Photo by Erik A. Ellison

Hot Enough Yet?

The Future of Extreme Weather in Austin, Texas

A report for **A Nurtured World** and the **City of Austin**

June 2015

Prepared by the **Geos Institute**

A dynamic, online summary of this report, with voiceover, is available at:
http://prezi.com/tavfbaikives/hot-enough-yet/

A pdf of this report can be downloaded at:
http://www.geosinstitute.org/climatewise-program/completed-projects/1162-temperature-and-precipitation-extremes-in-central-texas.html

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Introduction

Austin, Texas has experienced many temperature and precipitation extremes in the last decade. As climate change accelerates, we can expect more days of extreme heat, fewer overnight freezes, and more frequent periods of drought than there have been historically. Many of the long-term impacts can be avoided if emissions are reduced, creating a more positive future for residents of Austin.


Photo by Erik A. Ellison

Boat on Lake Travis during the 2011 drought

Most people experience climate through the extremes. Crops are affected when temperatures drop below freezing, and we change our behavior when the day's high is over 100°F. A Nurtured World, Geos Institute, and the City of Austin collaborated to assess recent past and future changes in extreme heat, low temperatures, extended drought, and wildfire. We used global climate models (GCMs) adjusted to local scales to provide information on potential future conditions. Model documentation is provided in the methods section on page 18.


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Hippie Hollow Park

Climate change presents us with a serious challenge as we plan for the future. Our current planning strategies rely on historical data to anticipate future conditions. Yet due to climate change and its associated impacts, the future is no longer expected to resemble the past. Managers and policy makers are encouraged to begin to plan for an era of change, even if the precise rate or trajectory of such change is uncertain.

The observed and projected future changes in extreme heat and heavy rainfall in the Austin area have numerous ongoing and potential future impacts to residents and the resources they rely on. As extreme heat and precipitation become more common, their impacts will worsen. People and resources will need to adapt.

Extreme heat affects human health through direct exposure and also because it leads to an increase in ground level ozone pollution. Higher levels of ground level ozone are linked to respiratory disease and heart disease. In the last decade, more people in the U.S. died from extreme heat than from any other weather-related cause.[1]

Extreme heat also leads to crop failures, loss of aquatic ecosystems, and loss of worker productivity for outdoor workers. Heat waves can cause roads and train tracks to buckle and other infrastructure to degrade, leading to potentially significant economic costs as well.

Drought and heavy rainfall can destroy crops and stress livestock. Droughts leave soils hardened, less productive, and more prone to flash flooding once rains return. Water for both people and nature can be scarce during extended periods of drought. Increased evaporation will contribute to a lack of water available for the region and exacerbate the impacts of droughts.

Whether or not wildfire will increase in the region is uncertain. Wildfire is an important part of ecosystem processes, and is not necessarily negative. Increases in wildfire, however, could lead to reduced air and water quality, severe health impacts and greater need for emergency evacuations.

While preparing for impacts in the short-term is critical, reducing the overall magnitude of climate change through emissions reductions is the most effective option for protecting people from increasingly severe impacts over the long term.

Models show that climate change can be slowed and level off by about 2040–60 if drastic cuts in emissions are made.[2] Such action would allow us to avoid many of the most severe impacts of climate change, thereby saving both lives and money. A recent report from the International Panel on Climate Change (IPCC) demonstrates that reducing emissions is highly cost effective compared to the cost of the damages if climate change were to continue unabated.[3]

SUMMARY OF PAST AND FUTURE CLIMATE EXTREMES IN AUSTIN, TEXAS

- The region has warmed by 2°F since the early 1900s.
- Frost free season is 10 days longer, on average, than the early 1900s.
- Extreme precipitation has become heavier and more frequent.
- Frequency of large wildfires has increased in Texas.
- Continued warming of 6-11°F by 2100 is expected if emissions remain high.
- With severe emissions reductions, warming could level off at 3–7°F by mid-century.
- Very few freezing nights are expected by 2050.
- Overnight temperature over 80°F could become common.
- Days over 100°F expected to become 2–5 times more common by mid-century.
- More year-to-year variation in precipitation is expected.
- Frequency of days with very low precipitation is expected to increase slightly by 2050.
- Soils are expected to become drier from heat and evaporation, even if precipitation increases.
- The area affected by wildfire is expected to increase through mid-century.
- Many of the most severe impacts can be avoided by reducing emissions.

Temperature Averages

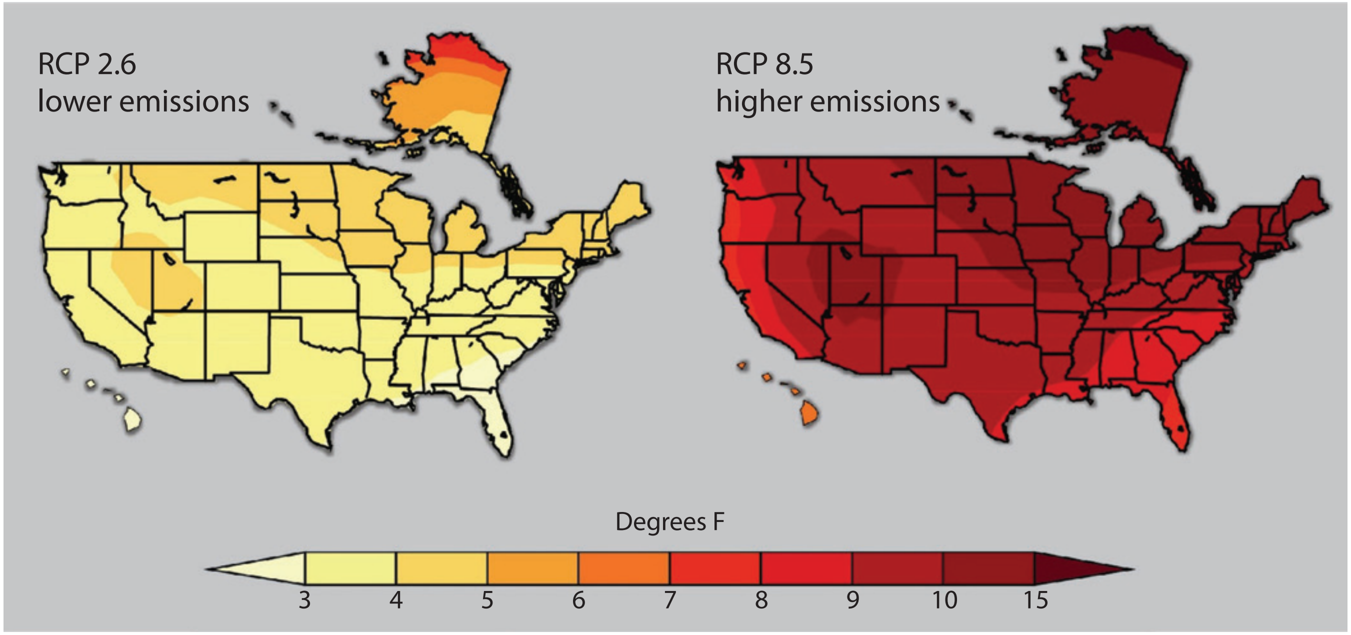
Average temperature in Texas has increased 2°F over the last century,[4] slightly more than the nation's average.[2] Continued warming is expected for Central Texas, as well as the rest of the nation, but emissions cuts could limit the magnitude of warming[2] (Fig. 1).

Based on models used for this project, temperature is projected to increase 3–7°F in Central Texas by 2040–69, whether or not emissions are reduced, because of greenhouse gases already released into the atmosphere. There are two main options for the future. If the international community works together to cut greenhouse gas emissions drastically (more than 70% by 2050[2]), warming could level off by the middle of the century. If emissions are not drastically reduced, Central Texas is projected to warm by 5.5–11.0°F by the end of this century (Table 1).

Photo by Steve Hopson, www.stevehopson.com

Austin City Limits Music Festival

Figure 1 Change in average surface air temperature from the historic period (1971–2000) to the end of the century (2071–2099) from the National Climate Assessment.[2] The lower emissions scenario (left) assumes more than 70% cuts in emissions by 2050, while the higher emissions scenario (right) assumes continued high emissions.[2]



NOTE: Terms in red are defined in the glossary, page 23.

