POTENTIAL CHANGES IN FUTURE REGIONAL CLIMATE AND RELATED IMPACTS:

A Brief Report for the Central New Mexico Climate Change Scenario Planning Project

Jeremy Weiss

Contents

Introduction

Similar to many other metropolitan areas in the western United States, Albuquerque and surrounding cities in central New Mexico comprise a rapidly growing region in an arid environment. Planning for such an area in the 21st century requires addressing a mixture of challenges from congestion, sprawl, energy use, vehicle emissions, water supply, and potential changes in future regional climate along with related impacts.

Led by the U.S. Department of Transportation's John A. Volpe National Transportation Systems Center and with funding from the Federal Highway Administration (FHWA), Fish and Wildlife Service (FWS), National Park Service (NPS), and Bureau of Land Management (BLM), a group of federal agencies and the Mid-Region Council of Governments of New Mexico (MRCOG)[1], is embarking on a project – the Central New Mexico Climate Change Scenario Planning Project – to help the region address these intertwined challenges. Through the process of scenario planning, which evaluates the costs and benefits of different types of, and strategies for, growth, development, and investments, this project aims to influence regional transportation and land-use decision making, and analyze strategies to reduce carbon emissions and prepare for impacts related to potential changes in future climate.

To support these efforts, this brief report summarizes current research on selected potential changes in future regional climate and related impacts. The following information regarding future climate change is based largely on recent synthesis reports at regional, national, and international levels, including those by the U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, and Sandia National Laboratories (Llewellyn and Vaddey 2013)[2], the Southwest Climate Alliance (Garfin et al. 2013)[3], and the Intergovernmental Panel on Climate Change (IPCC 2012)[4].

The first part of this brief report addresses the potential future changes in the atmospheric variables of temperature and precipitation. This is followed by similar information about phenomena that influence these variables such as the North American monsoon. The final part considers impacts on the natural physical environment like droughts and floods related to the previously discussed changes in climate. Attention is not only given to the magnitude and direction of such changes, but also to the level of confidence that experts have in such changes, an important aspect of interpreting climate projections.

1 The Mid-Region Council of Governments of New Mexico (MRCOG; mrcog-nm.gov) provides planning services in the areas of transportation, agriculture, workforce development, employment, land-use, water availability, economic development for Bernalillo, Valencia, Torrance, and Sandoval counties. MRCOG is the federally-designated Metropolitan Planning Organization for transportation investments in the region.

2 usbr.gov/WaterSMART/wcra/reports/urgia.html

3 swcarr.arizona.edu

4 ipcc-wg2.gov/SREX

Weather and Climate Variables

The Southwestern U.S.[5] has one of the most variable climates[6] in the nation. The region's seasonal cycles, natural climatic variability, and extreme weather[7] create conditions unlike those in any other part of the country. Add to that a complex terrain of mountains, valleys, plains, and plateaus that range in elevation from below sea level to above treeline, and a highly variable environment spanning from warm, subtropical deserts to cool, moist forests is the result. Human-caused changes to climate have been and will be superimposed on the highly seasonal and variable natural climate of the region.

Temperature

Temperature in the Southwest follows the typical seasonal cycle from a winter minimum to a summer maximum (Sheppard et al. 2002). In winter, minimum temperatures typically are below freezing in the region except for coastal areas and the lower interior deserts of southern California and southern Arizona. During summer, maximum temperatures in the lower interior deserts of California, Arizona, and New Mexico regularly top 100°F. On any given day during the year, temperatures typically are about 20°F to 30°F cooler at higher elevations relative to those at lower elevations.

Average temperatures across the Southwest since the 1990s have been over 1°F higher for the region than the 1901-1960 average (Walsh and Wuebbles 2013)[8], and it is expected that warming will continue in coming decades (Table 1; Box 1). Considering a suite of climate models, annual mean temperature across the region could increase relative to the 1971-1999 historical reference period by 1.3°F to 3.8°F during the 2021-2050 time period, 1.8°F to 6.0°F during 2041-2070, and 2.7°F to 10.1°F during 2070-2099 (Kunkel et al. 2013). Projected increases in mean seasonal temperatures are greatest during summer and least during winter (Table 2). The central feature of these projections is that all future time periods indicate further regional warming (Box 2).

5 the six-state region of California, Nevada, Utah, Arizona, Colorado, and New Mexico

6 the average weather conditions at a location over a long period of time

7 the state of atmospheric variables such moisture, pressure, temperature, and wind at a location for a point in time

8 Additional summaries of regional, state-level, and wilderness area temperature trends are in Appendix B, Literature Review of Observed and Projected Climate Changes, of the West-Wide Climate Risk Assessment: Upper Rio Grande Impact Assessment (Llewellyn and Vaddey 2013).

Box 1 - Climate Projection Uncertainties

Uncertainties in projections of future climate stem from three main sources: 1) Despite a large and rapidly growing knowledge of the climate system, scientific understanding of it remains incomplete; 2) There are a number of different global climate models, each with varying strengths and weaknesses, used to project future climate; and 3) Future greenhouse gas (GHG) emissions may evolve over the 21st century in a wide range of ways. Importantly, the different hypothetical emissions trajectories used for projecting future climate do not diverge substantially over the next two to three decades (Seneviratne et al. 2012).

