

Anthropogenic Climate Change at Springfield Armory National Historic Site, Massachusetts

Patrick Gonzalez

Natural Resource Stewardship and Science, U.S. National Park Service, Berkeley, California

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Historical Climate Change Trends

- **Historical temperature** Greenhouse gas emissions from human activities have caused increases in temperatures and altered precipitation patterns globally (IPCC 2013), across the United States (USGCRP 2017), and in United States (US) national parks (Gonzalez et al. 2018). In the area within the boundaries of Springfield Armory National Historic Site (NHS), temperature increased at the statistically significant rate of $0.5 \pm 0.2^{\circ}\text{C}$ ($0.9 \pm 0.4^{\circ}\text{F.}$) per century from 1895 to 2016 (Figure 1) (Gonzalez et al. 2018). Since 1895, the greatest warming occurred in February, with a rate of increase of $1.8 \pm 0.8^{\circ}\text{C}$ ($3.2 \pm 1.4^{\circ}\text{F.}$) per century (Table 1). The rate of temperature increase becomes greater northeast and south of the park (Figure 2).

For the historical time periods in the tables and figures, the analyses of monthly, seasonal, and annual climate were originally run for the periods 1895-2010 and 1950-2010 (Table 1), the data available at the time of the original research (Gonzalez et al. 2018). Analyses of annual trends were later run for the period 1895-2016 when that data became available. In addition, climatologists use 1971-2000 (Table 1) as the standard baseline for comparing future projections with historical observations.

- **Historical precipitation** For the area within park boundaries, total annual precipitation increased slightly from 1895 to 2016, but the change was not statistically significant (Figure 3) (Gonzalez et al. 2018). October precipitation increased at a statistically significant rate of $35 \pm 16\%$ per century from 1895 to 2010 and $86 \pm 43\%$ per century from 1950 to 2010 (Table 2) (Gonzalez et al. 2018). Precipitation increases were greater east, west, and south of the park (Figure 4).
- **Extreme precipitation** For the northeastern US as a whole, the amount of precipitation in 20-year storms (a day with more precipitation than any other day in 20 years) increased in all four seasons from 1948 to 2015 (Easterling et al. 2017). In addition, the number of five-year storms (a two-day period with more precipitation than any other two-day period in five years) increased 74% from 1901 to 2016. Analyses have found that these trends are attributable in part to anthropogenic climate change (Easterling et al. 2017).
- **Tornadoes** The area around Springfield, Massachusetts, recorded a tornado on average once a year in the period 1950-1986 (Leathers 1993), although tornadoes are much more common in

the midwestern US than the northeastern US (Agee et al. 2016). Analyses of historical records of US tornadoes from 1954 to 2013 indicate that the total number of tornadoes in the country has shown no statistically significant trend (Brooks et al. 2014). For the US as a whole, the number of days with over 30 tornadoes, however, has increased (Brooks et al. 2014, Elsner et al. 2015) and the number of tornadoes per tornado outbreak has increased (Moore 2017, Tippet and Cohen 2016). Moreover, tornado power, a function of wind speed, tornado path area, and air density, has increased $5\% \pm 1\%$ per year from 1994 to 2016 (Elsner et al. 2019).

- **Connecticut River flow** River flow at the US Geological Survey gauge station at Thompsonville, Connecticut, south of the park, increased in spring and autumn from 1950 to 2011, but the changes were not statistically significant (Parr and Wang 2014). Modeling of runoff indicated that an increase in precipitation has caused an increase in runoff for the Connecticut River basin as a whole (Parr and Wang 2014).

Projected Climate Change Trends

- **Projected temperature** Without reductions of greenhouse gas emissions from power plants, cars, and other human sources, the set of general circulation models (GCMs) of global climate in IPCC (2013) (up to 33 GCMs) project additional heating of the area within park boundaries of $5.2 \pm 1^\circ\text{C}$ ($9.4 \pm 1.8^\circ\text{F}$.) by 2100 under the highest emissions scenario (representative concentration pathway [RCP] 8.5). The temperature increase could be kept to $1.8 \pm 0.8^\circ\text{C}$ ($3.2 \pm 1.4^\circ\text{F}$.) under a scenario of emissions reductions (RCP2.6) (Tables 3, 4, Figure 5) (Gonzalez et al. 2018). GCMs project the highest temperature increases in winter. With continued climate change under the highest emissions scenario, the period of the year with monthly average temperatures above freezing would increase from 10 months to the entire year (Figure 6).
- **Projected precipitation** With continued greenhouse gas emissions, the set of GCMs in IPCC (2013) (up to 33 GCMs) project future increases in total annual precipitation in the park $15 \pm 7\%$ per century by 2100 under the highest emissions scenario (RCP8.5), but $7 \pm 6\%$ under a scenario of emissions reductions (RCP2.6) (Tables 5, 6, Figure 5) (Gonzalez et al. 2018). Under continued climate change, precipitation would increase most in winter (Figure 7).
- **Projected snow** Almost all GCMs project increases in total precipitation for the park (Figure 5), but warmer temperatures would reduce the fraction of winter precipitation falling as snow and increase the fraction falling as rain. In the area of Springfield, Massachusetts, the fraction

of precipitation in January falling as snow could decrease from ~75% (1981-2000) to ~60% under the low emissions scenario (RCP4.5) and to ~50% (2081-2100) under the highest emissions scenario (RCP8.5) (Ning and Bradley 2015). The number of days in the area with measurable snowfall (greater than 1 cm (half an inch)) could decrease by half from 2000 to 2100 under a high emissions scenario (Notaro et al. 2014).

