



The Economic Impacts of Extreme Weather: Tucson and Southern Arizona's Current Risks and Future Opportunities

Making Action Possible in Southern Arizona (MAP Dashboard)
White Paper #4
February 02, 2017

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Executive Summary

Extreme weather impacts the economy of cities across the Western United States in many ways. Since 2010, the state of Arizona has lost more than \$3 billion in direct damages from extreme weather. Averaging \$500 million per year, losses equal more than 5% of the state government's annual operating budget. However, extreme weather losses vary greatly in magnitude across major Western U.S. cities, due in part to differences in underlying frequency of weather extremes as well as differences in economic sector composition. It is therefore essential to understand the current risks posed by weather extremes as well as strategies and opportunities to cope with them.

This white paper analyzes Tucson's economy and extreme weather. We compare the story in Tucson with that of other Metropolitan Statistical Areas (MSAs) across the Western United States. We find that Tucson has a strong economy, with major sectors including government, trade, professional services, and construction. However, Tucson also suffers large losses from extreme weather. Thunderstorms and flooding dominate Tucson's extreme weather losses, accounting for an average of 84 percent of all extreme weather events and 96 percent of all property losses. Extreme weather losses across Tucson and surrounding Pima County average \$9,449,667 per year (real 2009 \$USD) in direct reported property damages, including wildfire damage. Tucson is also an outlier in the frequency of events. At 47 events per year, Tucson averages the highest yearly extreme storm count across major MSAs in the Western United States. Weather events can be disruptive to Tucson's economic activity, with flash flooding creating hazards for transportation, heat extremes impacting outdoor worker productivity, and hail destroying crops. Note that we do not address long term extreme weather such as drought in this white paper. However, Tucson's weather also provides opportunities for economic activity, including a vibrant winter tourism economy and growing solar industry across Southern Arizona.

While extreme weather risks are detrimental, many strategies from the academic and policy literature provide innovative solutions. We review three important strategies: information, adaptation, and insurance. Information, such as the Arizona Department of Transportation's "Pull Aside Stay Alive" campaign to prevent traffic accidents and fatalities in dust storms, is a critical resource to combat extreme weather losses. While information does not reduce damages directly, it allows for better decision making that will reduce destruction and save lives, often at low cost. Thus, it is essential for businesses to stay up to date on current weather information relevant to their industries. Adaptation, such as valuable large scale infrastructure projects to reduce flash flooding, directly lowers disaster losses. However, care must be taken to balance the costs of adaptation with the benefits for each specific project. It may be prohibitively costly to reduce damages to zero. Lastly, insurance can be beneficial because it smooths extreme weather costs over time. Instead of a business suffering large losses in any given year, it can, instead, pay a known annual premium and have losses covered if an extreme event hits. Many extreme weather insurance products exist, including flood insurance through the National Flood Insurance Program.

Tucson's economy is always changing and extreme weather will continue to affect Tucson and Southern Arizona's business sectors in a variety of ways. Thus, it is important for individuals, businesses, and policy makers to consider the risks of extreme weather in everyday decisions as well as take proactive steps to mitigate future impacts in order to allow Tucson and Southern Arizona's economy to continue to thrive.

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1. Introduction

Extreme weather impacts the economy and society in many ways. Since 2010, the state of Arizona has lost more than \$3 billion in direct damages from extreme weather. Averaging \$500 million per year, losses equal more than 5% of the state government's annual operating budget.¹ Tucson, and the surrounding areas within Pima County, experiences an average of 47 extreme weather events per year, with thunderstorms, floods, and hail occurring most commonly.² Tucson averages the highest yearly extreme storm count among twelve large Metropolitan Statistical Areas in the Western United States. On average, extreme storms cost Tucson and Pima County \$9,449,667 per year in direct reported property damages, including wildfire damage.³ Extreme storms cause an average of one death and 3.3 injuries per year, according to data from the National Center for Environmental Information's Storm Events Database.

Broadly, extreme weather can impact Tucson's economy through multiple channels including the costs of property damage and lives lost, as well as the municipal costs of storm cleanup and mitigation.^{4,5,6} Extreme storms, and their affiliated outcomes, can also cause losses to productivity for workers. For example, on days with high heat, outdoor employers must follow Occupational Safety and Health Administration regulations on safe work practices, which mandate reductions in active outdoor work time.⁷ Extreme weather can also trigger lost hours from employees who cannot get to work safely, must leave early, or are late due to extreme weather.^{8,9} These impacts are in addition to the millions of dollars in reported and direct damages, costs lives and safety, as well as productivity impacts around Tucson due to extreme weather. Given the impacts, a better understanding of extreme weather risks, as well as strategies to reduce losses, is an important social, economic, and policy goal.

This white paper provides an overview of the impacts of weather extremes on Tucson and Southern Arizona's business sectors, contextualizing Tucson's story with comparisons to other Metropolitan Statistical Areas (MSAs) around the Western United States. The paper will provide insight into the following five questions: 1) What are Tucson and Southern Arizona's major business industries, relative to other comparison regions across the Western United States? 2) What are the dominant extreme weather risks facing Tucson and Southern Arizona, relative to other comparison regions across the Western United States? 3) Drawing from historical data and

¹ Statistics in this paragraph were calculated by the authors using data sources detailed in Section 2.

² We define thunderstorms as thunderstorms, extreme rain events, and lightning. An exhaustive list of how we grouped weather events is in Section 2.

³ Throughout this white paper, all dollar values are in real 2009 dollars USD.

⁴ Pima County. (2012). Pima County Multi-Jurisdictional Hazard Mitigation Plan. Online https://www.tucsonaz.gov/files/em/PimaCounty_Multi_Juris_Haz_Mit_Plan_MainBody_Final_Draft.pdf.

⁵ City of Tucson Storm Water. (2012). The City of Tucson's Stormwater Management Program (SWMP). Online https://www.tucsonaz.gov/files/transportation/stormwater/SWMP_2012.pdf.

⁶ Washington, C. (2016, July 16). Pima County to spend \$200K maintaining roads during monsoon. Tucson News Now. Retrieved from <http://meredithaz.worldnow.com/story/32433221/pima-county-to-spend-200k-maintaining-roads-during-monsoon>

⁷ Kjellstrom, T., Kovats, R. S., Lloyd, S. J., Holt, T., & Tol, R. S. (2009). The direct impact of climate change on regional labor productivity. *Archives of Environmental & Occupational Health*, 64(4), 217-227.

⁸ Koetse, M. J., & Rietveld, P. (2009). The impact of climate change and weather on transport: An overview of empirical findings. *Transportation Research Part D: Transport and Environment*, 14(3), 205-221.

⁹ Suarez, P., Anderson, W., Mahal, V., & Lakshmanan, T. R. (2005). Impacts of flooding and climate change on urban transportation: A systemwide performance assessment of the Boston Metro Area. *Transportation Research Part D: transport and environment*, 10(3), 231-244.

the academic literature, what are examples of how industries across Tucson and Southern Arizona impacted by extreme weather? 4) What is the intuition behind potential solutions and strategies for risk reduction to extreme weather currently facing Tucson and Southern Arizona? 5) Looking ahead, what does the future hold for sectoral growth and extreme weather in Tucson and Southern Arizona?

The white paper is organized as follows: Section 2 overviews our methodology including data sources, comparison regions, and literature review. Section 3 analyzes the data on Tucson's current weather risks including the theoretical impact on economic performance. Section 4 provides illustrative examples of how extreme weather impacts Tucson's business sectors in both negative and positive ways. Section 5 reviews the economic intuition and literature on opportunities and risk reduction strategies including information, adaptation, and insurance. Section 6 highlights future opportunities in the nexus between Tucson's economy and weather extremes. Section 7 concludes.

2. Methodology

In this white paper, we combine insights from the academic literature with real world data on economic activity and weather in order to shed light on five key questions regarding the impacts of extreme weather on Tucson's economy. We also compare activities in Tucson with those from other Western United States Metropolitan Statistical Areas. In this section, we detail our data sources as well as present the comparison MSAs. Lastly, we describe our literature review.

2.1. Data

We utilize data on economic activity, including gross domestic product by industry and employment by industry, as well as weather extremes, including event frequencies and impacts.

2.1.1. Economic Data

Gross domestic product (GDP) is an aggregate indicator of economic activity. It is a measure of the sum of final expenditures for goods and services within the economy that estimates the good being produced in a given time period, often one year.¹⁰ While it is not a perfect measure of the welfare of a society, it is, nonetheless, a useful statistic to determine and compare overall economic performance as well as relative economic activity.¹¹ For the purposes of this white paper, gross domestic product data for each economic sector in each of the 12 Western Metropolitan Statistical Area were obtained from the U.S. Bureau of Economic Analysis (BEA) for the years 2001 to 2014.¹² All figures are inflation adjusted and are presented in real 2009 US dollars. We amended the BEA dataset to make the information as streamlined as possible. For example, missing data and data qualified as "confidential" was not included in our calculations. Each sector was grouped into the categories used by the Making Action Possible Dashboard (MAP): construction, education and health services (including higher education), government, information (including all media sources), leisure and hospitality (including restaurants, hotels, and entertainment), manufacturing (including all aeronautic manufacturing), natural resources (including agriculture), professional and business services (like real estate, accounting, and miscellaneous corporate businesses), trade (including retail trade), and transportation and utilities. Given that we utilized the MAP sectors for

¹⁰ Grimm, B. T. (2007). The statistical discrepancy. BEA Working Papers.

¹¹ Fleurbaey, M. (2009). Beyond GDP: The quest for a measure of social welfare. *Journal of Economic literature*, 47(4), 1029-1075.

¹² All economic data was aggregated for the purpose of generating summary statistics. We generated average of employment data for each month to find the average employment numbers per sector, per MSA, per year.

the GDP data, this white paper looks as a subset of the total MSA economy. For this white paper, we utilize both the overall size of each sector as well as the relative share of economic activity from each sector.

In addition to GDP data, we gather data on employment by industry for each MSA from the U.S. Bureau of Labor Statistics. We then aggregate employment data using the same sectors reported on the MAP Dashboard and are consistent with the GDP sectors presented above. These data include the total number of employees, both goods and service producing, in each MSA from 2006 through June of 2016.^{13, 14} Employment can be a useful indicator of economic activity. Employment data implies strength of a sector by showing the demand for labor and the services the sector provides. In addition, while sector-specific GDP reflects the flow of overall value added to a local economy, employment data reflects concentration of employed labor. But, like GDP data, employment data only shows one facet of sector strength. The data we analyze only shows the employment of an area, or the total number of people employed at a given time. It does not measure other relevant labor statistics such as unemployment. In the context of extreme weather impacts, both GDP and number of employees can shed useful light on potential impacts. As such, we analyze both in this white paper.

2.1.2. Extreme Weather Data

Lastly, we collect data on extreme weather events from the National Centers for Environmental Information's Storm Events Database (NCEI). The storm event reports in the database are generated by local National Weather Service (NWS) offices, where personnel record event details including event type, date, location, and estimates of direct and indirect fatalities, as well as property and crop losses.¹⁵ We collect all events from 1996 to 2016 and group them into broad categories: winter weather, thunderstorms, tornadoes, extreme heat, floods, ocean events, wind events, hail, droughts, and wildfires.¹⁶ While the individual events are recorded based on either the county or National Weather Service zone, we aggregate the events to the MSA level via their county. From these data we calculate descriptive statistics including the average annual count, total property damages (in 2009 \$USD), total fatalities, and total injuries from the storm events. Thus, all reports on weather extremes in this paper are from the MSA's county(s) and not necessarily from the MSA itself.¹⁷ All data from the NCEI dataset was divided by the number of counties within the MSA for an average value per MSA.

¹³ Stock, J. H., & Watson, M. W. (1989). New indexes of coincident and leading economic indicators. In NBER Macroeconomics Annual 1989, Volume 4 (pp. 351-409). MIT press.

¹⁴ Data was collected in July 2016 when only six months of data were available. All data for the second half of 2016 (July through December) has been estimated by using an average of the first six months of the year.

¹⁵ Detailed information regarding the preparation and inclusion of events in the database can be found in the National Weather Service Instruction (NWSI) 10-1605 entitled "Storm Data Preparation" available online at: <https://www.ncdc.noaa.gov/stormevents/pd01016005curr.pdf>.

¹⁶ We code each distinct weather event in the NCEI dataset by the larger "bucket" type. Winter weather events include avalanche, blizzard, cold/wind chill, extreme cold/wind chill, frost/freeze, heavy snow, ice storm, lake-effect snow winter storm, and winter weather. Thunderstorm events include dense fog, heavy rain, lightning, sleet, and thunderstorm wind. Tornado events include all tornadoes. Extreme heat events include excessive heat, and heat. Flood events include coastal flood, debris flow, flash flood, flood, and storm surge/tide. Ocean (specifically dealing with the coast or waves and not related to flooding directly) events include high surf, rip current, tropical storm, and tsunami. Wind events include dust devil, dust storm, funnel cloud, high wind, landslide, strong wind, and waterspout. Hail events include hail. Drought events include only drought and wildfire events include only wildfire.

