, Navajo, and portions of adjacent counties). The "binomial filter" represents a weighted average of the central point and four surrounding points on each side. Points that are further away receive less weight. Source: NCDC Climate at a Glance (http://www.ncdc.noaa.gov/cag/time-series/us)

trend for maximum temperatures, the latter one-third of the record demonstrates less variability than the first two-thirds –with recent nighttime temperatures being more consistent than during the earlier record.

The period, 2000-2014, shows a slight cooling trend. This area of the state has no large cities except Flagstaff, and all of the data examined for this region are from rural areas. Therefore, these trends are not affected by urban development or the urban heat island.

Figure 11 shows precipitation trends. The Plateau experienced a significant drought between 1895 and 1904, followed by a significantly wet year in 1905. After that, precipitation on the Colorado Plateau showed a slight but steady decrease until the mid-1940s, when another significantly wet year was followed by an extended drought with intermittent precipitation spikes. Between the late 1960s and the late 1970s, precipitation spikes decreased and the drought worsened. A wet period followed this drought and continued until about 1995, when another drought period began. This drought continues to the present. The entire record is characterized by extreme annual variability.

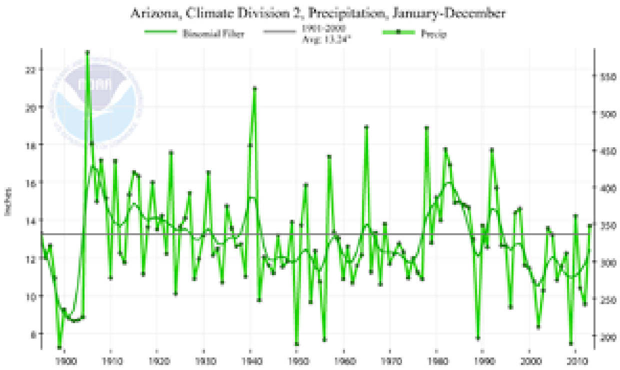


Figure 11 Annual average precipitation on the Colorado Plateau (Apache, Coconino, Navajo, and portions of adjacent counties). The "binomial filter" represents a weighted average of the central point and four surrounding points on each side. Points that are further away receive less weight. Source: NCDC Climate at a Glance (http://www.ncdc.noaa.gov/cag/time-series/us)

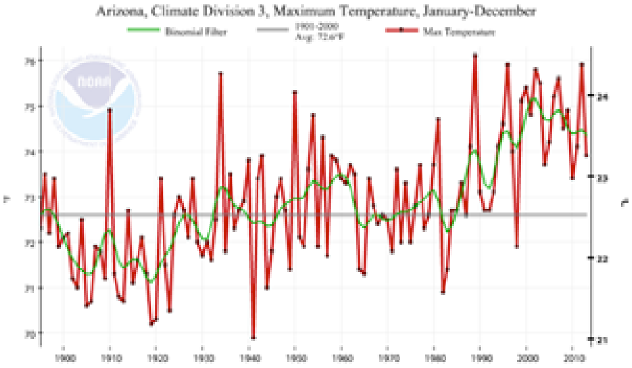


Figure 12 Maximum temperatures in the western Central Highlands (Yavapai and Mohave counties). The "binomial filter" represents a weighted average of the central point and four surrounding points on each side. Points that are further away receive less weight. Source: NCDC Climate at a Glance (http://www.ncdc.noaa.gov/cag/time-series/us)

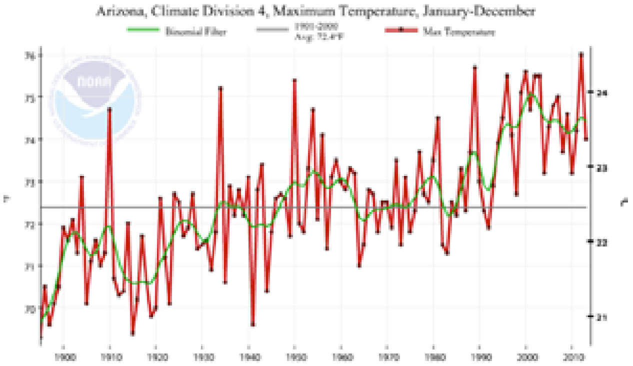


Figure 13 Maximum temperatures in eastern Central Highlands (Gila and northern Graham and Greenlee counties). The "binomial filter" represents a weighted average of the central point and four surrounding points on each side. Points that are further away receive less weight. Source: NCDC Climate at a Glance (http://www.ncdc.noaa.gov/cag/time-series/us)

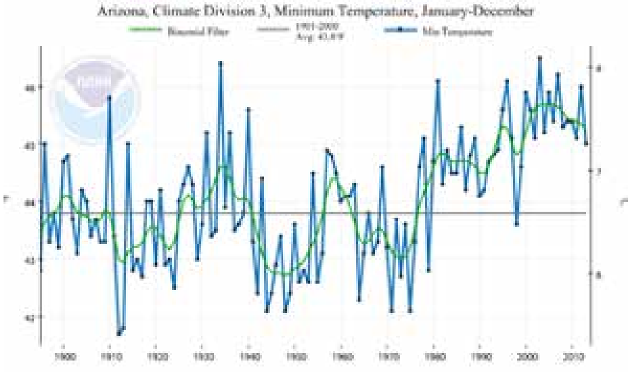


Figure 14 Minimum temperatures in the western Central Highlands (Yavapai and Mohave counties). The "binomial filter" represents a weighted average of the central point and four surrounding points on each side. Points that are further away receive less weight. Source: NCDC Climate at a Glance (http://www.ncdc.noaa.gov/cag/time-series/us)

Central Highlands (Yavapai County – Western; Gila County - Eastern)

The western half of the Central Highlands (Yavapai County), which falls into Arizona's climate division 3, experienced no increases in temperature until 1920, when warming began. It did, however, show extreme variability through the mid-1950s (Figure 12), when a period of prolonged drought began. Another warming trend started in the early 1970s and continued through the early part of the current century. The early part of that period shows little variability, but the latter two-thirds were extremely variable (similar in magnitude to the variability seen during the 1930s and 1940s). There has been a cooling trend since then.

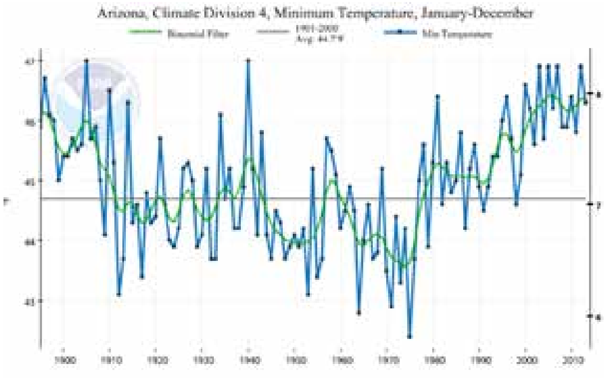


Figure 15 Minimum temperatures in the eastern Central Highlands (Gila and northern Graham and Greenlee counties). The "binomial filter" represents a weighted average of the central point and four surrounding points on each side. Points that are further away receive less weight. Source: NCDC Climate at a Glance (http://www.ncdc.noaa.gov/cag/time-series/us)

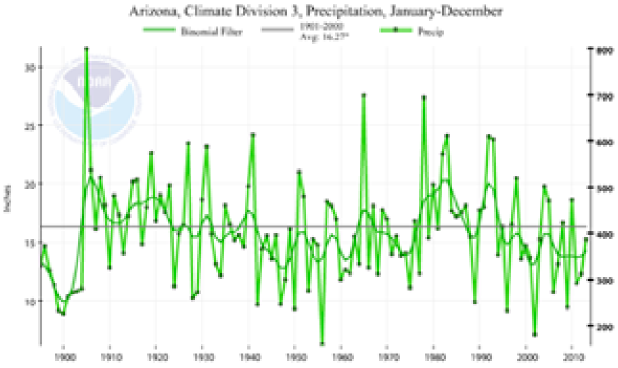


Figure 16 Annual average precipitation in the western Central Highlands (Yavapai and Mohave counties). The "binomial filter" represents a weighted average of the central point and four surrounding points on each side. Points that are further away receive less weight. Source: NCDC Climate at a Glance (http://www.ncdc.noaa.gov/cag/time-series/us)

The eastern part of the Central Highlands (Gila County), which falls into Arizona's Climate division 4, shows a warming trend throughout the recordkeeping period, with a slight cooling from 1950 to the late 1960s (Figure 13). The subsequent warming trend then began, with little annual variability until the 1980s, when variability became extreme. This trend has continued to the present.

In the western Central Highlands (Yavapai County), minimum temperatures (Figure 14) did not show evidence of an increasing trend until the early 1980s. Before that time, temperatures were near average for about 35 years; then, dropped to cooler than normal for almost 40 years. The ensuing warming trend leveled out in 2000. Variability was very high until the warming trend began, and has remained relatively low since 1980.

In the eastern Central Highlands (Gila County), minimum temperatures (Figure 15) cooled in the early 1900s; then, held steady for almost 30 years. After 1930, temperatures cooled again for 25 years, before beginning a sharp warming trend that now has continued for about the same amount of time. The record shows extreme variability up until the last 12 years.

Precipitation in the western Central Highlands (Yavapai County) shifted from a 10-year drought at the end of the 19th century to a wet period, lasting from 1904 until 1932 (Figure 16). Drought conditions recurred from 1933 through 1976. These were followed by another wet period through 1994, when the current drought began. The drought periods do not correlate with temperature, as the warming trends are concurrent with both wet and drought periods.

Precipitation in the eastern Central Highlands (Gila County) has occurred on essentially the same timeline as in the western Central Highlands, in terms of wet and drought periods (Figure 17). However, the eastern and western parts of the transitional zone are subject to very different absolute precipitation ranges. Specifically, the eastern transitional zone has higher elevations that can squeeze more snowfall out of winter storms and generally has a more active monsoon season than the western highlands.

Southern Basin and Range

Maximum temperatures in the Southern Basin and Range (Pima, Cochise, Santa Cruz, Graham and Greenlee counties), which fall into Arizona's climate division 7, were extremely variable during the first 65 years of the record; but showed no significant trends until the mid-1980s, when temperature increases began to be noted (Figure 18). The extreme variability continued through the warming period; but has decreased since 2000, as the trend has leveled off.

Minimum temperatures in the Southern Basin and Range (Pima, Cochise, Santa Cruz, Graham, and Greenlee counties) had a trajectory similar to maximum temperatures – with extreme variability, but no trend until the mid-1950s, when a cooling period developed and extended into the mid-1970s (Figure 19). This warming period leveled off in 2000, at which time the variability also decreased.

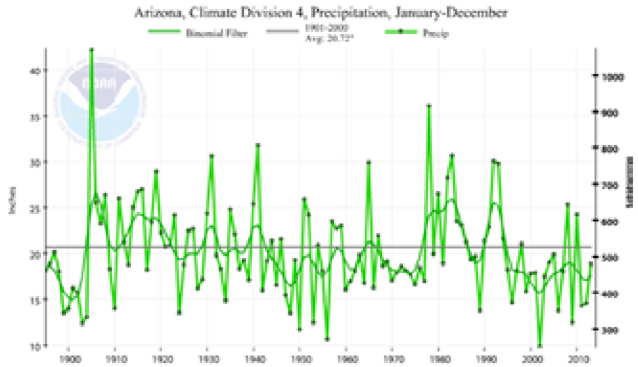


Figure 17 Annual average precipitation in eastern Central Highlands (Gila and northern Graham and Greenlee counties). The "binomial filter" represents a weighted average of the central point and four surrounding points on each side. Points that are further away receive less weight. Source: NCDC Climate at a Glance (http://www.ncdc.noaa.gov/cag/time-series/us)

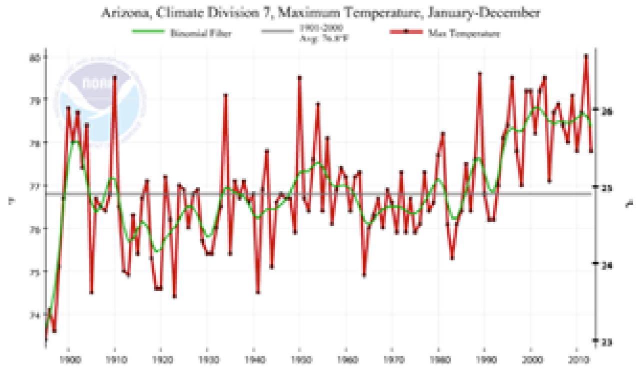


Figure 18 Maximum temperatures in the Southern Basin and Range (Pima, Cochise, Santa Cruz, La Paz, Yuma, Maricopa, Pinal and southern Graham and Greenlee counties). The "binomial filter" represents a weighted average of the central point and four surrounding points on each side. Points that are further away receive less weight. Source: NCDC Climate at a Glance (http://www.ncdc.noaa.gov/cag/time-series/us)

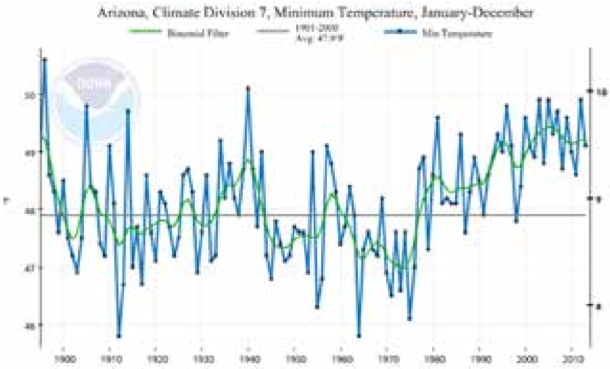


Figure 19 Minimum temperatures in the Southern Basin and Range (Pima, Cochise, Santa Cruz, La Paz, Yuma, Maricopa, Pinal and southern Graham and Greenlee counties). The "binomial filter" represents a weighted average of the central point and four surrounding points on each side. Points that are further away receive less weight. Source: NCDC Climate at a Glance (http://www.ncdc.noaa.gov/cag/time-series/us)

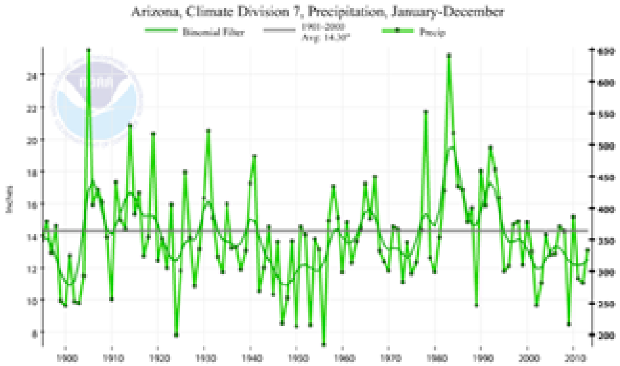


Figure 20 Annual average precipitation in the Southern Basin and Range (Pima, Cochise, Santa Cruz, La Paz, Yuma, Maricopa, Pinal and southern Graham and Greenlee counties). The "binomial filter" represents a weighted average of the central point and four surrounding points on each side. Points that are further away receive less weight. Source: NCDC Climate at a Glance (http://www.ncdc.noaa.gov/cag/time-series/us)

Note: The values aren't exact for all counties in figures 9-20, but the trends and variability are very similar.

Precipitation in the Southern Basin and Range (Pima, Cochise, Santa Cruz, Graham, and Greenlee counties) occurs on a timeline similar to that of the rest of the state, in terms of dry and wet periods (Figure 20). However, it appears that this area, where most of the annual precipitation falls in summer, has not experienced the severe droughts endured by the rest of the state, where most of the precipitation falls in winter. Thus, the Southern Basin and Range is less affected by the dry winters that characterize drought in the rest of the state and more susceptible to drought from dry summers.

Climate projections

One way to assess the health hazards and vulnerabilities that could be associated with future environmental conditions is to use computer simulations of the Earth's climate. Such computer simulations attempt to capture the complex interactions between natural and manmade (anthropogenic) "forcings" of the planetary energy balance– including effects from:

- Well-mixed greenhouse gases (e.g., carbon dioxide, methane, halocarbons, nitrous oxide),
- Short-lived gases and aerosols (e.g., carbon monoxide, volatile organic compounds, dust, black carbon),
- Changes in the surface albedo (reflective power of a surface) and other biophysical parameters due to land use conversion, and
- Variations in solar irradiance.

The output from these models can be used to consider mitigation and adaptation options; and to identify societal vulnerabilities (van Vuuren et al. 2011a).

As Earth's climate is sensitive to the composition of gases in the atmosphere, as well as to properties of the surface, models are often run to explore how changes to the atmosphere and surface driven by human activities might impact future conditions. Anthropogenic activities are commonly incorporated into the modeling process using scenarios that describe plausible future changes in terms of emissions of gases and/or changes to the land surface based on the best current understanding of the complex relationships between various components of the climate system.

Over the last decade, most discussion of scenarios for projecting temperature changes involved those that emerged from the Intergovernmental Panel on Climate Change's *Special Report on Emissions Scenarios* (SRES) (Nakicenovic and Swart 2000). The SRES scenarios (e.g., A1, A2, B1, B2) were designed using a linear process: Future plausible societies with different populations, economies, technologies, energy, and land use and agricultural practices were identified – each of which was subsequently associated with an internally consistent set of emissions of greenhouse gases (GHGs), resultant concentrations of GHGs in the atmosphere, and subsequent changes in climate.

The new climate scenario framework built around representative concentration pathways (RCPs) expands and improves upon the research and application capabilities offered by the SRES approach. The new process begins with the identification of different projected changes in the concentrations of GHGs and no consideration of the underlying socioeconomic or technological developments. From this starting point, scientists explore how concentrations of GHGs influence global and regional weather patterns– including how different development pathways might lead to the same (or different) outcomes. Other differentiating features of the RCPs, compared with the SRES scenarios, are that they were created directly by the scientific community rather than by the IPCC, are based on published literature, contain dynamic information about land use change, and span a wider range of plausible concentrations (O'Neill et al. 2014).

The four most widely used RCPs are RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5. The numbers refer to radiative forcing – the difference between insolation (sunlight) absorbed by the Earth and energy

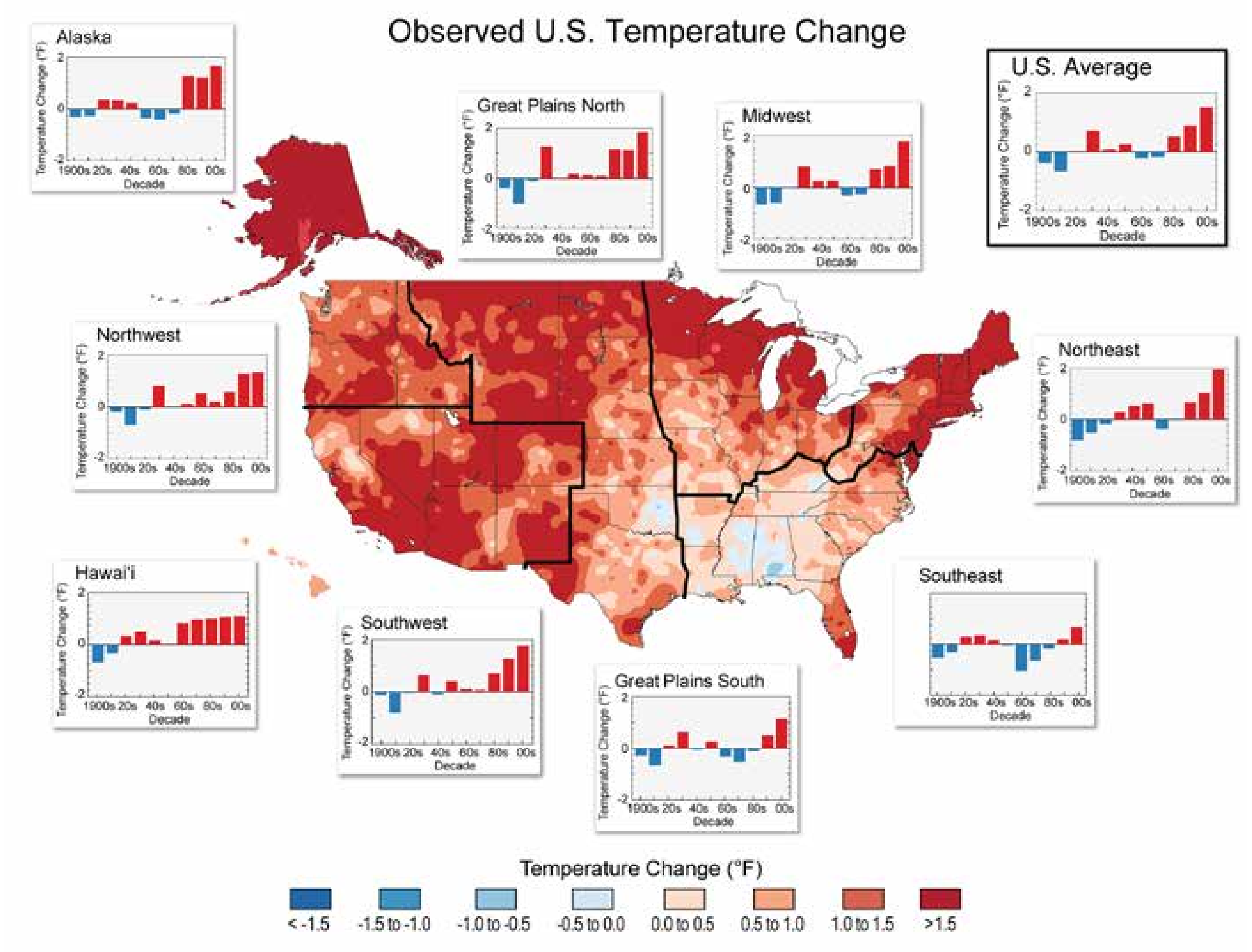


Figure 21 Temperature change (1991-2011) in °F compared to the 1901-1960 average. The far right bar in each graph (2000s decade) includes 2011. Source: Melillo et al. (2014, p. 29)

radiated back to space, or energy from the sun measured in watts per square meter (W/m^2). These RCPs largely span the range of possible future emissions contemplated in the scientific literature (van Vuuren et al. 2011a). RCP 8.5 simulates a high emissions trajectory, in which radiative forcing increases to 8.5 W/m^2 by 2100 (~1370 ppm carbon dioxide [CO_2] equivalency) (Riahi et al. 2011; van Vuuren et al. 2011b).

