State Climate Summaries: Technical Details and Additional Information

Historical Climate

The description of historical climate conditions for each state are based on an analysis of core climate data (the primary data sources are described below). However, to help understand, prioritize, and describe the importance and significance of different climate conditions, additional input was derived from climate experts in each state, some of whom are authors on these state summaries. In particular, input was sought from the NOAA Regional Climate Centers and from the State Climatologists. The historical climate conditions are meant to provide a perspective on what has been happening in each state and what types of extreme events have historically been noteworthy, to provide a context for assessment of future impacts.

Future Scenarios

The future climate scenarios are intended to provide an internally consistent set of climate conditions that can inform analyses of potential impacts of climate change. The scenarios are not intended as projections as there are no probabilities for their future realization attached. They simply represent an internally consistent climate picture under certain assumptions about the future pathway of greenhouse gas emissions. By "consistent" we mean that the relationships among different climate variables and the spatial patterns of these variables derive directly from the same set of climate model simulations and are therefore physically plausible. The future climate scenarios are based on well-established sources of information. No new climate model simulations or downscaled data sets were produced for use in these state summaries.

Main Datasets

Historical seasonal and annual temperature and precipitation conditions for the contiguous U.S. and Alaska were analyzed using data from NOAA NCEI's Climate Divisional Dataset (nClimDiv), version 2. This dataset is of monthly time resolution and has incorporated several modern techniques to adjust data to remove biases arising from observing station inhomogeneities. It is now the standard dataset used by the National Centers for Environmental Information to assess the state of the climate in the continental United States.

Graphics illustrating daily extreme metrics of temperature and precipitation were based on NOAA NCEI's Global Historical Climatology Network-Daily (GHCN-D), version 3. This dataset is a comprehensive compilation of available data from climate observing stations. Relevant to these state climate summaries, it includes the complete records of digital data from stations in the U.S. Cooperative Observer Network (COOP), which is the core climate network of the United States. Some stations in the COOP have observations extending back to the late 19th century. The core observations of COOP stations include daily precipitation, daily maximum temperature, daily minimum temperature, daily snowfall, and daily snow depth. The siting of stations has been done with the intent to provide a representative sampling of all areas of the country. The great value of this network is its longevity and spatial sampling. For this reason, it is the best observational resource to establish long-term variations and trends in the surface climate of the United States. GHCN data were also used for historical seasonal and annual temperature and precipitation analyses of Hawaii, Puerto Rico, and the U.S. Virgin Islands.

Projections of future climate use analyses of data from the Coupled Model Intercomparison Project Phase 5 (CMIP5). Such analyses are included in the statewide temperature time series for both higher and lower emissions pathways, as well as maps depicting projected changes in annual or seasonal precipitation under a higher emissions pathway.

Choice of Reference Periods for Time Period Averages

Most of the graphics illustrate historical changes and future trends in climate with respect to some reference period. A common reference period for all graphics was not used. The choice of a specific reference period was determined by the purpose of the graphic and the availability of data. The great majority of graphics were based on one of two possible reference periods. The period 1901–1960 was used for Figure 1, which follows the usage for several graphics in the Third National Climate Assessment (NCA3; Melillo et al. 2014). The specific motivation for use of this period is to illustrate climate changes occurring as a result of the recent acceleration in greenhouse gas concentrations, and specifically how models simulate those changes. As shown in Meehl et al. (2003), anthropogenic forcing exhibits a slow rise during the early part of the 20th century but then accelerates after 1960. The choice of 1960 as the ending date of this period is because of the acceleration that occurs after this date. Thus, these graphics highlight changes in climate during the period of rapid increase in anthropogenic forcing and also reveal how well climate models simulate the observed changes during the more recent period of increased forcing. The beginning date of 1901 was chosen because earlier historical observations for the U.S. are less reliable.

A second primary reference period is 1971–2000, which is consistent with the World Meteorological Organization's recommended use of 30-year periods for climate statistics. This was used for precipitation projection maps. The purpose of these graphics is to show how climate might change with respect to a period that is in people's memory and experience. This is the same period used for precipitation projection graphics in the NCA3.

The reference period for all other graphics was simply the entire period of good observational records, which varies somewhat from state-to-state. For most states, this is 1900–2014. For most of the remaining states, it is 1950–2014. A few use other periods, such as 1930–2014 and 1910–2014. Since the purpose of most of the observational graphics is to illustrate relative changes, there is no compelling rationale for an alternative reference period. **The 2019 revision of each State Climate Summary extends these analyses through 2018.**

Meehl, Gerald A., Warren M. Washington, T. M. L. Wigley, Julie M. Arblaster, Aiguo Dai, 2003: Solar and greenhouse gas forcing and climate response in the twentieth century. *J. Climate*, **16**, 426–444. doi:10.1175/1520-0442(2003)016<0426:SAGGFA>2.0.CO;2.

Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2. [Available online at http://nca2014.globalchange.gov/]

Use of 5-year Averages

Most of the graphics are based on annual values but are displayed as 5-year averages of those annual values. The choice of averaging is a compromise between the clear and uncluttered presentation of long-term variations and any trends versus the inclusion of all available details. While the graphical presentation of the underlying annual data has the advantage that the year-to-year variability can be seen, it can obscure any longer-term behavior. Since the main focus of the summaries is on longer-term behavior, we opted to apply block averages to provide a clear presentation of this aspect of the time series. **Graphics in the 2019 revision include an additional 4-year average calculation for the period 2015–2018. Long-term averages were recalculated to encompass these additional 4 years. Annual values were also added to the charts, which are now presented with all bars extending upwards.**

Figure 1 Content

Figure 1 is based on Fig. 17.3 in the Third National Climate Assessment (Carter et al. 2014). The most recent set of coordinated climate model simulations (the Coupled Model Intercomparison Project Phase 5, or CMIP5) includes a large number of individual models. In addition, most modeling groups performed multiple simulations with their models. Each of these simulations follows a slightly different path over time because of natural variability in the climate system, which varies between models and within the multiple simulations of a single model. The path of annual temperature in a specific simulation represents this random natural variability plus the known increasing greenhouse gas forcing. Because of this random natural variability, there is no expectation that a model simulation will exactly match the observed annual temperature path. However, with a large number of simulations, we can examine statistically whether the model simulations bound the actual observations. The purpose of Figure 1 is to illustrate this by comparing the observed annual temperature with the entire distribution of climate model simulations for the historical period. In addition, this analysis also shows the uncertainty of the future evolution of climate out to 2100. **The 2019 revision of each State Climate Summary extends the observed data through 2018.**

In Figure 1, the statewide-average observed annual temperature is displayed at annual time resolution. As noted in "Choice of Reference Periods for Time Period Averages" above, each annual value is expressed as the difference between annual temperature and the 1901–1960 average annual temperature. In order to provide an apples-to-apples comparison, the model simulations are summarized at the annual resolution. The details of the model simulation analysis are presented with the figure metadata. A couple of points are particularly noteworthy. First, the model-simulated statewide average temperature values are also expressed as the difference between the annual temperature and the model's 1901–1960 average. Second, the shading in Figure 1 indicates the spread of the model simulated annual values, specifically the 5th to 95th percentile range. For each year, the set of individual model values are ranked and then the 5th and 95th percentile values are determined.

Carter, L. M., J. W. Jones, L. Berry, V. Burkett, J. F. Murley, J. Obeysekera, P. J. Schramm, and D. Wear, 2014: Ch. 17: Southeast and the Caribbean. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 396-417. doi:10.7930/J0NP22CB. [Available online at https://nca2014.globalchange.gov/report/regions/southeast]

Data and Methods used to Produce Threshold Graphics

There are a number of graphics in each state summary that display the number of days that daily temperature or precipitation is above or below a selected threshold. These were developed from individual stations in NOAA NCEI's Global Historical Climatology Network-Daily (GHCN-D).

The climate observing stations were selected based on data availability. Specifically, only stations with less than 10% missing data for the period of analysis were used. This approach was adopted to ensure that the mix of stations is relatively static throughout the period of analysis; otherwise, it is possible to introduce artificial trends because of stations dropping in and out.

The detailed procedures used to produce these graphics are provided in the metadata associated with each figure on the web site. A few general points are provided here with regard to the motivation for certain aspects of the methodology. The values that are plotted should be viewed as an index with the absolute numbers representing a typical station for that state. The method used to produce the graphed index recognizes that the climatology of the specific variable can vary considerably across a state, particularly for those states with substantial topographic variations. For example, the average number of days with daily maximum temperature above 100°F is 55 at Tucson and only 11 at Tombstone, Arizona. Without considering such differences, the year-to-year variations at Tucson could easily negate potentially opposite behavior at Tombstone. Another potential issue is an uneven distribution of stations. In large states in particular (e.g. California, Texas), the temporal trends and variations could be different in different regions. If one region of the state had fewer stations than other regions, the results could be skewed. To address these two specific issues, the following general approaches were adopted:

1. In order to incorporate all stations equally into the computed index, the station time series values were converted from numbers of days into standardized anomalies. These are calculated by subtracting the station's time series mean and dividing by the station's time series standard deviation for each annual count for that station. This results in a time series with a mean of zero and a distribution of values that will approximately follow the standard normal distribution. All of the averaging to produce a statewide number was done using the standardized anomaly time series. Once the averaging was completed, which results in a state-average standardized anomaly time series, the values were converted back to real numbers using statewide average values of the mean and standard deviation.
2. In order to minimize unequal weighting of different regions of a state, we did not simply average all of the stations together. Instead, a state was divided into 1°x1° degree grid boxes. Then, grid box time series were produced by averaging all stations within that grid box. Finally, a state-average time series was created by averaging the grid box time series.

