

**Climate Change Trends and Vulnerabilities in
Charles Young Buffalo Soldiers National Monument
and Dayton Aviation Heritage National Historical Park, Ohio**

Patrick Gonzalez

Natural Resource Stewardship and Science, U.S. National Park Service, Berkeley, California
July 13, 2017

Historical Climate Change Trends

- **Historical temperature** Average annual temperature in the period 1950-2010 increased in both national parks (Tables 1, 2, Figures 1, 2, 3), but the rates for each park as a whole were not statistically significant.
- **Historical precipitation** Total annual precipitation in the period 1950-2010 increased in both national parks (Tables 1, 3, Figures 4, 5), but only the rate for Charles Young Buffalo Soldiers National Monument (NM) as a whole ($24 \pm 10\%$ per century) was statistically significant.
- **Extreme events** For the U.S. Midwest as a whole, five-year storms (a storm with more precipitation than any other storm in five years) showed a statistically significant increase of 30% from 1901 to 2012 (Walsh et al. 2014).

Historical Impact in the Area Attributed to Human-Caused Climate Change

- **Bird range shifts** Analyses of Audubon Christmas Bird Count data across the United States, including the count circle in Dayton, Ohio, detected a northward shift of winter ranges of a set of 254 bird species at an average rate of 0.5 ± 0.3 km per year from 1975 to 2004, attributable to human climate change (La Sorte and Thompson 2007). Further analyses found northward shifts in winter distributions of six raptor species (Paprocki et al. 2014), including the American Kestrel (*Falco sparverius*), which has decreased in the Dayton count.

Projected Climate Trends

- **Projected temperature** If the world does not reduce emissions from power plants, cars, and deforestation by 40-70%, models project additional future heating in the two parks of up to 5.2°C (9.3°F.) by 2100 under the highest emissions scenario, but as low as 1.7°C (3.2°F.) under a scenario of carbon emissions reductions (Tables 1, 4, Figure 6).
- **Projected precipitation** With continued carbon emissions, models project future increases in total

annual precipitation up to 13% by 2100 (Tables 1, 5). The range of four scenarios and variation in projections among the climate models generates a cloud of possible futures (Figure 6).

- **Extreme heat** Under the highest emissions scenario, models project an increase of 15 to 20 more days per year with a maximum temperature $>35^{\circ}\text{C}$ (95°F.) (Kunkel et al. 2013).
- **Extreme storms** Under the highest emissions scenario, models project an increase in 20-year storms (a storm with more precipitation than any other storm in 20 years) to once every four to five years (Walsh et al. 2014) and two more days with precipitation > 2.5 cm (1 inch) (Kunkel et al. 2013).
- **Tornadoes** The Xenia tornado of April 3, 1974, which killed 33 people in an area very close to the two national parks, highlights the potential vulnerability of the area to destructive tornadoes. Analyses of historical records of U.S. tornadoes from 1954 to 2013 indicate that the total number of tornadoes for year has shown no statistically significant trend (Brooks et al. 2014). The numbers 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). The number of tornado days in the summer has increased in southwestern Ohio (Agee et al. 2016). Changes in methods for recording tornadoes prevent attribution of the causes of tornado trends (Brooks et al. 2014), so they cannot be definitively attributed to climate change (Brooks et al. 2014).

Under 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 in the eastern U.S. with severe thunderstorms that could produce tornadoes (Diffenbaugh et al. 2013). Increasing urban and suburban development in tornado-prone areas increases the exposure to damage for the U.S. as a whole (Strader et al. 2017).

Future Projected Vulnerabilities

- **Stream flooding** In much of the Midwest, flood magnitudes have increased since 1920, although climate is just one contributing factor (Peterson et al. 2013), with land cover change exerting a strong influence. In the area of the parks, stream runoff could increase in the spring and occur earlier, due to earlier snow melt under climate change (Demaria et al. 2016).
- **Tree shifts** In Ohio, climate change could reduce sugar maple (*Acer saccharum*) and white ash (*Fraxinus americana*) trees as oak and hickory trees shift from the south (Iverson et al. 2008).

- **Wildfire** Wildfire ignition probability in the area of the two national parks is low due to high moisture throughout the year and the large fraction of land under agriculture and no wildfires were recorded in the area from 2000 to 2009 (Peters et al. 2013, Peters and Iverson 2017). Climate change may increase the potential wildfire frequency of the area (Moritz et al. 2012).
- **Invasive plants** Under high emissions, hotter conditions may make the area more favorable to the invasive plants Japanese honeysuckle (*Lonicera japonica*) (Kilkenny and Galloway 2016), kudzu (*Pueraria lobata*), and privet (*Ligustrum sinense*) (Bradley et al. 2010).
- **Indiana bat** Under high emissions, hotter temperatures may shift the range for the endangered Indiana Bat northward away from the park due to a loss of suitable summer climate for maternity colonies (Loeb and Winters 2013).

