

Climate Change Trends, Golden Gate National Recreation Area, Fort Point National Historic Site, and Muir Woods National Monument, California

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Preliminary report on climate change trends:

- Historic temperature and precipitation

- Projected future temperature and precipitation

- Assessment of impacts and vulnerabilities in progress

Table 1. Climate Change Trends. Historical rates of change (mean $\pm$ standard error) and projected future changes (mean $\pm$ standard deviation) in annual average temperature ($^{\circ}\text{C}$ per century) and total annual precipitation (% per century) (data Daly et al. 2008, IPCC 2013; analysis Wang et al. in preparation). IPCC = Intergovernmental Panel on Climate Change, NHS = National Historic Site, NM = National Monument, NRA = National Recreation Area, RCP = Representative Concentration Pathway.

	Golden Gate NRA legislative boundary	Golden Gate NRA managed area	Golden Gate NRA managed north	Golden Gate NRA managed south	Fort Point NHS	Muir Woods NM
Historical						
1895-2010						
temperature	0.9 ± 0.2	0.7 ± 0.1	0.9 ± 0.1	0.6 ± 0.1	0.9 ± 0.2	1 ± 0.2
precipitation	1 ± 9	-1 ± 8	-3 ± 8	1 ± 8	9 ± 9	
Historical						
1950-2010						
temperature	1.4 ± 0.5	1.1 ± 0.3	1.2 ± 0.3	1.1 ± 0.3	1.6 ± 0.6	1.3 ± 0.5
precipitation	7 ± 25	-2 ± 20	-3 ± 8	1 ± 22	19 ± 27	
Projected (compared to 1971-2000)						
Reduced emissions (IPCC RCP 2.6)						
temperature	1.4 ± 0.6	1.4 ± 0.6	1.4 ± 0.6	1.4 ± 0.6	1.4 ± 0.6	1.4 ± 0.6
precipitation	5 ± 12	5 ± 12	5 ± 12	5 ± 12	5 ± 12	5 ± 12
Low emissions (IPCC RCP 4.5)						
temperature	2.1 ± 0.6	2.1 ± 0.6	2.1 ± 0.6	2.1 ± 0.6	2.1 ± 0.6	2.1 ± 0.6
precipitation	5 ± 9	5 ± 9	5 ± 9	5 ± 9	5 ± 9	5 ± 9
High emissions (IPCC RCP 6.0)						
temperature	2.4 ± 0.7	2.4 ± 0.7	2.5 ± 0.7	2.4 ± 0.7	2.5 ± 0.7	2.5 ± 0.7
precipitation	7 ± 14	7 ± 14	7 ± 14	7 ± 14	7 ± 14	7 ± 14
Highest emissions (IPCC RCP 8.5)						
temperature	3.7 ± 0.8	3.7 ± 0.8	3.7 ± 0.8	3.7 ± 0.8	3.8 ± 0.8	3.8 ± 0.8
precipitation	9 ± 16	9 ± 16	9 ± 16	9 ± 16	9 ± 16	9 ± 16

