Continental United States Climate Outlook

Kenneth E. Kunkel, Laura Stevens, and Scott Stevens
CICS-NC, National Climatic Data Center
Asheville, North Carolina

Draft-November 4, 2011

1. Summary

The National Climate Assessment Development and Advisory Committee (NCADAC), at its May 20, 2011 meeting, directed the "use of simulations forced by the A2 emissions scenario as the primary basis for the high climate future and by the B1 emissions scenario as the primary basis for the low climate future for the 2013 report" for climate scenarios. Furthermore, they approved the "the use of both statistically- and dynamically-downscaled data sets". Finally, they decided that "regional teams should be given the latitude to incorporate results from the CMIP5 RCP8.5 and RCP2.6 simulations as time and resources permit". This outlook responds to these directives by incorporating analyses from multiple sources. The core source is the set of model simulations performed for the IPCC Fourth Assessment Report (AR4), also referred to as the Climate Model Intercomparison Project 3 (CMIP3) suite. These have undergone extensive evaluation and analysis. A second source is a set of statistically-downscaled data sets based on the CMIP3 simulations. A third source is a set of dynamically-downscaled simulations, driven by CMIP3 models. This outlook does not incorporate any CMIP5 simulations as relatively few are available at the present time.

The outlook information contained herein provides a nationally-consistent baseline for use in regional assessments. However, experts are encouraged to comment on this draft document and provide additional relevant information consistent with the guidelines of the NCADAC. This could include dynamically- and statistically-downscaled data sets and process studies. Any information that is added will be required to meet the information quality standards of the NCADAC.

The following outlook information provides statistics for the periods of 2021-2050, 2041-2070, and 2070-2099, with changes calculated with respect to the historical climate reference period of 1971-2000. These future periods will be denoted in the text by their mid-points of 2035, 2055, and 2085, respectively. Three different types of analyses are represented, as follows:

- **Multi-model mean maps** – to produce these, each model's data is first re-gridded to a common grid. Then, each grid point value is calculated as the mean of all the available models' values at that grid point. Finally, the mean grid point values are mapped.

Although this type of analysis weights all models equally, a number of research studies have found that the multi-model mean is superior to any single model in reproducing the present-day climate. A multi-mean analysis of future spatial patterns may be the most robust estimate of future change.

- **Spatially-averaged products** – to produce these, all the grid point values within the continental US boundaries are averaged and represented as a single value. This is useful for general comparisons of different models, periods, and data sources. Because of the spatial aggregation, this product may not be suitable for many types of impacts analyses.
- **Probability density functions (pdfs)** – These are used here to illustrate the differences among models. To produce these, spatially-averaged values are calculated for each model simulation. Then the distribution of these spatially-averaged values is displayed. This product provides an estimate of the uncertainty of future changes.

2. Description of data sources

This initial outlook for the National Climate Assessment (NCA) is based on the following model data sets:

- CMIP3 GCM output – Fifteen models identified in the 2009 NCA report were used. These also serve as the basis for the following downscaled data sets.
- Statistically-downscaled monthly temperature and precipitation – These data are at 1/8° (latitude and longitude) resolution. The data were downscaled using the bias-corrected spatial disaggregation (BCSD) method. Sixteen models were downscaled for the period of 1961-2100.
- Statistically-downscaled daily temperature and precipitation – These data are also at 1/8° (latitude and longitude) resolution. Daily data were created from the monthly data by randomly sampling historical months and adjusting the values using the “delta” method. Sixteen models were downscaled for the period of 1961-2100.
- The North American Regional Climate Change Assessment Program (NARCCAP) – This multi-institutional program is producing regional climate model (RCM) simulations in a coordinated experimental approach. At this time, there are 9 simulations available using different combinations of a RCM driven by a GCM. Each simulation includes the periods of 1971-2000 and 2041-2070 for the A2 scenario only, and is at a resolution of approximately 50 km.

3. Mean temperature outlook

Figure 1 shows the spatial distribution of the 15 CMIP3 multi-model mean annual temperature for the three future time periods (2035, 2055, 2085) and two emissions scenarios (A2, B1). All three periods indicate an increase everywhere in temperature compared to 1971-2000. Spatial variations are generally small, with the exception of the A2 scenario for 2085, which shows more pronounced warming toward the northern parts of the country. Coastal areas exhibit less warming than areas inland, and this pattern becomes more defined with time. Temporally, both scenarios and all areas show increased warming as time progresses, and the differences between the two scenarios also increase with time, with A2 being warmer. Values are similar for the two scenarios in 2035, ranging from 1.5 to 3.5°F. By 2055, the A2 scenario is roughly 1°F warmer than the B1 in all areas, with warming ranging from 2.5 to 5.5°F. In the 2085 projection, the B1 scenario shows a warming that closely resembles the A2 scenario from 30 years prior, while the A2 scenario shows dramatic warming in all areas, ranging from 4.5°F in Florida to 9.5°F in the upper Midwest and parts of northern Utah.

Figure 2 shows the mean annual and seasonal temperature changes between 2041-2070 and 1971-2000 for the A2 scenario, for the 9 NARCCAP regional climate model simulations. Annual changes are generally uniform, with most areas experiencing warming between 3.5 and 5.5°F. However, some seasons show more spatial variability. Spring shows the least warming in most areas, ranging from 2.5-3.5°F over most of the country to 3.5-4.5°F in the southwestern and northeastern parts of the country. Fall shows the same level of spatial uniformity, with values ranging from 2.5°F in the Pacific Northwest to 5.5°F over most of the interior US. The winter season shows a general south to north gradient, with the greatest warming (up to 6.5°F) occurring in the northern reaches of the country, and the least (2.5-3.5°F) occurring along the Gulf and Pacific coasts. Finally, summer is characterized by a swath of enhanced warming across the central Rockies and Great Plains, up to 6.5°F, from Nevada to western Kentucky. The magnitude of warming decreases outward from this region, but all areas are projected to experience warming of at least 3.5°F.

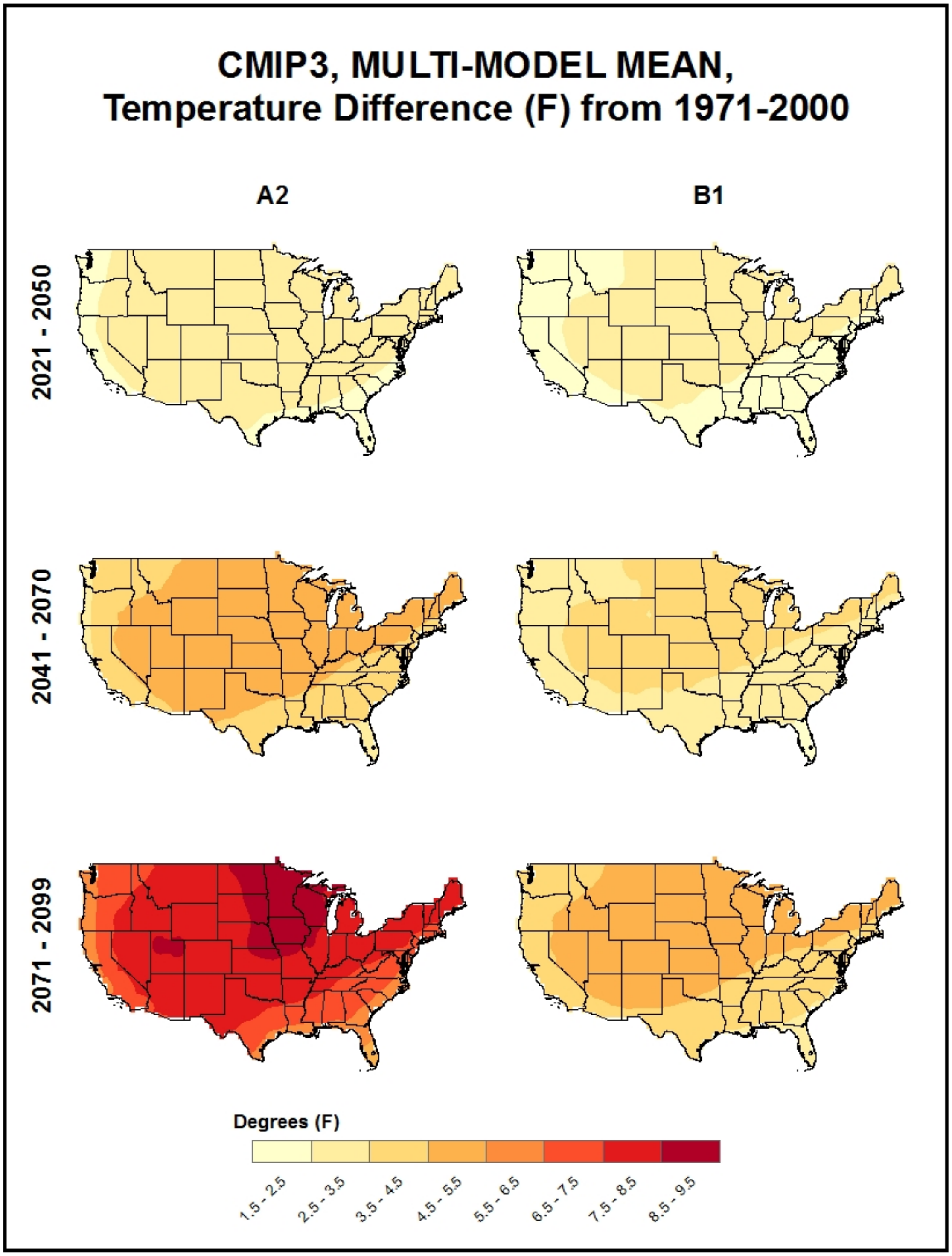


Figure 1. Multi-model mean annual differences in temperature (°F) between the 3 future periods and 1971-2000, from 15 CMIP3 model simulations.

