Urban Resilience to Extremes
Sustainability Research Network


# Scenarios of Climate Extremes

## Phoenix, AZ



prepared by
Andrew Ballinger
Ken Kunkel

North Carolina State University

# Contents

# 1 Introduction

## 1.1 Downscaling methodology

The daily output of three climate fields of interest (maximum temperature, minimum temperature and precipitation) from 32 CMIP5 models (Taylor et al., 2012) were statistically downscaled to a $1/16^\circ \times 1/16^\circ$ horizontal latitude-longitude grid over the contiguous United States using the Localized Constructed Analogs (LOCA) method. For further details on the LOCA downscaling technique and the development of this dataset see Pierce et al. (2014, 2015) and loca.ucsd.edu, which includes comparison with observations and a discussion of alternative statistical downscaling methods.

## 1.2 Climate scenarios and projection periods

Three suites of global climate model experiments were analyzed in the preparation of this report:

1. A set of *historical* climate simulations forced by past emissions, designed to reproduce a past model climatology from 1950–2005.

2. A set of future climate simulations following a pathway of relatively *lower* emissions (RCP4.5; Thomson et al., 2011) from 2006–2100.

3. A set of future climate simulations following a pathway of relatively *higher* emissions (RCP8.5; Riahi et al., 2011) from 2006–2100.

These climate model data have been analyzed over three different 30-year periods, each separated by 50 years: 1971–2000, 2021–2050, and 2071–2100. Hence there are five climatologies produced for comparison; a historical reference climatology and four model-derived projected climatologies (two different emission scenarios analyzed over two different future periods):

- HIST (1971–2000) — "Historical"
- RCP4.5 (2021–2050) — "Lower Emissions (+50 yr)"
- RCP4.5 (2071–2100) — "Lower Emissions (+100-yr)"
- RCP8.5 (2021–2050) — "Higher Emissions (+50-yr)"
- RCP8.5 (2071–2100) — "Higher Emissions (+100-yr)"

## 1.3 Analysis Region

The LOCA dataset covers the contiguous United States (CONUS) and partial contiminous regions of Canada and Mexico, at $1/16° \times 1/16°$ horizontal latitude-longitude grid resolution. The climatology over the $1° \times 1°$ region (256 gridboxes) surrounding the geographical coordinates of Phoenix ($33.45°\text{N}, 112.07°\text{W}$) were analyzed in order to explore the regional spatial pattern of climate extremes (Figure 1). More extensive analysis of the climatology of the single gridbox closest to central Phoenix was also conducted.

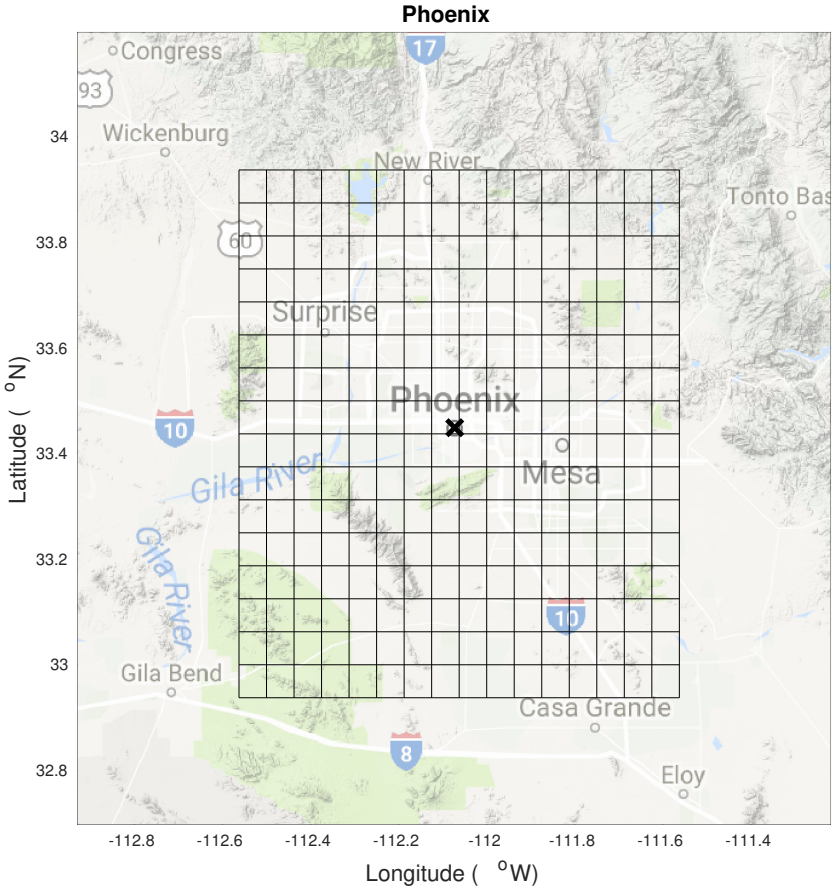


Figure 1: Map of the $1° \times 1°$ analysis region surrounding Phoenix ($33.45°\text{N}, 112.07°\text{W}$; black cross), showing the 256 ($16 \times 16$) gridboxes in the LOCA dataset.

## 1.4 Computing extreme indices

Several temperature- and precipitation-based climate extreme *indices* of interest (Tables 1,2) were computed from the downscaled daily maximum and minimum temperature and precipitation. These indices were computed annually, and also over different months and seasons, in order to provide a measure of the climate extremes "observed" in the different climate model simulations.

| **Climate Indices** | **Short Description** | **Units** |
|---|---|---|
| $T_X$ | Mean value of maximum temperature | °F |
| $T_N$ | Mean value of minimum temperature | °F |
| $T_{XX}$ | Maximum value of maximum temperature | °F |
| $T_{XN}$ | Minimum value of maximum temperature | °F |
| $T_{NX}$ | Maximum value of minimum temperature | °F |
| $T_{NN}$ | Minimum value of minimum temperature | °F |
| $T_{XnX}$ | Maximum $n$-day maximum temperature | °F |
| $T_{XnN}$ | Minimum $n$-day maximum temperature | °F |
| $T_{NnX}$ | Maximum $n$-day minimum temperature | °F |
| $T_{NnN}$ | Minimum $n$-day minimum temperature | °F |
| $T_X$90F | Number of days with $T_X > 90$°F | days |
| $T_X$95F | Number of days with $T_X > 95$°F | days |
| $T_X$100F | Number of days with $T_X > 100$°F | days |
| $T_{X,N}$99p | Number of days above 99$^{\text{th}}$ percentile | days |
| $T_{X,N}$1p | Number of days below 1$^{\text{st}}$ percentile | days |
| HDD | Heating Degree Days | days |
| CDD | Cooling Degree Days | days |
| $T_X$32F | Number of days with $T_X < 32$°F | days |
| $T_N$32F | Number of days with $T_N < 32$°F | days |
| $DT_{XX}$, $DT_{XN}$ | Date of max/min maximum temperature | date |
| $DT_{NX}$, $DT_{NN}$ | Date of max/min minimum temperature | date |
| $DFZ_F$, $DFZ_L$ | Date of the first/last Freeze | date |
| GrowSeas | Length of Growing Season (based on 32°F) | days |

Table 1: Selection of the temperature-based climate extreme indices computed at each gridbox.

| Climate Indices | Short Description | Units |
|---|---|---|
| Pr | Mean value of daily precipitation | inches |
| $\mathrm{Pr}_X$ | Maximum value of daily precipitation | inches |
| $\mathrm{Pr}_{nX}$ | Maximum $n$-day total precipitation | inches |
| $\mathrm{Pr}_X1$ | Number of days with precipitation $> 1$ inches | days |
| $\mathrm{Pr}_X2$ | Number of days with precipitation $> 2$ inches | days |
| $\mathrm{Pr}_X3$ | Number of days with precipitation $> 3$ inches | days |
| $\mathrm{Pr}_X4$ | Number of days with precipitation $> 4$ inches | days |
| WD | Number of wet days (Pr $> 0.01$ inches) | days |
| DD | Number of dry days | days |
| ConWD/$\mathrm{ConWD}_X$ | Mean/Maximum consecutive wet-day period | days |
| ConDD/$\mathrm{ConDD}_X$ | Mean/Maximum consecutive dry-day period | days |

Table 2: Selection of the precipitation-based climate extreme indices computed at each gridbox.

## 1.5 Weighting of CMIP5 models

In order to compute the mean of the 32-model ensemble a set of individual model weighting factors has been applied, following the current approach being employed in the preparation of the Fourth National Climate Assessment. These weighting factors incorporate both a measure of the individual model's developmental independence (with respect to the other models in the CMIP5 archive), as well as a measure of the individual model's ability to reproduce the mean climate, along with a number of climate extreme indices, observed over the historic period.

This second aspect of the weighting is designed to minimize the differences in the model simulations (versus observations) accumulated across the entire CONUS region. One could consider computing and applying the weighting factors over a more limited geographic area for regional studies, but in order to prioritize consistency and applicability for inter-regional comparison, the same weighting factors have been applied uniformly across the entire geographic region. As with any consideration of weighting, simply minimizing the difference between the model and past observations (at a given gridbox) does not necessarily guarantee higher model fidelity in future climate projections. This judgement seeks to balance the various weighting considerations.

# References


Pierce, D. W., D. R. Cayan, E. P. Maurer, J. T. Abatzoglou, and K. C. Hegewisch, 2015: Improved bias correction techniques for hydrological simulations of climate change. *J. Hydrometeor.*, **16**, 2421–2442, doi:10.1175/JHM-D-14-0236.1.

Pierce, D. W., D. R. Cayan, E. P. Maurer, and B. L. Thrasher, 2014: Statistical downscaling using Localized Constructed Analogs (LOCA). *J. Hydrometeor.*, **15**, 2558–2585, doi:10.1175/JHM-D-14-0082.1.

Riahi, K., and Coauthors, 2011: RCP 8.5—a scenario of comparatively high greenhouse gas emissions. *Climatic Change*, **109**, 33, doi:10.1007/s10584-011-0149-y.

Taylor, K. E., R. J. Stouffer, and G. A. Meehl, 2012: An overview of CMIP5 and the experiment design. *Bull. Amer. Meteor. Soc.*, **93 (4)**, 485–498, doi:10.1175/BAMS-D-11-00094.1.

Thomson, A. M., and Coauthors, 2011: RCP4.5: a pathway for stabilization of radiative forcing by 2100. *Climatic Change*, **109**, 77–94, doi:10.1007/s10584-011-0151-4.

# 2 Summary of climate extremes

The following tables summarize the suite of LOCA-downscaled climate model simulation results for the various climate scenarios evaluated at the gridbox nearest to Phoenix, AZ. A selection of annually-derived temperature-based climate extreme indices are displayed in the tables in Section 2.1, followed by the precipitation-based climate extreme indices in Section 2.2.

## 2.1 Temperature extremes

| **Climate Scenario** | $\mathbf{T}_X$ | $\mathbf{T}_{XX}$ | $\mathbf{T}_{XN}$ | $\mathbf{T}_N$ | $\mathbf{T}_{NX}$ | $\mathbf{T}_{NN}$ |
|---|---|---|---|---|---|---|
| HIST (1971-2000) | 86.5 | 113.1 | 52.0 | 58.6 | 87.0 | 26.5 |
| RCP4.5 (2021-2050) | 89.4 | 116.6 | 54.3 | 61.2 | 90.5 | 28.4 |
| RCP4.5 (2071-2100) | 91.6 | 119.1 | 56.6 | 63.3 | 93.0 | 30.1 |
| RCP8.5 (2021-2050) | 89.9 | 117.3 | 55.0 | 61.7 | 91.1 | 28.9 |
| RCP8.5 (2071-2100) | 95.5 | 123.2 | 60.4 | 67.2 | 97.2 | 33.6 |

Table 3: The multi-model ensemble-mean time-mean annual mean, annual maximum, and annual minimum values of daily maximum and minimum temperature (°F).

| **Climate Scenario** | $\mathbf{T}_X$**90F** | $\mathbf{T}_X$**95F** | $\mathbf{T}_X$**100F** | $\mathbf{T}_X$**32F** | $\mathbf{T}_N$**32F** |
|---|---|---|---|---|---|
| HIST (1971-2000) | 167.8 | 136.4 | 96.8 | 0.0 | 6.0 |
| RCP4.5 (2021-2050) | 185.2 | 157.0 | 123.7 | 0.0 | 3.8 |
| RCP4.5 (2071-2100) | 198.1 | 170.1 | 139.8 | 0.0 | 2.4 |
| RCP8.5 (2021-2050) | 187.7 | 159.9 | 127.7 | 0.0 | 3.3 |
| RCP8.5 (2071-2100) | 220.5 | 192.7 | 164.6 | 0.0 | 0.9 |

Table 4: The multi-model ensemble-mean time-mean annual mean count of days with a maximum temperature in excess of 90°F, 95°F, and 100°F; the count of days with a maximum temperature $< 32$°F; and the count of days with a minimum temperature $< 32$°F.

| **Climate Scenario** | $\mathbf{T}_{X1X}$ | $\mathbf{T}_{X2X}$ | $\mathbf{T}_{X3X}$ | $\mathbf{T}_{X4X}$ | $\mathbf{T}_{X5X}$ |
|---|---|---|---|---|---|
| HIST (1971-2000) | 113.1 | 112.0 | 111.0 | 110.1 | 109.3 |
| RCP4.5 (2021-2050) | 116.6 | 115.4 | 114.4 | 113.4 | 112.6 |
| RCP4.5 (2071-2100) | 119.1 | 117.9 | 116.7 | 115.7 | 114.9 |
| RCP8.5 (2021-2050) | 117.3 | 116.1 | 115.1 | 114.1 | 113.2 |
| RCP8.5 (2071-2100) | 123.2 | 122.0 | 121.0 | 119.9 | 119.1 |

Table 5: The multi-model ensemble-mean time-mean annual maximum value of daily maximum temperature (°F) over a duration of $n$ consecutive days.

| **Climate Scenario** | $\mathbf{T}_{X1N}$ | $\mathbf{T}_{X2N}$ | $\mathbf{T}_{X3N}$ | $\mathbf{T}_{X4N}$ | $\mathbf{T}_{X5N}$ |
|---|---|---|---|---|---|
| HIST (1971-2000) | 52.0 | 54.6 | 56.7 | 58.5 | 60.0 |
| RCP4.5 (2021-2050) | 54.3 | 57.2 | 59.2 | 60.9 | 62.4 |
| RCP4.5 (2071-2100) | 56.6 | 59.3 | 61.3 | 63.0 | 64.4 |
| RCP8.5 (2021-2050) | 55.0 | 57.6 | 59.7 | 61.4 | 62.9 |
| RCP8.5 (2071-2100) | 60.4 | 63.0 | 65.0 | 66.7 | 68.2 |

Table 6: The multi-model ensemble-mean time-mean annual minimum value of daily maximum temperature (°F) over a duration of $n$ consecutive days.

| **Climate Scenario** | $\mathbf{T}_{N1X}$ | $\mathbf{T}_{N2X}$ | $\mathbf{T}_{N3X}$ | $\mathbf{T}_{N4X}$ | $\mathbf{T}_{N5X}$ |
|---|---|---|---|---|---|
| HIST (1971-2000) | 87.0 | 85.3 | 84.2 | 83.1 | 82.3 |
| RCP4.5 (2021-2050) | 90.5 | 88.7 | 87.5 | 86.4 | 85.7 |
| RCP4.5 (2071-2100) | 93.0 | 91.2 | 89.8 | 88.8 | 87.9 |
| RCP8.5 (2021-2050) | 91.1 | 89.4 | 88.1 | 87.1 | 86.2 |
| RCP8.5 (2071-2100) | 97.2 | 95.4 | 94.1 | 93.1 | 92.2 |

Table 7: The multi-model ensemble-mean time-mean annual maximum value of daily minimum temperature (°F) over a duration of $n$ consecutive days.

| **Climate Scenario** | $\mathbf{T}_{N1N}$ | $\mathbf{T}_{N2N}$ | $\mathbf{T}_{N3N}$ | $\mathbf{T}_{N4N}$ | $\mathbf{T}_{N5N}$ |
|---|---|---|---|---|---|
| HIST (1971-2000) | 26.5 | 29.3 | 31.5 | 33.5 | 35.2 |
| RCP4.5 (2021-2050) | 28.4 | 31.1 | 33.4 | 35.5 | 37.0 |
| RCP4.5 (2071-2100) | 30.1 | 32.8 | 35.1 | 37.0 | 38.6 |
| RCP8.5 (2021-2050) | 28.9 | 31.7 | 33.8 | 35.7 | 37.4 |
| RCP8.5 (2071-2100) | 33.6 | 36.1 | 38.4 | 40.3 | 41.9 |

Table 8: The multi-model ensemble-mean time-mean annual minimum value of daily minimum temperature (°F) over a duration of $n$ consecutive days.

## 2.2 Precipitation extremes

| Climate Scenario | Pr | $\mathbf{Pr}_X$ |
|---|---|---|
| HIST (1971-2000) | 0.02 | 0.91 |
| RCP4.5 (2021-2050) | 0.02 | 0.96 |
| RCP4.5 (2071-2100) | 0.02 | 0.98 |
| RCP8.5 (2021-2050) | 0.02 | 0.96 |
| RCP8.5 (2071-2100) | 0.02 | 1.00 |

Table 9: The multi-model ensemble-mean time-mean annual mean and annual maximum values of daily precipitation (inches).

| Climate Scenario | $\mathbf{Pr}_X\mathbf{1}$ | $\mathbf{Pr}_X\mathbf{2}$ | $\mathbf{Pr}_X\mathbf{3}$ | $\mathbf{Pr}_X\mathbf{4}$ |
|---|---|---|---|---|
| HIST (1971-2000) | 0.5 | 0.0 | 0.0 | 0.0 |
| RCP4.5 (2021-2050) | 0.6 | 0.0 | 0.0 | 0.0 |
| RCP4.5 (2071-2100) | 0.6 | 0.0 | 0.0 | 0.0 |
| RCP8.5 (2021-2050) | 0.5 | 0.0 | 0.0 | 0.0 |
| RCP8.5 (2071-2100) | 0.6 | 0.1 | 0.0 | 0.0 |

Table 10: The multi-model ensemble-mean time-mean annual mean count of days with precipitation in excess of 1–4 inches.

| Climate Scenario | $\mathbf{Pr}_{1X}$ | $\mathbf{Pr}_{2X}$ | $\mathbf{Pr}_{3X}$ | $\mathbf{Pr}_{4X}$ | $\mathbf{Pr}_{5X}$ |
|---|---|---|---|---|---|
| HIST (1971-2000) | 0.91 | 1.35 | 1.56 | 1.67 | 1.75 |
| RCP4.5 (2021-2050) | 0.96 | 1.41 | 1.63 | 1.74 | 1.83 |
| RCP4.5 (2071-2100) | 0.97 | 1.46 | 1.69 | 1.80 | 1.87 |
| RCP8.5 (2021-2050) | 0.96 | 1.40 | 1.63 | 1.74 | 1.83 |
| RCP8.5 (2071-2100) | 0.99 | 1.47 | 1.68 | 1.78 | 1.86 |

Table 11: The multi-model ensemble-mean time-mean annual maximum value of total precipitation (inches) over a duration of $n$ consecutive days.

| **Climate Scenario** | **WD** | **ConWD** | **ConWD$_X$** |
|---|---|---|---|
| HIST (1971-2000) | 56.3 | 2.0 | 6.2 |
| RCP4.5 (2021-2050) | 52.7 | 2.0 | 6.0 |
| RCP4.5 (2071-2100) | 51.3 | 1.9 | 5.9 |
| RCP8.5 (2021-2050) | 52.0 | 2.0 | 6.0 |
| RCP8.5 (2071-2100) | 46.3 | 1.9 | 5.5 |

Table 12: The multi-model ensemble-mean time-mean annual mean count of *wet* days (precipitation $> 0.01$ in); and the annual mean and maximum duration of wet-day spells.

| **Climate Scenario** | **DD** | **ConDD** | **ConDD$_X$** |
|---|---|---|---|
| HIST (1971-2000) | 308.7 | 11.1 | 65.2 |
| RCP4.5 (2021-2050) | 312.3 | 11.9 | 69.2 |
| RCP4.5 (2071-2100) | 313.7 | 12.2 | 71.0 |
| RCP8.5 (2021-2050) | 313.0 | 12.1 | 70.8 |
| RCP8.5 (2071-2100) | 318.7 | 13.8 | 78.5 |

Table 13: The multi-model ensemble-mean time-mean annual mean count of *dry* days (precipitation $< 0.01$ in); and the annual mean and maximum duration of dry-day spells.

# 3 Local analysis of climate extremes

## 3.1 Daily Maximum Temperature

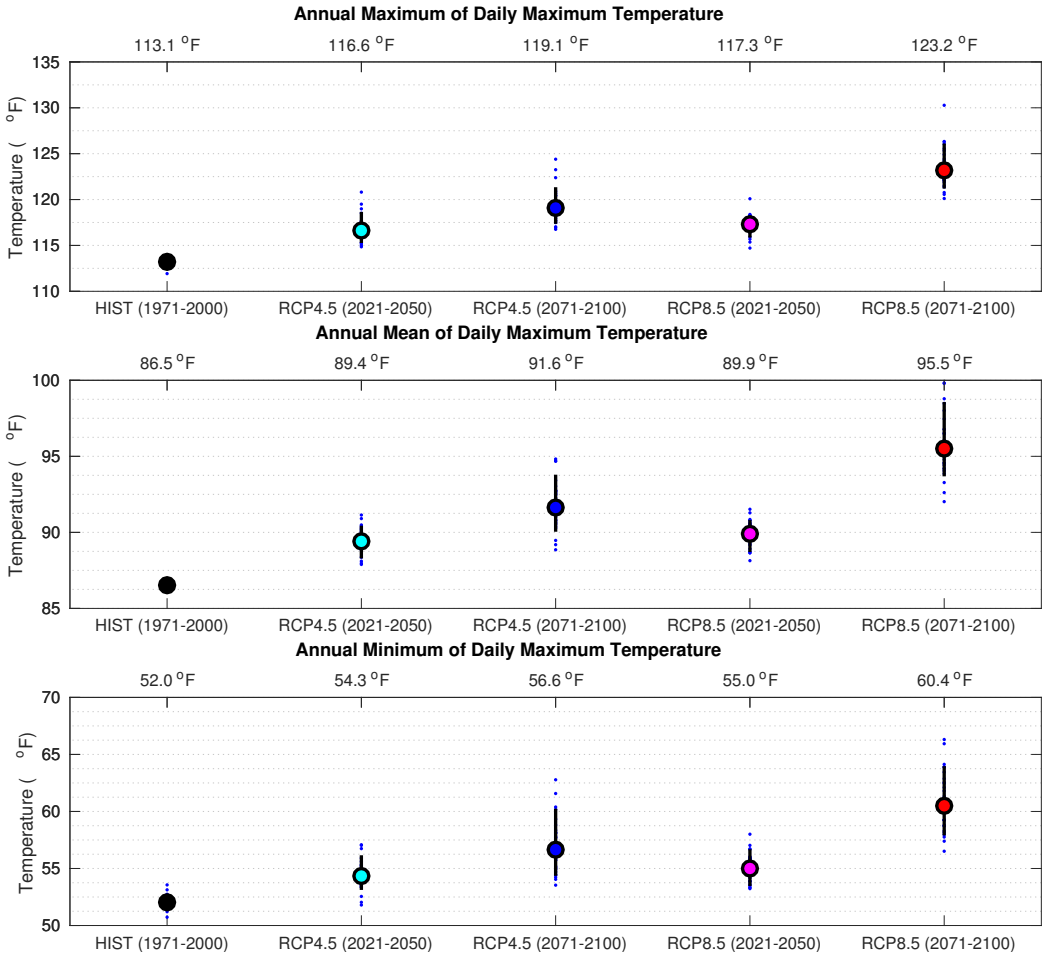


Figure 2: The annual maximum (upper panel), annual mean (middle panel), and annual minimum (lower panel) multi-model ensemble-mean time-mean values of daily maximum temperature; black lines indicate the 10th–90th percentile range of individual model time-mean results, with additional small blue points indicating the outlier models.