Table 1. Charles Young Buffalo Soldiers NM. Climate change trends. Historical rates of change and projected future changes per century in annual average temperature and annual total precipitation for the park as a whole (data Daly et al. 2008, IPCC 2013; analysis Wang et al. in preparation). The table gives the historical rate of change per century calculated from data for the period 1950-2013. The U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. The table gives central values with standard errors (historical) and standard deviations (projected).

	1950-2013	2000-2100
Historical		
temperature	+0.4 ± 0.5°C per century (0.8 ± 0.8°F.)	
precipitation	+24 ± 10% per century	
Projected (compared to 1971-2000)		
Reduced emissions (IPCC RCP2.6)		
temperature	+1.7 ± 0.7°C per century (+3.1 ± 1.3°F.)	
precipitation	+6 ± 5% per century	
Low emissions (IPCC RCP4.5)		
temperature	+3 ± 0.9°C per century (+5.3 ± 1.6°F.)	
precipitation	+8 ± 7% per century	
High emissions (IPCC RCP6.0)		
temperature	+3.4 ± 0.9°C per century (+6.1 ± 1.6°F.)	
precipitation	+9 ± 6% per century	
Highest emissions (IPCC RCP8.5)		
temperature	+5.2 ± 1.1°C per century (+9.3 ± 2°F.)	
precipitation	+13 ± 9% per century	

Table 2. Dayton Aviation Heritage NHP. Historical average temperatures and temperature trends of the area within the boundaries of the park. SD = standard deviation, SE = standard error, sig. = statistical significance, * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$. (Data: Daly et al. 2008; Analyses: Wang et al. in preparation)

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	°C		°C century ⁻¹			°C century ⁻¹		
Annual	11.5	0.7	0	0.2		0.2	0.6	
December-February	-0.7	2	0	0.6		-0.7	1.8	
March-May	11	1.3	0.3	0.3		1	0.8	
June-August	23.1	0.8	0.1	0.2		0.4	0.5	
September-November	12.6	1.1	-0.1	0.3		0.1	0.7	
January	-2.5	3.1	-1.3	1		-1.1	3.1	
February	-0.4	3	0.8	1		-1.2	2.8	
March	5.1	2.3	-0.1	0.6		1.8	1.2	
April	10.9	1.5	0.8	0.5		1.2	1.2	
May	16.9	2	0.1	0.4		-0.1	1.1	
June	22	1.3	0.4	0.4		0.4	0.7	
July	24.2	1	-0.2	0.3		-0.1	0.6	
August	23	1.3	0.2	0.3		1	0.8	
September	19.1	1.3	-0.5	0.4		-0.1	1.1	
October	12.5	1.8	-0.4	0.5		-1.4	1.3	
November	6.3	1.9	0.6	0.4		1.9	1.1	
December	0.4	3	0.2	0.6		0	1.5	

Table 3. Dayton Aviation Heritage NHP. Historical average precipitation totals and precipitation trends of the area within the boundaries of the park. SD = standard deviation, SE = standard error, sig. = statistical significance, * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$. (Data: Daly et al. 2008; Analyses: Wang et al. in preparation)

	1971-2000		1895-2010		1950-2010	
	mean	SD	trend	SE	trend	SE
	mm y ⁻¹		% century ⁻¹		% century ⁻¹	
Annual	1002	153	6	4	20	11
December-February	199	56	-4	10	-7	25
March-May	289	81	9	8	19	19
June-August	296	74	9	6	35	21
September-November	217	70	8	10	29	26
January	67	32	-19	20	-27	56
February	59	31	-2	16	-40	37
March	76	28	-27	17	1	40
April	100	43	21	11	*	7
May	113	50	28	13	*	43
June	108	40	11	12	35	34
July	103	40	16	9	46	24
August	85	41	-4	13	22	38
September	68	40	2	14	9	37
October	68	34	9	14	79	32
November	81	44	13	15	7	42
December	74	36	5	12	36	31