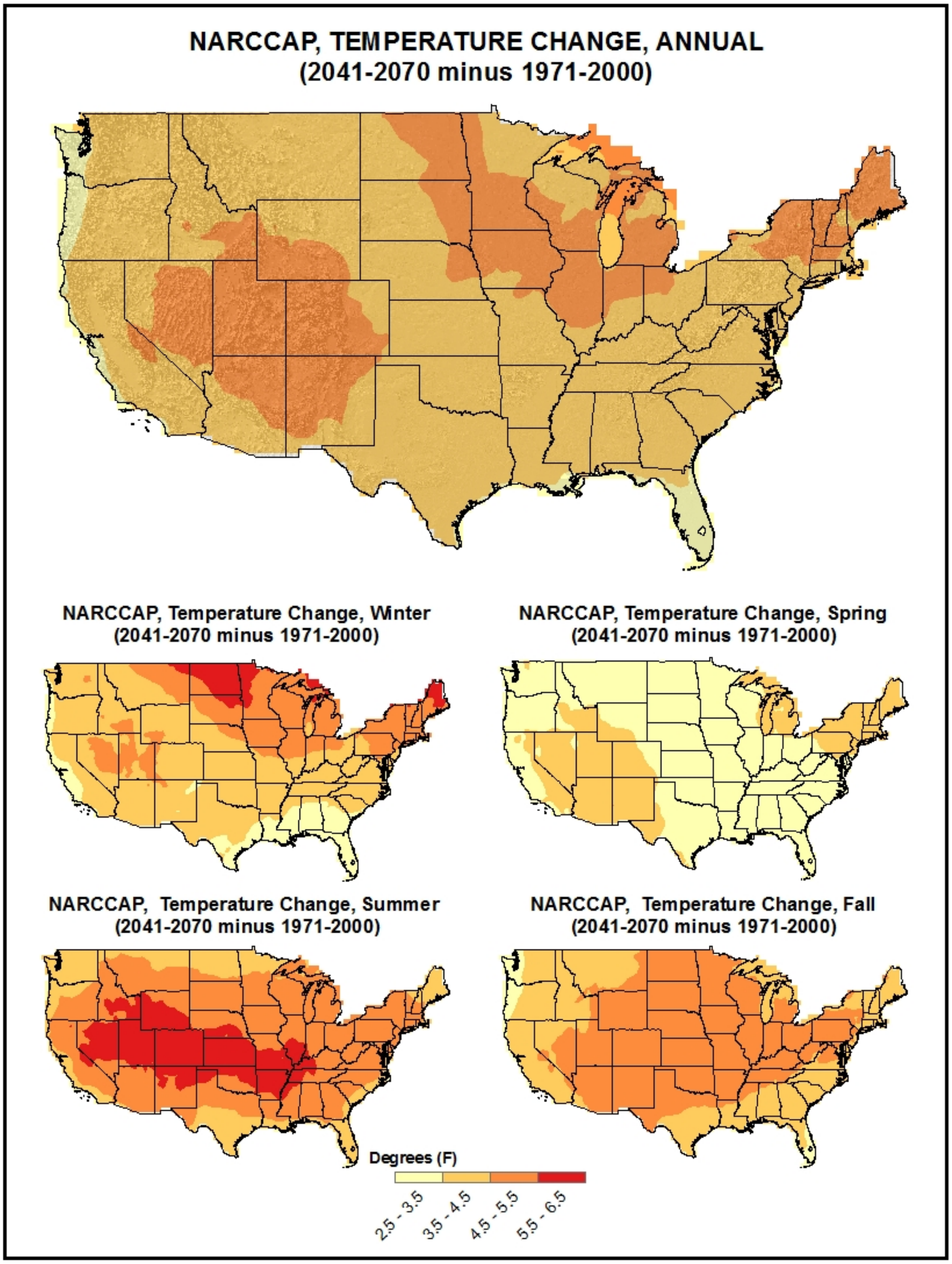


Figure 2. Multi-model mean annual and seasonal differences in temperature (°F) between 2041-2070 and 1971-2000, from the 9 NARCCAP regional climate model simulations.

Figure 3 shows the mean annual temperature changes for each future time period and both emissions scenarios, averaged over the entire continental US for the 15 CMIP3 models. In addition, averages for the 9 NARCCAP simulations and the 4 GCMs used in the NARCCAP experiment are shown for 2055 (A2 scenario only). The small crosses represent the values for individual models, while the filled circles depict the overall means. For the A2 scenario, the CMIP3 models project average increases of 2.9°F by 2035, 4.7°F by 2055, and nearly 8°F by 2085. The increases for the low B1 scenario are nearly as large in 2035 at around 2.5°F, but by 2085 the increase of 4.7°F is just over half of the increase seen in the A2 scenario. For 2055, the average temperature change simulated by the NARCCAP models (4.2°F) is close to the mean of the CMIP3 GCMs for the A2 scenario.

A notable feature is the increased sensitivity to emissions with time, as the two scenarios diverge quickly over the simulation period. However, the range of individual model changes is quite large. There is considerable overlap between the A2 and B1 results, even by 2085. The range of changes in 2055 for the NARCCAP GCMs is small relative to the range for all CMIP3 models and is probably largely responsible for the relatively small range for the NARCCAP models.

Figure 4 shows the mean seasonal changes for each future time period for the A2 scenario, averaged over the entire Continental US for the 15 CMIP3 models. The summer season consistently shows the largest average warming, while the spring and summer generally show the least. For all seasons, warming increases with time, and the difference between them increases as well. The spread of individual model values is large in all cases, and also increases with time. The models have a range of roughly 3°F in 2035, increasing to approximately 7°F by 2085.

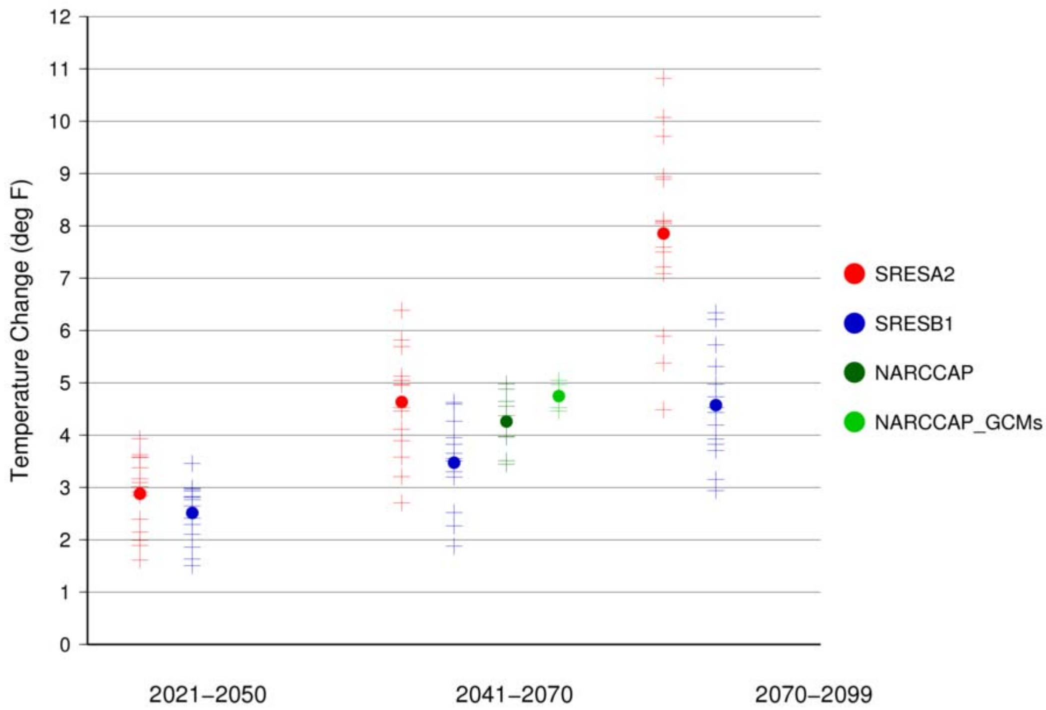


Figure 3. Mean annual temperature changes (°F) for each future time period with respect to the reference period of 1971-2000 for all 15 CMIP3 models, averaged over the entire Continental US for the high (A2) and low (B1) emissions scenarios. Also shown are results for the NARCCAP simulations for 2041-2070 and the 4 GCMs used in the NARCCAP experiment (A2 only). The small plus signs are values for each individual model and the circles depict the overall means.

The distribution of changes in mean annual temperature for each future time period and both emissions scenarios across the 15 CMIP3 models is shown in Table 1. The range of changes from lowest to highest varies from 1.5°F in 2035 for the B1 scenario to 10.8°F in 2085 for the A2 scenario. The inter-quartile range of changes across the CMIP3 models is between 0.7 and 1.8°F. Although the total range is seen to increase for each future time period, the inter-quartile range varies little.

This table also illustrates the overall uncertainty arising from the combination of model differences and emission pathway. For 2035, the projected changes range from 1.5°F to 3.9°F and arise almost entirely from model differences. By 2085, the range of projected changes has increased to 2.9°F to 10.8°F, with roughly equal contributions to the range from model differences and emission pathway uncertainties.

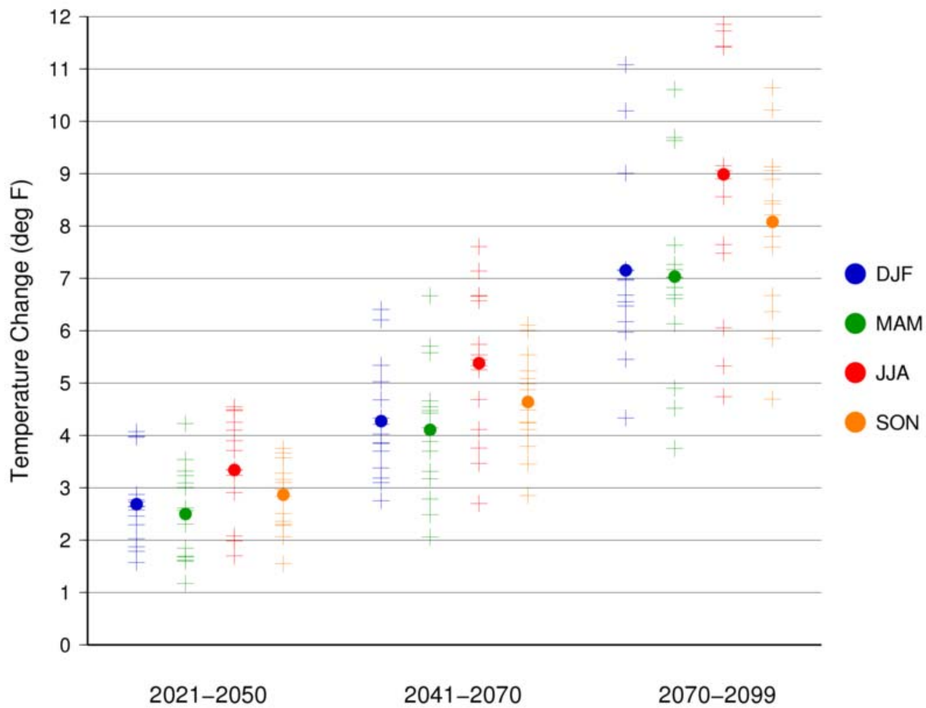


Figure 4. Mean seasonal temperature changes (°F) for each future time period with respect to the reference period of 1971-2000 for all 15 CMIP3 models, averaged over the entire Continental US for the high (A2) emissions scenario. The small plus signs are values for each individual model and the circles depict the overall means.

4. Extreme temperature projections

A number of metrics of extreme temperatures were calculated from the daily NARCCAP and CMIP3 statistically-downscaled data sets. Maps of a few selected variables and a table summarizing all of the results follow. Each figure includes the difference between the 2055 period (2041-2070) and the climatology reference period (1971-2000), as well as a map of the reference period for comparison.

Figure 5 shows the spatial distribution of the NARCCAP multi-model mean change in the number of days with maximum temperatures exceeding 95°F, between 2055 and the historical reference period. The largest absolute increases of more than 25 days occur in the Southeast region and the southern Great Plains, as well as the southern portion of the Southwest region. These are areas with the greatest number of days exceeding 95°F in the present climate.

Table 1. Distribution of changes in mean annual temperature (°F) for the Continental US for the 15 CMIP3 models.

Scenario	Period	Low	25%ile	Median	75%ile	High
A2	2021-2050	1.6	2.3	3.0	3.5	3.9
	2041-2070	2.7	4.0	5.0	5.1	6.4
	2070-2099	4.5	7.1	8.0	8.9	10.8
B1	2021-2050	1.5	2.2	2.7	2.9	3.5
	2041-2070	1.9	3.2	3.5	3.9	4.6
	2070-2099	2.9	3.9	4.5	5.2	6.3

Some parts of the southernmost states may see the number of days per year increase by more than 35. The smallest increases of less than 10 days occur in the northernmost regions of the US, where the general increase in temperature is not large enough to markedly increase the chances for such warm days.