CMIP5 Representative Concentration Pathways (RCP)

The Coupled Model Intercomparison Project (CMIP) is a project of the World Climate Research Programme (WCRP) Working Group on Coupled Modeling (WGCM). This project provides a standard experimental protocol for studying Global Climate Models (GCMs). In CMIP Phase 5 (CMIP5), 25 different modeling groups produced simulations that were used in the IPCC Fifth Assessment Report (AR5), with over 60 representations from 28 different models.

CMIP5 includes models with higher spatial resolutions and a more developed representation of physical processes than for previous CMIP3 simulations. The spatial resolution of the great majority of CMIP5 simulations is in the 1°–2° range, or about 60–130 miles.

CMIP5 includes the following experiments:

a. Simulations of the 20th century using best estimates of the temporal variations in external forcing factors (such as greenhouse gas concentrations, solar output, and volcanic aerosol concentrations); and

b. Simulations of the 21st century assuming changing greenhouse gas concentrations following various scenarios.

CMIP5 21st century simulations use a set of scenarios called Representative Concentration Pathways (RCPs). These are based on radiative forcing trajectories and are named according to the radiative forcing level at the year 2100. There are four RCPs: 2.6, 4.5, 6.0, and 8.5, with the numbers representing the 2100 radiative forcing increase relative to pre-industrial levels in W m^{-2}. The projected multi-model mean temperature increases at the end of the 21st century (with respect to a base period of 1901–1960) are 2.8°F, 4.2°F, 5.2°F, and 8.3°F under RCPs 2.6, 4.5, 6.0, and 8.5, respectively.

The State Climate Summaries analyses use simulations under RCP4.5 (a lower emissions pathway) and RCP8.5 (a higher emissions pathway). A full list of models used in these analyses can be found in the metadata accompanying each relevant figure.

For additional information on CMIP5 RCP simulations and how they compare to previous CMIP3 simulations, see the following report:

Sun, L., K.E. Kunkel, L.E. Stevens, A. Buddenberg, J.G. Dobson, and D.R. Easterling, 2015: Regional Surface Climate Conditions in CMIP3 and CMIP5 for the United States: Differences, Similarities, and Implications for the U.S. National Climate Assessment, NOAA Technical Report NESDIS 144, 111 pp. [Available online at
https://www.nesdis.noaa.gov/content/technical-reports]

Statistical Significance Criteria in Precipitation Maps

Each state summary includes a map depicting projected changes in annual or seasonal precipitation between the middle of the 21st century (2041–2070) and the model reference period (1971–2000) under a higher emissions pathway. These maps include hatching representing areas where the majority of climate models indicate a statistically significant change. The hatched areas were determined using the following technique:

The statistical significance regarding the change in precipitation was determined using a 2-sample t-test assuming unequal variances for those two samples. For each period (present and future climate), the mean and standard deviation were calculated using the 30 annual values. These were then used to calculate t. In order to assess the agreement between models, the following three categories were determined for each grid point:

Category 1: If less than 50% of the models indicate a statistically significant change then the multi-model mean is shown in color. This means that model results are in general agreement that simulated changes are within historical variations;

Category 2: If more than 50% of the models indicate a statistically significant change but less than 67% of the significant models agree on the sign of the change, then the grid points are masked out, indicating that the models are in disagreement about the direction of change;

Category 3: If more than 50% of the models indicate a statistically significant change and more than 67% of the significant models agree on the sign of the change, then the multi-model mean is shown in color with hatching. Model results are in agreement that simulated changes are statistically significant and in a particular direction.

More information, and U.S. precipitation maps for additional emissions pathways and time periods, can be found in the following report:

Sun, L., K.E. Kunkel, L.E. Stevens, A. Buddenberg, J.G. Dobson, and D.R. Easterling, 2015: Regional Surface Climate Conditions in CMIP3 and CMIP5 for the United States: Differences, Similarities, and Implications for the U.S. National Climate Assessment, NOAA Technical Report NESDIS 144, 111 pp. [Available online at https://www.nesdis.noaa.gov/content/technical-reports]