Heatwave Dataset - Metadata and Documentation

Background

A heatwave is broadly defined as a period of unusually hot weather lasing two to three or more days. This hot weather is typically warmer than the historical averages for the affected region and is also much warmer than the temperatures preceding and following the heatwave event.

Heatwaves have a direct impact on human health, the local environment, and the economy. Heat stress from extreme heat events is the leading cause of weather-related deaths in the United States. [1] A heatwave represents time when the ambient temperatures often outpace the body's ability to cool itself via perspiration, resulting in greater incidences of heat-related illnesses, hospital admissions, and deaths among vulnerable populations. [2] Additionally, heatwaves can result in crop failures, excessive load on the electricity grid from increased air conditioner use, and can affect the health of the local ecosystem. [3]

The average number and duration of heatwaves have been increasing across the U.S. in recent decades [4] and this trend is expected to continue with climate change. Planning for emergency response to future heatwaves will necessitate projections of how heatwaves may change in New Jersey counties over the coming century. This dataset provides a measure of change in future heatwave number and duration compared to a historical period of 1981–2010.

Defining a Heatwave

Heatwave Temperature Threshold

This dataset bases heatwave metrics on the daily average temperature. The average temperature is a synthesis of the daily maximum and minimum temperatures. Daily maximums emphasize the highest heat conditions a person may be exposed to, but daily minimums have been shown to be more important for heat stress and illness when elevated for an extended period. The daily average combines these effects so that neither is entirely discounted. Additionally, Anderson and Bell (2009) [5] found that daily average temperature was the most consistent predictor of heatwave mortality.

The exact temperature thresholds and durations used to identify heatwaves within temperature records are not consistently defined in scientific literature. In this dataset, an extreme heat day is defined as a day where the average temperature exceeds a predetermined threshold. We calculated the threshold as the 95th percentile [6–8] of 30 years (1981–2010) of daily average temperature data during the warm season (May 1st–September 30th). The benefit of using a percentile approach is that each location can have a slightly different threshold. For example, the climates of Capy May and Sussex Counties can be very different, Sussex being inland with more topography (generally cooler) while Cape May is coastal, topographically flat, and further south (generally warmer).

Heatwave Duration Threshold

Equally important in identifying a heatwave is the number of consecutive days that the temperature threshold is exceeded. A heatwave is essentially multiple extreme heat days in succession. We selected a minimum duration of three consecutive days of extreme temperatures [3,9,10] to define a heatwave. It is also common to select two days as a minimum as heat illness may be present with a shorter exposure time. [4–6] While we elected to use a three-day minimum as it represents a greater heat stress impact (exposure to heightened temperatures for a longer duration), it is likely the calculated trends will hold true for shorter heatwaves as well.

Data Sources

The data in this analysis are composed of an observational dataset and a series of climate model outputs. The observational data is a gridded dataset of about 20,000 NOAA Cooperative Observer (COOP) stations across the conterminous United States. [11] We used NOAA's Applied Climate Information System (ACIS, http://www.rcc-acis.org/) to extract the daily average temperature for the State of New Jersey for over 1981–2010 to establish a historical baseline of annual heatwave statistics. These daily temperatures were averaged by county such that each county had a single record of daily average temperatures from 1981–2010.

The modeled data were also retrieved through ACIS, again extracting daily average temperature data by county. The modeled data was composed of 31 individual climate models that are part of the Coupled Model Intercomparison Project 5 and were scaled regionally to New Jersey using the Localized Constructed Analogues (LOCA) method. [12] The climate models provide data for three separate time periods. The first was a historical period (1981–2010) to correspond to the observational data. The other two were future time periods: 2036–2065 to represent the mid-21st century and 2070–2099 to represent the end of the 21st century.

The projected future climates were modeled using 2 different greenhouse gas emissions scenarios. The first, Representative Concentration Pathway (RCP) 4.5 represents moderate greenhouse gas emissions though the end of the century. [13] The second, RCP 8.5 represents unmitigated and growing greenhouse gas emissions by the end of the century [14] and is generally considered the upper plausible limit of the magnitude of climate change. In general, under both scenarios, the climate warms and heatwaves become stronger, but RCP 8.5 creates much higher temperatures and greater heatwaves.

Table 1. Description of the Data Parameters used in this Analysis

Data Descriptions	Description
Historic Time Period	1981–2010
Mid-Century Time Period	2036–2065, defined as a 30-year interval centered on approximately 2050
End-Century Time Period	2070–2099, as a 30-year interval centered on approximately 2085
Representative Concentration Pathways (RCPs)	Narrative descriptions about how global greenhouse gas emissions (such as carbon dioxide and methane), air pollutants, and land use may change over the 21st century.
RCP 4.5	The moderate greenhouse gas emissions scenario where emissions peak in the mid-century and are reduced by the end of the 21st century.
RCP 8.5	The continued and expanding greenhouse gas emissions scenario where emissions rise throughout the 21st century without any significant reductions.
Observed Data	A gridded dataset of daily average temperatures created by Livneh and others (2013). [11] Data were extracted for New Jersey counties for the time period of 1980–2010. Daily temperatures were spatially averaged by county.
Modeled Data	Gridded daily average temperature datasets of 31 climate models available through ACIS. Data were extracted for New Jersey counties for historic, mid-century, and end-century time periods. Daily temperatures were spatially averaged by county and calculated heatwave metrics of each model were combined using a weighted average. [12]