Figure 6 shows the spatial distribution of the NARCCAP multi-model mean change in the number of days with minimum temperatures below 10°F between 2055 and the historical reference period. Areas along the Rocky Mountains and in the northernmost states are projected to experience a large decrease in the number of days, compared to little or no change in southern regions. The largest absolute decreases occur in higher elevation areas with changes of up to 30 days. The smallest decreases occur in southern areas and the Pacific coast, where the number of occurrences of days below 10°F in the present-day climate is small.

Consecutive warm days can have large impacts and are analyzed here as one metric of heat waves. Figure 7 shows the NARCCAP multi-model mean change in the average annual maximum run of days with maximum temperatures exceeding 95°F between 2055 and the historical reference period. The pattern is similar to that of the change in the total number of days exceeding 95°F. In parts of the Southwest region, the average annual longest string of days with such high temperatures increases by 20 days or more. Little or no change is seen in the Northwest, Northeast and northern parts of the Great Plains and Midwest regions. Most other areas see between 2 and 20 more consecutive 95°F days.

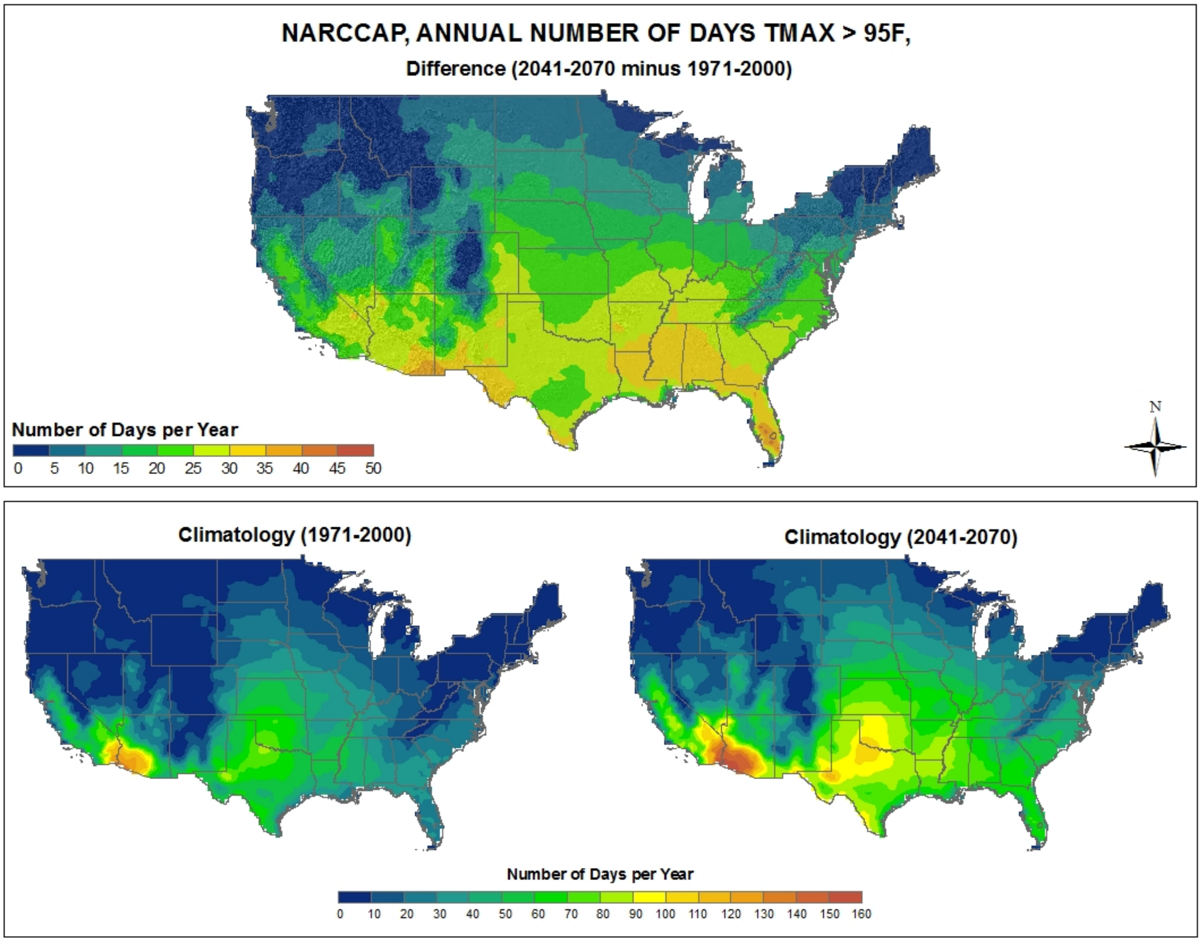


Figure 5. Spatial distribution of the NARCCAP multi-model mean change in the number of days with a maximum temperature greater than 95°F between 2041-2070 and 1971-2000 (top). Climatology of the number of days with a maximum temperature greater than 95°F for 1971-2000 (bottom left) and 2041-2070 (bottom right).

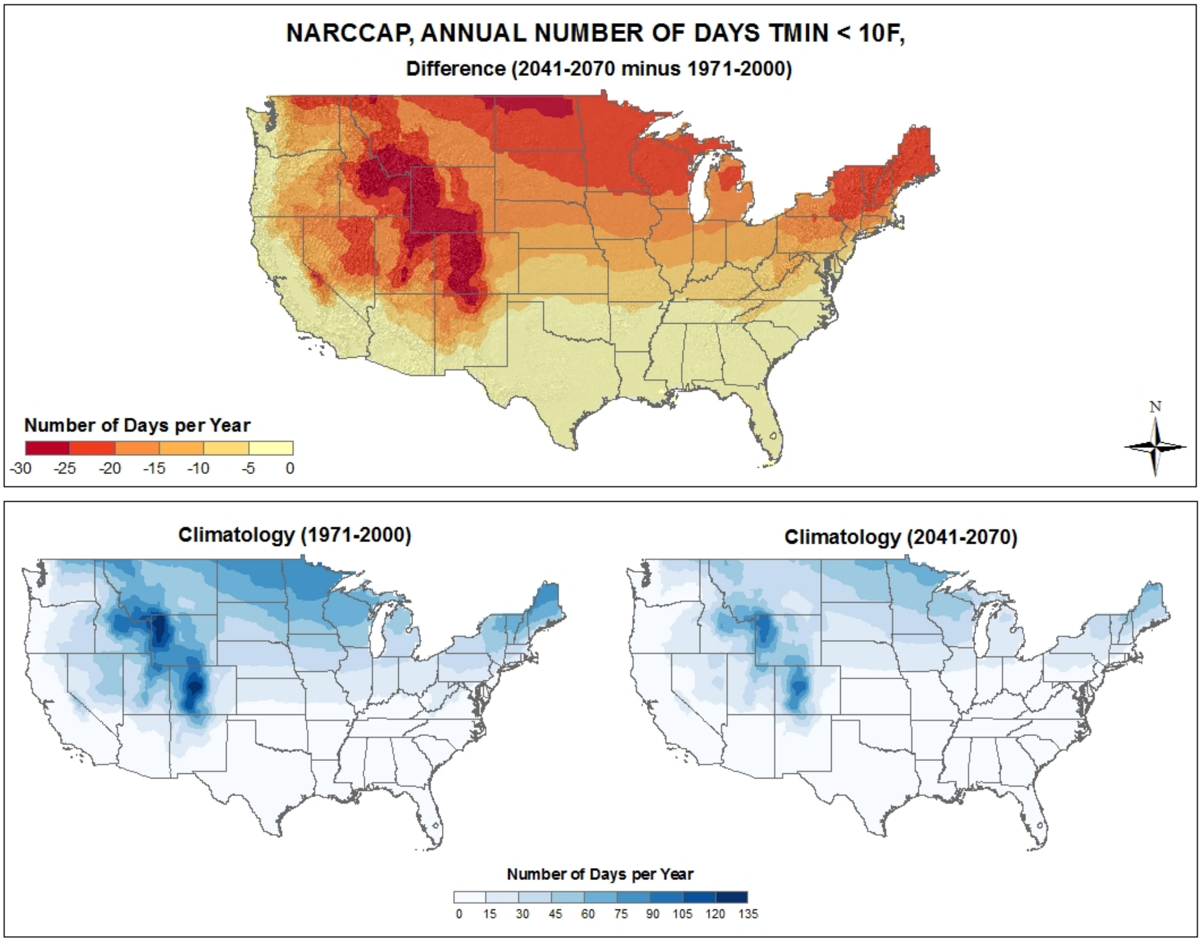


Figure 6. Spatial distribution of the NARCCAP multi-model mean change in the number of days with a minimum temperatures below 10°F between 2041-2070 and 1971-2000 (top). Climatology of the number of days with a minimum temperature less than 10°F for 1971-2000 (bottom left) and 2041-2070 (bottom right).

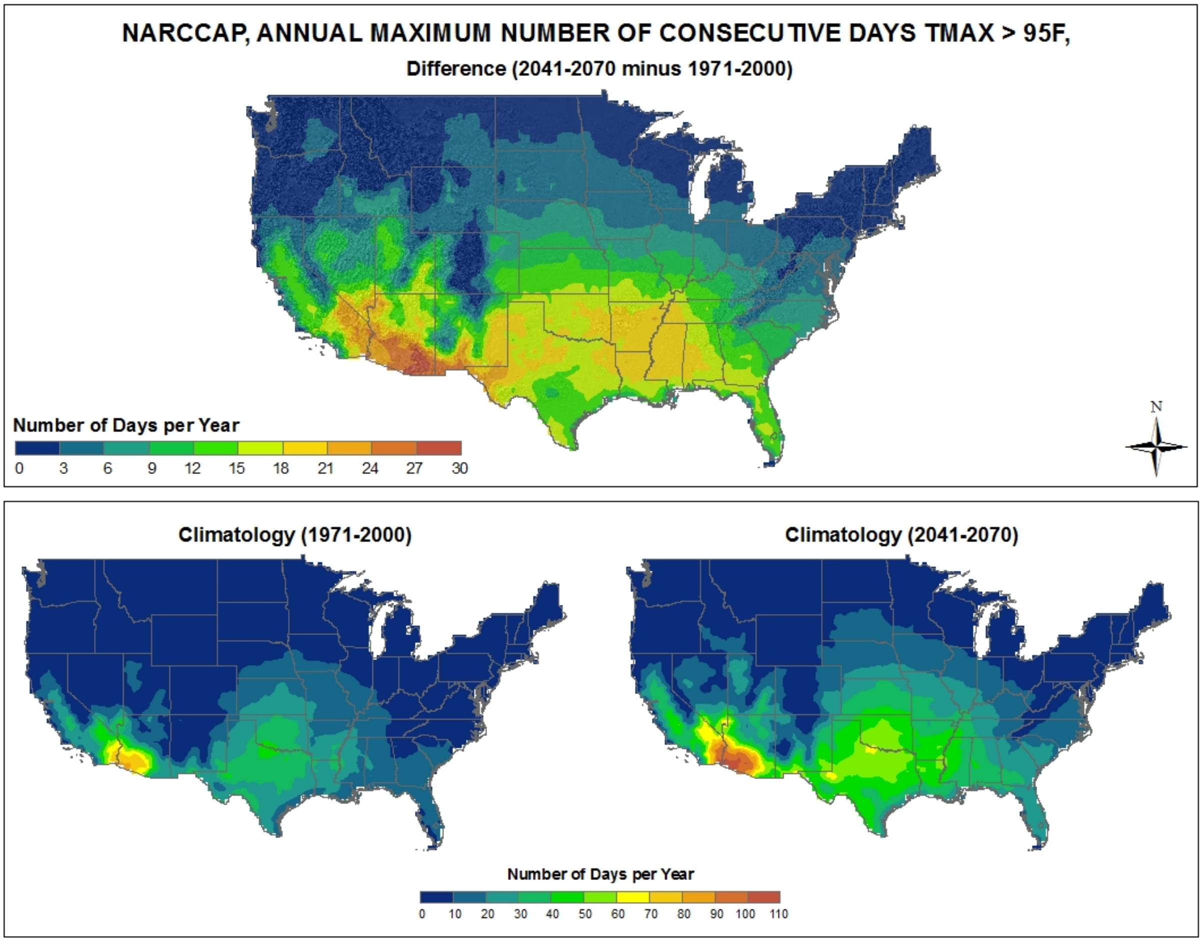


Figure 7. Spatial distribution of the NARCCAP multi-model mean change in the annual maximum number of consecutive days with a maximum temperature greater than 95°F between 2041-2070 and 1971-2000 (top). Climatology of the annual maximum number of consecutive days with a maximum temperature greater than 95°F for 1971-2000 (bottom left) and 2041-2070 (bottom right).