One part per million (PPM), is a unit of a measure that is roughly equivalent to one drop of water in a 50-liter container. RCP 6.0 and RCP 4.5 involve stabilization of radiative forcing effects at 6.0 W/m^2 and 4.5 W/m^2, respectively, (~850 ppm CO_2 equivalency and ~650 ppm CO_2 equivalency) by 2100 (Fujino et al. 2006; Wise et al. 2009; Thomson et al. 2011).

RCP 2.6 (often referred to as RCP 3PD/RCP2.6) simulates a low-emissions scenario with radiative forcing that peaks at approximately 3 W/m^2 before 2100 and subsequently declines (van Vuuren et al. 2011a; van Vuuren et al. 2011b). This scenario assumes that net global emissions are negative near the end of the century (i.e., sequestration exceeds emissions).

All four scenarios include not only time pathways for emissions and concentrations of GHGs, but also for aerosols and chemically active gases, as well as for land use/land cover change. The four RCPs were examined with the coupled Earth system model HadGEM2-ES (Met Office Hadley Centre, UK), used in this study to examine projected changes in Arizona's climate for the years 2030 and 2060. In addition to consideration of generic atmospheric

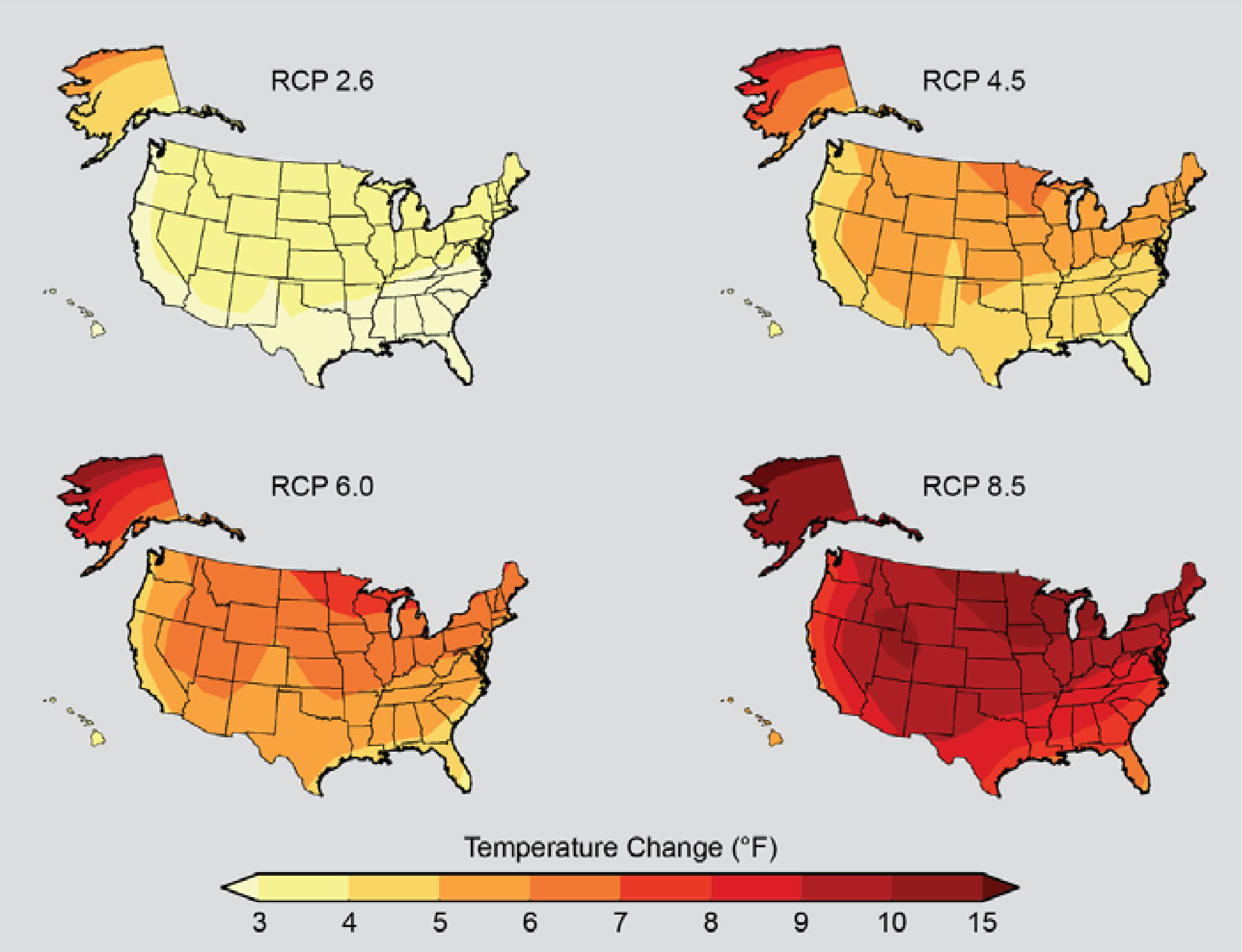


Figure 22 RCP modeled temperature projections. The largest uncertainty in projecting long-term temperature changes beyond the next few decades is the level of heat-trapping gas emissions. The most recent model projections (CMIP5) take into account a wider range of options with regard to human behavior, including a lower scenario than has been considered to date (RCP 2.6). This scenario assumes rapid reductions in emissions–including more than 70% cuts from current levels by 2050, further large decreases by 2100, and a corresponding smaller amount of warming. On the higher end, the scenarios include one that assumes continued increases in emissions (RCP 8.5) and correspondingly greater amounts of warming. Also shown are temperature changes for the intermediate scenarios, RCP 4.5 and RCP 6.0. Projections show change in average temperature in the later part of this century (2071-2099) relative to the late part of last century (1970-1999). Source: NOAA NCDC / CICS-NC)

and oceanic components, HadGEM2-ES includes dynamic vegetation, atmospheric chemistry, and ocean biology.

U.S. observations and projections

This section provides a brief description of the observed trends and projections for temperature and precipitation in the United States, in order to compare climatic conditions for Arizona and the Southwest with those in the rest of the country. These findings are derived from the *Third National Climate Assessment* (Melillo et al. 2014), and the National Oceanic and Atmospheric Administration's (NOAA's) technical report on climate change (NOAA 2013).

Temperature observation and projection

In the United States, since recordkeeping began in 1895, average temperatures have increased by 1.3°F to 1.9°F nationally. More than 80% of this increase has occurred since 1980 (Melillo et al. 2014).

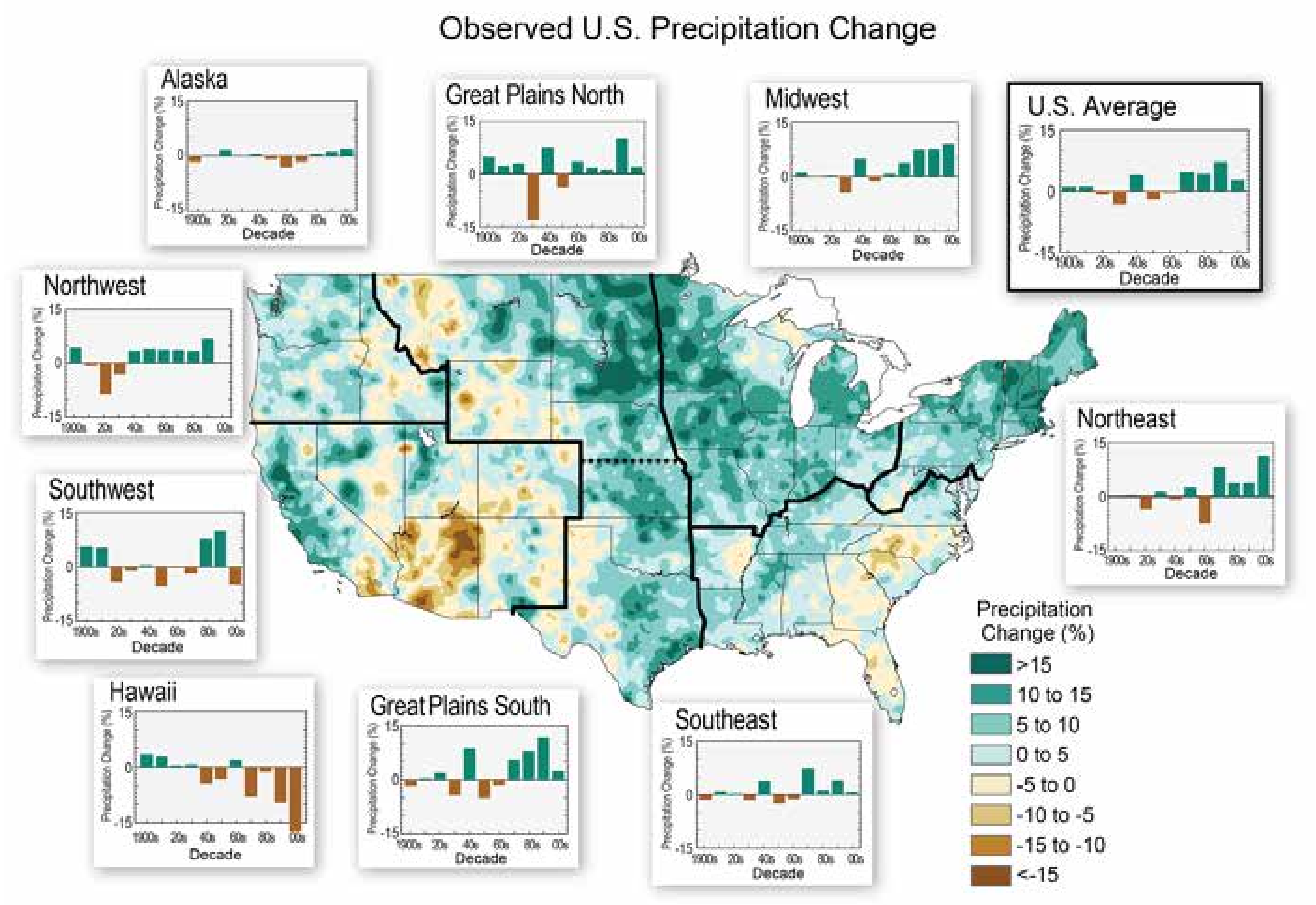


Figure 23 Average U.S. regional precipitation differences by decade for 1901-2012 (relative to the 1901-1960 average). The far right bar in each graph is for 2001-2012. Source: Melillo et al. (2014, p. 32)

The most recent decade has been the warmest on record, and temperatures are expected to continue to rise. However, the uptick in temperature is not uniform across space and time. Since 1991, average temperatures have been 1.0°F to 1.5°F higher than they were during the period 1901-1960 over most of the nation except for the Southeast, where warming has been less than 1.0°F. Aside from natural variability, the projected temperature increases for the next two to three decades can be attributed to a combination of the warming already built into the climate system due to past emissions and the expected future emissions of those gases.

In addition, due to rapid urbanization, nighttime temperatures have increased in the past decades, creating urban heat islands, which affect urban residents as well as ecosystems–especially in the hotter and drier urban regions. Figure 21 shows average temperature changes between 1991 and 2011, as compared to changes between 1901 and 1960. The bars indicate average temperature change by decade.

In the next few decades, temperature is projected to rise a further 2°F to 4°F in most parts of the country (Melillo et al. 2014). The projected increase toward the end of this century (2071–2099) is highly variable across the four different RCPs. For example, in the RCP 2.6 scenario, in which emissions are reduced rapidly and dramatically, annual average temperature increases are confined to less than 5°F across much of the country; while projected long-term temperature increases are much greater under the RCP 8.5 scenario, which assumed continued increases in global emissions. Under this scenario,

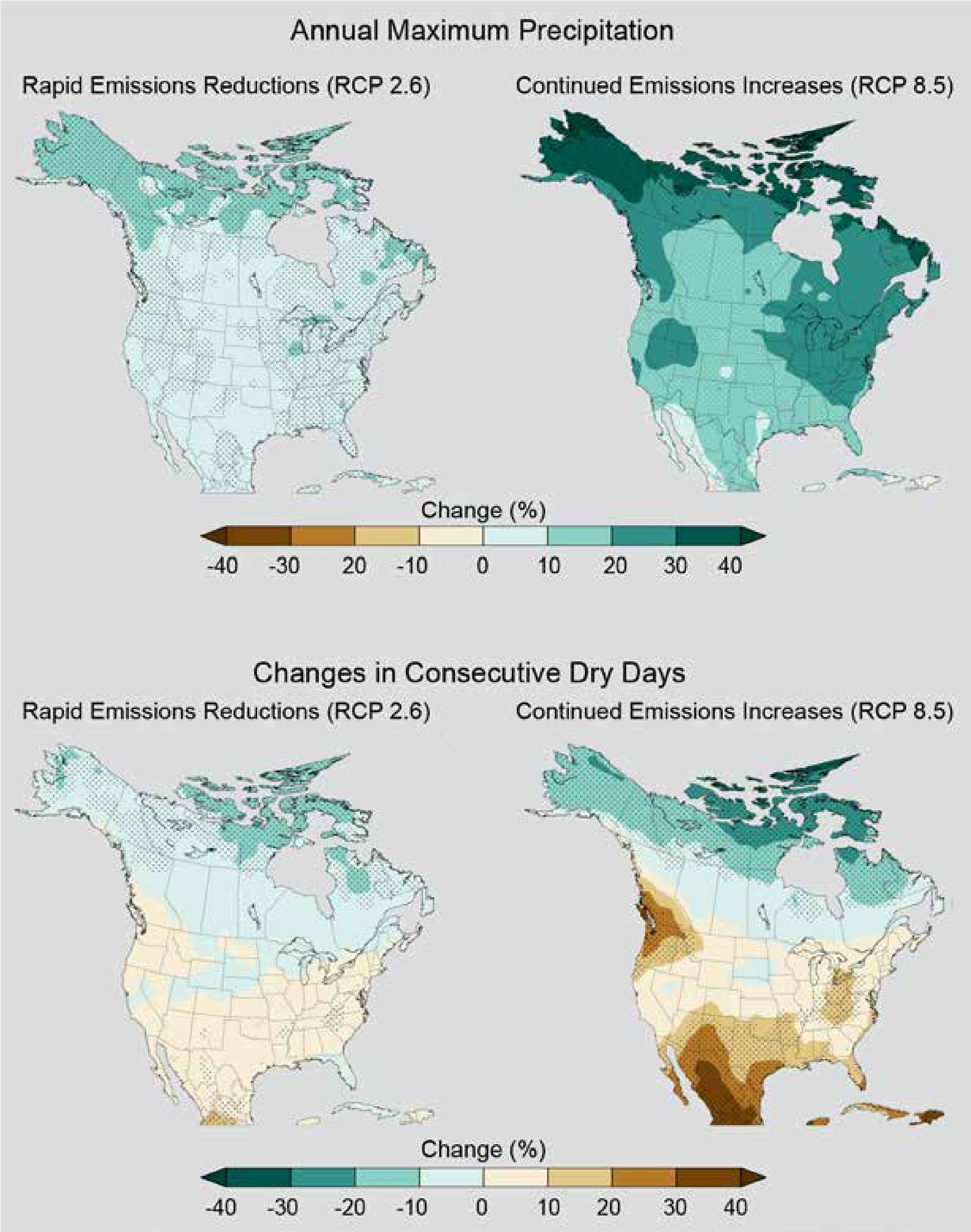


Figure 24 RCP modeled annual maximum U.S. precipitation and changes on consecutive dry days. Top panel shows simulated changes in the average amount of precipitation on the wettest day of the year for the period, 2070-2099, as compared to 1971-2000 under a scenario that assumes rapid reductions in emissions (RCP 2.6) and one that assumes continued emissions increases (RCP 8.5). Bottom panel shows simulated changes in the annual maximum number of consecutive dry days (days receiving less than 0.04 inches [1 mm] of precipitation) under the same two scenarios. Simulations are from CMIP5 models. Stippling indicates areas where changes are consistent among at least 80% of the models used in this analysis. Source: NOAA NCDC / CICS-NC)

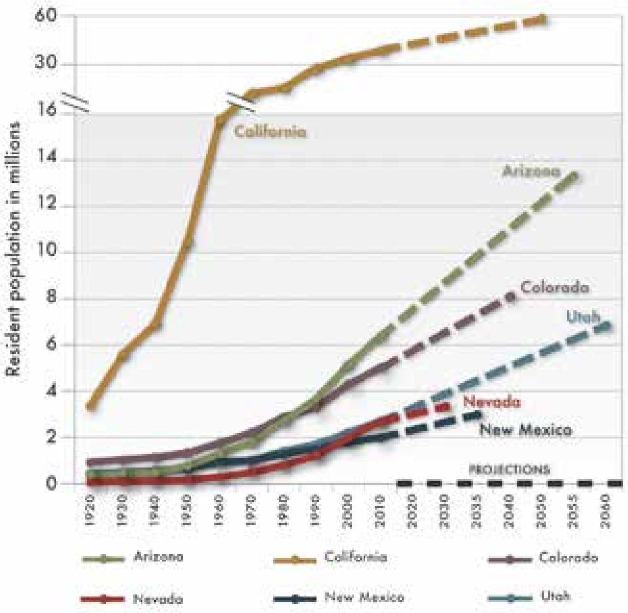


Figure 25 Population projections for the southwestern U.S. Source: Overpeck et al. (2013)

annual average temperatures could increase by more than 10°F in some parts of the United States (Figure 22).

Precipitation observation and projection
Nationally, average precipitation has increased since 1900, but there are regional variations – with some areas experiencing much wetter than average precipitation and with others seeing greater decreases. Figure 23 shows observations of the annual total precipitation changes for 1991-2012 compared to a 1901-1960 average, in which the Northeast (8%), Midwest (9%), and Southern Plains (8%) show increased precipitation.

Heavy precipitation events increased in frequency in the United States between 1958 and 2011. These events occurred particularly in the Northeast (71%) and the Midwest (37%).

The timing and amount of precipitation are projected to change in the future. In general, wet regions are expected to become wetter, while dry regions will become drier. Summers are projected to be drier overall, especially in the Northwest and the southern Great Plains.

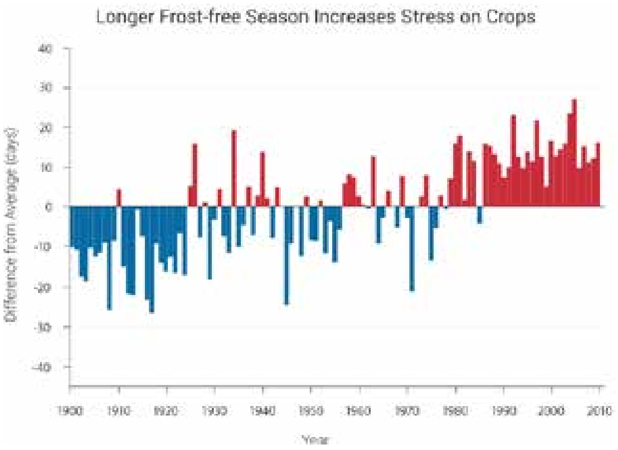


Figure 26 Changes in length of the frost-free season (number of days between the last frost in the spring and first frost in the fall), and difference from average between 1900 and 2010. Source: Theobald et al. (2013)

Under higher emissions scenarios, the northern part of the United States is projected to receive more winter and spring precipitation. The Southwest is expected to experience less precipitation in the spring. Winter and spring precipitation events are vital for replenishing water supplies and, therefore, have substantial social and economic implications for decision-makers (Figure 24).