- **Extreme temperatures** For the area of Springfield, Massachusetts, under the highest emissions scenario (RCP8.5), models project an increase of 20 to 40 more days per year with a maximum temperature >32°C (90°F.), an increase of 3–4°C (6–8°F.) in the hottest temperature of the year, and a decrease of 20 to 30 fewer days per year below freezing (0°C, 32°F.), from 1990 to 2050 (Vose et al. 2017).
- **Extreme storms** For the northeastern US as a whole, models project an increase in five-year storms (a two-day period with more precipitation than any other two-day period in five years) to once every two years (low emissions scenario, RCP4.5) or every year (highest emissions scenario, RCP8.5) (Easterling et al. 2017). In addition, models project a 22% increase in the amount of precipitation in 20-year storms (a storm with more precipitation than any other storm in 20 years) under the highest emissions scenario (RCP8.5) (Easterling et al. 2017).
- **Tornadoes** With continued climate change, the potential for severe thunderstorms that provide conditions for tornadoes may increase substantially (Diffenbaugh et al. 2013, Gensini and Mote 2015). Under the highest emissions scenario, models project a 40% increase from 2000 to 2100 of the number of days in spring with severe thunderstorms that could produce tornadoes in the eastern US (Diffenbaugh et al. 2013).

Future Projected Risks

- **River flooding** In the area of Springfield, Massachusetts, peak spring streamflow could increase slightly due to earlier snow melt under climate change (Parr et al. 2015, Demaria et al. 2016). The park is 30 m higher in elevation than the Connecticut River (USGS 2018). It is not in the 100-year flood area (FEMA 2013), based on historical climate that does not account for climate change.
- **Building damage** The projections of increases in total rainfall, the frequency of extreme storms, and tornado conditions under continued climate change suggests increased risk for building damage.

Scientific Abbreviations

GCM	<u>general circulation models</u> of global climate
P	<u>probability</u> that a phenomenon is due to random chance, a value <0.05 denotes statistical significance
RCP	<u>representative concentration pathway</u> , a scenario of future greenhouse gas emissions based on a storyline of potential future population, energy use, and economic conditions
SD	<u>standard deviation</u> , statistical measure of the variability of a sample of observations, such that 68% of the observations are one standard deviation or less from the average value
SE	<u>standard error</u> , statistical measure of the variability of sample averages drawn from a population of observations, such that 68% of the averages are one standard error or less from the average value, used here for historical trends

Figure 1. Average annual temperature, 1895-2016, for the area within park boundaries. The trend, calculated by linear regression, corrected for temporal autocorrelation, shows a statistically significant long-term increase (Gonzalez et al. 2018) due to human-caused climate change (IPCC 2013, USGCRP 2017).

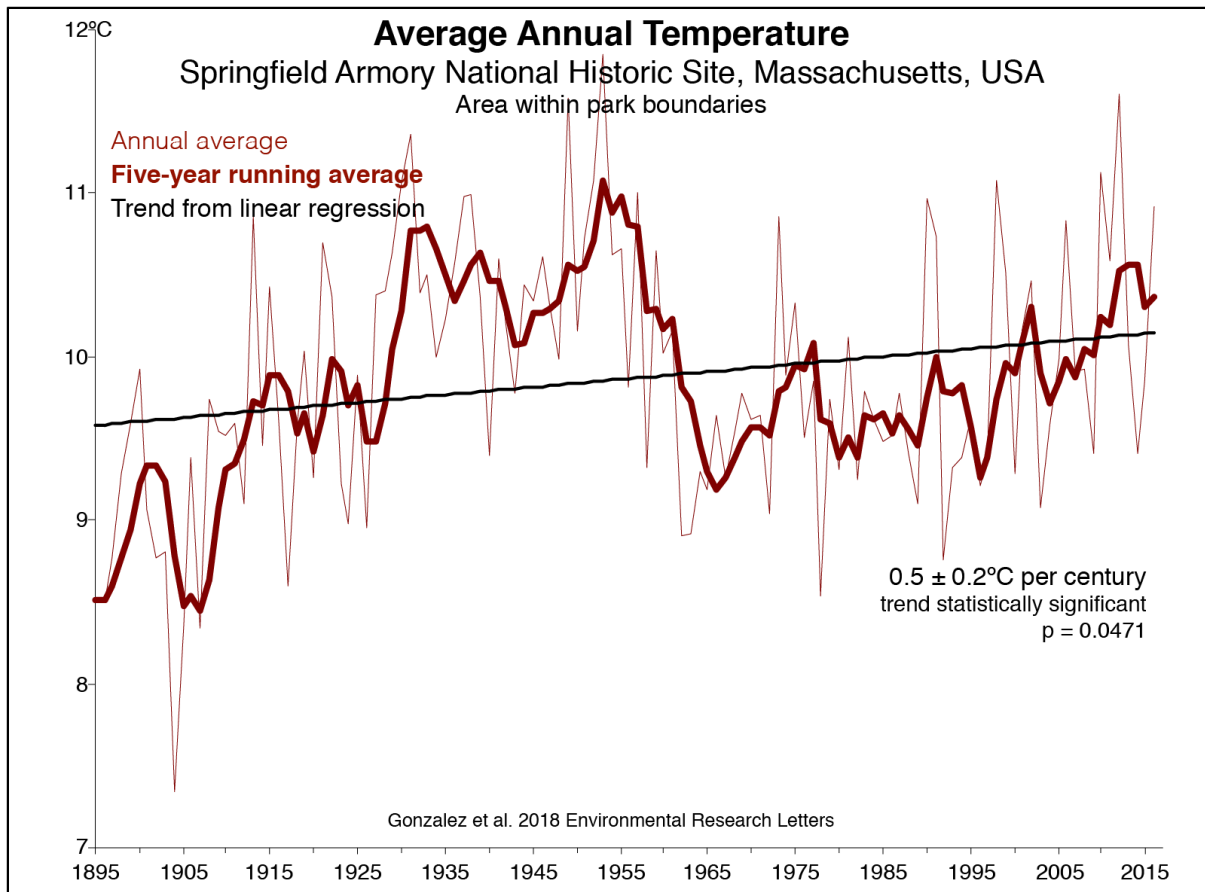


Figure 2. Trend in annual average temperature, 1895-2016, at 800 m spatial resolution, from linear regression, corrected for temporal autocorrelation (Gonzalez et al. 2018).

