Climate Change Trends and Vulnerabilities at Flight 93 National Memorial, Pennsylvania

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Historical Climate Change Trends

- **Historical temperature** Average annual temperature in the period 1950-2016 increased in the park at a rate of 0.4 ± 0.4ºC (0.7 ± 0.7ºF.) per century (Figure 1, Tables 1, 2), but the rate was not statistically significant.
- **Historical precipitation** Total annual precipitation in the period 1950-2016 increased at a rate of 8 ± 8 % per century) (Figure 2, Tables 1, 3), but the rate was not statistically significant.
- **Extreme events** For the northeastern U.S. as a whole, 100-year storms (a storm with more precipitation than any other storm in 100 years) increased 55% from 1958 to 2016 (Easterling et al. 2017).

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

- **Bird range shifts** Analyses of Audubon Christmas Bird Count data across the United States, including the count circles in Pennsylvania, 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-caused climate change (La Sorte and Thompson 2007), and extirpation of the Evening Grosbeak (*Coccothraustes vespertinus*) across the state. Further analyses found northward shifts in winter distributions of six raptor species (Paprocki et al. 2014), including the American Kestrel (*Falco sparverius*).

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 5.1ºC (9.2º F.) by 2100 under the highest emissions scenario, but as low as 1.8ºC (3.2ºF.) with emissions reductions (Figure 3, Table 4).
- **Projected precipitation** With continued carbon emissions, models project future increases in total annual precipitation up to 12% by 2100 (Figure 3, Table 5). The range of four scenarios and

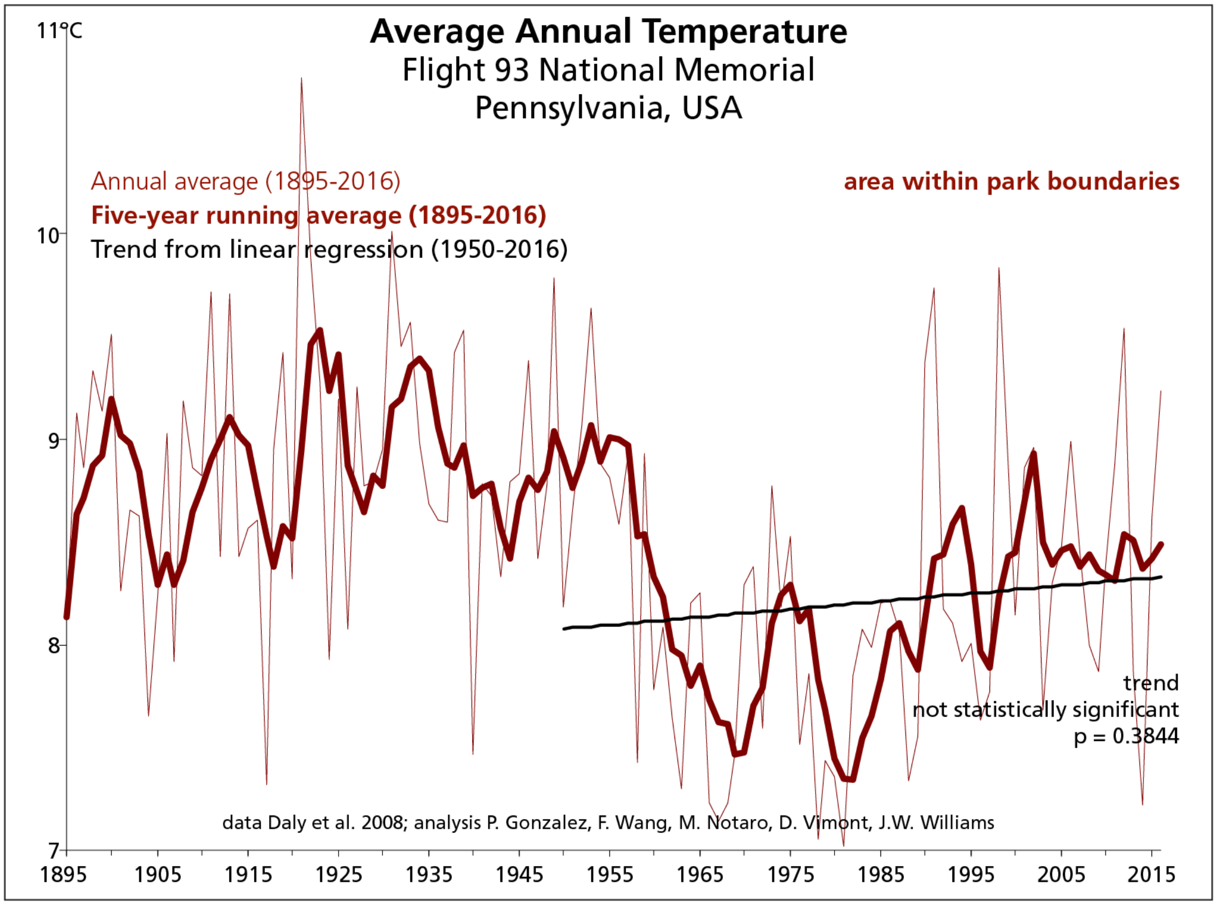
variation in projections among the climate models generates a cloud of possible futures (Figure 3).