Human GHG Emissions Scenario[9]	Years	Low	25%ile	Median	75th %ile	High
A2 (relatively high)	2021 - 2050	+1.7	+2.1	+3.1	+3.5	+3.8
	2041 - 2070	+2.8	+4.0	+5.0	+5.4	+6.0
	2070 - 2099	+4.7	+7.3	+8.3	+8.8	+10.1
B1 (relatively low)	2021-2050	+1.3	+2.1	+2.5	+3.0	+3.5
	2041 - 2070	+1.8	+2.9	+3.6	+4.0	+4.8
	2070 - 2099	+2.7	+3.8	+4.5	+5.6	+6.3

Table 1. Projected changes in annual mean temperature (°F) for the Southwest during different time periods in the 21st century, as compared to the 1971-1999 historical reference (Kunkel et al. 2013). Values are spatial averages of the entire region, and based on the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project – Phase 3 (CMIP3) global projections (Meehl et al. 2007). Kunkel et al. (2013) also present projected changes in temperature for the 2041-2070 time period based on a smaller number of regional climate models used in the North American Regional Climate Change Assessment Program (NARCCAP) under the A2 scenario. NARCCAP temperature projections fall within the range of values under the A2 scenario as listed in this table.

Projections of average temperature used in the Upper Rio Grande Impact Assessment[10] suggest 4°F to 6°F of warming by the end of the 21st century (Llewellyn and Vaddey 2013). These values fall within the range of projected values for the 2070-2099 time period for the Southwest listed in Table 1, regardless of emissions scenario.[11]

9 A2 and B1 are part of a suite of scenarios that represent a range of possible future human impacts on climate through social, economic, technological, and demographic dynamics, developed by the Intergovernmental Panel on Climate Change (IPCC 2000). Modeling efforts of future global climate utilize the projected CO2 concentrations from these scenarios to simulate their effects. The A2 scenario projects relatively high human emissions of CO2, whereas the B1 scenario projects relatively low human emissions. Importantly, scenarios are not forecasts, and do not have probabilities associated with their occurrences.

10 This report incorporated statistically downscaled projections of temperature and precipitation derived from 16 models in the CMIP3 database, under the A2, A1B, or relatively moderate, and B1 emissions scenarios.

11 Additional summaries of temperature projection studies for the Upper Rio Grande region can be found in Appendix B, Literature Review of Observed and Projected Climate Changes, of the West-Wide Climate Risk Assessment: Upper Rio Grande Impact Assessment (Llewellyn and Vaddey 2013).

Human GHG Emissions Scenario	Years	Summer	Winter
A2 (relatively high)	2021 - 2050	+3.5	+2.5
	2041 - 2070	+5.6	+3.9
	2070 - 2099	+8.9	+6.8

Table 2. Projected changes in summer (June-July-August) and winter (December-January-February) mean temperature (°F) for the Southwest during different time periods in the 21st century, as compared to the 1971-1999 historical reference (Kunkel et al. 2013). The winter value for 2041-2070 is estimated from Figure 17. Values are spatial averages of the entire region, and based on the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project – Phase 3 (CMIP3) global projections (Meehl et al. 2007).

As reported in the Southwest Climate Change Assessment Report (SWCCAR), there is 'high' confidence[12] that surface temperatures across the region will be more than 3°F warmer than 20th century averages by the end of this century, with 'medium-high' confidence that warming amounts will be higher in summer and fall than in winter and spring (Cayan et al. 2013). Importantly, there also is 'high' confidence that prominent year-to-year and decade-to-decade variations historically observed in the Southwest will continue to occur in the 21st century. It is expected that this regional natural variability in climate will be larger than variations and changes in weather and climate due to increasing GHG concentrations over the next 30 years (Seneviratne et al. 2012).

Box 2 - Warmer Temperatures and Air Pollution

Atmospheric chemical reactions accelerate with warmer temperatures, and could lead to higher concentrations of ozone and fine particles, or PM2.5 (Brown et al. 2013). The interaction between temperature and other meteorological variables such as humidity and wind also could influence pollutant concentrations.

Changes in mean climatic conditions like warmer average temperatures can lead to changes in the occurrence and magnitude of extreme events like cold spells and heat waves (Box 3). For instance, there has been a decrease in the number of four-day cold periods during recent decades and an increase in the number of four-day warm periods concurrent with recent regional warming (Hoerling et al. 2013). In contrast to expectations with 'medium-high' confidence of fewer and possibly less-intense cold spells[13], heat waves[14] during the 21st century are anticipated with 'high' confidence to become warmer, occur more frequently, and last for more consecutive days (Gershunov et al. 2013).

12 As defined in SWCCAR, confidence is "a subjective judgment of the reliability of an assertion, based on systematic evaluation of the type, amount, quality, and consistency of evidence, and the degree of agreement among experts".

13 daily maximum or minimum temperatures below the 5th percentile

14 daily maximum or minimum temperatures above the 95th percentile

Box 3 - Heat Waves and Urban Environments

The urban environment can compound impacts of weather events. For example, surfaces like asphalt can intensify temperature-related extremes like heat waves by releasing heat at night and increasing minimum temperatures (Pincetl et al. 2013). Incidences of mortality and morbidity due to high temperatures can escalate during heat waves (Brown et al. 2013).

Other measures of temperature thresholds and extremes give additional information about possible future changes in this variable (Box 4). It is expected that the annual number of days with a minimum temperature below 32°F will decrease across the region up to 45 days per year during the 2041-2070 time frame relative to the 1980-2000 reference period, with the greatest decrease occurring in high-elevation areas (Kunkel et al. 2013)[15]. Such a decline may be about 25 to 35 days in central New Mexico.

In contrast, the annual number of days with a maximum temperature greater than 95°F will increase by five to 40 during the 2041-2070 time frame relative to the 1980-2000 reference period for most areas of the Southwest (Kunkel et al. 2013). Northern, high-elevation areas appear to have the least increase, whereas southern, low-elevation areas appear to have the greatest. Such an increase appears to range approximately from 15 to 25 days for central New Mexico.

In the context of energy use, it is anticipated that cooling degree days[16] could increase by approximately 65% for the region, whereas heating degree days[17] could decline by almost 20% during the 2041-2070 time frame relative to the 1980-2000 reference period (Kunkel et al. 2013). Increases in cooling degree days are greatest for southern and eastern low-elevation areas, and decreases in heating degree days are greatest for northern high-elevation areas. For central New Mexico, increases in cooling degree days could range approximately up to 100%. Decreases in heating degree days could range approximately 10% to 20%.