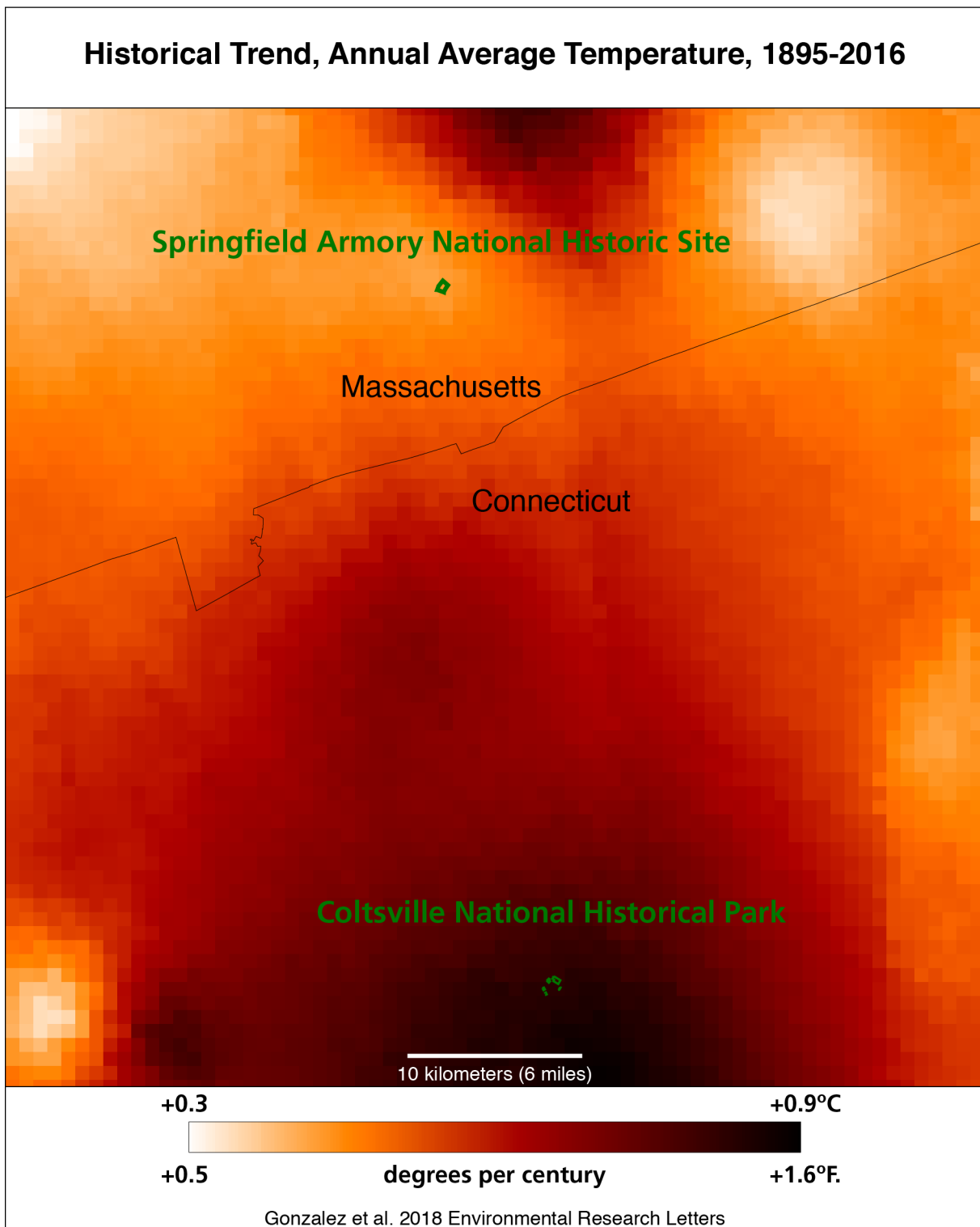


Figure 3. Total annual precipitation, 1895-2016, for the area within park boundaries. The trend, calculated by linear regression corrected for temporal autocorrelation, shows no statistically significant long-term change (Gonzalez et al. 2018).