Heatwave Calculations and Change

Heatwaves were calculated for the observed dataset and for each model output for the historical, mid-century, and end-century time periods. First, the 95th percentile threshold was calculated for each county for the historical period using both the observed and modeled data. For each time period, the annual average number, the average annual duration, and the maximum average duration (the average of the longest heatwave each year over 30 years of data) of the identified heatwaves were calculated with respect to the 95th percentile threshold.

The modeled heatwave statistics were combined into a muti-model average using a weighted averaged defined by the LOCA downscaling approach. [12] This process was utilized to produce averages for the historical, mid-century, and end-century time periods for both RCP 4.5 and RCP 8.5. To project the statistics of future heatwaves, it is inadvisable to just use the model outputs. Instead, a common approach is to calculate the percent change between the modeled historical period and the future time periods. These percent change values were applied to the observed historical heatwave data to yield future heatwave projections more firmly anchored to real values. This approach is conceptually visualized in Figure 1. These projections are not perfect but are likely to be more accurate when using this approach.

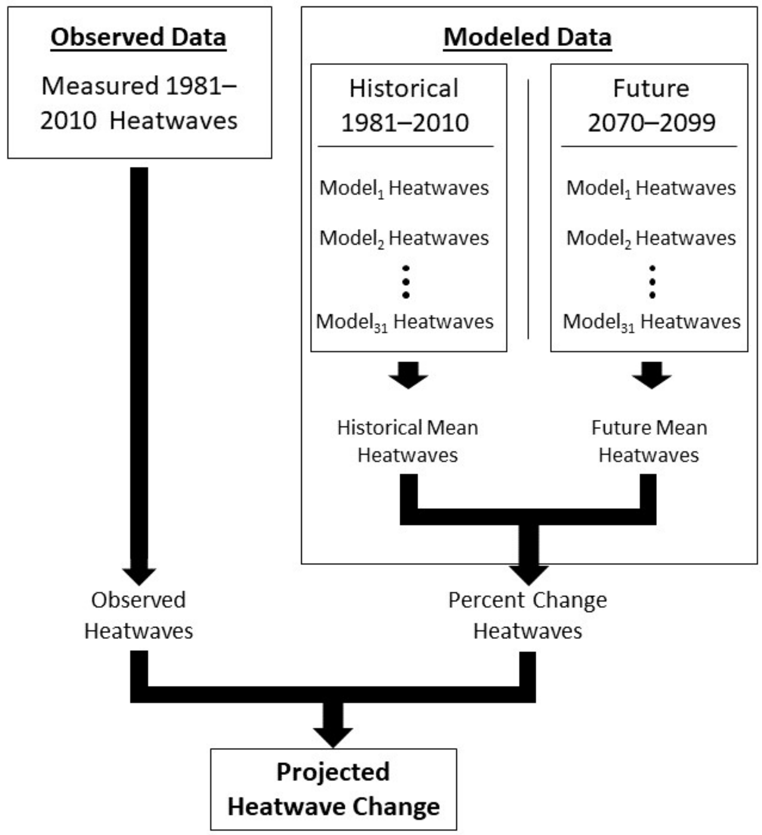

Figure 1. Flowchart of how modeled heatwave metrics are averaged and how a percent change between modeled historical and modeled projected averages is applied to observed heatwave metrics. This example used a future period of 2070–2099, but the approach is the same for the mid-century time period and for both RCP 4.5 and 8.5.

Finally, a "percentile range" of future heatwave change was defined for each future scenario. The range is described in the heatwave data file by the 10th and 90th percentile columns for each parameter (heatwave number, duration, and maximum duration) for the future scenarios. The percentiles are computed by taking the heatwave outputs for the 31 climate modes before averaging and removing the lower 10th percentile and upper 90th percentile of individual outputs from the 31 climate models. This approach provides a constrained range of model projections akin to (but different from) a confidence interval by excluding the highest and lowest 10% of the individual model outputs. For example, the annual number of heatwave events is computed for each model, so a single county will have 31 separate modeled values for the number of heatwaves for a future time period and emissions scenario (such as mid-century under RCP 4.5). The 10th and 90th percentiles for the number of heatwaves for this period of are calculated from these 31 data values. This process was repeated for the other time periods, emissions scenarios, and counties. The percentile values where then computed as a percent change from the modeled historical mean and the percent change applied to the observed number of heatwaves to define the future limits relative to the observed values.