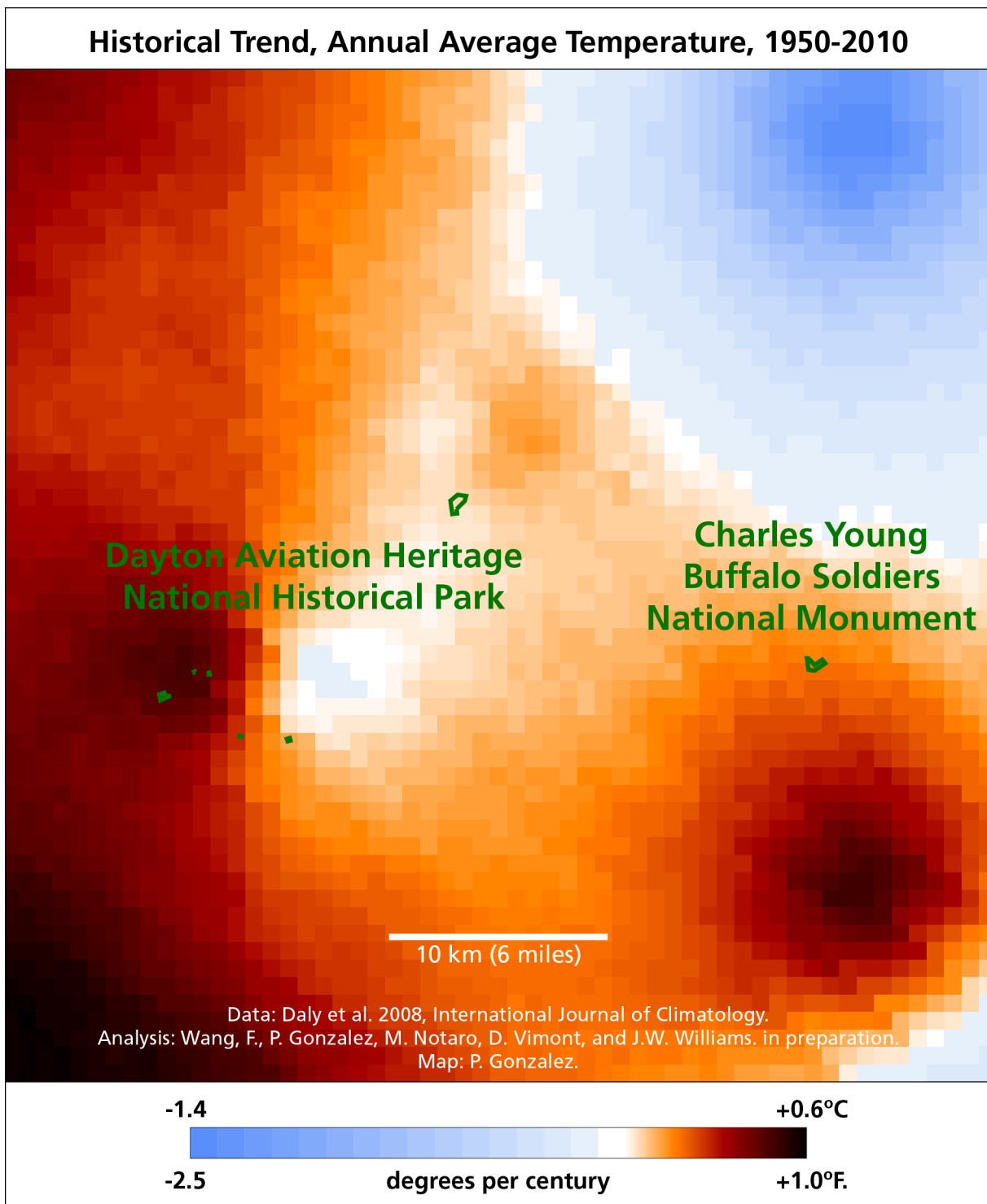
Table 4. Dayton Aviation Heritage NHP. Projected temperature increases (°C), 2000 to 2100, for the area within the boundaries of the park, from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation. (Data: IPCC 2013; Analyses: Wang et al. in preparation)

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	1.7	0.7	3	0.9	3.4	0.9	5.2	1.1
December-February	1.8	0.9	3.1	1.2	3.4	1.1	5	1.4
March-May	1.5	0.7	2.4	1.4	3	0.9	4.3	1.5
June-August	1.8	0.8	3	1.1	3.6	1.1	5.6	1.4
September-November	1.8	0.9	3.3	1.9	3.5	1.1	5.8	2.3
January	1.8	1.2	3.2	1.4	3.5	1.1	5.1	1.7
February	1.7	1.1	2.9	1.2	3.3	1.3	4.8	1.2
March	1.4	0.9	2.3	1.6	2.8	1.1	3.9	1.6
April	1.6	0.8	2.5	1.5	3.1	1	4.3	1.5
May	1.5	0.8	2.5	1.2	3.2	0.7	4.7	1.5
June	1.7	0.7	2.8	1.1	3.4	0.9	5.1	1.4
July	1.9	0.8	3	1.1	3.7	1.1	5.7	1.4
August	1.9	1	3.3	1.4	3.8	1.4	6.1	1.9
September	2	1.2	3.5	2	3.9	1.4	6.3	2.5
October	1.8	1	3.4	2.1	3.6	1.1	6	2.5
November	1.7	0.8	3	1.9	3.1	0.8	5.1	2
December	1.9	1	3.2	2	3.4	1.3	5.1	2.1