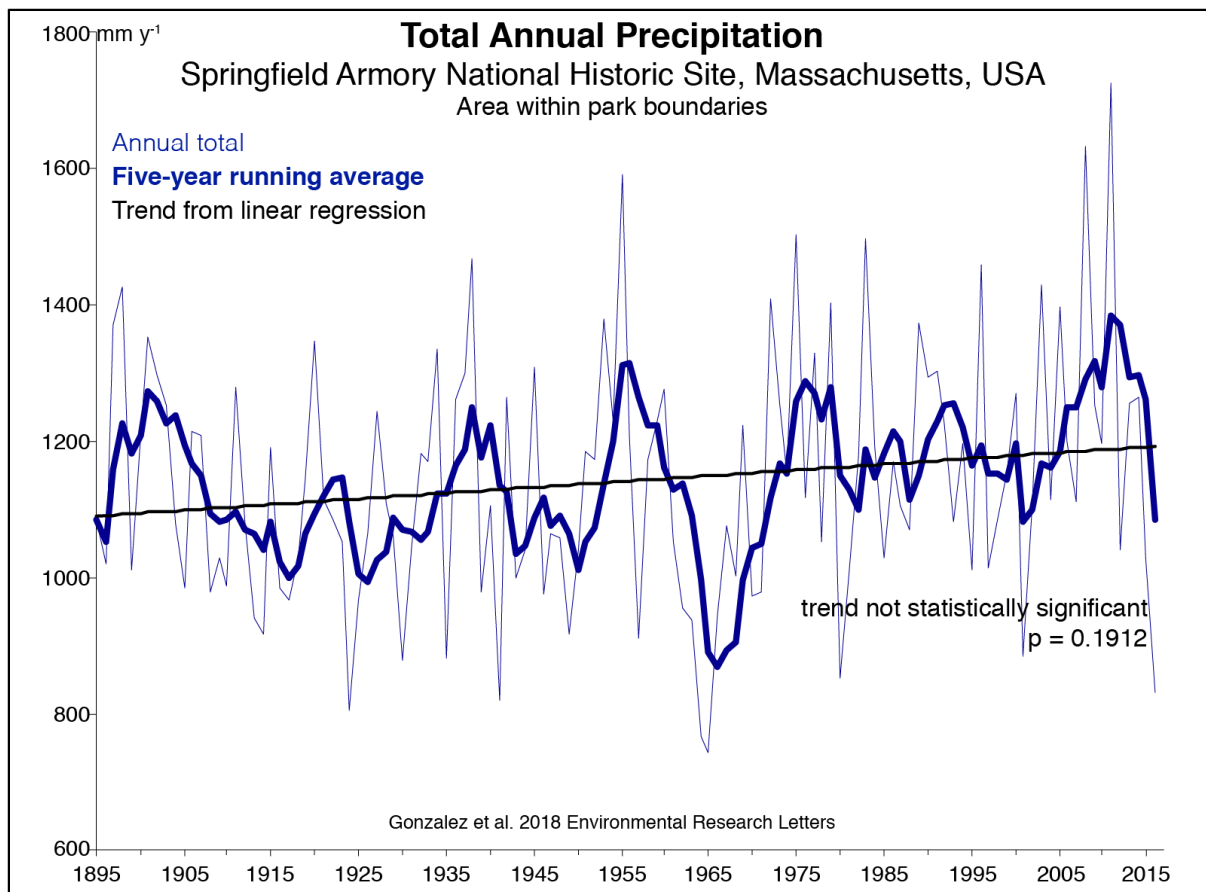


Figure 4. Trend in total annual precipitation, 1895-2016, at 800 m spatial resolution, from linear regression, corrected for temporal autocorrelation (Gonzalez et al. 2018).