- **Extreme heat** Under the highest emissions scenario, models project an increase of up to 20 more days per year with a maximum temperature over 32ºC (90ºF.) (Vose et al. 2017).
- **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 16 to 18 years (Easterling et al. 2017).

Future Projected Vulnerabilities

- **Stream flooding** In much of the Northeast, 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 park, stream runoff could occur earlier in the spring, but decrease in magnitude, due to earlier snow melt, but less snow under climate change (Demaria et al. 2016).
- **Tree shifts** In Pennsylvania, climate change could reduce black cherry (*Prunus serotina*) and sugar maple (*Acer saccharum*) trees as oak (*Quercus spp.*) and hickory (*Carya spp.*) trees shift from the south (Iverson et al. 2008).
- **Wildfire** Wildfire ignition probability in woodlands and forests in the area of the park is approximately 10-50% in spring and summer, based on wildfire recorded Somerset County, Pennsylvania 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 (*Myotis sodalis*), species listed as endangered under the Endangered Species Act, northward away from the park due to a loss of suitable summer climate for maternity colonies (Loeb and Winters 2013).

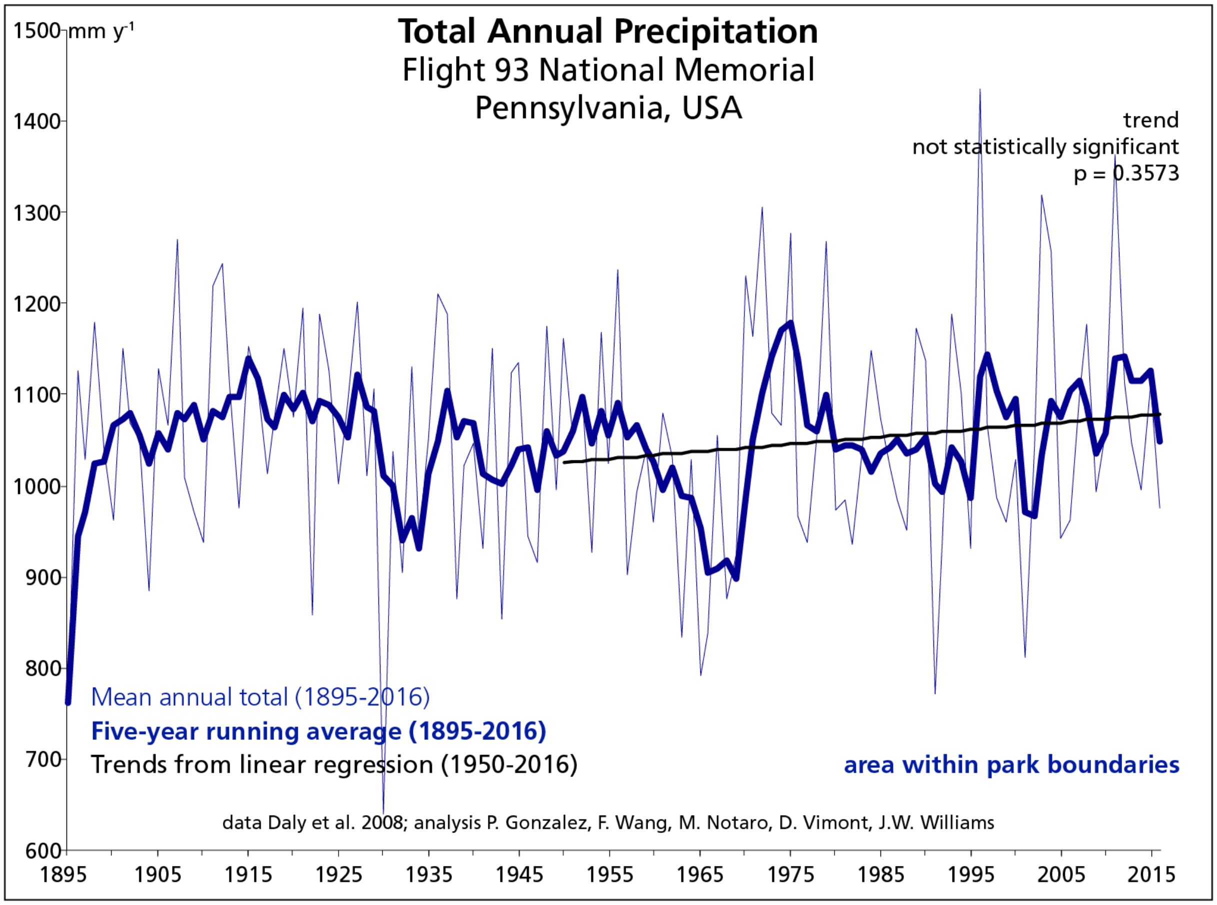
Figure 1.



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: Gonzalez et al. manuscript drafted).

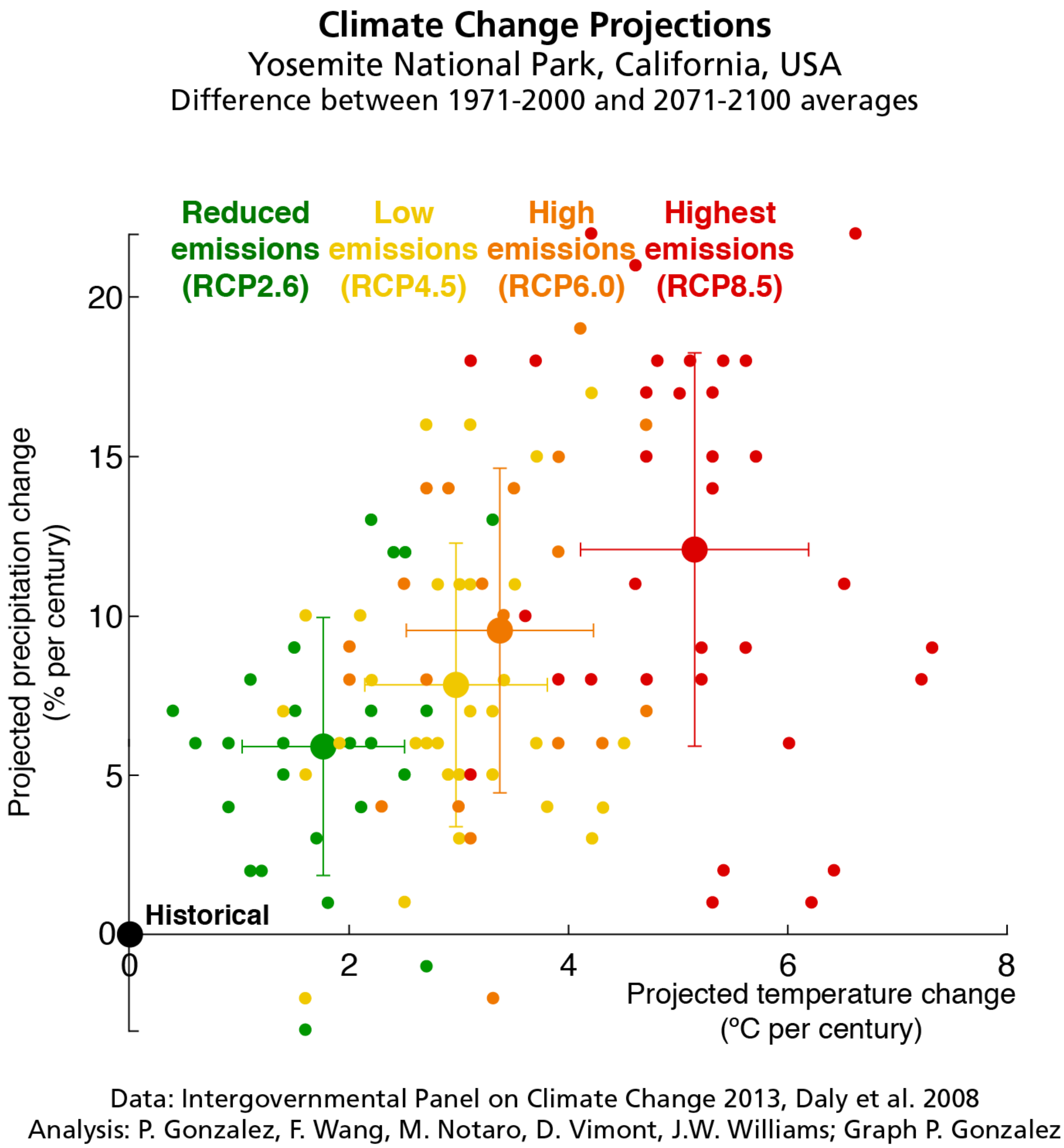
Figure 2.