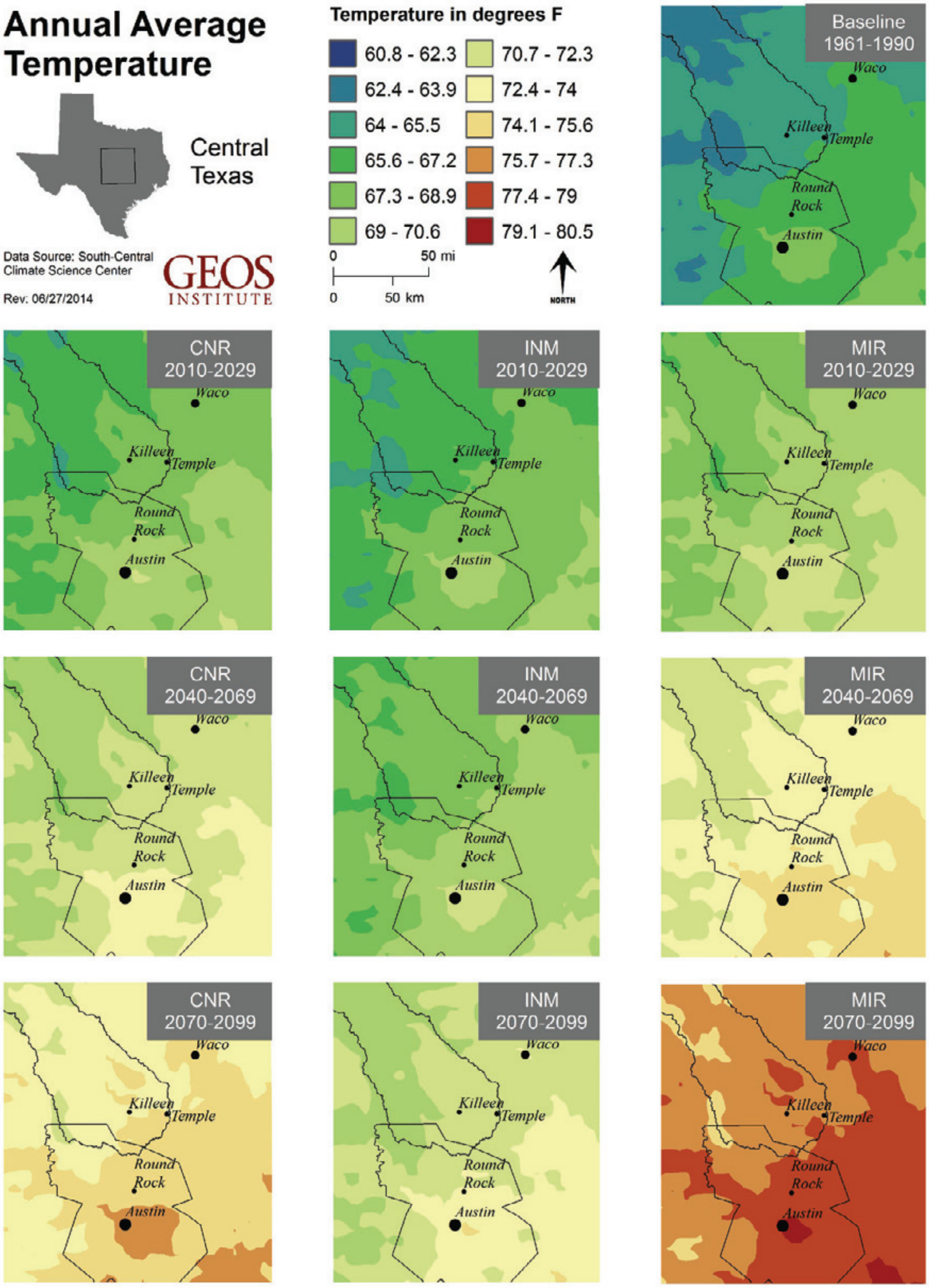
The projections for 2070–99 (Table 1) are less certain than mid-century projections due to uncertainty in emissions, models, and natural feedback loops. Natural feedback loops occur when warming induces the release of additional greenhouse gases from natural systems, such as the methane releases that are being observed in northern Russia.

Table 1 Projected change in average temperature across the CAMPO management region, based on output from three different GCMs (CNR, INM and MIR) and assuming continued higher emissions (RCP 8.5).

	Historic	2010–39	2040–69	2070–99
Annual	66.7° F	+1.5 to 3.6° F	+3.0 to 7.1° F	+5.5 to 11.0° F
Spring Mar, Apr, May	69.3° F	+0.7 to 6.2° F	+3.8 to 11.4° F	+6.1 to 16.7° F
Summer Jun, Jul, Aug	82.2° F	+1.0 to 3.7° F	+2.2 to 5.4° F	+3.1 to 8.7° F
Fall Sep, Oct, Nov	64.9° F	-1.6 to +3.4° F	-2.1 to +7.0° F	-1.4 to +10.4° F
Winter Dec, Jan, Feb	50.5° F	+2.5 to 4.2° F	+5.1 to 9.3° F	+9.7 to 14.7° F

NOTE: Terms in red are defined in the glossary, page 23.

Figure 2 Annual average temperature across Central Texas for the historical period (1961–1990) and three future time periods (2010–29, 2040–69, and 2070–99), based on three different GCMs (CNR, INM and MIR) and the higher emissions RCP 8.5 scenario.



NOTE: Terms in red are defined in the glossary, page 23.

Temperature Extremes

In addition to averages, the frequency of extreme temperatures has already begun to change. Throughout the central U.S., for instance, the frost-free season has lengthened by 10 days, as compared to 1900–1960.[2] Minimum temperatures below freezing are expected to be extremely rare in Austin by mid- to late-century (Table 2; Fig. 3, top).

While all three GCMs used in this study agreed on continued warming for the region, there was variation among them with respect to projected minimum temperatures. One model projected minimum nighttime temperatures above 80°F for close to 100 days per year by the end of the century, while another model shows an increase from 0.4 days (historic) to 2 days, on average (Fig. 3, bottom).

The National Climate Assessment shows that extreme heat events are expected to be 8–10°F hotter by 2081–2100, relative to those at the end of the last century.[2]

Table 2 Historic and projected number of days per year with minimum nighttime temperature below freezing, minimum nighttime temperature above 80° F, and maximum daytime temperature greater than 95°, 100°, and 110° F, at the Camp Mabry weather station in Austin, TX. Future projections based on three GCMs (CNR, INM and MIR) and continued higher emissions (RCP 8.5). Percent change is shown in parentheses.

Number of days	Historic	2010–39	2040–69	2070–99
Min <32° F	18	3–13 (–25 to –83%)	0–8 (–55 to –100%)	0 (-100%)*
Min >80° F	0.4	0.4-2 (0 to +433%)	0.5–20 (+33 to 4,766%)	2–60 (+342 to 14,675%)
Max >95° F	40	48–73 (+20 to 82%)	60–99 (+50 to 147%)	86–139 (+114 to 245%)
Max >100° F	10	12–32 (+22 to 230%)	22–50 (+126 to 417%)	36–94 (+274 to 872%)
Max >110° F	0	0.1–0.3 (NA)	0.5–1.3 (NA)	1.5–10.3 (NA)

* **Note:** The data in the table are not exactly the same as those shown in the graphs. For an explanation of the two different methods used for calculating 30-year averages and displaying annual data in the graphs, please see the methods on page 19.

NOTE: Terms in red are defined in the glossary, page 23.

Our analysis showed that extreme heat events are also expected to be more frequent, with temperatures over 100°F becoming 2 to 5 times more common by mid-century (Table 2). Of note is the fact that recent extreme temperature records (2008 and 2011) are not predicted to occur by the models until later this century, indicating that actual extremes may be higher than the models predict (Fig. 4).

In addition to the frequency of extreme heat, average summer high temperatures are expected to continue to increase across the region through the end of the century, if emissions are not reduced (Fig. 5).

Figure 3 Observed and projected number of days per year with minimum temperatures below 32°F (top) and above 80°F (bottom) at the Camp Mabry weather station in Austin, TX. Projections based on three different GCMs (CNR, INM, MIR) and the higher emissions RCP 8.5 scenario.