Figure 1

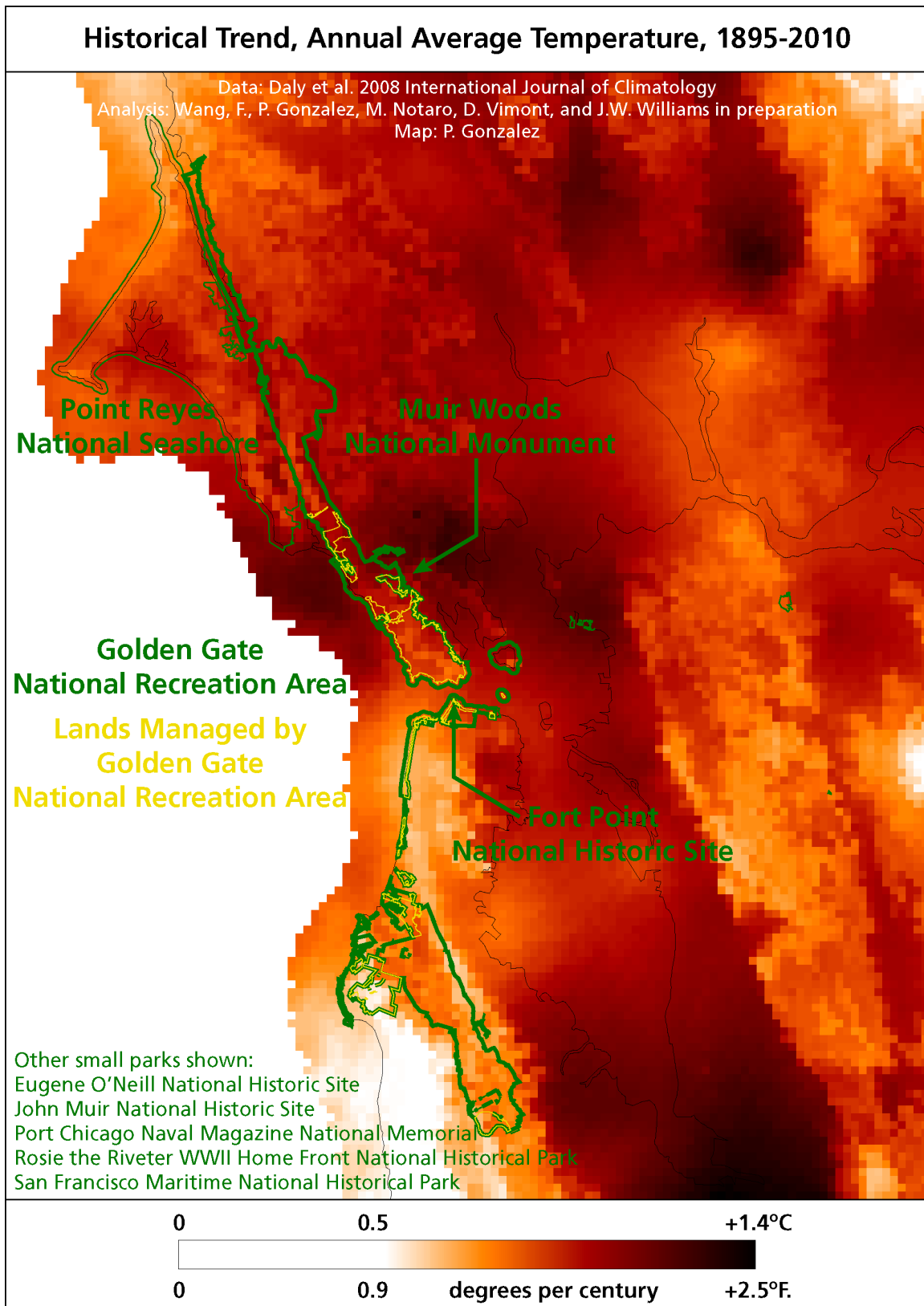


Figure 2

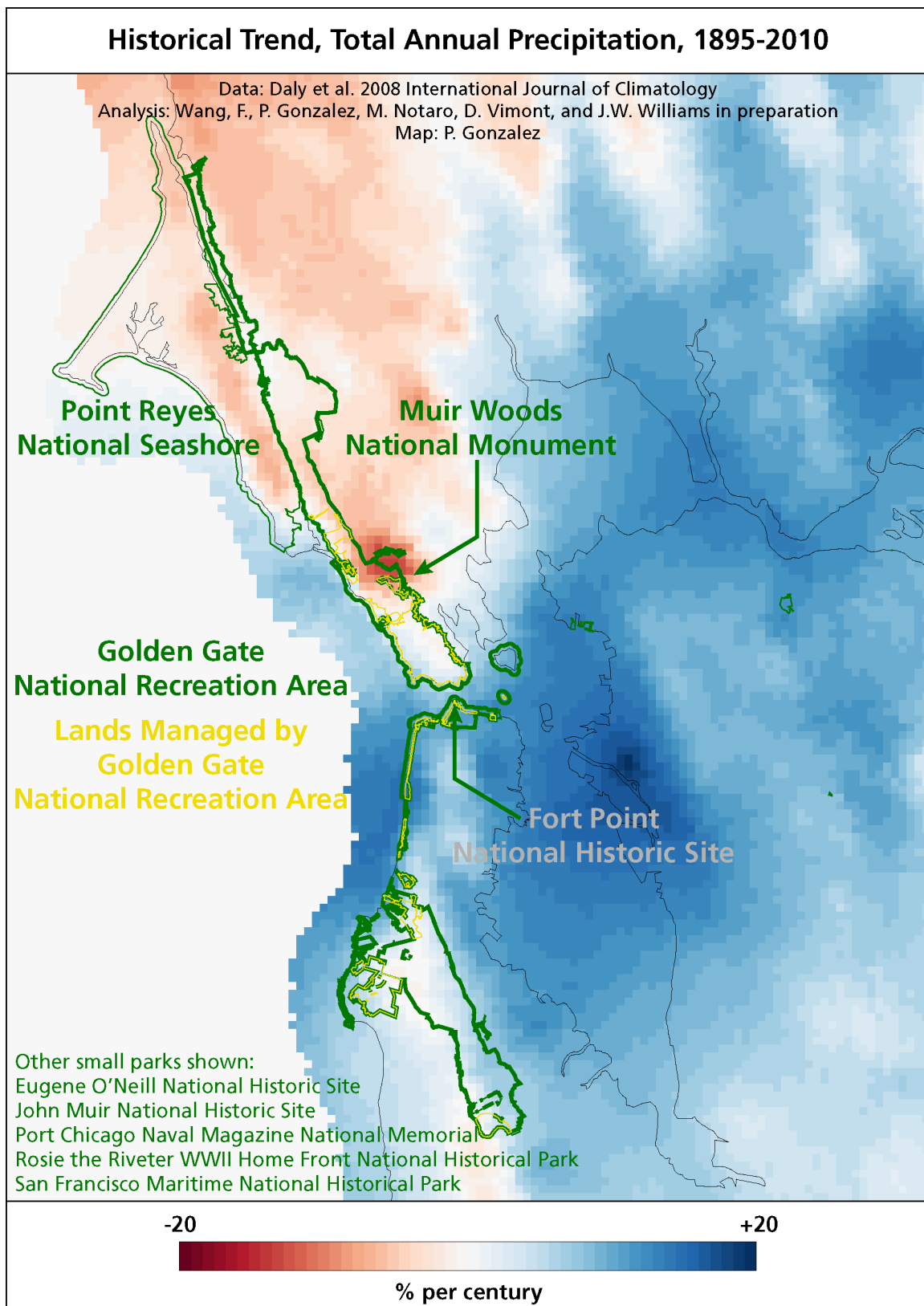


Figure 3. Golden Gate National Recreation Area. Historical annual average temperature for the area within the legislative boundary. Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