Table 5. Dayton Aviation Heritage NHP. Projected precipitation changes (%), 2000 to 2100, for the area within the boundaries of the park, from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation. (Data: IPCC 2013; Analyses: Wang et al. in preparation)

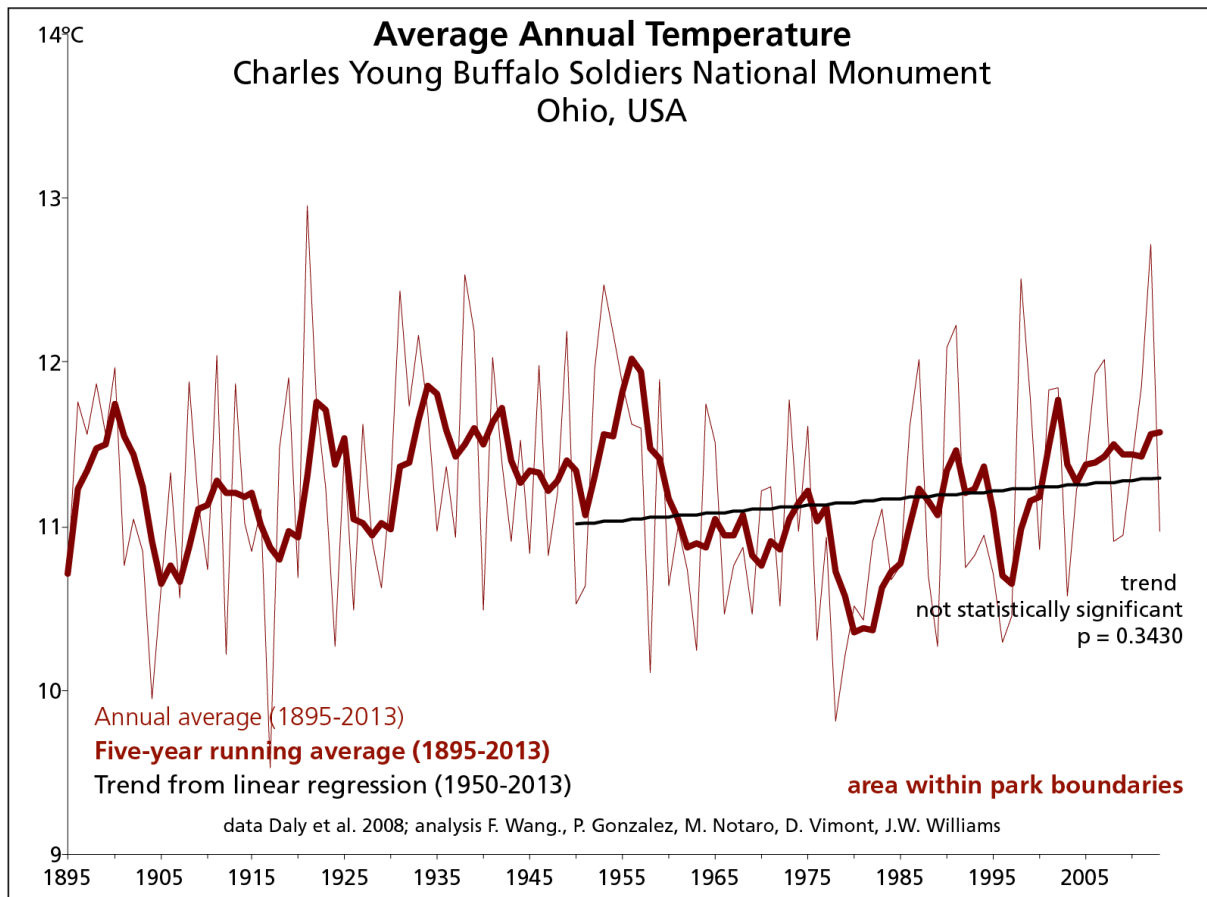
	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	6	5	8	7	9	6	13	9
December-February	7	11	15	15	17	13	25	20
March-May	9	7	12	11	16	10	20	12
June-August	3	7	3	9	0	9	3	14
September-November	3	8	2	9	5	9	5	10
January	5	24	21	30	19	25	31	30
February	10	19	12	19	21	19	23	19
March	11	13	15	16	21	23	29	17
April	12	11	15	12	21	14	25	15
May	6	13	8	15	10	11	11	16
June	4	12	3	12	1	12	-1	19
July	4	11	5	13	0	13	6	19
August	2	8	0	11	-1	10	3	12
September	6	14	1	15	4	18	-1	20
October	1	17	2	15	2	16	5	18
November	3	11	5	14	11	18	10	18
December	8	13	15	20	14	16	24	29

Figure 1.



Main conclusion: Temperature increased across the park.