15 for the relatively high A2 emissions scenario
16 amount by and duration over which daily mean temperature is above 65°F
17 amount by and duration over which daily mean temperature is below 65°F

Box 4 - Definitions of Extreme Events

Different and sometimes complex definitions are often used for extreme weather and climate events (Seneviratne et al. 2012, Gershunov et al. 2013). Such events may be considered in a strictly statistical context, as a maximum value or an exceedance of a threshold, or even in combinations with aspects of social or ecological vulnerabilities. It is also worth noting that such events may arise from a mixture of conditions that are not extreme individually and that are caused by natural variations of weather and climate (Seneviratne et al. 2012). Human-caused climate change may alter characteristics of extreme weather and climate events, such as frequency, intensity, and duration. Confidence in projections of such extreme events varies by type and season, as well as by the scientific understanding of processes that drive these events.

Natural year-to-year and decade-to-decade variations in regional climate will remain an influence on future occurrences of cold spells and heat waves, even as average temperatures across the Southwest continue to warm.

Precipitation

Precipitation in the Southwest mostly occurs at two distinct times of the year (Comrie and Glenn 1998, Sheppard et al. 2002). Broad-scale, westerly frontal systems[18] bring both rain and snow during winter and spring via widespread cloudy and stormy conditions that typically last a few days. From midsummer through early autumn, the North American monsoon[19] and, to a lesser degree, dissipating tropical cyclones[20] from the eastern Pacific Ocean deliver rain. Precipitation during the monsoon contrasts with that of winter and spring, as thunderstorms are much more local in scale and shorter in duration, lasting only hours (Sheppard et al. 2002). Prominence of either of these relatively wet seasons in the annual precipitation cycle differs geographically, with a regional gradient from a cool-season regime in the west to one strongly influenced by the monsoon in the east. Both cool- and warm-season precipitation sources affect central New Mexico.

For annual total precipitation across the Southwest since the 1990s, there is not much of a consistent, region-wide change when compared to the 1901-1960 average (Walsh and Wuebbles 2013)[21], but there are some indications that annual totals may decline in coming decades (Table 3). Annual mean precipitation across the region could change relative to the 1971-1999 historical reference period by -10% to +7% during the 2021-2050 time frame, -17% to +7% during 2041-2070,

18 a boundary between air masses of different densities moving from west to east, associated with changes in weather

19 a seasonal reversal of the prevailing winds over a region that directs moist air over land from the adjacent ocean

20 a non-frontal cyclone with deep, organized convection and a closed circulation that originates over tropical or subtropical waters

21 Additional summaries of regional, state-level, and wilderness area precipitation trends are in Appendix B, Literature Review of Observed and Projected Climate Changes, of the West-Wide Climate Risk Assessment: Upper Rio Grande Impact Assessment (Llewellyn and Vaddey 2013).

and -20% to +10% during 2070-2099 (Kunkel et al. 2013). The central feature of these projections is that there is a wide range of plausible changes that includes both decreases and increases in the amount of precipitation for the region (see also Table 4 and Box 5). Similar to values in Table 3, projections of annual average precipitation used in the Upper Rio Grande Impact Assessment are inconsistent (Llewellyn and Vaddey 2013)[22].

Human GHG Emissions Scenario	Years	Low	25%ile	Median	75th %ile	High
A2 (relatively high)	2021 - 2050	-10	-3	-2	+2	+5
	2041 - 2070	-17	-6	-3	+1	+7
	2070 - 2099	-20	-10	-3	+3	+8
B1 (relatively low)	2021-2050	-10	-3	+1	+3	+7
	2041 - 2070	-10	-3	-2	0	+3
	2070 - 2099	-10	-5	-2	+1	+10

Table 3. Projected changes in annual mean precipitation (% change) for the Southwest during different time periods in the 21st century, as compared to the 1971-1999 historical reference (Kunkel et al. 2013). Values are spatial averages of the entire region, and based on the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project – Phase 3 (CMIP3) global projections (Meehl et al. 2007). Kunkel et al. (2013) also present projected changes in temperature for the 2041-2070 time period based on a smaller number of regional climate models used in the North American Regional Climate Change Assessment Program (NARCCAP) under the A2 scenario. NARCCAP precipitation projections fall within the range of values under the A2 scenario as listed in this table, except for the '75th %ile' and 'High' values which are both -3%.

Spatial variability of changes in precipitation within the region is possible. As reported in SWCCAR, there is 'medium-low' confidence that lower annual precipitation will occur across the southern part of the Southwest, which includes central New Mexico, and little change or higher annual precipitation in the northern part (Cayan et al. 2013). This pattern of future changes in regional precipitation could manifest in winter and especially spring as rain and snow events during this part of the year are determined strongly by the jet stream[23], which is expected on a global scale to shift northwards in a warming climate (also see Table 4). However, regional projections of climate-change-induced shifts in the jet stream are inconsistent (Seneviratne et al. 2012).

22 Additional summaries of precipitation projections for the Southwest, New Mexico, and the Upper Rio Grande region can be found in Appendix B, Literature Review of Observed and Projected Climate Changes of Llewellyn and Vaddey (2013).

23 a narrow stream of strong winds in the atmosphere at high altitudes along which storms can track

Human GHG Emissions Scenario	Season	Low	25%ile	Median	75th %ile	High
A2 (relatively high)	DJF	-19	-8	+3	+8	+31
	MAM	-36	-29	-12	-10	+2
	JJA	-44	-13	-9	+3	+20
	SON	-21	-8	-1	-1	+38
B1 (relatively low)	DJF	-12	-6	+2	+5	+17
	MAM	-27	-9	-7	-1	+11
	JJA	-16	-7	0	+3	+18
	SON	-24	-4	-2	+6	+13

Table 4. As in Table 3, but for seasonal mean precipitation (% change) during the 2070-2099 time frame. Seasons are based on the three-month periods of December-January-February (DJF), March-April-May (MAM), June-July-August (JJA), and September-October-November (SON).