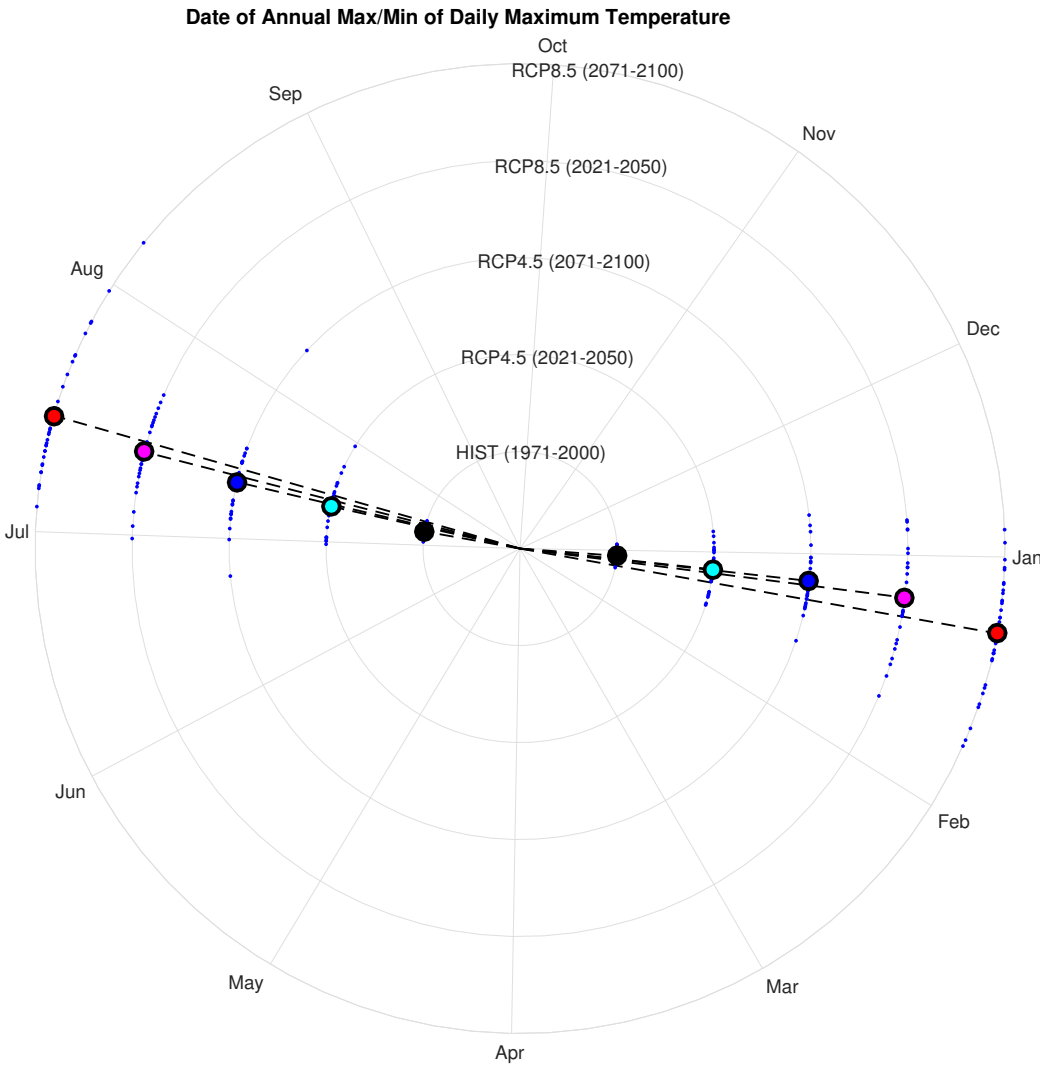


Figure 3: The multi-model ensemble-mean time-mean occurrence date of the annual maximum and minimum in maximum daily temperature; blue dots indicate the time-mean of the individual CMIP5 models.

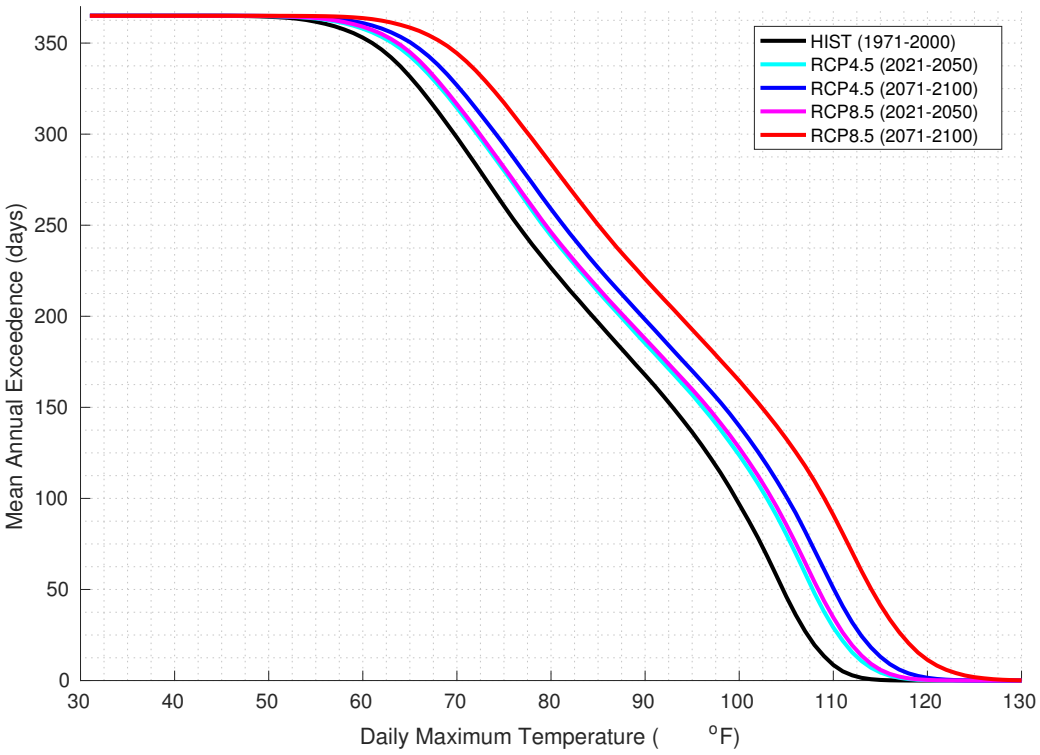


Figure 4: The multi-model ensemble-mean time-mean annual mean count of days with a maximum temperature greater than a specified threshold.

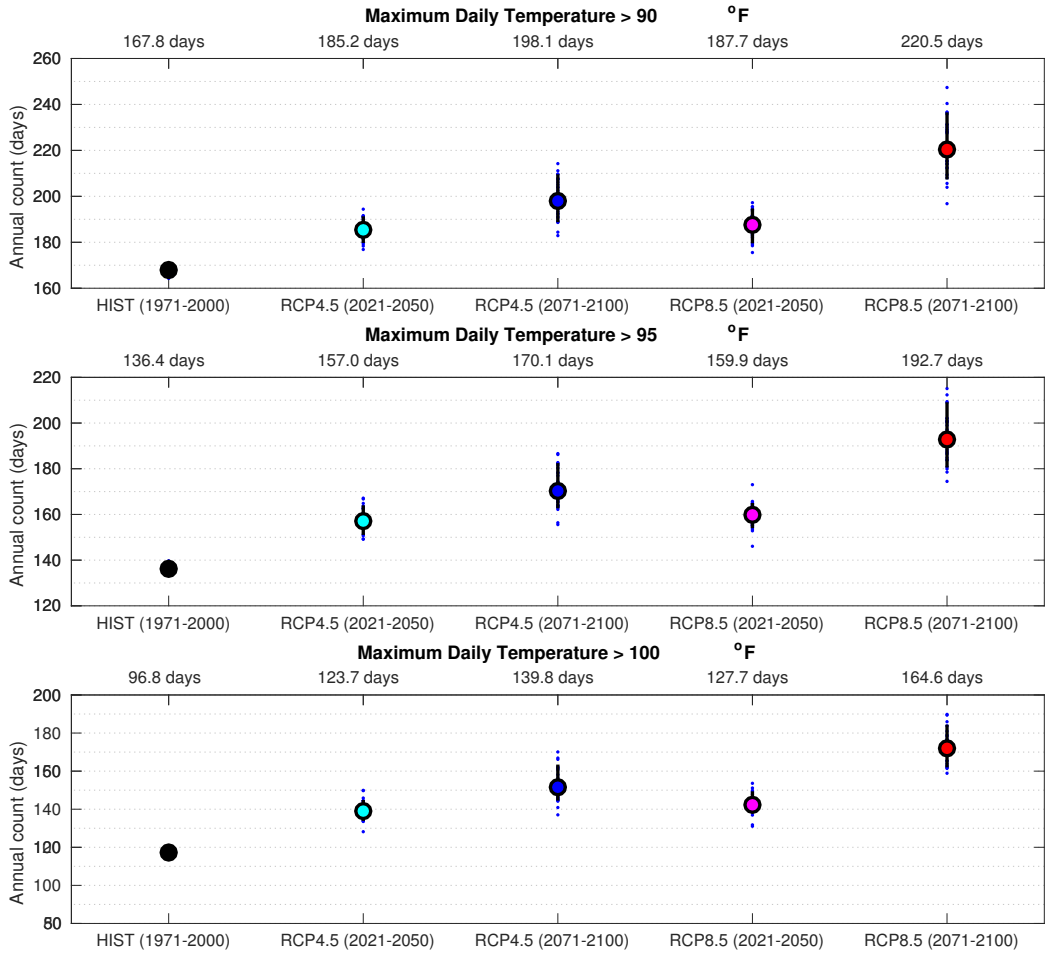


Figure 5: The annual mean count of days with a maximum temperature in excess of 90°F (upper panel), 95°F (middle panel), and 100°F (lower panel). Circle markers indicate the multi-model ensemble-mean time-mean annual count; black lines indicate the 10th–90th percentile range of individual model time-mean results, with additional small blue points indicating the outlier models.

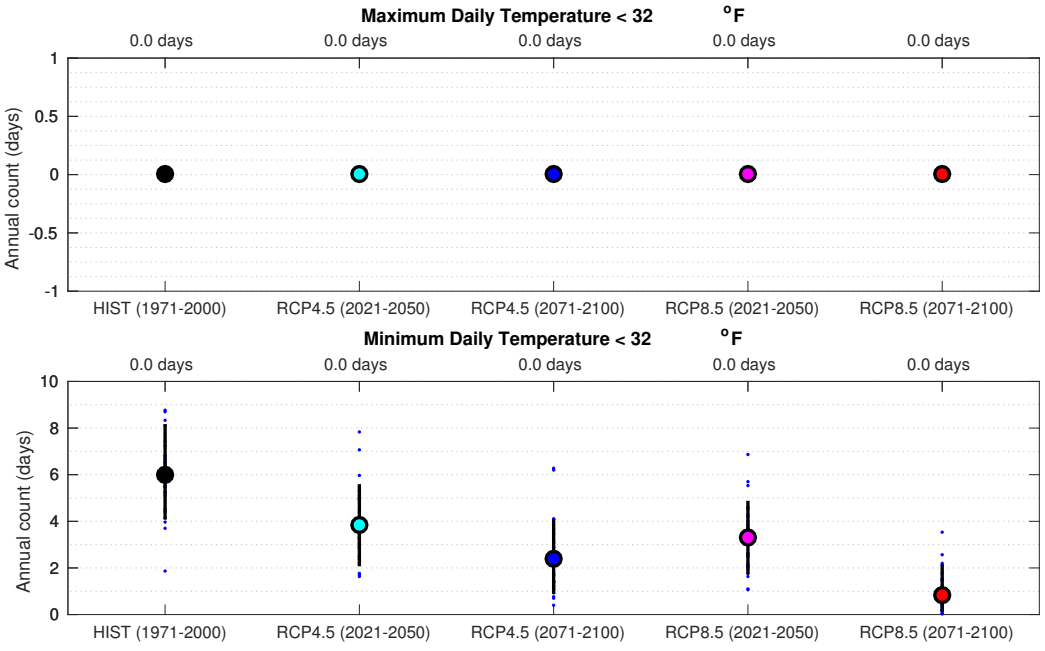


Figure 6: The annual mean count of days with a maximum temperature $< 32°$F (upper panel), and minimum temperature $< 32°$F (lower panel). Circle markers indicate the multi-model ensemble-mean time-mean annual count; black lines indicate the 10th–90th percentile range of individual model time-mean results, with additional small blue points indicating the outlier models.

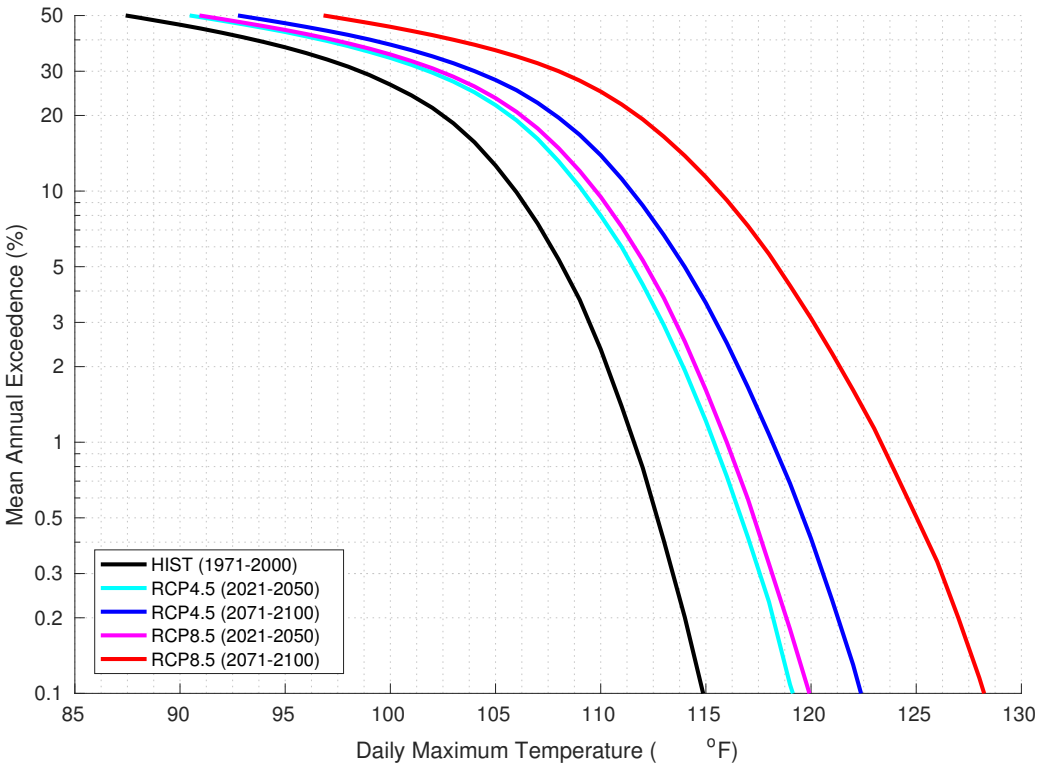


Figure 7: The multi-model ensemble-mean time-mean proportion of annual days (%) with a maximum temperature greater than a specified threshold.

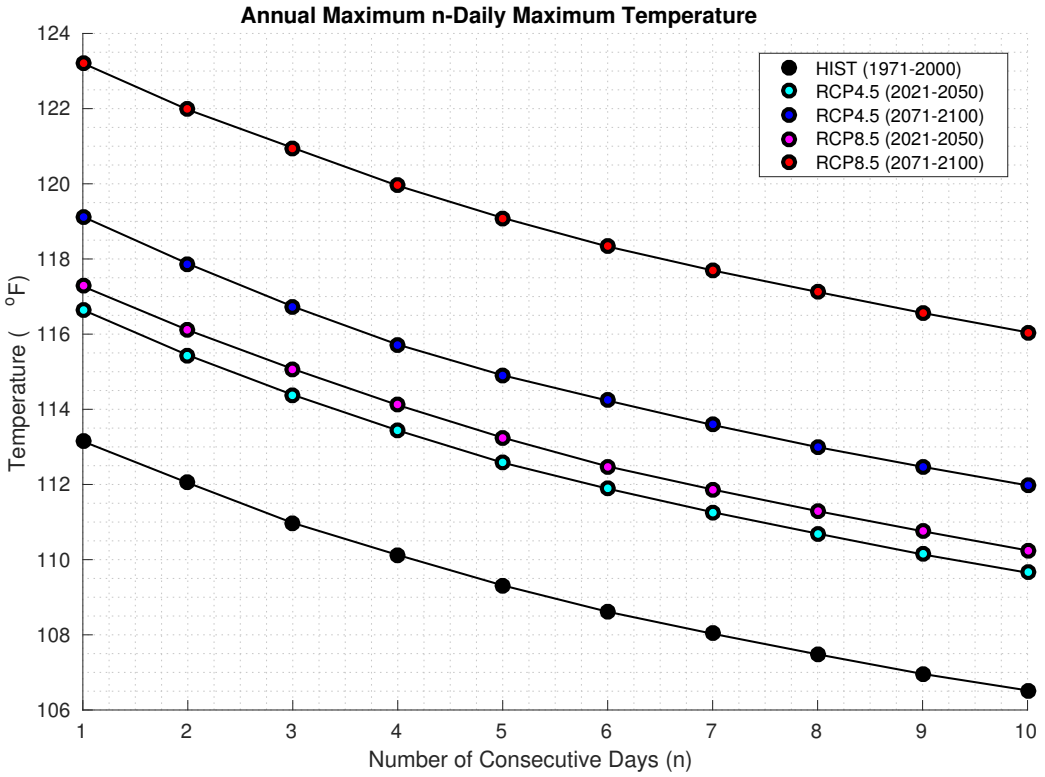


Figure 8: The multi-model ensemble-mean time-mean annual maximum value of daily maximum temperature over a duration of $n$ consecutive days.

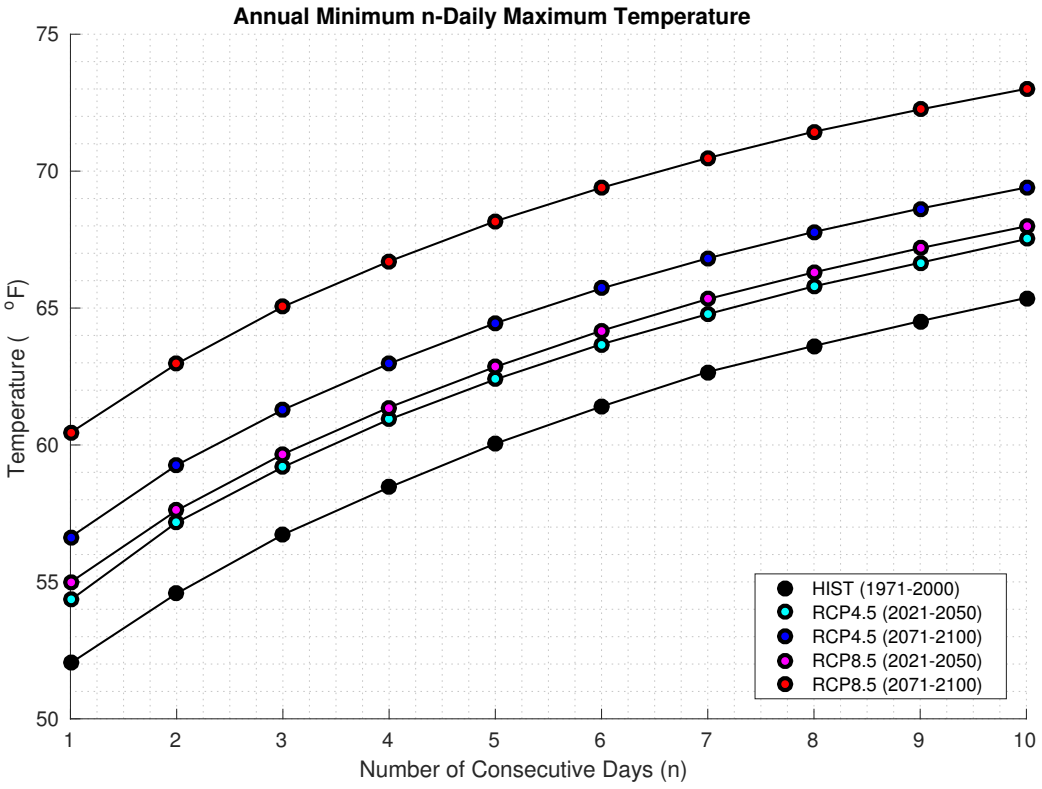


Figure 9: The multi-model ensemble-mean time-mean annual minimum value of daily maximum temperature over a duration of $n$ consecutive days.

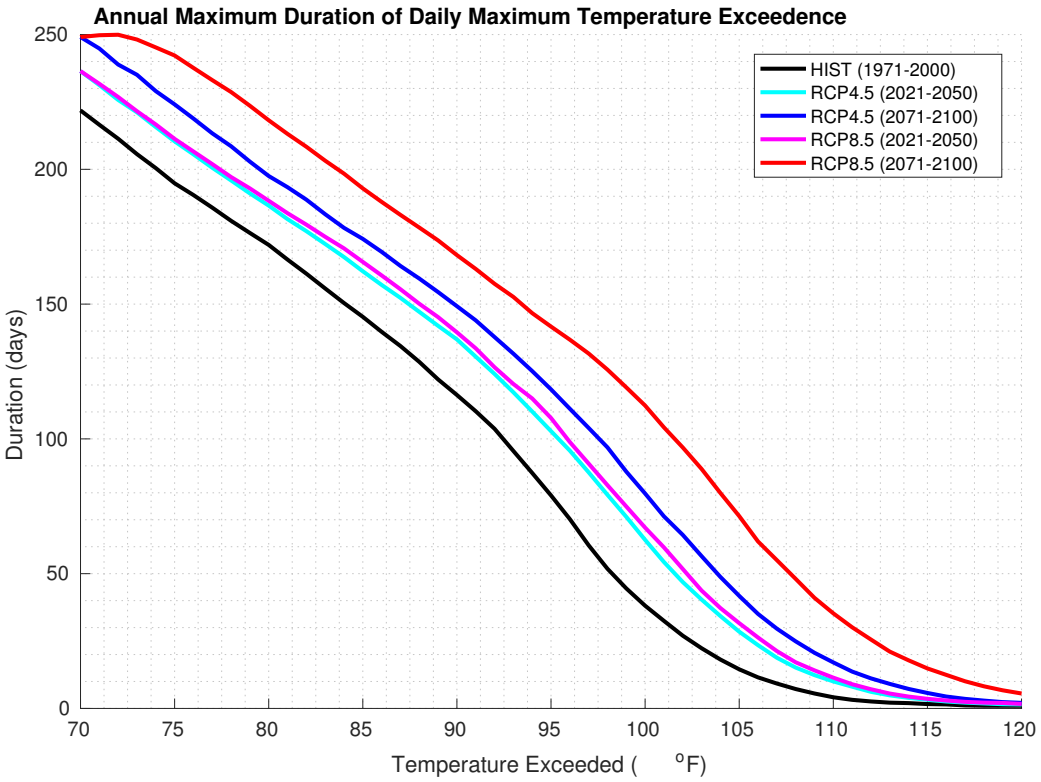


Figure 10: The multi-model ensemble-mean time-mean annual maximum duration of consecutive days that have a daily maximum temperature greater than a specified threshold.

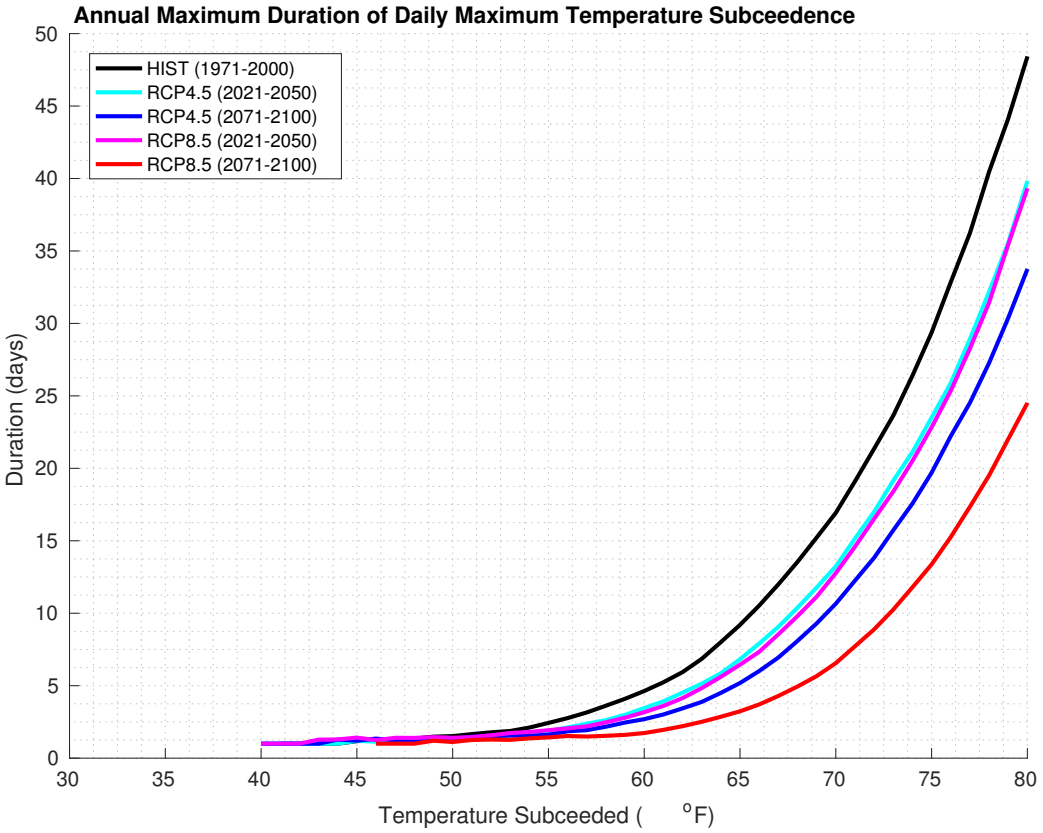


Figure 11: The multi-model ensemble-mean time-mean annual maximum duration of consecutive days that have a daily maximum temperature below a specified threshold.