Southwest observations and projections

The southwestern United States comprises Arizona, California, Colorado, Nevada, New Mexico, and Utah. It is bordered by Oregon, Idaho, and Wyoming to the north, the Rocky Mountains to the east, Mexico to the south, and the Pacific Ocean to the west.

Due to its location and geomorphology, the region is known for a wide range of climate types. Southern California, Nevada, and Arizona–which encompass the Mojave and Sonoran deserts–are the hottest and driest areas. The West Coast, Northern California, Sierra Nevada, and the Rocky Mountains are much cooler and wetter regions. Natural climate variability has caused severe events in the past, ranging from long-term droughts and heat waves to floods, cold snaps, and air quality issues.

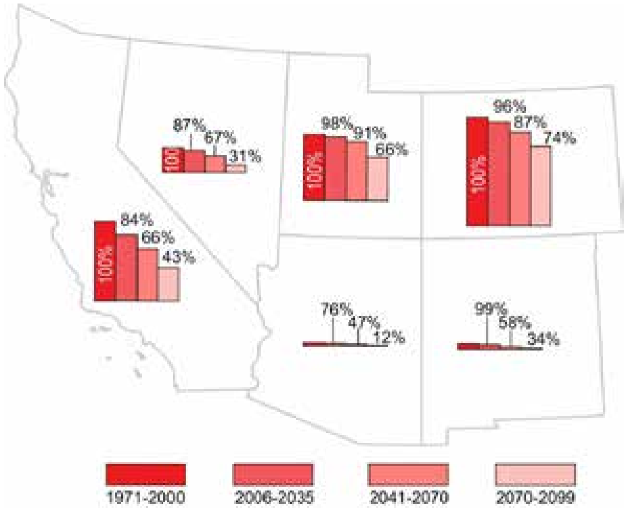


Figure 27 Projected snow water equivalent under the high emissions scenarios, as compared to a 30-year (1971 – 2000) historical baseline. Source: Theobald et al. (2013)

At the same time, the Southwest has experienced rapid population growth over the last few decades. Between 2000 and 2010, each state in this region exceeded the national average growth rate of 9.7%, with some states more than doubling the national average (U.S. Census Bureau, 2010). In 2010, 56 million people lived in the Southwest, and it is estimated that 94 million people will be living in the region by 2050 (Figure 25). Rapid urbanization has caused extensive land use and land cover alterations and has put additional stress on urban ecosystems in the area. The *National Climate Assessment* identifies the Southwest as one of the most climate-challenged regions in North America (Overpeck et al. 2013).

Historical climate and severe weather observations in the Southwest

Historical records of temperature and precipitation show that the averages are shifting in the Southwest. Average temperatures between 2001 and 2010 were the highest recorded since 1901, and the average annual temperature in this region increased almost 2°F over the past century. At the same time, more heat waves and fewer cold waves were observed, compared to other decades in the 20th Century. The frost season has shortened significantly since the 1980s, compared to the 110-year average (Figure 26).

Over the past 50 years, regional warming and recent drought across most of the Southwest already have contributed to decreasing spring snowpack, earlier snowmelt, and shifted runoff. The four river basins in the Southwest (Colorado River at Lees Ferry, Sacramento-San Joaquin Rivers, Humboldt River at Palisade, NV, and the Rio Grande at El Paso), which are the key water suppliers for urban and agricultural areas, have experienced decreased stream flows of 5% to 37% during the past decade, compared to the 20th Century average.

Projected climate and extreme weather

Climate scientists are highly confident in their predictions that the southwestern United States will become progressively warmer–and that droughts will become substantially drier and hotter, more severe, longer-lasting, and more frequent than observed in recent decades (Overpeck et al. 2013). The most comprehensive synthesis of climate model output for this region is available in the *Assessment of Climate Change in the Southwest United States* (Garfin et al. 2013). Climate projections described in the assessment yield a regional annual average temperature increase between 2.5°F and 5.5°F by mid-century and between 5.5°F and 9.5°F by the end of this century under a high global emission scenario. Assuming a substantial reduction of global emissions, regional temperatures are still projected to increase from 2.5°F to 4.5°F and from 4.5°F to 5.5°F, respectively. Warming is expected to be greatest in the summer and fall, resulting in longer and hotter heat waves, fewer wintertime cold air events, and a longer frost-free season.

Precipitation projections vary spatially and are less certain than temperature projections. Under the high-emission scenario, precipitation changes throughout the northern states in the region are within natural variations. Within the southern parts of the region, the amount of winter and spring

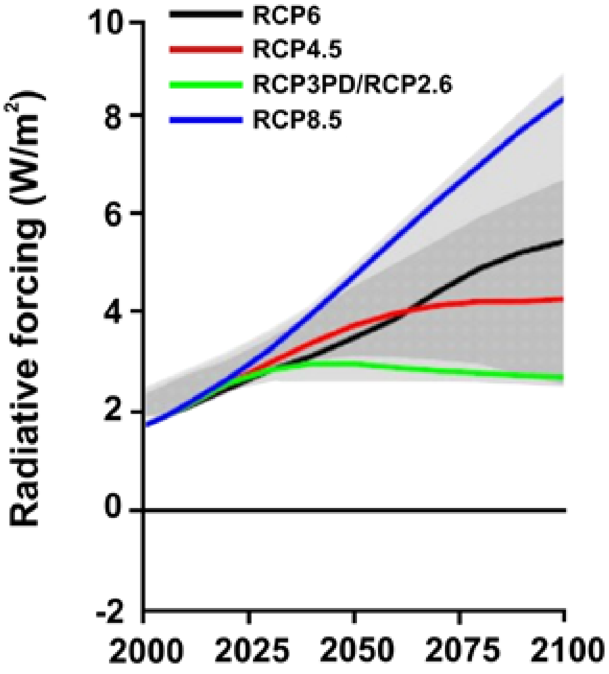


Figure 28 Radiative forcing of the Representative Concentration Pathways (RCPs). The light grey area captures 98% of the range in previous integrated assessment modeling (IAM) scenarios, and the dark grey area represents 90% of the range. Source: van Vuuren et al. (2011a)

rainfall is projected to decrease by the end of the century.

Climate models further project a reduction of snowpack and subsequently declining stream flows as well as reduced runoff and soil moisture in parts of the southwestern United States. Figure 27 summarizes the projections for snow water equivalent (i.e., the amount of water held in a volume of snow) under the high emissions scenarios, using the years, 1971-2000, as a baseline. Although the contribution of each state to the region-wide snowpack varies, a reduction in snow water equivalent is projected for the whole southern United States.

Impacts of projected changes

The projected changes in the Southwest could have significant impacts on the area's cities, agriculture, and ecosystems. Rising temperatures and recent drought have already been linked to tree mortality, more frequent wildfires, and forest insect outbreaks (Gershunov et al. 2013). More wildfires are projected through the end of this century, putting some communities at risk.

The projected changes will also have both positive and negative impacts on Arizona's agricultural sector. In general, longer periods of warm weather in the winter will accelerate crop ripening, increase irrigation demand–and either may reduce or increase yield and productivity, depending on the crop. Increased temperatures, more severe droughts, and a reduction in snowpack will also threaten the region's water supplies, which are further challenged by rapid population growth.

Projected warming, which will be exacerbated by the UHI effect in cities, and prolonged heat waves will significantly impact urban public health –imposing more heat stress on the southwestern population and increasing the risk of heat-related illnesses and deaths. Past research has indicated that low-income neighborhoods are more likely to feel the impacts of increased warming because of a lack of green spaces and limited access to air-conditioning (Harlan et al. 2006). Heat waves can further cause respiratory distress through increased ground level ozone concentrations.

Climate projections for Arizona

As described above, the *Third National Climate Assessment,* NOAA's technical report on climate change, and the *Assessment of Climate Change in the Southwest United States* provide an overview of climate trends, scenarios, and impacts at regional and national scales (Garfin et al. 2013; NOAA 2013; Melillo et al. 2014). However, the relatively coarse spatial resolution of these assessments makes it difficult to use them as local decision-making tools.

Applying a downscaled climate projection model is one way to transfer coarse projections to finer geographic scales that would aid in adaptation planning and decision-making. In this section, the project team visualized future temperature scenarios using a downscaled climate model, HadGEM2-ES, and the RCPs to provide state- and

county-level results that can support vulnerability and adaptation planning and decision making.

RCPs provide a framework by which the climate science community can undertake long- and near-term modeling experiments (van Vuuren et al. 2011a). They represent the total radiative forcing (cumulative measure of human GHG emissions) that occurred between 2000 and 2010 because of modifications to global GHG concentrations.

Figure 28 shows the radiative forcing of each RCP. RCP 3PD/2.6 represents the lowest emissions scenario, whereas RCP 8.5 represents the highest emissions scenario. The fifth assessment report of the IPCC uses the four RCPs shown in Figure 28 (IPCC 2013). Therefore, the team used these four in this study, as well.

Source of climate projections used

Our criteria for model selection included a model that:

1) Covers all four RCP scenarios;

2) Is recognized and cited by the Fifth Assessment Report of the IPCC and local climatologists; and

3) Has been evaluated or assessed by climatologists.

Based on the literature on downscaled models for North America, the ASU team recommended the use of two models for implementing BRACE in Arizona—HadGEM2-ES, published by the Met Office Hadley Centre in the UK, and GFDL-ESM2G/GFDL-ESM2M, released by NOAA's U.S. Geophysical Fluid Dynamics Laboratory. Only one was used as a starting point for this Step 1 analysis. HadGEM2-ES model run 1 was chosen because its historical simulation has relatively low bias across North America compared with other models (Sheffield et al. 2013).

The disadvantage of using a single model output in this preliminary analysis is that it will not represent the entire range of future projections. To overcome this shortcoming and increase reliability for the future estimations conducted under future BRACE efforts, the project team will incorporate additional downscaled models into future analyses.

The spatial resolution of the downscaled HadGem2-ES model is 1/8 degree, approximately

12 km per pixel. The original data files were downloaded from the U.S. Bureau of Reclamation's "Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections" archive (U.S. Bureau of Reclamation 2014). These data were subsequently post-processed in ArcGIS, an integrated collection of geographic information system (GIS) software products.

Summary of climate projections for 2030 and 2060

There is no universally agreed upon temperature metric for the evaluation of heat stress in epidemiological and health geography studies. National and international comparisons of the association between various heat stress indicators and health issues reveal inconsistencies in the identification of the best variables to use as predictors (e.g., Barnett et al. 2010; Hajat et al. 2010). The best measure depends on the location and health outcome of interest.

Previous studies in the Phoenix metropolitan area have found that maximum temperature is more important than minimum and mean temperatures as a factor in heat-related ambulance dispatches in the inner city (Hartz et al. 2006; Golden et al. 2008; Chuang and Gober 2013). In principle, since daytime maximum temperatures are associated with the time of maximum possible thermal stress experienced by people, examination of how these temperatures may change in the future may reveal insights for human health issues associated with heat exposure.

The team analyzed the anticipated changes in monthly maximum temperatures in July for the years 2030 and 2060. To ensure the consistency of the comparative analysis and minimize the impact of model bias, the baseline temperature that the team used, which represents the current state, is the modeled averaged daily maximum temperature during July 2010 from HadGEM2-ES.

Each projection layer is the average of a five-year record. For instance, the simulation of 2030 is the average July maximum temperature over the five-year period, 2028-2032. Figures 29-32 illustrate

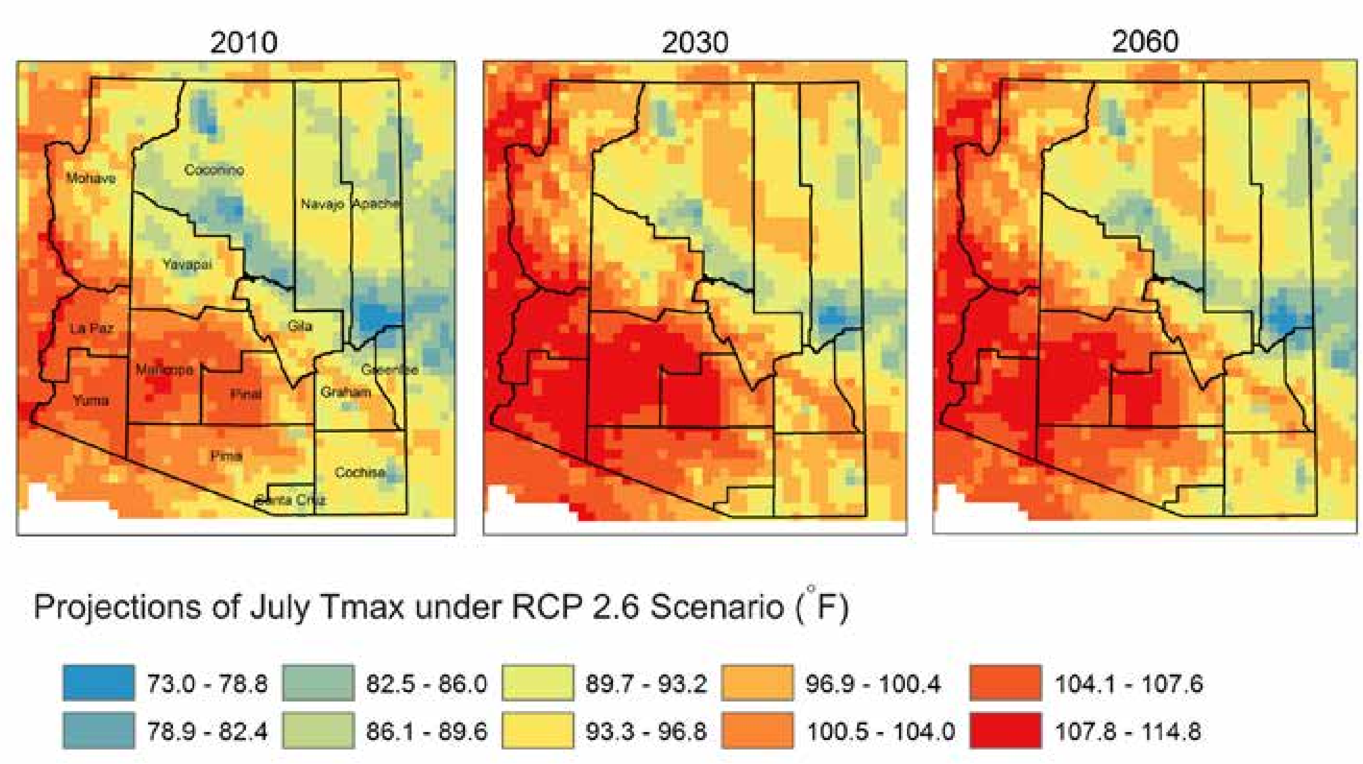


Figure 29 RCP 2.6: Projections of maximum temperature (Tmax) in July 2010 (baseline), 2030, and 2060.

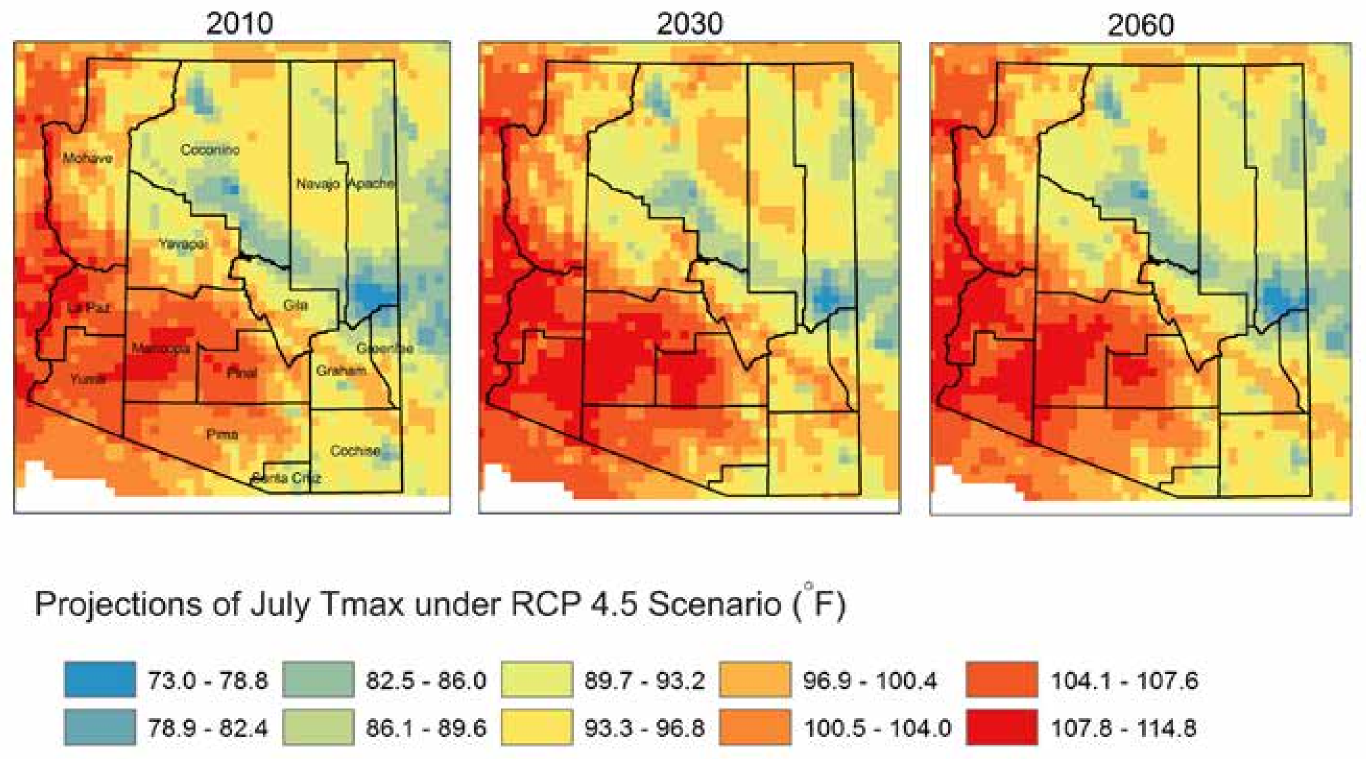


Figure 30 RCP 4.5: Projections of maximum temperature (Tmax) in July 2010 (baseline), 2030, and 2060.

the maximum temperatures for July 2010, 2030, and 2060, under the four RCP scenarios. A brief description of the changes suggested by each of these model runs follows:

RCP 2.6 scenario (Figure 29): Warming is particularly evident in Mohave County and west Pima County between 2010 and 2030. In 2060, large temperature increases are expected in Mohave and La Paz. However, the areas with Tmax above 107.8°F shrink in Maricopa, Pinal, Coconino, and Navajo County. Overall, the temperatures in July 2060 under the RCP 2.6 scenario are lower than the temperatures in 2030. Yuma, Yavapai, Gila, Graham, Greenlee, Santa Cruz and Apache counties do not have significant changes between 2030 and 2060 with the RCP 2.6 scenario. While the RCP 2.6 scenario is associated with declining emissions and radiative forcing in mid-century, this decline cannot account for the projected temperature decrease over much of the state between 2030 and 2060. Lags in the climate system between radiative forcing and subsequent equilibration will cause temperatures to continue to increase for decades after emissions reductions begin (or emissions are completely eliminated): some warming during the remainder of the 21st century is already "committed" according to climate models (e.g., Meehl et al. 2006).

RCP 4.5 scenario (Figure 30): Between 2010 and 2030, modeled temperature increases range from 0.29°F to 4.55°F. The largest temperature increases are projected in Yuma, West Pima, La Paz, Maricopa, South Navajo, Apache, Greenlee, and Cochise counties. For the temperature patterns in July 2060, surprisingly, the data show that the range of temperature increases is lower and the average temperature is milder than in 2030 (as also was projected for RCP 2.6). The largest temperature increase range in July 2060 is 2.5°F, with warming projected in Yuma, La Paz, Maricopa, Santa Cruz, southern Mohave, Santa Cruz, and western Pima counties. Coconino, Yavapai, Gila, Pinal, and Graham counties do not have significant changes between 2030 and 2060 with the RCP 4.5 scenario.