Box 5 - Widely Ranging Projections of Regional Precipitation

Exact reasons for the wide range of plausible changes in precipitation across the Southwest are currently unknown. However, this range may stem in part from the ability of global climate models (GCMs) to represent the numerous global, regional, and local factors that influence precipitation in the Southwest. In addition to the present challenges in simulating phenomena like El Niño-Southern Oscillation and the North American monsoon (see below), GCMs cannot resolve key regional and local processes important for precipitation such as those related to topography (Cayan et al. 2013).

Even though there may be less total annual precipitation in the future, heavy precipitation events can still occur (Box 6). Part of this is due to the fact that a warmer atmosphere can hold more water vapor, allowing the storms that do take place in the region to carry extra moisture and deliver more rain and snow. In the SWCCAR, this phenomenon carries 'medium-low' confidence in the context of its future impact in the region (Gershunov et al. 2013).

The number of consecutive days with little or no precipitation is another characteristic that can give additional information about possible future changes in rainfall and snowfall. For example, it appears that the average annual maximum number of such days with amounts less than 0.1 inches will increase for the Southwest, particularly for the driest areas of the region, up to 15 days during the 2041-2070 time period relative to the 1980-2000 reference period (Kunkel et al. 2013)[24]. For central New Mexico, changes in the average annual maximum number of such days may increase up to 10 days per year.

Box 6 - Extreme Weather and Transportation

Extreme weather and climate events may expose design and operational vulnerabilities in transportation systems (Niemeier et al. 2013). For example, extreme heat can deteriorate pavement and shorten its lifespan, buckle runways, and deform rail lines. Intense rainfall raises concern about flooding and overloaded drainage infrastructure, as well as pavement damage and washout.

As with temperature, features of historical and current Southwest climate such as natural year-to-year and decade-to-decade variations of precipitation will continue to occur in the 21st century. Importantly, natural variability appears to be greater than precipitation changes induced by human-caused climate change for much of this century and across most of the region, regardless of GHG emissions scenario (Kunkel et al. 2013). This is relevant to both annual and seasonal amounts, as well as to measures of extreme precipitation such as the number of days per year with precipitation exceeding one inch. Phenomena that influence such variations and expectations of their potential changes in future decades are discussed in the following section.

Phenomena Influencing Atmospheric Weather and Climate Variables

Variations of several global- and regional-scale phenomena over annual and longer time scales can influence weather and climate in the Southwest. Such factors originate from sea surface temperature[25] variations across the tropics and entire ocean basins, as well as from broad-scale atmospheric circulation patterns across mid-latitude and Arctic regions. For this brief report, discussion will focus on El Niño-Southern Oscillation and the North American monsoon.

24 for the relatively high A2 emissions scenario

25 the mean temperature in the upper few meters of the ocean

El Niño-Southern Oscillation (ENSO)

El Niño-Southern Oscillation (ENSO) is a combination of sea surface temperature and air pressure variations across the tropical Pacific Ocean that typically fluctuates over a period of two to seven years. ENSO variations ultimately affect the track of the jet stream. In the Southwest, this means that ENSO can influence seasonal temperature variations as well as the number of westerly frontal systems that traverse the region in winter, the ability of monsoon moisture to enter the region in summer, and the conditions for tropical cyclone development in the eastern Pacific Ocean in summer and autumn.

El Niño events take place over several seasons and ultimately raise the chances of westerly frontal systems traversing the Southwest and bringing cool and wet conditions into the region during the winter months (Ropelewski and Halpert 1987, Redmond and Koch 1991, Seager et al. 2005). El Niño conditions also can promote lower warm-season precipitation amounts by weakening the high-pressure ridge that forms over the western United States during the North American monsoon, which allows less moisture to enter the Southwest (Castro et al. 2001). Furthermore, El Niño conditions can create a more favorable environment of warmer sea surface temperatures and less wind shear for tropical cyclone development in the eastern Pacific Ocean (Reyes and Mejia-Trejo 1991, Englehart and Douglas 2001). This may result in an increase of moisture being drawn into the region, leading to additional warm-season precipitation.

In contrast, anomalously cool sea surface temperatures span the eastern and central Pacific Ocean during La Niña events, and influence the jet stream during the winter months such that westerly frontal systems that bring cool and wet conditions have lower-than-normal chances of crossing the region (Trenberth and Branstator 1992, Seager 2007). For warm-season precipitation, however, La Niña conditions help strengthen the high-pressure ridge over the western United States, which brings about an earlier-than-normal onset of the monsoon (Castro et al. 2001). La Niña conditions additionally promote less tropical cyclone activity in the eastern Pacific Ocean due to cooler sea surface temperatures and more wind shear, reducing possibilities for warm-season precipitation (Reyes and Mejia-Trejo 1991, Englehart and Douglas 2001).

Global model projections of future ENSO variability and frequency of El Niño and La Niña events are inconsistent (Seneviratne et al. 2012, Cayan et al. 2013). Because of this large uncertainty, the Intergovernmental Panel on Climate Change (IPCC) assigned ‘low’ confidence[26] to projected changes in this phenomenon.

26 The IPCC qualitatively expresses confidence in its findings “based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and the degree of agreement” (Mastrandrea et al. 2010).