Table 2. Descriptions of the Heatwave Data Fields Presented in the *Heatwave_Data.xlsx* File

Heatwave Data Field	Description
95th Percentile Temperature (F)	The threshold above which an average daily temperature constitutes an extreme heat day. Three or more consecutive days above this threshold constitutes a heatwave. The threshold is different for each county to account for local effects. The threshold is calculated as the 95th percentile of observed daily average temperatures during the warm season for 1981–2010.
Mean Annual Heatwave Number	The annual average number of heatwaves a county experiences/is projected to experience based on 30 years of data.
Mean Annual Heatwave Duration (Days)	The annual average duration of the heatwaves a county experiences/is projected to experience based on 30 years of data.
Max Annual Heatwave Duration (Days)	The average annual maximum duration of the heatwaves a county experiences/is projected to experience based on 30 years of data.
10% Annual Heatwave Number/Heatwave Duration/Max Heatwave Duration	The 10th percentile value for a given parameters (heatwave number, duration, or maximum duration) based on the spread of results of 31 climate models. Only available for projected future heatwaves. Consider this as the lower end of a "constrained range" of change from observed conditions.
90% Annual Heatwave Number/Heatwave Duration/Max Heatwave Duration	The 90th percentile value for a given parameters (heatwave number, duration, or maximum duration) based on the spread of results of 31 climate models. Only available for projected future heatwaves. Consider this as the upper end of a "likely constrained" of change from observed conditions.

Interpretation

The future heatwave data within the Heatwave_Data.xlsx file are categorized by RCP emissions scenario, RCP 4.5 or RCP 8.5, and by the future time period. These data are annual averages, not the total for the time period, so many of the values are not whole numbers. Additionally, since these values are averages for 30-year periods of time, one should not try to pinpoint an exact year when these conditions are most likely to occur but should use them as a guide for the general mid- and end-century time periods. Following this approach, these projections are a guide, and the absolute values presented should be viewed as an approximation of projected change, not the exact future conditions. The 10^{th} and 90^{th} percentiles provide a constrained range of possible change from the observed conditions and can be interpreted as 80% of the modeled outputs agree that the future heatwave metrics are within the range bounded by the 10^{th} and 90^{th} percentiles.

Finally, the future heatwave metrics are relative to the threshold defined for the historical period. A new threshold is not determined for each time period. The reason for this approach is to help clarify the magnitude of future changes relative to the observed period's extreme conditions. Under a changing climate, what could be defined as an extreme temperature day may change as people acclimate and emergency infrastructure adapts to warmer temperatures. However, it is most useful to present these changes relative to conditions that managers and the public have experienced.

References

1. NOAA. Weather Related Fatality and Injury Statistics. National Oceanic and Atmospheric Administration (NOAA).
2. Moran, D. *et al. New Jersey Climate and Health Profile Report. New Jersey Climate Adaptation Alliance*. (2017).
3. Agel, L., Barlow, M., Skinner, C., Colby, F. & Cohen, J. Four distinct Northeast US heatwave circulation patterns and associated mechanisms, trends, and electric usage. *Npj Clim. Atmospheric Sci.* **4**, 1–11 (2021).
4. Habeeb, D., Vargo, J. & Stone, B. Rising heatwave trends in large US cities. *Nat. Hazards* **76**, 1651–1665 (2015).
5. Anderson, B. G. & Bell, M. L. Weather-Related Mortality. *Epidemiol. Camb. Mass* **20**, 205–213 (2009).
6. Anderson, G. B. & Bell, M. L. Heatwaves in the United States: Mortality Risk during Heatwaves and Effect Modification by Heatwave Characteristics in 43 U.S. Communities. *Environ. Health Perspect.* **119**, 210–218 (2011).
7. Nairn, J. & Fawcett, R. *Defining heatwaves: heatwave defined as a heat impact event servicing all community and business sectors in Australia*. The Centre for Australian Weather and Climate Research, CAWCR technical report 060, 84 (2013).
8. Argüeso, D., Di Luca, A., Perkins-Kirkpatrick, S. E. & Evans, J. P. Seasonal mean temperature changes control future heatwaves. *Geophys. Res. Lett.* **43**, 7653–7660 (2016).
9. Meehl, G. A. & Tebaldi, C. More Intense, More Frequent, and Longer Lasting Heatwaves in the 21st Century. *Science* **305**, 994–997 (2004).
10. Peng, R. D. *et al.* Toward a Quantitative Estimate of Future Heatwave Mortality under Global Climate Change. *Environ. Health Perspect.* **119**, 701–706 (2011).
11. Livneh, B. *et al.* A Long-Term Hydrologically Based Dataset of Land Surface Fluxes and States for the Conterminous United States: Update and Extensions. *J. Clim.* **26**, 9384–9392 (2013).
12. Pierce, D. W., Cayan, D. R. & Thrasher, B. L. Statistical Downscaling Using Localized Constructed Analogs (LOCA). *J. Hydrometeorol.* **15**, 2558–2585 (2014).

13. Thomson, A. M. *et al.* RCP4.5: a pathway for stabilization of radiative forcing by 2100. *Clim. Change* **109**, 77–94 (2011).
14. Riahi, K. *et al.* RCP 8.5—A scenario of comparatively high greenhouse gas emissions. *Clim. Change* **109**, 33 (2011).