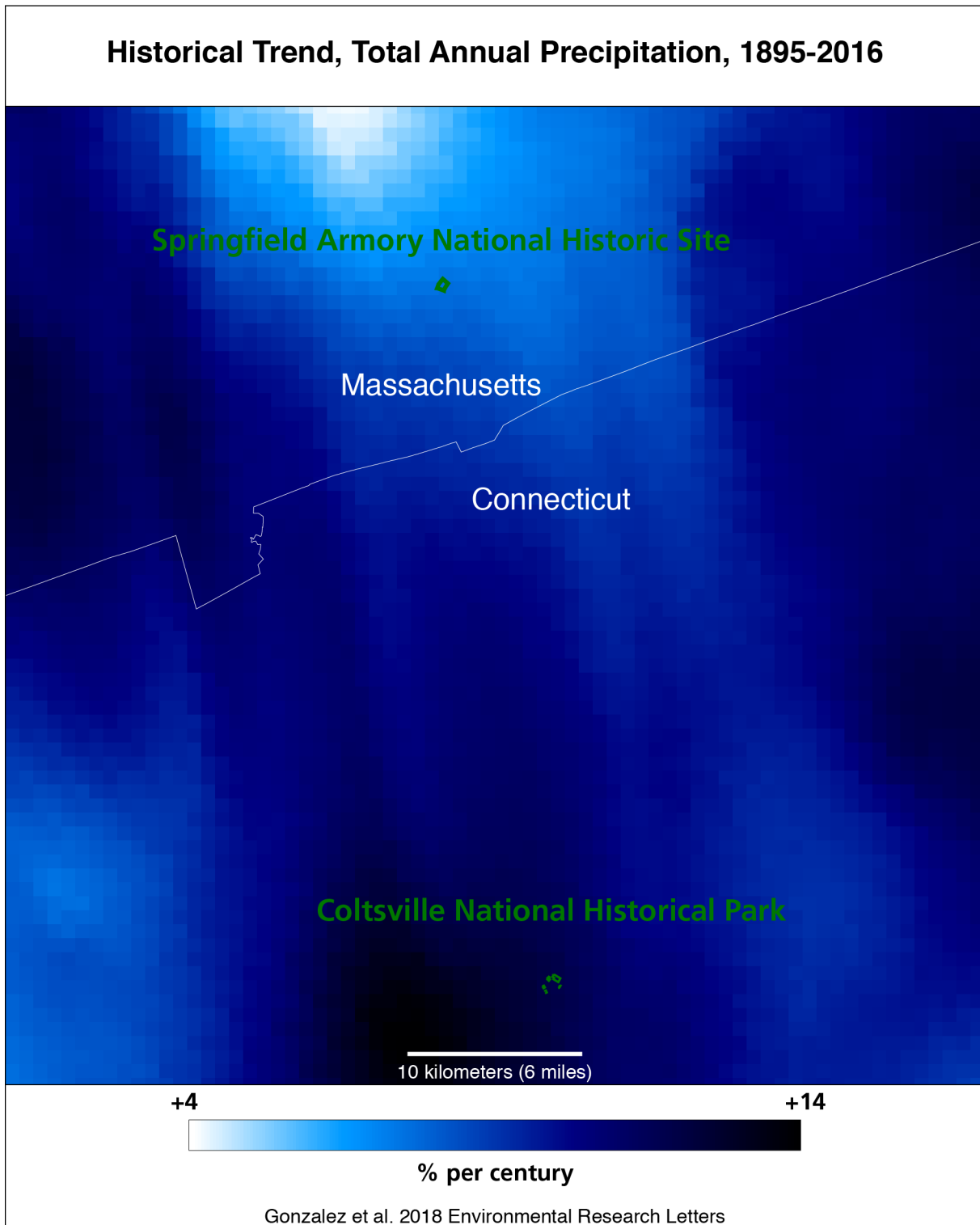


Figure 5. Projections of future climate change due to human causes, for the area within park boundaries, relative to 1971-2000 average values. Each small dot is the output of a single GCM. The large color dots are the average values for the four IPCC emissions scenarios. The crosses are the standard deviations of the average values. Most models project increased temperature and precipitation.

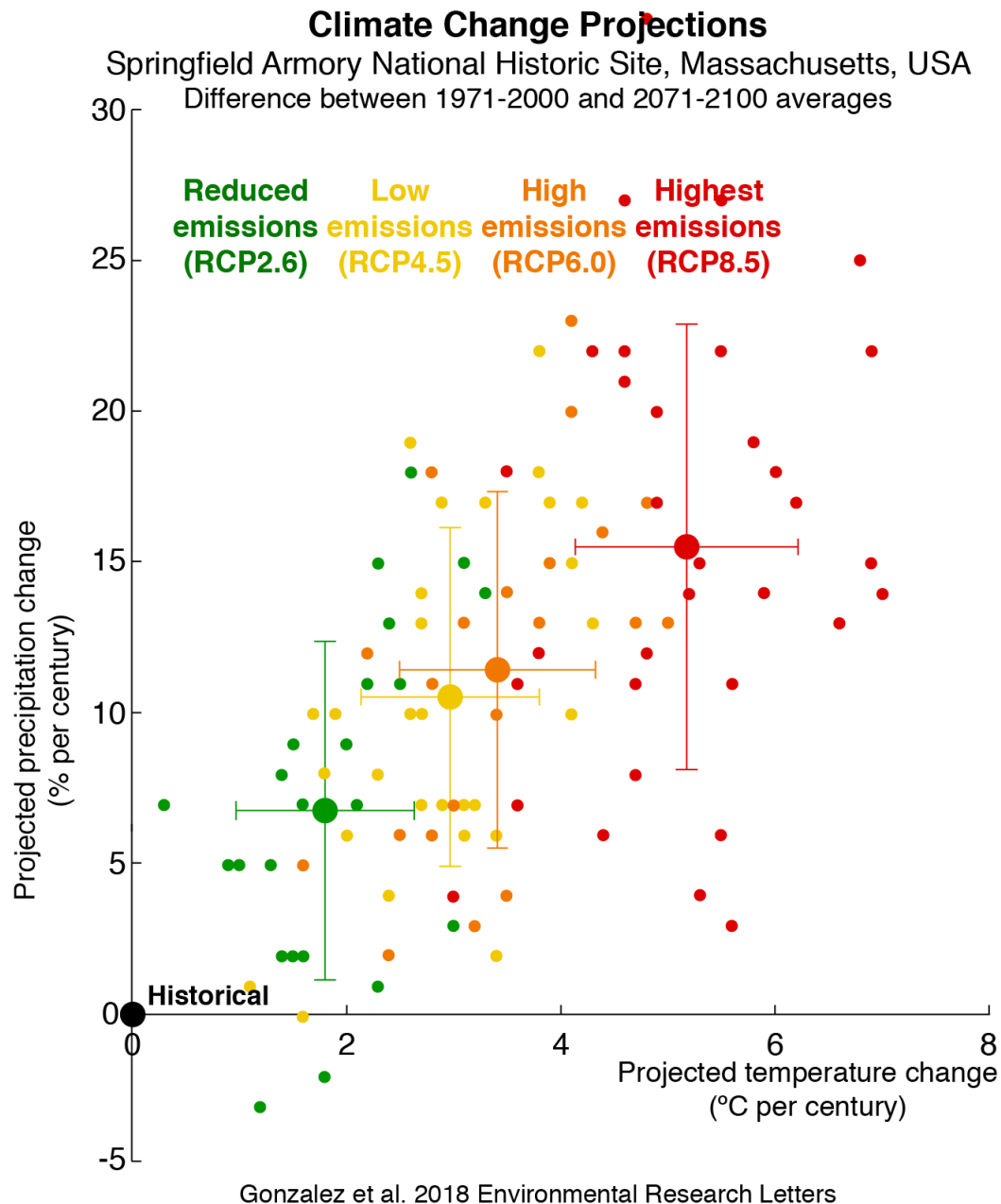


Figure 6. Monthly average temperature for the area within park boundaries. The period of below-freezing temperatures reduced approximately a week from 1895 to 2010. With continued climate change under the highest emissions scenario, all monthly average temperatures would be above freezing.