North American monsoon (NAM)

As previously mentioned, the North American monsoon (NAM) typically delivers rain to the Southwest in the form of localized and short-duration thunderstorms from midsummer through early autumn. Due to these storm characteristics, as well as other aspects such as daytime initiation of storms over complex mountain terrain, modeling and hence projecting future variability of the NAM is extremely challenging (Cayan et al. 2012). Furthermore, as year-to-year variability of the NAM can be influenced in part by ENSO, future changes in the NAM – similar to monsoon systems worldwide – show large uncertainty. Due to this, and a lack of agreement in model projections of monsoons, the IPCC has 'low' confidence regarding future changes in monsoon phenomena (Seneviratne et al. 2012).

Impacts on the Natural Physical Environment

Droughts, floods, and other impacts of weather and climate events on the natural physical environment come about through a combination of several weather and climate variables, as well as land surface conditions, rather than a single one (Seneviratne et al. 2012). Partly because of this, projecting such impacts at regional scales is difficult. Existing knowledge and modeling of pertinent physical processes, however, allows a partial description of plausible future changes.

Drought

Prolonged periods of below-normal precipitation are a recurring feature of climate in the region, evident in both observations over the past ~100 years and in paleoclimate proxy[27] data. Several droughts similar to as well as longer and more severe than those observed in the 20th century have affected the Southwest over the past two millennia (Cook et al. 2004, Meko et al. 2007, Routson et al. 2011).

As phenomena such as ENSO and NAM influence precipitation in the Southwest, they can play a major role in the occurrence of regional drought[28]. Inconsistent projections of these global- and regional-scale phenomena, however, make projections of drought difficult. Drought projections also are difficult due to factors such as definitional issues and limits in historical observations (Seneviratne et al. 2012). In addition to simple precipitation deficits, definitions of drought can be in agricultural, hydrological, and ecological contexts, which consider additional aspects such as soil moisture, streamflow, and vegetation productivity, respectively. Nonetheless, other aspects of dryness or aridity that relate additionally to temperature can provide insight into the nature of

27 natural archives such as lake sediments and tree rings that record past environmental conditions, often used to infer climate variability over periods of time that predate the observational record

28 defined simply here as a deficit of precipitation, or meteorological drought droughts that possibly occur in coming decades.

As previously mentioned, a warmer atmosphere can hold more water vapor and carry extra moisture. This means that a warmer atmosphere also can create a greater demand for evaporation and transpiration[29], that is, an increase the atmosphere's ability to act like a sponge and take up moisture from water bodies, soil, and vegetation. As reported in SWCCAR, there is 'high' confidence that droughts will become more severe under warmer temperatures as soil moisture decreases with greater atmospheric demand for evaporation and transpiration (Gershunov et al. 2013). Furthermore, greater demand for evaporation and transpiration due to warmer temperatures may hinder recovery from droughts in periods of relatively greater precipitation that could occur during this century (Gutzler and Robbins 2010).

Flooding

Projected changes in seasonal temperature and precipitation, as well as in the potential for heavy precipitation events due to a warmer atmosphere that can hold more moisture, imply possible changes in the timing, frequency, and magnitude of floods (Seneviratne et al. 2012, Gershunov et al. 2013; see also Box 7). For example, warmer temperatures may cause a greater proportion of winter precipitation to fall as rain instead of snow (Knowles et al. 2006) and an increase in the number of days with heavy precipitation (Kunkel et al. 2013). However, there are several key uncertainties that keep confidence 'low' in projections of changes in fluvial floods at the regional scale (Seneviratne et al. 2012).

Phenomena such as ENSO and NAM also are linked to regional flooding as they can bring high amounts of precipitation, sometimes over short time periods, that cause additional runoff and higher flows in streams and rivers (Webb and Betancourt 1992). Much as is the case with drought, inconsistent projections of such phenomena that influence precipitation translate into uncertainties about future changes in flooding (Gershunov et al. 2013). This also applies to particular weather events that deliver moisture to the Southwest. For example, regional flooding can result from the interaction of westerly frontal systems with high amounts of moisture drawn from the tropics[30] in winter, remnant tropical cyclones in autumn (Webb and Betancourt 1992), and cut-off low-pressure systems[31] year-round.

Another uncertainty in flood projections is that the ability of climate models to realistically reproduce aspects related to precipitation extremes such as precipitation frequency and intensity

29 the process by which water moves through a plant and is exchanged with the atmosphere as carbon dioxide is taken up for photosynthesis

30 Such events sometimes are referred to as atmospheric rivers like the "Pineapple Express", a narrow but lengthy plume of moisture that transports a large amount of water vapor from the tropics and subtropics northward (esrl.noaa.gov/psd/atmrivers/).

31 "A closed upper-level low which has become completely displaced (cut off) from basic westerly current, and moves independently of that current. Cutoff lows may remain nearly stationary for days, or on occasion may move westward opposite to the prevailing flow aloft" (w1.weather.gov/glossary) is largely unknown (Gershunov et al. 2013). Nonetheless, as warming regional temperatures are expected to reduce late-winter and spring snowpack, there is 'high' confidence among SWCCAR authors that snowmelt-driven spring and summer floods will decrease in both frequency and magnitude.

Box 7 - Precipitation and Urban Environments

As with temperature, the built environment also can compound the impacts of precipitation events. The impermeability of urban surfaces like asphalt and buildings reduces infiltration of rainfall and raises the potential for flooding (Pincetl et al. 2013). Additional infrastructure and open space may be required to manage such increases in overland water flow. Moreover, changes in water quality may arise, as higher overland flows could carry more suspended sediments and pollutants that affect urban areas and ecosystems receiving this runoff.

Wildland Fire

For the eastern part of the Southwest, which includes central New Mexico, climatologically hot and dry conditions from late spring through early summer prime the landscape for wildland fires (Swetnam and Betancourt 1990, Crimmins 2011; see also Box 8). These conditions, along with wind, do not need to be extreme for fire outbreaks to occur (Gershunov et al. 2013). Human factors, such as fire ignition, management, and suppression practices also factor into the occurrence of wildland fires, as do the availability and flammability of fuels across the landscape.