¹⁷ MSAs and counties included in the weather data: Albuquerque data includes Bernalillo, Sandoval, Torrance, and Valencia Counties; Austin data includes Bastrop, Caldwell, Hays, Travis and Williamson Counties; Colorado Springs

Climate is the average of weather across space and time, often average across 20 or 30 years.¹⁸ Weather refers to the short term atmospheric conditions in an area. Both climate and daily weather have important impacts on society. For example, Southern Arizona’s climate, including mild winters, makes it a pleasant destination for seasonal tourism.¹⁹ As this white paper focuses only on weather extremes, we do not focus on the important impacts of day-to-day weather and climate on local economic activity and society. Climate also has important impacts for the types of agricultural crops that can be produced across different regions.²⁰ In addition, Southern Arizona’s ample sunshine is conducive to solar energy production, relative to other areas.²¹ However, due to this white paper’s focus on weather extremes, we leave detailed discussion of the impacts of climate and non-extreme weather for future work. We note that changes in climate can affect the extremity of day-to-day weather.

2.1.2.1. Droughts and Wildfires

Droughts and wildfires are important natural disasters in the Western United States—the impacts in the Southwest United States, specifically, are prevalent and detrimental.^{22, 23} In the last 21 years, there have been 177 weather-caused wildfires in these MSAs; there have been 278 instances of weather-caused drought. Wildfires have cost the 12 MSAs a total of \$2.84 billion in the past 21 years in property damage. And, on average each wildfire event causes around five deaths. The four recorded wildfires in Pima County have cost a total of \$152 million, nearly 16 times the yearly average of extreme property damage in Tucson and 77% of the total extreme storm property damage in the past 21 years. Similarly, 88% of the total property damage in Colorado Springs was caused by wildfires. However, these events are different than other extreme weather events that we consider in this white paper due to the longer timeframes, data limitations, and management strategies. As a result, we do not cover droughts or wildfires in detail in this white paper.

First, wildfires and especially droughts are likely underreported in the NCEI’s Storm Events Database as it can be difficult for the event reporters to include. These extremes are typically longer lasting and harder to quantify damages, relative to short-term extremes such as hailstorms. This makes it difficult to define the start and end point of the event, especially for droughts. It can be difficult to estimate the losses from drought within the 90-day timeframe of the dataset’s

data includes El Paso and Teller Counties; Denver data includes Adams, Arapahoe, Broomfield, Clear Creek, Denver, Douglas, Elbert, Gilpin, Jefferson, and Park Counties; El Paso data includes El Paso and Hudspeth counties; Las Vegas data includes Clark County; Phoenix data includes Maricopa and Pinal Counties; Portland data includes counties from Oregon and Washington—Clackamas, Columbia, Multnomah, Washington, Yamhill, Clark, and Skamania Counties; Salt Lake City data includes Salt Lake and Tooele Counties; San Antonio data includes Atascosa, Bandera, Bexar, Comal, Guadalupe, Kendall, Medina, and Wilson Counties; San Diego data includes San Diego County; Tucson data includes Pima County.

¹⁸ National Aeronautics and Space Administration. (2016). NASA - What's the Difference Between Weather and Climate?. Retrieved from http://www.nasa.gov/mission_pages/noaa-n/climate/climate_weather.html

¹⁹ Farquhar, L., Hogan, T., & Happel, S. (2003, June 23). ASU news & information from the office of media relations and public information. Retrieved October 16, 2016, from Arizona State University, https://www.asu.edu/news/community/snowbird_count_062503.htm

²⁰ Mendelsohn, R., Nordhaus, W. D., & Shaw, D. (1994). The impact of global warming on agriculture: a Ricardian analysis. *The American economic review*, 753-771.

²¹ Association, S. E. I. Arizona solar. Retrieved October 16, 2016, from <http://www.seia.org/state-solar-policy/arizona>

²² Engle, N. L. (2010). Adaptation to extreme droughts in Arizona, Georgia, and South Carolina: evaluating adaptive capacity and innovative planning and management approaches for states and their community water systems (Doctoral dissertation, The University of Michigan).

²³ Crimmins, M. A. (2006). Synoptic climatology of extreme fire-weather conditions across the southwest United States. *International Journal of Climatology*, 26(8), 1001-1016.

requirements. Thus, losses are likely unreported for these types of events. For example, from 1996 to 2010, the NCEI’s Storm Events Database lists no direct damages from drought in Pima County. This is likely an underreporting of the true losses.²⁴

Second, human management of water resources and forests can greatly impact the severity and duration of droughts and wildfires, respectively. Both wildfires and droughts can be triggered and exacerbated by many factors that are not weather related, such as meteorological, agricultural, hydrological, and social-economic, and the areas they affect may spread beyond the geographical constraints of an MSA. Given the long timeframes, data limitations from the dataset we draw on, and important management implications of both wildfires and droughts, we leave these events for special treatment in future work.

2.2. Comparison MSAs

Consistent with the Making Action Possible Dashboard, we contextualize data from Tucson with 11 other Western United States MSAs. The MAP Dashboard chose these MSAs based on their geographic, economic, and compositional comparability with Tucson. The MSAs are listed by state in Table 1. In the following sections, we compare the economic and weather events data from Tucson with these comparison MSAs.

Table 1: Metropolitan Statistical Areas by State

State	MSAs
Arizona	Phoenix/Mesa/Scottsdale, Tucson
California	San Diego/Carlsbad
Colorado	Colorado Springs, Denver/Aurora/Lakewood
Nevada	Las Vegas/Henderson/Paradise
New Mexico	Albuquerque
Oregon	Portland/Vancouver/Hillsboro
Texas	Austin/Round Rock, El Paso, San Antonio/New Braunfels
Utah	Salt Lake City

2.3. Literature Review

In order to contextualize our data within the broader academic literature, including both social science literatures from economics, public policy, and disaster management as well as natural science literature on weather and climate, we conducted a broad Google Scholar search to find the relevant literature on extreme weather for the Southwest. In addition, we bring general insight from the broader literature and apply it to Tucson. This literature gives insight into the academic theories on how extreme weather affects facets of everyday life, including economic sectors. We utilized key search terms that consisted of combinations of each weather event and each economic sector as well as each weather event and MSA. After analyzing the academic literature, we turned to Tucson and Pima County specific grey literature, such as local and state government reports and local and state websites, to understand the more immediate impacts and plans for extreme weather. Lastly, we turned to local news reports about the day-to-day effects of extreme weather in Tucson

²⁴ National Weather Service. (2007). National Weather Service instruction storm data preparation (NWSI 10-1605). Online. <http://www.nws.noaa.gov/directives/>.

and Pima County. We summarize key insights from the literature in this white paper and cite individual sources in footnotes throughout this document.

3. Current Risks: Tucson's Economy and Extreme Weather

In this section, we present data on Tucson's economic and extreme weather events in order to capture both the relative rates and impacts of different types of extreme weather as well as the relevant concentrations of sectors in harm's way. We compare the story in Tucson with other Metropolitan Statistical Areas across the Western United States to compare and contrast the Tucson setting with other locations.

3.1. Tucson's Economy

Tucson hosts a vibrant and varied economy. Figure 1 displays Tucson's average yearly GDP by sector. The top sectors by gross domestic product (GDP) in Tucson are government (24% of GDP), trade (19%), professional and business services (14%), and construction (13%). Tucson's largest employment sectors are government (24% of the total employment), education and health services (17%), and professional and business services (15%). All three sectors combined comprise over half of Tucson's total employment. Figure 2 displays Tucson's average employment by sector.

Figure 1: Tucson's Average Yearly GDP from 2001 to 2014 by Sector

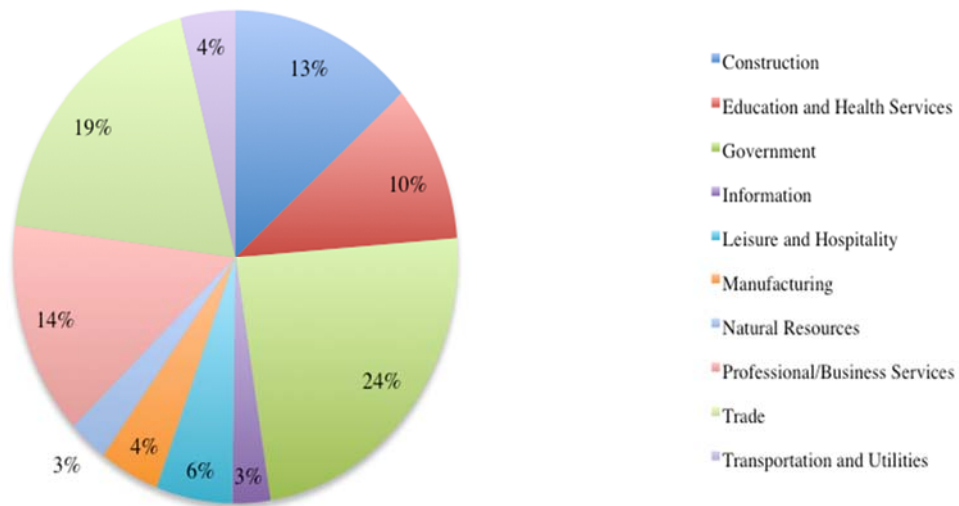
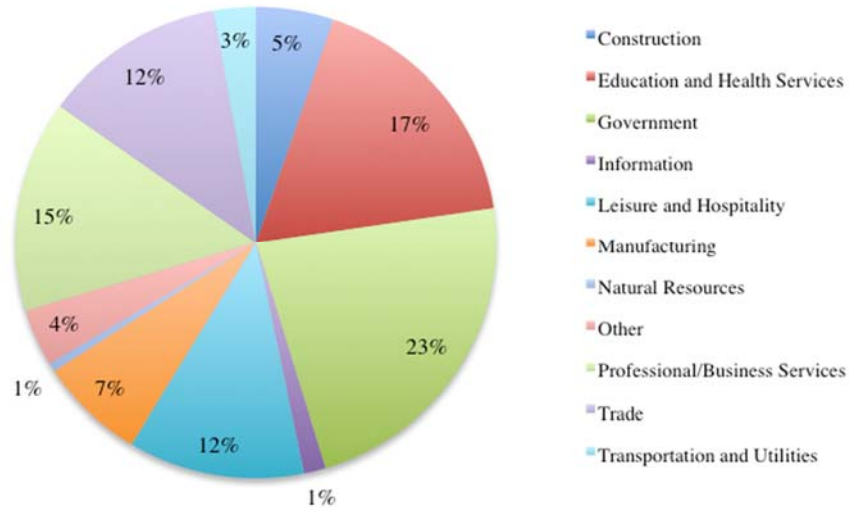


Figure 2: Tucson's Average Employment from 2006 to 2016 by Sector



3.1.1. Tucson's GDP Relative to Comparison MSAs

In terms of average yearly gross domestic product by sector, Tucson's economy is smaller relative to other MSAs, due in part to its smaller population. However, Tucson performs above average in education and health services, government, natural resources, transportation, and utilities. Tucson performs at or below the MSA average in construction, information, leisure and hospitality, manufacturing, professional and business services, and trade. The following will compare Tucson to other MSAs specifically looking at Tucson's own top performing sectors: government, trade, professional and business services, and construction. We present the relative average GDP shares of each sector by MSA in Figure 3.

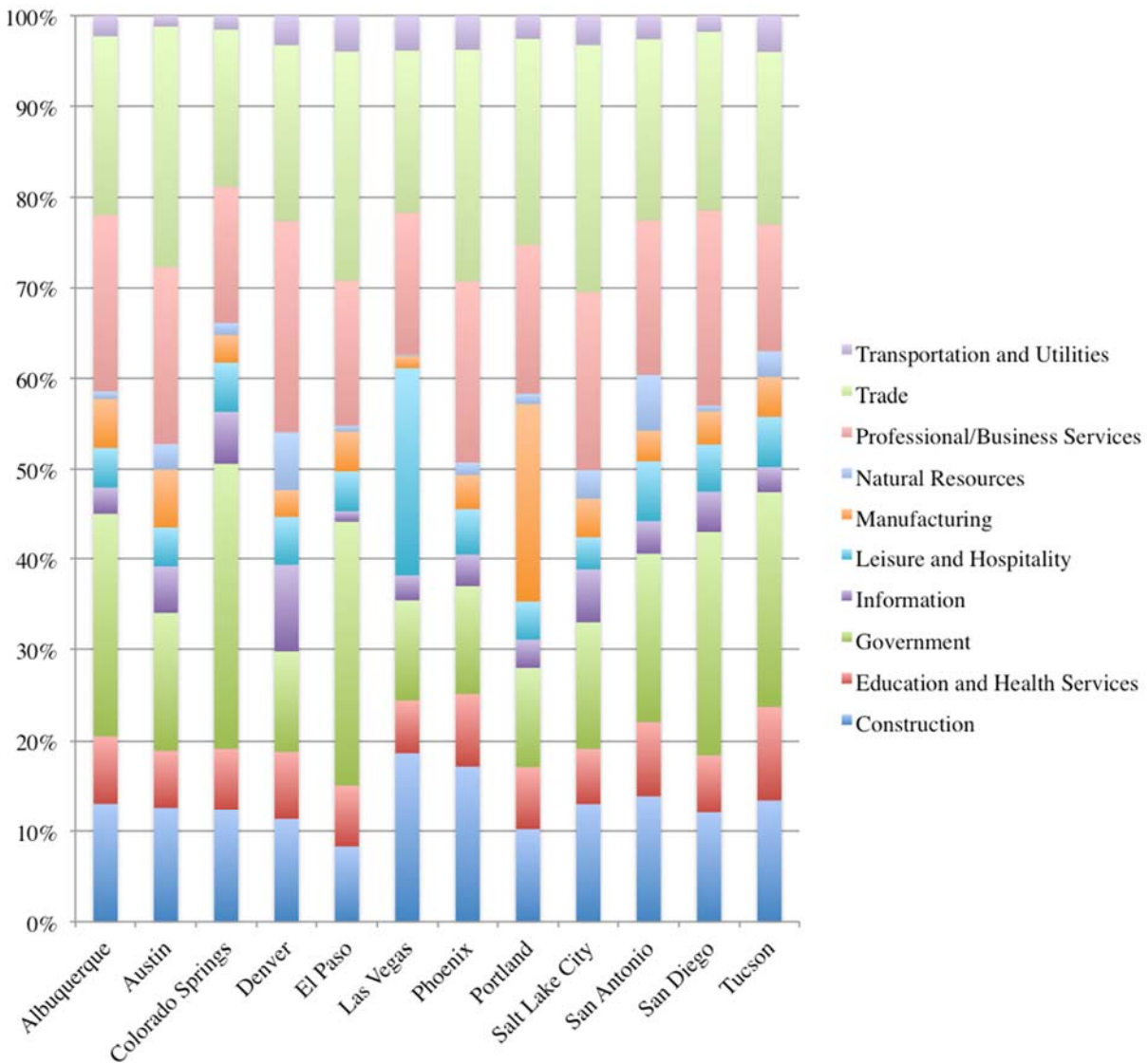
First, government is Tucson's largest sector, in terms of average yearly GDP, along with four other MSA's. The government makes up at least 20% of GDP in Albuquerque (25%), Colorado Springs (31%), El Paso (29%), and San Diego (25%), like Tucson.