5. Projections for other temperature variables

The spatial distribution of the NARCCAP multi-model mean change in the frost-free season between 2055 and the historical reference period is shown in Fig. 8. There are increases of at least 20 more days in the annual frost-free season across the US. The only exception is some parts of the northern Great Plains and southern Florida, which shows increases of 0-20 days. The largest increases are in the far west with values of greater than 40 days along the Pacific coast.

The spatial distribution of the NARCCAP multi-model mean change in cooling degree days between 2055 and the historical reference period is shown in Fig. 9. In general, the changes are quite closely related to mean temperature with the warmest (coolest) areas showing the largest (smallest) changes. The hottest areas, such as southern Texas and Florida, are simulated to have the largest increase in cooling degree days per year (up to 1,200). The Northwest region has the smallest simulated increases, around 200 or less. The rest of the Continental US indicates between 200 and 1,000 more cooling degree days, with a north-south gradient.

The spatial distribution of the NARCCAP multi-model mean change in heating degree days between 2055 and the historical reference period is shown in Fig. 10. With the exception of Florida, the entire US is projected to experience a decrease of at least 400 heating degree days per year. The largest changes occur in the high elevation areas of the Rockies, with decreases of up to 2,000. The Southeast region is projected to experience the smallest decreases in heating degree days per year, along with Texas, Oklahoma, and parts of California and Arizona.

6. Mean precipitation projections

The distribution of the CMIP3 multi-model mean changes in annual precipitation is shown in Fig. 11, for the three future periods (2035, 2055, 2085) and two emissions scenarios (A2, B1). Spatially, there is a north-south gradient in changes. The southern Great Plains region shows the largest decreases while the northern parts of the Midwest and Northeast regions show the greatest increases. This gradient increases in magnitude as time progresses for the A2 scenario. The gradient in the B1 scenario, however, is strongest for 2055 but moderates slightly by 2085. The largest north-south differences are for the A2 scenario in 2085, varying from increases of 8-10% in the far northeast to decreases of 10-12% in the far southwest and Texas.

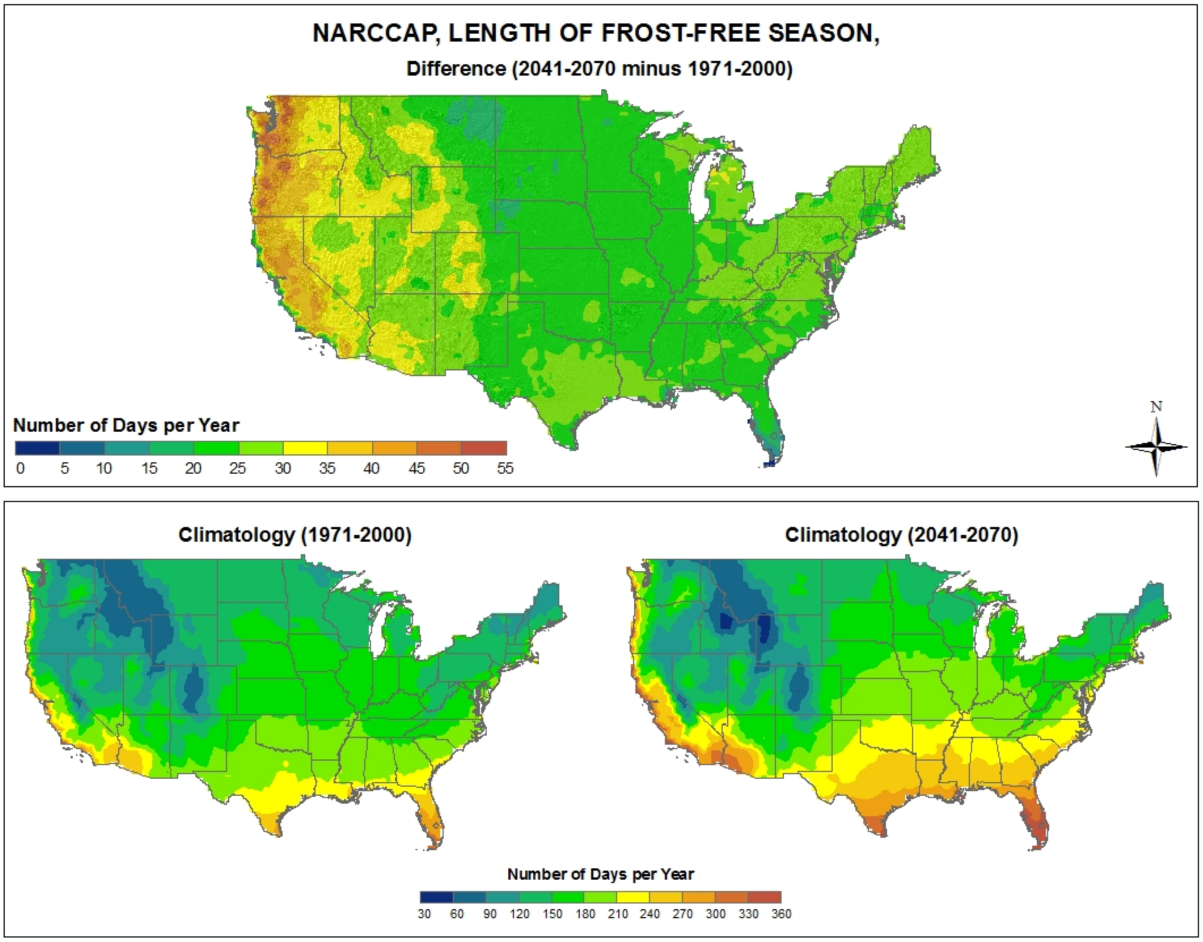


Figure 8. Spatial distribution of the NARCCAP multi-model mean change in the length of the frost-free season between 2041-2070 and 1971-2000 (top). Climatology of the length of the frost-free season for 1971-2000 (bottom left) and 2041-2070 (bottom right).

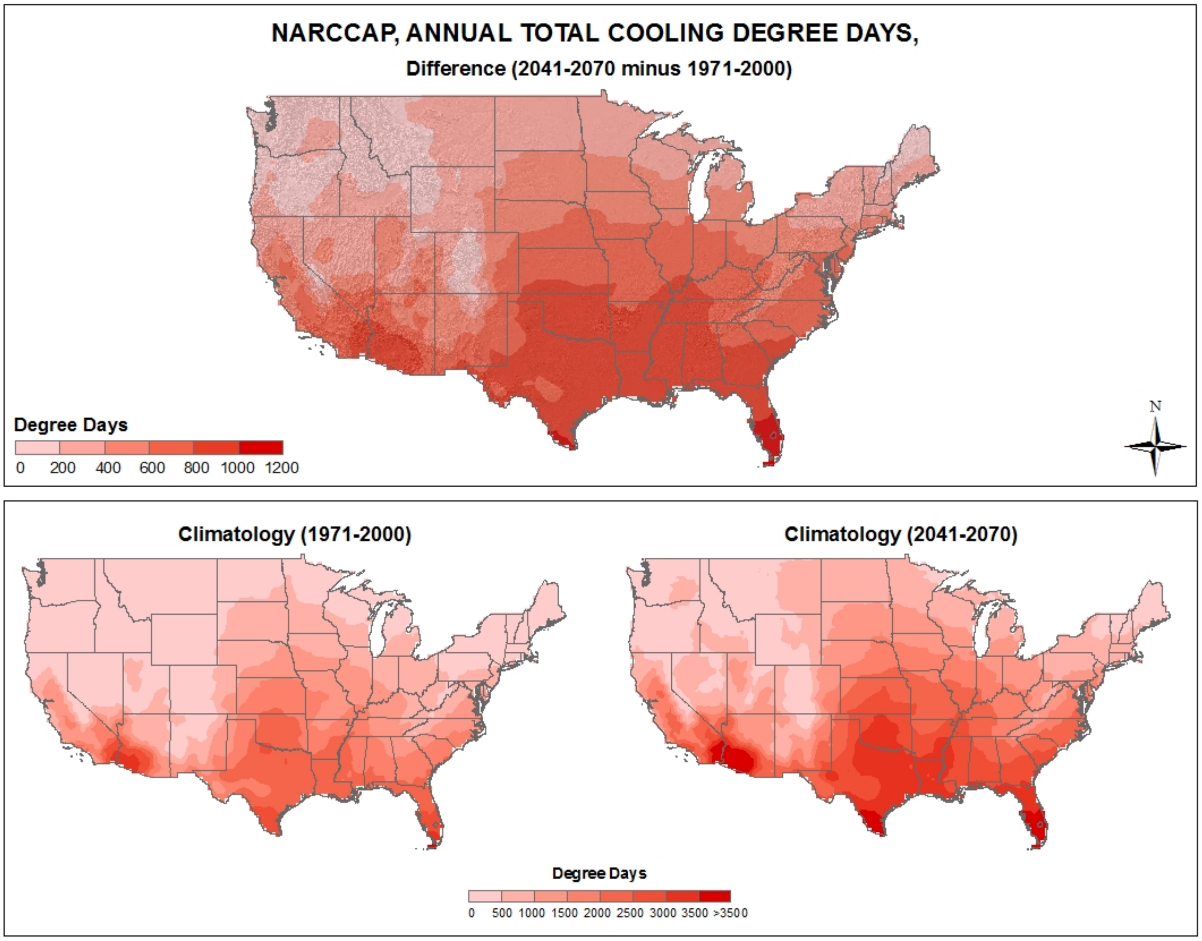


Figure 9. Spatial distribution of the NARCCAP multi-model mean change in the number of cooling degree days between 2041-2070 and 1971-2000 (top). Climatology of the number of cooling degree days for 1971-2000 (bottom left) and 2041-2070 (bottom right).