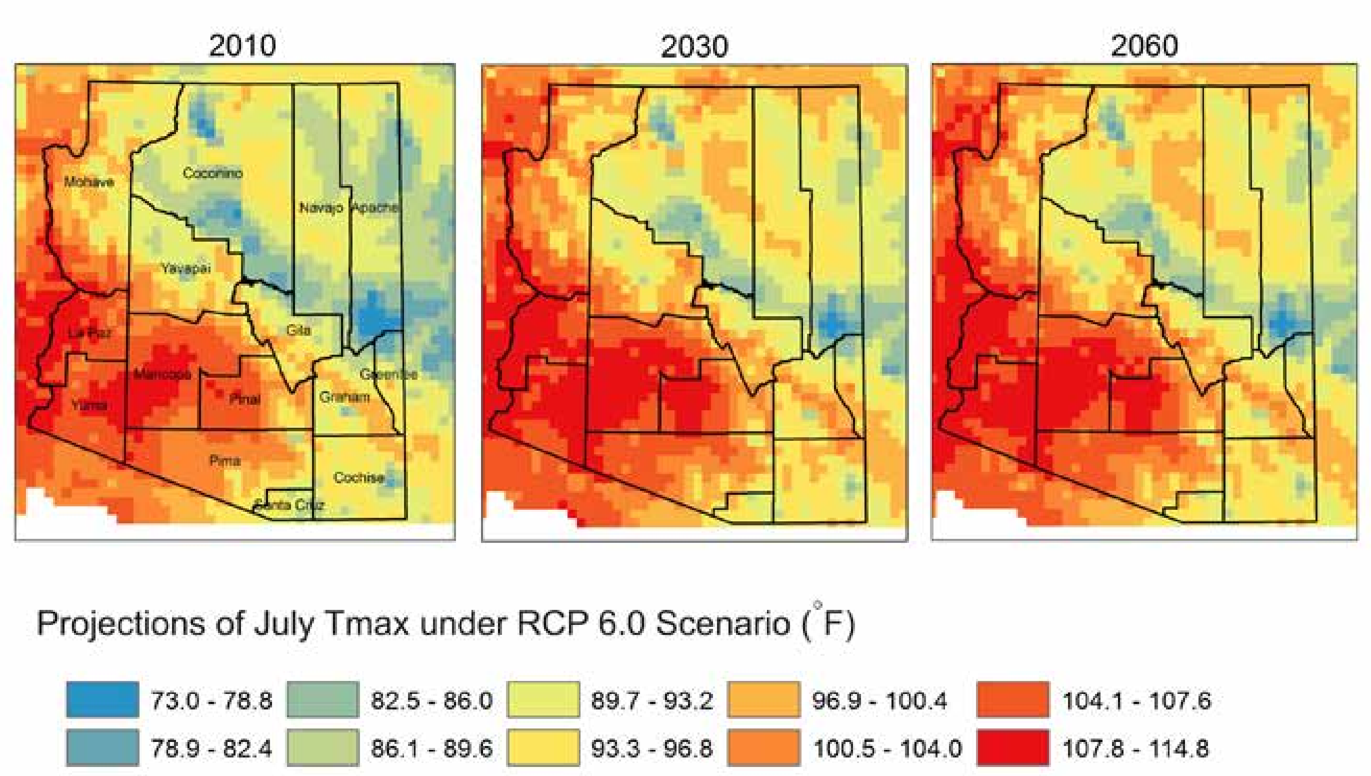


Figure 31 RCP 6.0: Projections of maximum temperature (Tmax) in July 2010 (baseline), 2030, and 2060.

RCP 6.0 scenario (Figure 31): Between 2010 and 2030, temperature increases are expected to range from 0.72°F to 4.77°F. The temperature increase between 2010 and 2060 reaches a high of 4.88°F. The areas experiencing the largest increase are Coconino, Navajo, and Apache counties. Although the largest temperature increases were projected in northeastern Arizona, Maricopa, Yuma, La Paz, and Pinal are the hottest areas of the state, and their July 2060 Tmax ranges from 105°F to 109°F. Mohave, Yavapai, Pima, Santa Cruz, Gila, Graham, Greenlee and Cochise counties do not have significant changes between 2030 and 2060 with the RCP 6.0 scenario.

RCP 8.5 scenario (Figure 32): Under this high-emission scenario, the maximum temperature increases are 3.3°F in 2030 and 4.41°F in 2060, compared with the 2010 baseline temperature under the same scenario. The magnitude of temperature increase under this scenario is not greater than the projected increase in either RCP 4.5 or RCP 6.0. Under the RCP 8.5 scenario, the statewide July average Tmax is 114.4°F in 2060. Significant temperature increases were projected in northern Arizona and Yuma County, but areas with the highest temperatures (above 107°F) cluster in La Paz, Yuma, Maricopa, and Pinal County. Yavapai, Pima, Santa Cruz, Gila, Graham, Greenlee, and Cochise counties do not have significant changes between 2030 and 2060 with the RCP 8.5 scenario.

Overall, the largest temperature changes were projected in the more rural parts of the state. In the medium and high RCP scenarios, the largest temperature increases were projected in northeastern and northern Arizona, including Mohave, Coconino, Navajo, and Apache counties. The highest temperature increase in 2030 was seen in Mohave County under the RCP 2.6 scenario, with a 4.56°F increase from the 2010 baseline. In 2060, Navajo and Apache could experience temperature increases as high as 3.64°F - 3.75°F under RCP 6.0–the highest values among the four RCPs.

The above output represents just one plausible prediction of Arizona's future climate and should

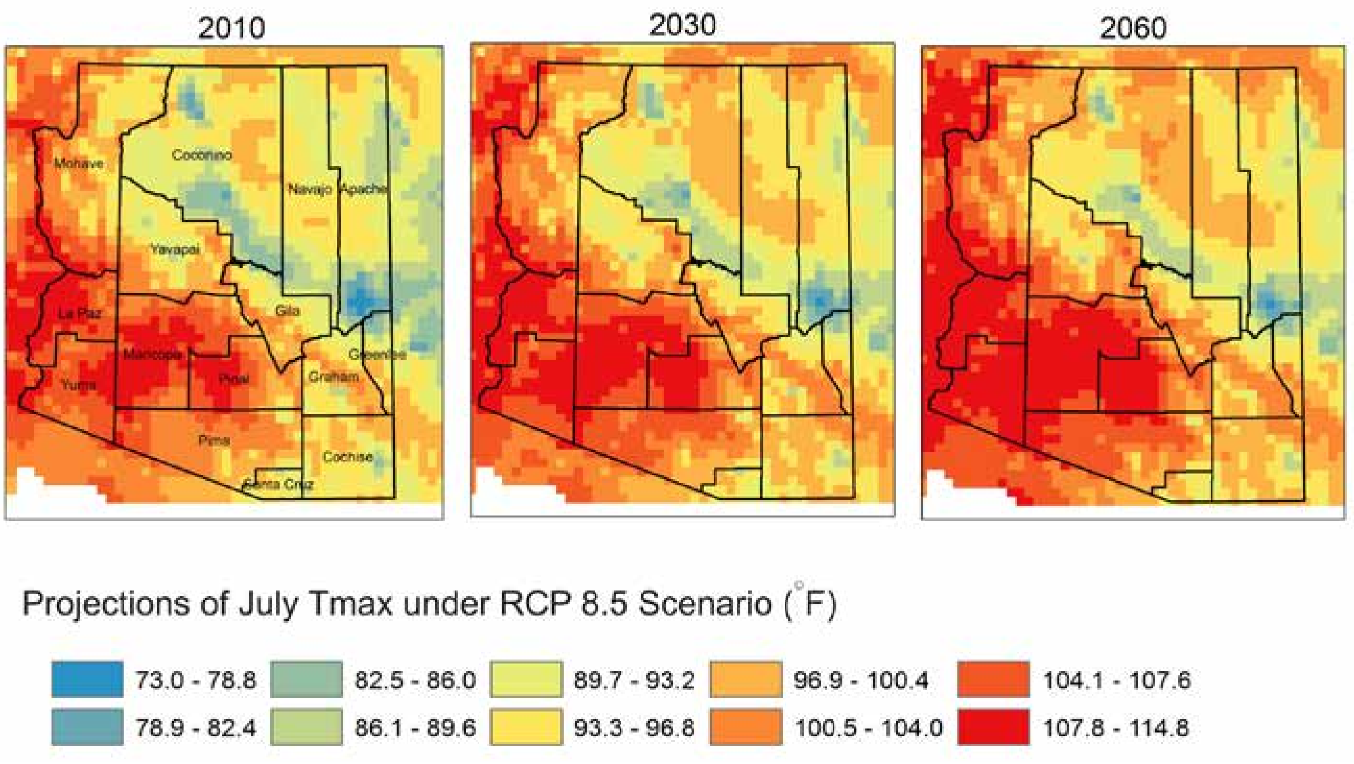


Figure 32 RCP 8.5: Projections of maximum temperature (Tmax) in July 2010 (baseline), 2030, and 2060.

not be considered a comprehensive assessment to be used in the formation of policy and practice. The extent to which the projected changes in summer maximum temperatures derived from the HadGEM2-ES model is representative of those that would be derived from a larger set (composed of dozens of climate models) is unclear. Assessment of the full set of CMIP5 models would help determine whether the spatial and temporal patterns identified in this report are more or less probable.

A fuller assessment still is necessary, since some projections for lower emissions scenarios resulted in greater temperature increases than the higher emissions scenarios in certain areas of the state. This is inconsistent with projections for global average temperature increases associated with these scenarios (although this does not imply that the projections suggesting the opposite for Arizona are necessarily “correct” or “incorrect,” as projected temperature changes are highly variable in space).

More rigorous analysis of the output of the particular model used herein (HadGEM2-ES) is needed to understand the physical drivers of the projected changes. There is notable spatial variability in the projections within the state–including large projected increases in western and northwestern Arizona, where continued expansion of urban corridors could result in considerable conversion of land use and cover in the coming decades. Such conversion would not be expected, however, to result in large increases in summer maximum temperatures, based on the documented “urban oasis effect” (Georgescu et al. 2011). Analysis of the land-cover-change components of the RCPs would help to determine the extent to which projected urbanization will contribute to expected temperature change in these regions.

An additional factor to consider concerning the use of climate model output is related to the time span over which projections are analyzed and averaged. Here, five years of model output were averaged to provide a representative depiction of a possible climate future at certain time periods of interest–2030 and 2060. The interdisciplinary team observed high variability in the temperature projections within the five years extracted. It is possible that a single year within that five-year period was particularly warm or cold, biasing the average. Sensitivity analysis on the averaging period for downscaled climate model output for Arizona will be addressed in future reports about the BRACE framework, along with output from additional climate models.

The accuracy of climate model output is, of course, dependent on the ability of the underlying equations and parameterizations to skillfully reproduce complex physical phenomena. At the spatial and temporal scales of interest to this report, there can be significant limitations where researchers have not yet sufficiently understood and/or measured the physical processes in order to correctly model them.

This can be argued to be the case for the summertime climate of Arizona, which is significantly influenced by the regional monsoon (Adams and Comrie 1997). Ongoing research involves the continued improvement of global and regional climate models and downscaling schemes with respect to their suitability for reproducing and forecasting future conditions in settings and seasons with a monsoonal influence (e.g., Gochis et al. 2002; Castro et al. 2012; Bukovsky et al. 2013).

Historical Arizona air quality

Unlike extreme heat, air pollution is regulated by federal, state, and local governments. In 1970, the U.S. Congress passed the *Clean Air Act*, requiring the newly formed Environmental Protection Agency (EPA) to establish protective health-based standards for air quality by limiting emissions from both stationary and mobile air pollution sources (EPA 2013b).

Major amendments to the Clean Air Act were passed in 1977 and 1990. The *National Ambient Air Quality Standards* (NAAQS) establish acceptable time-averaged concentrations of six "criteria pollutants." Counties and states must not exceed the standards to be in compliance or "attainment." Regions that exceed the standards are designated as nonattainment areas and are required to develop a State Implementation Plan (SIP) to come into compliance.

SIPs detail which pollution abatement (reduction) measures and how much time will be needed for a region to come into attainment. Potential abatement measures may include, but are not limited to:

- Use of advanced emission control technologies and fuel switching or reformulation for stationary and mobile sources;
- Establishment of mandatory vehicle inspection and maintenance programs;
- Implementation of new source review to ensure that new emissions sources are offset with reductions elsewhere;
- Execution of transportation control measures aimed at reducing driving (e.g., employer-based trip reduction programs); and
- Creation of policies aimed at behavioral changes (e.g., "No Burn" days to mitigate particulate matter emissions from fires).

Potential consequences of continued nonattainment include a loss of federal transportation funding and permitting delays.

Historical monitoring has found that certain parts of Arizona will need additional help to meet federal air quality standards for several air pollutants. In their *Regional Technical Report* conducted for the U.S. National Climate Assessment, Brown et al. (2013) summarize health effects associated with high concentrations of ozone and $PM_{2.5}$ because of identified nonattainment issues in southwestern states. However, the confluence of populations in areas of Arizona that are in ozone and PM_{10} NAAQS nonattainment (or have recently come into compliance) compels a focus on these two air pollutants specifically. The health effects of both particulate and ozone exposure are well established.

Conversely, some elements of air quality in Arizona have improved over the past several decades, due to advances in emissions control technology both for stationary sources (e.g. power plants, manufacturing facilities) and mobile sources (e.g. automobiles), and the implementation of pollution control measures in accordance with various SIPs. A telling example is attainment of the CO NAAQS in Maricopa County. Previously a serious CO nonattainment area, Maricopa County was redesignated as an attainment area in 2005 after seven years of successfully attaining the standards (MAG 2013). Because approximately 75% of CO emissions in the region originate from on-road mobile sources, policies targeted the automotive sector. Specifically, state and local agencies switched to cleaner-burning gasoline and implemented emissions inspection programs, among other measures (EPA 2005).

As a condition of the 2005 redesignation, the EPA required the preparation and execution of a maintenance plan to prevent backsliding on air quality gains for a period of eight years. The Maricopa Association of Governments (MAG), the region's metropolitan planning organization, completed its final CO maintenance plan in 2013 (MAG 2013).

Despite these advances, there are ongoing challenges, as parts of Arizona continue to struggle with sulfur dioxide, particulate matter, and ozone. These areas are largely concentrated around the most heavily urbanized parts of the state—including Maricopa County (specifically, the Phoenix metropolitan area) and Pinal County (extending southeast towards Tucson). This area is home to nearly two-thirds of Arizona's population,[4] and thus presents a particularly challenging situation with respect to both PM_{10} and ozone.

Figure 33 shows the location of all nonattainment areas in Arizona, as well as maintenance areas– those areas that were previously nonattainment areas but have since come into attainment, as of 2012.

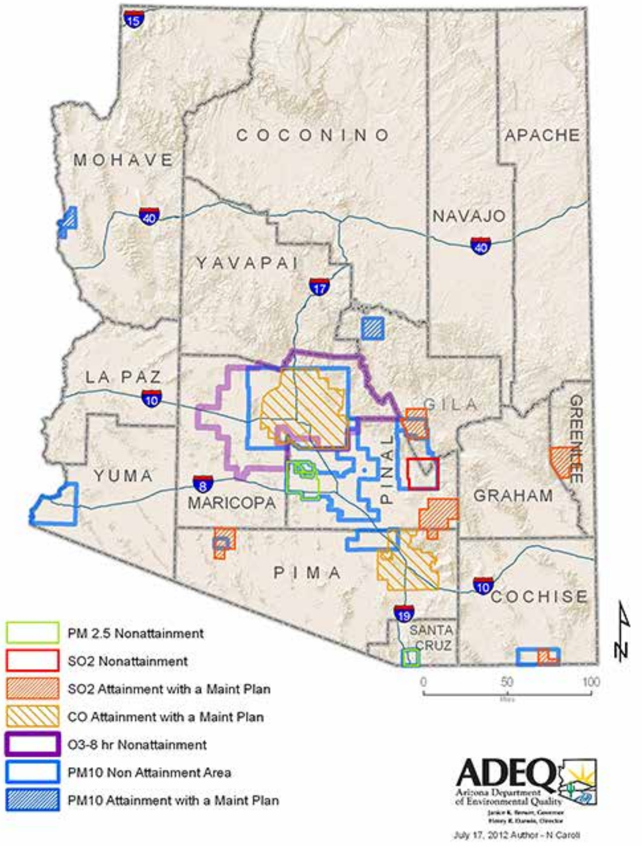


Figure 33 Nonattainment areas in Arizona as of 2012. Source: Arizona Department of Environmental Quality (http://www.azdeq.gov/environ/air/plan/images/notmeet.jpg)

Table 2 summarizes the counties that currently contain nonattainment areas, the pollutants of concern, and the level of severity. Nonattainment areas do not necessarily follow county boundaries, but are set by the EPA to ensure that all important emissions sources contributing to NAAQS violations are captured (EPA 2013a). Arizona's Eight-Hour Ozone Nonattainment Area, for example, covers parts of Maricopa and Pinal counties; while there are two separate PM_{10} nonattainment areas (Hayden and West Pinal) entirely located within Pinal County alone). Part of the Phoenix PM_{10} nonattainment area also crosses into Pinal County.

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[4] Comparing the population of the state to the Phoenix-Mesa-Glendale Metropolitan Statistical Area using data from the 2010 decennial census.

Sulfur dioxide

Sulfur dioxide (SO_2) emissions are of ongoing concern in parts of eastern Pinal County with most of the emissions traced to one or two smelting operations. Previously, all areas of the state except for the Hayden planning area had attained the SO_2 NAAQS. However, in 2010, the sulfur dioxide standard was made more stringent and parts of Gila and Pinal counties were designated nonattainment areas (EPA 2013d).

Particulate matter less than 10 microns in aerodynamic diameter (PM_{10})

The sources of PM_{10} are relatively well-understood and are described at length by the EPA (2004, pp. 2-2 ff.). PM_{10} does not refer to a static chemical entity, but comprises solid or liquid particles suspended in the air and composed of organic material, metals, dust, and combustion products. As the diameter of aerodynamic particles decreases, they are more likely to be composed of combustion materials than of dust. The components of PM_{10} can originate from primary sources, such as dry desert soils, unpaved roads, empty lots, dust storms, and winter wood burning. They can also form secondarily through various chemical processes.

Accumulation of PM_{10} is aided by meteorological conditions including stagnant air that traps particles near the earth, thermal inversions, and high winds that suspend desert dust (MAG 2012). Particularly relevant for Arizona are springtime cold fronts that sometimes result in days-long dust events, during which it is quite difficult to minimize personal exposure.

According to the Maricopa County Air Quality Department (MCAQD) (2014b), on-road sources accounted for 45% of direct PM_{10} emissions in the Maricopa County nonattainment area as of 2011. Miscellaneous area sources–including travel on unpaved parking lots, fugitive dust generated by off-road recreational vehicles, tilling, and windblown dust–represented 33% of total direct PM_{10} emissions.

Both Maricopa and Pinal counties have identified difficulties in achieving the PM_{10} standard. In 2012, the EPA classified parts of western Pinal County as PM_{10} nonattainment areas (EPA 2012a). That same year, a revised plan to reduce PM_{10} emissions by 5% per year was officially approved by the EPA, and Maricopa achieved the NAAQS for PM_{10} as of December 31. The county is now working on a maintenance plan to enable redesignation as a maintenance area (MCAQD 2014d).

County	Pollutant	Highest classification standard[a]
Cochise	PM_{10}	Moderate
Gila	PM_{10}	Moderate
	Sulfur dioxide	Nonattainment
Maricopa	8-Hr Ozone	Marginal
	PM_{10}	Serious
Pima	PM_{10}	Moderate
Pinal	8-Hr Ozone	Marginal
	PM_{10}	Serious
	$PM_{2.5}$	Moderate
	Sulfur dioxide	Nonattainment
Santa Cruz	PM_{10}	Moderate
	$PM_{2.5}$	Moderate
Yuma	PM_{10}	Moderate

Table 2 Arizona counties in nonattainment of the NAAQs as of late 2014.

Finally, two areas along the U.S.-Mexico international border also are experiencing particulate matter attainment issues. Nogales, Arizona, was found to meet the PM_{10} NAAQS in 2012 only after international emissions originating in Mexico were taken into account (EPA n.d.). In 2013, the area attained the $PM_{2.5}$ NAAQS, as well. The Paul Spur/Douglas nonattainment area attained the NAAQS for PM_{10} in 2012 (EPA 2012b).

Ozone

Arizona's physical geography and population behaviors complement the formation and concentration of ozone. Ozone is not directly emitted, but forms when precursors–namely, volatile organic compounds (VOCs) and nitrogen oxides (NOX)–react in the presence of sunlight. Important sources of precursor emissions include light industry, such as auto body shops and dry cleaners (EPA 2013c); as well as automobiles, which account for almost 52% of these emissions (MCAQD 2014a). In the Phoenix metropolitan area, the combination of high average temperatures, abundant sun, high automobile traffic, and physical geography that prevents pollution dispersion (e.g., mountains, low wind speeds) supports high ozone accumulation (Ellis et al. 2000; Atkinson-Palombo et al. 2006).