Second, Tucson falls just behind the average relative share of GDP by the trade sector (22%) within the MSAs. Austin (27% of GDP), El Paso (25%), Phoenix (26%), Portland (23%), and Salt Lake City (27%) all outperform Tucson by at least a percentage point. El Paso and Salt Lake City are more similar to Tucson in terms of population—thus, the general market for trade would be comparable. Tucson's trade sector is larger relative to Las Vegas (18%) and Colorado Springs (17%).

Third, Tucson's professional and business services sector is four percentage points smaller, in terms of relative sectorial composition, relative to the average MSA. Albuquerque (20%), Denver (23%), and Phoenix (20%) have the highest percentage for professional and business services. Albuquerque is smaller than Tucson in terms of population and overall GDP, but has a larger professional and business services sector share of total GDP relative to Tucson.

Fourth, Tucson’s yearly average GDP for construction is at the average amount for the MSAs—three other MSAs have the same GDP for construction. Tucson enjoys a larger construction sector relative to total GDP than Colorado Springs (12%), Denver (11%), El Paso (8%), Portland (10%), and San Diego (12%). Las Vegas (19%) and Phoenix (17%) have the largest construction sectors relative to their overall GDP.

Figure 3: Yearly Average GDP from 2001 to 2014 by Sector and MSA



3.1.2. Tucson’s Employment Relative to Comparison MSAs

We next describe the composition of Tucson’s employment by sector and relative to other comparison MSAs. Tucson is above average in terms of relative sector share by employees in construction, education and health services, government, and natural resources. Tucson is below or at average in terms of average employment by sector relative to total employment for

information, leisure and hospitality, manufacturing, professional and business services, trade, and transportation. We compare Tucson with other MSAs in each of Tucson's top employment sectors: government, education and health services; professional and business services; and leisure, hospitality, and trade. We present the relative average employment shares of each sector by MSA in Figure 4.

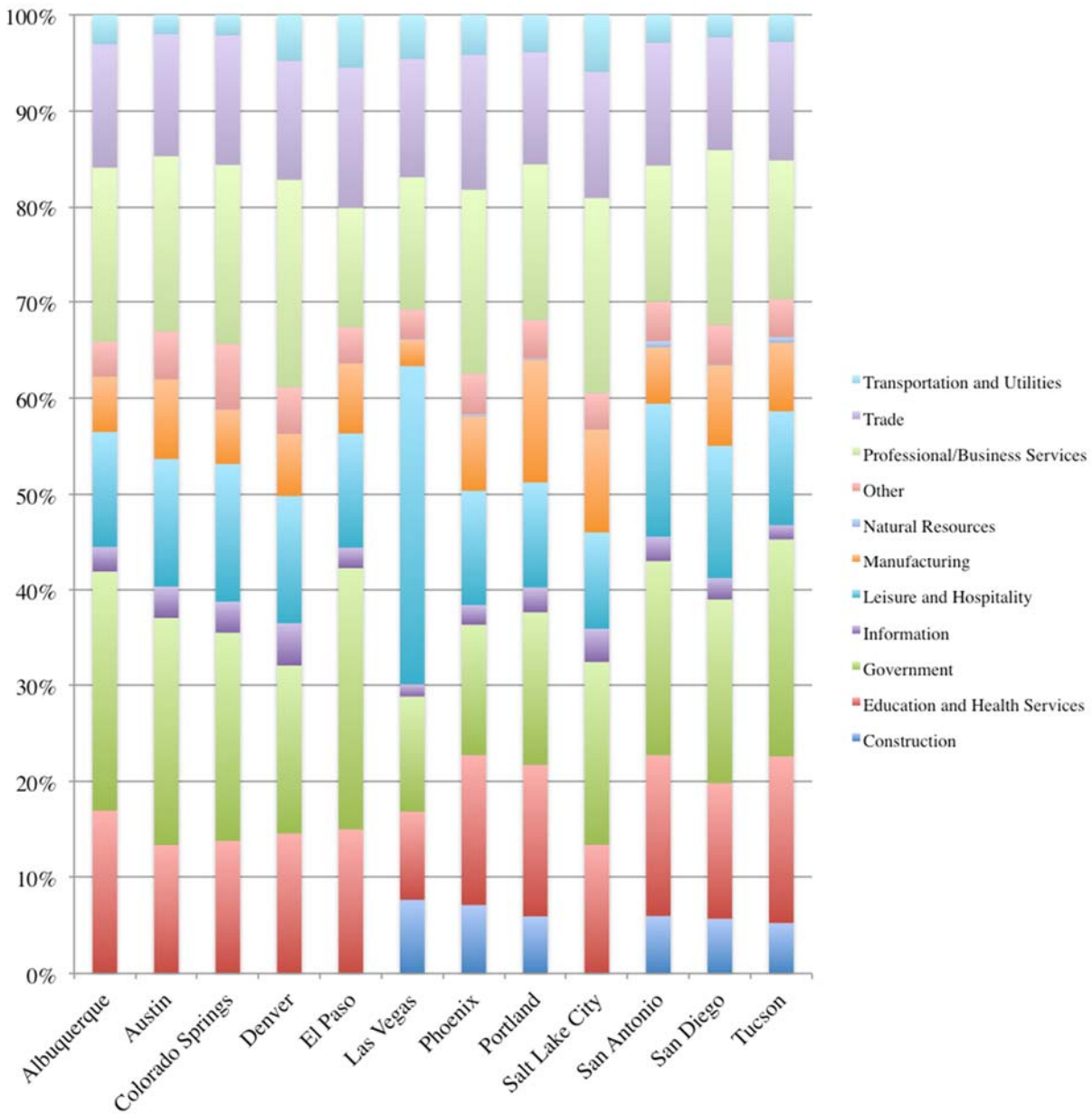
First, as with GDP, Tucson's largest sector by employment share is the government. Albuquerque (25% of employment), Austin (24%), Colorado Springs (22%), and El Paso (27%) have the highest percentages of government within their total employment. Tucson has a much higher percentage of employees in government relative to Phoenix (14%) and Las Vegas (12%).

Second, Tucson has above average education and health services employment sectors as a percentage of total the employment. Education and health services make up 17% of Tucson, Albuquerque, and San Antonio's total employment—these are the highest percentages across the comparison MSAs. Phoenix and Portland are a close second at 16%.

Third, Tucson, El Paso, Las Vegas, and San Antonio all have similar levels of employment shares for professional and business services at around 14%. However, they all lag behind the other MSAs by three to nine percentage points. Austin (18%), Denver (22%), Phoenix (19%), and Salt Lake City (20%) have the highest percentages of professional and business services as a total of the employment. Again, Tucson and Salt Lake City are relatively close in population and yet there is a five percentage point difference in the yearly average percentage of total employment within this sector.

Fourth, Tucson is below average for leisure and hospitality and trade employment—24% of employment in Tucson is made up by the leisure and hospitality and trade sectors (12% each). There is little variance within both of these sectors among the MSAs (1-2%) with the exception being Las Vegas, where 33% of their employment is in leisure and hospitality, while these sectors constitute 23% of their GDP. Las Vegas is, understandably, an outlier in this sector for both GDP and employment, given its focus on entertainment and tourism. Tucson's leisure, hospitality, and trade sectors employ a similar share of the employment relative to other MSAs.

Figure 4: Yearly Average Employment Share from 2006 to 2016 by Sector and MSA



3.2. Tucson’s Extreme Weather

We now turn to Tucson’s weather and extreme weather. Tucson is a semi-arid desert with higher levels of precipitation and elevation than average deserts. There are two major seasons (summer and winter) and three minor seasons (spring, fall, and the North American Monsoon) in Tucson. Summers are hot (average temperature is 84.8-degrees Fahrenheit with a high of 100.3-degrees Fahrenheit) and winters are mild (average temperature is 52.6-degrees Fahrenheit).²⁵ Annual

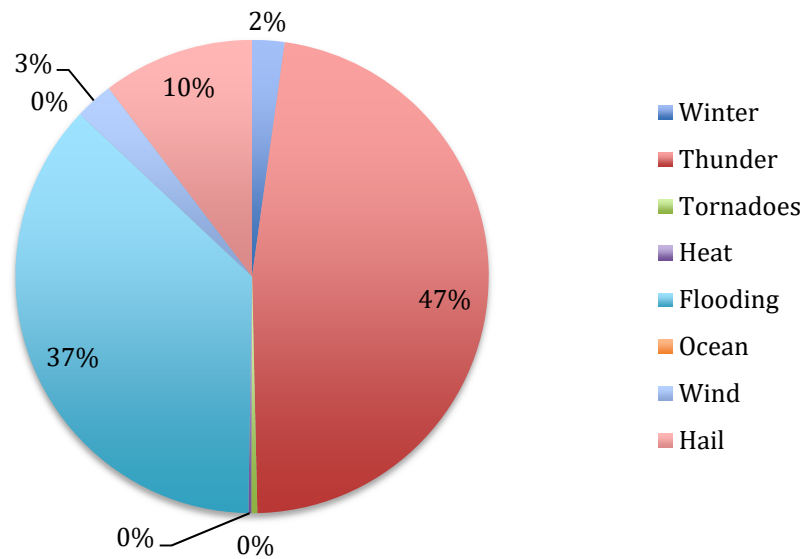
²⁵ National Oceanic and Atmospheric Administration. (January 2016). Monthly and Daily Normals (1981-2010) plus Daily Extremes (1895-2016) for Tucson, Arizona. Retrieved from <http://www.wrh.noaa.gov/twc/climate/tus.php>.

average precipitation in Tucson is 11.59” and 6.06” during Monsoon.^{26, 27} Over 95% of thunderstorm events and 93% of hail events occur during the Monsoon that takes place June through September.

The North American Monsoon is a series of storms that occur from early June (through North Western Mexico) to mid-September (through the North West Plains of the United States) caused by a mixture of wind shifts, pressure changes, and topographical factors in Northern Mexico and the Baja de California.²⁸ While the actual event can develop suddenly, knowing the frequency can help with awareness and information campaigns. Monsoonal storms make up about 50% of precipitation in Southeast Arizona.²⁹ Non-Monsoon events (that can occur during the Monsoon) can be caused by cyclonal events.

Figures 5 and 6 display the fraction of extreme weather events and damages by each extreme weather type.³⁰ The dominant extreme weather events in Tucson are thunderstorms and flooding, accounting for 84% of all extreme weather events. Similarly, thunderstorms and flooding accounts for 96% of property losses as recorded in the NCEI’s Storm Events database.

Figure 5: Extreme Events in Tucson from 1996 to 2016 (% of Total Extreme Events in Tucson)



²⁶ National Oceanic and Atmospheric Administration. Monsoon rainfall averages across southeast Arizona. Retrieved from <http://www.wrh.noaa.gov/twc/monsoon/season/normals.php>.