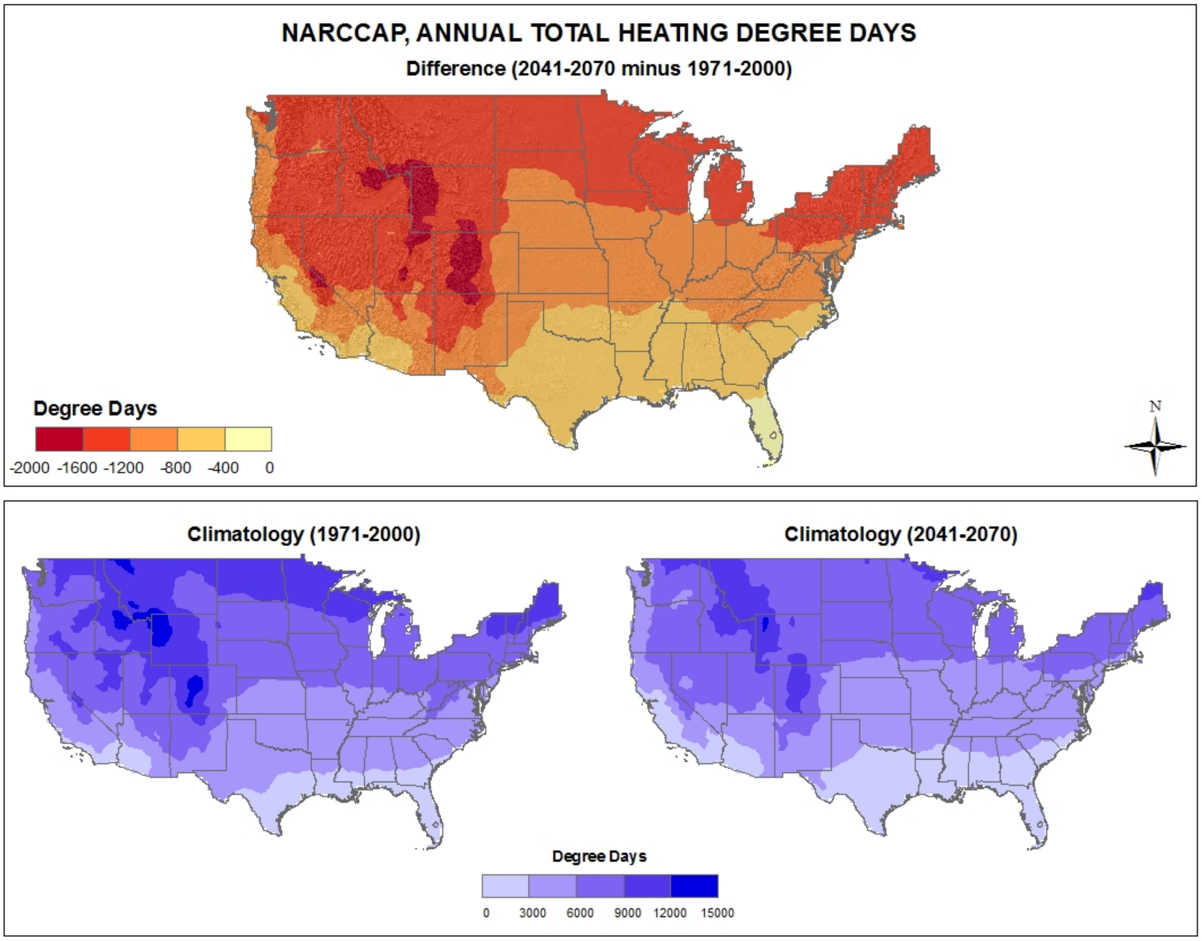


Figure 10. Spatial distribution of the NARCCAP multi-model mean change in the number of heating degree days between 2041-2070 and 1971-2000 (top). Climatology of the number of heating degree days for 1971-2000 (bottom left) and 2041-2070 (bottom right).

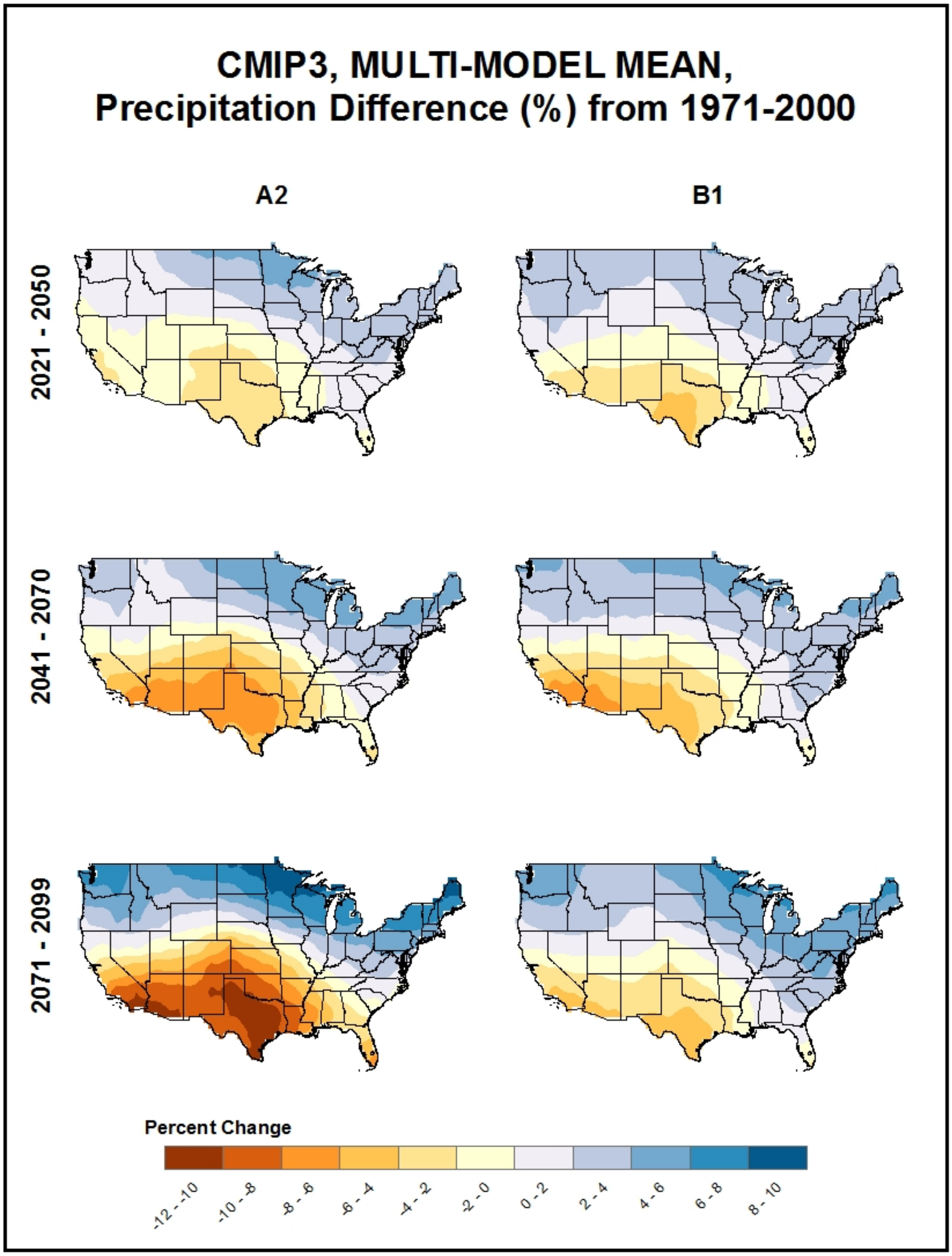


Figure 11. Multi-model mean annual differences in precipitation (%) between the 3 future periods and 1971-2000, from the 15 CMIP3 model simulations.

Figure 12 shows the annual and seasonal precipitation change between 2041-2070 and 1971-2000 for the A2 scenario, for the 9 NARCCAP regional climate model simulations. The annual changes are both positive and negative. The largest decreases occur in west Texas as well as southern Arizona and New Mexico; the largest increases can be seen in the interior north. Winter changes exhibit the smallest spatial variations, ranging from -16 to +24% over the entire Continental US. Changes are mostly positive for winter, but mostly negative in the summer. The largest variability also occurs in summer, ranging as high as +40% and as low as -38%. This is most notable in southern California, where the difference occurs within a couple of hundred miles.

Figure 13 shows the mean annual changes in precipitation for each future time period and both emissions scenarios, averaged over the entire Continental US for the individual 15 CMIP3 models. In addition, averages for the 9 NARCCAP simulations and the 4 GCMs used in the NARCCAP experiment are shown for 2055 (A2 scenario only). The small plus signs are values for each individual model, and the circles depict the overall means. While such large area averages mask all-important regional differences, this analysis illuminates the magnitude of inter-model differences and thus provides insights into the overall uncertainties of the projections. All the mean changes are close to zero for the A2 scenario and slightly positive for B1. The mean of the NARCCAP simulations is more positive than the mean of the CMIP3 GCMs (+2% compared to 0%), but close to the mean of the 4 GCMs used in the NARCCAP experiment. The range of individual model changes in Fig. 14 is large compared to the differences in the multi-model means. In fact, for all three future periods and for the two scenarios, the individual model range is much larger than the differences in the CMIP3 multi-model means.

Figure 14 shows the mean seasonal changes in precipitation for each future time period for the A2 scenario, averaged over the entire Continental US for the individual 15 CMIP3 models, as well as the NARCCAP models for 2055. Decreases occur in summer, ranging from around 4% in 2035 to more than 9% in 2085, with increases of up to 6% in the other seasons. The NARCCAP models, which are displayed during 2055, are close to the same as the CMIP3 models for all four seasons. As was the case for the annual totals in Fig. 13, the model ranges in Fig. 14 are large compared to the multi-model mean differences. This illustrates the large uncertainty in the precipitation estimates using these simulations.