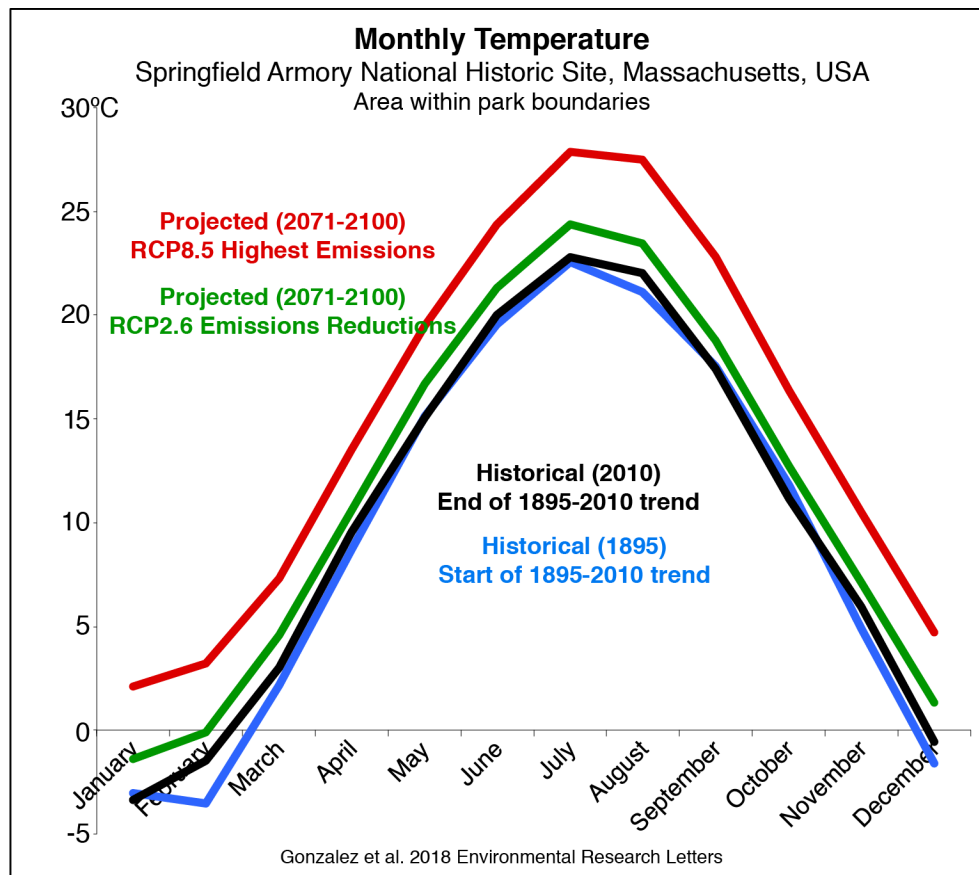


Table 1. Historical average temperatures and temperature trends (Gonzalez et al. 2018) of the area within the boundaries of Springfield Armory National Historic Site. Historical average and standard deviation (SD) given for a standard historical period (1971-2000). Historical trends, standard errors (SE), and statistical significance (sig.) given for longer periods. Statistical significance gives the probability (P) that a trend is random. The lower the probability, the more significant the trend. * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	°C		°C century ⁻¹			°C century ⁻¹		
Annual	9.8	0.6	0.5	0.3		-0.3	0.6	
December-February	-2.1	1.5	0.9	0.5		-0.2	1.5	
March-May	9	1.1	0.4	0.3		0.2	0.7	
June-August	21.4	0.7	0.5	0.3		0	0.5	
September-November	11.1	0.8	0.1	0.3		-1.1	0.6	
January	-3.6	2.5	-0.3	0.7		-0.9	2	
February	-2.1	2.5	1.8	0.8	*	-0.5	2.5	
March	2.9	1.6	0.7	0.5		0.7	0.9	
April	9	1.4	0.7	0.4		0	1	
May	15.1	1.3	-0.1	0.4		-0.2	0.9	
June	19.7	1.1	0.4	0.4		-0.4	0.6	
July	22.6	1	0.2	0.3		-0.3	0.6	
August	21.7	0.9	0.8	0.4	*	0.7	0.8	
September	17	0.9	-0.1	0.4		0.3	0.9	
October	10.9	1.5	-0.6	0.5		-2.8	1.1	*
November	5.3	1.5	0.9	0.4	*	-0.9	0.9	
December	-0.8	2.4	0.9	0.6		0.9	1.4	

Table 2. Historical average precipitation totals and precipitation trends (Gonzalez et al. 2018) of the area within the boundaries of Springfield Armory National Historic Site. Historical average and standard deviation (SD) given for a standard historical period (1971-2000). Historical trends, standard errors (SE), and statistical significance (sig.) given for longer periods. Statistical significance gives the probability (P) that a trend is random. The lower the probability, the more significant the trend. * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

	1971-2000		1895-2010		1950-2010	
	mean	SD	trend	SE	trend	SE
	mm y ⁻¹		% century ⁻¹		% century ⁻¹	
Annual	1180	161	8	5	15	13
December-February	261	74	4	7	-1	19
March-May	308	92	9	8	9	24
June-August	297	78	1	8	14	20
September-November	313	91	20	8	35	19
January	95	55	5	16	20	51
February	72	35	-14	12	-12	30
March	99	40	-1	11	6	28
April	102	50	12	12	-11	32
May	108	54	17	14	32	46
June	100	65	19	12	43	31
July	101	39	-3	13	53	31
August	96	53	-13	18	-58	55
September	106	65	12	15	44	32
October	106	51	35	16	86	43
November	101	41	14	11	-28	23
December	94	50	14	12	-10	34