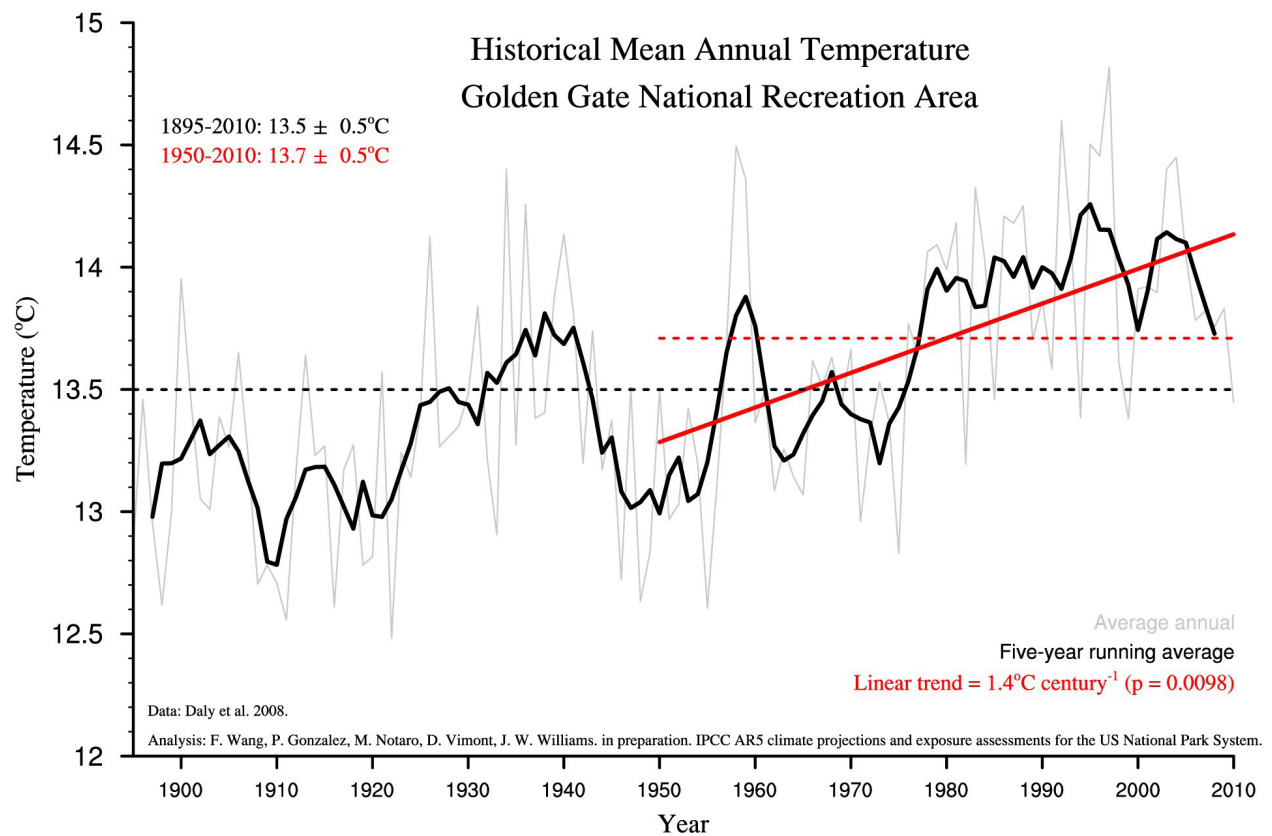


Figure 4. Fort Point National Historic Site. Historical annual average temperature for the area within the park boundary. Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