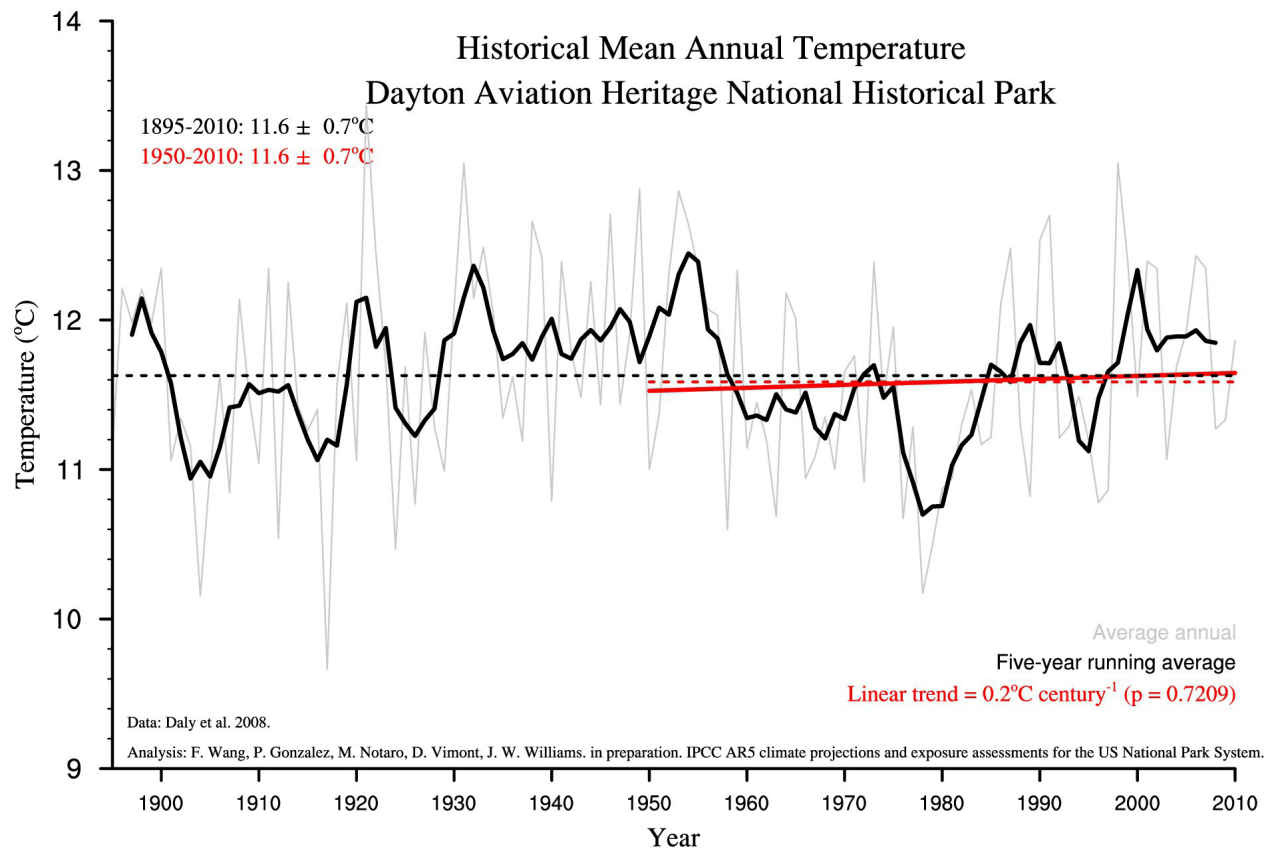
Figure 2.



Main conclusion: Temperature increased, but the rate was not statistically significant.

Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

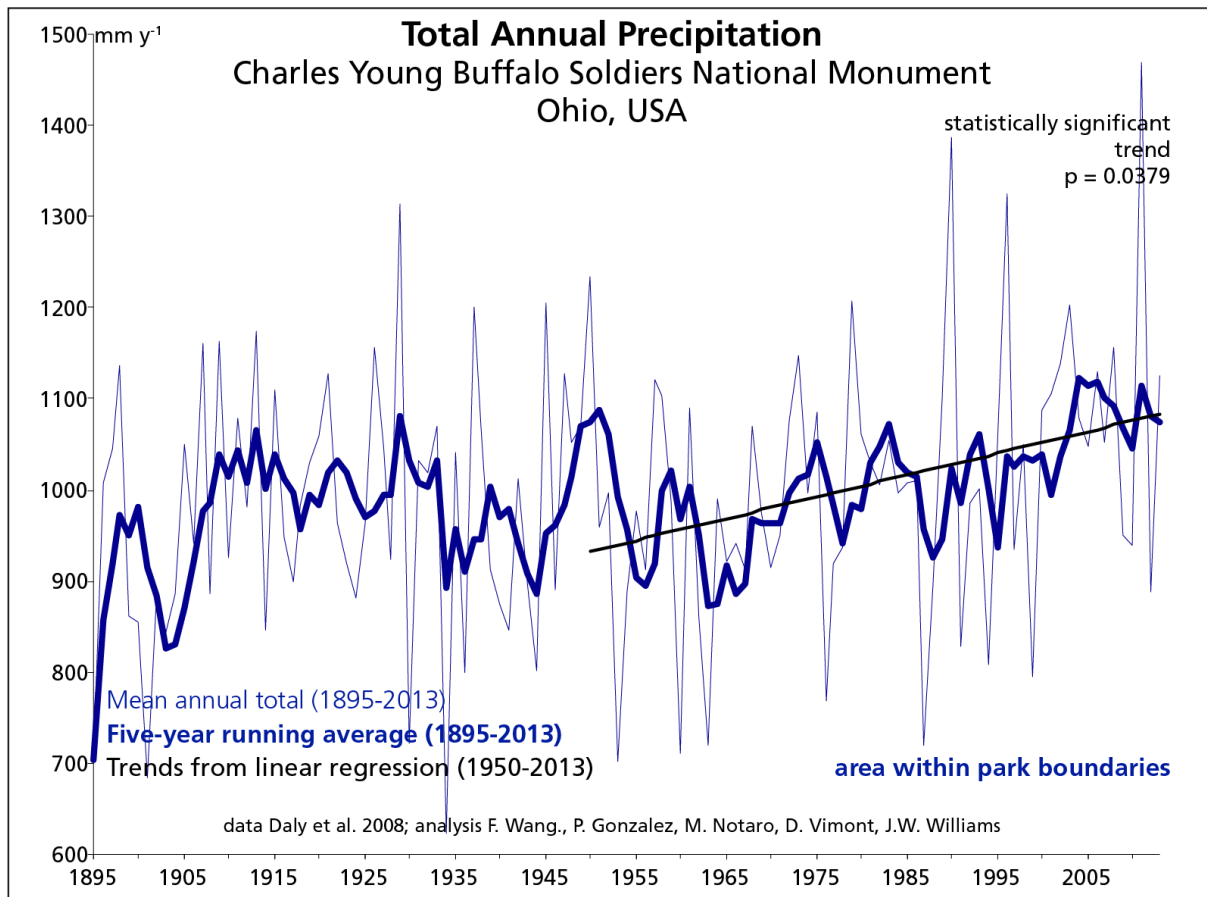
Figure 3.



Main conclusion: Temperature increased, but the rate was not statistically significant.

Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

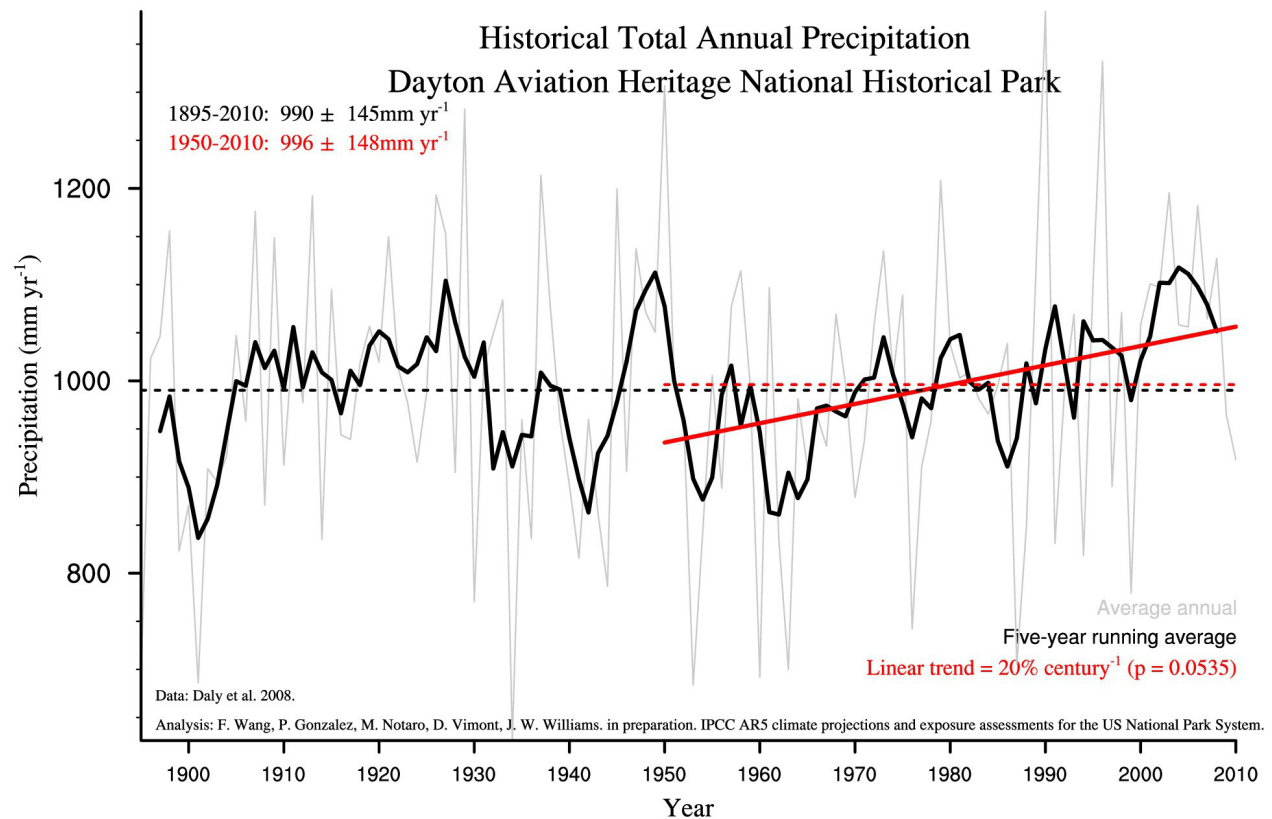
Figure 4.