Weather and climate can influence the availability and flammability of fuels in different types of ecosystems (Fleishman et al. 2013). For example, fuel availability is typically high in relatively dense high-elevation forests, but prolonged dry periods are necessary for these fuels to become flammable. In contrast, fuel availability is typically low in relatively open low-elevation forests, but more flammable as seasonally warm and dry conditions typically occur on a yearly basis. An increase of fuels in such ecosystems, however, can occur during prolonged wet periods.

In general, regional occurrence of wildland fire is associated with drought (Fleishman et al. 2013). As projections of global- and regional-scale phenomena like ENSO and the NAM are inconsistent, projecting future prolonged dry periods, and hence wildland fire outbreaks, is difficult. Nonetheless, similar to expectations of warmer temperatures leading to more severe droughts due to greater atmospheric demand for evaporation and transpiration, warmer temperatures – particularly during spring and summer – also are expected to intensify the hot and dry conditions during the peak wildland fire season (Westerling et al. 2006). Such conditions also may increase attendant effects on vegetation via stressors such as insects and disease. This may raise the frequency, extent, and severity of wildland fires in coming decades. For example, estimates suggest that warming of approximately 2°F to 4°F could led to increases in burned areas between 43% and

380% across Arizona and New Mexico (Spracklen et al. 2009, National Research Council 2011).

Box 8 - Wildland Fire and Urban Environments

Like many other metropolitan areas in the western United States, Albuquerque and surrounding cities have a substantial urban-wildland interface that is potentially in need of protection and susceptible to property damage from wildland fires (Pincetl et al. 2013). Furthermore, the entire metropolitan area can be subject to direct effects of wildland fires such as air pollution, as well as indirect effects such as evacuation and dislocation (Brown et al. 2013).

Streamflow

Increasing temperatures in the Southwest over recent decades have impacted regional hydrological processes by raising elevations of freezing levels (Abatzoglou 2011), lowering ratios of snowfall to total winter precipitation (Knowles et al. 2006), increasing rain-on-snow events (McCabe et al. 2007), and advancing annual timing of snowpack loss (Mote et al. 2005, McCabe and Wolock 2009).[32]

Mostly due to the effects of further regional warming, there is 'high' confidence among SWCCAR authors that late winter and spring snowpack will decline, and 'medium-high' confidence that runoff and streamflow will decline after the mid-21st century (Overpeck et al. 2012; Box 9). Furthermore, there is 'high' confidence that the latter could affect surface water quality, an issue additionally highlighted in the Upper Rio Grande Impact Assessment (Llewellyn and Vaddey 2013).

Box 9 - Regional Groundwater Recharge

Infiltration of storm runoff in ephemeral streams and along mountain bases is very important for groundwater recharge in the region. As runoff is a function of rainfall and snow melt, annual and decadal variability of precipitation can influence rates of groundwater recharge on these time scales, particularly during winter (Ajami et al. 2012). Above-average precipitation serves to enhance groundwater recharge, whereas below-average precipitation corresponds with below-average recharge (Pool 2005).

Projections of streamflow in the Upper Rio Grande Basin reflect those for the broader region, suggesting overall declines and increases in variability (Llewellyn and Vaddey 2013). Native and imported flows are projected to decrease on average by about 25% to 33% during this century,

32 Llewellyn and Vaddey (2013) present a more in-depth review of studies on observed changes in regional hydrology, including snowpack, snowmelt, streamflow, and runoff.

seasonality of streamflow is expected to change as the timing of snowmelt occurs earlier in the year, and projections of winter flow vary from lesser decreases to possible increases for the Rio Grande. Furthermore, month-to-month and year-to-year variations of Rio Grande flows are expected to increase, as temperature-driven increases in evaporation and possible changes in precipitation affect moisture availability.

Box 10 - Warmer Temperatures and Water Supply

Declines in snowpack and increases in evaporative losses are expected to reduce water supply, whereas increased temperatures could increase water demand, particularly in agriculture and urban landscaping (Llewellyn and Vaddey, 2013). This could lead to greater stress on local water supplies.

Natural Resources

Over recent decades, higher temperatures in the Southwest appear to have reduced the number of cool-season freezes (Weiss and Overpeck 2005), advanced annual timing of flowering, leafout, insect emergence, and bird breeding (Brown et al. 1999, Cayan et al. 2001, Forister and Shapiro 2003, Bowers, 2007, Crimmins et al. 2009, Ault et al. 2011), and raised vegetative water stress (Breshears et al. 2005, van Mantgem et al. 2009). Further changes in the regional climate, as well as in land cover and land use, species distributions, and ecosystem disturbances such as fire and insect outbreaks – and the relationships between these factors – may affect plant and animal habitats and ecosystem processes and services (Fleishman et al. 2013). Due to this level of complexity, projections of climate change impacts to natural resources have large uncertainties. However, under current projections, lower flows in the Rio Grande and related groundwater tables may negatively affect riparian vegetation, which could have subsequent effects on fish and wildlife habitat (Llewellyn and Vaddey 2013).

Conclusion

The material above provides a summary of current research on anticipated changes to temperature and precipitation in the Southwest over the course of this century, as well as some of the potential impacts related to these changes. Along with information regarding the magnitude and direction of such changes, this brief report also presents the level of confidence that experts have in such changes, which is an important aspect of interpreting climate projections. More details regarding recent and potential future climate change and its impacts in the region can be found in several of the references listed throughout the text.