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: Gonzalez et al. manuscript drafted).

Figure 3.



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.

Table 1. Climate change trends, Flight 93 National Memorial. 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 Gonzalez et al. draft). The table gives the historical rate of change per century calculated from data for the period 1950-2016. 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).

	1950-2016	**2000-2100**
Historical		
temperature	+0.4 ± 0.4ºC per century (0.7 ± 0.7ºF. per century)	
precipitation	+8 ± 8% per century	
Projected (compared to 1971-2000)		
Reduced emissions (IPCC RCP2.6)		
temperature		1.8 ± 0.7ºC (3ºF.)
precipitation		6 ± 4%
Low emissions (IPCC RCP4.5)		
temperature		3.0 ± 0.8ºC (5ºF.)
precipitation		8 ± 4%
High emissions (IPCC RCP6.0)		
temperature		3.4 ± 0.8ºC (6ºF.)
precipitation		9 ± 5%
Highest emissions (IPCC RCP8.5)		
temperature		5.1 ± 1.0ºC (9.2ºF.)
precipitation		12 ± 6%

Table 2. 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: Gonzalez et al. manuscript drafted)

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	°C		°C century^{-1}			°C century^{-1}		
Annual	7.9	0.7	-0.6	0.3	*	0.1	0.7	
December-February	-3.2	1.8	-0.3	0.6		-0.4	1.9	
March-May	7.2	1.1	-0.6	0.3	*	0.6	0.7	
June-August	18.4	0.7	-0.6	0.2	**	0.2	0.4	
September-November	9.1	1	-0.9	0.3	**	0	0.7	
January	-4.7	2.9	-1.3	0.9		-1	2.8	
February	-3.1	2.7	0.4	1		-0.7	2.9	
March	1.6	2.1	-0.9	0.6		1.5	1.2	
April	7.2	1.3	0.1	0.4		0.7	1	
May	12.7	1.7	-1.2	0.4	**	-0.5	1	
June	17.2	1.1	-0.6	0.3		0.2	0.6	
July	19.4	1	-0.9	0.3	**	-0.1	0.6	
August	18.6	1.1	-0.4	0.3		0.7	0.7	
September	15	1.2	-1.4	0.4	**	-0.1	1	
October	8.8	1.8	-1.2	0.5	*	-1.3	1.2	
November	3.5	1.9	0	0.4		1.4	1	
December	-2	2.7	-0.3	0.6		0.3	1.6	