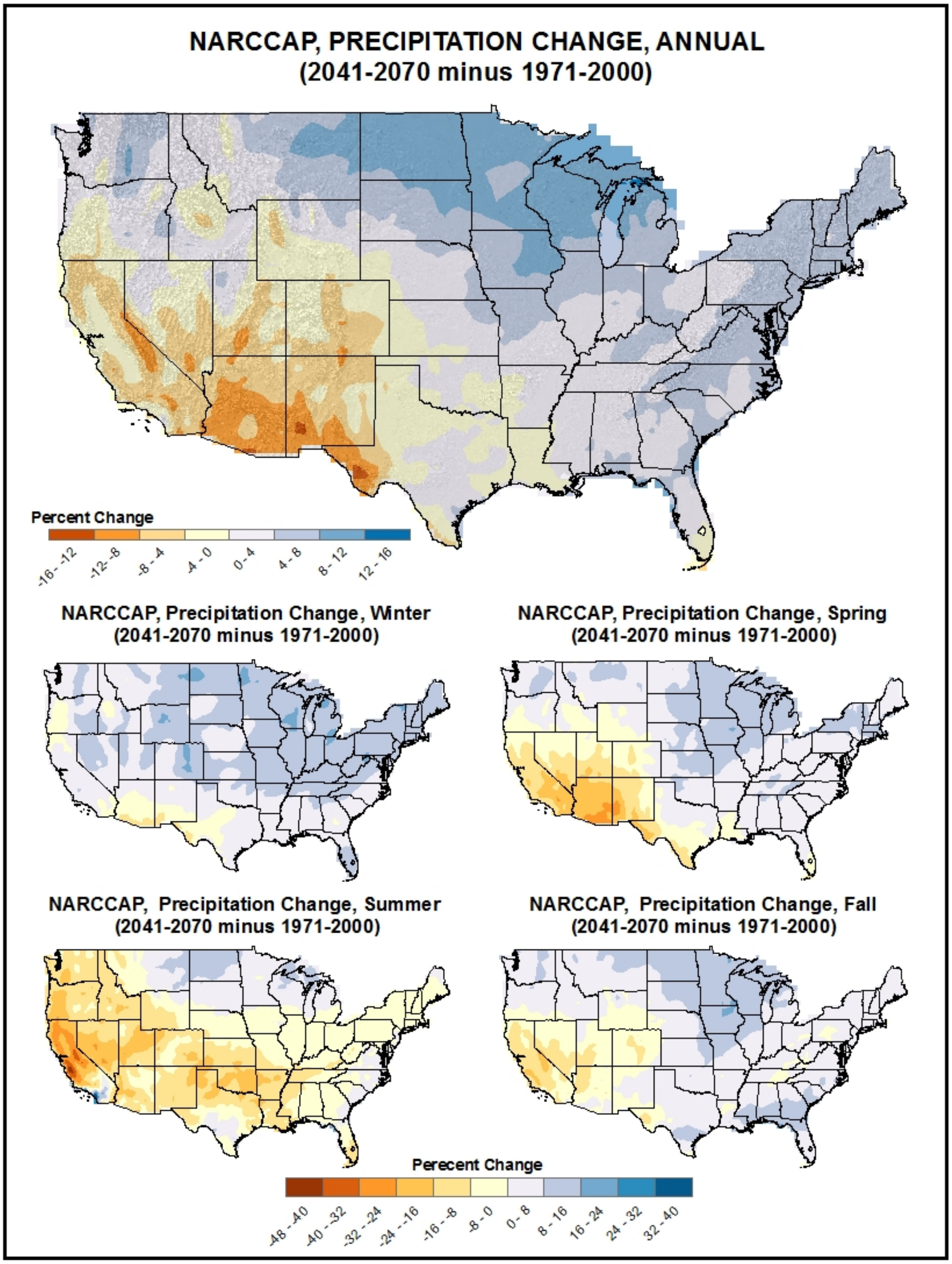


Figure 12. Multi-model mean annual and seasonal differences in precipitation (%) between 2041-2070 and 1971-2000, from the 9 NARCCAP regional climate model simulations.

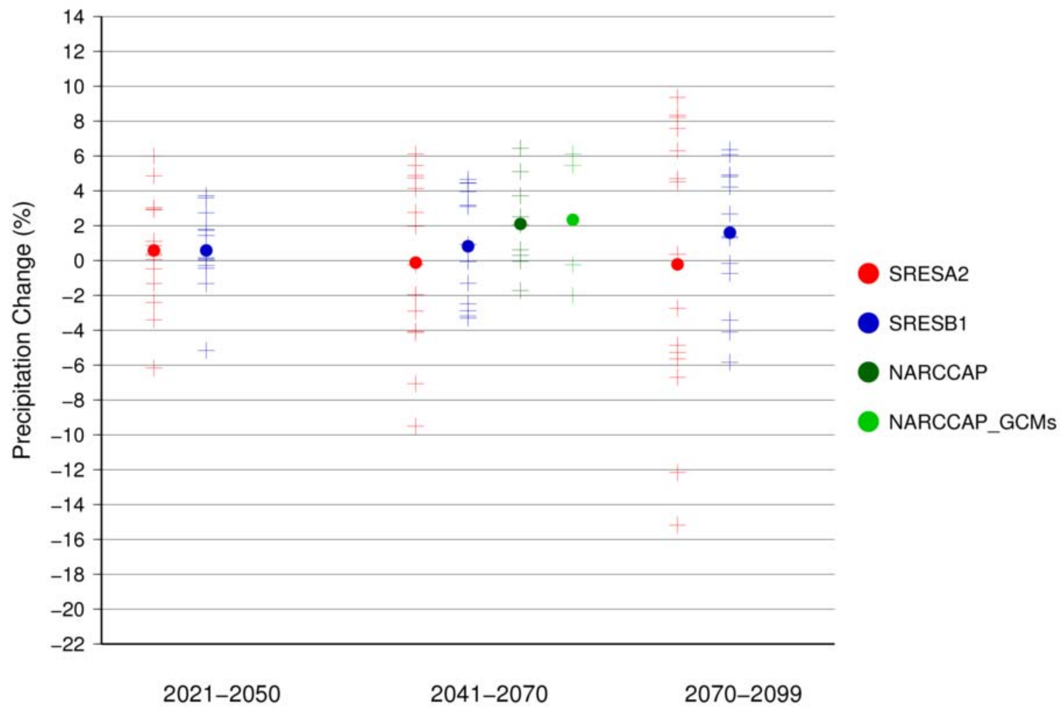


Figure 13. Mean annual precipitation changes (%) for each future time period with respect to the reference period of 1971-2000 for all 15 CMIP3 models, averaged over the entire Continental US for the high (A2) and low (B1) emissions scenarios. Also shown are results for the NARCCAP simulations for 2041-2070 and the 4 GCMs used in the NARCCAP experiment (A2 only). The small plus signs are values for each individual model and the circles depict the overall means.

7. Extreme precipitation projections

The spatial distribution of the NARCCAP multi-model mean change in number of days with precipitation exceeding 1 inch is shown in Fig. 15. Again this is the difference between the period of 2041-2070 and the climatology from 1971-2000. The climatology maps are also displayed for reference. Most areas exhibit increases, the exception being parts of the Southwest region. Areas such as eastern Colorado, southern Arizona and southwestern New Mexico show decreases of up to 20%. The largest changes are located between the Cascades and Rocky Mountains, where some locations indicate increases of over 100%. Regions which can be identified as having the fewest number of days over 1 inch in the climatology are generally those which experience the greatest percentage changes.

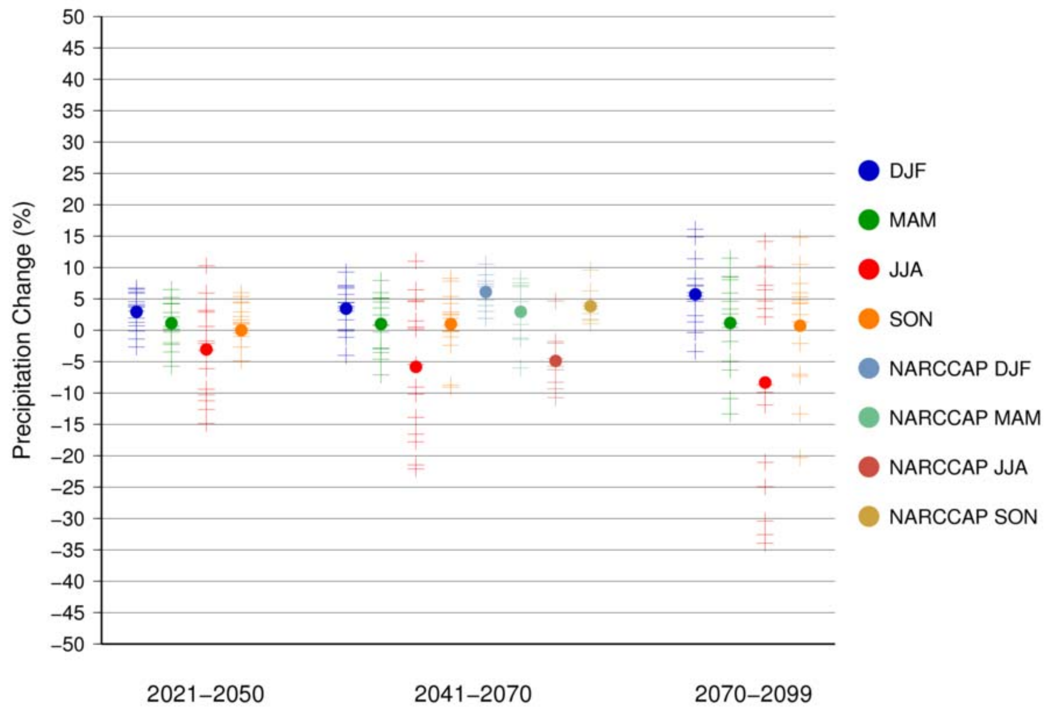


Figure 14. Mean seasonal precipitation changes (%) for each future time period with respect to the reference period of 1971-2000 for all 15 CMIP3 models, averaged over the entire Continental US for the high (A2) emissions scenario. Also shown are results for the NARCCAP simulations for 2041-2070 and the 4 GCMs used in the NARCCAP experiment. The small plus signs are values for each individual model and the circles depict the overall means.

Figure 16 shows the results of Fig. 15 expressed as a return period (inverse of the frequency). The return period distributions are shown for 2041-2070 and 1971-2000 and are the return period equivalents of the bottom panels of Fig. 15. In the late 20th Century climatology return periods in the much of the eastern third of the U.S. are less than 0.2 years, or about 1 event per 2 months. Return periods in parts of the intermountain west are greater than 3 years (i.e. an average interval between events of 3 years or more). In most areas, the return periods for 2041-2070 are smaller, representing an increase in the frequency of events, as noted in the top panel of Fig. 15. For example, the area covered by return periods of 0.2 years or smaller expands to the west and north in 2041-2070 and the area of return periods greater than 0.5 years shrinks in the northern areas.