While the region has seen declines in some ozone precursor emissions in recent years (e.g., VOCs from solvent use), vehicular emissions are steadily increasing (MCAQD 2014c). MAG forecasts that daily vehicle miles traveled will increase from nearly 80 million at present to more than 140 million by 2030 (MCAQD 2014a). In light of this, and despite improving technology and the adoption of clean fuels and vehicles, mobile sources are expected to continue to pose serious air quality challenges for the region and its residents in the decades ahead.

Adding to these challenges is the fact that ozone's complex chemistry can differ across climatic conditions and geographical locations, making it difficult to implement across-the-board solutions. To illustrate, ozone concentrations near roadways are typically low because nitric oxide (NO) directly emitted from automobiles destroys ozone (Karner et al. 2010). This is also why ozone concentrations often are higher in suburban and rural areas as opposed to dense urban ones (Ellis et al. 2000). Furthermore, ozone is a long-lasting pollutant that is often transported over long distances that can affect regions well beyond its point of origin.

Air quality index

Ongoing issues with air quality are summarized in Figure 34, which shows the proportion of monitored air quality days in each of four EPA-defined Air Quality Index (AQI) categories—moderate, unhealthy for sensitive groups, unhealthy for all groups, and very unhealthy. The chart maps pollution concentrations to expected health effects as a means of communicating air quality information to the public (EPA 2012c). The AQI reflects the highest concentration of one of five monitored criteria pollutants or the "main pollutant."

Among the most heavily populated counties, Maricopa has seen some decrease in days that are considered unhealthy for sensitive groups and unhealthy overall – but its number of moderate days has increased. After the turn of this century, Pinal County saw an increase in days with some of the highest AQI ratings. In contrast, Pima County has seen steady improvements in its AQI since the early 1980s. Among the lesser-populated counties, Gila has consistently seen a relatively high proportion of days that are unhealthy for sensitive groups. Copper mining and smelting likely contribute to these AQI ratings for Gila County. Overall, the AQI ratings in Arizona show varied levels of success in combating air quality issues; and provide additional evidence that attainment and health challenges will likely need to be considered well into the future.

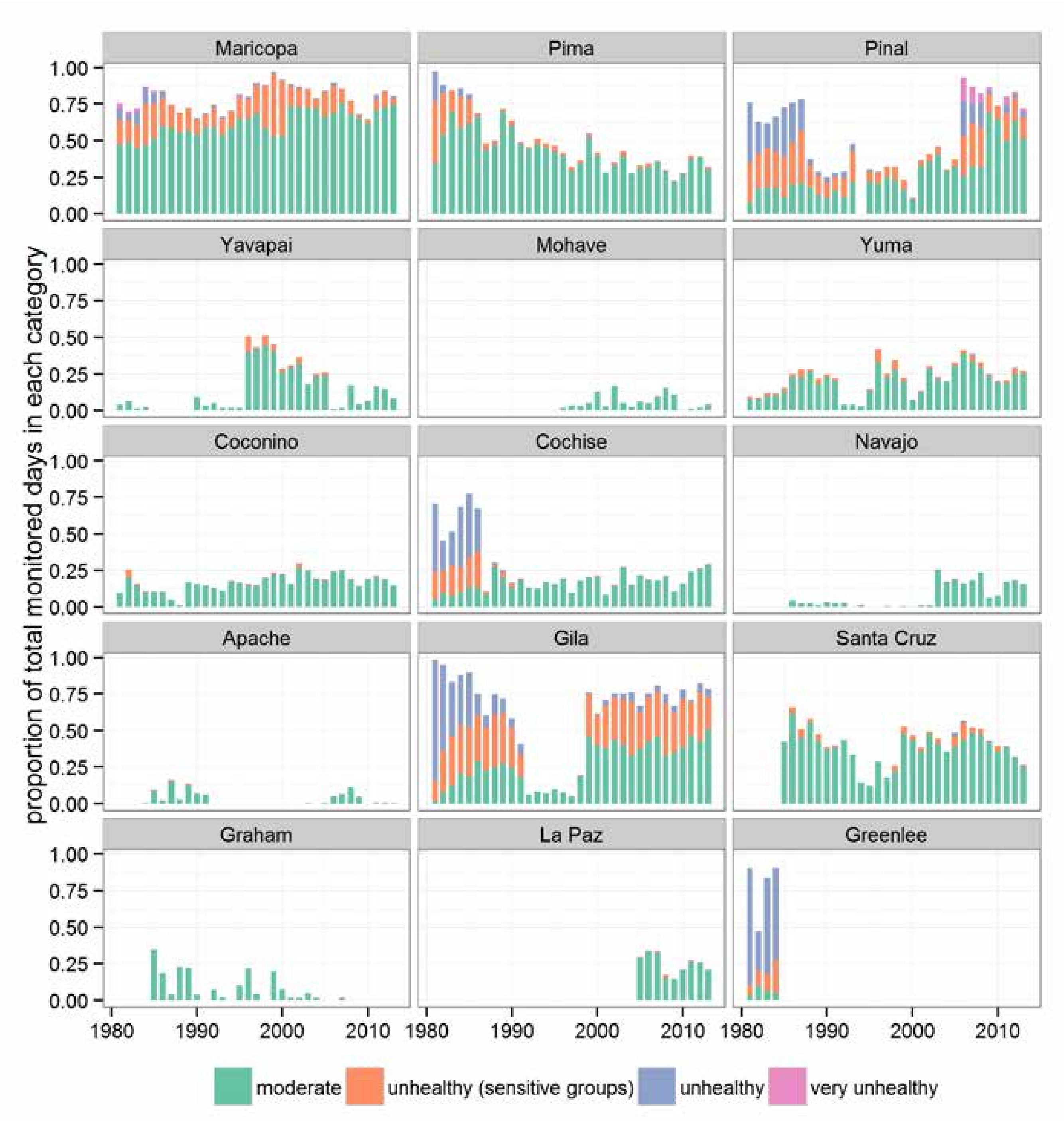
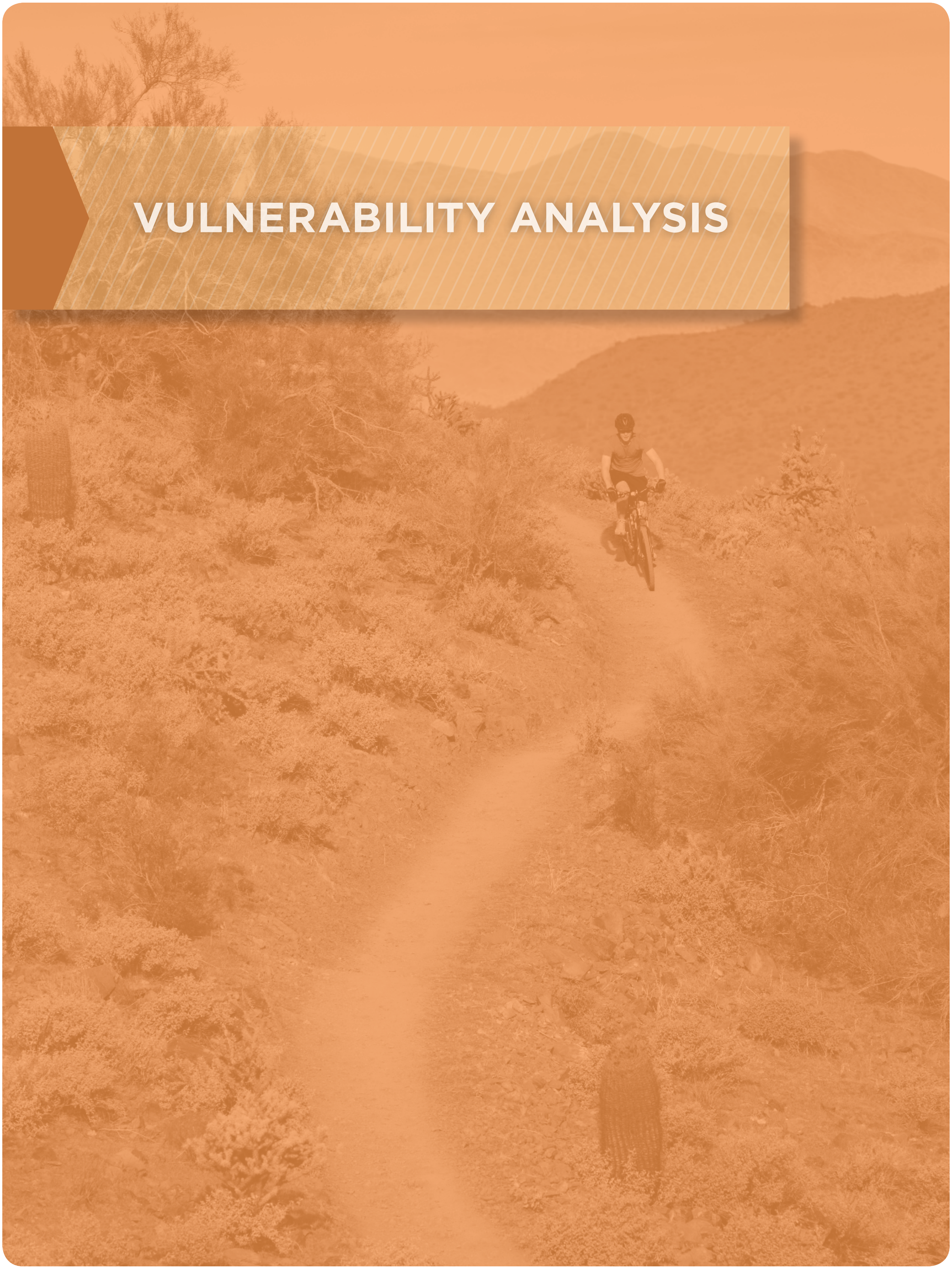


Figure 34 Proportion of total monitored days falling into each air-quality index category by county, 1981-2013. Note that counties are ordered in terms of their total population as of 2010. Data are from the U.S. EPA Air Quality Index Report http://www.epa.gov/airdata/ad_rep_aqi.html.

VULNERABILITY ANALYSIS



VULNERABILITY ANALYSIS

Public health vulnerability is defined as "the degree to which a system is susceptible to injury, damage, or harm" (Smit and Pilfosova 2001). Scholars have identified three major factors that affect a system's degree of vulnerability—exposure, sensitivity, and adaptive capacity.

Similarly, in its introduction to the *Third National Climate Assessment* (2014), the U.S. Global Change Research Program describes vulnerability as "a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity." Physical exposure includes proximity to environmental hazards, such as heat waves, extreme precipitation, drought, or disease vectors. Sensitivity refers to population characteristics that influence degree of susceptibility to the hazard, including race, ethnicity, poverty, access to health care, or access to transportation. Finally, adaptive capacity refers to the ability to change behavior to reduce the impacts of future hazardous events.

In this section of the report, the project team first will describe the conceptual pathways by which exposure to extreme heat and poor air quality are linked to public health issues and the ways in which these pathways can be expected to change in a warming climate. Next, the team will consider population sensitivity to extreme heat and air pollution using measures that indicate vulnerability. The interdisciplinary team used data available at both the census tract and county scale, as local data are beneficial for identifying geographic areas of concern. These results will be important for prioritizing adaptation efforts in subsequent BRACE analyses.

Connecting climate and health issues: The conceptual framework

A wide range of human health issues are known to be sensitive to environmental triggers and conditions. The prevalence and distribution of these issues are anticipated to shift with a future projected temperature increase, and subsequent impacts on aquatic, terrestrial, and atmospheric environments and ecosystems (NIEHS 2010). In fact, national and international research bodies have established numerous conceptual links between a shifting climate and human health. The total incidence and geographic distribution of climate-sensitive health effects is also sensitive to technological, behavioral, and demographical changes (some of which are themselves affected by climatic shifts).

The pathways connecting projected climate exposures and health range from those that occur over brief (e.g., minutes, days) periods with direct links to climatic conditions or extreme weather events to those that occur over decadal (or longer) time scales and involve many intermediary environmental and/or human processes or behaviors.

Short-term, direct pathways are relatively straightforward, as the exposures themselves are the cause of injury or death (Donoghue et al. 1997; Bouchama and Knochel 2002). For example, the increased frequency and severity of extreme high temperatures (assuming all other relevant vulnerability and risk factors remain the same) are very likely to increase the rate and prevalence of hyperthermia. Conversely, reductions in extreme temperature frequency or severity, or changes in vulnerability and risk factors that increase societal resilience, could lead to declines in these outcomes.

Health issues directly related to extreme heat exposure are of particular concern in Arizona because much of the state experiences dangerously hot weather during the warm season. Figure 35 provides a framework for visualizing the many direct and indirect pathways. The diagram, adapted from the U. S. Global Change Research Program (USGCRP), demonstrates not only the links between health and climate; but also causative human activities, such as development, land use, adaptation, and mitigation.

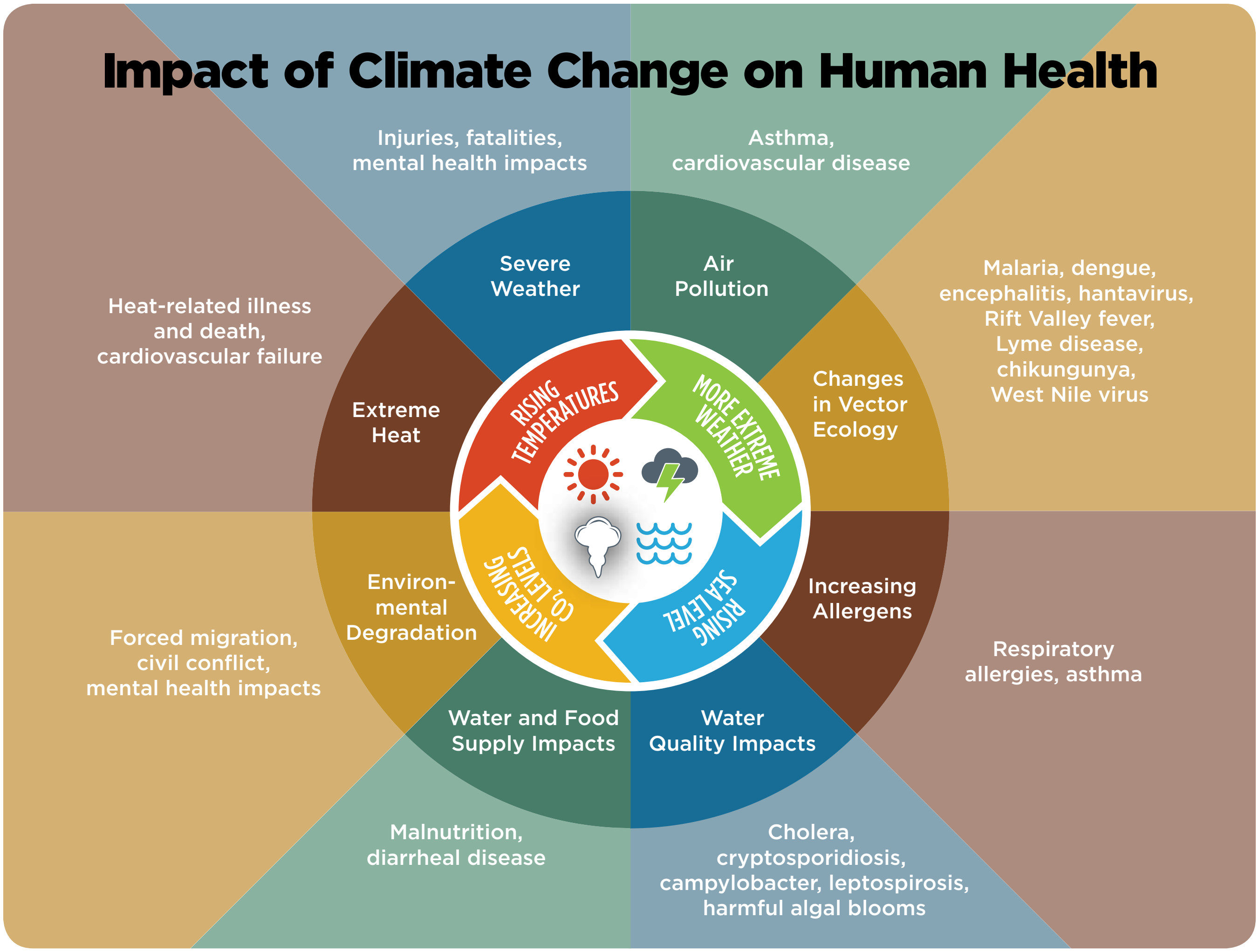


Figure 35 Conceptual Pathways of Climate and Health. Source: CDC Climate Effects on Health – www.cdc.gov/climateandhealth/effects/

Indirect, longer-term pathways connecting projected climate exposures and health issues are more difficult to measure and observe, but likely affect a much larger proportion of the global and local populations due to the variety of mechanisms and extended time periods involved.

Extending the example above, the increased frequency and severity of extreme temperatures could lead to human health impacts via a number of indirect mechanisms. For example, increases in the number and intensity of uncomfortable or intolerable outdoor temperature events would likely discourage outdoor exercise and recreation and the use of non-motorized transportation like bicycling (Tucker and Gilliland 2007; Bélanger et al. 2009).

Taking the example a step further, a reduction in physical activity could then increase adverse chronic health conditions associated with sedentary lifestyles (e.g., Warburton et al. 2006).

Climatic impacts on agricultural production and water supplies are also likely to influence health issues, such as malnutrition, dehydration, and food- and water-borne diseases (Schmidhuber and Tubiello 2007). In Arizona, the climatic impacts on human health through the indirect mechanism of changing air quality are relevant for a large portion of the state's population that lives in regions where it is challenging to meet federal air quality standards.

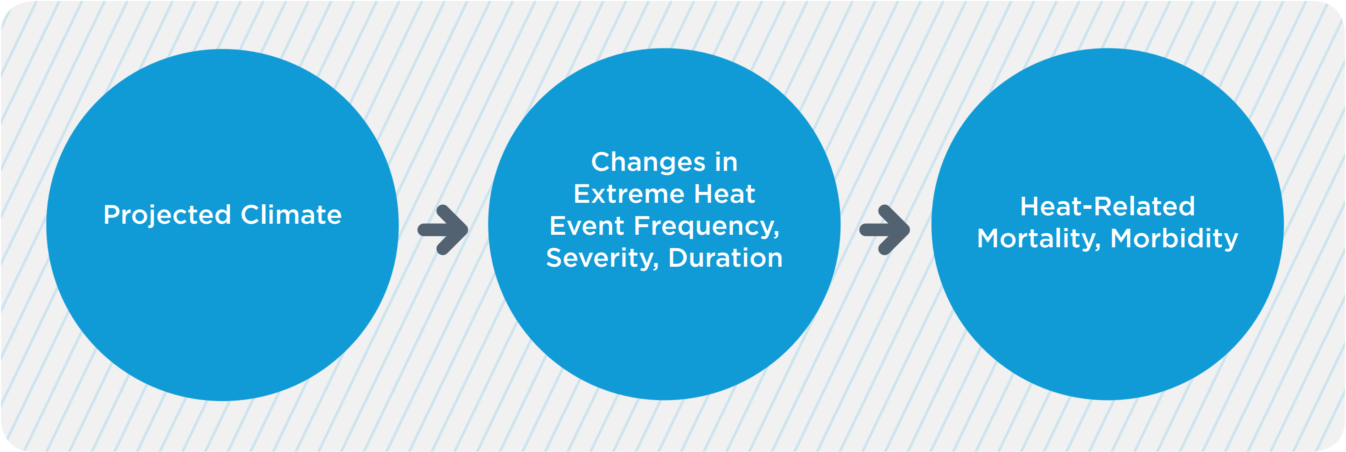


Figure 36 Conceptual pathways linking projected climatic conditions, extreme heat, and human health. Adopted from the U.S. Global Change Research Program. Source: http://www.globalchange.gov/what-we-do/climate-change-health

Conceptual pathways linking climate, extreme heat, and human health

Temperatures regularly observed in the warmer parts of Arizona during the summer are high enough that increases in core body temperatures would be expected, even for an individual at rest. A typical, healthy human body operates within a relatively narrow range of internal core temperatures (98-102°F or 37-39°C) and has a suite of mechanisms to maintain this range, even when exposed to large fluctuations in external thermal conditions. Physiological mechanisms include dilation of blood vessels near the skin and sweating, which transfers heat to the environment via conduction, convection, and evaporative cooling. Extreme and prolonged high temperature conditions, however, can compromise the effectiveness of these physiological cooling mechanisms. They can also be compromised by high humidity (Winslow and Herrington 1949; Koppe et al. 2004).