Table 3. Projected temperature increases (°C), 2000 to 2050 (Gonzalez et al. 2018), for the area within the boundaries of Springfield Armory National Historic Site, from the average of all available general circulation model projections (up to 33) in IPCC (2013) for the four emissions scenarios (RCPs = representative concentration pathway). The lower the standard deviation (SD), the closer together the model projections within and emissions scenario.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	1.8	0.7	2.3	0.6	2	0.6	2.9	0.6
December-February	2	0.9	2.6	1	2.1	0.8	3.3	1.1
March-May	1.7	0.8	1.9	1.3	1.9	0.7	2.5	1.3
June-August	1.8	0.7	2.2	0.8	2	0.6	2.9	0.8
September-November	1.9	0.7	2.5	1.3	2.1	0.5	3.2	1.4
January	2.2	0.9	2.8	1.4	2	1	3.5	1.3
February	1.8	1.1	2.3	1	2.1	1	3	1
March	1.8	1	2	1.3	2	1	2.6	1.5
April	1.7	0.8	1.9	1.4	1.9	0.8	2.4	1.3
May	1.5	0.8	1.9	1.2	1.8	0.6	2.4	1.2
June	1.6	0.7	2	1.1	1.9	0.6	2.6	1
July	1.9	0.7	2.2	0.9	2.1	0.6	3	0.9
August	1.9	0.8	2.4	0.7	2.2	0.7	3.1	0.8
September	2	0.7	2.6	1.1	2.3	0.7	3.2	1.2
October	2	0.7	2.5	1.6	1.9	0.6	3.2	1.6
November	1.8	0.7	2.6	1.5	2	0.5	3	1.6
December	2	0.9	2.8	1.7	2.2	0.8	3.4	1.8

Table 4. Projected temperature increases (°C), 2000 to 2100 (Gonzalez et al. 2018), for the area within the boundaries of Springfield Armory National Historic Site, from the average of all available general circulation model projections (up to 33) in IPCC (2013) for the four emissions scenarios (RCPs = representative concentration pathway). The lower the standard deviation (SD), the closer together the model projections within and emissions scenario.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	1.8	0.8	3	0.8	3.4	0.9	5.2	1
December-February	2.1	1	3.3	1.2	3.7	1.1	5.5	1.4
March-May	1.6	0.8	2.5	1.3	3.1	1	4.4	1.5
June-August	1.7	0.8	2.8	1	3.4	1	5.2	1.2
September-November	1.8	0.8	3.2	1.6	3.5	1	5.5	1.9
January	2.2	1.2	3.5	1.4	3.7	1.1	5.7	1.6
February	2	1.2	3.1	1.1	3.6	1.3	5.3	1.2
March	1.7	1	2.5	1.5	3.1	1.3	4.4	1.6
April	1.6	0.9	2.6	1.4	3.1	1.1	4.5	1.5
May	1.6	0.8	2.4	1.2	3	0.9	4.4	1.4
June	1.6	0.8	2.5	1.2	3.1	0.9	4.7	1.3
July	1.8	0.9	2.8	1.1	3.5	1	5.3	1.4
August	1.8	0.9	3.1	1	3.6	1.1	5.8	1.4
September	1.8	0.9	3.3	1.4	3.6	1.1	5.8	1.8
October	1.8	0.8	3.1	1.7	3.3	1.1	5.5	2.1
November	1.8	0.8	3.1	1.8	3.4	0.9	5.2	2
December	2.1	1	3.5	1.9	3.7	1.1	5.5	2

Table 5. Projected precipitation changes (%), 2000 to 2050 (Gonzalez et al. 2018), for the area within the boundaries of Springfield Armory National Historic Site, from the average of all available general circulation model projections (up to 33) in IPCC (2013) for the four emissions scenarios (RCPs = representative concentration pathway). The lower the standard deviation (SD), the closer together the model projections within and emissions scenario.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	8	6	8	5	8	5	10	5
December-February	12	12	11	8	13	9	16	11
March-May	8	7	9	8	7	6	11	7
June-August	9	10	8	9	6	11	9	10
September-November	4	8	6	7	6	8	6	8
January	18	19	15	15	19	21	22	21
February	8	12	9	14	10	12	11	12
March	8	11	13	13	10	10	16	12
April	7	13	9	14	4	8	9	11
May	11	10	5	11	8	10	8	12
June	11	16	7	18	9	13	9	16
July	6	9	5	11	3	10	4	12
August	10	14	12	18	6	18	13	21
September	3	14	5	16	4	13	6	12
October	6	14	7	17	5	19	2	16
November	6	9	6	10	9	10	9	12
December	11	15	11	12	12	10	15	14

Table 6. Projected precipitation changes (%), 2000 to 2100 (Gonzalez et al. 2018), for the area within the boundaries of Springfield Armory National Historic Site, from the average of all available general circulation model projections (up to 33) in IPCC (2013) for the four emissions scenarios (RCPs = representative concentration pathway). The lower the standard deviation (SD), the closer together the model projections within and emissions scenario.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	7	6	11	6	11	6	15	7
December-February	9	9	16	8	19	9	27	14
March-May	8	8	10	8	12	7	18	9
June-August	8	10	11	11	9	12	12	14
September-November	3	7	5	8	7	7	7	10
January	12	20	20	17	21	17	34	23
February	7	12	16	16	18	12	25	15
March	8	12	14	11	15	12	21	14
April	8	11	11	16	11	11	18	17
May	8	16	7	12	11	13	15	12
June	8	16	12	17	11	19	13	18
July	8	13	9	14	7	15	8	16
August	8	15	15	20	9	16	15	29
September	4	11	6	14	6	12	4	16
October	1	17	1	15	0	14	4	20
November	5	9	8	12	15	11	12	14
December	9	13	14	10	20	16	24	17