## 3.2 Daily Minimum Temperature

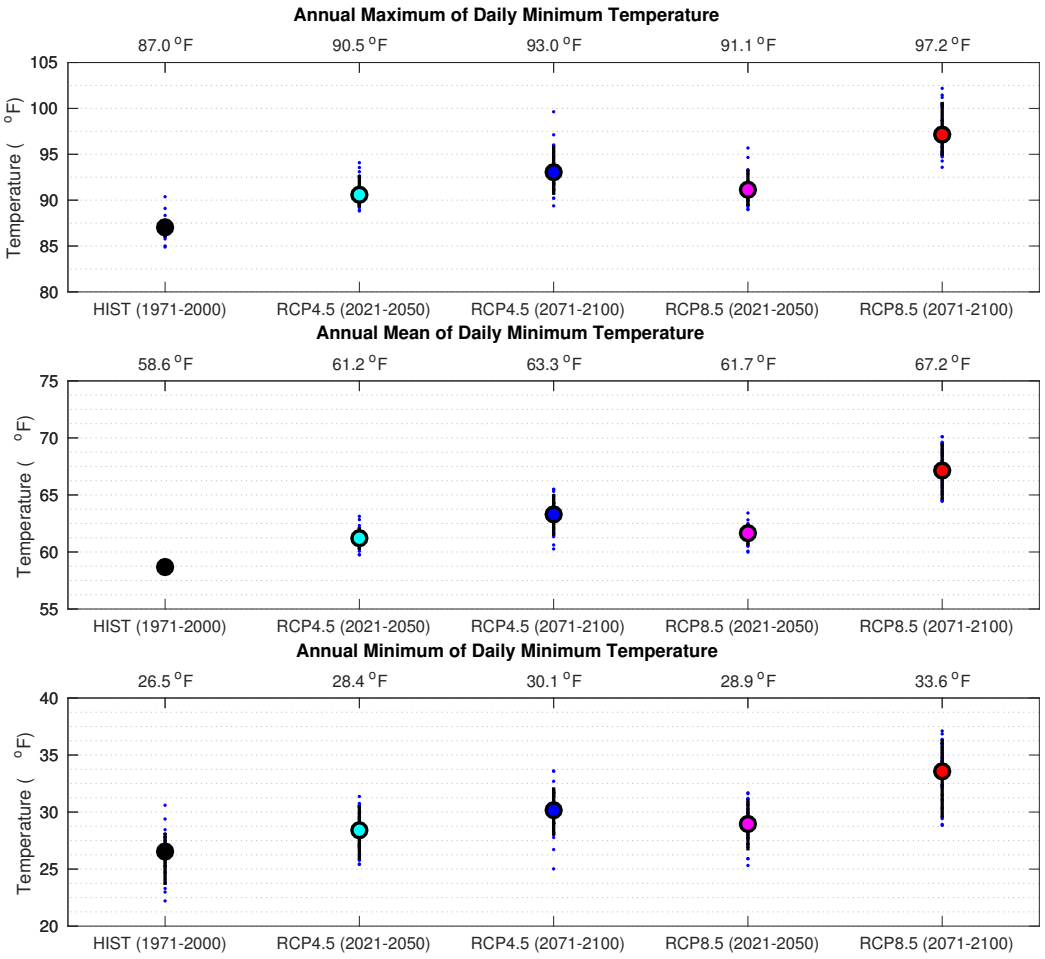


Figure 12: The annual maximum (upper panel), annual mean (middle panel), and annual minimum (lower panel) multi-model ensemble-mean time-mean values of daily minimum temperature; black lines indicate the 10th–90th percentile range of individual model time-mean results, with additional small blue points indicating the outlier models.

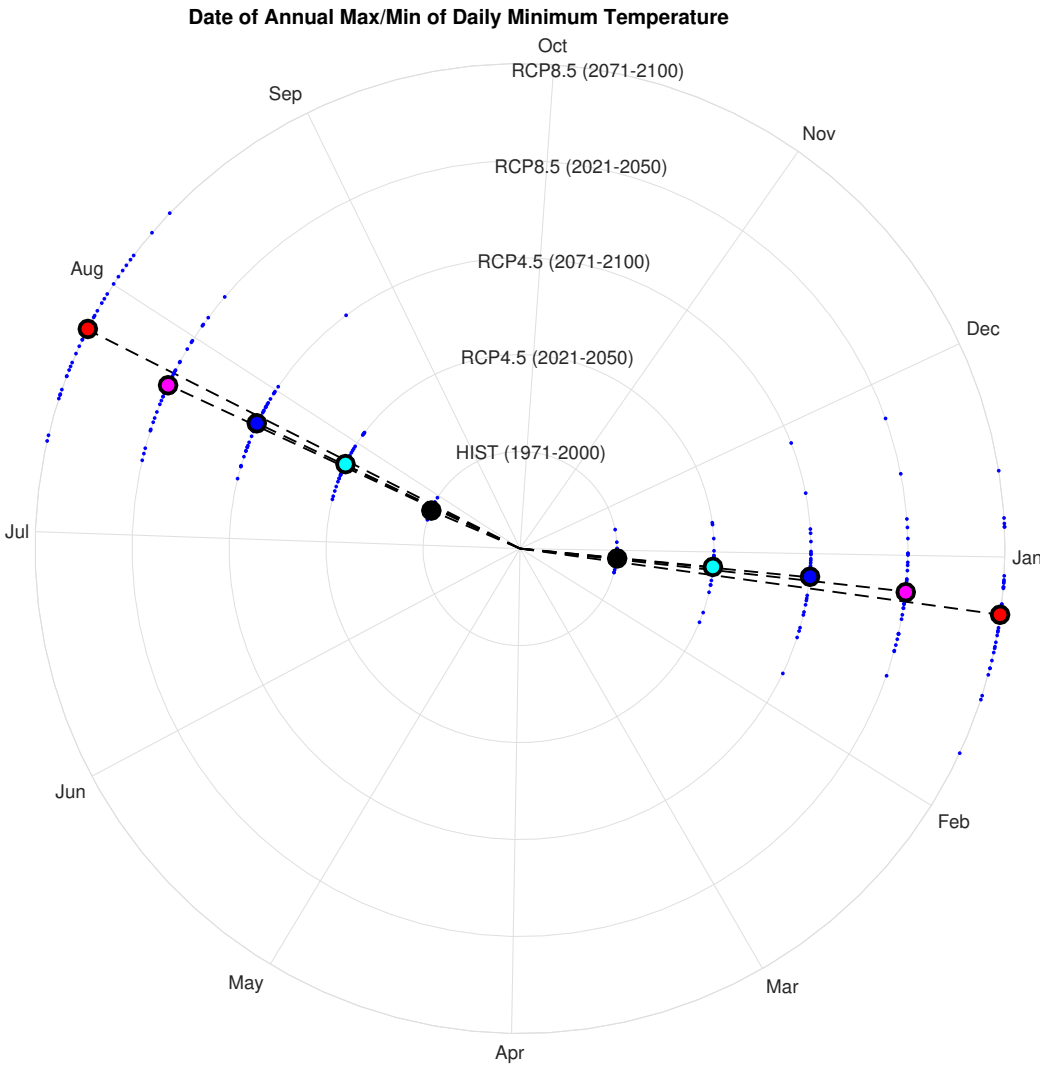


Figure 13: The multi-model ensemble-mean time-mean occurrence date of the annual maximum and minimum in minimum daily temperature; blue dots indicate the time-mean of the individual CMIP5 models.

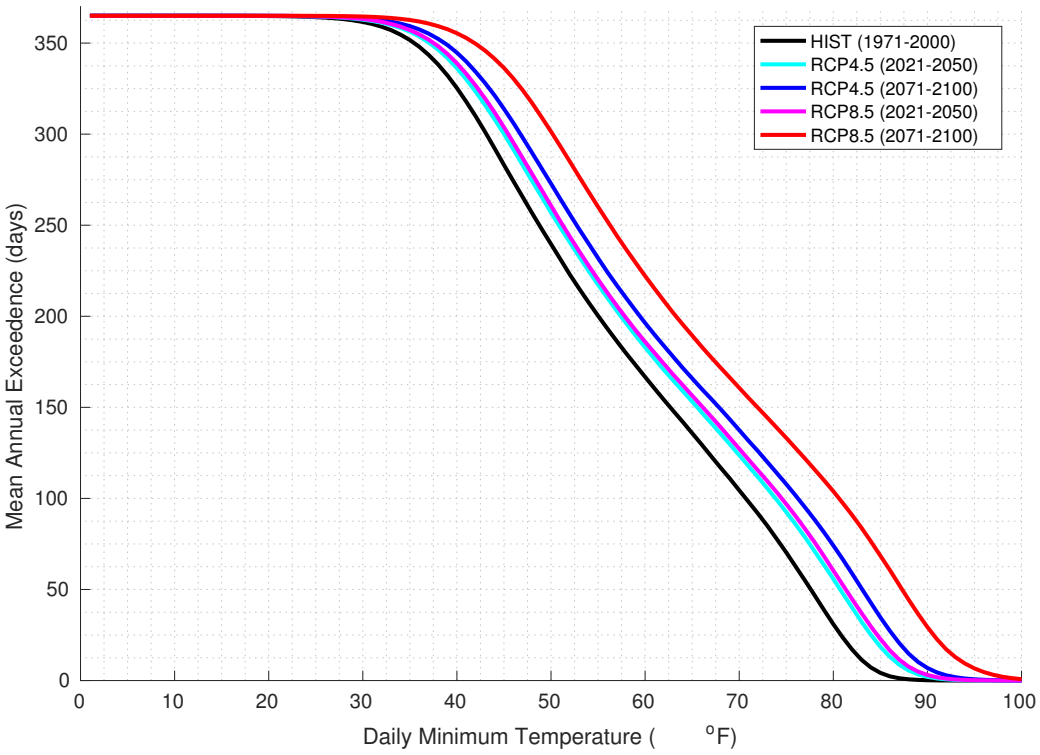


Figure 14: The multi-model ensemble-mean time-mean annual mean count of days with a minimum temperature greater than a specified threshold.

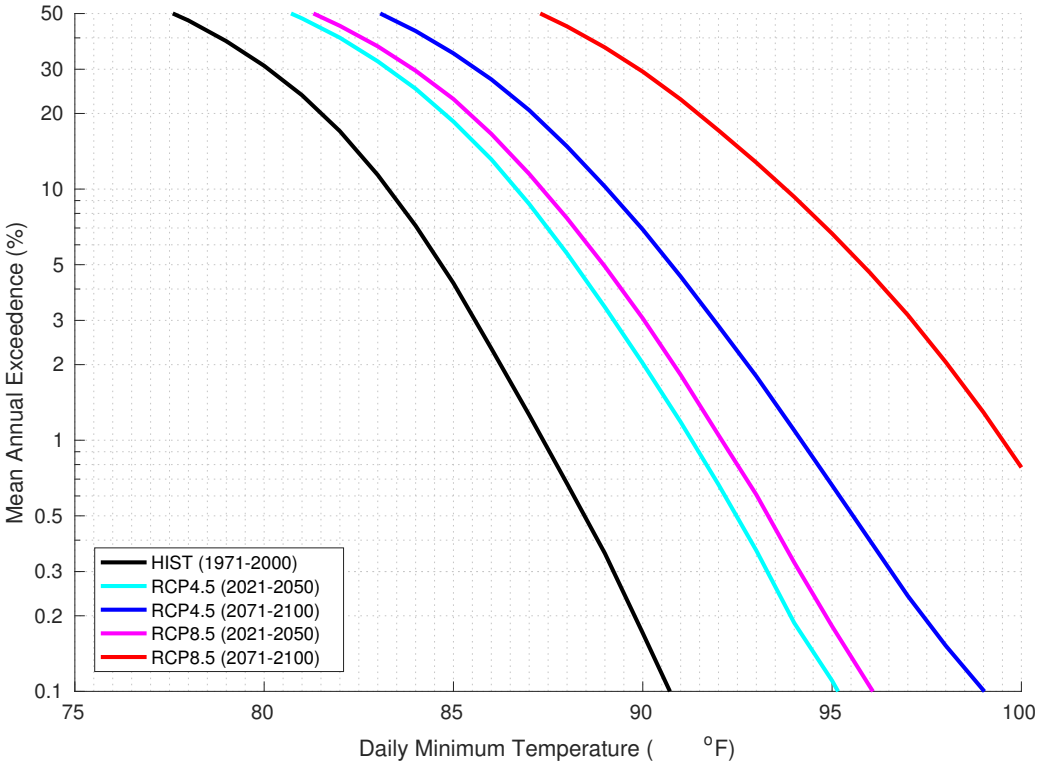


Figure 15: The multi-model ensemble-mean time-mean proportion of annual days (%) with a minimum temperature greater than a specified threshold.

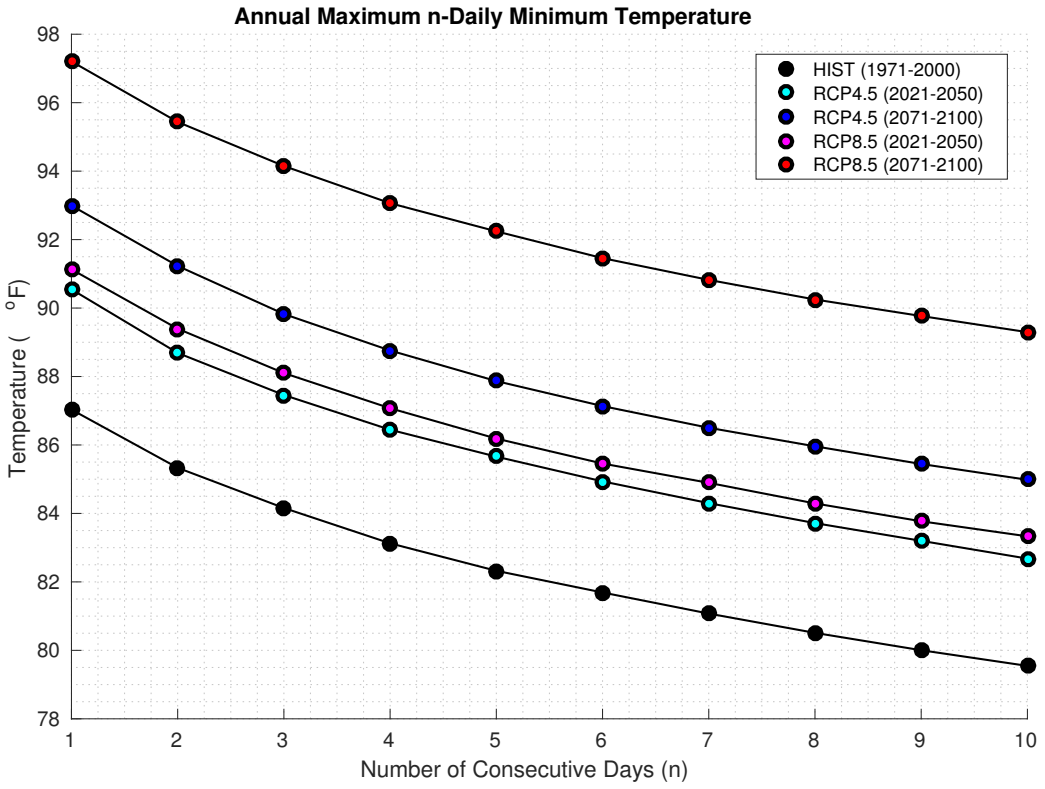


Figure 16: The multi-model ensemble-mean time-mean annual maximum value of daily minimum temperature over a duration of $n$ consecutive days.

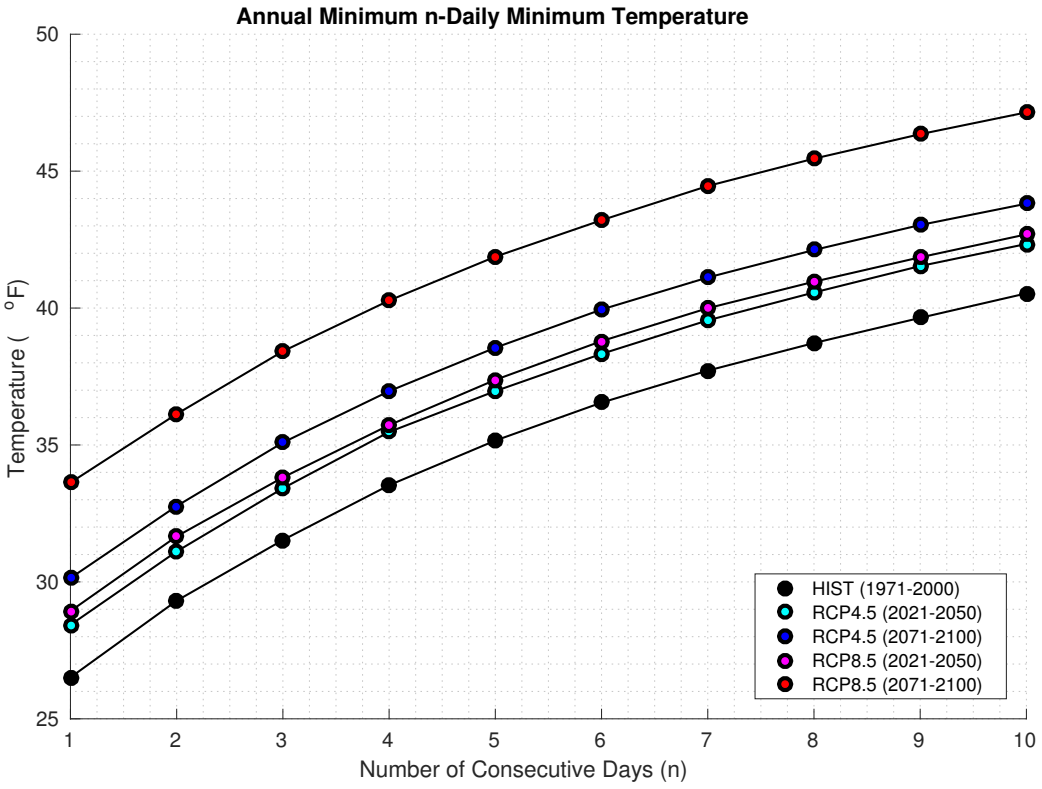


Figure 17: The multi-model ensemble-mean time-mean annual minimum value of daily minimum temperature over a duration of $n$ consecutive days.

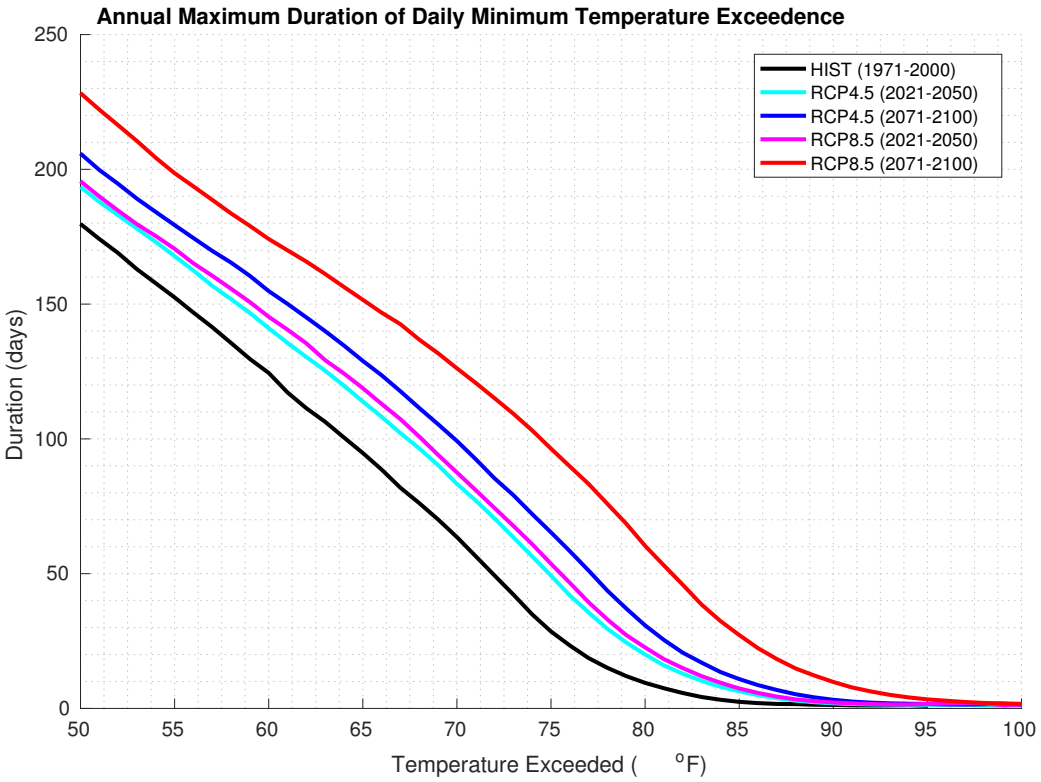


Figure 18: The multi-model ensemble-mean time-mean annual maximum duration of consecutive days that have a daily minimum temperature greater than a specified threshold.

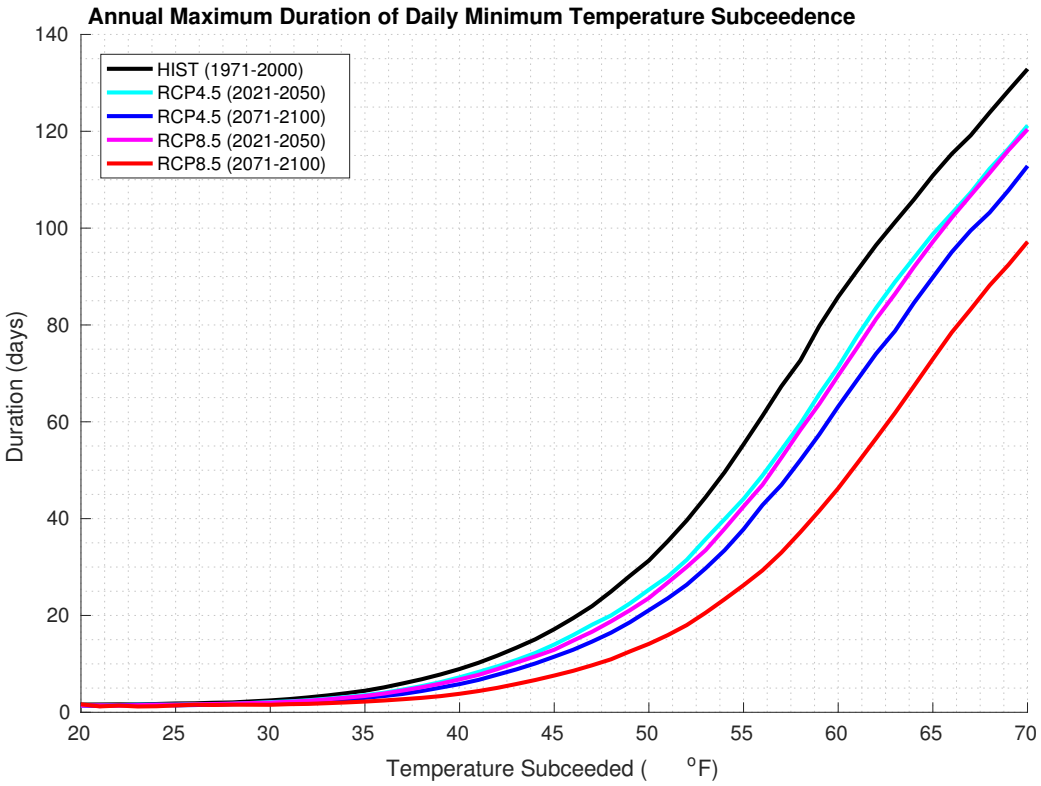


Figure 19: The multi-model ensemble-mean time-mean annual maximum duration of consecutive days that have a daily minimum temperature below a specified threshold.

## 3.3 Daily Rainfall

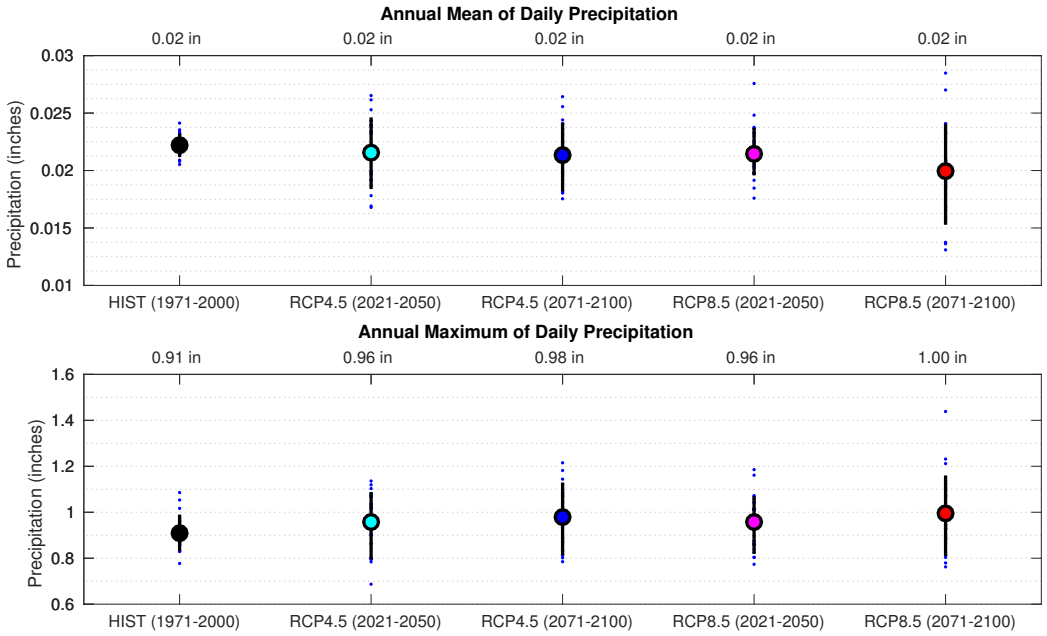


Figure 20: The annual mean (upper panel) and annual maximum (lower panel) multi-model ensemble-mean time-mean values of daily precipitation; black lines indicate the 10th–90th percentile range of individual model time-mean results, with additional small blue points indicating the outlier models.