When these thermoregulatory mechanisms begin to fail, core body temperatures increase beyond the desirable range, which can result in illness and death. Mild illnesses and symptoms include dehydration, when the body has insufficient fluids remaining after loss during sweating; and heat syncope, when increased blood flow to the peripheries results in insufficient blood pressure to supply oxygen to the brain, resulting in light-headedness or fainting (Kavaler 1981).

The most severe condition associated with severe heat is heat stroke, diagnosed when core temperatures exceed 104°F or 40°C. At this core temperature, cellular and tissue damage occurs that can be so severe, it leads to death (Bouchama and Knochel 2002).

Heat stroke is not the only fatal outcome associated with extreme heat, however. Literature to date has focused largely on cardiovascular- and respiratory-related causes of death. Positive associations have been reported in some, but not all studies (e.g., Applegate et al. 1981; Wainwright et al. 1999; Basu and Samet 2002; Harlan et al. 2014), but associations with other outcomes have also been documented (e.g., Deschenes 2013; Fralick et al. 2013).

In the United States, the number of deaths resulting from excessive heat exposure far exceeds the number due to all other natural hazards besides cold exposure (Berko et al. 2014). Individual extreme events can have drastic health impacts as well. For instance, heat waves in 2003 claimed over 15,000 lives in France, and a 1995 heat wave in Chicago killed more than 700 people (EPA 2006b).

These health impacts are expected to increase, as more intense, longer-lasting, and more frequent heat waves occur, based on climate projections (Knowlton et al. 2007; Meehl and Tebaldi 2004; Patz 2005). Public health officials are progressively becoming more concerned about the adverse health effects associated with EHEs (Hajat et al. 2010; Luber and McGeehin 2008; U.S. EPA 2006). EHEs are defined with reference to typical conditions (temperature, relative humidity) in a particular area so there is no absolute definition that applies in all locations (EPA 2006b; Pincetl et al. 2013).

A particular challenge facing Arizona is that, in many parts of the state, extreme heat occurs as a chronic, rather than episodic, hazard with dangerously high temperatures persisting throughout the warm season (Harlan et al. 2014). Continual high nighttime lows do not allow the body to recover from the daytime heat, if no access to cooling is available. Vulnerable populations are at particular risk when nighttime temperatures remain high, as they typically do for several consecutive days in the summer in Arizona. The worst impacts of EHEs will likely be felt in urban areas, where large numbers of vulnerable people reside, urban heat island effects exist, and air quality is more likely to be poor (Revi et al. 2014).

In the absence of technological, behavioral, or physiological adaptations, the conceptual pathway connecting changes in climate, extreme heat, and human health is straightforward (Figure 36).

Conceptual pathways linking climate, air quality, and human health

Major air pollution episodes during the latter half of the 20th century sensitized the public to the human health effects of exposure to poor air quality and spurred efforts to ensure clean air. Dense smog overtook London, in late 1952, resulting in a threefold increase in deaths (Bell and Davis 2001). The first major U.S. air pollution incident took place in 1948 in Donora, Pennsylvania, when unusual meteorological conditions combined with particulate matter and sulfur dioxide emissions from industrial activity resulted in 20 deaths. In addition, 43% of the total population (6,000 people) suffered respiratory issues (Bachmann 2007).

U.S. air pollution science and policy underwent rapid development and advancement following these and similar episodes. For example, the first ambient monitors were established in Los Angeles in 1955 and California politicians proposed the idea of setting standards for air pollution concentrations. Later epidemiological studies clearly established the links between exposure to poor air quality and health issues (see, e.g., Dockery et al. 1993; Brunekreef and Holgate 2002).

A number of large epidemiological studies examining the association between air quality and premature mortality were published in the early 1990s. Several of these studies provided evidence for a link between exposure to both fine and coarse particulates and death (Dockery et al. 1993; Pope et al. 1995; Abbey et al. 1999). Additional studies ensued because of the regulatory and public health implications and potentially high costs of air pollution controls (see, e.g., Health Effects Institute 2000).

Brunekreef and Holgate (2002) reviewed the literature early in the current century and found increasingly sophisticated analytical techniques for discerning direct effects of air pollution on health issues. From studies that spanned different geographic regions, climatic regimes, and demographics, they described associations between increasing PM_{10} concentrations and total death rates, hospital admissions for asthma, COPD, cardiovascular disease, decreased lung function, and other respiratory symptoms. In children, exposure to particulates was found to reduce lung development. The review authors also reported the results of some natural experiments that lend credibility to the causal nature of the relationship between air pollution and poor health.

The Environmental Protection Agency analyzed animal, human, and epidemiological studies of

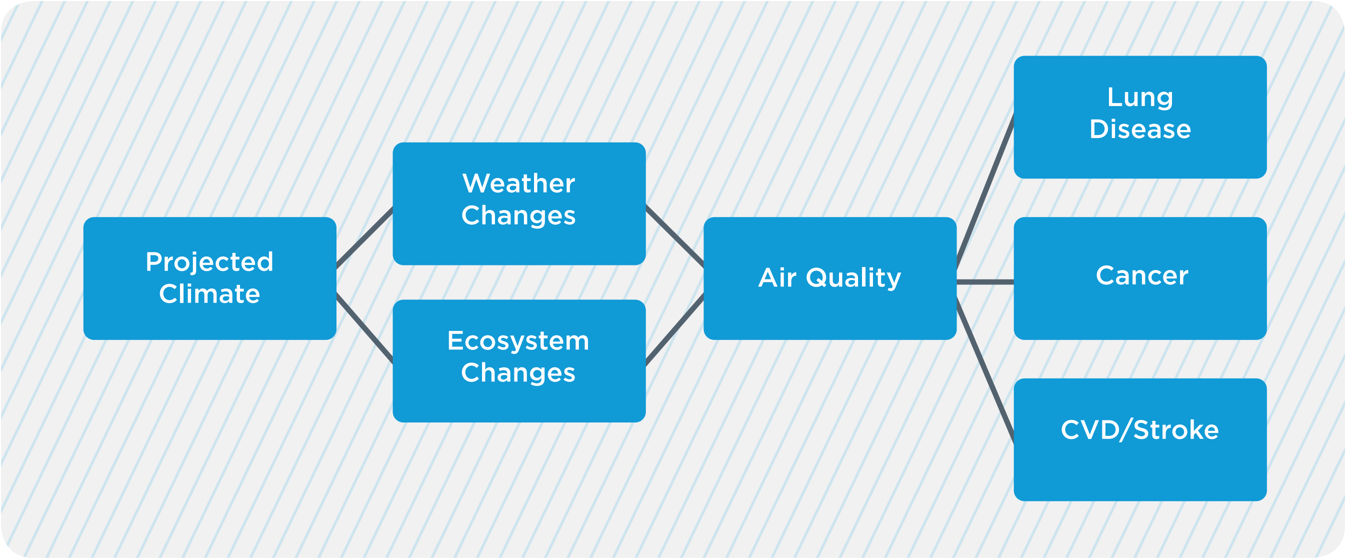


Figure 37 Conceptual pathways linking projected climatic conditions, air quality, and human health. Adapted from the U.S. Global Change Research Program. Source: http://www.globalchange.gov/what-we-do/climate-change-health

ozone exposure as part of a NAAQS review in 2006 (EPA 2006a). The work showed substantial evidence that short-term ozone exposure results in respiratory health issues–including decreased lung function, cough, chest pain, shortness of breath, inflammation, as well as suggestive evidence that ozone exposure is associated with cardiovascular morbidity and total death rates. Kampa and Castanas (2008) summarized the medical literature pointing to air pollution effects on health, providing additional evidence for the associations between particulate and ozone exposure and adverse respiratory and cardiovascular issues. Finally, comprehensive reports that address the likely health effects of projected climatic conditions consistently cite worsening air quality as a major concern (Brown et al. 2013; Revi et al. 2014).

The conceptual pathway linking projected climatic shifts, air pollutants, and human health is complex, involving both meteorological processes and ecosystem performance (Figure 37). In addition to sunlight, atmospheric concentrations of criteria pollutants depend in part on meteorological conditions, such as temperature, wind speed, cloud cover, and boundary layer height, as well as large-scale weather patterns (Davis et al. 2010). Specifically, higher warm season temperatures enhance the formation of certain pollutants; but increased boundary layer heights in urban areas associated with urban heat island effects could increase the volume within which these pollutants are dispersed thereby lowing concentrations.

The way these factors interact can vary with climate and geography, carrying implications for air quality (Bloomfield et al. 1996; Davis et al. 1998; Bernard et al. 2001; Mickley et al. 2004; Davis et al. 2010; Tai et al. 2010). Wise and Comrie (2005) investigated the relationship among weather conditions, ozone, and particulate matter concentrations in the Southwest, including the Phoenix metropolitan area and Tucson. They found strong links between meteorological conditions and concentrations of ozone and particulate matter. Interestingly, and in contrast to previous findings for the Northeast, temperature in the Southwest had a relatively minor effect on ozone concentrations. The authors hypothesized that this was because of the relatively uniform clear and sunny conditions that prevail in the Southwest.

In a comprehensive review of the relationship among meteorological conditions, ozone, and particulate matter concentrations–combined with a summary of global climate models–Jacob and

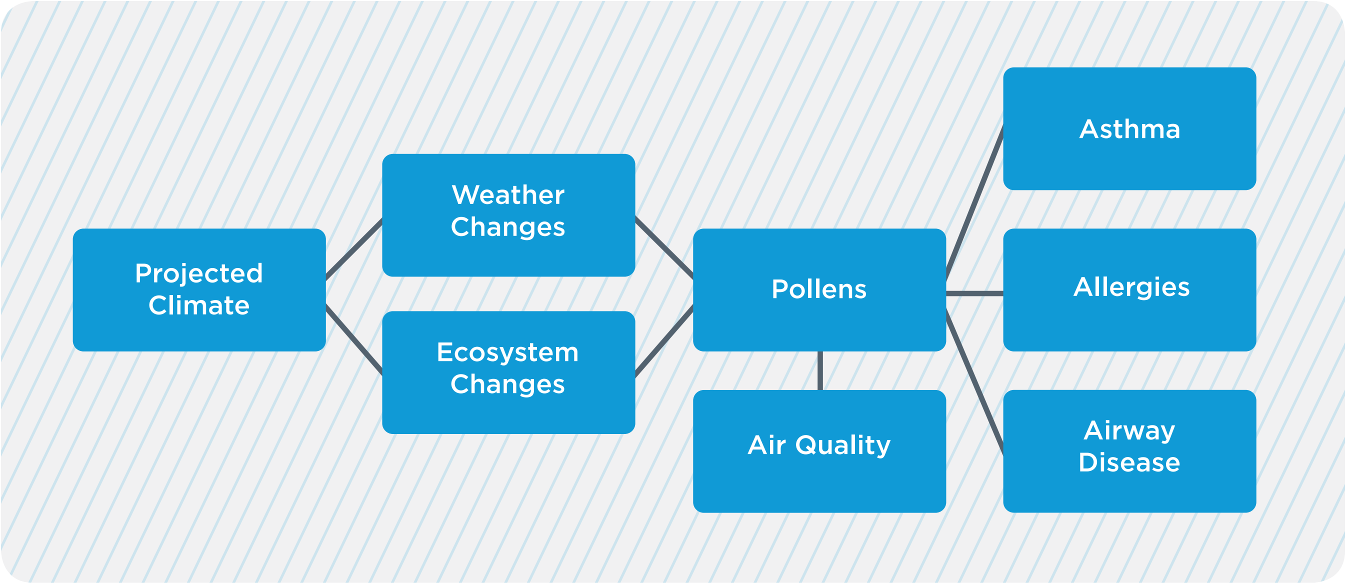


Figure 38 Conceptual pathways linking projected climatic conditions, aeroallergens, and human health. Adopted from the U.S. Global Change Research Program. Source: http://www.globalchange.gov/what-we-do/climate-change-health

Winner (2009) concluded that ozone production in the United States is likely to increase, because rising temperatures will increase biogenic (produced by living organisms) production of ozone precursors. The effect of projected climatic shifts on particulate matter concentrations was found to be less certain.

Other work has found that a shifting climate partly offsets the benefits of reducing ozone precursor emissions–meaning that even stricter controls will be required to achieve future reductions (Steiner et al. 2006; Wu et al. 2008; Millstein and Harley 2009).

Concentrations of air pollutants also depend in part on land surface characteristics (e.g., moisture, ground cover) and ecosystem health. Decreasing moisture increases the risk of wildfires, for example, which would lead to increased particulate concentrations from resultant smoke (Westerling et al. 2003; Henderson and Johnston 2012).

Understanding the net impact of the many pathways by which future climate conditions could influence the concentrations of air pollutants requires rigorous observational and modeling approaches that have only recently begun to be deployed (Nolte et al. 2014; Sujaritpong et al. 2014).

In addition to the increases in criteria pollutants discussed above, the production and distribution of aeroallergens, such as pollens and molds, also are likely to change under projected climate conditions (Beggs 2004; Gamble et al. 2008; Kinney 2008). Many individuals are sensitive to and suffer allergic reactions from airborne pollens (tree, weed, and grass) and mold (Peat et al. 1998; D'Amato et al. 2007). Common allergic diseases include rhinitis, asthma, and eczema.

The conceptual pathways linking projected climate shifts to aeroallergens and health are similarly complex (Figure 38) to those linking climate conditions to air pollutant-sensitive health issues. In both situations, meteorology directly affects atmospheric concentrations of aeroallergens, as does the abundance of various plant species (Hirst 1953; Subiza et al. 1992).

Expansion of zones favorable to pollen-generating plant species also will expose a larger human population to aeroallergens (Ziska et al. 2011; Barnes et al. 2013). Geographic shifts in the presence of certain plants species (responding to shifts in climate and land use) could introduce certain pollens to new regions and decrease concentrations

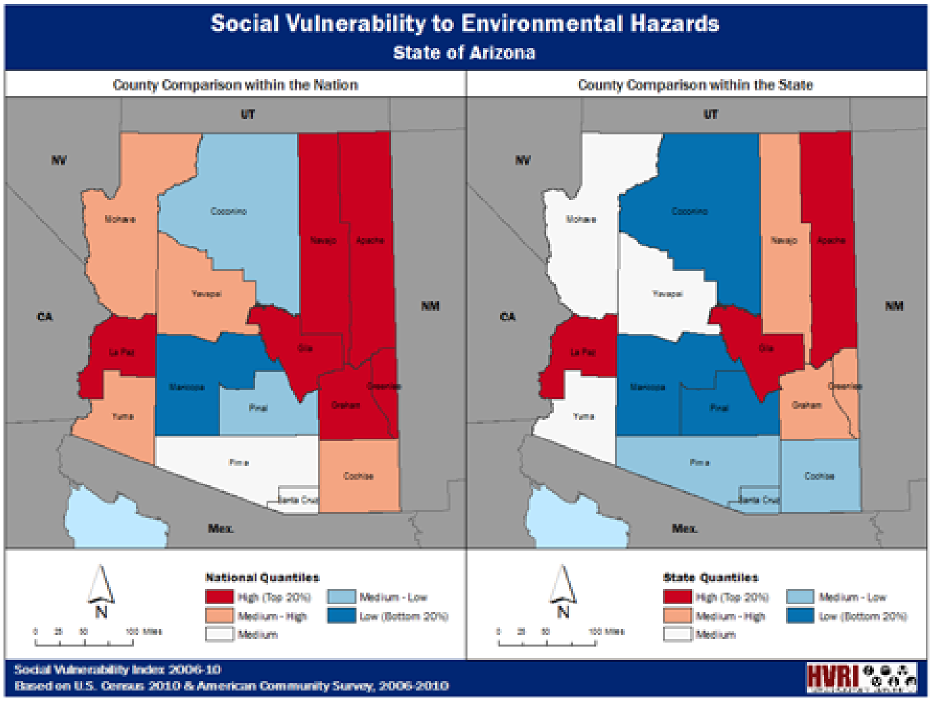


Figure 39 Social vulnerability index to environmental hazards for Arizona. Source: http://webra.cas.sc.edu/hvri/products/sovi2010_maps.aspx.

elsewhere. An additional consideration for aeroallergens is that their abundance is influenced by air pollutant concentrations, which also depend on meteorological and ecosystem factors (Arbabian et al. 2011; Beck et al. 2013). These temporal and physical shifts in aeroallergen production can affect the length and amount of exposure during sensitization. Both of these factors are likely to increase the probability of developing an allergy. Additionally, higher doses can lead to more severe allergic responses, once sensitized.

The effects of climate on mold production and dispersion are less well-studied (Beggs 2004), but observational research has noted associations between peak spore counts, mold season length, and initial timing (Corden and Millington 2001). Kinney (2008) notes that the prevalence of indoor mold is likely to increase, especially after extreme precipitation events and when combined with building construction practices. He cited widespread mold issues in the wake of Hurricane Katrina as an important example.

In a study of asthma prevalence in Phoenix, Grineski (2007) identified an independent effect of "indoor hazards" on asthma risk. In the study, parameters included the age of the housing and proportion of renters by zip code. The author found that older rental housing in Phoenix was likely to be of poor quality and to contain asthma triggers, including aeroallergens. These variables also were correlated with socioeconomic status. To the extent that a shift in climate will affect the amount of indoor aeroallergens and mold, it may result in increased asthma prevalence, especially among socially vulnerable populations.

As is the case for air pollutants, the necessary data, observational platforms, and research methodologies for determining the net impact of future climate hazards on aeroallergen-sensitive health issues are in the early stages of development today (e.g., Berger et al. 2014; Orlandi et al. 2014).

Vulnerability indicators

Population vulnerability to climate-related public health impacts is often assessed using one or more quantitative metrics or indices calculated for targeted geographic areas. These measurements capture the underlying factors affecting vulnerability. A number of studies have used these concepts to develop measures of risk for local and national populations (Reid et al. 2009; Chow et al. 2012; Harlan et al. 2012; Johnson et al. 2012; Reid et al. 2012).

In one prominent example, Cutter et al. (2003) developed a "Social Vulnerability Index" (SoVI) using data from the 1990 decennial U.S. Census for all 3,141 U.S. counties. A motivating principle of the SoVI is that socioeconomically disadvantaged populations are more vulnerable to environmental hazards than populations that are not disadvantaged. Figure 39 shows the landscape of the SoVI for Arizona, calculated using 2010 decennial census data combined with the five-year American Community Survey estimates (2006-2010).

This section of the report identifies Arizona populations that are vulnerable to extreme heat events and air pollution. Methods are drawn from Cutter et al. (2003), based on the SoVI and supplemented with the ASTHO Climate Change Population Vulnerability Screen Tool (CDPH 2013). The California Department of Public Health's Environmental Health Tracking Program (CEHTP) developed the latter tool for assessing climate vulnerability in California. Whereas the SoVI emphasizes sensitivity and adaptive capacity variables drawn from the U.S. Census, the CEHTP method incorporates additional variables that address exposure. Combining both indicators in our analysis leads to a fuller consideration of population vulnerability than would be possible with each indicator alone.

When interpreting the vulnerability assessments, it is important to note that these methods provide no information about geographical variability in hazard frequency and/or severity. In other words, a place may have a high vulnerability score based on population demographics, even if heat waves or poor air quality episodes only occur there infrequently.

Vulnerable populations and places to extreme heat

Human vulnerability to heat involves more than physical exposure to extreme heat events. It also involves individual and population sensitivity to EHEs and adaptive capacity (Turner et al. 2003; Wisner 2004; Polsky et al. 2007). Sensitivity depends on the underlying characteristics of a population, such as age and ethnicity. Adaptive capacity reflects the capability of a system, population, or individual to cope with changes. Physical exposure, sensitivity, and adaptive capacity are the three pivots of vulnerability assessment (Chow et al. 2012).

Researchers have identified the characteristics that make populations vulnerable to heat and the locations most in need of high temperature mitigation (i.e., the places where vulnerable populations congregate). Census demographics, hospital admission records, and death certificate databases typically are used to develop metrics of heat-related death and illness during EHEs, although other designs are possible (Basu and Samet 2002). Reviews of this work show that low-income individuals, African Americans, Latino Americans, Hispanic Americans, Native Americans, people with weak social ties, infants, the elderly, and those without access to air conditioning, are among the sub-groups that usually suffer the effects of heat stress at rates that exceed those found in the general population (McGeehin and Mirabelli 2001; Basu and Samet 2002).

Chicago's 1995 heat wave has been studied extensively from a social vulnerability perspective (Semenza et al. 1996; Klinenberg 2002; Browning et al. 2006). About 700 Chicagoans died over an extended multi-day period of sustained high temperatures (Whitman et al. 1997). Klinenberg (2002) found the highest incidence of heat-related deaths in census tracts that housed the poor, African Americans, and elderly people living alone. Interestingly, places with disproportionately poor Latinos had a much lower death rate than areas in which African Americans with similar incomes lived. Klinenberg (2002) concluded that ethnically based social support systems played a role in these disparate death patterns.