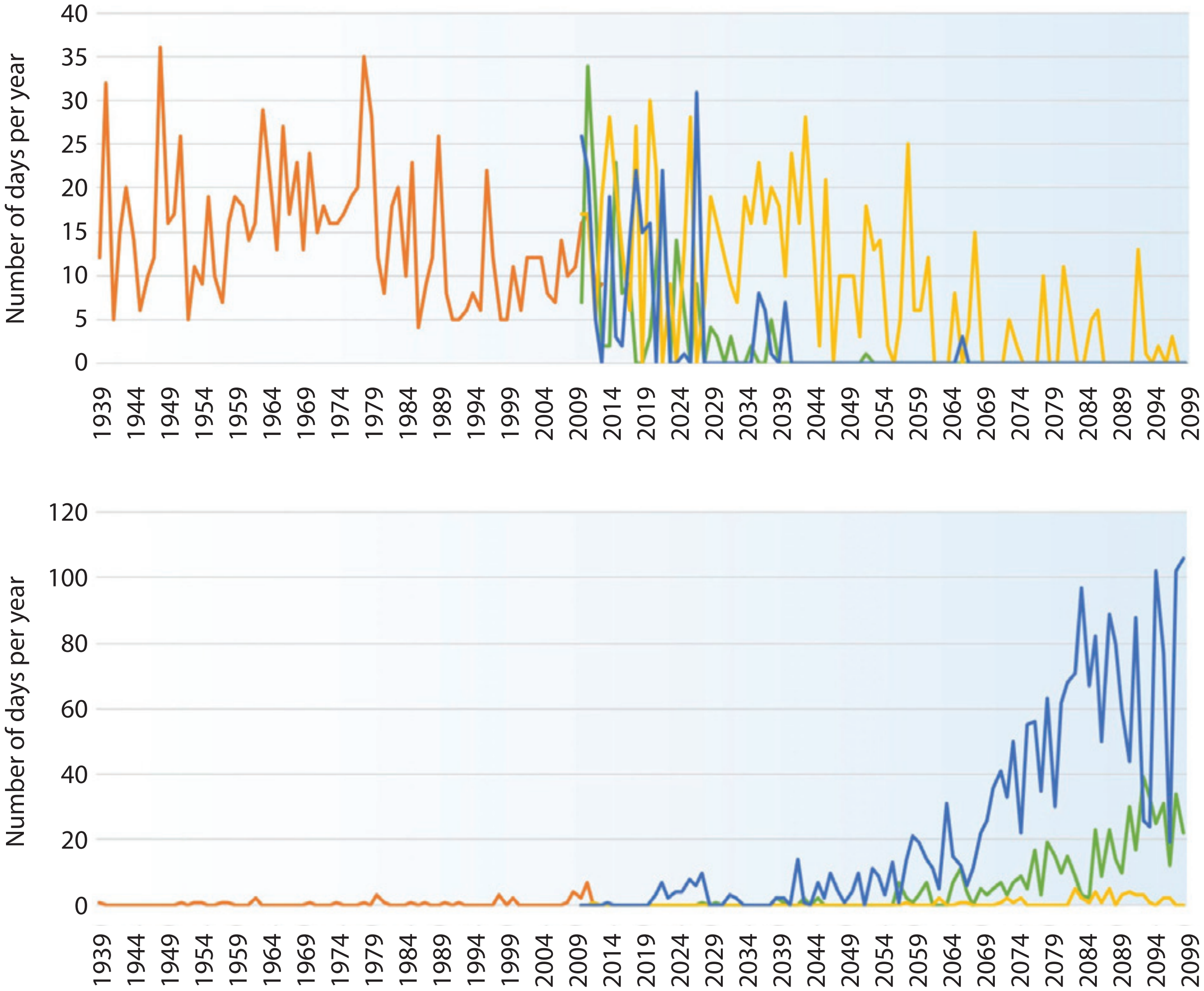


Figure 4 Observed and projected number of days per year with maximum temperatures above 95°F (top), 100°F (middle) and 110°F (bottom) at the Camp Mabry weather station in Austin, TX. Projections based on three different GCMs (CNR, INM, MIR) and the higher emissions RCP 8.5 scenario.

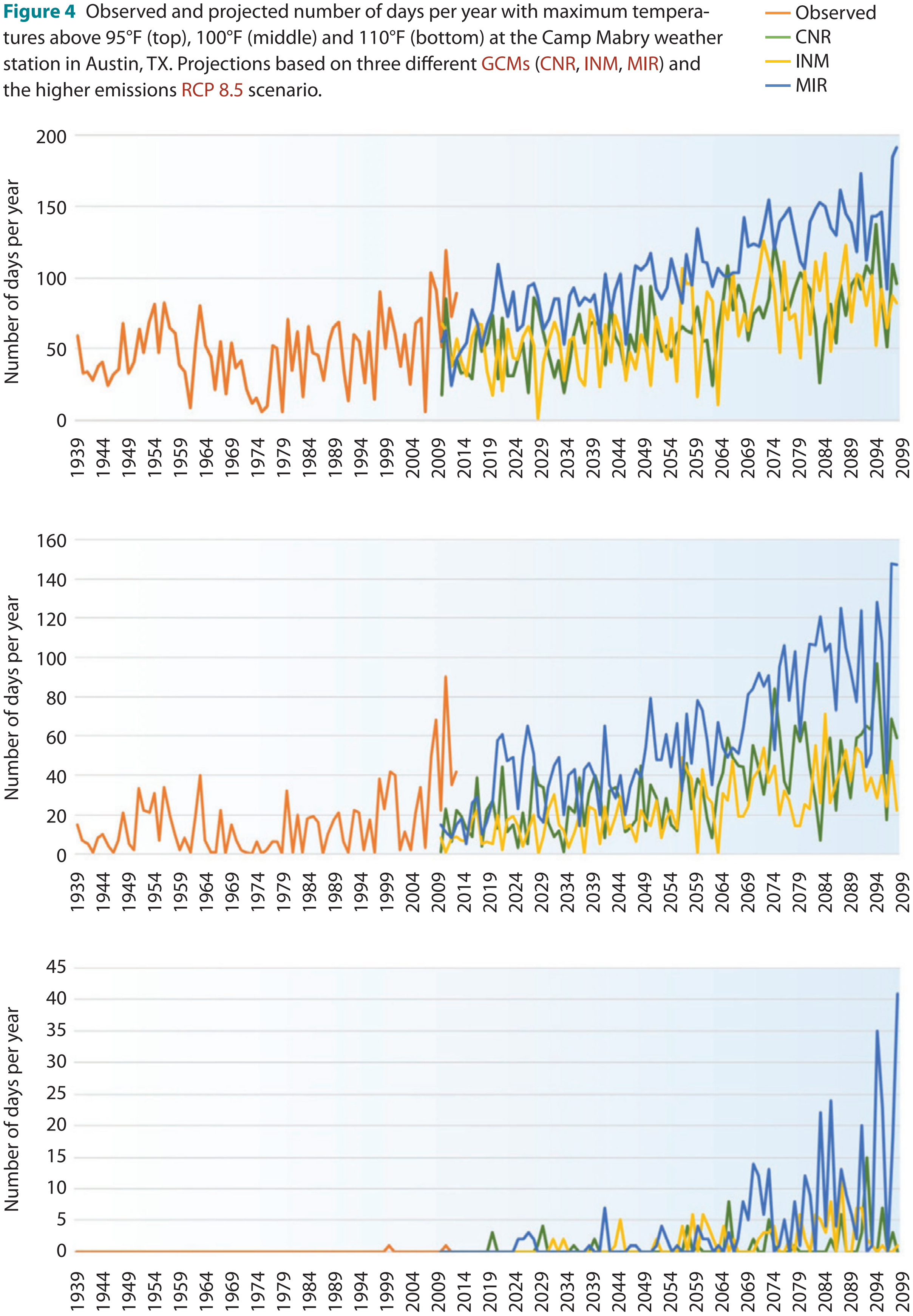
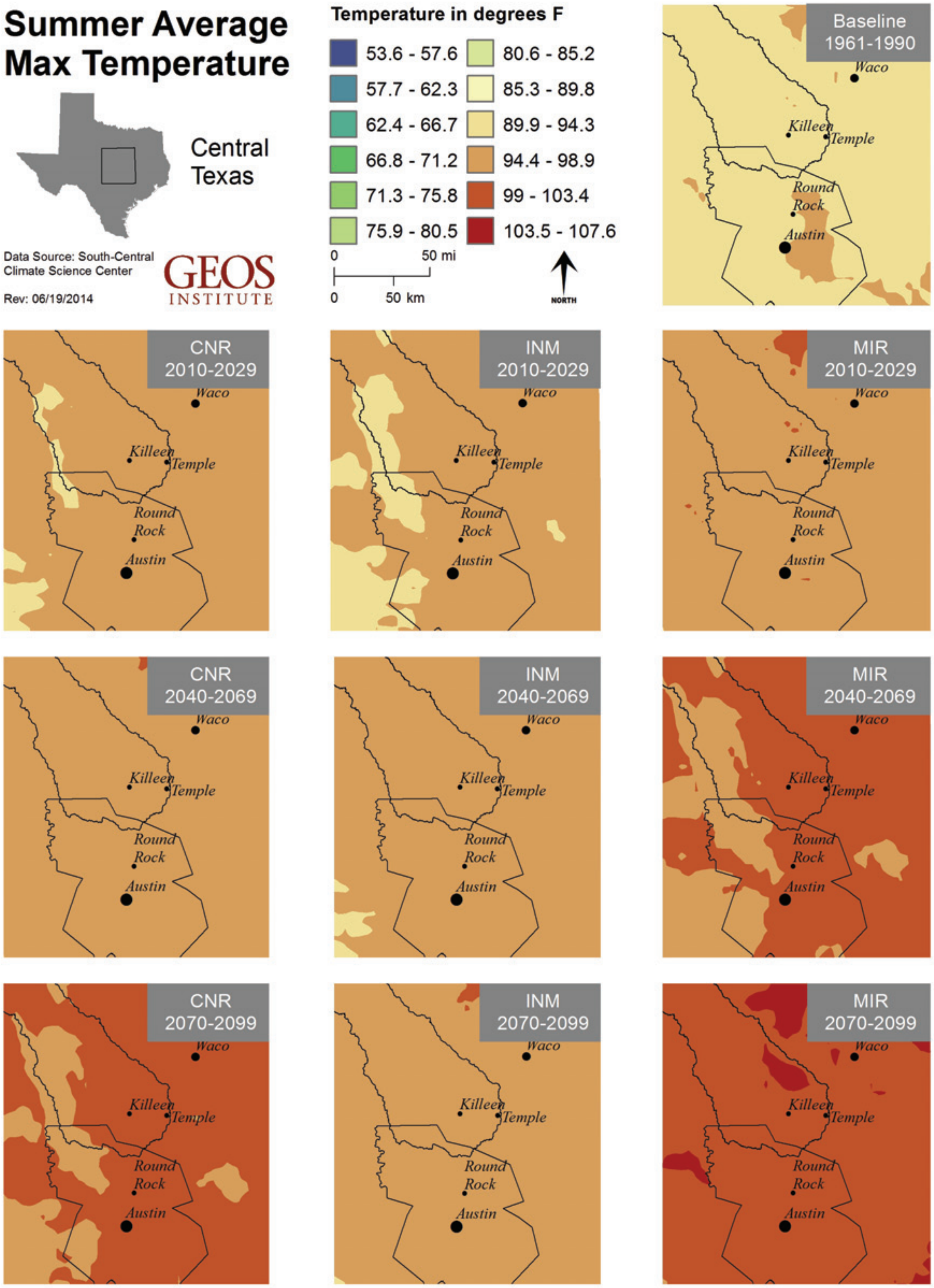