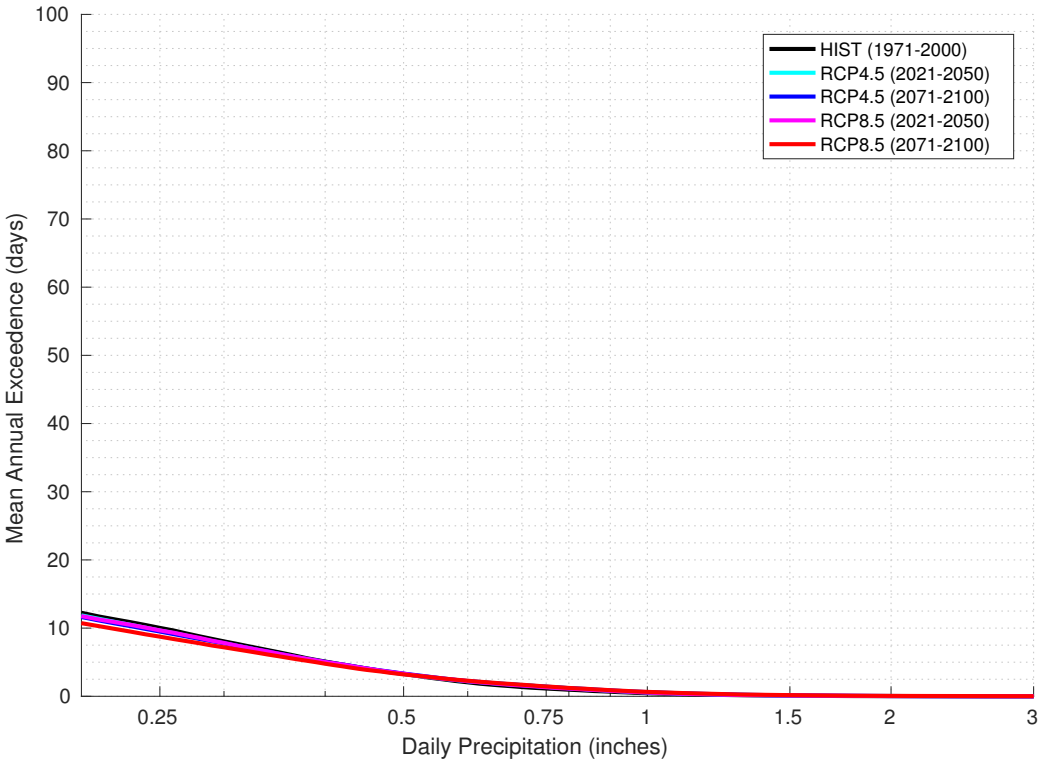


Figure 21: The multi-model ensemble-mean time-mean annual mean count of days with precipitation greater than a specified threshold.

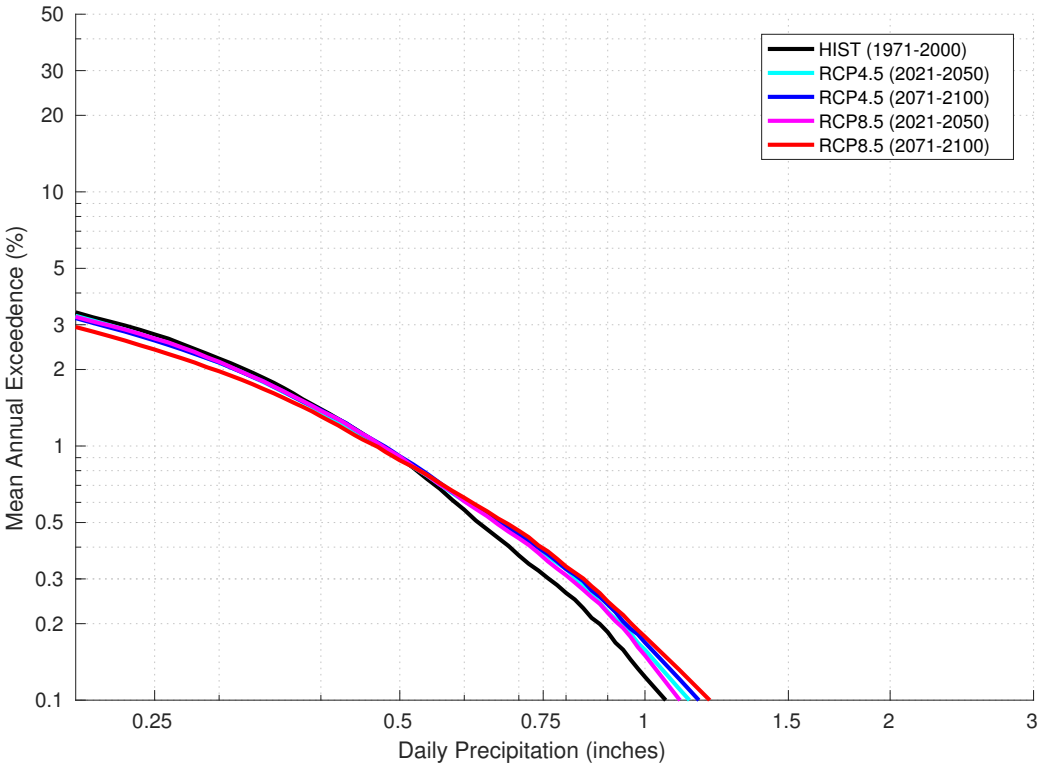


Figure 22: The multi-model ensemble-mean time-mean proportion of annual days (%) with precipitation greater than a specified threshold.

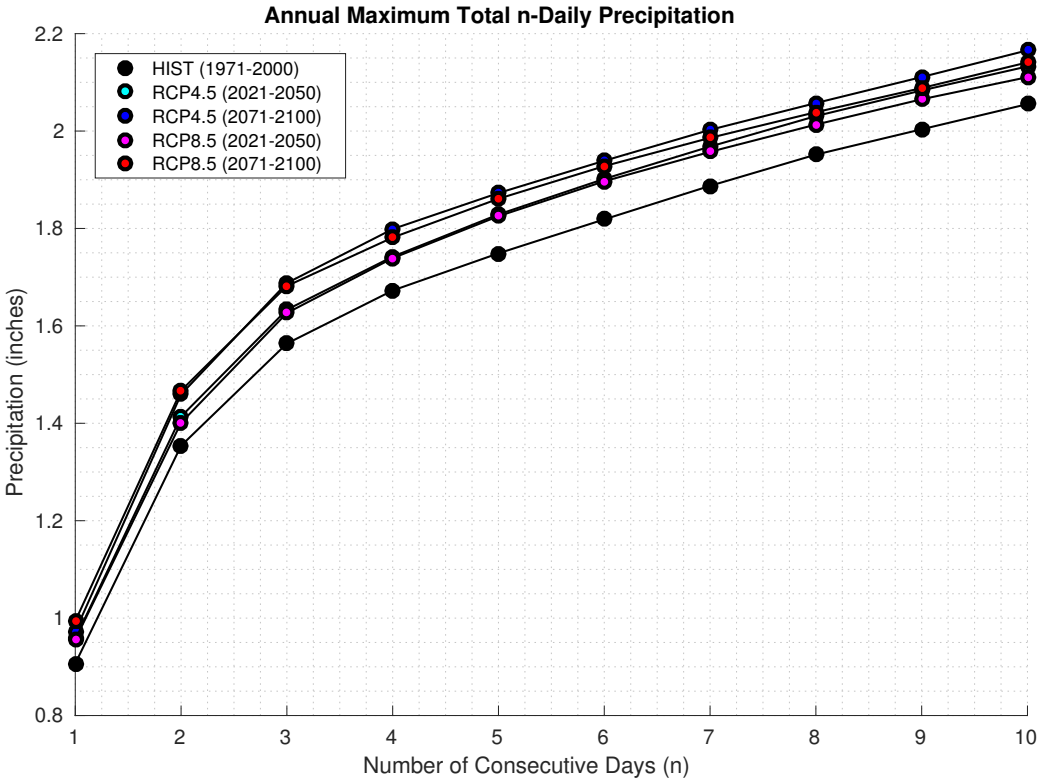


Figure 23: The multi-model ensemble-mean time-mean annual maximum value of total precipitation over a duration of $n$ consecutive days.

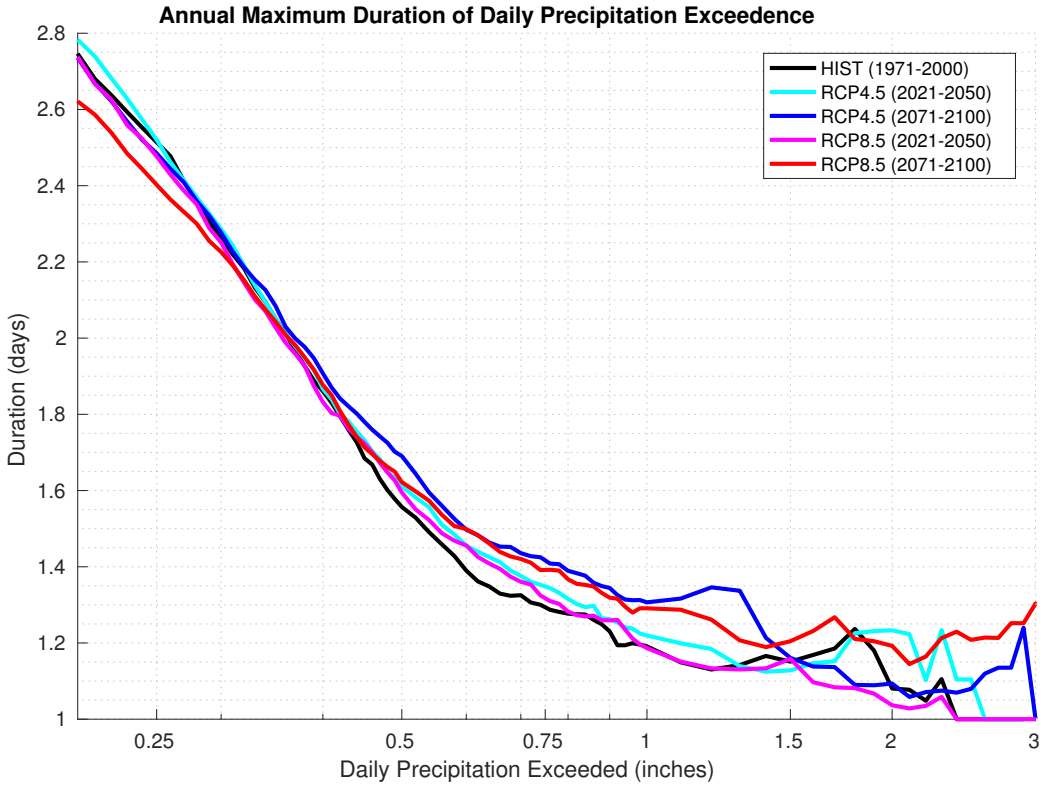


Figure 24: The multi-model ensemble-mean time-mean annual maximum duration of consecutive days that have a daily precipitation rate greater than a specified threshold.

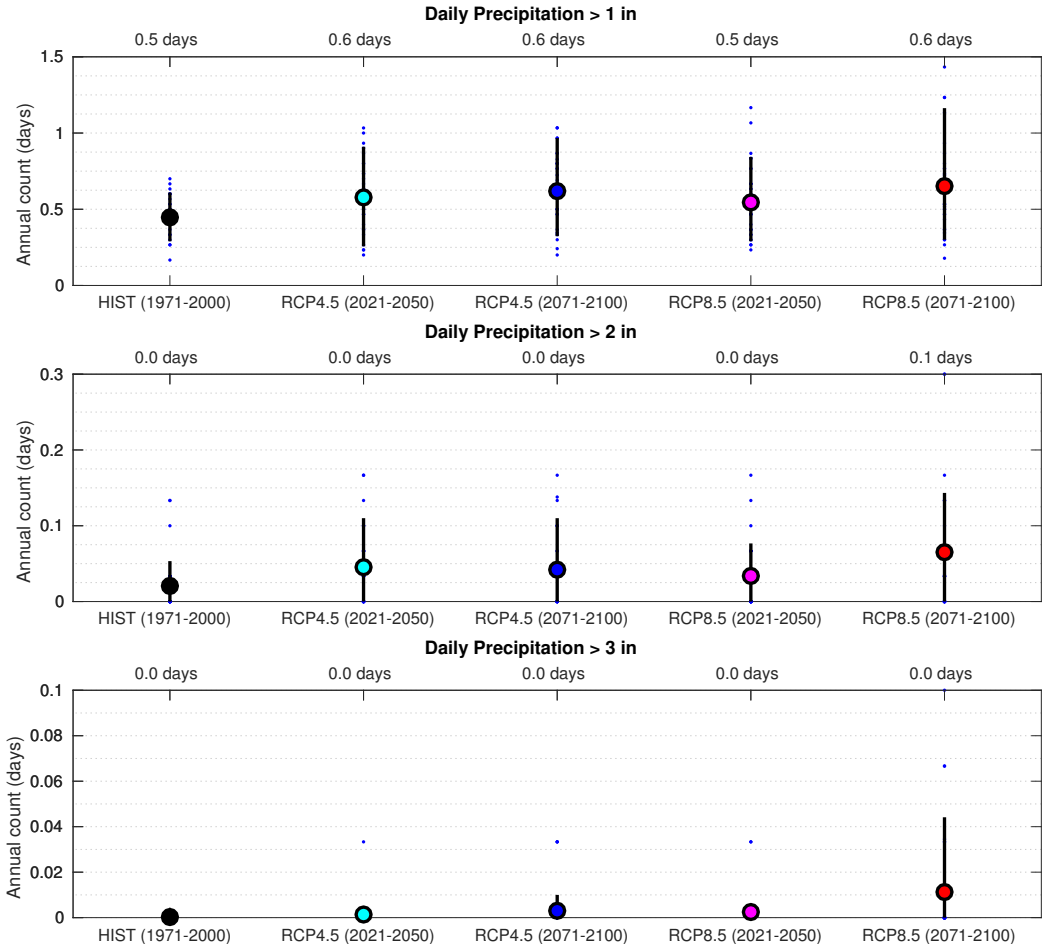


Figure 25: The annual mean count of days with daily precipitation in excess of 1 inch (upper panel), 2 inches (middle panel), and 3 inches (lower panel). Circle markers indicate the multi-model ensemble-mean time-mean annual count; black lines indicate the 10th–90th percentile range of individual model time-mean results, with additional small blue points indicating the outlier models.

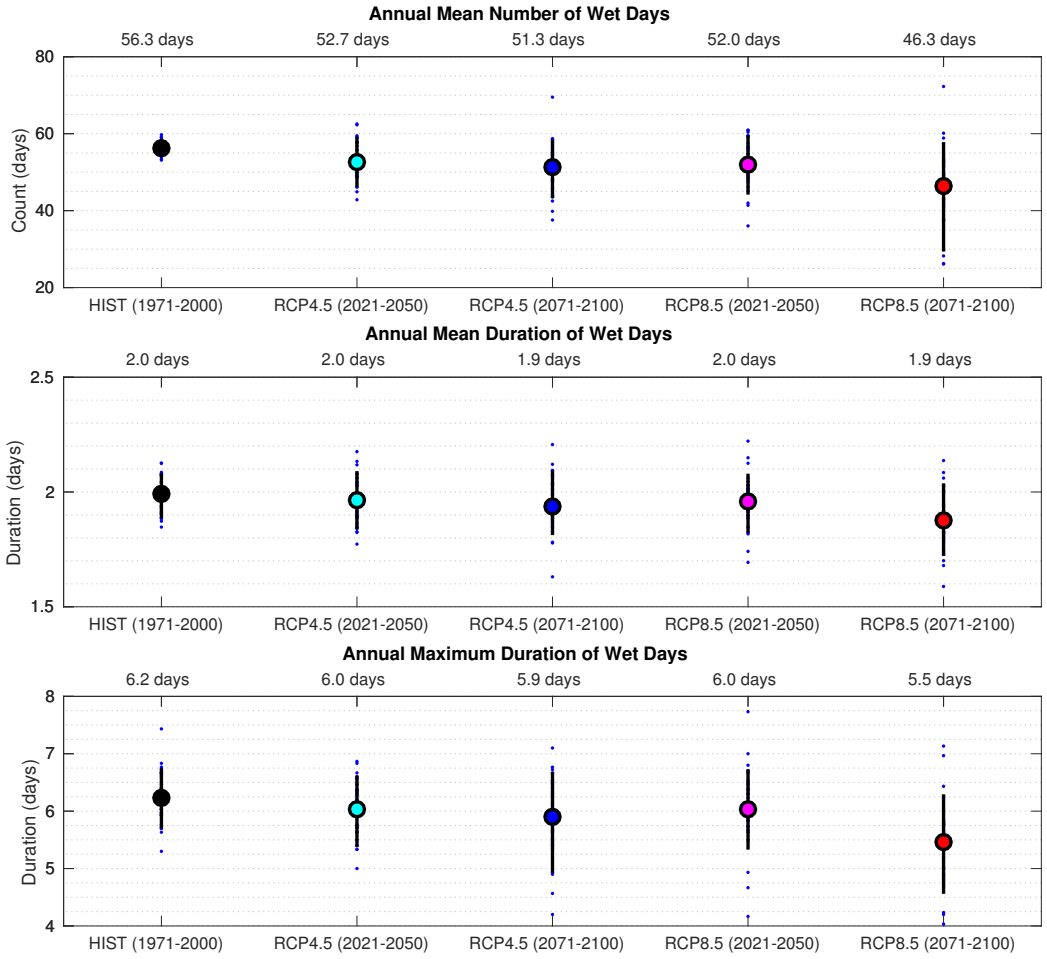


Figure 26: Annual mean count of wet days (daily precipitation $> 0.01$ inches; upper panel), along with the annual mean duration (middle panel), and annual maximum duration (lower panel) of consecutive wet-day spells. Circle markers indicate the multi-model ensemble-mean time-mean; black lines indicate the 10th–90th percentile range of individual model time-mean results, with additional small blue points indicating the outlier models.

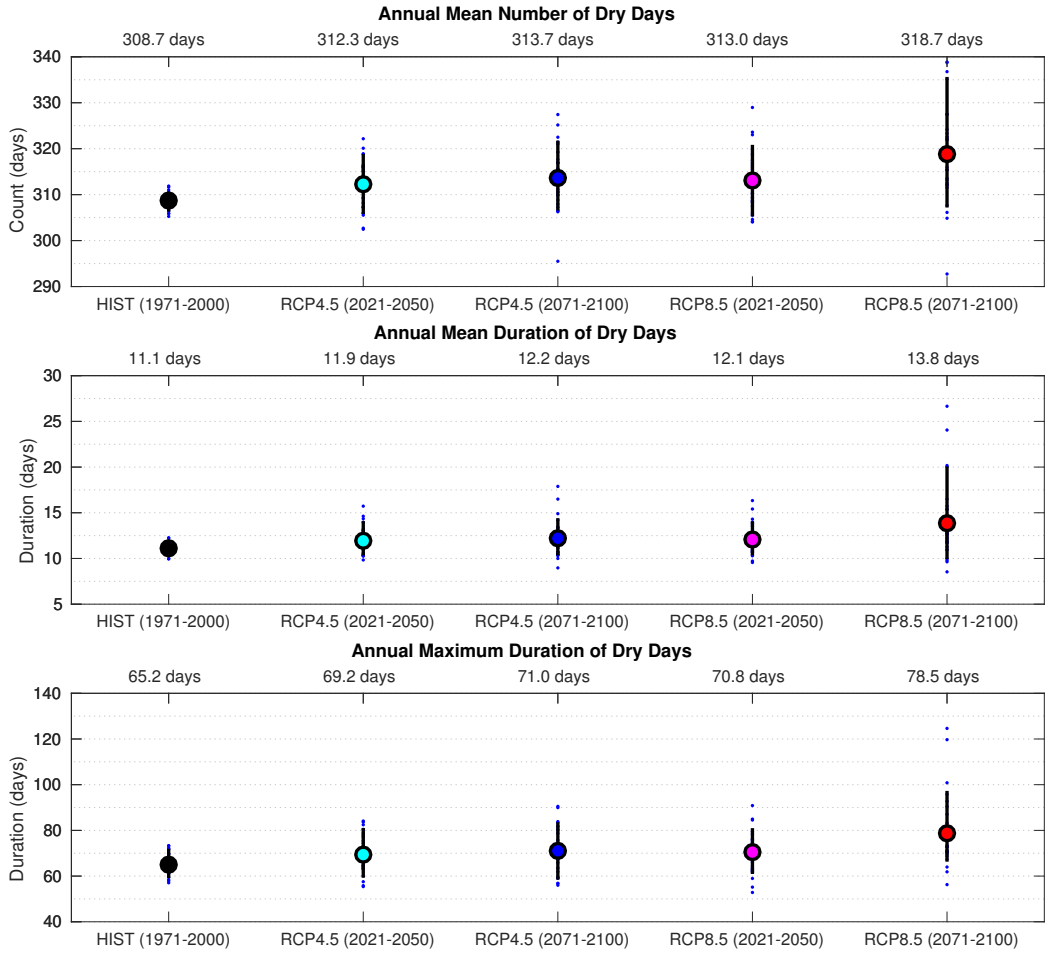


Figure 27: Annual mean count of dry days (upper panel), along with the annual mean duration (middle panel), and annual maximum duration (lower panel) of consecutive dry-day spells. Circle markers indicate the multi-model ensemble-mean time-mean; black lines indicate the 10th–90th percentile range of individual model time-mean results, with additional small blue points indicating the outlier models.