Harlan et al. (2006) found similar environmental inequalities in eight Phoenix neighborhoods with different socio-economic characteristics. The research team developed a measure of heat stress based on the energy balance of a person exposed to the surrounding microclimate, or an outdoor "human thermal comfort index." They found that

high heat exposure significantly impacted areas with high population densities and heavily Latino populations, but did not impact neighborhoods in which people had higher incomes and irrigated yards quite as significantly. Neighborhoods with higher heat exposure offered fewer adaptation mechanisms (e.g., swimming pools, lower-albedo roofs), as well as weaker networks of social support. The frequency of communication among neighbors, as reported by residents in a household survey, was used to evaluate network strength.

They also found that in the poorest neighborhoods, where most residents spoke only Spanish and were newcomers, residents suffered more heat stress than in whiter, more affluent neighborhoods due to increased occupational and urban heat exposure. High physical exposure to heat from outdoor occupations (e.g., landscaping, construction.) was coincident with high social vulnerability. Exposure to more intense UHI effects is consistent with the findings of Chow et al. (2012), which showed that African Americans, Latino Americans, Hispanic Americans, Native Americans in Phoenix lived in areas more susceptible to UHI than more affluent, typically white residents do. Similar results have been found in other U.S. cities, as well as internationally (McMichael et al. 2008; Hondula et al. 2012).

Chow et al. (2012) compared human vulnerability to heat in metropolitan Phoenix in 1990 and 2000. They derived their heat index from seven equally weighted measures—climate data from local weather stations, vegetation indices from remote-sensing data (both representing physical exposure), and five social variables from the census data (representing adaptive capacity). They found that the landscape of heat vulnerability changed substantially between 1990 and 2000. Specifically, Latinos became increasingly vulnerable to heat stress while the number of vulnerable whites decreased because of both demographic shifts and intensified UHI effects in traditionally minority neighborhoods.

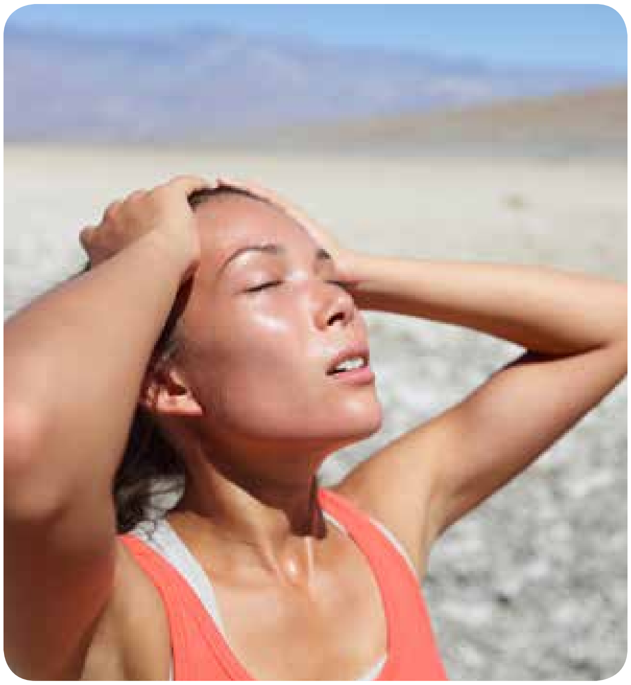
Finally, Reid et al. (2009) used known vulnerability factors and environmental variables to estimate heat impacts for all metropolitan statistical areas in the United States. They generated a cumulative heat vulnerability index using demographic characteristics and household air conditioning variables from the U.S. Census Bureau, vegetation cover from satellite images, and diabetes-prevalence data from a national survey. These factors commonly are identified as risk factors for adverse health impacts in epidemiological studies. Their heat vulnerability maps identified metropolitan areas of increased vulnerability.

Table 3 Measures of heat vulnerability

Indicator	Description
Social and demographic vulnerability	
Percentage of people without high school diploma	Education level affects individual's ability to understand warning information or acquire resources. It is also relevant to income level (Cutter et al. 2003; Harlan et al. 2006; Reid et al. 2009).
Median household income	Income determines the adaptive capacity to absorb losses or shock of impact (Cutter et al. 2003; Harlan et al. 2006; Reid et al. 2009).
Unemployment rate	Economic constraints that limit one's adaptive capacity to cope with an impact.
Percentage living alone	Social isolation limits one's ability to seek help or resources to cope with heat (Klinenberg 2002; Cutter et al. 2003; Harlan et al. 2006; Chow et al. 2012; Reid et al. 2012).
Percentage > 65 years old	Elderly populations are a high-risk group, due to their physical, economic, mobility, and social constraints (Cutter et al. 2003; EPA 2006b; Reid et al. 2009; Chow et al. 2012).
Percentage > 65 years old and living alone	A population that has combined vulnerability factors described above (Harlan et al. 2006; Chow et al. 2012; Reid et al. 2012).
Percentage African Americans, Latino Americans, Hispanic Americans, Native Americans	Historical land use patterns and discrimination may limit access to resources or receipt of preventive/warning information (Cutter et al. 2003; Harlan et al. 2006; Reid et al. 2009).
Percentage with limited English proficiency[a]	Language barriers may limit access to resources or preventive/warning information.
Percentage of people below poverty line	Poverty is associated with low adaptation capacity and increased vulnerability (Cutter et al. 2003; Harlan et al. 2006; Reid et al. 2009).
Percentage of renters	Indicator of reduced socioeconomic status and weak neighborhood ties (Chow et al. 2012).
Percentage of vacant housing units	Indicator of reduced socioeconomic status and weak neighborhood ties (Chow et al. 2012).
Percentage of mobile homes	Mobile home occupants are likely to experience more severe impacts during an EHE due to reduced ability to adjust thermal comfort (Cutter et al. 2003).
Percentage of zero vehicle households	Households with access to vehicles have enhanced mobility and access to resources to cope with/recover from an impact.
Occupational vulnerability	
Percentage of employment in extractive industries (mining, forestry, agriculture, etc.)	Excessive exposure to heat due to working outdoors.
Percentage of employment in the construction industry	Excessive exposure to heat due to working outdoors.
Percentage of employment in transportation, warehousing, and utilities	Excessive exposure to heat due to working outdoors.
Environmental vulnerability	
Percentage of vegetation cover[b]	Increased cover can mitigate heat stress (Harlan et al. 2006; Jenerette et al. 2007; Reid et al. 2009).

[a] Percentage of people in a census tract that speak English less than "very well."

[b] Source: National land cover database, 2011. Note: Sources for all data were the American Community Survey, 2008-2012 5-year estimates unless otherwise noted.



Based on the results of the literature review and data availability, the project team selected 17 indicator variables to identify populations vulnerable to heat stress in Arizona (Table 3).

Our vulnerability assessment followed a similar procedure developed for the SoVI and the ASTHO screening tools (Cutter et al. 2003). Some authors have cautioned that vulnerability indices should be designed with local context in mind, in order to maximize their utility (Reid et al. 2012; Chuang 2013). To this end, the team consulted several local empirical studies, modifying the indicators to make the vulnerability index more specific to Arizona. The final set of heat vulnerability indicators for Arizona is, therefore, different from those included in the SoVI or ASTHO screening tools.

The team developed three categories of variables for environmental exposure and social vulnerability in Arizona:

1. *Social and demographic vulnerability:* This category includes measures of sensitivity and adaptive capacity. Variables in this category are highly associated with the socioeconomic status, ethnic, and biophysical characteristics of a population. Housing and neighborhood characteristics including percentage of renters, vacancy rates, and mobile homes also belong to this category.
2. *Occupational vulnerability:* A measure of population sensitivity, this category refers to outdoor workers, such as farmers and construction labors, who are more likely to suffer from heat injuries and heat-related death due to the prolonged exposure in their occupational environment.
3. *Environmental vulnerability:* A measure of location sensitivity, this category refers to the ways in which vegetation cover mitigates heat stress. Thus, areas with minimal or no vegetation will be more susceptible to and significantly impacted by extreme heat.

Health risk assessment for extreme heat

The analysis of vulnerable populations and places above is separate from the question of expected severity and incidence of EHEs on Arizonans. According to the CDC, extreme heat is responsible for most weather-related deaths in the United States. Arizona has the largest number of heat-related deaths in the nation (Brown et al. 2013). Extreme heat-related deaths and illnesses are so prevalent in Arizona because of the consistent and increasing number of days with both high minimum and maximum temperatures (see prior discussion of the conceptual pathways linking climate, extreme heat, and human health). Long-term projections indicate that rising temperatures and a growing older adult population will increase the burden of heat-related death and illness in the state.

Understanding which populations historically have been affected by extreme heat in Arizona is useful for projecting the potential future health burden of heat illness, and helpful for identifying where to target public health resources effectively.

Between 2000 and 2012, 1,535 people died from exposure to excessive natural heat in Arizona (shown by year in Figure 40) (ADHS, 2012). Data

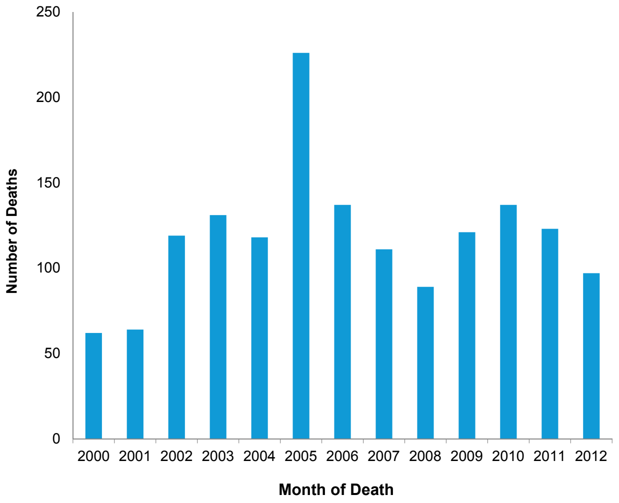


Figure 40 Deaths from exposure to excessive natural heat in Arizona by year, 2000-2012. Source: Arizona Department of Health Services (2012)

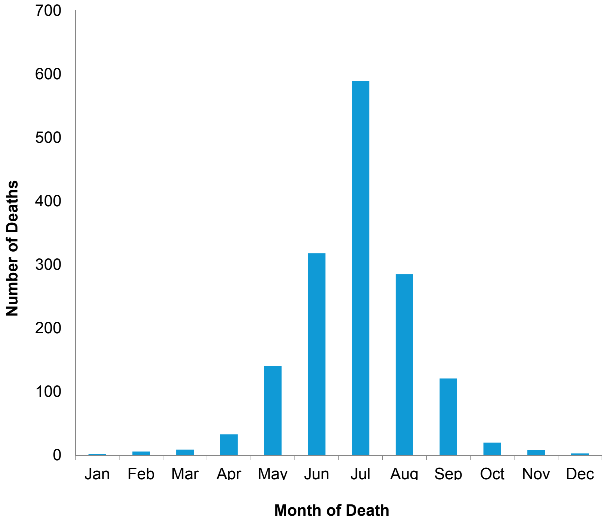


Figure 41 Deaths from exposure to excessive natural heat in Arizona by month, 2000-2012. Source: Arizona Department of Health Services (2012)

from the ADHS Trends in *Morbidity and Mortality from Exposure to Excessive Natural Heat in Arizona, 2012 Report* indicate that the majority of those heat-related deaths occurred in Maricopa, Pima, and Yuma counties (ADHS 2012). Approximately seven out of every ten of those deaths were males and 58.5% were Hispanic or Latino individuals. Migrants from Mexico, Central America, or South America accounted for approximately half of all deaths (specifically, 736 deaths, or 47%). There were 589 deaths from exposure to excessive natural heat among Arizona residents and 82 deaths of visitors to Arizona from elsewhere in the United States or from Canada. Not surprisingly, most deaths from excessive natural heat occur during the late spring and summer, with the highest number of deaths occurring in July (Figure 41). The median age of those who suffered a heat-related death among Arizona residents was 57 years. In contrast, the median age of those who suffered a heat-related death among people from Mexico, Central America, or South America was 29.

Between 2008 and 2012, Arizona saw a rise in the number of hospital emergency room (ER) visits and inpatient admissions for a heat-related illness (Table 4). The majority of cases occurred in Maricopa, Mohave, Pima, and Yuma Counties. Similar to heat-related deaths, the majority of heat-related illness cases occurred from May through September. Arizona residents accounted for the majority of heat-related illness inpatient admissions and emergency department visits. Young adults, 20-44 years of age, made the majority of ER visits prompted by heat-related illness. In contrast, the majority of heat-related illness inpatient admissions were middle-aged adults 45-64 years of age and elderly over 65 years of age.

Table 4 Heat-related illness in Arizona, 2008-2012

Year	Inpatient admissions	Emergency room visits
2008	374	1643
2009	476	1720
2010	524	1907
2011	585	2368
2012	548	2415

Source: Arizona Department of Health Services (2012).

Vulnerable populations and places to air pollution

The project team reviewed work that studied the impacts of air pollution on human health and selected seven indicators representing the characteristics of populations vulnerable to these hazards. The indicators can be divided into three types: 1) Social and demographic vulnerability, 2) Occupational vulnerability, and 3) Environmental vulnerability measured by the proximity to highway or arterial transportation system. Detailed descriptions of each indicator are listed in Table 5.

Health risk assessment for air pollution

According to the Arizona Behavioral Risk Factor Surveillance Survey, in 2011 approximately 14.1% of adults in Arizona had been diagnosed with asthma at some point during their lives. Among adults with asthma in Arizona, 56.7% reported they had suffered an asthma attack in the previous year. Additionally, 13% of children were diagnosed with asthma.

As described previously, ozone standards have historically been difficult to meet in parts of the state. Short-term ozone exposure can reduce lung function and increase respiratory symptoms. Although there is some uncertainty regarding future ozone levels, depending on advances in air quality regulations and climatic regimes, in higher warming scenarios, ozone concentrations are likely to increase across much of the United States, along with attendant health effects (Kim et al. 2015).

Pollen seasons also may worsen in the future, as long-term (>15 years from now) projected temperature increases are expected to create a longer and earlier spring period. These increased temperatures will lead to increased pollen production among numerous plant species and may cause more frequent allergic responses for those who are sensitive to pollen.

Table 5 Measures of vulnerability to air pollution

Indicator	Description
Social and demographic vulnerability	
Percentage < 12 years old	Children are at a higher risk of developing allergies and asthma (Dimitrova et al. 2011).
Percentage > 65 years old	Elderly are less able to compensate for the effect of poor air quality, which exacerbates lung disease, asthma, etc.
Percentage of people below poverty line	This group of people may lack resources and access to medical care.
Percentage of people without high school diploma	Low education level is associated with low income. This population may be less able to take preventive actions.
Occupational vulnerability	
Percentage of employment in the construction industry	Excessive exposure to poor air quality due to working outdoors and likely uncontrolled dust emissions.
Percentage of employment in transportation, warehousing, and utilities	Excessive exposure to poor air quality due to working outdoors.
Environmental vulnerability	
Percentage of the population near heavily traveled roadways[a]	Exposure to traffic pollution (Boehmer et al. 2013; Sarnat et al. 2014).

Note: Sources for all data were the American Community Survey, 2008-2012 5-year estimates unless otherwise noted.
[a] Numbers calculated using a 150-meter buffer around major and minor arterial transportation systems (including highway). Spatial data representing the 2011 transportation system were acquired from the Arizona Department of Transportation.

COLLABORATIONS

Successfully completing subsequent steps in the BRACE framework will require incorporating additional collaborators. Future partnerships will build on existing relationships established by ADHS and ASU. In addition to the agencies and organizations already engaged, the Arizona Division of Emergency Management, Arizona Department of Environmental Quality, and Arizona Division of Occupational Safety and Health will be invited to participate in BRACE workgroups. Table 6 lists potential future partners, the workgroup to which they should be invited, their expertise, and ideas for effective engagement.

Stakeholder engagement is critical throughout all steps of the BRACE framework. Partnerships with agencies and organizations that have access to local climate data and projections, as well as those that can review and summarize literature on related health impacts, have helped to inform Step 1.

Table 6 Key partnerships and collaborations for implementing CDC's BRACE framework in Arizona.

	Current/ Proposed	**Workgroup**	**Expertise/Role**	**Engagement**
Government				
Centers for Disease Control & Prevention (CDC)	C	• Evalution	Subject matter experts, Mentors	Meetings; Participation in workgroups: Disseminate findings
ADHS programs Infectious Diseases, Emergency Preparedness, Chronic Diseases, Emergency Medical Services, Office of Environmental Health	C	• Climate & health profile • Future projections • Interventions • Climate adaptation plan	Subject matter experts	
Arizona Division of Emergency Management	P	• Climate adaptation plan	Subject matter experts	
Arizona Department of Environmental Quality	P	• Vulnerability Assessment	Collaboration, Information sharing	
Arizona Division of Occupational Safety and Health	P	• Vulnerability Assessment • Interventions • Climate adaption plan	Collaboration, Information sharing	
Local Health Departments	C	• Interventions • Climate adaption plan	Communication channels to the community	
Other CDC BRACE grantees **Minnesota Department of Health (MDH)*	C/P	• Climate & health syndromic surveillance	Collaboration, Information sharing, **Co-facilitate workgroup*	
National Weather Service	C	• Interventions	Subject matter experts	
Universities / Climate experts				
Arizona State University	C	• Climate & health profile • Vulnerability assessment • Future projections • Interventions • Climate adaption plan	Subject matter experts with previous experience in climate & health projections; 80+ faculty working in climate & health	Meetings; Participation in workgroups: Disseminate findings
University of Arizona	C	• Climate & health profile • Vulnerability assessment • Future projections	Subject matter experts in assessing climate variability and making projections of impacts on health in SW	

Table 6 continued Key partnerships and collaborations for implementing CDC's BRACE framework in Arizona.

International				
Health Canada	C	• Climate & health syndromic surveillance	Experience in syndromic surveillance and heat-related illness interventions, as well as information-sharing	Meetings; Participation in workgroups: Disseminate findings
Non-governmental organizations				
Association of State & Territorial Health Officials (ASTHO)	C	• Future projections	Subject matter experts	Meetings; Participation in workgroups: Disseminate findings
Council of State & Territorial Epidemiologists (CSTE)	C	• Future projections	Subject matter experts	
Various non-profits (Salvation Army, Red Cross)	C	• Future projections	Communication channels to the community	

Engaging organizations that can employ qualitative and quantitative approaches to assess the data can help to inform Step 2.

Collaborators will be essential in identifying the range of health interventions available for each health outcome, assessing the capacity to deliver each intervention, and prioritizing health interventions deemed most suitable for Arizona (Step 3).

Collaborators will also be essential in dissemination of the Arizona Strategic Climate and Health Adaptation Plan, because those agencies and organizations may play a part in implementing the interventions (Step 4).

Additionally, stakeholder engagement will be crucial for evaluating effective implementation of interventions, assessing whether climate and health is considered in broader public health planning, and establishing whether actions taken have mitigated health issues (Step 5).

CONCLUSIONS

This report focuses on Step 1 of the BRACE framework for Arizona with a focus on two environmental conditions likely to shift under future climate projections: extreme heat and air pollution. It provides detailed information on the baseline climatic conditions in Arizona, with an analysis of temperature, precipitation, and extreme heat patterns dating back to the early 20th Century. Using the results of downscaled climate models, the interdisciplinary team has shown that statewide temperatures are likely to be higher across all future emissions scenarios in 2030 and 2060, with the highest temperatures occurring in the west and the urbanized areas of Phoenix and Tucson.

Because of the limitations of employing results from a single model run for this initial work, the generalizability of specific spatial results is limited. Future work undertaken by the study team will combine the results from dozens of downscaled models to develop more robust, future climatic condition estimates. Another important outcome from this report is the identification of populations and places vulnerable to the hazards.