Despite 'high' confidence that climate in the Southwest – and central New Mexico – will continue to change in coming decades, not all aspects of variations and changes in climate, along with their potential impacts, can be projected with equal confidence (Overpeck et al. 2013). Furthermore, the magnitude and direction of future changes in climate, particularly those in the later half of the 21st century, are strongly dependent on the amount of GHG emissions to the atmosphere. Several groups in the Southwest – including the one carrying out the Central New Mexico Climate Change Scenario Planning Project – already are taking steps to address changes in regional climate. Although much remains to be learned about future climate change, current knowledge is sufficient to support these efforts.

References

Abatzoglou. J. T. 2011. Influence of the PNA on declining mountain snowpack in the western United States. International Journal of Climatology, 31, 1135–1142.

Ajami, H., T. Meixner, F. Dominguez, J. Hogan, and T. Maddock. 2012. Seasonalizing mountain system recharge in semi-arid basins - Climate change impacts. Ground Water, 50, 585–597.

Ault, T. R., A. K. Macalady, G. T. Pederson, J. L. Betancourt, and M. D. Schwartz. 2011. Northern hemisphere modes of variability and the timing of spring in western North America. Journal of Climate, 24, 4003–4014.

Bowers, J. E. 2007. Has climatic warming altered spring flowering date of Sonoran Desert shrubs?. Southwestern Naturalist, 52, 347–355.

Breshears, D. D., et al. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences of the United States of America. 102, 15,144–15,148.

Brown. J. L., S. H. Li, and N. Bhagabati. 1999. Long-term trend toward earlier breeding in an American bird: A response to global warming?. Proceedings of the National Academy of Sciences of the United States of America, 96, 5565–5569.

Brown, H. E., A. C. Comrie, D. M. Drechsler, C. M. Barker, R. Basu, T. Brown, A. Gershunov, A. M. Kilpatrick, W. K. Reisen, and D. M. Ruddell. 2013. "Human Health." In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 312–339. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Castro, C. L., T. B. McKee, and R. A. Pielke Sr. 2001. The relationship of the North American monsoon to tropical and North Pacific sea surface temperatures as revealed by observational analyses. Journal of Climate, 14, 4449–4473.

Cayan, D., M. Tyree, K. E. Kunkel, C. Castro, A. Gershunov, J. Barsugli, A. J. Ray, J. Overpeck, M. Anderson, J. Russell, B. Rajagopalan, I. Rangwala, and P. Duffy. 2013. "Future Climate: Projected Average." In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 101–125. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Cayan, D. R., S. A. Kammerdiener, M. D. Dettinger, J. M. Capiro, and D. H. Peterson. 2001. Changes in the onset of spring in the western United States, Bulletin of the American Meteorological Society, 82, 399–415.

Crimmins, M. A. 2011. Interannual to decadal changes in extreme fire weather event frequencies across the southwestern United States. International Journal of Climatology, 131, 573–1583.

Crimmins, T. M., M. A. Crimmins, and C. D. Bertelsen. 2009. Flowering range changes across an elevation gradient in response to warming summer temperatures. Global Change Biology, 15, 1141–1152.

Comrie, A. C., and E. C. Glenn. 1998. Principal components-based regionalization of precipitation regimes across the southwest United States and northern Mexico, with an application to monsoon precipitation variability. Climate Research, 10, 201–215.

Cook, E. R., C. A. Woodhouse, C. M. Eakin, D. M. Meko, and D. W. Stahle. 2004. Long-term aridity changes in the western United States. Science, 306, 1015–1018.

Englehart, P. J., and A. V. Douglas. 2001. The role of eastern North Pacific tropical storms in the rainfall climatology of western Mexico. International Journal of Climatology, 21, 1357–1370.

Fleishman, E., J. Belnap, N. Cobb, C. A. F. Enquist, K. Ford, G. MacDonald, M. Pellant, T. Schoennagel, L. M. Schmit, M. Schwartz, S. van Drunick, A. L. Westerling, A. Keyser, and R. Lucas. 2013. "Natural Ecosystems." In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 148–167. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Forister, M. L., and A. M. Shapiro. 2003. Climatic trends and advancing spring flight of butterflies in lowland California. Global Change Biology, 9, 1130–1135.

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds. 2013. Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Gershunov, A., B. Rajagopalan, J. Overpeck, K. Guirguis, D. Cayan, M. Hughes, M. Dettinger, C. Castro, R. E. Schwartz, M. Anderson, A. J. Ray, J. Barsugli, T. Cavazos, and M. Alexander. 2013. "Future Climate: Projected Extremes." In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 126–147. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Gutzler, D. S., and T. O. Robbins. 2010. Climate variability and projected change in the western United States: Regional downscaling and drought statistics. Climate Dynamics, 37, 835–849.

Hoerling, M. P., M. Dettinger, K. Wolter, J. Lukas, J. Eischeid, R. Nemani, B. Liebmann, and K. E. Kunkel. 2013. "Present Weather and Climate: Evolving Conditions." In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 74–100. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

IPCC. 2000. Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, edited by N. Nakicenovic and R. Swart. Cambridge University Press, 570 pp.

IPCC. 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change, edited by Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

Knowles, N., M. D. Dettinger, and D. R. Cayan. 2006. Trends in snowfall versus rainfall in the western United States, Journal of Climate, 19, 4545–4559.

Kunkel, K. E., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K. T. Redmond, and J. G. Dobson. 2013. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. NOAA Technical Report NESDIS 142-5.

Llewellyn, D., and S. Vaddey. 2013. West-Wide Climate Risk Assessment: Upper Rio Grande Impact Assessment. U.S. Department of the Interior, Bureau of Reclamation, Upper Colorado Region, Albuquerque Area Office. 169 pp.

Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L. Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach,

P.R. Matschoss, G.-K. Plattner, G.W. Yohe, and F.W. Zwiers. 2010. Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties. Intergovernmental Panel on Climate Change (IPCC).