# 4 Regional analysis of climate extremes

## 4.1 Mean value of daily maximum temperature

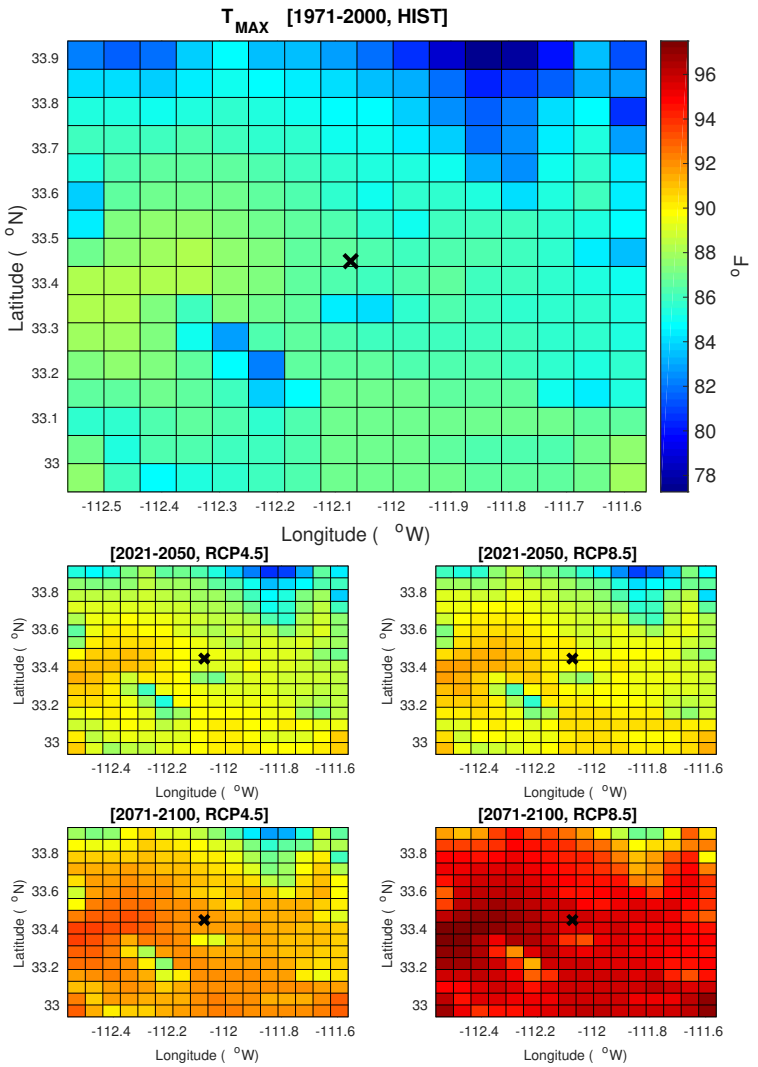


Figure 28: The multi-model ensemble-mean time-mean annual mean value of daily maximum temperature, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

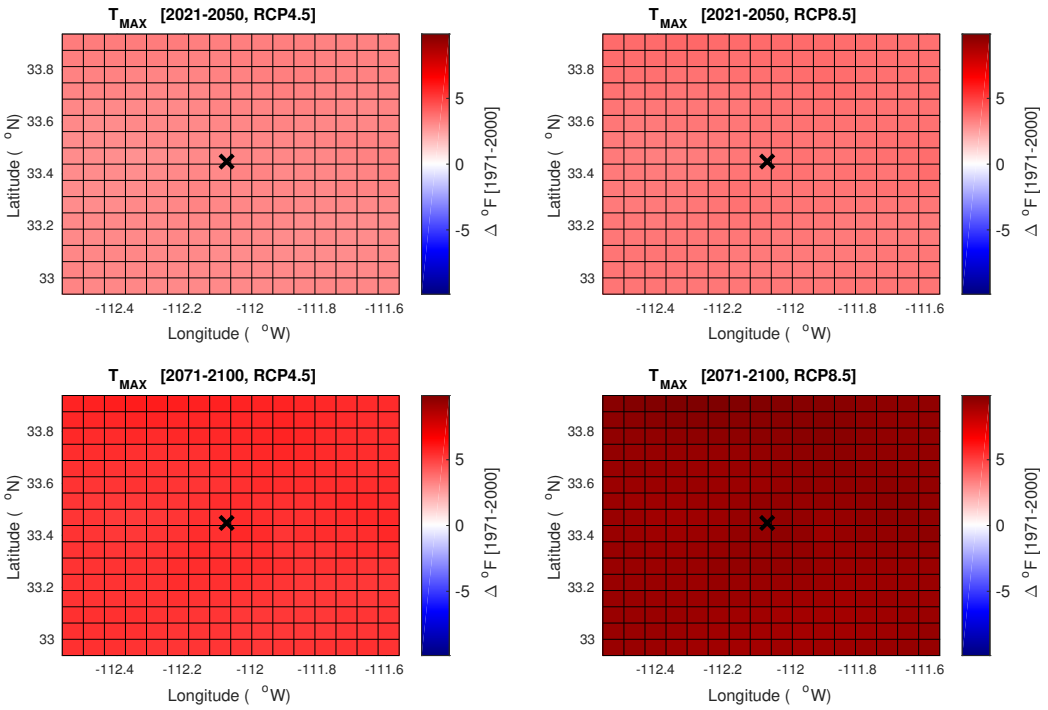


Figure 29: The difference in the multi-model ensemble-mean time-mean annual mean value of daily maximum temperature projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

## 4.2 Mean value of daily minimum temperature

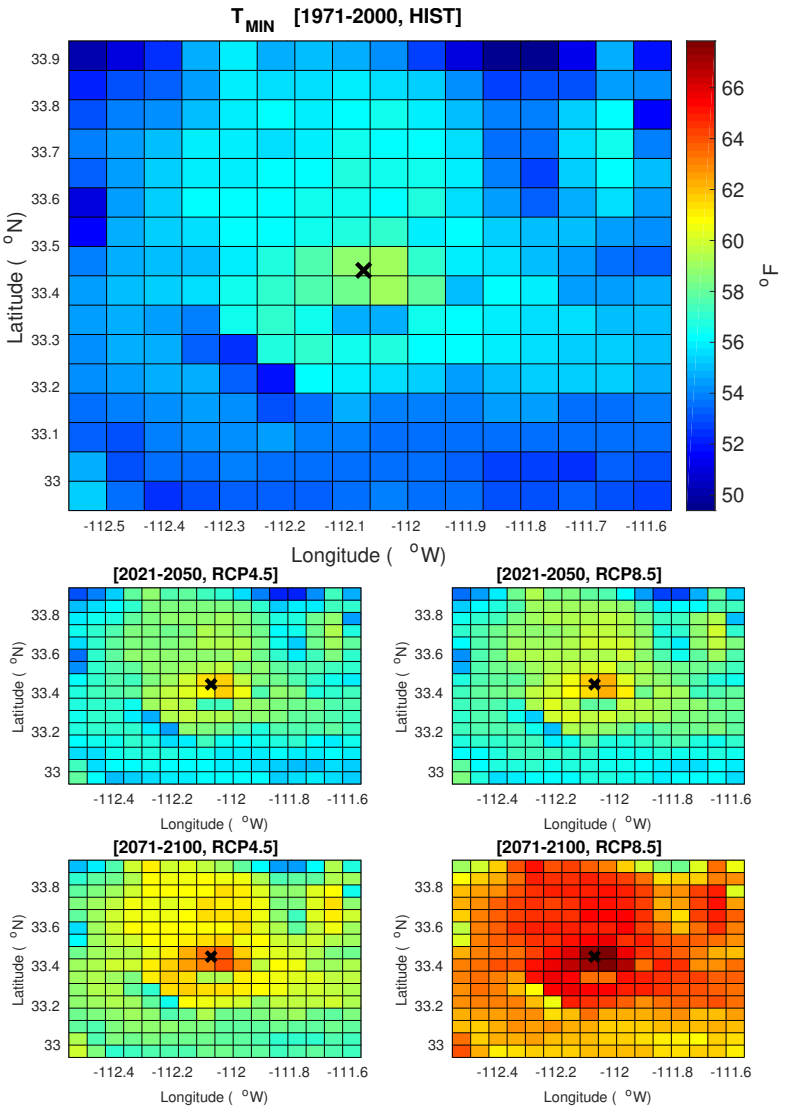


Figure 30: The multi-model ensemble-mean time-mean annual mean value of daily minimum temperature, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

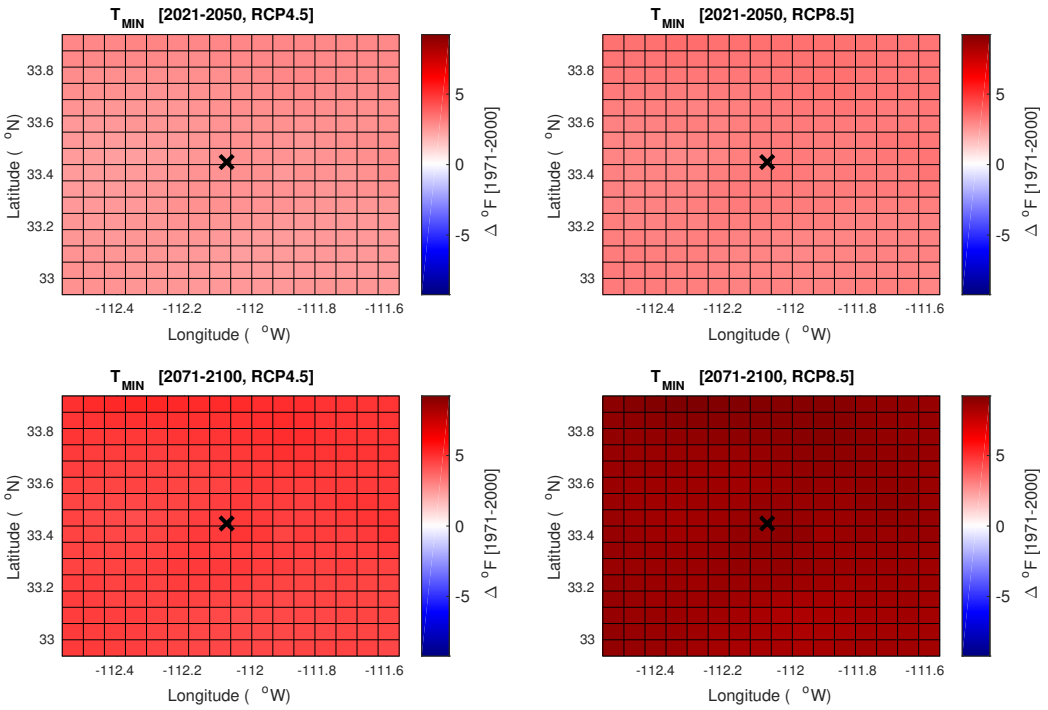


Figure 31: The difference in the multi-model ensemble-mean time-mean annual mean value of daily minimum temperature projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

## 4.3 Maximum value of daily maximum temperature

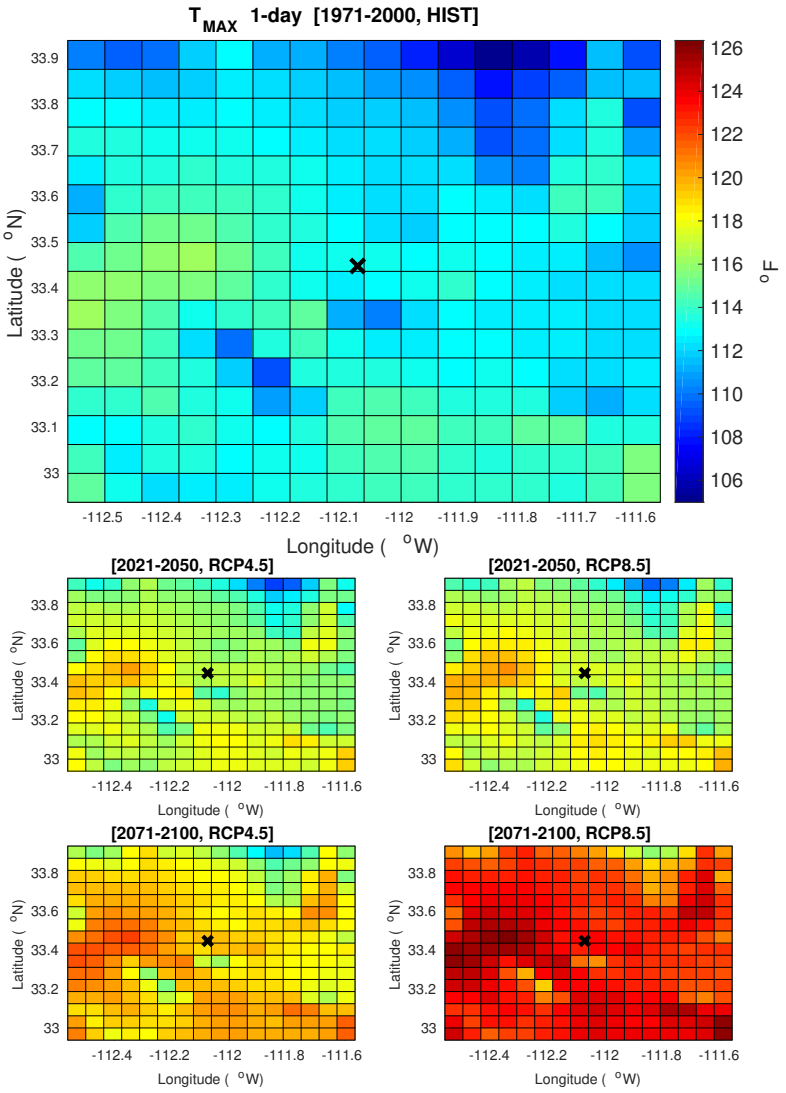


Figure 32: The multi-model ensemble-mean time-mean annual maximum value of daily maximum temperature, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

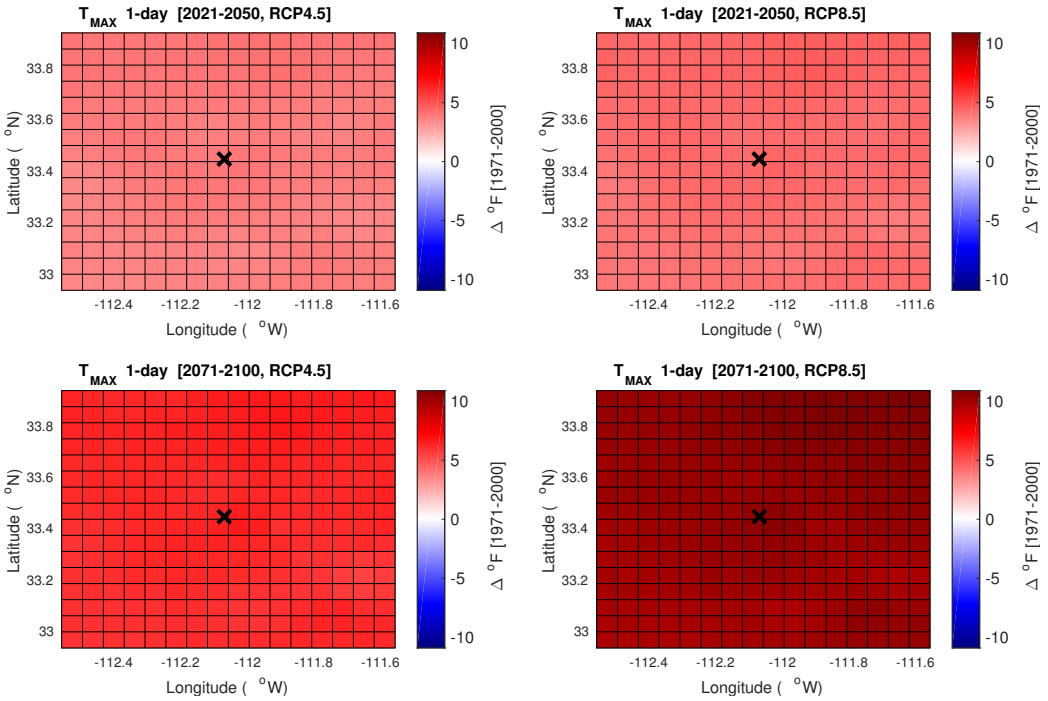


Figure 33: The difference in the multi-model ensemble-mean time-mean annual maximum value of daily maximum temperature projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

## 4.4 Minimum value of daily minimum temperature

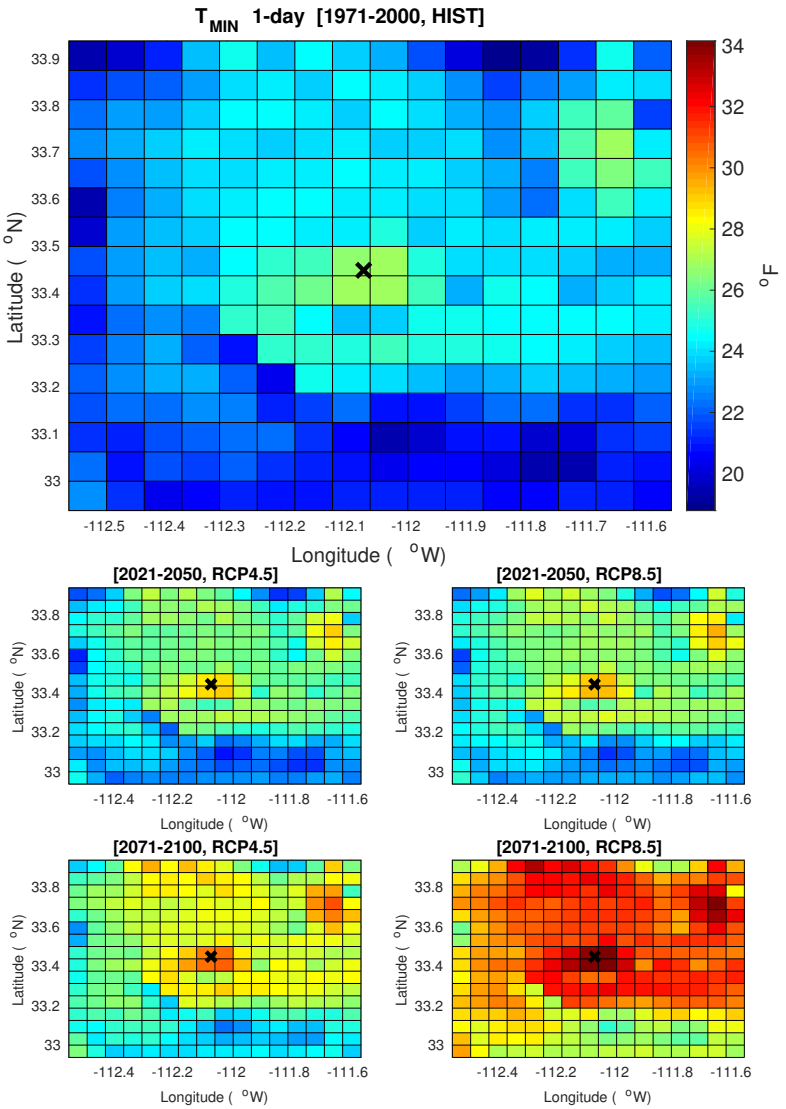


Figure 34: The multi-model ensemble-mean time-mean annual minimum value of daily minimum temperature, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

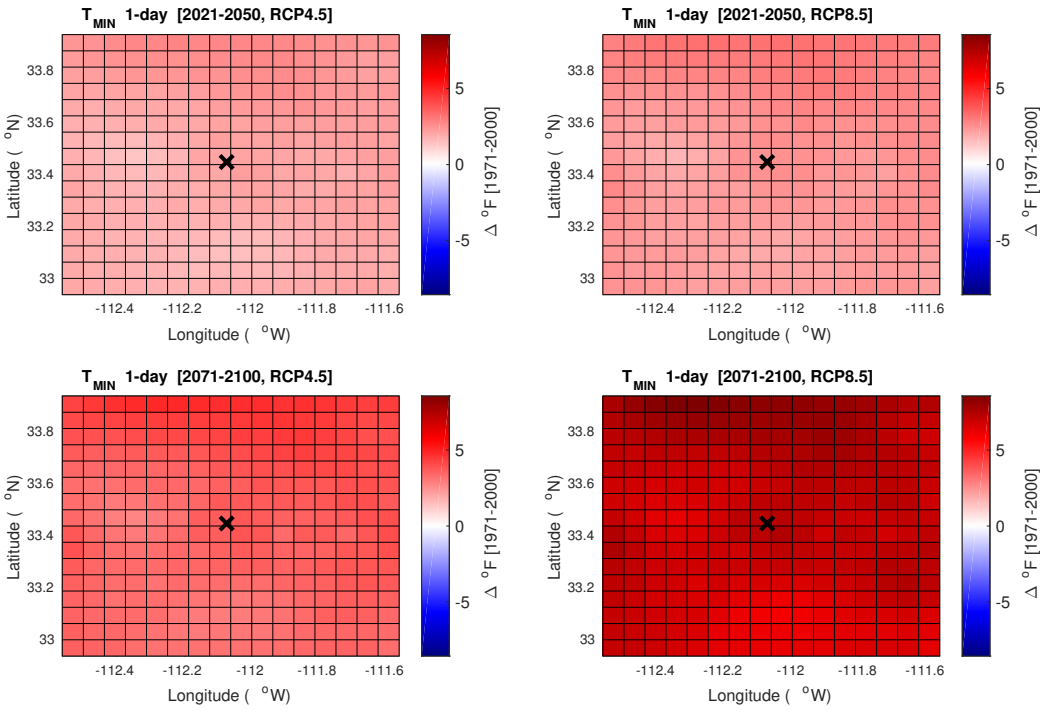


Figure 35: The difference in the multi-model ensemble-mean time-mean annual minimum value of daily minimum temperature projected in future model simulations, compared with the historic period (1971–2000). Only those grid-boxes where the difference is statistically significant are shaded.

## 4.5 Maximum value of 5-day maximum temperature

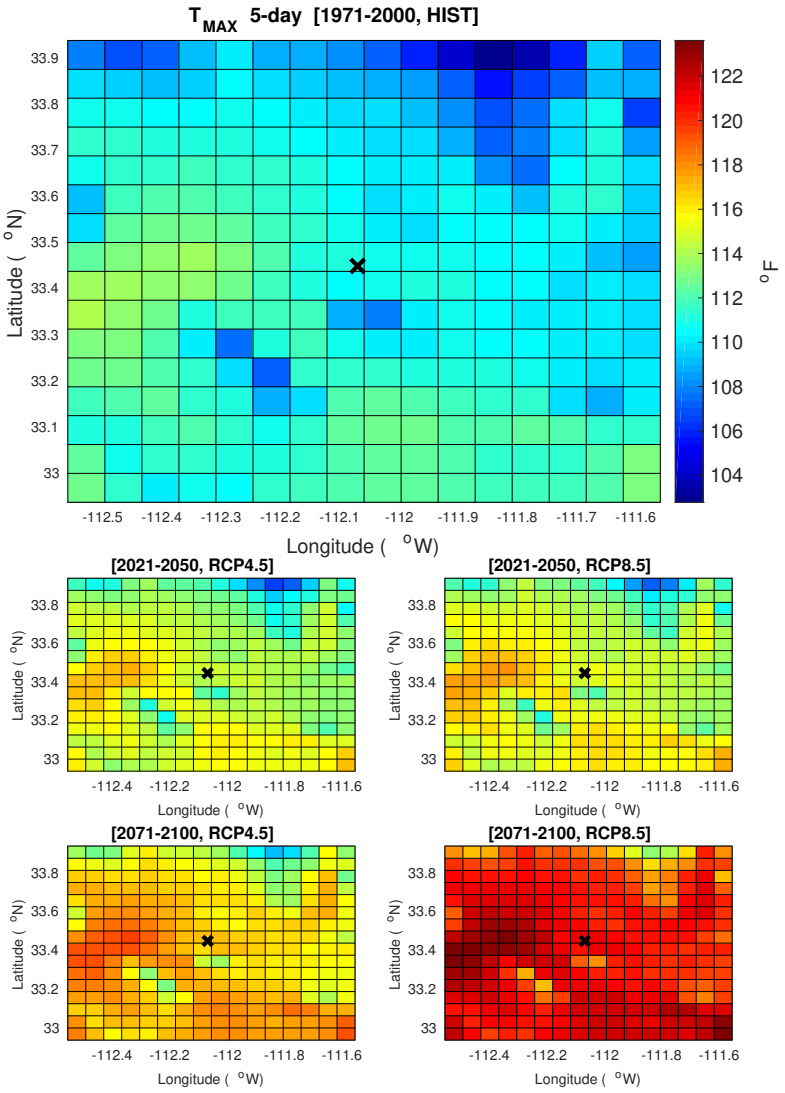


Figure 36: The multi-model ensemble-mean time-mean annual maximum value of 5-day maximum temperature, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

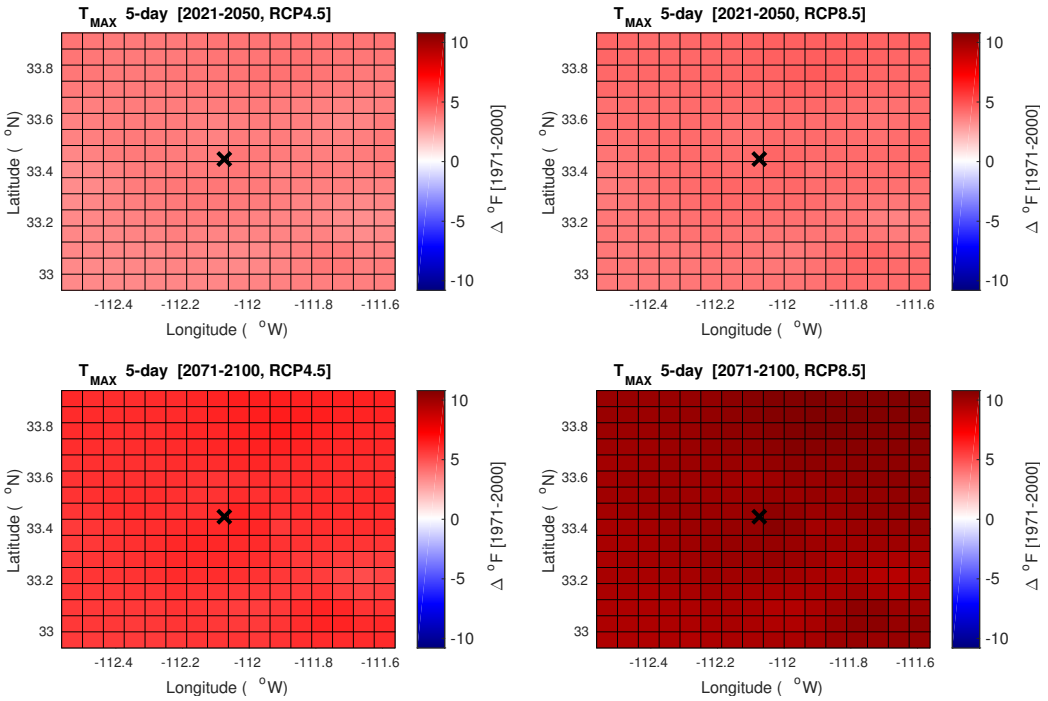


Figure 37: The difference in the multi-model ensemble-mean time-mean annual maximum value of 5-day maximum temperature projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