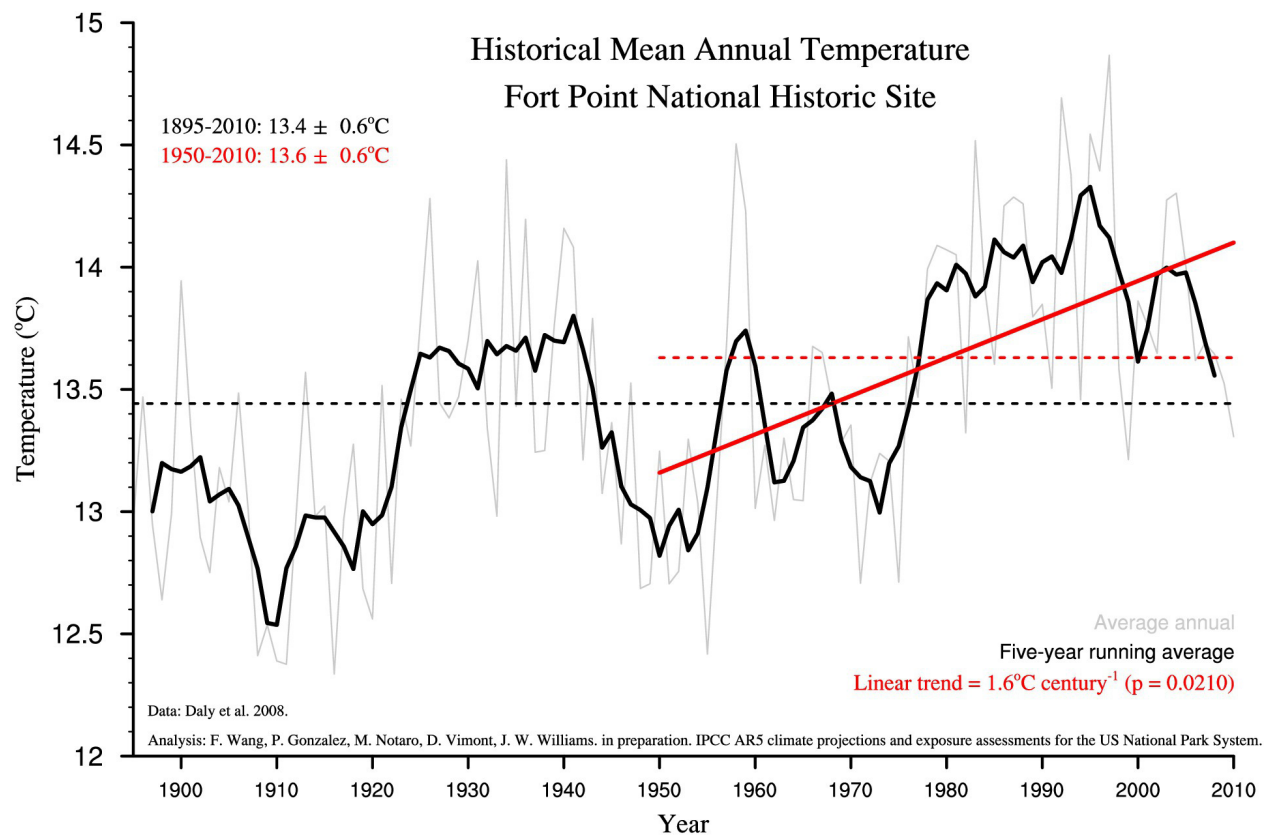


Figure 5. Muir Woods National Monument. Historical annual average temperature for the area within the park boundary. Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