Main conclusion: Precipitation increased at a statistically significant rate.

Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

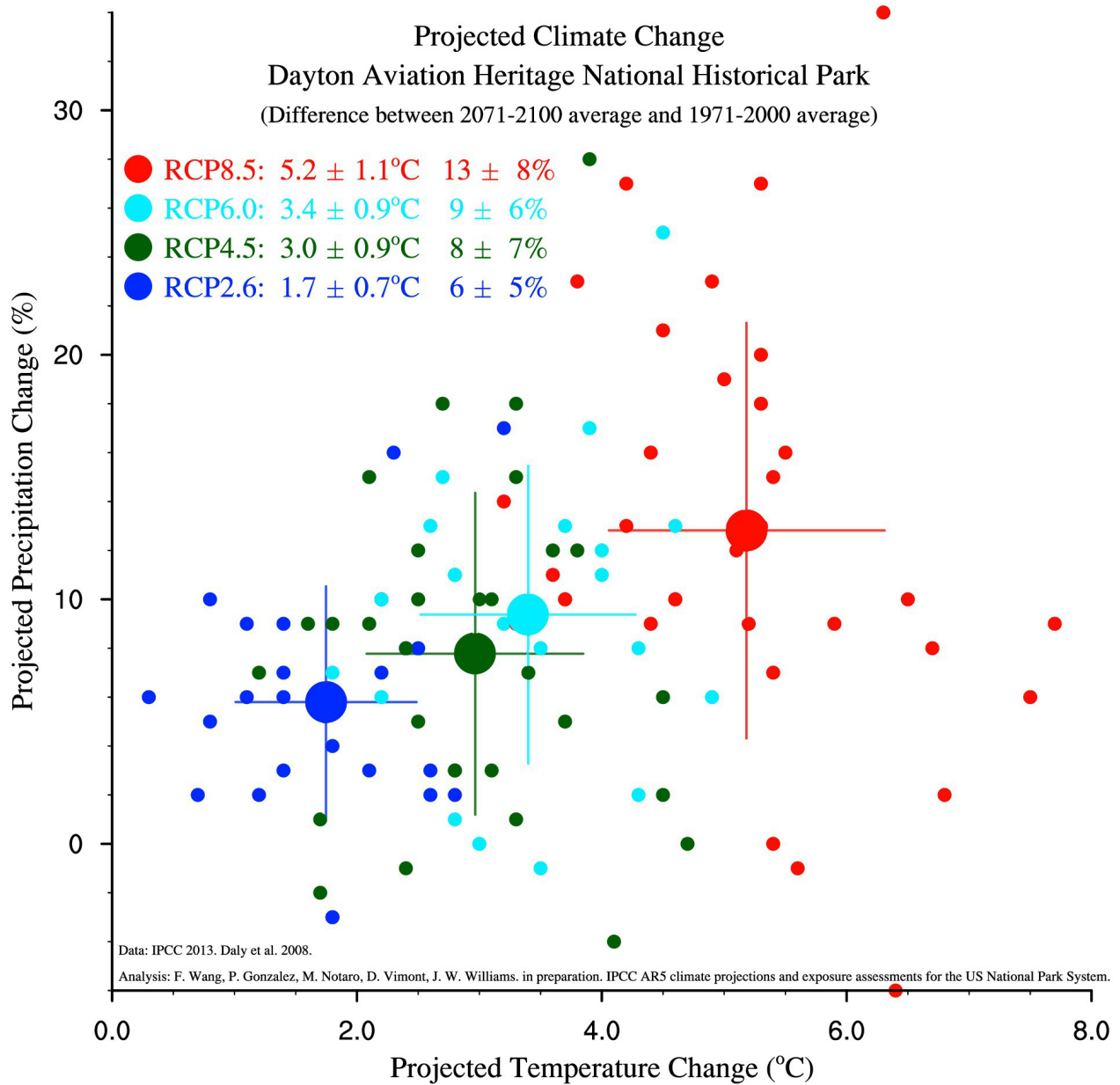
Figure 5.