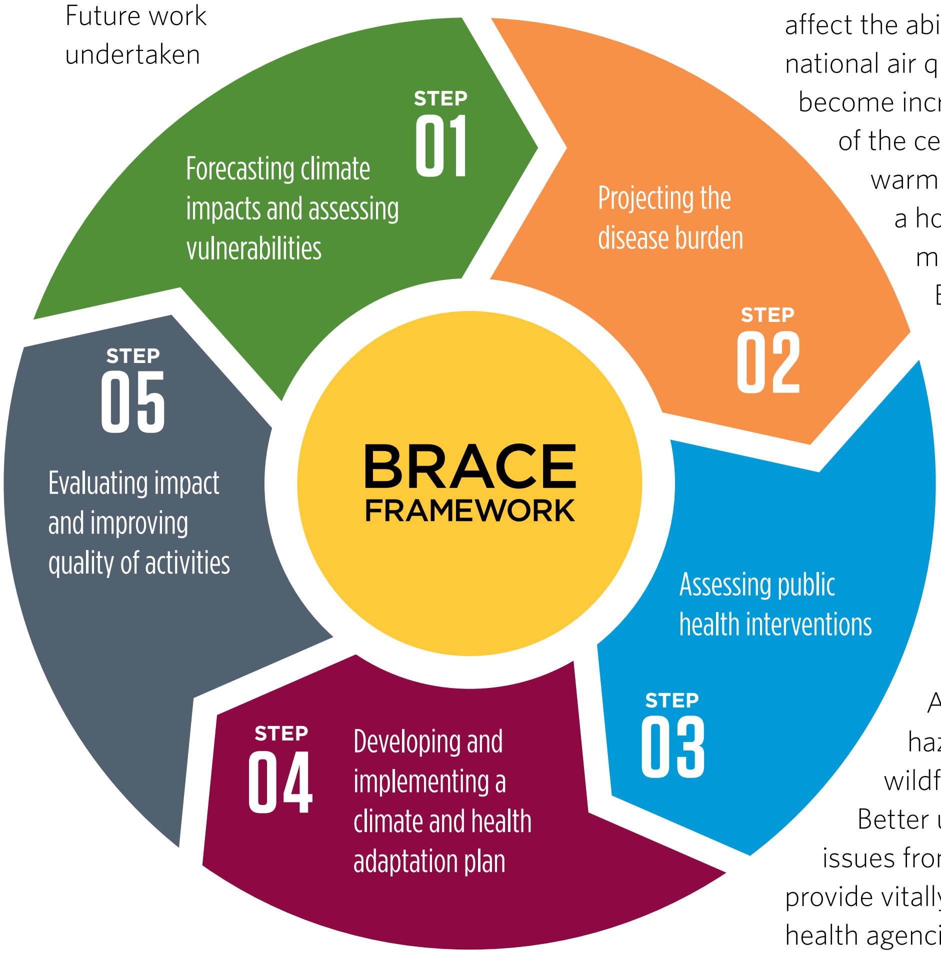


Figure 42 The five-step BRACE framework. Source: Adapted from Marinucci et al. (2014).

Notwithstanding these limitations, higher temperatures are likely to result in increases in heat-related deaths and illnesses associated with pollens, mold, and other aeroallergens. Depending on future air-quality regulations and technological developments, future concentrations of ozone and PM_{10} may exceed concentrations experienced today, leading to increased air pollution-related deaths and illnesses.

The effects of a climatic shift on air quality are less certain than the effects on heat and aeroallergens. However, even small changes in air quality can affect the ability of certain areas of the state to meet national air quality standards, since they are likely to become increasingly stringent over time. Because of the certainty of some amount of future warming, ADHS already has implemented a host of programs and undertaken early mitigating work. Implementing the BRACE framework is only the latest step.

Ongoing BRACE work undertaken by the project team will include in-depth mapping and ranking of vulnerability, as well as estimation of the expected disease burdens from projected climate conditions and inclusion of much more robust estimates of Arizona's future climate. Additional climate-sensitive health hazards also will be considered, including wildfires, drought, and infectious diseases. Better understanding of the expected health issues from projected climate hazards will provide vitally important information to local public health agencies and officials, allowing them to effectively target mitigating efforts where they are most needed and where they are likely to have the greatest effect.

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APPENDIX A: MAPPING LAND COVER AND HEAT VULNERABILITY

Land cover influences microclimatic conditions. For example, impervious surfaces such as concrete can exacerbate heat stress by retaining more heat than natural vegetation. During the day, impervious surfaces absorb heat from solar radiation that is subsequently reradiated overnight. This results in higher temperatures in urban cores than in surrounding rural areas–a phenomenon known as the urban heat island (UHI) effect.

To better understand the effects of the UHI on vulnerable populations, the project team compared our heat vulnerability map to land cover data (30 meter per pixel resolution) from the National Land Cover Database (NLCD). The team identified neighborhood vulnerability to heat using a color ramp (Figure A.1), and then superimposed the vulnerability map onto the land cover data.

Figure A.2 shows the bivariate representation of the heat vulnerability index and land cover in the Phoenix metropolitan area. Figure A.3 shows the same results for Arizona. The team found that central Phoenix, southern Glendale, northern Tempe, and western Mesa are the areas with both high vulnerability and a high density of impervious surfaces.

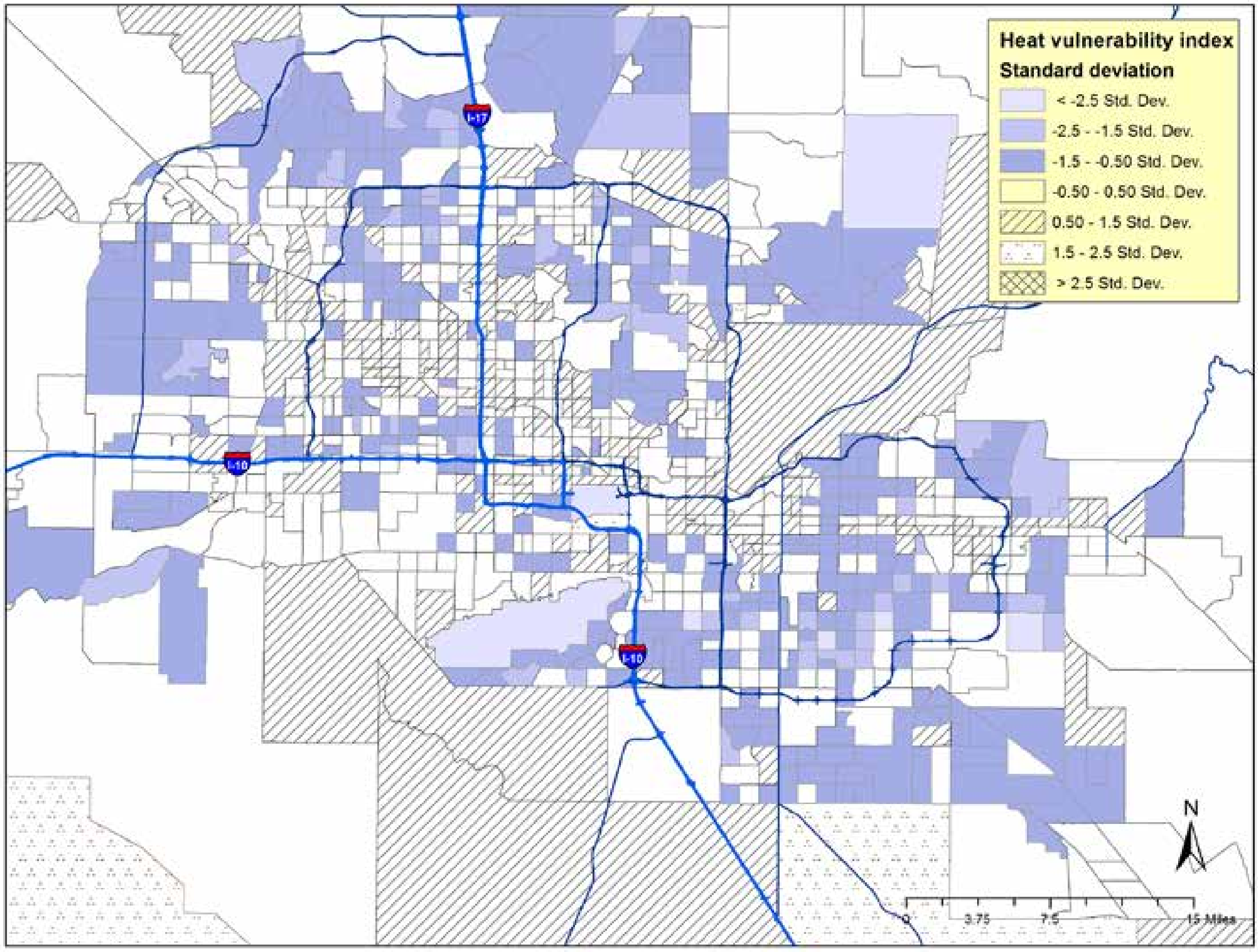


Figure A.1 Spatial distribution of the heat vulnerability index (sorted by standard deviation) in the Phoenix metropolitan area.

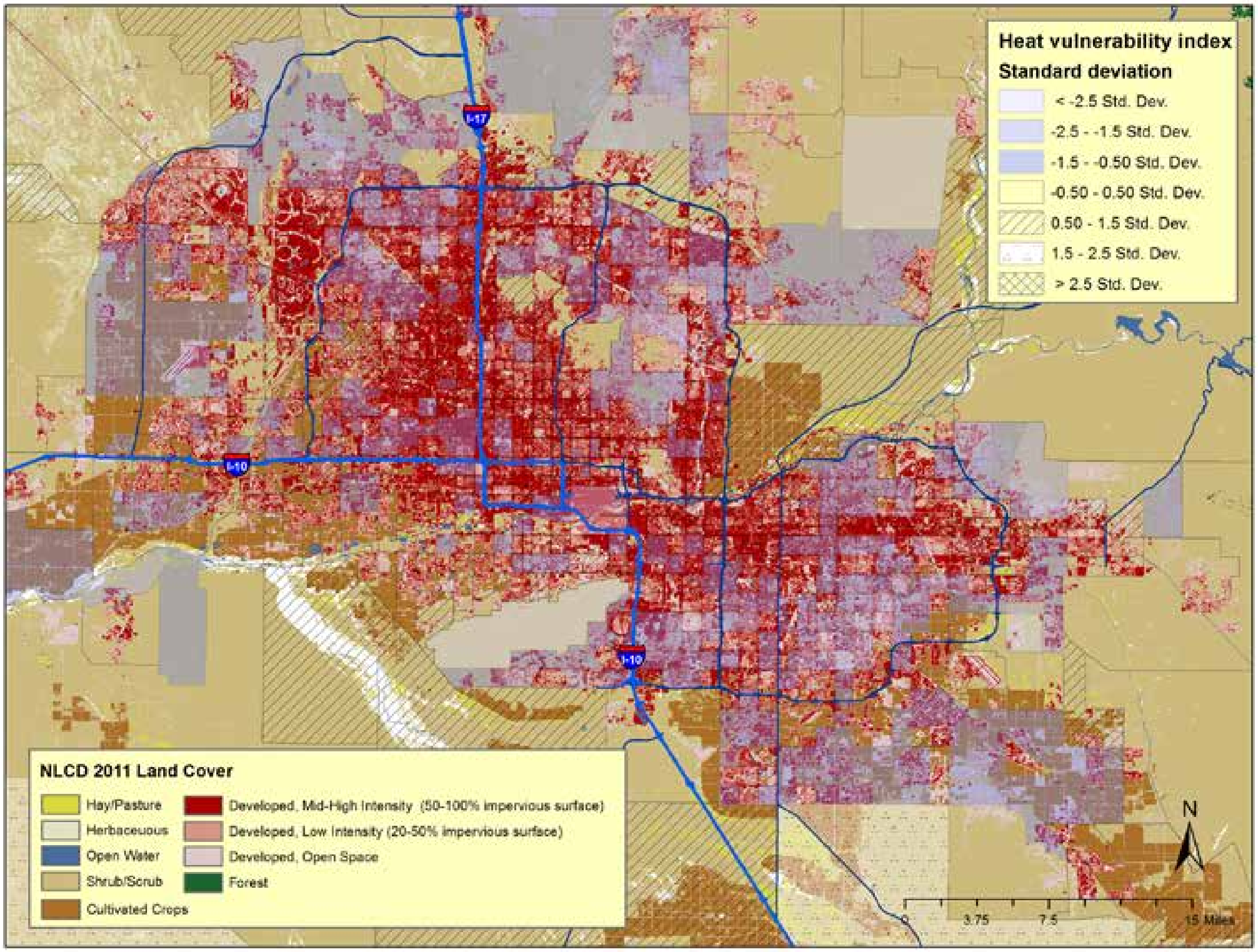


Figure A.2 Heat vulnerability overlaid on the NLCD 2011 land cover map for the Phoenix metropolitan area.

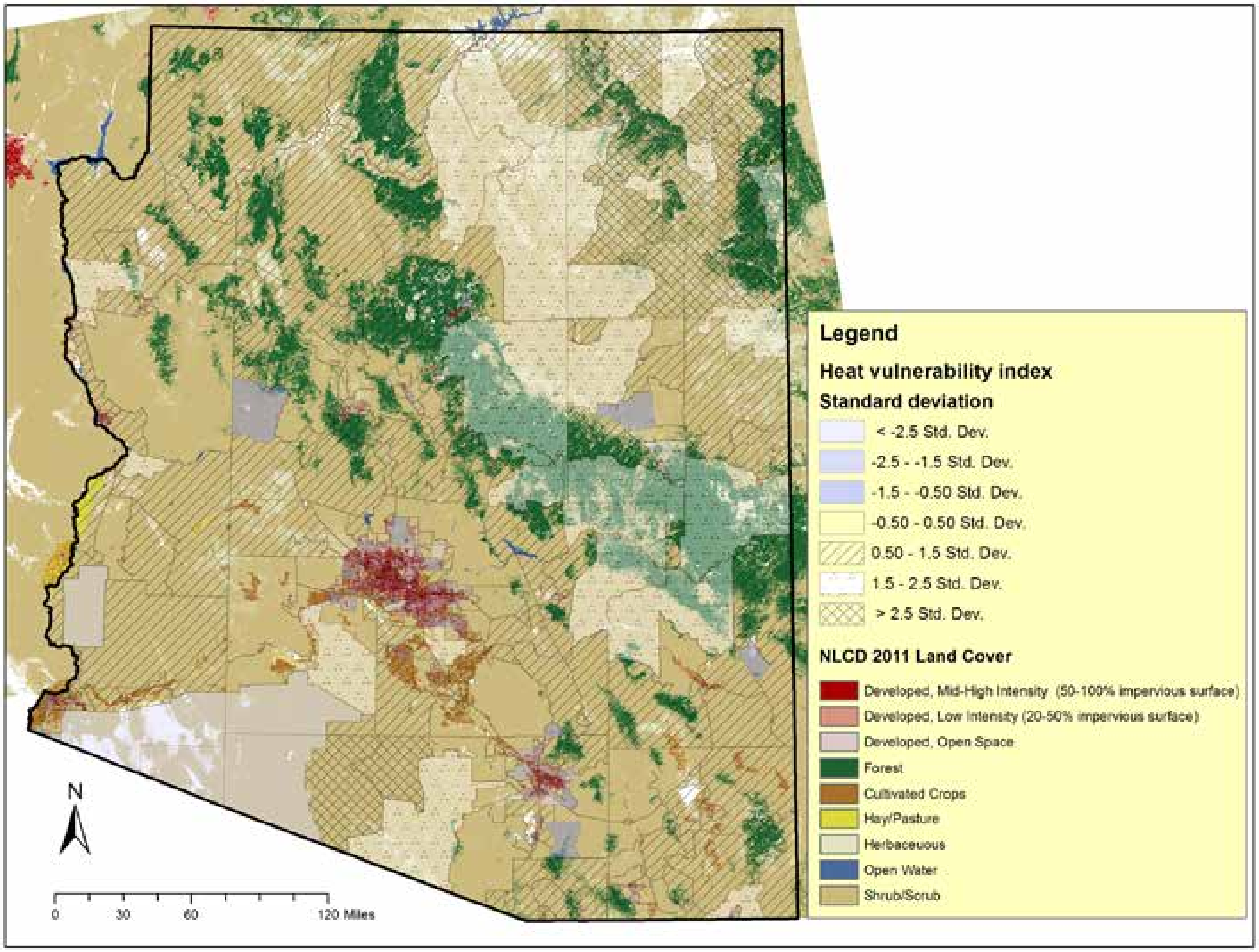
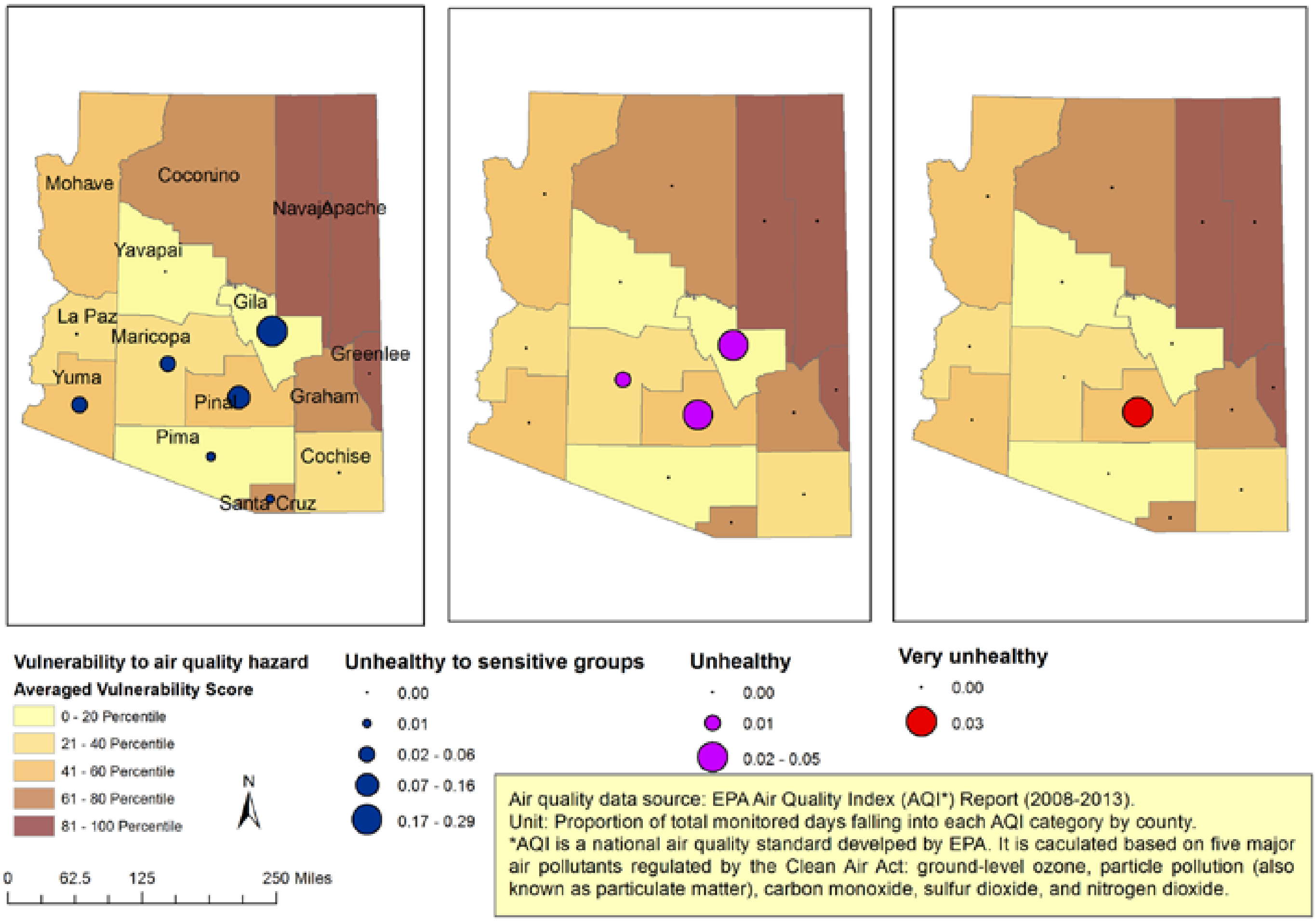


Figure A.3 Heat vulnerability overlaid on the NLCD 2011 land cover map for Arizona.

APPENDIX B: MAPPING AIR QUALITY INDEX AND VULNERABILITY TO AIR POLLUTION

Using the U.S. EPA's Air Quality Index (AQI) data from2008 through 2013, the research team then superimposed the proportion of total monitored days at the county level for the following categories: number of days unhealthy to sensitive groups, unhealthy, and very unhealthy (Figure B.1). Pinal County has mid-high vulnerability and experiences relatively higher air pollution than other counties. Although Gila County had relatively high levels of pollution, its vulnerability score falls into the lowest category on the vulnerability scale.



Air quality data source: EPA Air Quality Index (AQI*) Report (2008-2013).
Unit: Proportion of total monitored days falling into each AQI category by county.
*AQI is a national air quality standard develped by EPA. It is caculated based on five major air pollutants regulated by the Clean Air Act: ground-level ozone, particle pollution (also known as particulate matter), carbon monoxide, sulfur dioxide, and nitrogen dioxide.

Figure B.1 Proportion of total monitored days falling into each air-quality index category by county, 2008-2013. Source: U.S. EPA Air Quality Index Report (http://www.epa.gov/airquality/airdata/ad_rep_aqi.html).