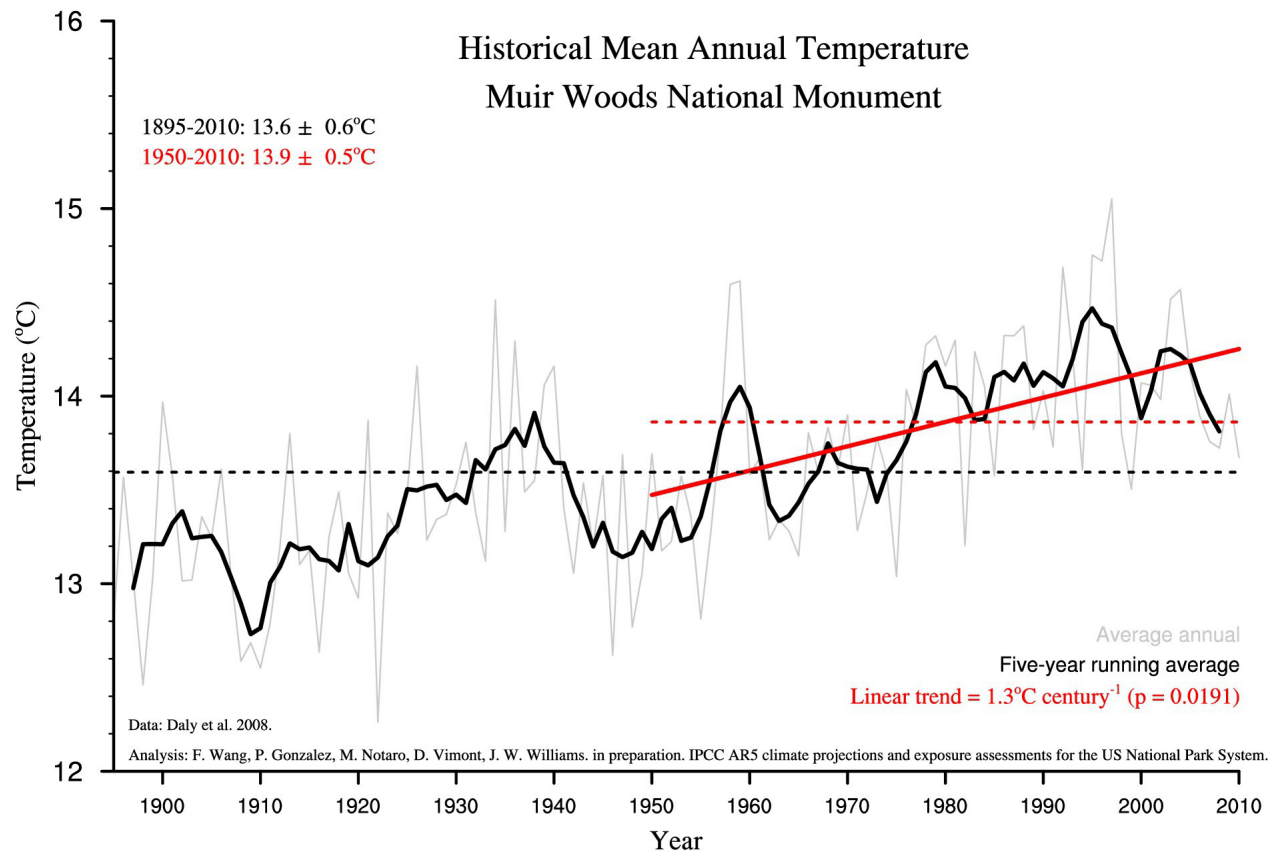


Figure 6. Golden Gate National Recreation Area. Historical total annual precipitation for the area within the legislative boundary. Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

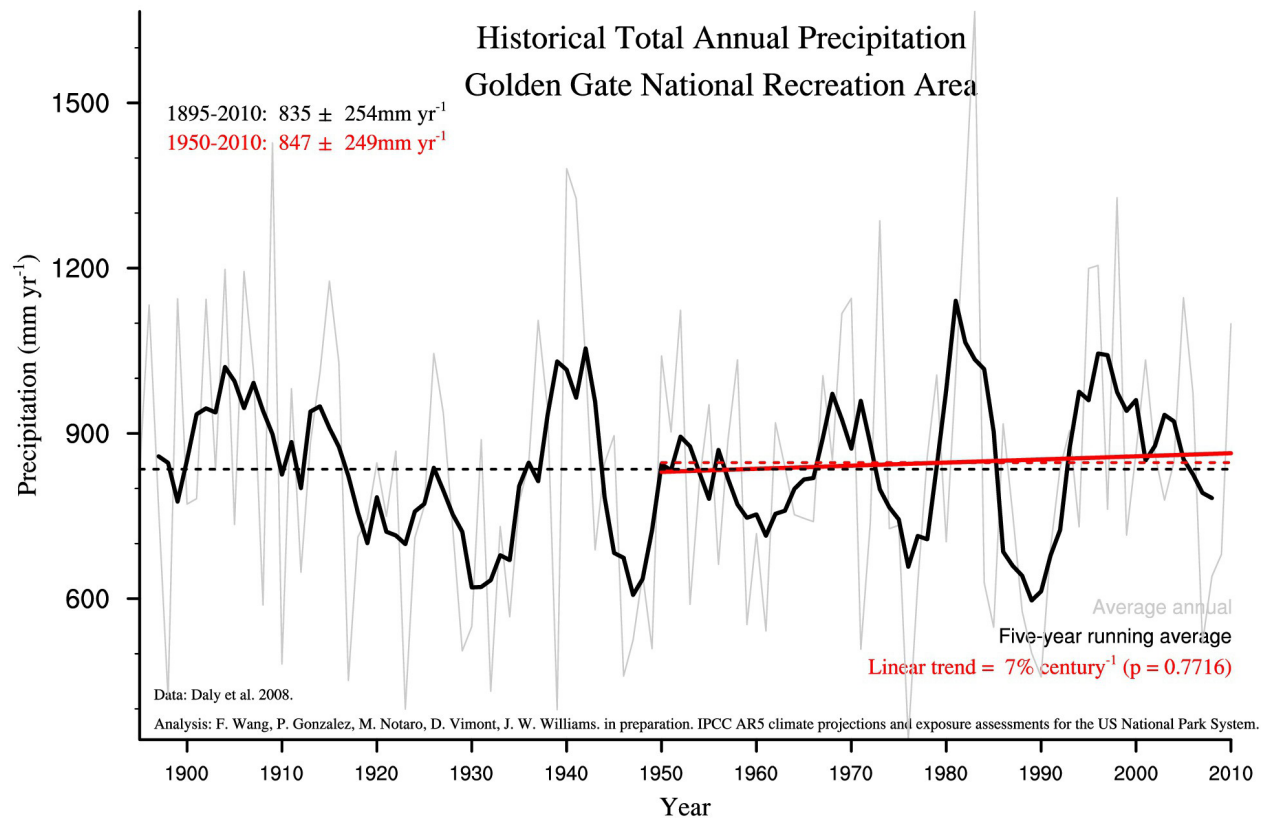


Figure 7. Fort Point National Historic Site. Historical total annual precipitation for the area within the park boundary. Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