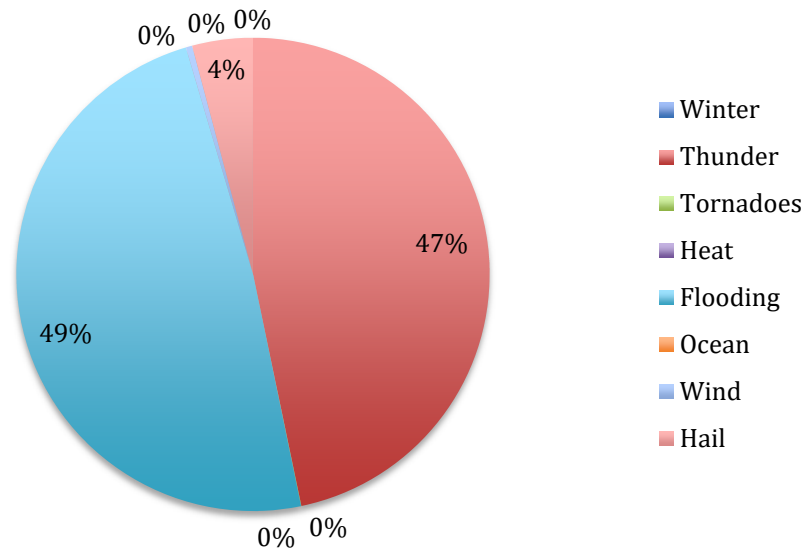
²⁷ NOAA, Monthly and Daily Normals.

²⁸ Adams, D. K., & Comrie, A. C. (1997). The North American monsoon. *Bulletin of the American Meteorological Society*, 78(10), 2197-2213.

²⁹ Arizona Department of Water Resources. Climate of the Southeastern Arizona Planning Area. Retrieved from <http://www.azwater.gov/AzDWR/StatewidePlanning/WaterAtlas/SEArizona/PlanningAreaOverview/Climate.htm>.

³⁰ Note that extreme event shares add to 99% in Figure 5 due to rounding.

Figure 6: Extreme Event Damages in Tucson from 1996 to 2016 (% of Total Damages by Event Type)



3.2.1. Tucson’s Extreme Weather Relative to Comparison MSAs

In Tucson³¹ the most common extreme storm events that occur are flooding (average 17.4 per year), thunderstorms (22.4 per year), and hailstorms (4.9 per year). Thunderstorms make up 47% of the 995 extreme storms events that occurred in the Tucson area in the past 21 years. The majority of these storms, and the hail and flooding that often accompany them, occur during the North American Monsoon in Southern Arizona. As with the MSA comparisons for GDP and employment, this section will present the storm event effects in other MSAs using the most common storms in Tucson as the reference points.

The most damaging storms in Tucson are the same as the most frequent: floods, thunderstorms, and hail. Thunderstorms have caused 47% of the total, reported, and direct property damage costs in the Tucson area and flooding has caused 49%. In the past 21 years flooding has cost \$1,074,769 (on average, \$51,179.48 per year) in direct property damages; thunderstorms have cost \$1,031,367 (\$49,112 per year); and, hailstorms have cost \$91,655.39 (\$4,364.54 per year). Tornadoes and wind events have caused minimal property damage in comparison to these three storms (about \$10,000 and \$650 total in the past 21 years, respectively). Winter storms and heat have caused no direct property damage, according to this dataset. However, this is likely an underestimate of the true impacts.

The majority of extreme weather related deaths in the Tucson area are due to flooding—71% of the deaths caused by storms were related to flooding. Floods have caused 15 deaths in the last 21 years, thunderstorms have caused three deaths, winter storms have caused two deaths, and wind has caused one death. Thunderstorms and wind have caused the majority of injuries in the past 21 years in the Tucson area at 37 and 17 respectively.

³¹ Recall that the extreme weather data for Tucson encompasses all extremes in Pima County. This is true for all extreme weather references in this white paper.

In Figures 7, 8, and 9 below, we present the relative shares of extreme events by count, extreme event direct damages, and extreme event fatalities by MSA. Flooding and hailstorms are common in most of the MSAs. Flooding makes up at least one third of the total extreme storms in Tucson, Austin, Las Vegas, and San Antonio. Like Tucson, nearly 40% of both Las Vegas' and San Antonio's total storms are floods. Even in cities where flooding is not as common, flooding causes 18% of the total property damage within the dataset and 24% of reported direct deaths. Flooding costs more than 40% of the total property damage in Albuquerque, Austin, Colorado Springs, El Paso, Las Vegas, Portland (at 92%), San Antonio, and Tucson. Flooding causes more than half of the extreme storm related deaths in Albuquerque, Phoenix, Portland, San Antonio (at 83%), and Tucson.

Hail, which causes far less damage relative to flooding, makes up one third (at least 29%) of total extreme storms in Albuquerque, Austin, Colorado Springs, and Denver. Thunderstorms are only one third or more of total storms in Tucson and Phoenix. Las Vegas is close at 27% of total storms from thunderstorms. Hail caused the highest amount of property damage in Phoenix and Denver (84% and 85% of total property damage, respectively). Thunderstorms make up 61% of storms in Phoenix, which is the highest concentration of storms in one category within these MSAs.

Finally, it is interesting to compare Tucson with Phoenix. Phoenix experiences major windstorms (known as Haboobs) during Monsoon given their unique location in a valley, proximity to off-season farms, and wind patterns. Tucson does not experience the same frequency of extreme wind events. The Phoenix area has experienced 63.5 windstorms in the past 21 years, whereas the Tucson area has only experienced 26. However, these Monsoonal windstorms directly affect transportation to Tucson given that Interstate-10 (I-10), the main thoroughfare between Phoenix and Tucson, is a common location for Haboobs. The Arizona Department of Transportation has taken an active stance on mitigating wind related car accidents by using marketing campaigns and large marquees on I-10.³²

³² National Oceanic and Atmospheric Administration. (July 2016). Blowing Dust and Dust Storms: One of Arizona's Most Underrated Weather Hazards. (NOAA Technical Memorandum NWS-WR 290). Salt Lake City, UT.

Figure 7: Extreme Event Types from 1996 to 2016 by MSA (% of Total Storms)

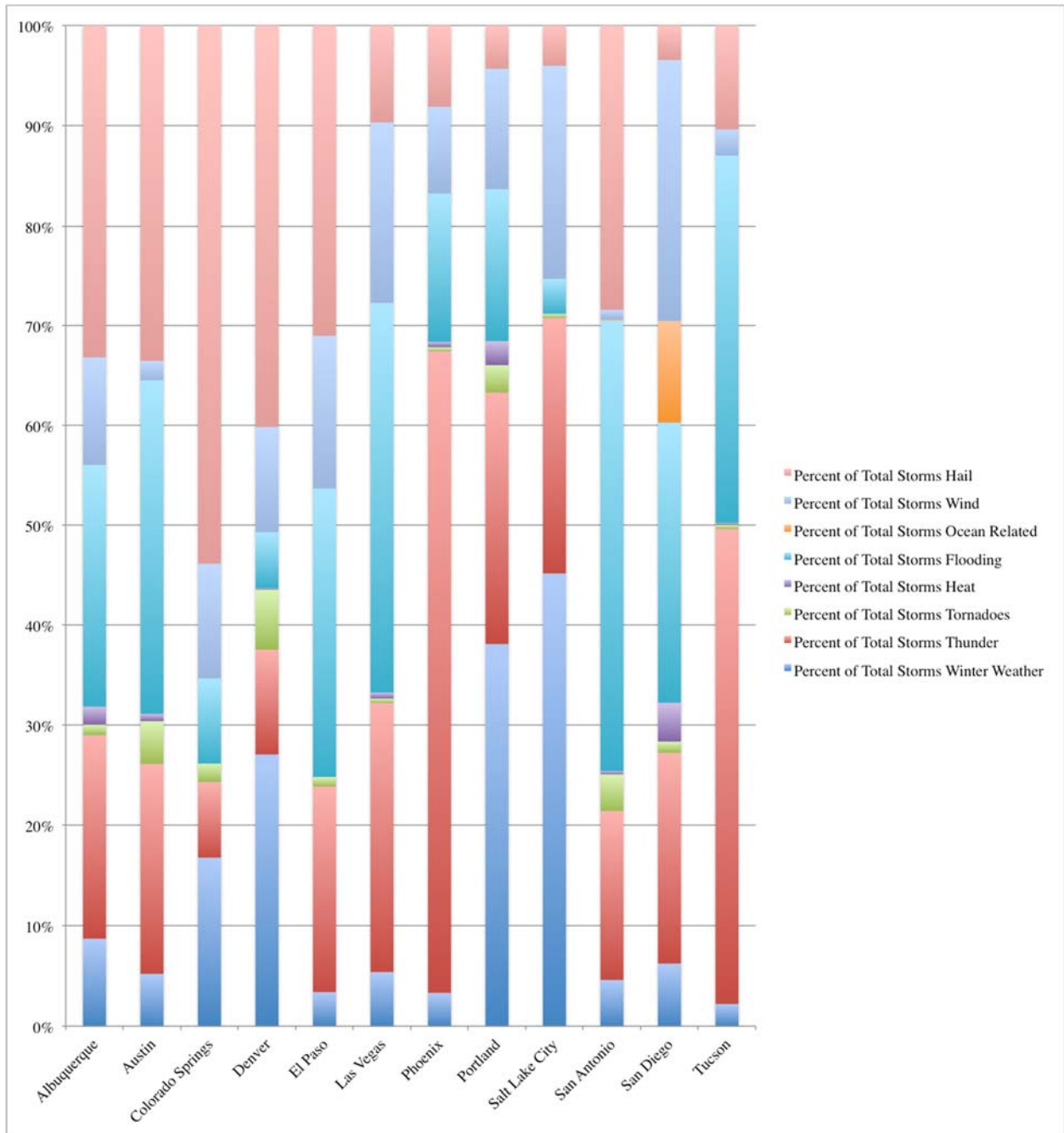


Figure 8: Extreme Event Property Damages from 1996 to 2016 by MSA (% of Total Damages by Type)