McCabe, G. J., and D. M. Wolock. 2009. Recent declines in western U.S. snowpack in the context of twentieth-century climate variability. Earth Interactions, 13, 1–15.

McCabe, G. J., M. P. Clark, and L. E. Hay. 2007. Rain-on-snow events in the western United States. Bulletin of the American Meteorological Society, 88, 319–328.

Meehl, G. A., C. Covey, K. E. Taylor, T. Delworth, R. J. Stouffer, M. Latif, B. McAvaney, and J. F. B. Mitchell. 2007. The WCRP CMIP3 multimodel dataset: A new era in climate change research. Bulletin of the American Meteorological Society, 88, 1383–1394.

Meko, D., C. A. Woodhouse, C. H. Baisan, T. Knight, J. J. Lukas, M. K. Hughes, and M. W. Salzer. 2007. Medieval drought in the upper Colorado River Basin. Geophysical Research Letters, 34, L10705, doi:10.1029/2007GL029988.

Mote, P. W., A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier. 2005. Declining mountain snowpack in western North America. Bulletin of the American Meteorological Society, 86, 39–49.

National Research Council. 2011. Climate stabilization targets: Emissions, concentrations, and impacts over decades to millennia. Washington, DC: National Academies Press. 298 pp.

Niemeier, D. A., A. V. Goodchild, M. Rowell, J. L. Walker, J. Lin, and L. Schweitzer. 2013. “Transportation.” In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 297–311. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Overpeck, J., G. Garfin, A. Jardine, D. E. Busch, D. Cayan, M. Dettinger, E. Fleischman, A. Gershunov, G. MacDonald, K. T. Redmond, W. R. Travis, and B. Udall. 2013. “Summary for Decision Makers.” In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 267–296. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Pincetl, S., G. Franco, N. B. Grimm, T. S. Hogue, S. Hughes, E. Pardyjak, A. M. Kinoshita, and P. Jantz. 2013. “Urban Areas.” In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 267–296. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Pool, D. R. 2005. Variations in climate and ephemeral channel recharge in southeastern Arizona, United States. Water Resources Research, 41, W11403, doi:10.1029/2004WR003255.

Redmond, K. T., and R. W. Koch. 1991. Surface climate and streamflow variability in the western United States and their relationship to large-scale circulation indices. Water Resources Research, 27, 2381–2399.

Reyes, S., and A. Mejía-Trejo. 1991. Tropical perturbations in the eastern Pacific and the precipitation field over northwestern Mexico in relation to the ENSO phenomenon. International Journal of Climatology, 11, 515–528.

Ropelewski, C. F., and M. S. Halpert. 1987. Global and regional scale precipitation patterns associated with the El Niño/ Southern Oscillation. Monthly Weather Review, 115, 1606–1626.

Routson, C. C., C. A. Woodhouse, and J. T. Overpeck. 2011. Second century megadrought in the Rio Grande headwaters, Colorado: How unusual was medieval drought?, Geophysical Research Letters, 38, L22703, doi:10.1029/2011GL050015.

Seager, R. 2007. The turn of the century North American drought: Global context, dynamics, and past analogs. Journal of Climate, 20, 5527–5552.

Seager R., N. Harnik, W. A. Robinson, Y. Kushnir, M. Ting, H. P. Huang, and J. Velez. 2005. Mechanisms of ENSO-forcing of hemispherically symmetric precipitation variability. Quarterly Journal of the Royal Meteorological Society, 131, 1501–1527.

Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang. 2012. Changes in climate extremes and their impacts on the natural physical environment. In Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, edited by Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.

Sheppard, P. R., A. C. Comrie, G. D. Packin, K. Angersbach, and M. K. Hughes. 2002. The climate of the US Southwest. Climate Research, 21, 219–238.

Spracklen, D. V., L. J. Mickley, J. A. Logan, R. C. Hudman, R. Yevich, M. D. Flannigan, and A. L. Westerling. 2009. Impacts of climate change from 2000 to 2050 on wildfire activity and carbonaceous aerosol concentrations in the western United States. Journal of Geophysical Research, 114, D20301.

Swetnam, T. W., and J. L. Betancourt. 1990. Fire–Southern Oscillation relations in the southwestern United States. Science, 249, 1017–1020.

Trenberth, K., and G. W. Branstator. 1992. Issues in establishing causes of the 1988 drought over North America. Journal of Climate, 5, 159–172.

van Mantgem, P. J., et al. 2009. Widespread increase of tree mortality rates in the western United States. Science, 323, 521–524.

Walsh, J., and D. Wuebbles. 2013. Our Changing Climate. In National Climate Assessment, National Climate Assessment and Development Advisory Committee, draft v. 11.

Webb, R. H., and J. L. Betancourt. 1992. Climatic Variability and Flood Frequency of the Santa Cruz River, Pima County, Arizona. U.S. Geological Survey Water-supply Paper 2379, 40 pp.

Weiss, J. L., and J. T. Overpeck. 2005. Is the Sonoran Desert losing its cool?. Global Change Biology, 11, 2065–2077.

Westerling, A. L., H. G. Hidalgo, D. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increases western U.S. forest wildfire activity. Science, 313, 940–943.

This report was prepared by the Climate Assessment for the Southwest (CLIMAS) at the Institute of the Environment, University of Arizona, under award number - NA10OAR4310185 from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration or the Department of Commerce.

Suggested citation:

Weiss, J.L. 2014. Potential Changes in Future Regional Climate and Related Impacts: A Brief Report for the Central New Mexico Climate Change Scenario Planning Project. Tucson, AZ: Climate Assessment for the Southwest. [http://www.climas.arizona.edu/publication/report/potential-changes-future-regional-climate-and-related-impacts-brief-report]

More information

Jeremy L. Weiss
Climate Assessment for the Southwest
The University of Arizona
jlweiss@email.arizona.edu
520-621-6144