Figure 5 Average summer maximum temperature in Central Texas, for the historical period (1961–1990) and three future time periods (2010–29, 2040–69, and 2070–99), based on three different GCMs (CNR, INM and MIR) and the higher emissions RCP 8.5 scenario. Additional seasons and variables are shown in Appendix 1.



NOTE: Terms in red are defined in the glossary, page 23.

Precipitation Averages

Average precipitation in Central Texas has increased slightly over the last century. Over the coming century, precipitation is expected to decrease by 5–10%.[2] The model projections for precipitation are far more variable than those for temperature, leading to high uncertainty associated with predicting future conditions (Table 3; Fig. 6).

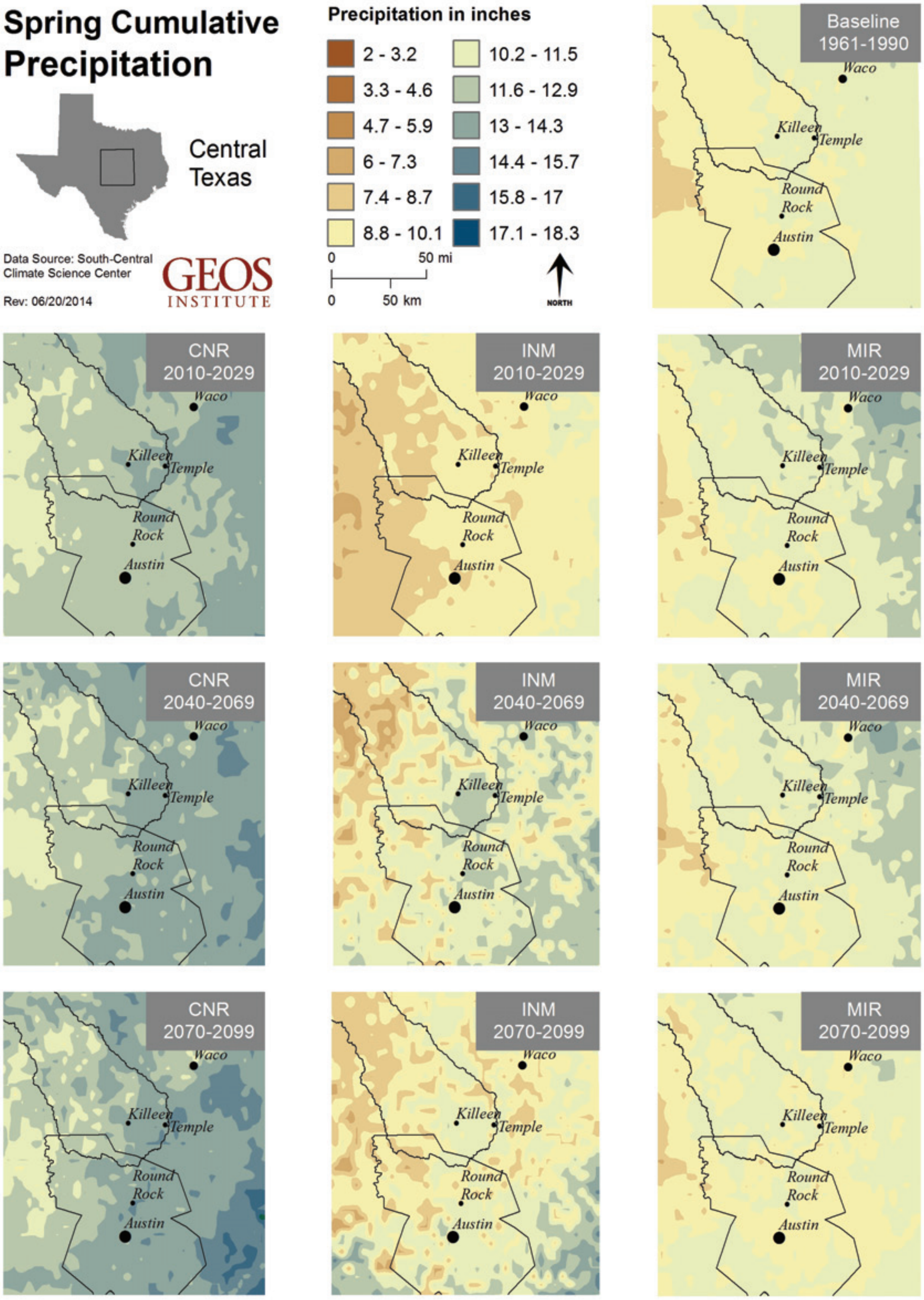
Because evaporation is expected to increase with temperature, drier soil conditions are expected, as well as more drought stress on the watershed, even if there are moderate increases in precipitation. Soil moisture in Central Texas (Fig. 7) is expected to decline by 5% to more than 15% if emissions continue unabated, and 1–10% if emissions are reduced.[2]

Table 3 Historic and future projected average precipitation, in inches, across the CAMPO management region, based on output from three GCMs (CNR, INM and MIR) and assuming higher emissions (RCP 8.5). Percent change from historic is shown in parentheses.

	Historic	2010–39	2040–69	2070–99
Annual	33.4 inches	31.5 to 36.2 in. (–5.8 to +8.3%)	32.3 to 37.1 in. (–3.3 to +10.9%)	28.4 to 36.8 in. (–15.1 to +10.0%)
Spring Mar, Apr, May	10.1 inches	9.0 to 12.3 in. (–10.6 to +22.6%)	10.2 to 12.8 in. (+1.4 to +27.3%)	10.0 to 13.2 in. (–0.9 to +31.3%)
Summer Jun, Jul, Aug	7.1 inches	7.0 to 8.2 in. (–1.0 to +16.5%)	7.2 to 12.1 in. (+1.5 to +71.2%)	6.2 to 8.0 in. (–11.7 to +13.9%)
Fall Sep, Oct, Nov	9.7 inches	8.5 to 10.3 in. (–12.2 to +7.2%)	7.4 to 9.4 in. (+23.3 to +10.0%)	6.5 to 9.4 in. (–32.5 to –2.1%)
Winter Dec, Jan, Feb	6.7 inches	6.0 to 7.5 in. (–10.5 to +11.8%)	6.3 to 6.7 in. (–5.9 to 0.0%)	5.7 to 7.1 in. (–15.1 to +6.7%)