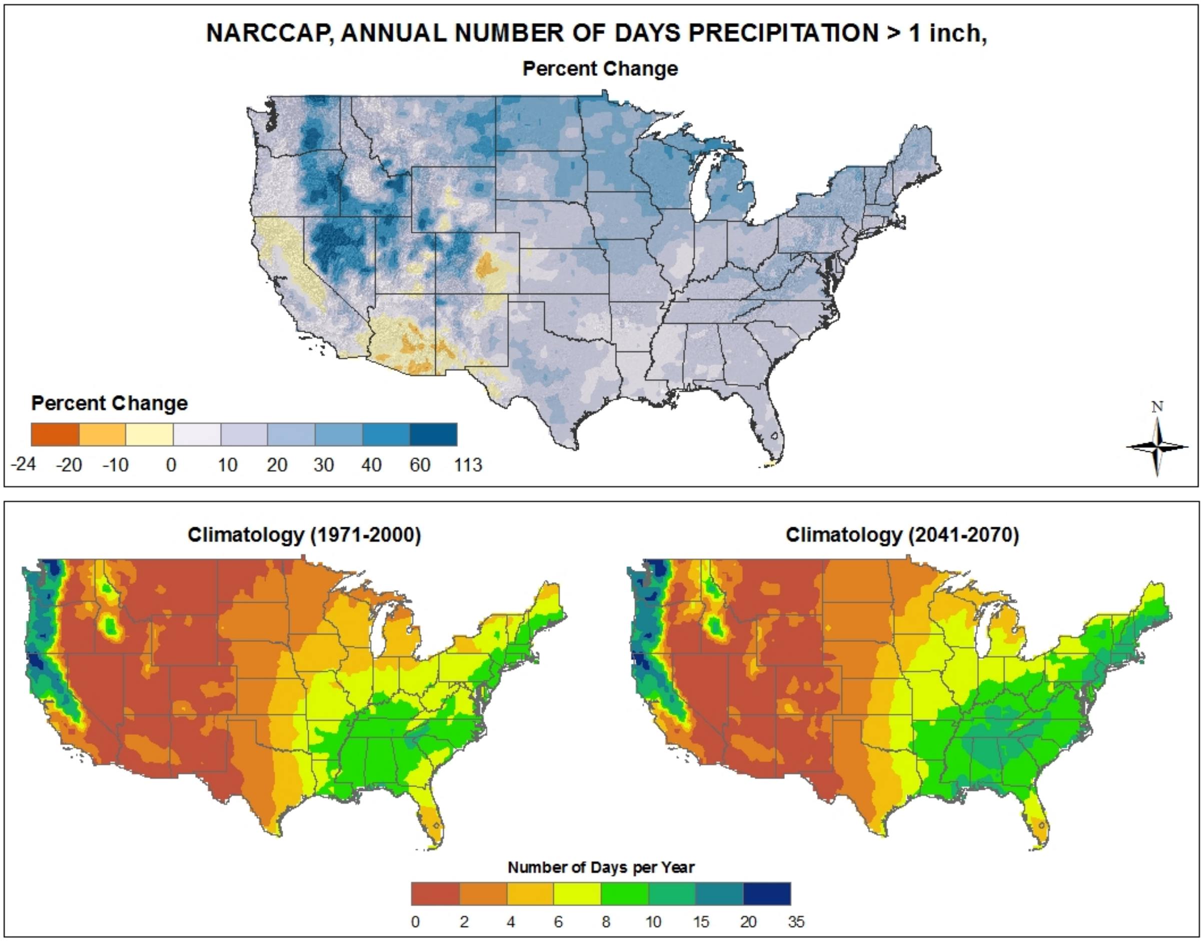
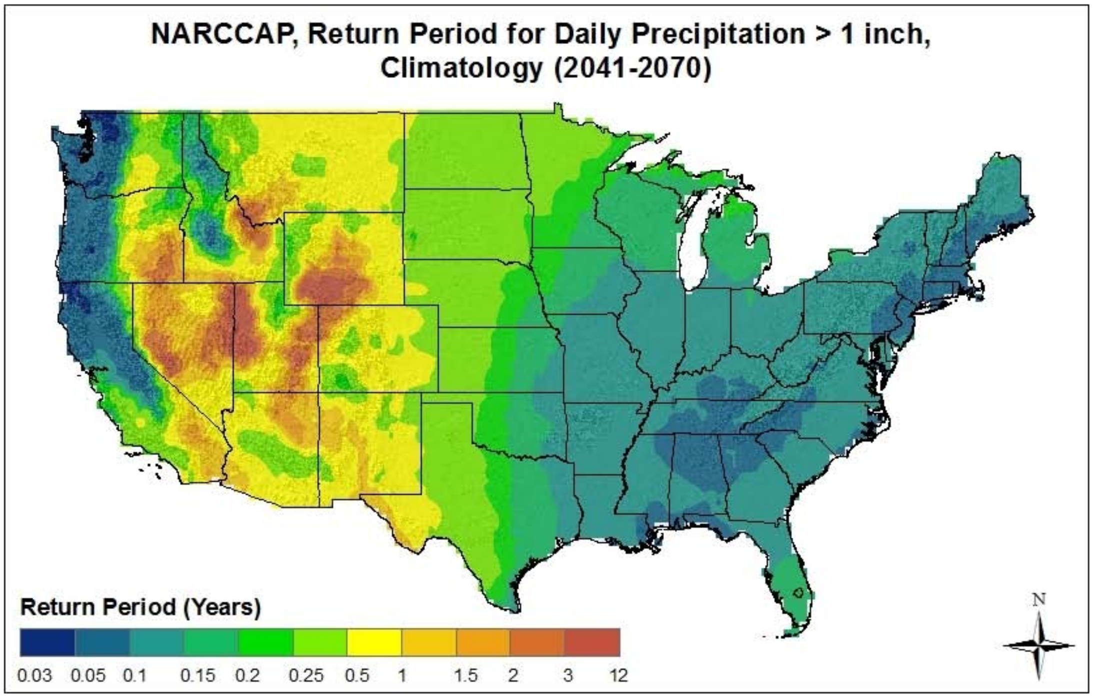


Figure 15. Spatial distribution of the NARCCAP multi-model mean change in the number of days with precipitation exceeding 1 inch between 2041-2070 and 1971-2000 (top). Climatology of the number of days with precipitation exceeding 1 inch for 1971-2000 (bottom left) and 2041-2070 (bottom right).



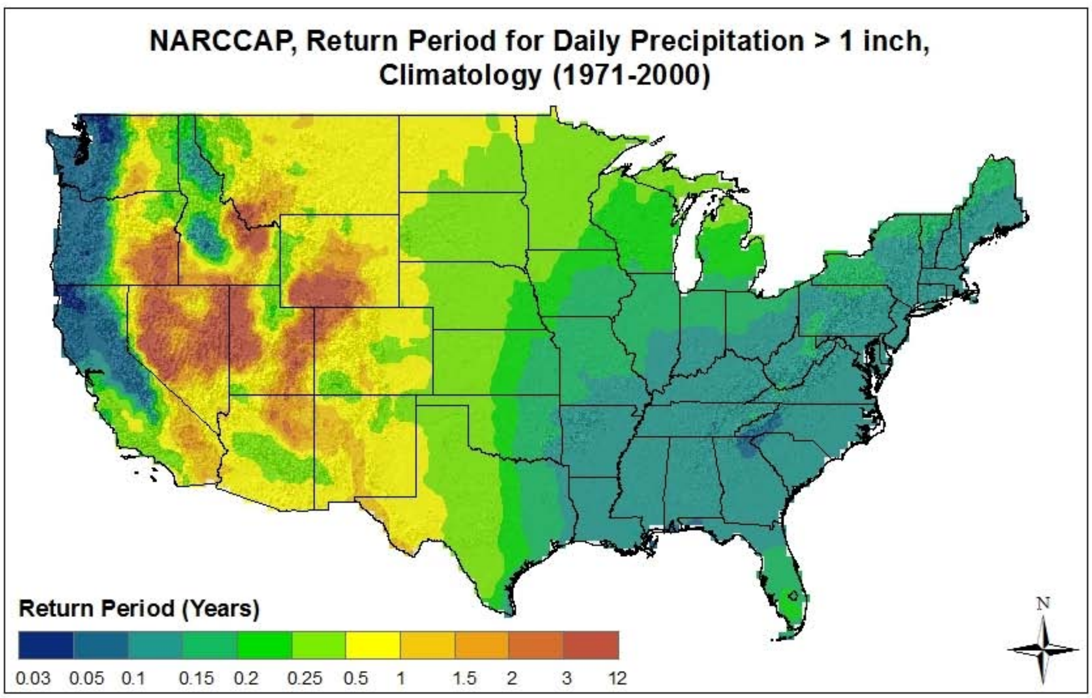


Figure 16. NARCCAP multi-model mean climatology of the return period of daily precipitation exceeding 1 inch for 2041-2070 (top) and 1971-2000 (bottom).

The spatial distribution of the NARCCAP multi-model mean change in number of days with precipitation exceeding 4 inches is shown in Fig. 17. Large parts of the western US do not experience days with such large amounts of daily precipitation. Most other areas indicate increases in the number of days, as also seen for the 1 inch map. The range of changes is large, varying from decreases of 100% to increases of 600%. The largest increases are generally seen in parts of the Midwest, Great Plains and Northeast regions, where the number of days in the present-day climatology is low.

Figure 18 shows the results of Fig. 17 expressed as a return period (inverse of the frequency). The return period distributions are shown for 2041-2070 and 1971-2000 and are the return period equivalents of the bottom panels of Fig. 17. In the late 20th Century climatology return periods the eastern half of the U.S. range from less than 5 years along the Gulf Coast to more than 50 years in the northern Midwest and Great Plains. A similar range is seen in the west with topographic variations dominant (smaller return values at higher elevations). For 2041-2070, there is a general shift to lower return period values, consistent with the general increases in the frequency of events. The area with return periods less than 10 years expands to the north and west in the eastern part of the U.S. and toward lower elevations in the west.

Consecutive days with little or no precipitation can have large impacts. Figure 19 shows the NARCCAP multi-model mean change in the average annual maximum run of days with precipitation less than 0.1 inches (3 mm). Areas that are already prone to little precipitation are expected to see an increase of days with little or no precipitation. Parts of southern California and Arizona could see an increase of up to 30 days per year. The projections for the northern Great Plains and Midwest are for small decreases or no change over time, with the majority of the country indicating increases of up to 15 days.