## 4.6 Minimum value of 5-day minimum temperature

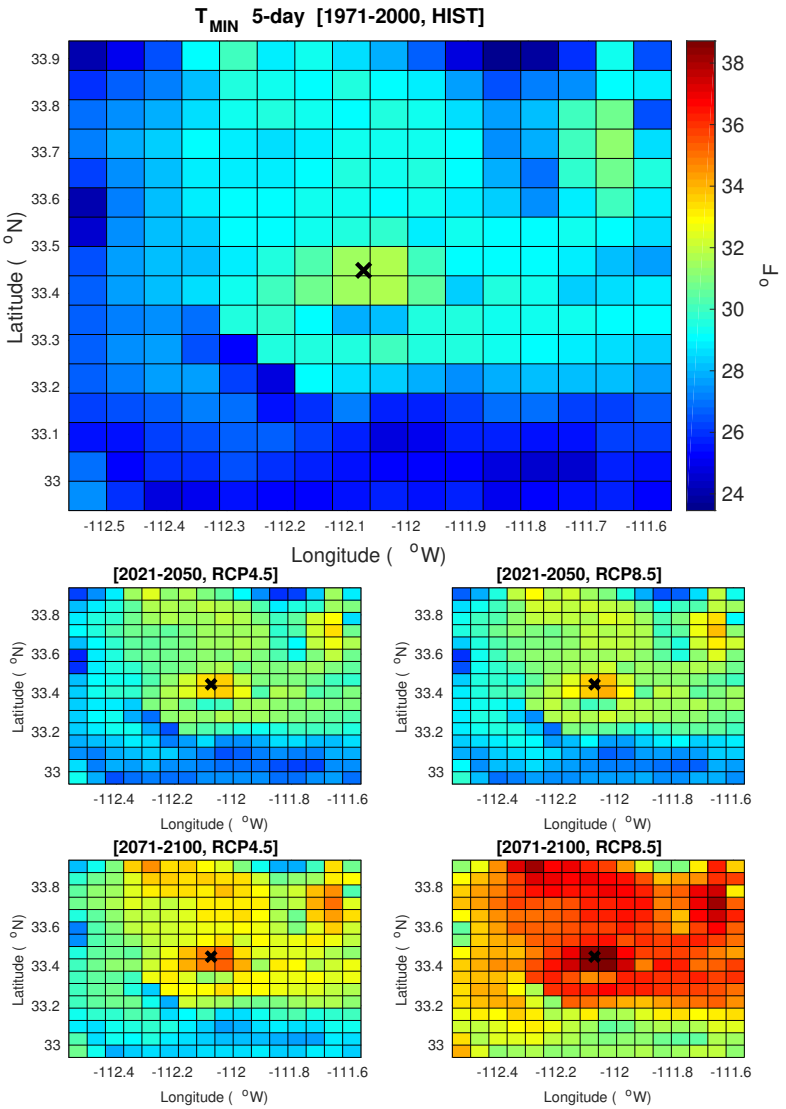


Figure 38: The multi-model ensemble-mean time-mean annual minimum value of 5-day minimum temperature, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

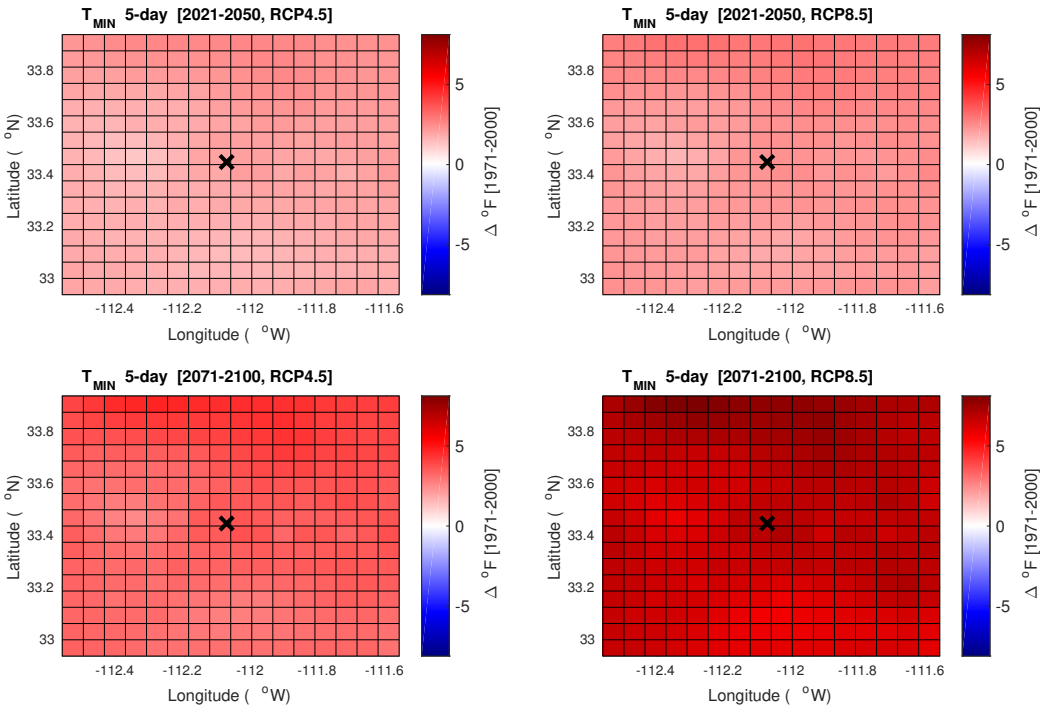


Figure 39: The difference in the multi-model ensemble-mean time-mean annual minimum value of 5-day minimum temperature projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

## 4.7 Number of days with temperature $> 90°$F

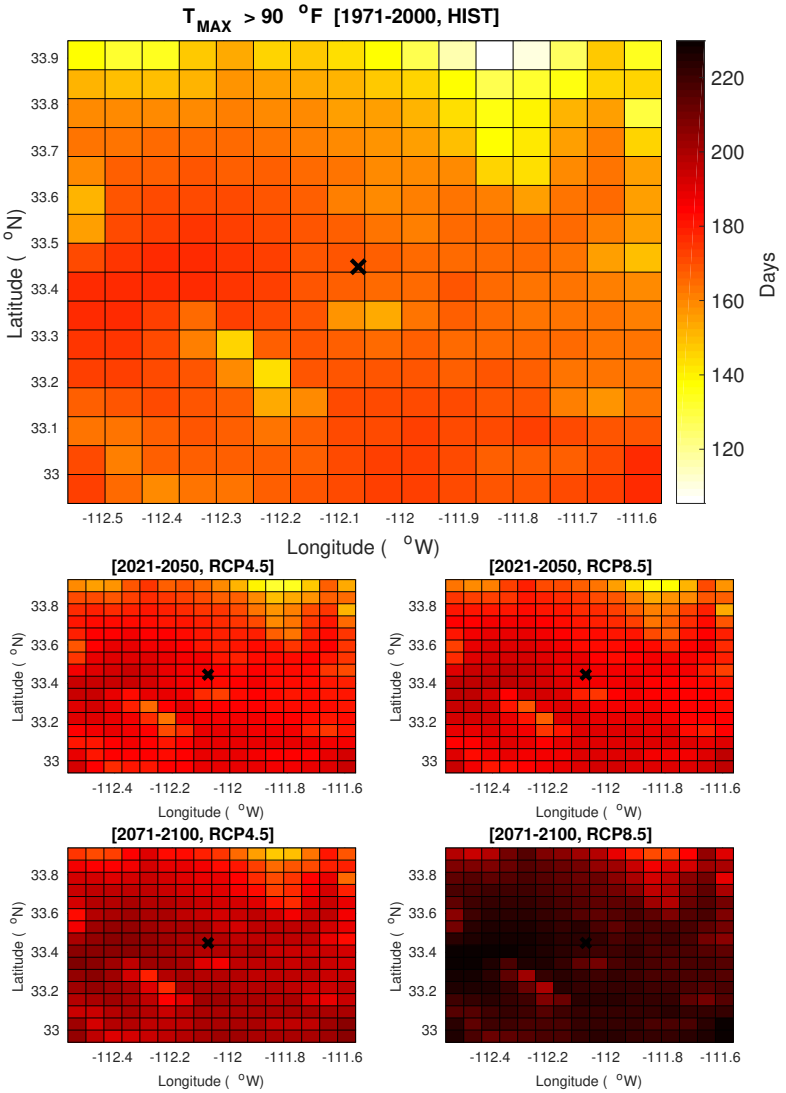


Figure 40: The multi-model ensemble-mean time-mean annual number of days with a maximum temperature greater than 90°F, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

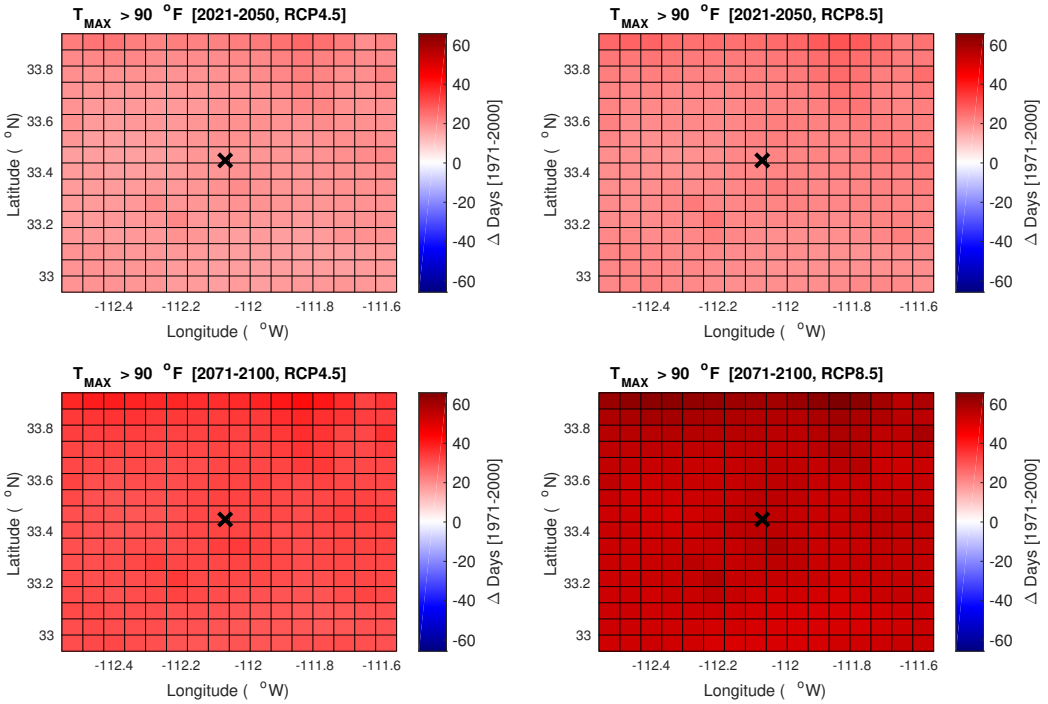


Figure 41: The difference in the multi-model ensemble-mean time-mean annual number of days with a maximum temperature greater than 90°F projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

## 4.8 Number of days with temperature $> 95°$F

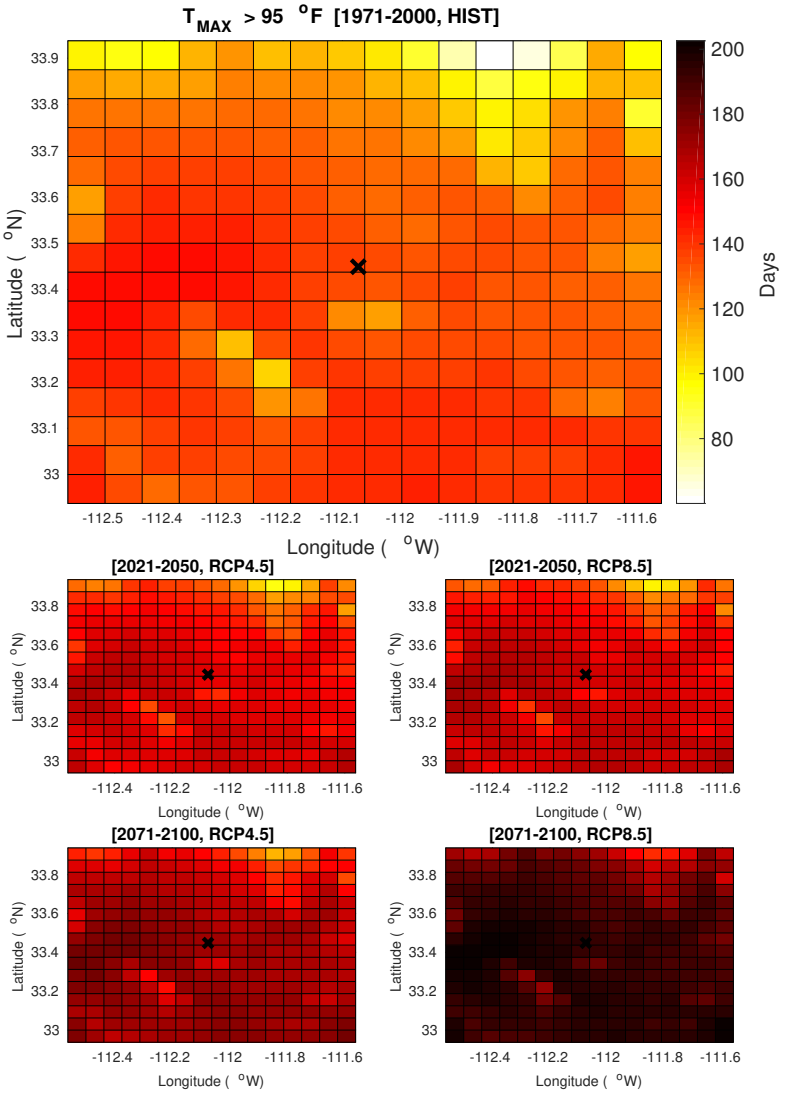


Figure 42: The multi-model ensemble-mean time-mean annual number of days with a maximum temperature greater than 95°F, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

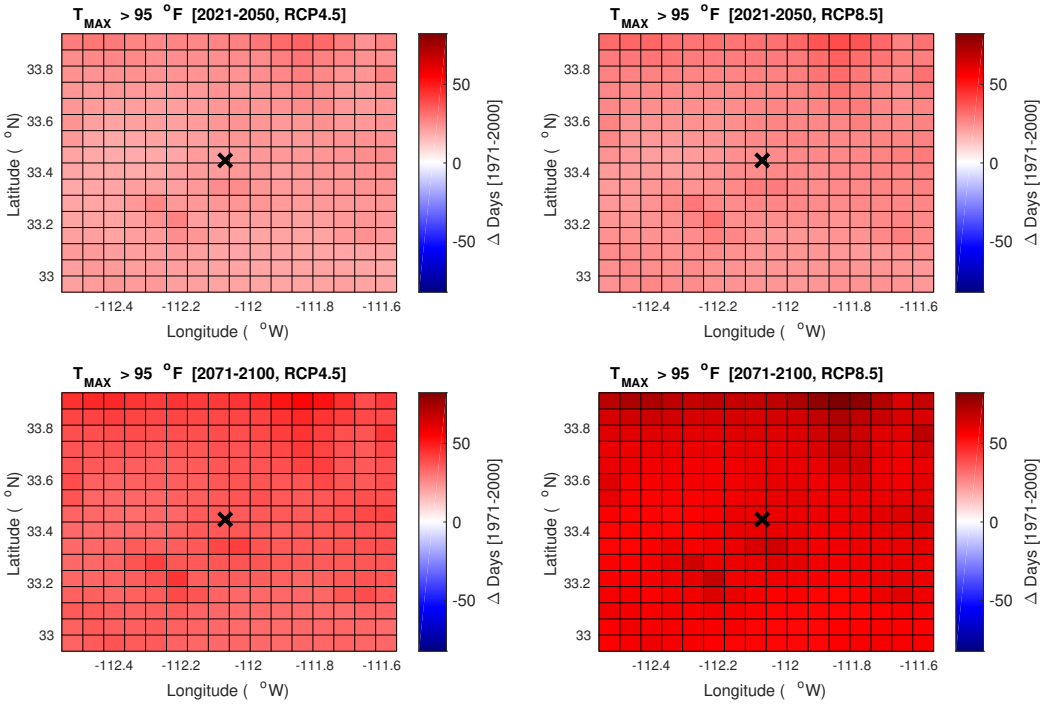


Figure 43: The difference in the multi-model ensemble-mean time-mean annual number of days with a maximum temperature greater than 95°F projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

## 4.9 Number of days with temperature $> 100°$F

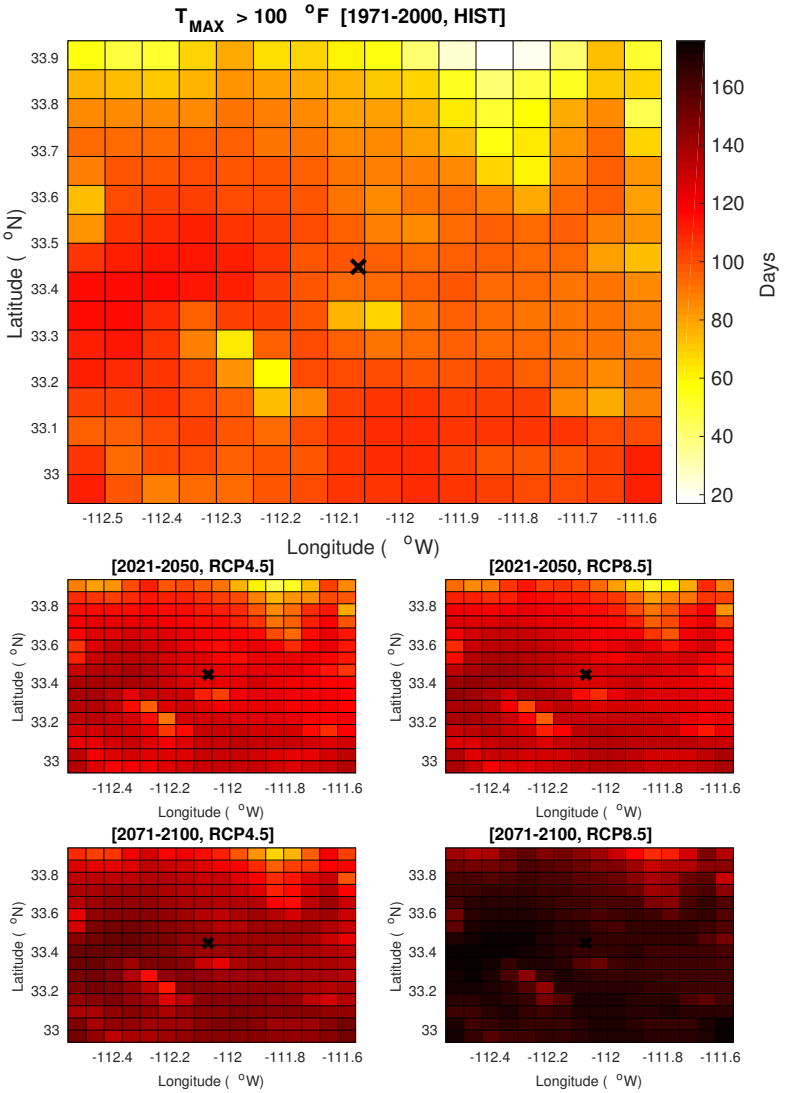


Figure 44: The multi-model ensemble-mean time-mean annual number of days with a maximum temperature greater than 100°F, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

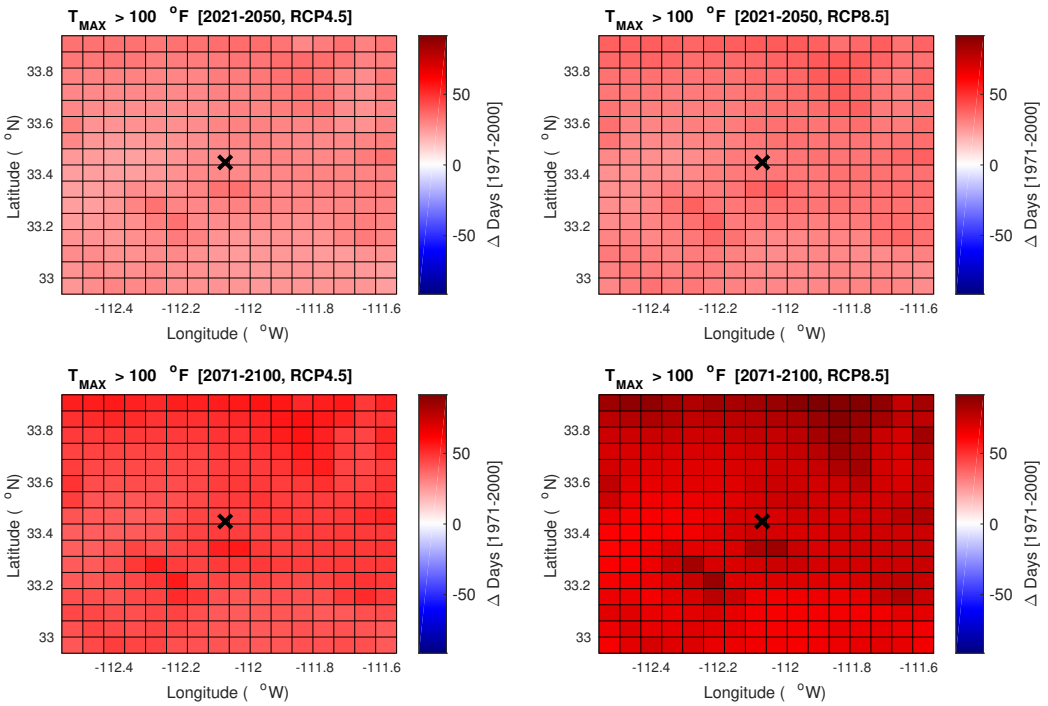


Figure 45: The difference in the multi-model ensemble-mean time-mean annual number of days with a maximum temperature greater than 100°F projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

## 4.10 Number of days with max temperature $< 32°$F

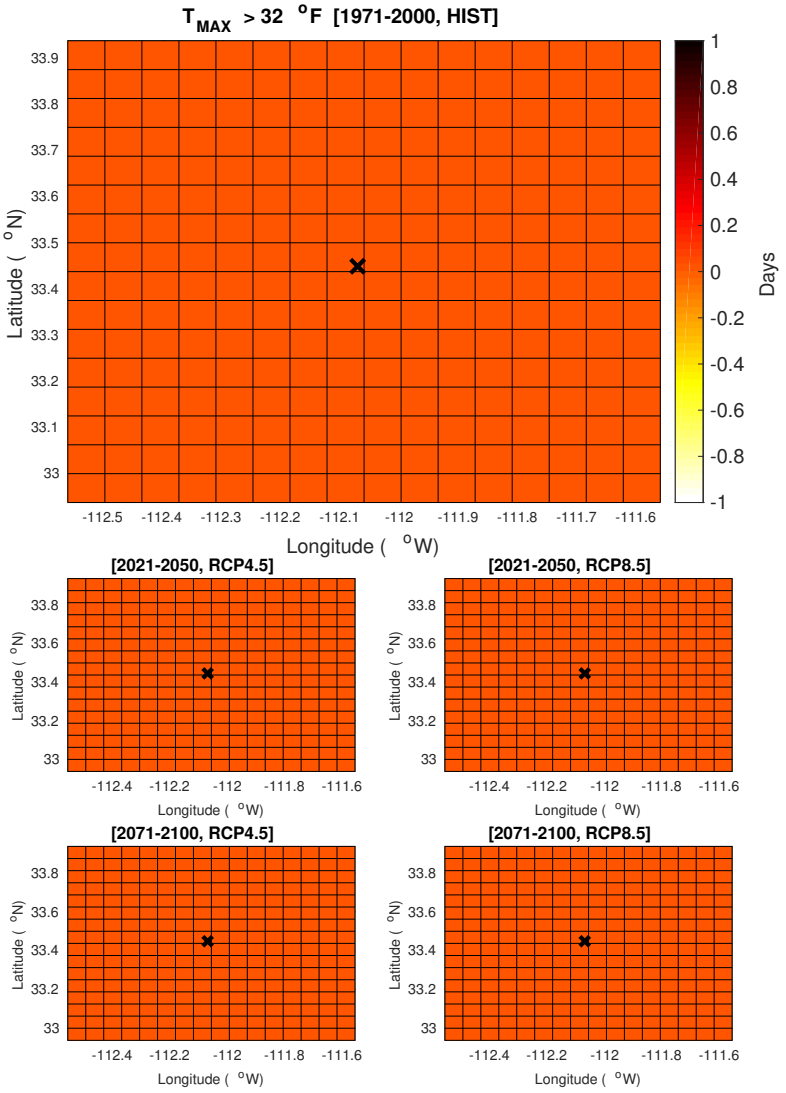


Figure 46: The multi-model ensemble-mean time-mean annual number of days with a maximum temperature less than 32°F, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

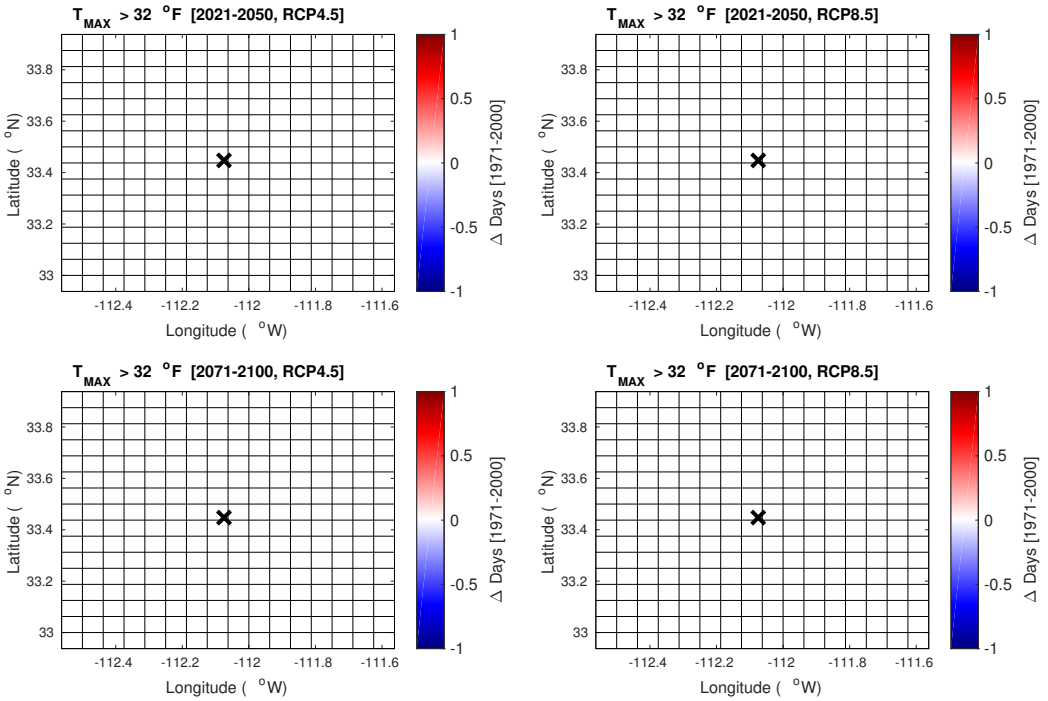


Figure 47: The difference in the multi-model ensemble-mean time-mean annual number of days with a maximum temperature less than 32°F projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