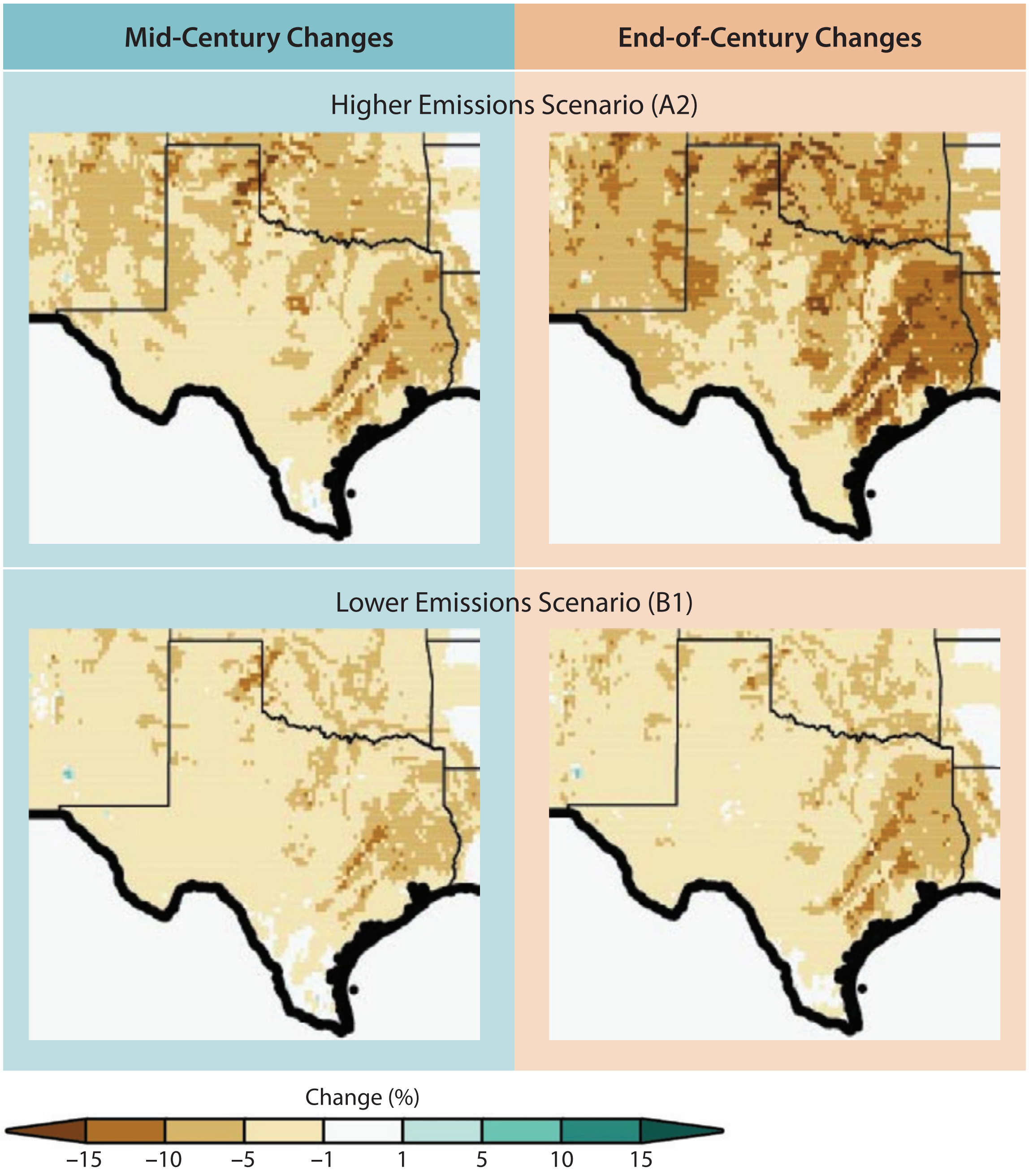
NOTE: Terms in red are defined in the glossary, page 23.

Figure 6 **Average spring precipitation in Central Texas, for the historical period (1961-1990) and three future time periods (2010–29, 2040–69, and 2070–99),** based on three different GCMs (CNR, INM, MIR) and the high emissions RCP 8.5 scenario. Additional seasons and variables are shown in Appendix 1.



NOTE: Terms in red are defined in the glossary, page 23.

Figure 7 **Average change in soil moisture compared to historic (1971–2000), as projected by the VIC model, for the middle of this century (2041–2070) and late this century (2071–2100)** under a lower emissions scenario (B1) and a higher scenario (A2). This figure adapted from the National Climate Assessment.[2]



NOTE: Terms in red are defined in the glossary, page 23.

Precipitation Extremes

Extremes in precipitation, including both heavy downpours and drought, are becoming more common. Because warmer air can hold more moisture than cooler air, rainfall events have become heavier and more frequent. Heavy downpours are expected to become 2–3 times more frequent through the next century if emissions are not reduced, and 1–2 times more frequent if they are.[2] The changes in climate are also increasing the likelihood of severe drought, such as the Texas drought in 2011.[2]

In order to assess extreme precipitation, local decision-makers helped identify three meaningful frequencies to calculate: the number of days in Austin with less than 0.01 inches, more than 2 inches, and more than 10.2 inches of precipitation.

The number of days with less than 0.01 inches of precipitation is expected to increase over time (Table 4; Fig. 8, top).

The number of days with more than two inches of precipitation showed increasing variability over time, with more high values (up to 12 days per year) and more low values (more frequent 0's; Fig. 8, middle). This indicates increasing year-to-year variability.

The frequency of days with rainfall greater than 10.2 inches may increase, according to one model, but the other models showed little change (Table 4; Fig. 8, bottom). Very rare events, such as 10.2 inches of rain in a day, are difficult to model.

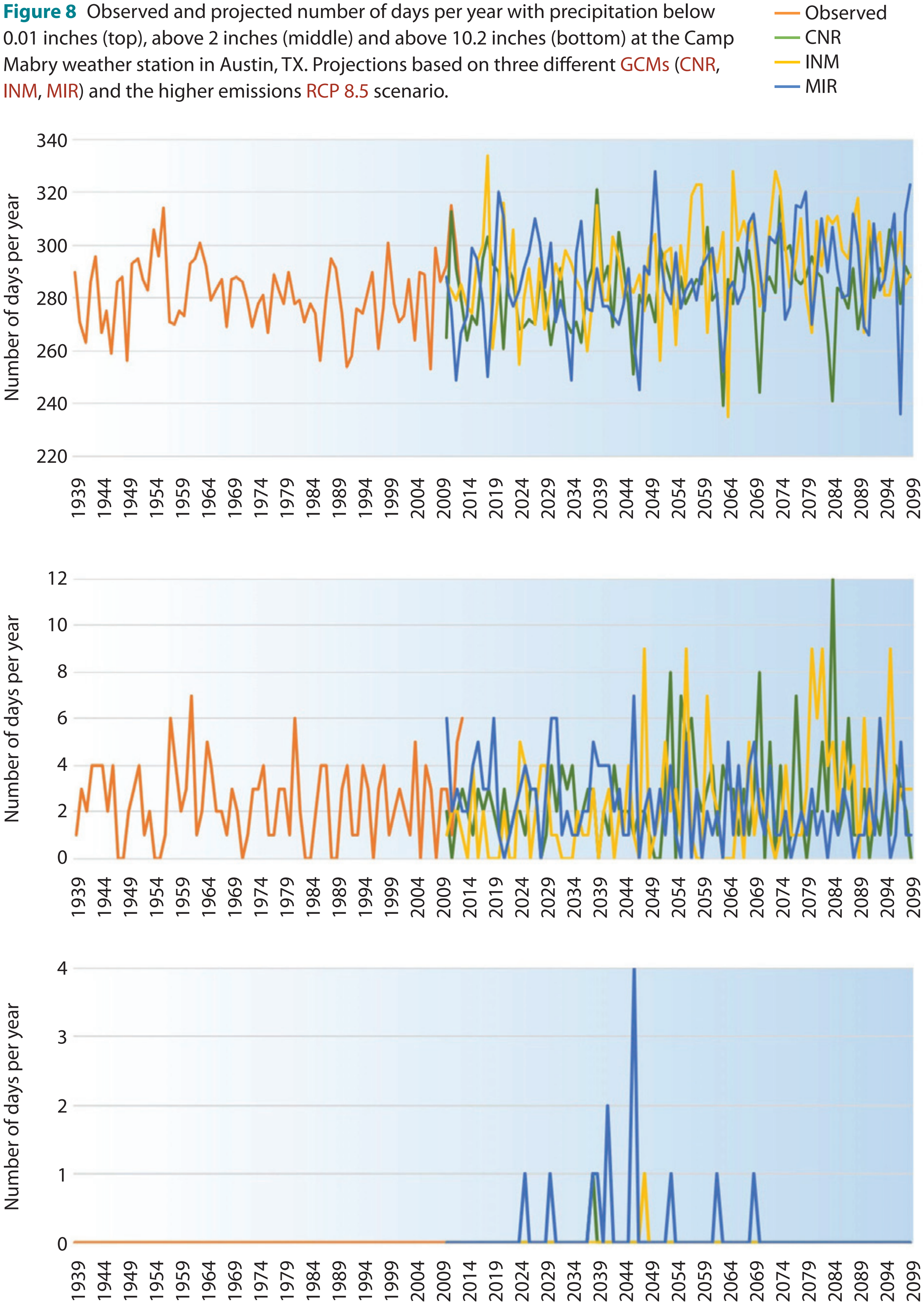
Table 4 Historic and future projected number of days per year with precipitation less than 0.01 in., more than 2 in., and more than 10.2 in. at the Camp Mabry weather station in Austin, TX. Projections based on three GCMs (CNR, INM and MIR) and higher emissions scenario (RCP 8.5). Percent change from historic is shown in parentheses.