Main conclusion: Precipitation increased, but the rate was not statistically significant.

Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

Figure 6.



Main conclusion: Models agree on projection of temperature increases and total precipitation increases in the park.

Each small dot is the output of a single climate model. The large color dots are the average values for the four IPCC emissions scenarios and the historical baseline. The lines are the standard deviations of each average value.

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.
- Bradley, B.A., D.S. Wilcove, and M. Oppenheimer. 2010. Climate change increases risk of plant invasion in the Eastern United States. *Biological Invasions* 12: 1855-1872.
- Brooks, H.E., G.W. Carbin, and P.T. Marsh. 2014. Increased variability of tornado occurrence in the United States. *Science* 346: 349-352.
- 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.
- 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.
- Gensini, V.A. and T.L. Mote. 2015. Downscaled estimates of late 21st century severe weather from CCSM3. *Climatic Change* 129: 307-321.
- Intergovernmental Panel on Climate Change (IPCC). 2013. *Climate Change 2013: The Physical Science Basis*. Cambridge University Press, Cambridge, UK.
- Iverson, L.R., A.M. Prasad, S.N. Matthews, and M. Peters. 2008. Estimating potential habitat for 134 eastern US tree species under six climate scenarios. *Forest Ecology and Management* 254: 390-406.
- Kilkenny, F.F. and L.F. Galloway. 2016. Evolution of marginal populations of an invasive vine increases the likelihood of future spread. *New Phytologist* 209: 1773-1780.
- Kunkel, K.E, L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, S.D. Hilberg, M.S. Timlin, L. Stoecker, N.E. Westcott, and J.G. Dobson. 2013. *Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 3. Climate of the Midwest U.S.* National Oceanic and Atmospheric Administration Technical Report NESDIS 142-3, Washington, DC.
- La Sorte, F.A. and F.R. Thompson. 2007. Poleward shifts in winter ranges of North American birds. *Ecology* 88: 1803-1812.

- Loeb, S.C and E.A. Winters. 2013. Indiana bat summer maternity distribution: effects of current and future climates. *Ecology and Evolution* 3: 103-114.
- Moore, T.W. 2017. On the temporal and spatial characteristics of tornado days in the United States. *Atmospheric Research* 184: 56-65.
- Moritz, M.A., M.A. Parisien, E. Batllori, M.A. Krawchuk, J. Van Dorn, D.J. Ganz, and K. Hayhoe. 2012. Climate change and disruptions to global fire activity. *Ecosphere* 3: art49. doi:10.1890/ES11-00345.1.
- Paprocki, N. 2014. Regional distribution shifts help explain local changes in wintering raptor abundance: Implications for interpreting population trends. *PLOS One* 9: e86814. doi:10.1371/journal.pone.0086814.
- Peters, M.P., L.R. Iverson, S.N. Matthews, and A.M. Prasad. 2013. Wildfire hazard mapping: exploring site conditions in eastern US wildland–urban interfaces. *International Journal of Wildland Fire* 22: 567-578.
- Peters, M.P. and L.R. Iverson. 2017. Incorporating fine-scale drought information into an eastern US wildfire hazard model. *International Journal of Wildland Fire* 26: 393-398.
- Peterson, T.C., R.R. Heim, R. Hirsch, D.P. Kaiser, H. Brooks, N.S. Diffenbaugh, R.M. Dole, J.P. Giovannettone, K. Guirguis, T.R. Karl, R.W. Katz, K. Kunkel, D. Lettenmaier, G.J. McCabe, C.J. Paciorek, K.R. Ryberg, S. Schubert, V.B. Silva, B.C. Stewart, A.V. Vecchia, G. Villarini, R.S. Vose, J. Walsh, M. Wehner, D. Wolock, K. Wolter, C.A. Woodhouse, and D. Wuebbles. 2013. Monitoring and understanding changes in heat waves, cold waves, floods, and droughts in the United States: State of knowledge. *Bulletin of the American Meteorological Society* 94: 821-834.
- Strader, S.M., W.S. Ashley, T.J. Pingel, and A.J. Kremenec. 2017. Projected 21st century changes in tornado exposure, risk, and disaster potential. *Climatic Change* 141: 301-313.
- 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.
- Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, and J. Willis. 2014. Our changing climate. In Melillo, J.M., T.C. Richmond, and G. W. Yohe (Eds.) *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program, Washington, DC.
- Wang, F., P. Gonzalez, M. Notaro, D. Vimont, and J.W. Williams. in preparation. Significant historical and projected climate change in U.S. national parks.