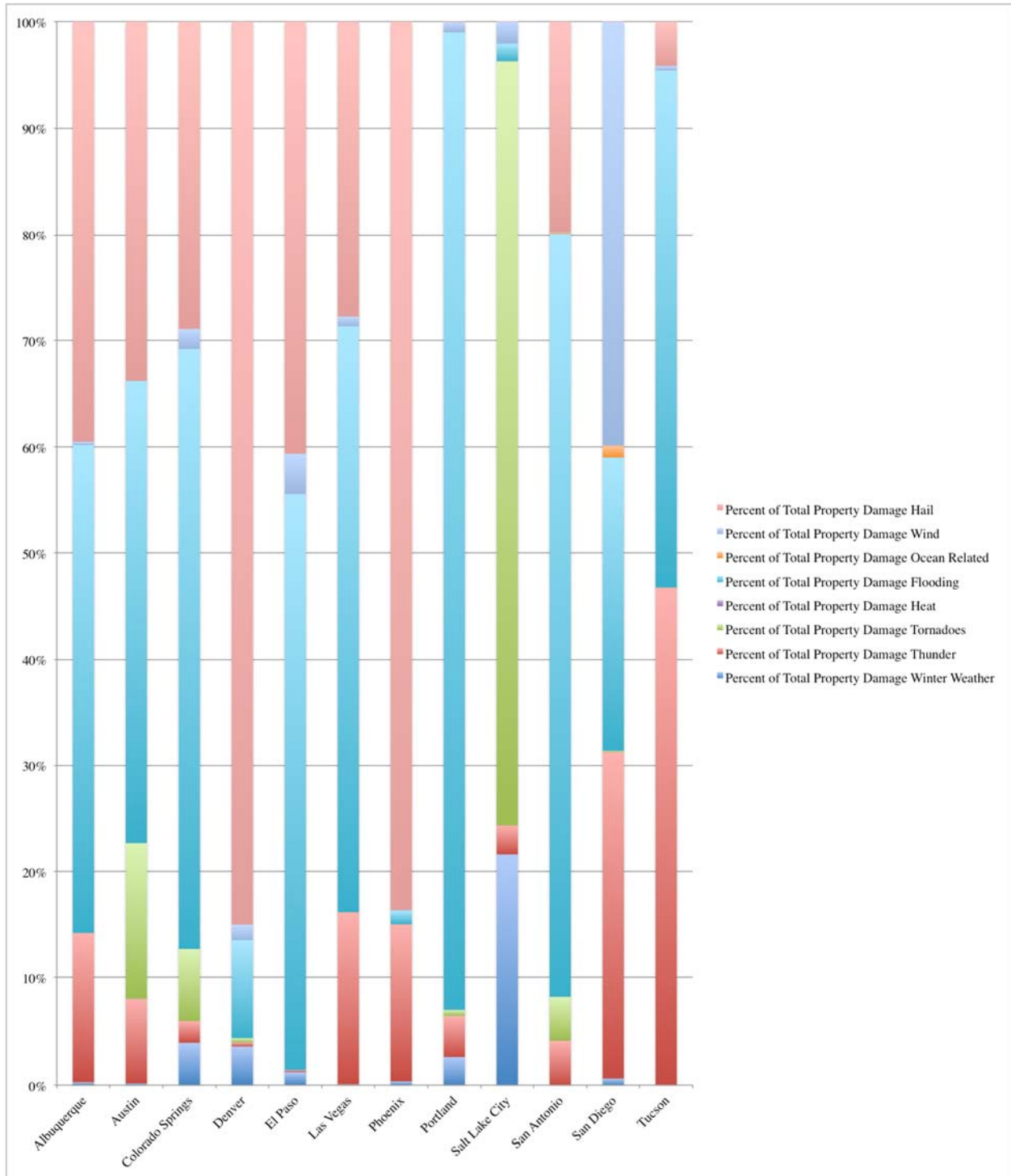
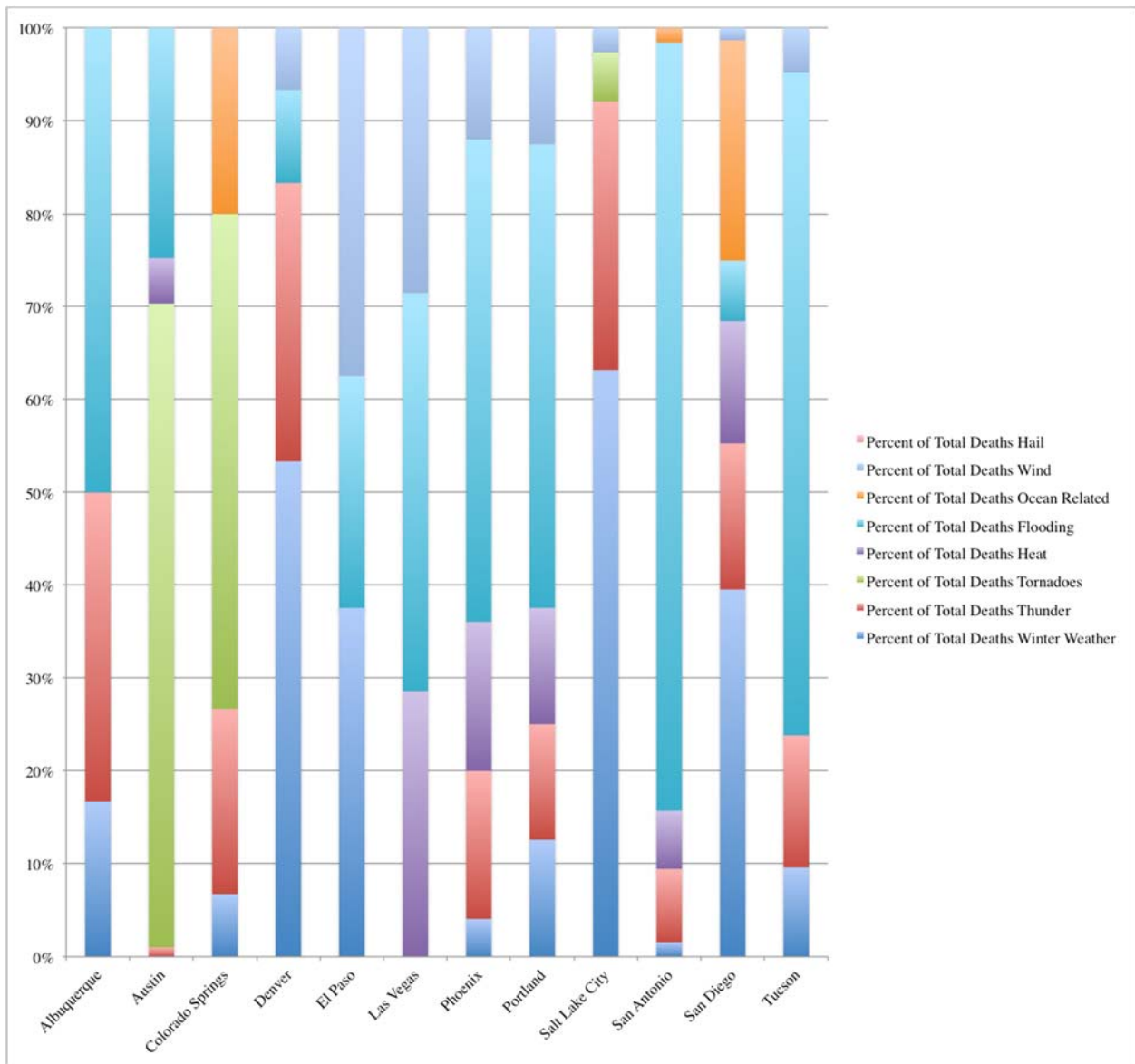


Figure 9: Extreme Event Fatalities from 1996 to 2016 by MSA (% of Total Fatalities by Type)



3.2.2. Extreme Weather Less Common in Tucson

There are some weather events that Tucson does not experience frequently—especially in comparison with the other MSAs. Tucson, unlike four of the MSAs within the comparison group, does not experience harsh winters. Only 2% of the total storms in Tucson are winter storms and they have caused no reported property damage. When winter storms do hit the Tucson area, they can pose a safety risk—10% of the total storm related deaths in the Tucson area are related to winter storms. Given that the winters in Tucson are mild, Tucsonans are not accustomed to winter safety protocols like citizens of Salt Lake City and Denver. Tucsonans may be caught off guard by hazardous road conditions caused by snow and ice.

At least 10% of storms in Colorado Springs, Denver, Portland, and Salt Lake City are winter storms. In Denver and Salt Lake City these storms cause over 30% of the total weather related deaths and over 20% of the total weather related injuries. Winter storms cause 63% of total

deaths and 72% of total injuries in Salt Lake City. Given Tucson's climate, weather during the typical winter months is relatively mild and freezing temperatures are less common.

Tucson is also relatively unaffected by tornadoes. Though, tornadoes are not very common in the Western United States. Denver is most affected by tornadoes with 6% of the total storms in Denver being tornadoes. Austin and Colorado Springs face the most damages from tornadoes in terms of property damage costs and deaths.

Tucson, and nine other MSAs, are completely unaffected by direct coastal weather events due to their geographic distance from coasts. There are only two coastal cities in this MSA grouping and, therefore, they are the only MSAs that are directly affected by coastal storms. That being said, only 8% of storms in San Diego are coastal storms, which cause about 20% of deaths and injuries in the MSA. San Antonio, the other "coastal" city, has experienced coastal extreme events in the data but suffers little to no damages caused by coastal storms.

Extreme heat is perhaps the most surprising weather event that has the fewest impacts on Tucson, according to the NCEI dataset. Four of the cities within these MSAs are considered to be some of the hottest cities in the United States (Las Vegas, Phoenix, San Antonio, and Tucson).³³ The definition for heat events (excessive heat or just heat), according to the NWS data documentation, is when the recorded temperature and level of humidity is above the locally established threshold warnings.³⁴ Given that the summer temperatures in these four cities always are quite high, "extreme heat" events do not occur as often. Average summer temperatures in these cities would be considered extreme heat events in many other MSAs. Data on fatalities from the Centers for Disease Control and Prevention paints a different picture of heat related deaths in Phoenix (443 deaths), Tucson (38 deaths), and Las Vegas (91 deaths). These deaths may not have been counted in the NCEI dataset because they were not directly associated with an extreme heat event or they were not reported through news outlets. High temperatures do cause harm to these MSAs, especially to vulnerable populations.^{35, 36, 37, 38}

4. Extreme Weather Impacts on Tucson's Business Sectors

In this section, we draw on insights from the academic literature to highlight examples of extreme weather impacts on Tucson and Southern Arizona's sectors. We include economic intuition behind heterogeneous impact of climate and weather on economic sectors. However, the impact of weather is not all negative. In this section, we also review examples of the positive impacts of weather on Tucson's business sectors.

³³ Climate Central. (2016, July 19). The hottest cities in U.S. Vs. The fastest warming. Retrieved September 16, 2016, from Climate Central, <http://www.climatecentral.org/news/fastest-warming-cities-20535>

³⁴ National Weather Service, 2007.

³⁵ Wilhelmi, O. V., & Hayden, M. H. (2010). Connecting people and place: a new framework for reducing urban vulnerability to extreme heat. *Environmental Research Letters*, 5(1), 014021.

³⁶ Hayden, M. H., Brenkert-Smith, H., & Wilhelmi, O. V. (2011). Differential adaptive capacity to extreme heat: a Phoenix, Arizona, case study. *Weather, Climate, and Society*, 3(4), 269-280.

³⁷ Harlan, S. L., Declet-Barreto, J. H., Stefanov, W. L., & Petitti, D. B. (2013). Neighborhood effects on heat deaths: social and environmental predictors of vulnerability in Maricopa County, Arizona. *Environmental Health Perspectives (Online)*, 121(2), 197.

³⁸ Harlan, S. L., & Ruddell, D. M. (2011). Climate change and health in cities: impacts of heat and air pollution and potential co-benefits from mitigation and adaptation. *Current Opinion in Environmental Sustainability*, 3(3), 126-134.

4.1. Examples of Negative Impacts of Weather Extremes on Tucson

We begin by reviewing illustrative examples of the negative impacts of weather extremes on Tucson's economy and society.

4.1.1. Flash Floods

Flooding has caused nearly half of the property damage in Tucson. Sheet flooding, when the water rises six inches above the designated channel, can be especially damaging.³⁹ This type of flooding is volatile and can cover roadways. Roadways are included in the storm water management plan for the City of Tucson. Storm water flows through the streets and eventually makes its way to "recharge in the regional water sources."⁴⁰ During extreme rain events the roads may flood and close for hours.⁴¹

Flooding can negatively impact business sectors through multiple channels, as shown in the academic literature. Suarez, et al. analyzed the performance of the Boston Metropolitan Area during floods. They found that disruptions to transportation networks followed extreme rain events.⁴² These disruptions deterred customers from being patrons at businesses, employees from working, and general transportation time to increase and become more dangerous. Suarez, et al. find that flood disruptions to transportation have economic costs that affect all citizens because of the flood's impacts on transportation. The negative impacts on transportation lead to general lack of productivity and spending within a city. They find that in the next 100 years, the time spent in cars due to flood-based road closures will increase by 80%. Given the propensity for flooding in Tucson, this general increase in lost productivity could also occur.

In addition, research finds that the infrastructure damage caused by floods leads to lack of productivity for employees and loss of commerce for the local economy.⁴³ The Department of Transportation has increased spending, and will continue to, as the presence of extreme weather has increased.⁴⁴ Flooding, and other extreme events, has caused a shift in local economic activities given that the weather has caused displacement of employees and productivity.⁴⁵ In addition, Koetse, et al. find that extreme weather, like flooding, can have an effect on the infrastructure surrounding transportation of goods.⁴⁶ Not only does flooding affect the local productivity, but floods can have negative affects nationally and internationally when it comes to importing and exporting goods.⁴⁷ Flooding can negatively impact the economy in many ways: property damage to businesses and homes, lives lost and injuries, and a loss in productivity for employees who cannot get to work or spend more time travelling to work.

³⁹Pima County. (2016). Flood hazard map and information - Pima county. Retrieved September 16, 2016, from Pima County, <http://webcms.pima.gov/cms/One.aspx?portalId=169&pageId=59581>

⁴⁰ City of Tucson. (2016). Floodplain Management Plan TSMS Phase V. (Exhibit A to Resolution No. 22619). Tucson, AZ.

⁴¹ City of Tucson. (2016, March 7). Floods and flash floods. Retrieved September 10, 2016, from City of Tucson, <https://www.tucsonaz.gov/em/floods-and-flash-floods>

⁴² Suarez, Anderson, Mahal, Lakshmanan, 2005.

⁴³ Rhodes, J., & Trent, R. (1993). Economics of floods, scour, and bridge failures. In Hydraulic Engineering (pp. 928-933). ASCE.

⁴⁴ Venner, M., & Zamurs, J. (2012). Increased maintenance costs of extreme weather events: preparing for climate change adaptation. Transportation Research Record: Journal of the Transportation Research Board, (2292), 20-28.

⁴⁵ *Ibid.*

⁴⁶ Koetse, Rietveld, 2009.

⁴⁷ *Ibid.*

4.1.2. Extreme heat

While there are few records in Tucson of extreme heat in the dataset we utilize for this white paper, high temperatures are the norm during the summer in Tucson. Annually, there are 62 days that reach 100-degrees Fahrenheit or higher and the average daily temperature is 84-degrees Fahrenheit (including both nighttime lows and daytime highs).⁴⁸ While many of Tucson businesses are indoors with air conditioning, outdoor occupations (construction, police officers, utility maintenance, etc.) are vulnerable to extreme heat regulations. When workers are exposed to extreme heat their productivity as well as mental and physical health can be compromised.⁴⁹ There are specific heat guidelines according to Occupational Safety and Health Administration. Employers must require their employees to take a certain number of breaks for varying amounts of time depending on the temperature and relative humidity.⁵⁰ Starting at 88.7-degrees Fahrenheit workers must start to take hourly breaks; at 102-degrees Fahrenheit work must stop all together. Given that Tucson has a high number of days over 100-degrees Fahrenheit and that the average temperature is in the 80s, outdoor workers in Tucson may have reduced capacity, relative to cooler temperatures.

Extreme heat can have psychological effects as well as physical detriments to health even to those who have adapted to the temperatures. It can cause general fatigue, increased aggression, cognitive performance, and increased risk of accidents.^{51, 52, 53, 54} If workplaces are not air-conditioned, or employees are working outside, heat can cause decreases in productivity and output. Though, people can acclimate to extreme heat and begin to perform better in all three realms.⁵⁵ The elderly, children, those in poverty, and those who are not acclimated are at higher risk of health impacts.