Number of days	Historic	2010–39	2040–69	2070–99
Min <0.01 inch	282	280–286 (–0 to +2%)	283–293 (+0 to +4%)	285–297 (+1 to +5%)
Max >2 inch	2	2–3 (–24 to +40%)	3 (+11 to +30%)	2–4 (–9 to +61%)
Max >10.2 inch	0*	0–0.1 (NA)	0–0.3 (NA)	0 (NA)

*A record rainfall event of 10.2 inches occurred in 2013, but this event was not captured in the weather station data for multiple potential reasons. First, the 24-hour period may be timed differently between weather station data and specific weather records, and second, the Camp Mabry station may not be the location of that specific rainfall record.

NOTE: Terms in red are defined in the glossary, page 23.

Figure 8 Observed and projected number of days per year with precipitation below 0.01 inches (top), above 2 inches (middle) and above 10.2 inches (bottom) at the Camp Mabry weather station in Austin, TX. Projections based on three different GCMs (CNR, INM, MIR) and the higher emissions RCP 8.5 scenario.



Wildfire

In the western U.S., wildfire is driven by a number of natural factors, including temperature, precipitation, wind, humidity, fuel availability, and lightning strikes, as well as human-caused fire starts. Natural factors are significantly affected by climate.[5]

Wildfire is also associated with large-scale climate patterns such as El Niño.[5] Wildfire activity increases during warm years, with relatively little activity in cool years. Since the mid-1980s the number of large fires and total area burned per year in the Southern Plains, which includes much of Texas, have increased.[6] Fire severity can also be expected to increase given warmer temperatures and drier soil conditions.[7]

In this section, we present the results of the MC1 model.[8] MC1 is a widely used model that provides estimates of future wildfire based on predicted vegetation and climate. MC1 has many limitations, which are described in the methods section.

Modeled wildfire projections for Central Texas were inconclusive. The MC1 model output for Central Texas projects an increase in area burned by mid-century (Table 5; Fig. 9), as climate-related shifts in the type of vegetation take place (Map 9; Appendix 1). Late-century wildfire projections are quite variable, with possible increases and decreases depending on the model (Fig. 9).

Table 5 Historic and projected future change in wildfire across the Central Texas region. Projections based on three GCMs (CSIRO, HadCM and MIR) and a higher emissions scenario (A2)

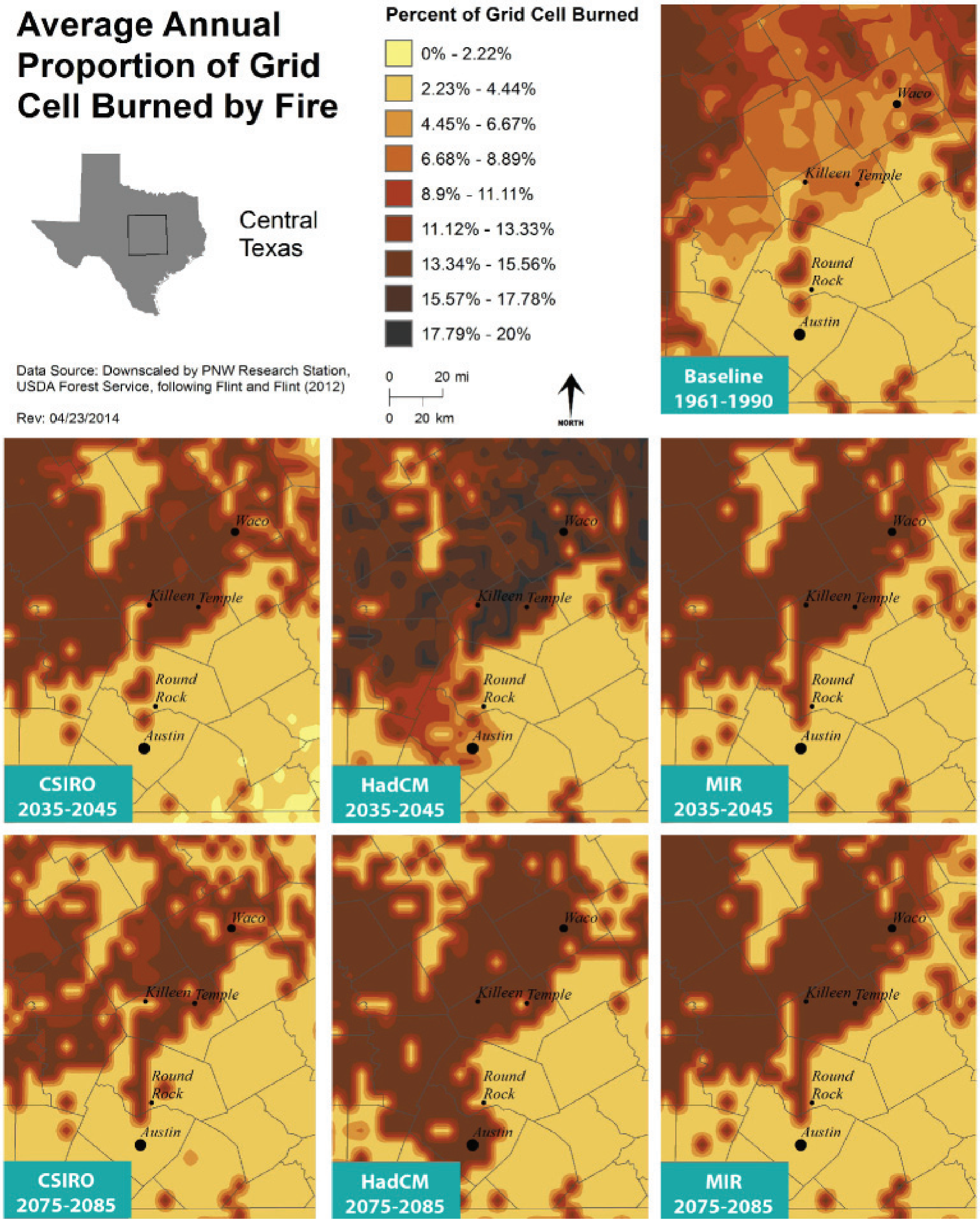
Variable	Historic	2035–45	2075–86
Percent burned*	8.9%	8.7–10.9 (–2 to +23%)	7.5–9.7 (–16 to +9%)
Biomass consumed**	16.6 g/m^2	12.6–21.2 (–24 to +28%)	10.7–19.2 (–36 to +16%)

*Percent burned refers to the overall area (percent of grid cells) burned in a wildfire.

**Biomass consumed refers to the amount of vegetation burned. A grass fire, for instance, would have lower biomass consumed when compared to a forest fire, even if the percent burned is the same.

NOTE: Terms in red are defined in the glossary, page 23.

Figure 9 The average percent of the area affected by wildfire each year, based on output from the MC1 vegetation model, three GCMs (HadCM, MIR, CSIRO), and a higher emissions scenario (A2). The historic period (top) is compared to mid-century (middle row) and late-century (bottom row). The models indicate uncertainty in whether wildfire will increase or decrease.



Data Source: Downscaled by PNW Research Station, USDA Forest Service, following Flint and Flint (2012)

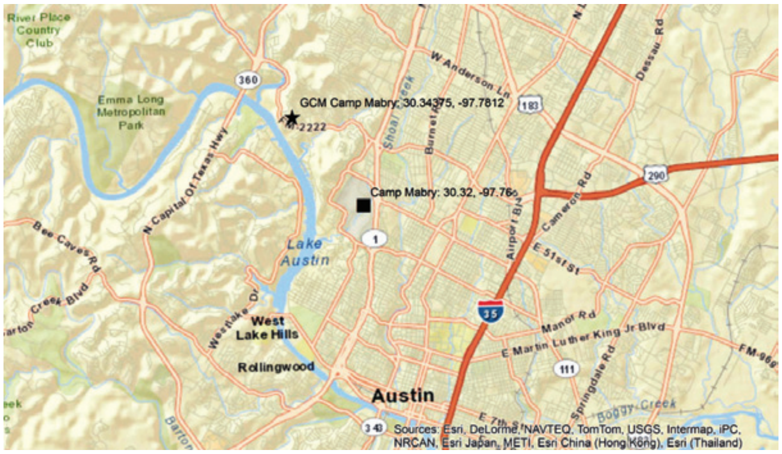
Rev: 04/23/2014

NOTE: Terms in red are defined in the glossary, page 23.