Table 3. **Historical precipitation** totals and precipitation trends of the area within the boundaries of the park. SD = standard deviation, SE = standard error, sig. = statistical significance, * P ≤ 0.05, ** P ≤ 0.01, *** P ≤ 0.001. (Data: Daly et al. 2008; Analyses: Gonzalez et al. manuscript drafted)

	1971-2000		1895-2010			1950-2010	
	mean	SD	trend	SE		trend	SE
	mm y^{-1}		% $century^{-1}$			% $century^{-1}$	
Annual	1053	134	-3	3		7	10
December-February	232	59	-12	9		7	21
March-May	285	51	2	5		-10	13
June-August	286	55	-17	6	**	0	17
September-November	253	68	22	8	**	38	20
January	81	35	-22	13		14	34
February	75	29	-13	11		-22	26
March	93	33	-11	10		-37	22
April	86	40	-1	10		-27	25
May	106	32	17	10		29	31
June	100	40	-19	10		1	30
July	92	40	-18	10		-5	30
August	94	34	-14	10		4	24
September	95	47	29	13	*	56	30
October	76	38	2	13		16	34
November	82	49	34	15	*	38	40
December	74	32	-6	12		18	39

Table 4. **Projected temperature increases** (ºC), 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: Gonzalez et al. manuscript drafted)

	Emissions Scenarios							
	Reductions RCP2.6		Low RCP4.5		High RCP6.0		Highest RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
	1.8	0.7	3	0.8	3.4	0.8	5.1	1
Annual								
	1.8	0.8	3	1.1	3.3	1	4.9	1.3
December-February	1.6	0.7	2.5	1.3	3.1	0.8	4.4	1.4
March-May	1.8	0.8	3.1	1	3.6	1.1	5.6	1.3
June-August	1.8	0.9	3.3	1.8	3.5	1	5.7	2.2
September-November								
	1.8	1.1	3	1.3	3.3	1	4.9	1.5
January	1.8	1.1	2.8	1.1	3.2	1.2	4.7	1.1
February	1.6	0.9	2.3	1.5	2.9	1.1	4	1.6
March	1.6	0.8	2.6	1.4	3.1	0.9	4.4	1.4
April	1.6	0.8	2.5	1.2	3.2	0.7	4.7	1.4
May	1.7	0.7	2.7	1.1	3.3	0.9	5	1.3
June	1.8	0.8	3.1	1.1	3.7	1.1	5.6	1.4
July	1.9	1	3.4	1.3	3.9	1.4	6.1	1.8
August	2	1.1	3.5	1.8	3.9	1.3	6.2	2.2
September	1.8	0.9	3.4	2	3.4	1.1	5.8	2.4
October	1.7	0.8	3	1.9	3.1	0.9	5	2.1
November	1.9	1	3.2	1.9	3.4	1.2	5.1	2
December	1.8	0.7	3	0.8	3.4	0.8	5.1	1

Table 5. **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: Gonzalez et al. manuscript drafted)

	Emissions Scenarios							
	Reductions RCP2.6		Low RCP4.5		High RCP6.0		Highest RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
	6	4	8	4	9	5	12	6
Annual								
	7	7	13	10	15	9	22	13
December-February	8	7	9	7	12	6	15	8
March-May	5	7	6	9	5	9	6	12
June-August	4	10	4	10	7	10	7	11
September-November								
	6	15	14	16	15	12	25	15
January	9	14	14	17	19	15	23	18
February	5	8	9	10	11	11	17	9
March	11	11	13	11	15	12	19	14
April	7	11	6	12	9	9	10	12
May	5	10	4	14	4	10	2	14
June	6	10	7	12	6	13	9	18
July	4	8	6	13	6	14	8	15
August	5	13	5	13	5	14	2	17
September	3	20	-2	17	1	20	4	22
October	6	14	10	17	14	17	15	16
November	8	11	13	13	15	13	21	19
December	6	4	8	4	9	5	12	6

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