The tourism industry in Arizona is sensitive to these heat extremes and tourism is one of the largest exports of the state. In 2010 nearly 37 million visitors to the state spent \$18 billion—80% of these visitors were not from Arizona.⁵⁶ There were six hiker heat related deaths during the hottest weeks in Tucson history (the week of June 21st 2016).⁵⁷

⁴⁸ NOAAs National Weather Service, & Team, N. I. S. (2016, June 22). National weather service - NWS Tucson. Retrieved August 15, 2016, from <http://www.wrh.noaa.gov/twc/climate/tus.php>

⁴⁹ Kjellstrom, T., Holmer, I., & Lemke, B. (2009). Workplace heat stress, health and productivity an increasing challenge for low and middle-income countries during climate change. *Global Health Action*, 2.

⁵⁰ The Wet Bulb Globe Temperature heat index measures the amount of humidity in the air as well as the temperature giving a range of ideal conditions for workers.

⁵¹ Tian, Z., Zhu, N., Zheng, G., & Wei, H. (2011). Experimental study on physiological and psychological effects of heat acclimatization in extreme hot environments. *Building and Environment*, 46(10), 2033-2041.

⁵² Anderson, C. A. (1989). Temperature and aggression: ubiquitous effects of heat on occurrence of human violence. *Psychological bulletin*, 106(1), 74.

⁵³ Hancock, P. A., & Vasmatazidis, I. (2003). Effects of heat stress on cognitive performance: the current state of knowledge. *International Journal of Hyperthermia*, 19(3), 355-372.

⁵⁴ Kjellstrom, T., Kovats, R. S., Lloyd, S. J., Holt, T., & Tol, R. S. (2009). The direct impact of climate change on regional labor productivity. *Archives of Environmental & Occupational Health*, 64(4), 217-227.

⁵⁵ Tian et al., 2011

⁵⁶ Repetto, R. (2011). *Economic and environmental impacts of climate change in Arizona*. Demos, New York, 8.

⁵⁷ Egeland, A. (2016, June 21). Missing German hiker found dead in Tucson; weekend heat toll rises to 6. *Arizona Central*. Retrieved from <http://www.azcentral.com/story/news/local/arizona-breaking/2016/06/21/missing-german-hiker-found-dead-tucson-weekend-heat-toll-rises-6/86215376/>

⁵⁷ Service, No. N. W., & Team, N. I. S. (2016, June 22). National weather service - NWS Tucson. Retrieved October 16, 2016, from <http://www.wrh.noaa.gov/twc/climate/tus.php>

4.1.3. Hail

Hail can be extremely costly to the agriculture sector.⁵⁸ Hail is often sporadic and it is very difficult to mitigate the damage.⁵⁹ While other areas in the United States are more affected by crop-hail damage, it does affect the agricultural sectors within Southern Arizona. Coles and Scott conducted a qualitative study on the farmers within Pima County. They found that hail was the most concerning extreme weather event for farmers near Tucson.⁶⁰ Crops can be completely damaged by hail (expected or not) whereas livestock ranchers can remain unscathed. The variability of extreme weather events has caused many farmers in Pima County to change professions or supplement their farming income. These farmers believe that hail makes them especially vulnerable to crop loss.⁶¹ There are indirect impacts of the crop loss caused by hail.⁶² As these farmers lose their products (primarily cotton), the same crops must be imported to Arizona or the market for supplementary goods (other fibers) will benefit while the market for complementary goods (wheat) will decrease.⁶³

4.2. Examples of Positive Impacts of Weather on Tucson

The story is not all negative. Tucson also enjoys benefits from its weather. In this section, we review informative examples of the positive impacts of weather on Tucson's economy and society.

4.2.1. Mild Seasonal Temperature

As stated earlier, tourism is a large sector for Arizona. While high heat days could deter or be detrimental to tourists, the mild winters in Southern Arizona are a draw. In 2015 there were 6.5 million domestic overnight visitors directly spending \$3.4 billion.⁶⁴ Pima and Cochise County State Park visitations peaked during March and April (average temperature ranging from 71-degrees Fahrenheit to 81-degrees Fahrenheit) in 2015 at nearly 65,000 total visits. Airport traffic was also highest during March and April.^{65, 66} Bigano, et al. analyzed the impacts of one degree fluctuations in temperature on the number of nights tourists stayed during their Italian vacations. For summer months a 1-degree increase in temperature increased the amount of bed-nights for domestic tourism. For winter months a 1-degree increase in temperature decreased the amount of bed nights.⁶⁷ Theoretically, in Tucson, this could be the opposite. In the winter a 1-degree increase

⁵⁸ Changnon Jr, S. A. (1972). Examples of economic losses, from hail in the United States. *Journal of Applied Meteorology*, 11(7), 1128-1137.

⁵⁹ Coles, A. R., & Scott, C. A. (2009, November). Vulnerability and adaptation to climate change and variability in semi-arid rural southeastern Arizona, USA. In *Natural Resources Forum* (Vol. 33, No. 4, pp. 297-309). Blackwell Publishing Ltd.

⁶⁰ *Ibid.*

⁶¹ *Ibid.*

⁶² Changnon, S. A. (2005). The 1993 flood's aftermath: risks, root causes, and lessons for the future. *Journal of Contemporary Water Research & Education*, 130(1), 70-74.

⁶³ Boggess, W., Lacewell, R. D., Zilberman, D., Carlson, G. A., & Miranowski, J. A. (1993). Economics of water use in agriculture. *Agricultural and environmental resource economics.*, 319-391.

⁶⁴ Arizona Office of Tourism. (2016, August 9). Arizona Office of Tourism. Retrieved August 10, 2016, from Arizona Office of Tourism, <https://tourism.az.gov/2015-year-end-data-review-tucson-southern-region>

⁶⁵ *Ibid.*

⁶⁶ Ponnaluru, S. (2005). Visitation to the national parks of the Southwest: The influence of economic and climate variables (Doctoral dissertation, Master's thesis. Tucson, AZ: Department of Agricultural and Resource Economics, University of Arizona).

⁶⁷ Bigano, A., Gorla, A., Hamilton, J. M., & Tol, R. S. (2005). The effect of climate change and extreme weather events on tourism.

could increase bed-nights, while a 1-degree increase during the summer could be detrimental to tourism.

Not only does Southern Arizona draw short-term guests during the winter, but the mild temperatures also lure second-home owners avoiding harsh winters called snowbirds. Farqhar estimates that 300,000 snowbirds relocated to Arizona during the winter of 2002-2003. During this time snowbirds added an estimated \$600 million to the Arizona economy.⁶⁸

4.2.2. Sunshine

On average Tucson is sunny 85% of the year.⁶⁹ Mayes has called Arizona, “the Saudi Arabia of solar” and encourages the use of solar energy as one of her positions of the Arizona Corporation Commission, Arizona’s public utility commission.⁷⁰ Arizona’s sunny climate makes it a prime location for solar energy. The Arizona Corporation Commission has mandated that 15% of total energy production be sustainable by 2025.⁷¹ In Arizona there are over 375 solar companies; as of 2015, \$582 million has been invested in solar energy in the state.⁷² In addition to direct energy production, Arizona’s sunshine can have positive impacts on individuals’ moods. According to the Mayo Clinic, spending more time in the sun can mitigate seasonal affective disorder (SAD). Sunshine can increase serotonin levels, which leads to happier dispositions.⁷³

4.2.3. Mild Winter Weather

According to Maze, et al. extreme winter weather affects traffic flow and traffic safety. The dangerous conditions lead to a lack in productivity—employees will choose to stay home on the majority of snowy days.⁷⁴ Given Tucson’s climate, winter weather is relatively mild. Freezing temperatures and precipitation do not often mix, so roads are not as likely to freeze or to become hazardous. And, because winter storms are not very common, the fatalities and property damage that occur due to these storms and the time lost due to snowy weather is far lower than in other MSAs like Salt Lake City and Denver.

5. Opportunities and Risk Reduction Strategies

Given the impacts of extreme weather on Tucson’s business sectors, what can be done in response? In this section, we draw on the academic literature to highlight examples of opportunities and risk reduction strategies to combat extreme weather in Tucson and Southern Arizona. Rather than an

⁶⁸ More recent research has not yet been completed. They claim that both the migratory nature of this population, and how quickly the population is growing, make it difficult to measure. Farquhar, L., Hogan, T., & Happel, S. (2003, June 23). ASU news & information from the office of media relations and public information. Retrieved October 16, 2016, from Arizona State University, https://www.asu.edu/news/community/snowbird_count_062503.htm

⁶⁹ National Oceanic and Atmospheric Administration. (2004). Ranking of cities based on % annual possible sunshine in descending order from most to least average possible sunshine. Retrieved September 23, 2016, from NOAA, <http://www1.ncdc.noaa.gov/pub/data/ccd-data/pctposrank.txt>

⁷⁰ Arizona Corporation Commission. (2013). Proceedings from Open Meeting 2013: comments and notes from December 2013 meeting. Phoenix, AZ.

⁷¹ Arizona Corporation Commission. (2014). Renewable Energy Standard and Tariff. Retrieved October 16, 2016, from Arizona corporation commission, <http://www.azcc.gov/divisions/utilities/electric/environmental.asp>

⁷² Association, S. E. I. Arizona solar. Retrieved October 16, 2016, from <http://www.seia.org/state-solar-policy/arizona>

⁷³ Staff, M. C. (2014). Seasonal affective disorder (SAD) causes. Mayo Clinic. Retrieved from <http://www.mayoclinic.org/diseases-conditions/seasonal-affective-disorder/basics/causes/con-20021047>

⁷⁴ Maze, T., Agarwai, M., & Burchett, G. (2006). Whether weather matters to traffic demand, traffic safety, and traffic operations and flow. Transportation research record: Journal of the transportation research board, (1948), 170-176.

exhaustive analysis of all options, this section motivates the economic intuition behind various strategies with real world examples relevant to Tucson: information, adaptation, and insurance.

5.1. Information

We overview information as our first risk reduction strategy. Information is a critical ingredient to combat natural disasters. Information, in and of itself, does not reduce damages or impacts. It must be combined with other strategies such as evacuations or seeking shelter to reduce fatalities or physical protection strategies to reduce damages. Nonetheless, it is a key component to make an informed decision regarding the best strategies to employ. Without good information, individuals and policy makers may unknowingly choose a suboptimal strategy, or they may spend resources in less efficient or effective manners. Thus, good quality information surrounding extreme weather, both in the moment as conditions are developing as well as longer term information surrounding the risks of weather extremes, are important for both public and private decision making. There are many types and sources of extreme weather information. We review three information products that are important for extreme weather: forecasts, warnings, and educational campaigns.

Weather forecasts are projections of near-term weather typical on times scales of days.⁷⁵ These forecasts are useful for individuals and businesses to plan accordingly regarding daily operations under expectations of future weather. Weather forecasts can be both publicly and privately provided. For example, the National Weather Service at <http://www.weather.gov/>, provides a seven-day forecast of key atmospheric conditions including maximum and minimum temperatures and information around general weather conditions such as wind speeds and precipitation probabilities. In addition to publicly provided weather forecasts, weather forecasts are available from private companies. These companies provide both general and detailed forecasts that can range from minute-level precipitation intensities to 90-day forecasts.⁷⁶ These public and private products are not view as competitors, but have historically been encouraged as forms of public-private partnerships to provide the best information to the public.^{77,78}

In contrast with more general weather forecasts, watches and warnings are a form of information to signal the high probability of impending extreme weather. Developed in 1995, Philadelphia Hot Weather–Health Watch/Warning System (PWWS) has been a successful example of a local-level weather extreme warning system. The system is estimated to have saved 117 lives, generating system benefits of \$468 million during its first three years of operation in the city.⁷⁹ In addition, the National Weather Service’s tornado warning has been shown to reduce tornado-related fatalities and injuries.⁸⁰ Significant to Southern Arizona, the Arizona Department

⁷⁵ Glahn, H. R., & Ruth, D. P. (2003). The new digital forecast database of the National Weather Service. *Bulletin of the American Meteorological Society*, 84(2), 195.

⁷⁶ For example, websites like Accuweather (<http://www.accuweather.com/>) or Intellicast (<http://www.intellicast.com/>). In addition, some weather websites report local weather reports generated by individuals across the public, including Weather Underground (<https://www.wunderground.com/>).

⁷⁷ Policy Statement on the Weather Service/Private Sector Roles. (1991). Retrieved October 16, 2016, from <http://www.nws.noaa.gov/im/fedreg.htm>

⁷⁸ Abunassar, E. (2007). National Oceanic and Atmospheric Administration (NOAA) Home Page. Retrieved October 16, 2016, from http://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216-112.html

⁷⁹ Kalkstein, L. S., Jamason, P. F., Greene, J. S., Libby, J., & Robinson, L. (1996). The Philadelphia hot weather-health watch/warning system: development and application, summer 1995. *Bulletin of the American Meteorological Society*, 77(7), 1519-1528.

⁸⁰ Simmons, K., & Sutter, D. (2013). *Economic and societal impacts of tornadoes*. Springer Science & Business Media.

of Transportation is developing a dust detection and warning system for I-10 between Tucson and Phoenix. The system should be completed by the fall of 2018.⁸¹ However, no warning system is perfect and credibility can be reduced due to false alarms.⁸² In addition, individuals may wait for credible confirmation that a warning is real before protecting themselves, attenuating the protective impact of the systems.⁸³ Nonetheless, these watch and warning systems provide critical and important information to help inform extreme weather decision making in the moment.