Methods for Calculating Frequencies of Extreme Events

Historic Climate

We obtained daily observed maximum and minimum temperature and daily precipitation values, spanning 1939–2013, from the Camp Mabry weather station in Austin, Texas (Fig. 10). The station is part of the U.S. Historical Climatology Network, which is a collection of long term weather stations selected to track climate trends. Data are available online http://www.ncdc.noaa.gov.



Sources: Esri, DeLorme, NAVTEQ, TomTom, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand)

Figure 10 Location of the Camp Mabry weather station in Austin, Texas (Lat/Long = 30.320/–97.760).

Global Climate Models

Global Climate Models (GCMs) are used to simulate the Earth's systems and project future conditions. We obtained downscaled model output for 9 GCMs at a resolution of 5 km^2 from the South Central Climate Science Center. These projections were extracted for a single location grid cell (Lat/Long = 30.3475/–97.7812), which was nearest to the Camp Mabry weather station.

We obtained data based on a higher emissions (RCP 8.5) pathway that assumes continued growth in emissions. We chose this modeled pathway because it most closely aligns with the "business as usual" path that the international community is currently on. However, changes in attitudes and technology could result in drastic emissions cuts. If that happens, the best case outcome would be for temperature rise to level off between 2040–60. Unfortunately, if emissions are lowered only slightly or even moderately, natural processes are expected to result in additional emissions (from forest fires, thawing peat, and other natural processes) thereby resulting in high emissions anyway.

Many GCMs have been developed. The International Panel on Climate Change (IPCC), the leading body of climate scientists, has evaluated them and adopted a suite of the more representative models for use in climate projections.[10] Within that suite of models, there is still much variation among projections. Some models indicate faster warming than others, and precipitation projections are highly variable across the globe. In order to adequately represent the variation among models, we graphed average annual precipitation and temperature using nine different GCMs (CCSM4, CNRM-CM5,

NOTE: Terms in red are defined in the glossary, page 23.

HadGEM2-CC, INM_CM4, IPSL-CM5A-LR, MIROC5, MPI-ESM-LR, MRI-CGCM3, CSIRO-Mk3-6-0), across Central Texas. From these nine, we chose three models that reflected the full range of output, from faster warming to slower, and from lower precipitation to higher, as well as one approximately in the middle. These three models included CNRM-CM5 (from the National Center for Meteorological Research in France), MIROC5 (from the Center for Climate System Research in Japan), and INM-CM4 (from the Institute for Numerical Mathematics in Russia).

Downscaling

Global models result in course-scale climate projections (cell sizes range from 1–5 degrees latitude/longitude per side). Projections at this scale are not necessarily useful for decision making at the local and regional level. In order to make the model outputs more useful, scientists have developed methods to "downscale" them to locally-relevant scales. The output from the GCMs for this project were statistically downscaled to 5 km^2 following the methods of Hayhoe and Stoner 2013.[11]

Thresholds

We used observational data on maximum and minimum daily temperature and daily precipitation to calculate the number of days per year that meet certain thresholds. Useful thresholds were identified by decision makers from Austin, TX. The thresholds that were chosen included number of days per year above 95°, 100°, and 110° F; the number of days with minimum temperatures below freezing or above 80° F; and the number of days per year with precipitation below 0.01 inches, above 2 inches, and above 10.2 inches.

Calibrating Model Projections Based on Historic Data

The downscaled GCMs provide model projections for both future periods and for the historic period. Historic model projections are especially useful for calculating differences between modeled data and observed data, to better understand and adjust for the biases of the models.

For the data in Tables 2 and 4, we calculated the modeled change in frequencies (days per year) for each of the three future 30-year time periods, as compared to the modeled frequency (days per year) for the historic 30-year period. We did this for each threshold using each of the three GCMs. We then added the modeled amount of change to the historic observed frequencies for each threshold. This method of adding modeled differences to observed frequencies is a common approach to calibrating models to better align with actual observed climate.[12]

NOTE: Terms in red are defined in the glossary, page 23.

When this approach is used, the results are reported as 30-year averages and the year-to-year variation shown in the graphs is lost. Because of this, we used a different approach, even though it is slightly less robust, for the graphical displays of change over time (Figs. 3, 4, and 8). Using two different approaches means that, in a few instances, the graphs do not align perfectly with the values shown in the tables.

To graphically display the number of days per year that the thresholds were crossed, from the observed period through 2099, we calculated the bias of the models and adjusted each year to account for that bias. The bias was calculated by comparing observed historic values (number of days per year that thresholds were surpassed from 1961–1990) with modeled historic values.

NOTE: Terms in red are defined in the glossary, page 23.

Methods For Calculating Climate Averages

Methods for calculating climate averages were similar to methods for extreme events, except that extreme events were calculated for a single location (Camp Mabry weather station) while averages were calculated over the entire CAMPO study area (Map 1, Appendix 1).

Global Climate Models

We obtained downscaled model output for the same three GCMs at a resolution of 5 km^2 from the South Central Climate Science Center. The data were clipped to the CAMPO boundaries for processing. The downscaling methods were the same as those in the previous section. We received data on daily temperature maximum and minimum, as well as cumulative daily precipitation.

We used PRISM data[13,14] for calculating baseline climate averages, in contrast to the thresholds analysis, where we used historical weather station data as the baseline. PRISM data is a set of gridded climate data that is based on weather station output from numerous weather stations, which are then run through a statistical mapping system to reflect geographic complexities at high resolution.

Output

We calculated average and monthly seasonal temperature and precipitation across the CAMPO study area. These averages are presented in a series of tables (Table 1 and 3) and maps (Figs 2, 5, and 6) throughout this report and in Appendix 1.

NOTE: Terms in red are defined in the glossary, page 23.

Methods For Wildfire Projections

The MC1 dynamic vegetation model[8] provided model output to assess changes in wildfire extent and biomass consumed by fire. MC1 explicitly simulates vegetation dynamics, nutrient cycles and dynamic impacts of disturbance due to fire and has been used in analyses of vegetation responses to climate change.[15]

We compiled results from the MC1 model, which was run in conjunction with three GCMs: Hadley CM3 (HadCM), Miroc 3.2 (MIR), and CSIRO mk3 (CSIRO) under a higher emissions scenario (A2) from the IPCC Third Assessment[17]. These data were obtained from the US Forest Service Pacific Northwest Research Station Mapped Atmosphere-Plant-Soil System (MAPSS) Team. The MAPSS Team uses these three GCMs as input to the MC1 model because they provide certain input variables that the MC1 model needs.

The MC1 model has many limitations. First, it only makes projections for native vegetation and does not account for land use change (i.e. agriculture and development), introduced species (i.e. non-native grasses), or human caused fire ignition. Second, it assumes immediate shifts from one type of mature vegetation to another. A lag time, which is not considered in the model, is expected between changes in climate conditions and establishment and maturation of new vegetation types on the ground – this lag time could be decades or even centuries.

Even with its limitations, the MC1 model provides valuable information about potential changes in wildfire. It is important to use the output in conjunction with a solid understanding of current conditions and wildfire patterns.

Glossary

30-year averages are a standard timeframe for reporting climate variables. Weather varies day to day, month to month, and year to year. In order to look at long term trends rather than short-term variation, many scientists consider the climate to consist of the average weather over a 30-year period. Many variables can be assessed, including average temperature or precipitation, average maximum temperature, average minimum precipitation, and average winter snowpack.

A2 Emissions Scenario is described in the IPCC's Special Report on Emissions Scenarios[16] (SRES) from 2000. This emissions scenario was used for projections that were published in the IPCC Third Assessment Report[17] from 2001, and assumed continuously increasing world population and continued economic development without coordinated international efforts to reduce emissions.

B1 Emissions Scenario is another SRES scenario (see A2) from 2000, but this one assumes slower population growth and a more collaborative and ecologically friendly world.

CAMPO is the Capital Area Metropolitan Organization, which covers Bastrop, Burnet, Caldwell, Hays, Travis, and Williamson Counties in Texas. CAMPO coordinates transportation planning with cities, counties, and agencies.