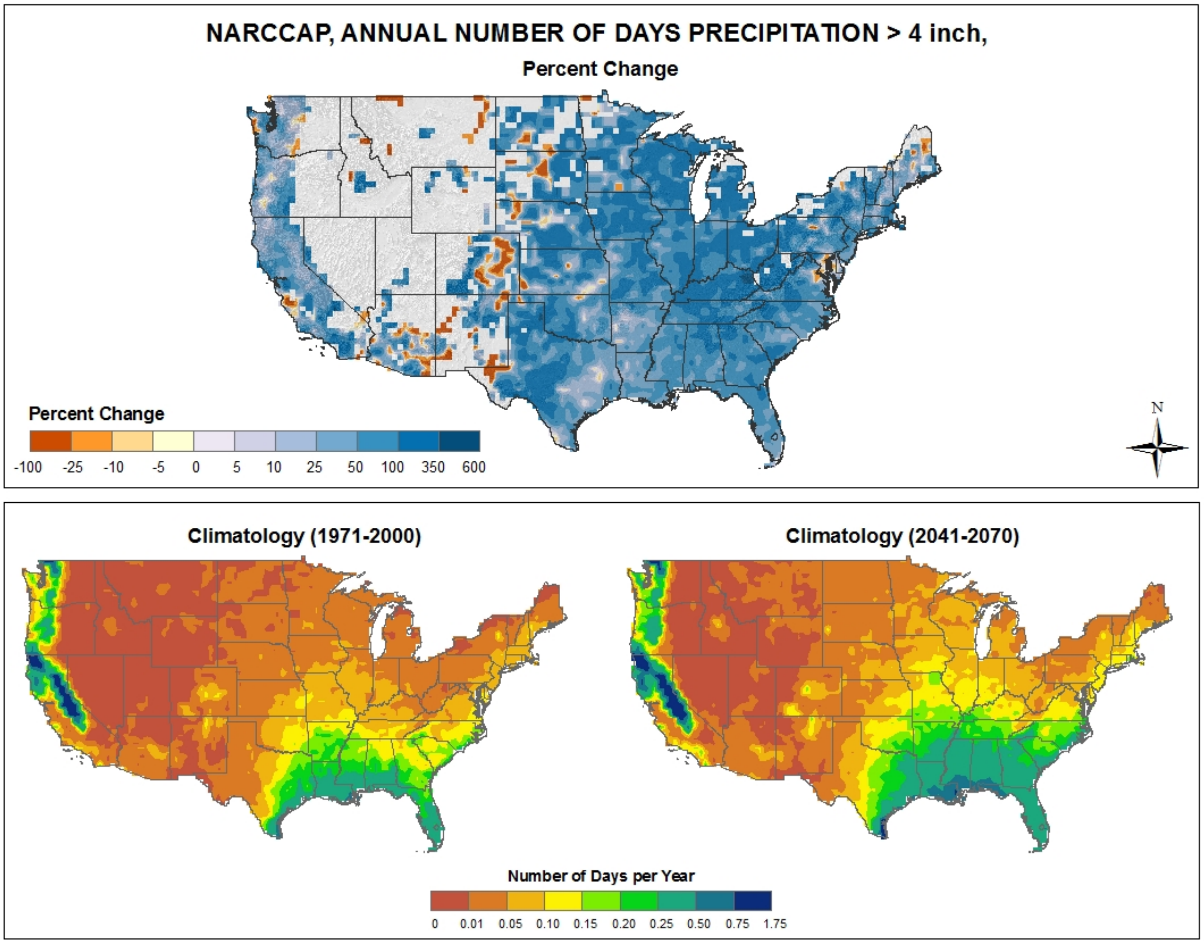
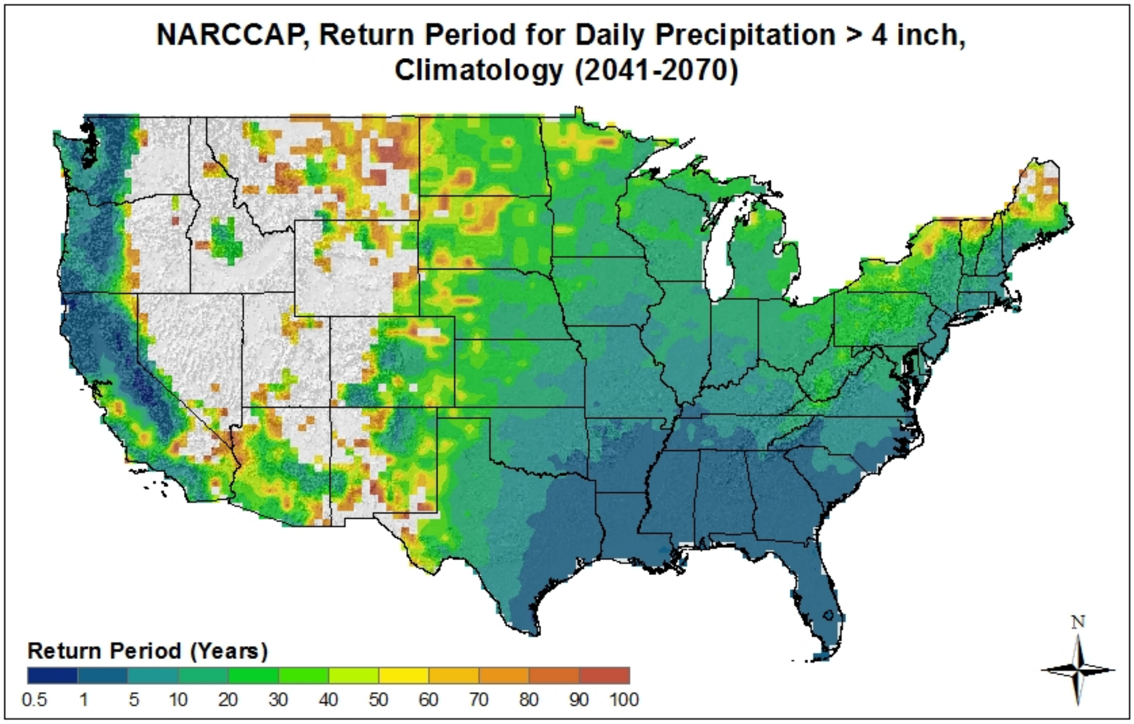


Figure 17. Spatial distribution of the NARCCAP multi-model mean change in the number of days with precipitation exceeding 4 inches between 2041-2070 and 1971-2000 (top). Climatology of the number of days with precipitation exceeding 4 inches for 1971-2000 (bottom left) and 2041-2070 (bottom right).



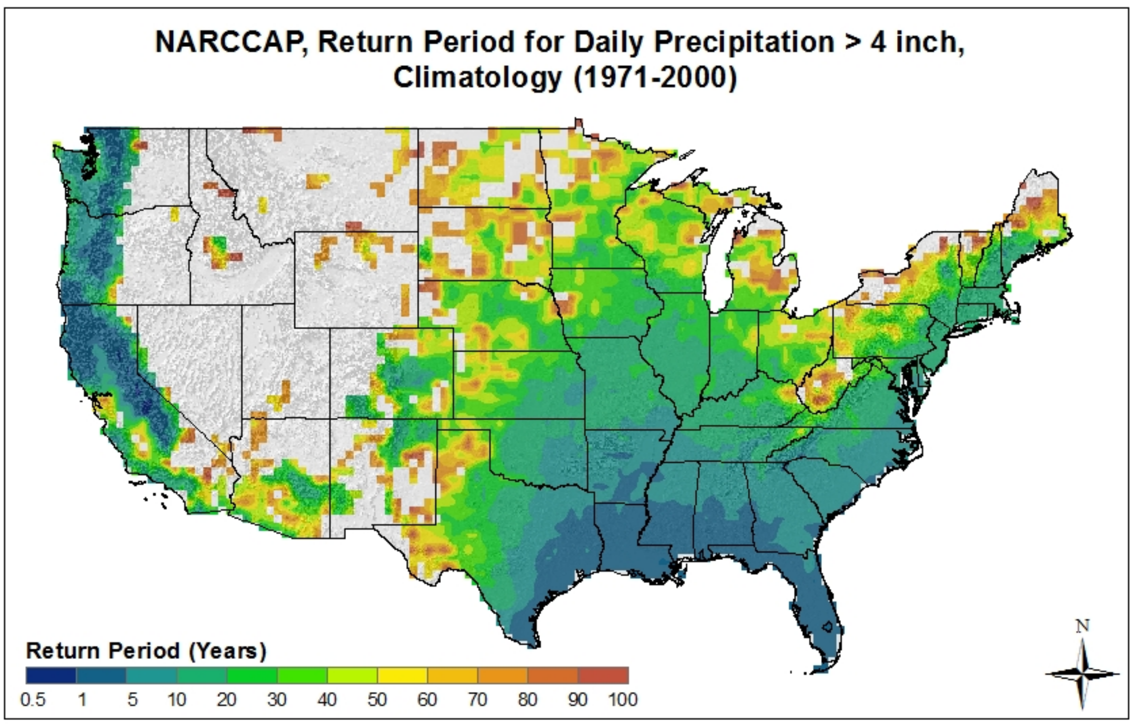


Figure 18. NARCCAP multi-model mean climatology of the return period of daily precipitation exceeding 4 inches for 2041-2070 (top) and 1971-2000 (bottom).

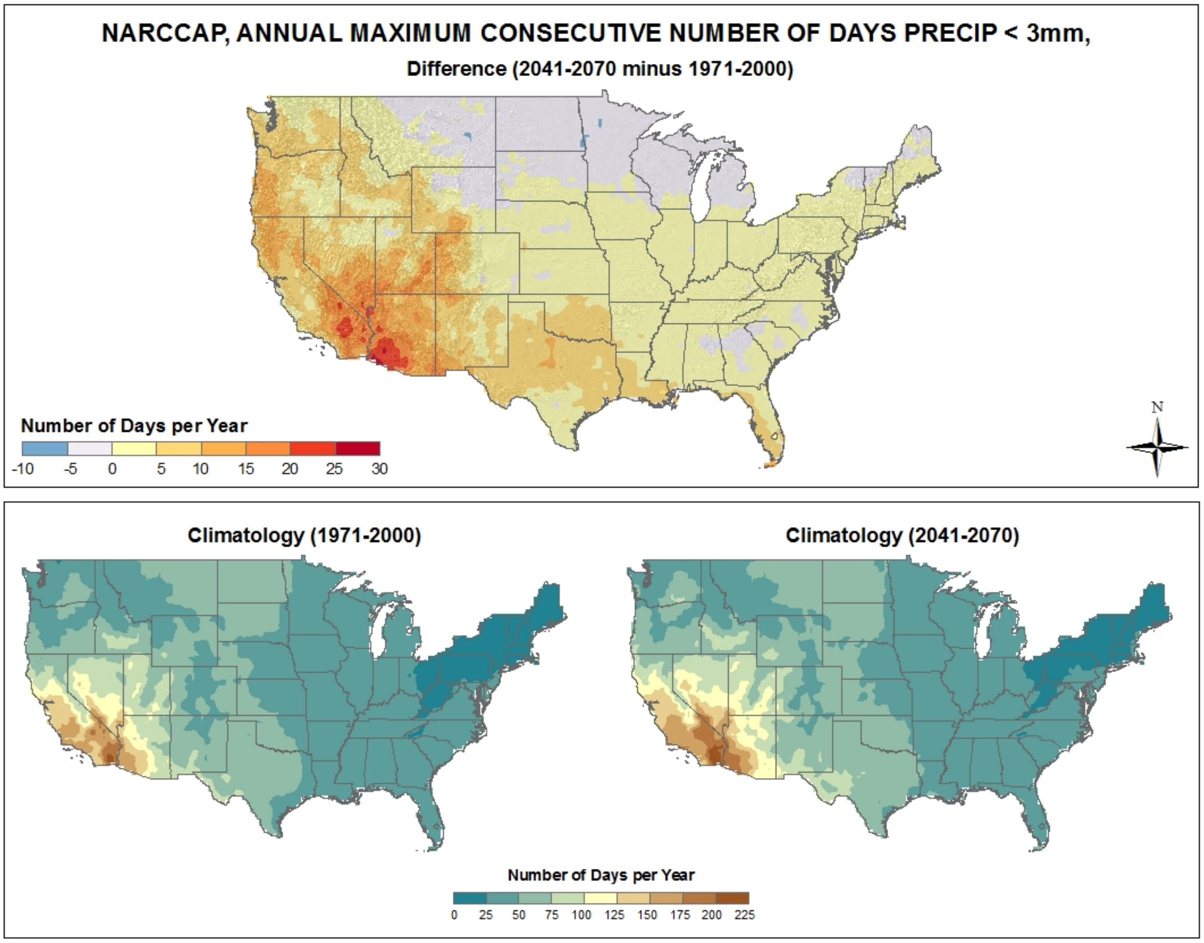


Figure 19. Spatial distribution of the NARCCAP multi-model mean change in the annual maximum number of consecutive days with precipitation less than 0.1 inches/3 mm between 2041-2070 and 1971-2000 (top). Climatology of the annual maximum number of consecutive days with precipitation less than 0.1 inches/3 mm for 1971-2000 (bottom left) and 2041-2070 (bottom right).

Acknowledgements

Analyses of the NARCCAP simulations were provided by Linda Mearns and Seth McGinnis of the National Center for Atmospheric Research and by Art DeGaetano and William Noon of the Northeast Regional Climate Center. Analysis of the CMIP3 GCM simulations was provided by Michael Wehner of the Lawrence Berkeley National Laboratory and by Jay Hnilo of the NOAA Cooperative Institute for Climate and Satellites (CICS). Analysis of the BCSD downscaled data was provided by Phil Duffy of Climate Central. Additional programming and graphical support was provided by Laura Stevens, Scott Stevens, Jun Zhang, and Jared Rennie of the NOAA CICS, Greg Dobson of the University of North Carolina-Asheville, and Byron Gleason of NCDC.