Lastly, another important source of information are education campaigns designed to inform the public about the risks of extreme weather as well as what to do if they find themselves in an event. Real work examples include the National Weather Services' "Turn Around Don't Drown" campaign to educate the public regarding the dangers of walking and driving around floodwater, which are the leading two causes of flood related deaths in the United States.⁸⁴ In addition, the Arizona Department of Transportation's "Pull Aside Stay Alive" campaign brings awareness to the threats of dust storms and the National Weather Services' Arizona H.E.A.T. awareness campaign (Hydrate, Environment/Weather, Awareness, Take Action) aims to inform the public of the dangers and responses to extreme heat.^{85, 86}

5.2. Adaptation and Risk Reduction Strategies

Adaptation and risk reduction strategies are important to reduce extreme weather losses. Selecting particular strategies depends on many factors including the relative costs and benefits, the loss targeted (such as protecting humans versus property), the extreme weather type to combat, as well as the timing of implementing the strategies. In this section, we overview the intuition behind these key pieces that go into selecting an adaptation or risk reduction strategy for each context.

We define adaptation and risk reduction strategies broadly as interventions to reduce the level of losses from extreme weather. These could include engineering solutions such as hurricane shutters to protect homes in Florida, sea walls to keep back high tides, cellars for tornado shelter, or building a home slightly farther from a river to avoid flooding. From many strategies available, the economic literature can shed light on which strategies to choose. From an efficiency objective, select a strategy that gives maximum net benefits, or the benefits minus the costs of the strategy.⁸⁷ The benefit of each strategy is the difference between losses without the strategy minus the losses

⁸¹ Arizona Department of Transportation. (2016). Design work to begin on I-10 dust detection and warning system. Retrieved October 16, 2016, from <https://www.azdot.gov/media/News/news-release/2016/10/12/design-work-to-begin-on-i-10-dust-detection-and-warning-system>

⁸² Golden, J. H., & Adams, C. R. (2000). The tornado problem: Forecast, warning, and response. *Natural Hazards Review*, 1(2), 107-118.

⁸³ Brotzge, J., & Donner, W. (2013). The tornado warning process: A review of current research, challenges, and opportunities. *Bulletin of the American Meteorological Society*, 94(11), 1715-1733.

⁸⁴ National Weather Service (2016). NWS Flood Safety Home Page. Retrieved October 16, 2016, from <http://www.nws.noaa.gov/os/water/tadd/>

⁸⁵ Arizona Department of Transportation. (2016). Pull Aside Stay Alive. Retrieved October 16, 2016 from <http://www.pullasidestayalive.org/>

⁸⁶ National Weather Service - Phoenix (2016). Arizona Heat Awareness. Retrieved October 16, 2016, from <http://www.wrh.noaa.gov/psr/heat/>

⁸⁷ Mendelsohn, R. (2000). Efficient adaptation to climate change. *Climatic Change*, 45(3-4), 583-600.

with the strategy implemented.^{88, 89} Is it important to note that efficient adaptation and risk reduction strategies may not reduce extreme weather losses to zero. This is because the costs to implement the strategies may be very large for complete reduction of losses, especially with regards to property damage.

A second important consideration when assessing adaptation and risk reduction strategies is the timing. When should you implement a strategy? New research shows that adaptation and risk reduction strategies have twice the impact in reducing damages when implemented before a disaster, rather than after.⁹⁰ Thus, spending more money up front will likely increase efficiency by reducing losses at a lower cost. However, currently in the United States, a majority of disaster funds are spent after an event, both for cleanup and recovery as well as longer-term adaptation and risk reduction efforts. One reason for this is because extreme weather risks are more salient, or on people's minds, after an extreme weather event, as people tend to forget about extreme weather risks during periods of calm.^{91, 92}

A third consideration in assessing adaptation and risk reduction strategies are differences in reducing damages versus fatalities. Some strategies may reduce both damages and fatalities. For example, increasing building code stringency may decrease damages to the property itself as well as better protect humans inside from extreme winds.⁹³ However, sometimes strategies may reduce fatalities or damages, but increase the other. For example, research has found that, due to advances in hurricane forecasting and evacuation coordination, hurricane fatalities have decreased in the United States. However, by reducing the risk of fatality in coastal areas, more people have moved to coastal areas, increasing the amount of property in the coast. This has likely led to increasing hurricane damages.⁹⁴ Thus, there can be tradeoffs between reducing fatalities and damages from weather extremes that should be taken into account when selecting a strategy.

One example of successful adaptation in Southern Arizona is adaptation to heat. Given that, on average, there are 62 days per year above 100-degrees Fahrenheit, one may think that the people of Southern Arizona are more at risk for death from extreme temperatures.⁹⁵ Instead, through adaptation strategies such as air conditioning and modifying outdoor activities to avoid the heat of the day, heat events, that may cripple other areas, are not highly fatal in Southern Arizona. For example, a single heat event in Chicago, Illinois where temperature reached only

⁸⁸ For example, if household damages from a hurricane without hurricane shutters installed is \$10,000 and damages from an identical house under the same hurricane with hurricane shutters is \$8,000, the benefits of the hurricane shutters is \$2,000 ($=\$10,000-\$8,000$).

⁸⁹ Bakkensen, L. and Mendelsohn, R. (2016). Risk and Adaptation: Evidence from Global Hurricane Damages and Fatalities. *Journal of the Association of Environmental and Resource Economists* 3(3): 555-587.

⁹⁰ Davlasheridze, M., Fisher-Vanden, K., & Klaiber, H. A. (2016). The Effects of Adaptation Measures on Hurricane Induced Property Losses: Which FEMA investments have the highest returns?. *Journal of Environmental Economics and Management*. *Forthcoming*.

⁹¹ Gallagher, J. (2014). Learning about an infrequent event: evidence from flood insurance take-up in the United States. *American Economic Journal: Applied Economics*, 6(3), 206-233.

⁹² Atreya, A., Ferreira, S., & Kriesel, W. (2012). Forgetting the flood: Changes in flood risk perceptions over time. *Flood Risk and Homeowners' Flood Risk Perceptions: Evidence from Property Prices in Georgia*, 5-34.

⁹³ Brooks, N. (2003). Vulnerability, risk and adaptation: A conceptual framework. *Tyndall Centre for Climate Change Research Working Paper*, 38, 1-16.

⁹⁴ Sadowski, N. C., & Sutter, D. (2005). Hurricane fatalities and hurricane damages: are safer hurricanes more damaging?. *Southern Economic Journal*, 422-432.

⁹⁵ NOAA's National Weather Service, 2016.

106-degrees in the summer of 1995 led to almost 700 fatalities.^{96,97} Similarly, the 2003 French heat wave led to almost 15,000 fatalities when temperatures reached 105-degrees Fahrenheit.⁹⁸ In comparison, according to the Centers for Disease Control and Prevention, there have been 38 heat related deaths in Pima County in the past 14 years.⁹⁹ While individuals in Arizona perish due to heat, the state does not often see the wide scale fatalities from heat, due in part to the effectiveness of its adaptation strategies.

A second and important example of adaptation are infrastructure projects to mitigate flood risk. Historically, the U.S. Army Corps of Engineers has been engaged in large scale flood mitigation projects across the United States, including river channelization and dams, and typically employs explicit estimates of the costs and benefits of each proposed project.¹⁰⁰ These projects can have big payoff, leading to an estimated \$13.3 billion in avoided flood damages during the spring of 2015.¹⁰¹ More locally, the Pima County Flood District is also actively engaged in flood mitigation and has completed over 250 infrastructure projects related to flood hazard mitigation. Both Tucson and Pima County are actively involved in infrastructure projects in the flood zones within the regions.¹⁰² In addition to the costs and benefits of infrastructure projects, it is important to consider the social context of infrastructure and other flash flood mitigation strategies.¹⁰³

5.3. Insurance

Insurance is another option to combat the negative impacts of extreme weather. Insurance can be beneficial because it can smooth out extreme weather costs. Instead of a business or household suffering large losses in any given year, they can, instead, pay a known annual premium and have the peace of mind that losses will be covered if an extreme event hits. Insurance premiums are set based on expected damages, or the probability of a loss occurring times the damages, if the event does occur. If premiums just equal expected damages, this is called actuarially fair insurance.¹⁰⁴ Insurance premiums from private companies are typically set at rates slightly above actuarially fair levels in order to cover the business costs. Public insurance premiums are not always set at the actuarially fair level, depending on the policy goals. For example, if affordability is a goal, premiums may be subsidized, or set at rates lower than the actuarially fair rate. However, there are other policy tools that can ensure affordability without lowering the premiums.¹⁰⁵

The largest public insurance program in the United States is the National Flood Insurance Program. Started in 1968 by Congress, this program was created to fill a void in the private

⁹⁶ Semenza, J. C., Rubin, C. H., Falter, K. H., Selanikio, J. D., Flanders, W. D., Howe, H. L., & Wilhelm, J. L. (1996). Heat-related deaths during the July 1995 heat wave in Chicago. *New England journal of medicine*, 335(2), 84-90.

⁹⁷ Note that humidity was also a factor in the Chicago heatwave, which likely contributed to the fatalities.

⁹⁸ Poumadere, M., Mays, C., Le Mer, S., & Blong, R. (2005). The 2003 heat wave in France: dangerous climate change here and now. *Risk analysis*, 25(6), 1483-1494.

⁹⁹ Calculated by the authors using the Center for Disease Control and Prevention's National Vital Statistics System Mortality Data available online at: <http://www.cdc.gov/nchs/nvss/deaths.htm>

¹⁰⁰ <http://www.iwr.usace.army.mil/Missions/Flood-Risk-Management/Flood-Risk-Management-Program/>

¹⁰¹ <http://www.usace.army.mil/Media/News-Archive/Story-Article-View/Article/616269/army-corps-of-engineers-projects-prevent-133-billion-in-flood-damages-during-sp/>

¹⁰² Information available here: http://webcms.pima.gov/government/flood_control/

¹⁰³ Montz, B. E., & Gruntfest, E. (2002). Flash flood mitigation: recommendations for research and applications. *Global Environmental Change Part B: Environmental Hazards*, 4(1), 15-22.

¹⁰⁴ Arrow, K. J. (1974). Optimal insurance and generalized deductibles. *Scandinavian Actuarial Journal*, 1974(1), 1-42.

¹⁰⁵ Kousky, C., & Kunreuther, H. (2014). Addressing affordability in the national flood insurance program. *Journal of Extreme Events*, 1(01), 1450001.

insurance market. To date, more than 20,000 communities participate with approximately 5.6 million policies across the nation in 2009.¹⁰⁶ Individuals can go online at www.floodsmart.gov to assess the flood risk for their home as well as receive information about premium prices.

In addition, insurance is offered for other types of extreme weather. Hail can be very damaging to crop in the United States but hail insurance can help to remedy the loss. The insurance follows a traditional insurance model. Colorado had some of the highest risks. Tobacco, corn, and cotton are the most vulnerable to hail damage.¹⁰⁷ Hail is very damaging to Pima and Cochise Counties—hail insurance can be expensive but can be useful given potential damage. Hail does the most damage and is the most commonly occurring extreme weather event in Pima County. Cotton and wheat farmers also claim that hail is the most difficult to mitigate because hail can occur without warning.¹⁰⁸ But, as Changnon finds, drought is more detrimental to crops than hail as the scale is greater and less isolated. Farmers in Arizona and other drought ridden areas have learned to grow and farm in drought resistant ways in order to adapt to the setting. Theoretically, extreme and surprising weather events can be mitigated through certain activities and the damage can be offset through insurance.¹⁰⁹

6. Future Opportunities: Projections for Tucson’s Economy and Weather Extremes

Tucson is always changing and the future will bring many new opportunities. In this section, we review the current knowledge of future projections for Tucson’s economy as well as extreme weather events. Better understanding what the future holds will allow individuals and policy officials to make good decisions regarding risk reduction strategies as well as opportunities to capitalize on future conditions.

6.1. Projections for Tucson’s Future Economy

Based on the University of Arizona’s Economic and Business Research Center projections, the employment in Tucson is forecasted to grow by 43 percent in the next 30 years—the population and, thus, the employment of Tucson is forecasted to grow steadily in the next three decades. The current sectoral composition is predicted to shift in the next 30 years. Three sectors, in particular, are expected to change in size: government, hospitality and leisure, and utilities and transportation. The government sector is expected to be a ten percentage point smaller share of total employment in the next 30 years. What is now the largest sector in Tucson is forecasted to shift to the future average size. The hospitality and leisure sector, on the other hand, is forecasted to increase by eight-percentage points of the total employment in the next 30 years. It is forecasted to become Tucson’s largest employment sector. The education and health services sector is not forecasted to change in relative share by 2046, but will remain the second largest employment sector in Tucson at 18 percent of total employment. The utilities and transportation sector is forecasted to increase by 12-percentage points of total employment by 2046—the largest percentage increase for employment in Tucson. This sector is currently one of the smallest in the Tucson employment (at three-percentage points of total employment); it is forecasted to be the third largest employer in

¹⁰⁶ Kousky, C. (2010). Understanding the demand for flood insurance. *Natural Hazards Review*, 12(2), 96-110.