CNR (CNRM-CM5[18]) is a GCM developed by the National Center for Meteorological Research in France. It is one of a many models used to produce the projections in the IPCC's Fifth Assessment Report.[19]

CSIRO (CSIRO-Mk3.5)[20] is a GCM developed by the Centre for Australian Weather and Climate Research. It is one of many models used to produce the projections in the IPCC's Third Assessment Report.[17]

El Niño is a phase of the "El Niño Southern Oscillation" (ENSO) that is associated with high surface pressure over the western Pacific, resulting in cooler and wetter conditions in the Southeastern U.S., including Texas. While El Niño conditions can occur every few years, a strong El Niño has not occurred since 1997–98.

Global Climate Models (GCMs) are complex land-ocean-atmosphere models that simulate the functioning of the Earth's systems and are often used to model the earth's climate and project future changes.

HadCM (HadCM3[21]) is a GCM developed by the Hadley Centre in the United Kingdom. It is one of many models used to produce the projections in the IPCC's Third Assessment Report.[17]

INM (INM-CM4[22]) is a GCM developed by the Russian Academy of Sciences. It is one of many models used to produce the projections in the IPCC's Fifth Assessment Report.[19]

MC1[8] Dynamic Global Vegetation Model (DGVM) is a computer program that simulates shifts in potential vegetation and the associated biogeochemical and hydrological cycles as a response to shifts in climate. DGVMs use time series climate data and, given constraints of latitude, topography, and soil characteristics, simulate monthly or daily dynamics of ecosystem processes. The MC1 DGVM has a complex fire module that provides output on changes in wildfire extent, biomass consumed by wildfire, and carbon storage in vegetation. It was created by scientists at the USDA Forest Service's Pacific Northwest Research Station.

MIR (MIROC[23]) is a GCM developed by the Center for Climate System Research in Japan. It is one of many models used to produce the projections in the IPCC's Third Assessment Report.[17] In this report, we used MIROC5 for climate projections and MIROC3.0 for wildfire projections.

National Climate Assessment (NCA) is a large scale collaborative effort of more than 300 of the nation's leading scientists, guided by a 60-member Federal panel and reviewed by the National Academy of Sciences, to assess the patterns and impacts of climate change on the United States. The Global Change Research Program releases a NCA report approximately every 4 years. The latest report[2] was released in 2014 and is available at nca2014.globalchange.gov. The NCA bases its climate projections on the models and scenarios developed for the IPCC reports.[17,19]

PRISM Climate Data[13,14] (www.prism.oregonstate. edu) is a dataset developed by the PRISM Climate Group to provide fine-scale information on historical climate (1895–present). The PRISM Climate Group gathers climate observations from a wide range of monitoring networks, applies sophisticated quality control measures, and develops spatial climate datasets to reveal short- and long-term climate patterns.

RCP 2.6[24] is a representative concentration pathway (RCP) that assumes that international socioeconomic conditions develop in a way that results in climate stabilization. This RCP was used for projections that were published in the IPCC Fifth Assessment Report[19] from 2014, and assumed that greenhouse gas emissions peak by 2020 due to international collaboration.

RCP 8.5[25] is a representative concentration pathway (RCP) that assumes continued rise in greenhouse gas emissions throughout this century. This RCP was used for projections that were published in the IPCC Fifth Assessment Report[19] from 2014.

Uncertainty as a scientific term refers to the quantitative variability among data points. When variability is high, it becomes more difficult to predict the value of any one data point, even if an overall trend is significant.

VIC Hydrologic Model[26] is a computer simulation of water and energy balances across largescale watersheds, developed at the University of Washington and applied to river basins across the globe. VIC stands for Variable Infiltration Capacity. It can be accessed at http://www.hydro.washington.edu/Lettenmaier/Models/VIC/

References

1. National Weather Service, "Natural hazard statistics," http://www.nws.noaa.gov/om/hazstats.shtml

2. Melillo, J. M., T. Richmond, and G. W. Yohe, Eds. 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program. http://www.globalchange.gov

3. Edenhofer, O. et al. Eds. 2014. Climate Change 2014: Mitigation of Climate Change. Working Group III Contribution to the IPCC 5th Assessment Report. http://www.ipcc.ch/report/ar5/wg3/

4. Tebaldi, C., D. Adams-Smith, and N. Heller. 2012. The Heat is On: U.S. Temperature Trends. Climate Central Report.

5. Westerling, A. 2008. Climate and Wildfire in the Western United States. 25 pp. UC Merced.

6. Dennison, P. E., S. C. Brewer, J. D. Arnold, and M. A. Moritz. 2014. Large wildfire trends in the western United States, 1984–2011. Geophysical Research Letters 41:2928–2933.

7. Brown, T. J., B. L. Hall, and A. L. Westerling. 2004. The impact of twenty-first century climate change on wildland fire danger in the western United States: an applications perspective. Climatic Change 62: 365–388, 2004.

8. Bachelet, D., J. M. Lenihan, C. Daly, et al. 2001. MC1: a dynamic vegetation model for estimating the distribution of vegetation and associated carbon, nutrients, and water – technical documentation. Version 1.0. General Technical Report. PNW-GTR-508. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station.

9. Flint, L. E. and A. L. Flint. 2012. Downscaling future climate scenarios to fine scales for hydrologic and ecological modeling and analysis. Ecological Processes 1. Accessed at http://www.ecologicalprocesses.com/content/1/1/2

10. Randall, D.A., et al. 2007. Climate Models and Their Evaluation. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., et al., Eds. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

11. Hayhoe, K., Stoner, et al., 2013. Development and Dissemination of a High-Resolution National Climate Change Dataset. http://cida.usgs.gov/thredds/fileServer/dcp/files/Hayhoe_USGS_downscaled_database_final_report.pdf

12. Walsh, J., D. Wuebbles, et al. 2014. Appendix 3: Climate Science Supplement. In Climate Change Impacts in the United States: The Third National Climate Assessment. J.M. Melillo, T. Richmond, and G. W. Yohe, Eds. U.S. Global Change Research Program.

13. National Center for Atmospheric Research Staff, Eds. Last modified 01 May 2014. "The Climate Data Guide: PRISM High-Resolution Spatial Climate Data for the United States: Max/ min temp, dewpoint, precipitation." Retrieved from https://climatedataguide.ucar.edu/climatedata/prism-high-resolution-spatial-climate-dataunited-states-maxmin-temp-dewpoint

14. Daly, C., W. P. Gibson, G. H. Taylor, G. L. Johnson, and P. Pasteris. 2002. A knowledge-based approach to the statistical mapping of climate. Climatic Research 22:99–113.

15. Lenihan, J. M., D. Bachelet, R. P. Neilson and R. Drapek. 2008. Response of vegetation distribution, ecosystem productivity and fire to climate change scenarios. Climatic Change 87 (Supp. 1):S215–230.

16. Naciocenovic, N. O. and R. Stuart, Eds. 2000. Emissions Scenarios: A Special Report of IPCC Working Group III. Cambridge University Press. Cambridge UK. Summary for Policymakers available at http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf

17. IPCC Third Assessment Report available at http://www.ipcc.ch/ipccreports/tar/

18. Voldoire, A. E. Sanchez-Gomez, D. Salas y Melia, et al. 2012. The CNRM-CM5.1 global climate model: description and basic evaluation. Climate Dynamics. www.cnrm.meteo.fr/cmip5/IMG/pdf/Voldoire_et_al_CD_online.pdf

19. IPCC Fifth Assessment Report available at http://www.ipcc.ch/report/ar5/

20. Gordon, H. B., S. O'Farrell, M. Collier, et al. 2010. The CSIRO Mk3.5 Climate Model. Centre for Australian Weather and Climate Research Technical Report No. 021.

21. Johns, T. C., R. E. Carnell, J. F. Crossley et al. 2002. Anthropogenic climate change for 1860 to 2100 simulated with the HadCM3 model under updated emissions scenarios. Climatic Dynamics 20:583–612.

22. Volodin, E. M., N. A. Dianskii, and A. V. Gusev. 2009. Simulating present-day climate with the INMCM4.0 coupled model of the atmospheric and oceanic general circulations. Atmospheric and Oceanic Physics 46:414–431.

23. Hasumi, H. and S. Emori. 2004. K-1 coupled GCM (MIROC) description, K-1 Technical Report 1. Center for Climatic Systems Research. University of Tokyo.

24. Van Vuuren, D. P., M. G. J. Den Elzen, P. L. Lucas, et al. 2007. Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. Climatic Change 81:119–159.

25. Riahi K., S. Rao, V. Krey, et al. 2011. RCP 8.5 – A scenario of comparatively high greenhouse gas emissions. Climatic Change. 109:33–57.

26. Gao, H., Q. Tang, X. Shi, et al. 2010. Water budget record from Variable Infiltration Capacity (VIC) Model. In Algorithm Theoretical Basis Document for Terrestrial Water Cycle Data Records.

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