## 4.11 Number of days with min temperature $< 32°$F

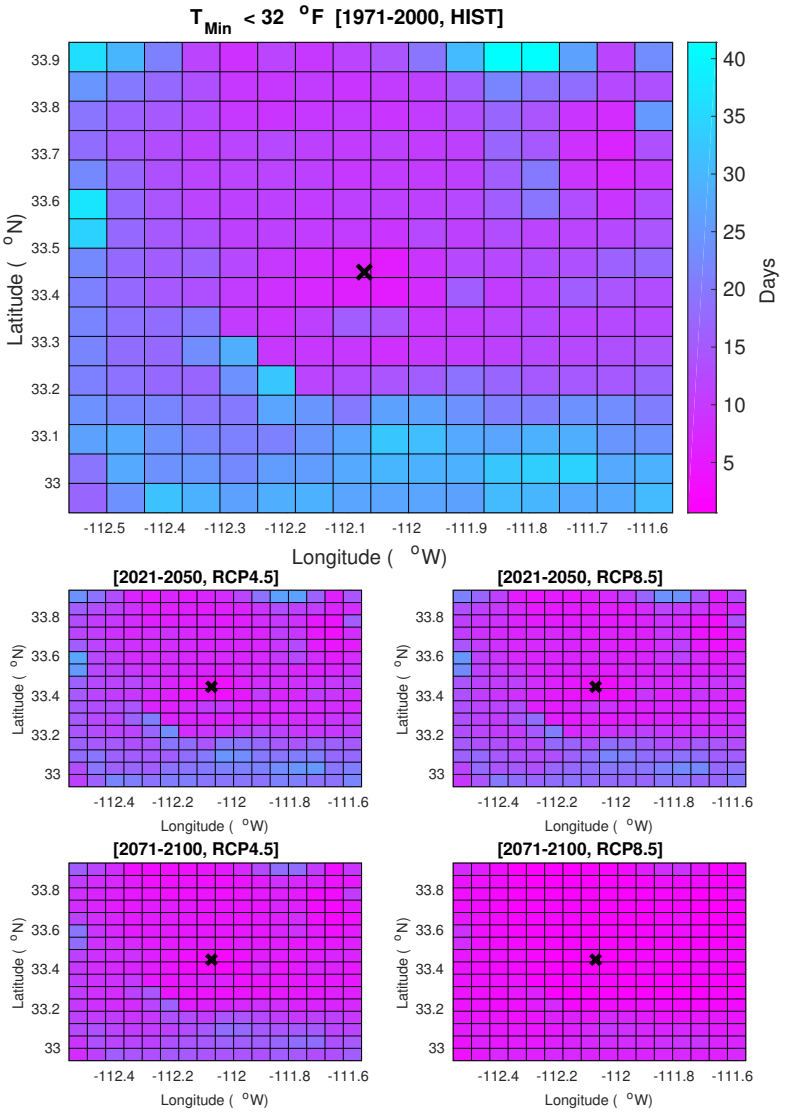


Figure 48: The multi-model ensemble-mean time-mean annual number of days with a minimum temperature less than 32°F, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

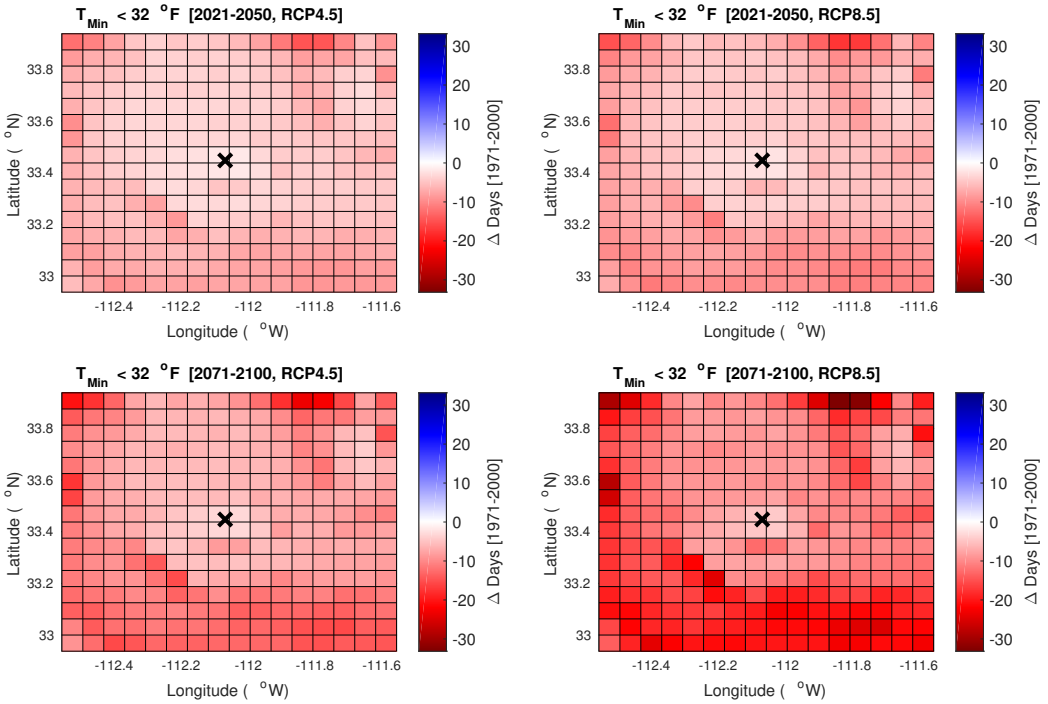


Figure 49: The difference in the multi-model ensemble-mean time-mean annual number of days with a minimum temperature less than 32°F projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

## 4.12 Heating Degree Days (HDD)

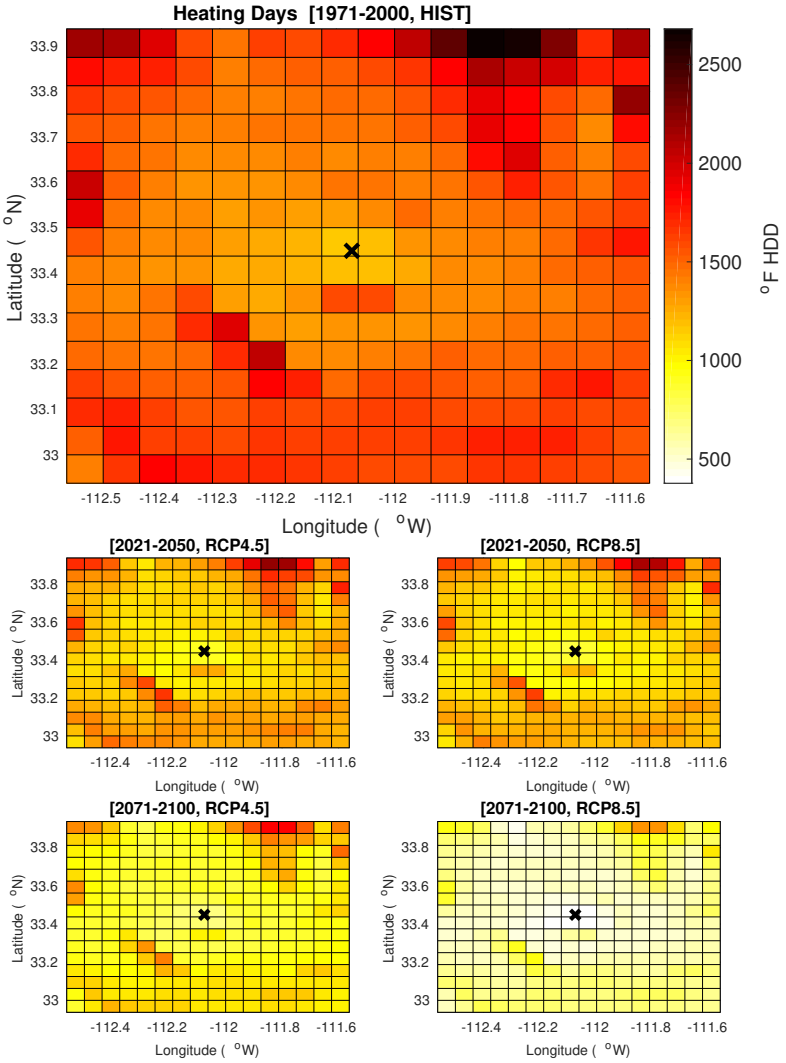


Figure 50: The multi-model ensemble-mean time-mean measure of Heating Degree Days (HDD*), analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

*$HDD = \sum_{i=1}^{365} \left[\frac{1}{2}\left(T_{Xi} i + T_{Ni}\right) - 65°\mathrm{F}\right]$, for $i : \left\{\frac{1}{2}\left(T_{Xi} + T_{Ni}\right) > 65°\mathrm{F}\right\}$.

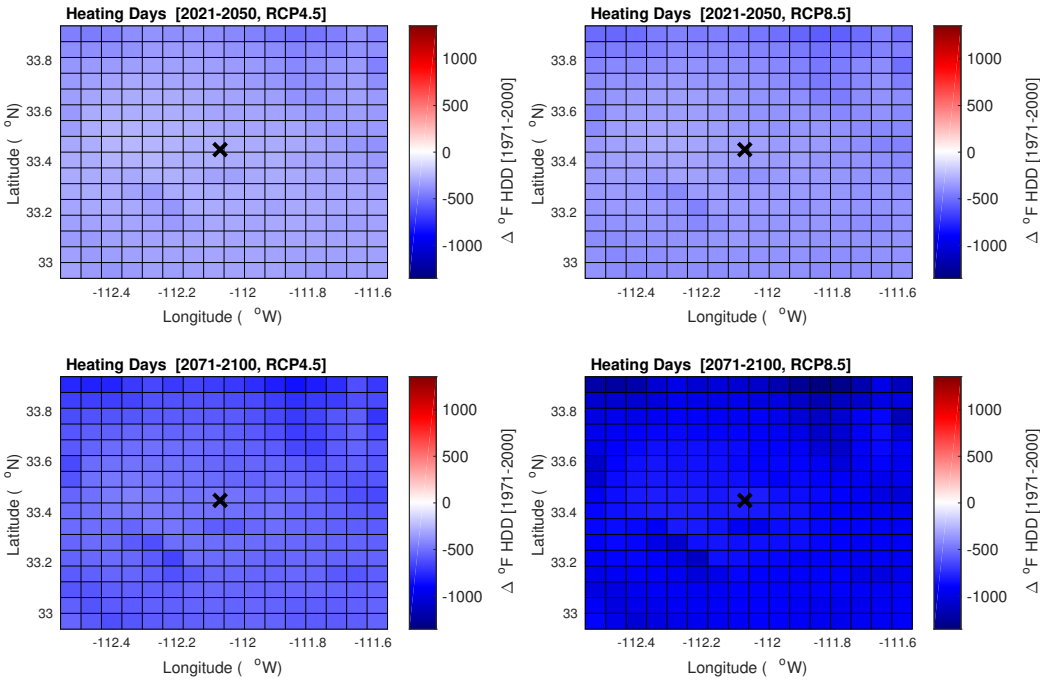


Figure 51: The difference in the multi-model ensemble-mean time-mean annual measure of Heating Degree Days (HDD*) projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

*$HDD = \sum_{i=1}^{365} \left[\frac{1}{2}\left(T_{Xi}i + T_{Ni}\right) - 65°\mathrm{F}\right]$, for $i : \left\{\frac{1}{2}\left(T_{Xi} + T_{Ni}\right) > 65°\mathrm{F}\right\}$.

## 4.13 Cooling Degree Days (CDD)

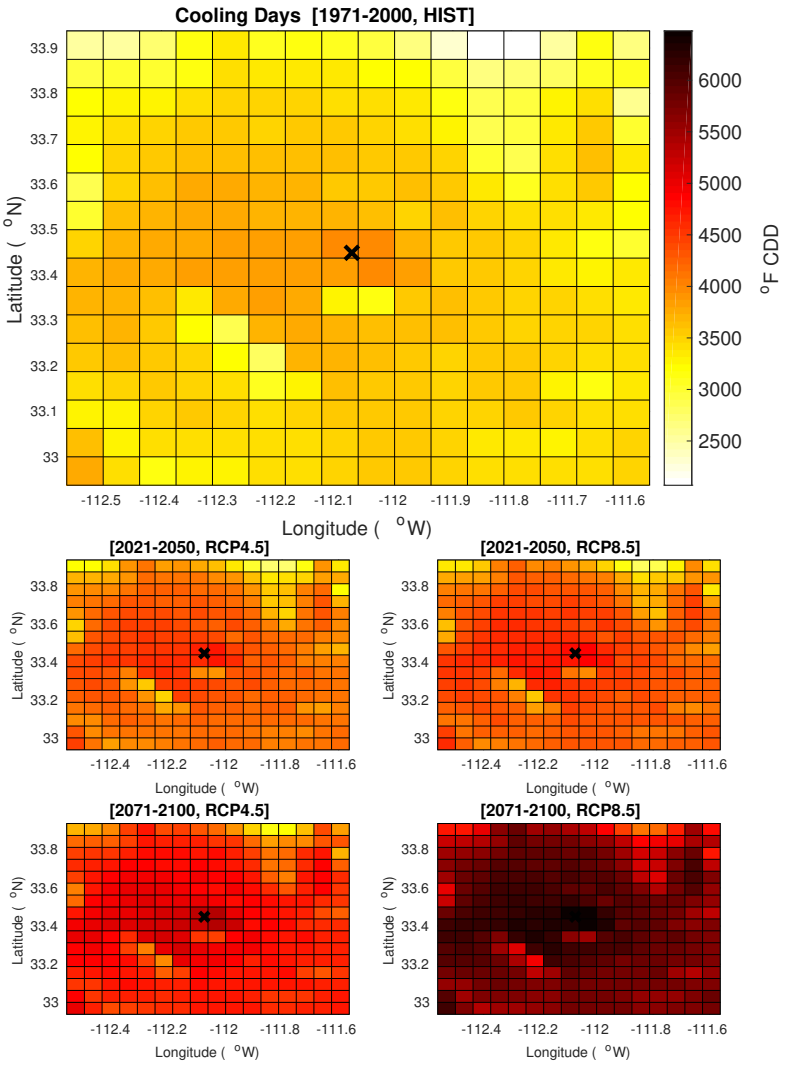


Figure 52: The multi-model ensemble-mean time-mean measure of Cooling Degree Days (CDD*), analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

*$CDD = \sum_{i=1}^{365} \left[65°\text{F} - \frac{1}{2}\left(T_{Xi} + T_{Ni}\right)\right]$, for $i : \left\{\frac{1}{2}\left(T_{Xi} + T_{Ni}\right) < 65°\text{F}\right\}$.

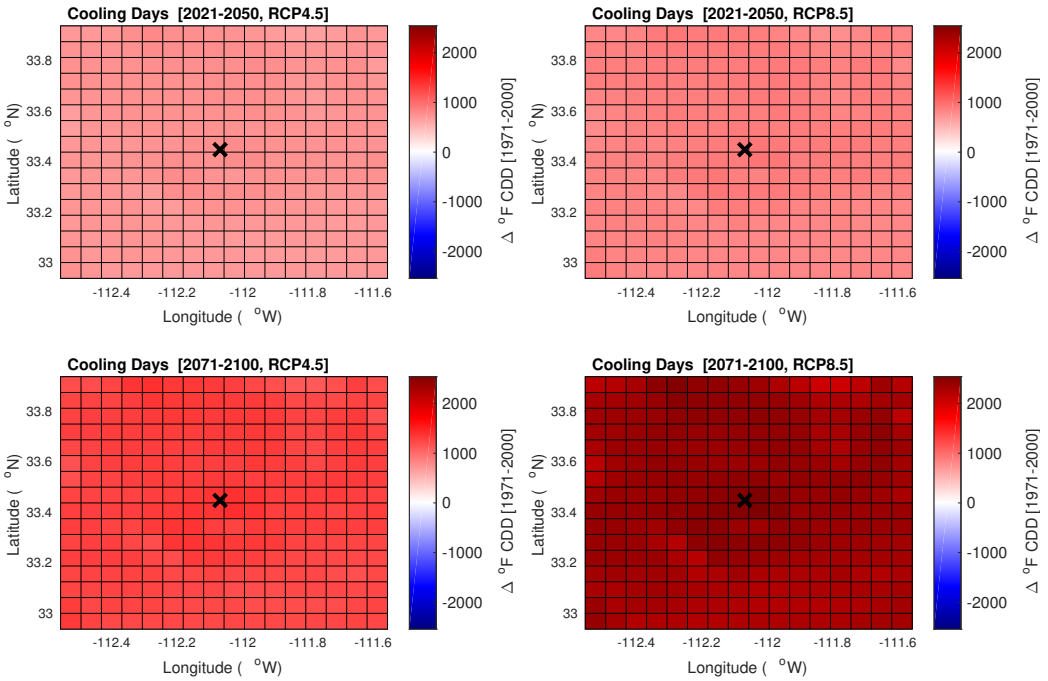


Figure 53: The difference in the multi-model ensemble-mean time-mean annual measure of Cooling Degree Days (CDD*) projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

*$CDD = \sum_{i=1}^{365} \left[65°\mathrm{F} - \frac{1}{2}\left(T_{Xi} + T_{Ni}\right)\right]$, for $i : \left\{\frac{1}{2}\left(T_{Xi} + T_{Ni}\right) < 65°\mathrm{F}\right\}$.

## 4.14 Maximum value of daily precipitation

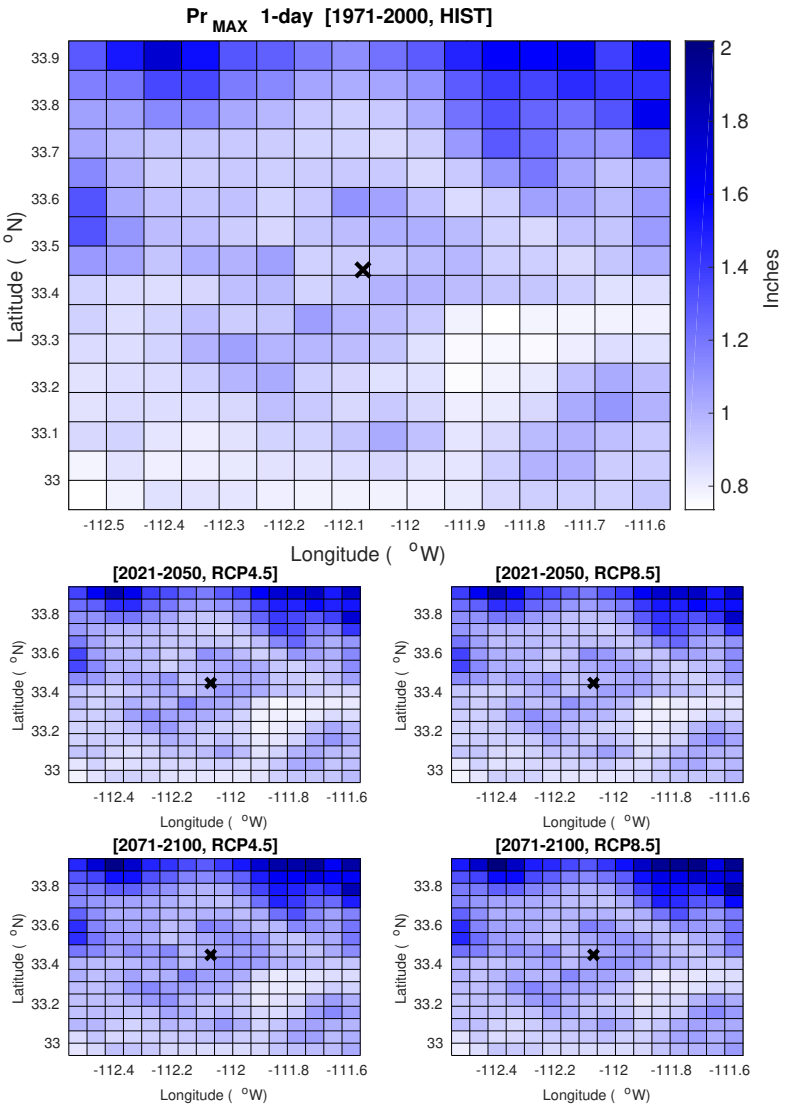


Figure 54: The multi-model ensemble-mean time-mean annual maximum value of daily precipitation, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

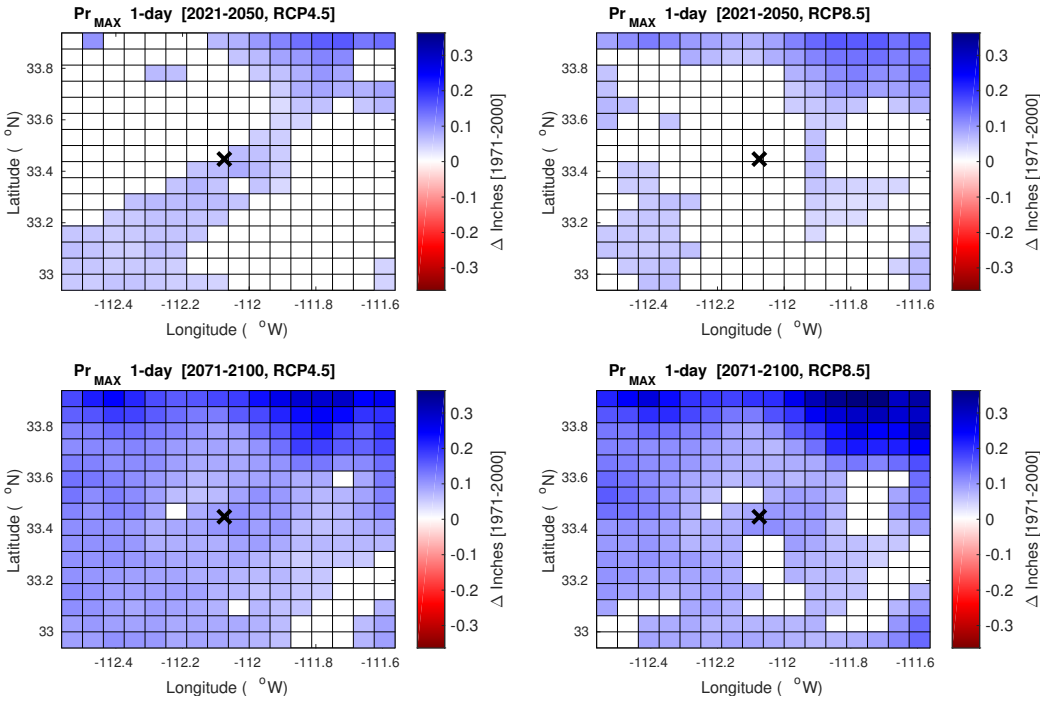


Figure 55: The difference in the multi-model ensemble-mean time-mean annual maximum value of daily precipitation projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

## 4.15 Maximum value of total 5-day precipitation

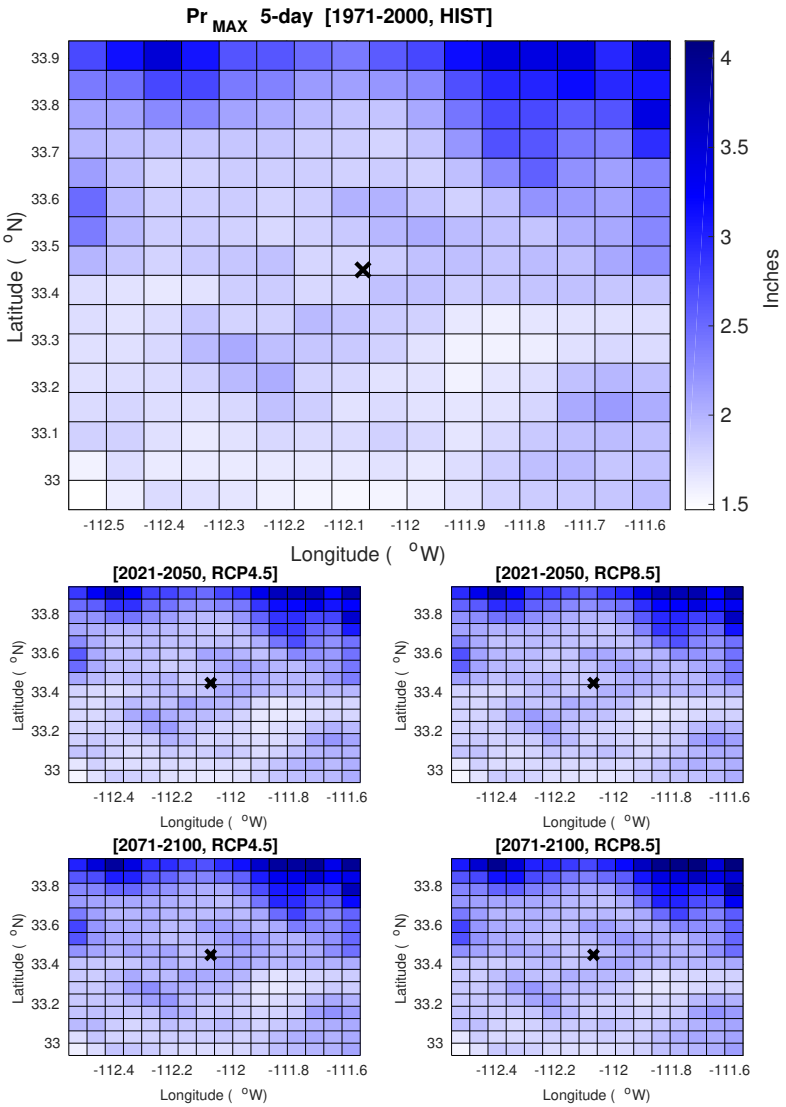


Figure 56: The multi-model ensemble-mean time-mean annual maximum value of 5-day total precipitation, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