References

- Agee, E., J. Larson, S. Childs, and A. Marmo. 2016. Spatial redistribution of U.S. tornado activity between 1954 and 2013. *Journal of Applied Meteorology and Climatology* 55: 1681-1697.
- Archfield, S.A., R.M. Hirsch, A. Viglione, and G. Blöschl. 2016. Fragmented patterns of flood change across the United States. *Geophysical Research Letters* 43: 10 232-10 239.
- Brooks, H.E., G.W. Carbin, and P.T. Marsh. 2014. Increased variability of tornado occurrence in the United States. *Science* 346: 349-352.
- Chu, J.E., A. Timmermann, and J.Y. Lee. 2019. North American April tornado occurrences linked to global sea surface temperature anomalies. *Science Advances* 5: eaaw9950. doi:10.1126/sciadv.aaw9950.
- Daly, C., M. Halbleib, J.I. Smith, W.P. Gibson, M.K. Doggett, G.H. Taylor, J. Curtis, and P.P. Pasteris. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology* 28: 2031-2064.
- Demaria, E.M.C., R.N. Palmer, J.K. Roundy. 2016. Regional climate change projections of streamflow characteristics in the Northeast and Midwest U.S. *Journal of Hydrology: Regional Studies* 5: 309-323.
- Diffenbaugh, N.S., M. Scherer, and R.J. Trapp. 2013. Robust increases in severe thunderstorm environments in response to greenhouse forcing. *Proceedings of the National Academy of Sciences of the USA* 110: 16 361-16 366.
- Easterling, D.R., J.R. Arnold, T. Knutson, K.E. Kunkel, A.N. LeGrande, L.R. Leung, R.S. Vose, D.E. Waliser, and M.F. Wehner. 2017. Precipitation change in the United States. In U.S. Global Change Research Program (USGRP). *Climate Science Special Report. Fourth National Climate Assessment, Volume I*. [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)] USGCRP, Washington, DC.
- Elsner, J.B., S.C. Elsner, and T.H. Jagger. 2015. The increasing efficiency of tornado days in the United States. *Climate Dynamics* 45: 651-659.
- Elsner, J.B., T. Fricker, and Z. Schroder. 2019. Increasingly powerful tornadoes in the United States. *Geophysical Research Letters* 46: 392-398.
- Federal Emergency Management Agency (FEMA). 2013. Flood Insurance Rate Map. Hampden County, Massachusetts. Panel 402 of 506. Map 25013C0402E. FEMA, Washington, DC.
- Gensini, V.A. and T.L. Mote. 2015. Downscaled estimates of late 21st century severe weather from CCSM3. *Climatic Change* 129: 307-321.
- Gonzalez, P., F. Wang, M. Notaro, D.J. Vimont, and J.W. Williams. 2018. Disproportionate

- magnitude of climate change in United States national parks. *Environmental Research Letters* 13: 104001. doi:10.1088/1748-9326/aade09.
- Intergovernmental Panel on Climate Change (IPCC). 2013. *Climate Change 2013: The Physical Science Basis*. Cambridge University Press, Cambridge, UK.
- Kunkel, K.E., M. Palecki, L. Ensor, K.G. Hubbard, D. Robinson, K. Redmond, and D. Easterling. 2009. Trends in Twentieth-Century U.S. snowfall using a quality-controlled dataset. *Journal of Atmospheric and Oceanic Technology* 26: 33–44.
- Kunkel, K.E., D.A. Robinson, S. Champion, X. Yin, T. Estilow, and R.M. Frankson. 2016. Trends and extremes in Northern Hemisphere snow characteristics. *Current Climate Change Reports* 2: 65–73.
- Leathers, D.J. 1993. A synoptic climatology of northeastern United States tornadoes. *Physical Geography* 14: 171-190.
- Moore, T.W. 2017. On the temporal and spatial characteristics of tornado days in the United States. *Atmospheric Research* 184: 56-65.
- Ning, L. and R.S. Bradley. 2015. Snow occurrence changes over the central and eastern United States under future warming scenarios. *Scientific Reports* 5: 17073. doi:10.1038/srep17073.
- Notaro, M., D. Lorenz, C. Hoving, and M. Schummer. 2014. Twenty-First-Century projections of snowfall and winter severity across central-eastern North America. *Journal of Climate* 27: 6526–6550.
- Parr, D. and G. Wang. 2014. Hydrological changes in the U.S. Northeast using the Connecticut River Basin as a case study: Part 1. Modeling and analysis of the past. *Global and Planetary Change* 122: 208-222.
- Parr, D., G. Wang, and K.F. Ahmed. 2015. Hydrological changes in the U.S. Northeast using the Connecticut River Basin as a case study: Part 2. Projections of the future. *Global and Planetary Change* 133: 167-175.
- Rupp, D.E., P.W. Mote, N.L. Bindoff, P.A. Stott, and D.A. Robinson. 2013. Detection and attribution of observed changes in Northern Hemisphere spring snow cover. *Journal of Climate* 26: 6904-6914.
- Tippett, M.K. and J.E. Cohen. 2016. Tornado outbreak variability follows Taylor's power law of fluctuation scaling and increases dramatically with severity. *Nature Communications* 7: 10668. doi:10.1038/ncomms10668.
- U.S. Geological Survey (USGS). 2018. U.S. Topographical map, 7.5 minute series. Springfield

South Quadrangle, Massachusetts, Connecticut. USGS, Reston , VA.

U.S. Global Change Research Program (USGCRP). 2017. Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC.

Vose, R.S., D.R. Easterling, K.E. Kunkel, A.N. LeGrande, and M.F. Wehner. 2017. Temperature changes in the United States. In U.S. Global Change Research Program (USGRP). Climate Science Special Report. Fourth National Climate Assessment, Volume I. [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)] USGCRP, Washington, DC.

Yang, Q., H. Tian, M.A.M. Friedrichs, M. Liu, X. Li, and J. Yang. 2015. Hydrological responses to climate and land-use changes along the North American East Coast: A 110-year historical reconstruction. *Journal of the American Water Resources Association* 51: 47-67.