¹⁰⁷ Changnon Jr, S. A. (1972). Examples of economic losses, from hail in the United States. *Journal of Applied Meteorology*, 11(7), 1128-1137.

¹⁰⁸ Coles, A. R., & Scott, C. A. (2009, November). Vulnerability and adaptation to climate change and variability in semi-arid rural southeastern Arizona, USA. In *Natural Resources Forum* (Vol. 33, No. 4, pp. 297-309). Blackwell Publishing Ltd.

¹⁰⁹ Changnon Jr, S. A. (1972). Examples of economic losses, from hail in the United States. *Journal of Applied Meteorology*, 11(7), 1128-1137.

30 years. As the employment in Tucson increases, the configuration of the sectoral make-up will also change.

6.2. Projections for Tucson's Future Weather Extremes

In addition to future changes in Tucson's economy, extreme weather events are expected to occur with different frequencies. According to the Assessment of Climate Change in the Southwest United States, the Southwest will generally become hotter in the future and the periods of extreme heat will expand.¹¹⁰ All of the predictions mentioned within this section are taken from this report on the climate future of the Southwest. The Southwest National Climate Assessment (SW-NCA) uses two emissions scenarios for their prediction models. The current estimate for high emissions is that by 2100 the average temperature in the Southwest will increase by 9-degrees Fahrenheit and the variance in temperature will widen. The current estimate for low emissions is a 4-degrees Fahrenheit.¹¹¹ The amount of freeze days is expected to increase by at least 10 days per year for the entire Southwest. The highest increase of freeze days (of 38 days) will occur in the far interior west states (Colorado and New Mexico). While there will be a wider spread within the average temperatures, the smallest spread will occur on the coast and southernmost cities, like Tucson. The high temperatures will increase while the low temperatures will not decrease proportionately.

According to the high emissions projection, the level of precipitation could decrease by 12% in the southern cities. Warmer air holds more moisture meaning extreme storms may produce more precipitation in comparison to today's extreme storms. With population increases, and increased asphalt and cement use, there will be less absorbent soil to naturally reduce flooding.¹¹² The frequency of the North American Monsoon is also expected to decrease.¹¹³ According to the high emissions estimate there could be a decrease in monsoonal storms, given the increase in temperature, by 10-20%. The SW-NCA estimates that the monsoons could become more "moderate." The decrease in precipitation and increasing temperatures could affect the water flow of major Southwest waterways such as the Colorado River.

The effects of increased heat in Southwest cities, which already experience Urban Heat Island effects, may be exacerbated increasing temperatures and heat waves coupled with reductions in water absorption increasing the amount of flooding.^{114, 115} While the overall level of precipitation is expected to decrease, extreme storms may become more common and intense, leading to higher damages for flooding.¹¹⁶ Extreme warm temperatures will feel more pronounced with the increase of humidity in the air. Extreme cold temperatures may decrease in frequency but not in extremity. Thus, it is important to keep these predictions of future weather extremes in mind in business and policy planning decisions.

¹¹⁰ Jardine, A., Merideth, R., Black, M., & LeRoy, S. (2013). Assessment of climate change in the southwest United States: a report prepared for the National Climate Assessment. Island press.

¹¹¹ "Temperature increases are largest in summer, with means around 3.5°F (1.9°C) in 2021–2050, 5.5°F (3.1°C) in 2041–2070, and 9°F (5°C) in 2070–2099. The least warming is in winter, starting at 2.5°F (1.4°C) in 2021–2050 and building to almost 7°F (3.9°C) in 2070–2099. However, it is important to note that differences between individual model temperature changes are relatively large." *Ibid.*

¹¹² *Ibid.*

¹¹³ Models are not as accurately specified yet for the specific predictions of the North American Monsoon.

¹¹⁴ Stone, B., Hess, J. J., & Frumkin, H. (2010). Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities. *Environmental health perspectives*, 118(10), 1425-1428.

¹¹⁵ Wilhelmi, O. V., & Hayden, M. H. (2010). Connecting people and place: a new framework for reducing urban vulnerability to extreme heat. *Environmental Research Letters*, 5(1), 014021.

¹¹⁶ The number of extreme storms may not become more common in and of themselves. But, the proportion of extreme storms to "normal" storms will increase.

7. Conclusion

Weather impacts our everyday life and provides both benefits and harm to economic sectors. In this white paper, we provide insight into the impact of extreme weather on Tucson's business sectors. We begin by analyzing data on Tucson's economy, including gross domestic product and employment by sector, as well as Tucson's weather extremes. We compare the story in Tucson with that of other Metropolitan Statistical Areas across the Western United States. We highlight examples of the impacts of extreme weather on Tucson's economy including flash floods, extreme heat, and hail – some of Tucson's most notorious extremes. We also overview some of the positive impacts of weather, including for the winter tourism sector and growing solar industry. We highlight the academic insight surrounding strategies to combat extreme weather losses including information, adaptation, and insurance. Lastly, as Tucson is always moving forward, we review forecasts of future economic activity and weather extremes.

Weather extremes significantly impact the economy of Tucson and Southern Arizona. Thus, it is up to individuals, businesses, and policy makers to take the risks into consideration in decision making for risk reduction, weighing the costs and benefits of various strategies. In addition, business sectors have heterogeneous impacts. Some are more impacted, such as outdoor workers in construction or the energy sector. However, there are many opportunities to capitalize on the unique weather of Tucson and Southern Arizona, for example through our tourism industry. Especially given that the hospitality and leisure sector is forecasted to grow, understanding the potential effects of extreme weather and how to utilize information networks will be imperative. Proactive strategies to understand our risks, minimize losses in a cost effective manner, as well as enjoy the benefits of weather will ensure that Tucson and Southern Arizona continues to grow and prosper for years to come.

Data Appendix

The Economic Impacts of Extreme Weather: Tucson and Southern Arizona's Current Risks and Future Opportunities

This data appendix details the data sources and processing procedure for the data used in the Making Action Possible white paper.

A. Gross Domestic Product

Gross domestic product data for economic sectors in each of the 12 Western Metropolitan Statistical Area (MSA) were obtained from the U.S. Bureau of Economic Analysis (BEA) for the years 2001 to 2014. All figures are inflation adjusted and are presented in real 2009 US dollars.¹¹⁷ Each sector was grouped into the categories used by the Making Action Possible Dashboard (MAP): construction, education and health services (including higher education), government, information (including all media sources), leisure and hospitality (including restaurants, hotels, and entertainment), manufacturing (including all aeronautic manufacturing), natural resources (including agriculture), professional and business services (like real estate, accounting, and miscellaneous corporate businesses), trade (including retail trade), and transportation and utilities. Given that we utilized the MAP sectors for the GDP data, this white paper looks as a subset of the total MSA economy. For this white paper, we utilize both the overall size of each sector as well as the relative share of economic activity from each sector.

The specific steps to process the data downloaded from the BEA are as follows:

- 1) "All Industry Totals" and "Private Industries" were removed because they were conglomerate totals and keeping them would lead to double counting.
- 2) Three categories of *non-normal* data points for each specific entry were removed:
 - a) All NAs were removed because they were classified as not available
 - b) All Ds were removed because they were classified as confidential
 - c) All Ls were changed to \$500,000 because they were, "Less than \$500,000 in nominal or real GDP by metropolitan area," and there was no information on how far below \$500k the actual number was.
- 3) Industries were coded into the different MAP sections and each coded value was added together. The total GDP amount listed on the BEA website includes all of the sector values, confidential information, more accurate depictions of the less than \$500,000 values, and values that are included in Industry and Private Industry totals that are not available via the website. Given this, the values used within this white paper are less than the values on the BEA website. The white paper analyzes a subset of the total economy for each MSA.
- 4) Three different variables that were used in the paper were calculated based on the sectors used and the information above.
 - a) An MSA GDP by year by sector
 - b) A yearly average by sector for each MSA (average GDP of sector in MSA over 14 years)

¹¹⁷ Data downloaded from the BEA was already in real 2009 US dollars, so no additional inflation adjustment was necessary.

c) An average sector GDP for each MSA

B. Employment Data

In addition to GDP data, data on employment by industry was obtained for each MSA from the U.S. Bureau of Labor Statistics. The employment data are aggregated using the same sectors reported on the MAP Dashboard and are consistent with the GDP sectors presented above. These data include the total number of employees, both goods and service producing, in each MSA from 2006 through June of 2016.¹¹⁸

The specific steps to process the employment data are as follows:

1) Data was already coded into large sector bins for each MSA so no additional coding was necessary for the raw data.

2) The following summary statistics were generated from the data:

a) Annual averages calculated for yearly growth rate (all years raw employees added and divided by # of years)

b) Current year minus previous year to get change in employment, by yearly average

c) For 2016, all data available was averaged and added to the previous formula for the final number

d) Raw totals are monthly numbers*1000 (to convert to people units)

e) Employment change is scaled by average population amount for the MSA (found via Census data—no data on 2009). Only used employment data for population years (2006-2014). Average employment total by sector / average population.

f) In combined dataset: average yearly growth in employees by thousands, by sector, by MSA

C. Extreme Weather Data

Extreme weather events data were obtained from the National Centers for Environmental Information's (NCEI) Storm Events Database. The storm event reports in the database are generated by local National Weather Service (NWS) offices, where personnel record event details including event type, date, location, and estimates of direct and indirect fatalities, as well as property and crop losses.¹¹⁹ All events from 1996 to 2016 were collected and group them into broad categories: winter weather, thunderstorms, tornadoes, extreme heat, floods, ocean events, wind events, hail, droughts, and wildfires.¹²⁰ While the individual events are recorded based on either the county or National Weather Service zone, events were aggregated to the MSA level via

¹¹⁸ Data was collected in July 2016 when only six months of data were available. All data for the second half of 2016 (July through December) has been estimated by using an average of the first six months of the year.

¹¹⁹ Detailed information regarding the preparation and inclusion of events in the database can be found in the National Weather Service Instruction (NWSI) 10-1605 entitled "Storm Data Preparation" available online at: <https://www.ncdc.noaa.gov/stormevents/pd01016005curr.pdf>.

¹²⁰ We code each distinct weather event in the NCEI dataset by the larger "bucket" type. Winter weather events include avalanche, blizzard, cold/wind chill, extreme cold/wind chill, frost/freeze, heavy snow, ice storm, lake-effect snow winter storm, and winter weather. Thunderstorm events include dense fog, heavy rain, lightning, sleet, and thunderstorm wind. Tornado events include all tornadoes. Extreme heat events include excessive heat, and heat. Flood events include coastal flood, debris flow, flash flood, flood, and storm surge/tide. Ocean (specifically dealing with the coast or waves and not related to flooding directly) events include high surf, rip current, tropical storm, and tsunami. Wind events include dust devil, dust storm, funnel cloud, high wind, landslide, strong wind, and waterspout. Hail events include hail. Drought events include only drought and wildfire events include only wildfire.

their county. From these data we calculate descriptive statistics including the average annual count, total property damages (in 2009 \$USD), total fatalities, and total injuries from the storm events. Thus, all reports on weather extremes in this paper are from the MSA's county(s) and not necessarily from the MSA itself.¹²¹ All data from the NCEI dataset was divided by the number of counties within the MSA for an average value per MSA.

The specific steps to process the extreme weather data are as follows:

1) State variable was cleaned to ensure that each FIPS code matched the MSA FIPS codes we needed. Stata was used to code the counties by their proper FIPS codes based on which counties were part of each MSA. Thus, each MSA in the weather data is actually measured at a county level.

2) All property and crop damages were reformatted to a numeric value (many of them were initially in terms of "K" for thousands of dollars).¹²²

3) The damage numbers from NCEI are in current dollars, so all dollar values were inflation adjusted to real 2009 \$USD using the BEA's GDP deflator.

4) Summary statistics were generated for each MSA including:

- a) Total and average annual count of all events by MSA
- b) Total and average annual count of each category of events by MSA
- c) Total and average property damages for all events by MSA
- d) Total and average property damages for each category events by MSA
- e) Total and average fatalities for all events by MSA
- f) Total and average fatalities for each category events by MSA

¹²¹ MSAs and counties included in the weather data: Albuquerque data includes Bernalillo, Sandoval, Torrance, and Valencia Counties; Austin data includes Bastrop, Caldwell, Hays, Travis and Williamson Counties; Colorado Springs data includes El Paso and Teller Counties; Denver data includes Adams, Arapahoe, Broomfield, Clear Creek, Denver, Douglas, Elbert, Gilpin, Jefferson, and Park Counties; El Paso data includes El Paso and Hudspeth counties; Las Vegas data includes Clark County; Phoenix data includes Maricopa and Pinal Counties; Portland data includes counties from Oregon and Washington—Clackamas, Columbia, Multnomah, Washington, Yamhill, Clark, and Skamania Counties; Salt Lake City data includes Salt Lake and Tooele Counties; San Antonio data includes Atascosa, Bander, Bexar, Comal, Guadalupe, Kendall, Medina, and Wilson Counties; San Diego data includes San Diego County; Tucson data includes Pima County.

¹²² An algorithm similar to this website was used to change the letter values to numbers: https://rstudio-pubs-static.s3.amazonaws.com/58957_37b6723ee52b455990e149edde45e5b6.html