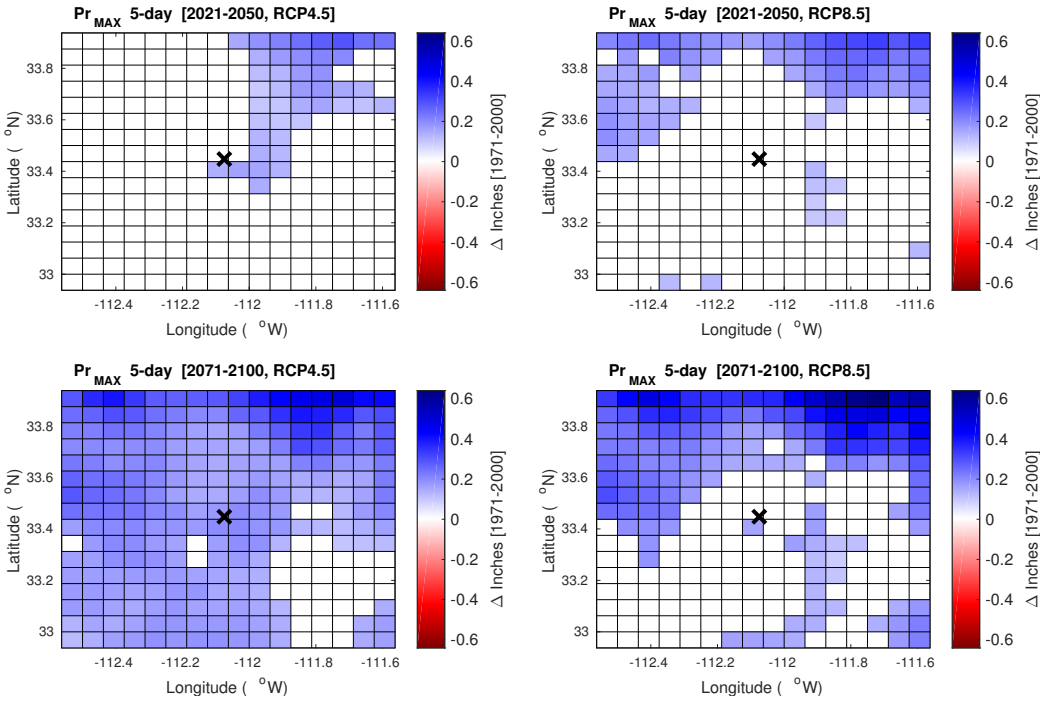


Figure 57: The difference in the multi-model ensemble-mean time-mean annual maximum value of 5-day total precipitation projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

## 4.16 Number of days with precipitation > 2 inches

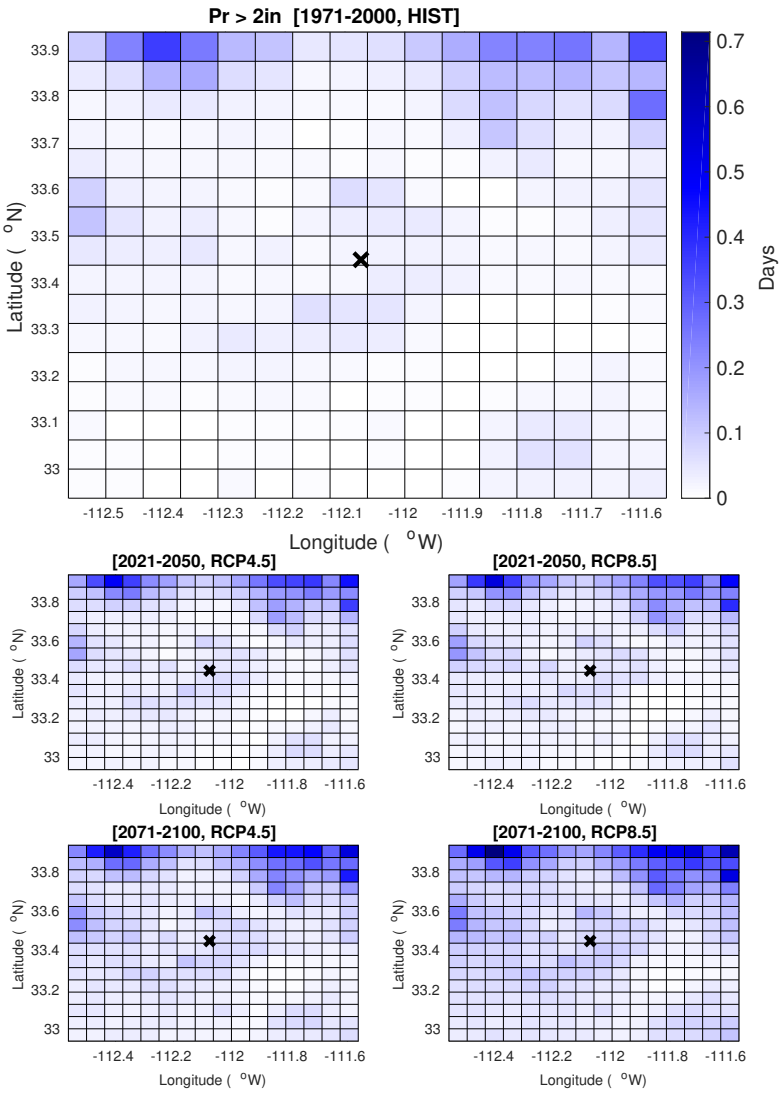


Figure 58: The multi-model ensemble-mean time-mean annual number of days with greater than 2 inches precipitation, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

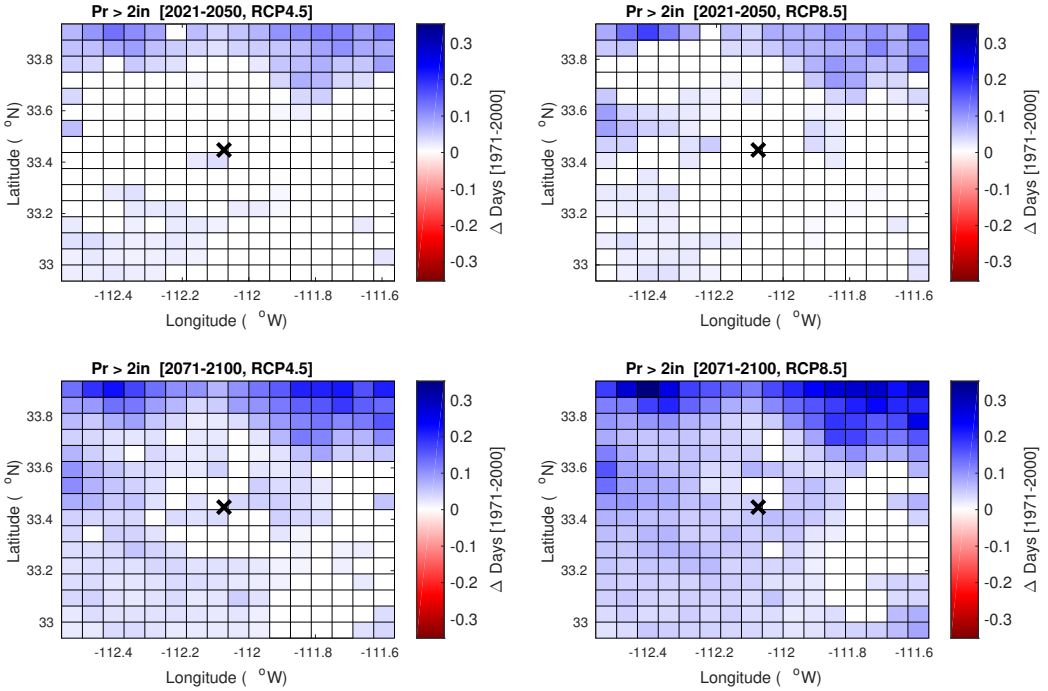


Figure 59: The difference in the multi-model ensemble-mean time-mean annual number of days with greater than 2 inches precipitation projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

## 4.17 Number of days with precipitation > 3 inches

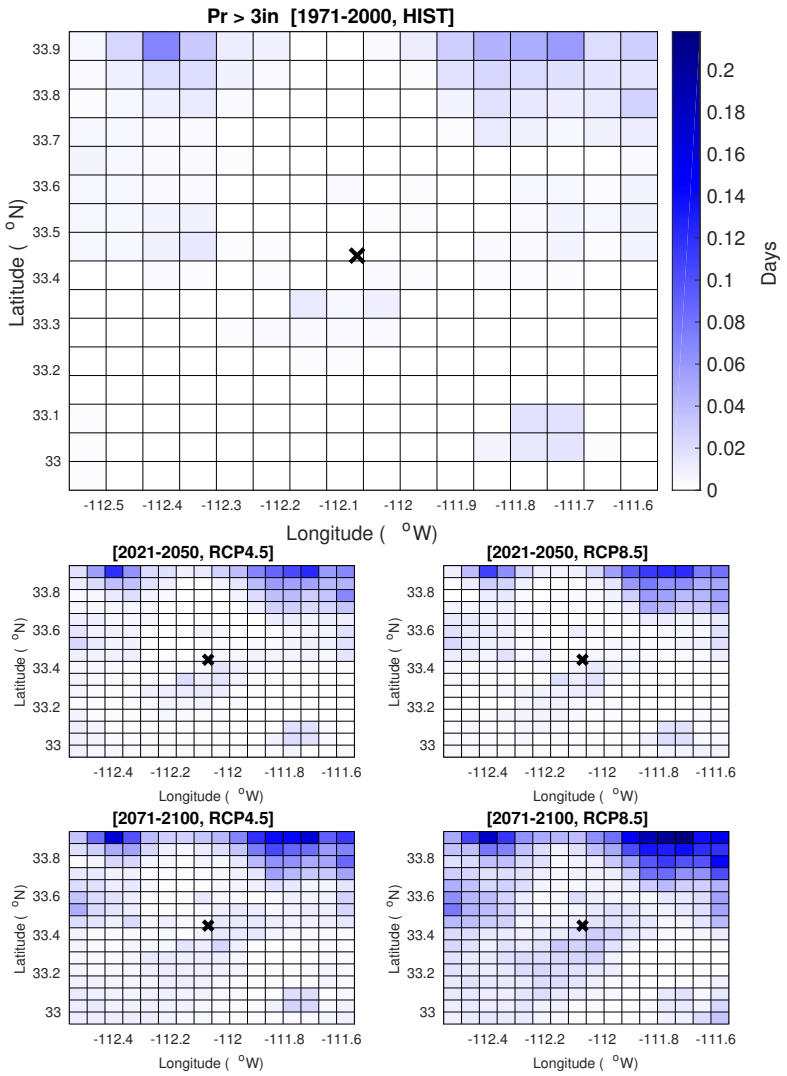


Figure 60: The multi-model ensemble-mean time-mean annual number of days with greater than 3 inches precipitation, analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

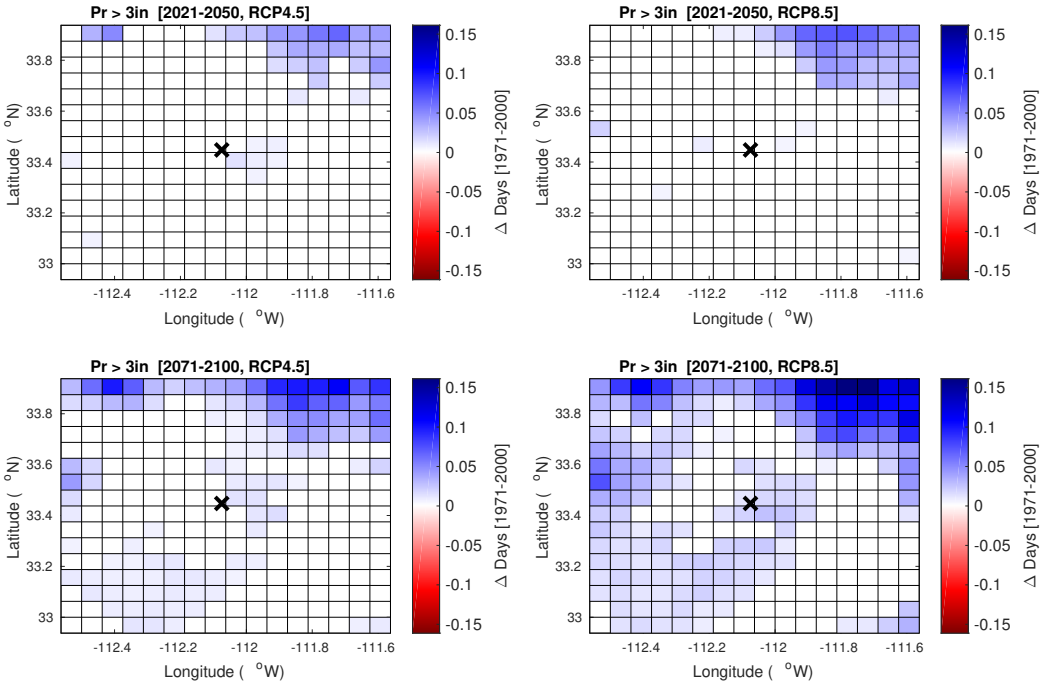


Figure 61: The difference in the multi-model ensemble-mean time-mean annual number of days with greater than 3 inches precipitation projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

## 4.18 Maximum number of consecutive wet days

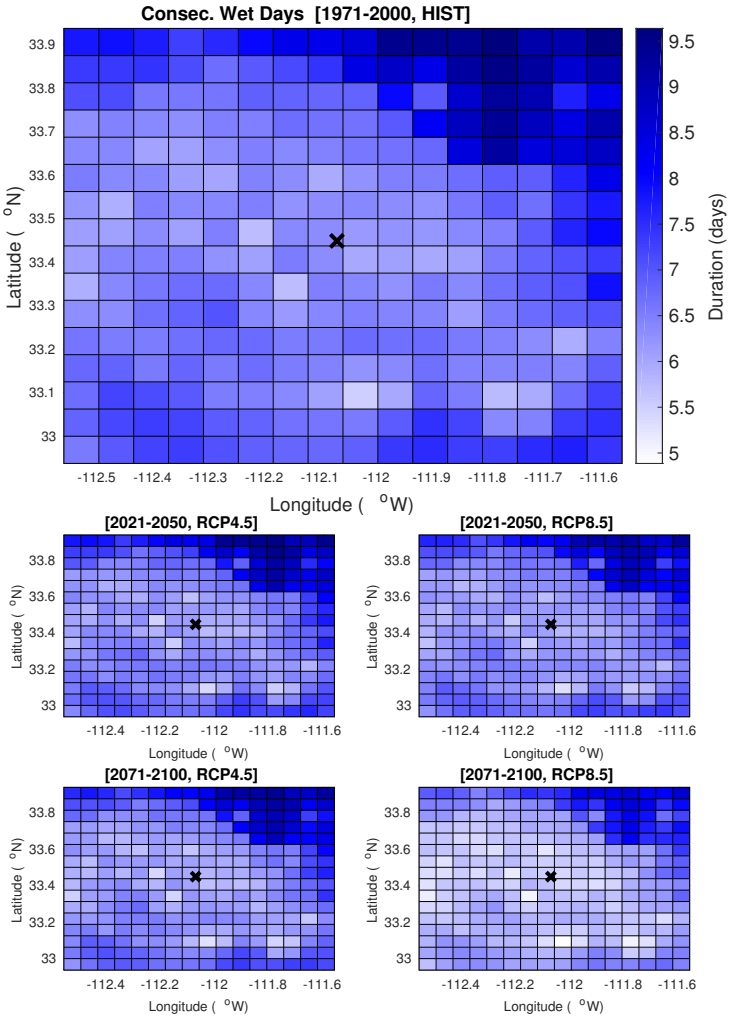


Figure 62: The multi-model ensemble-mean time-mean annual maximum duration of consecutive wet days* analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

*Daily precipitation $> 0.01$ inches.

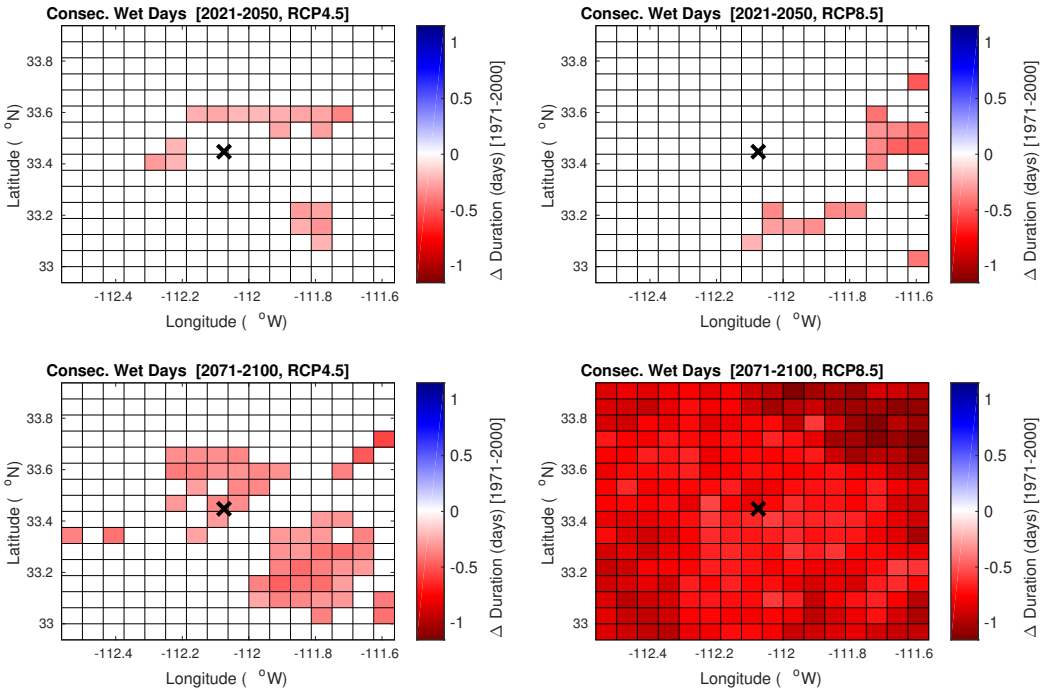


Figure 63: The difference in the multi-model ensemble-mean time-mean annual maximum duration of consecutive wet days* projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.

*Daily precipitation $> 0.01$ inches.

## 4.19 Maximum number of consecutive dry days

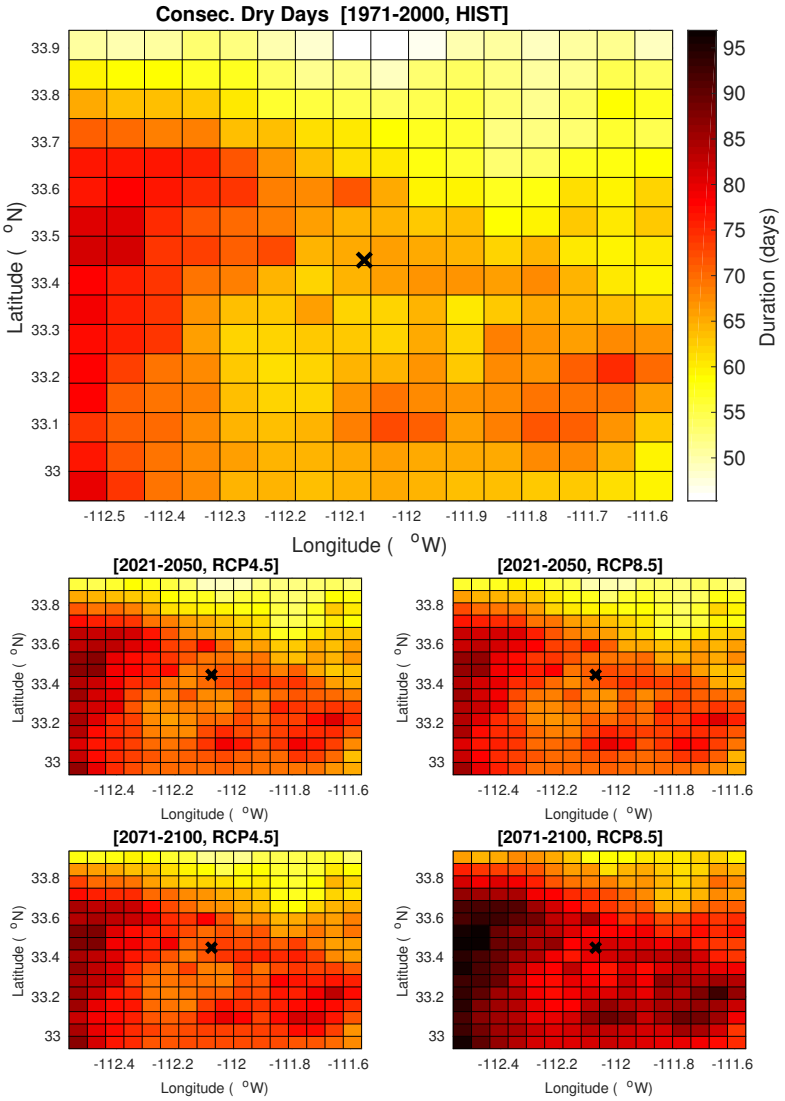


Figure 64: The multi-model ensemble-mean time-mean annual maximum duration of consecutive dry days analyzed over the historic period [1971–2000 (main panel)] and over two future time periods [2021–2050 (middle panels); 2071–2100 (lower panels)], following two different future emission pathways [RCP4.5 (left panels); RCP8.5 (right panels)].

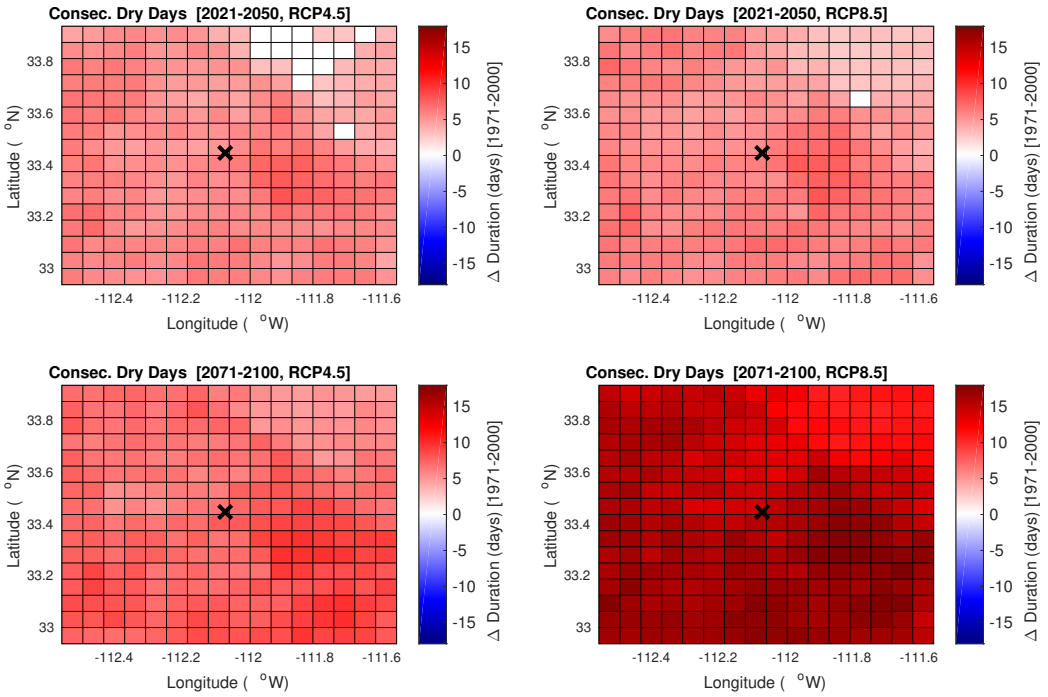


Figure 65: The difference in the multi-model ensemble-mean time-mean annual maximum duration of consecutive dry days projected in future model simulations, compared with the historic period (1971–2000). Only those gridboxes where the difference is statistically significant are shaded.