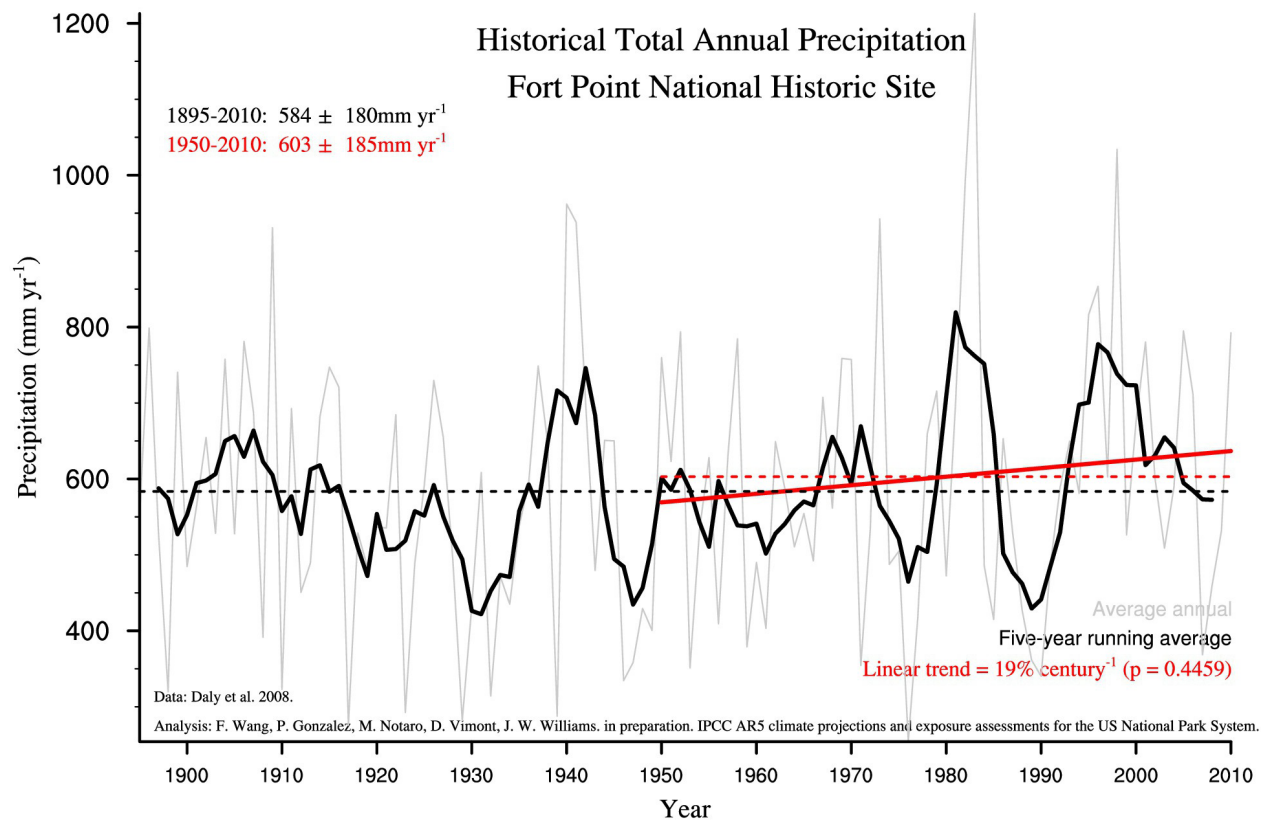


Figure 8. Muir Woods National Monument. Historical total annual precipitation for the area within the park boundary. Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

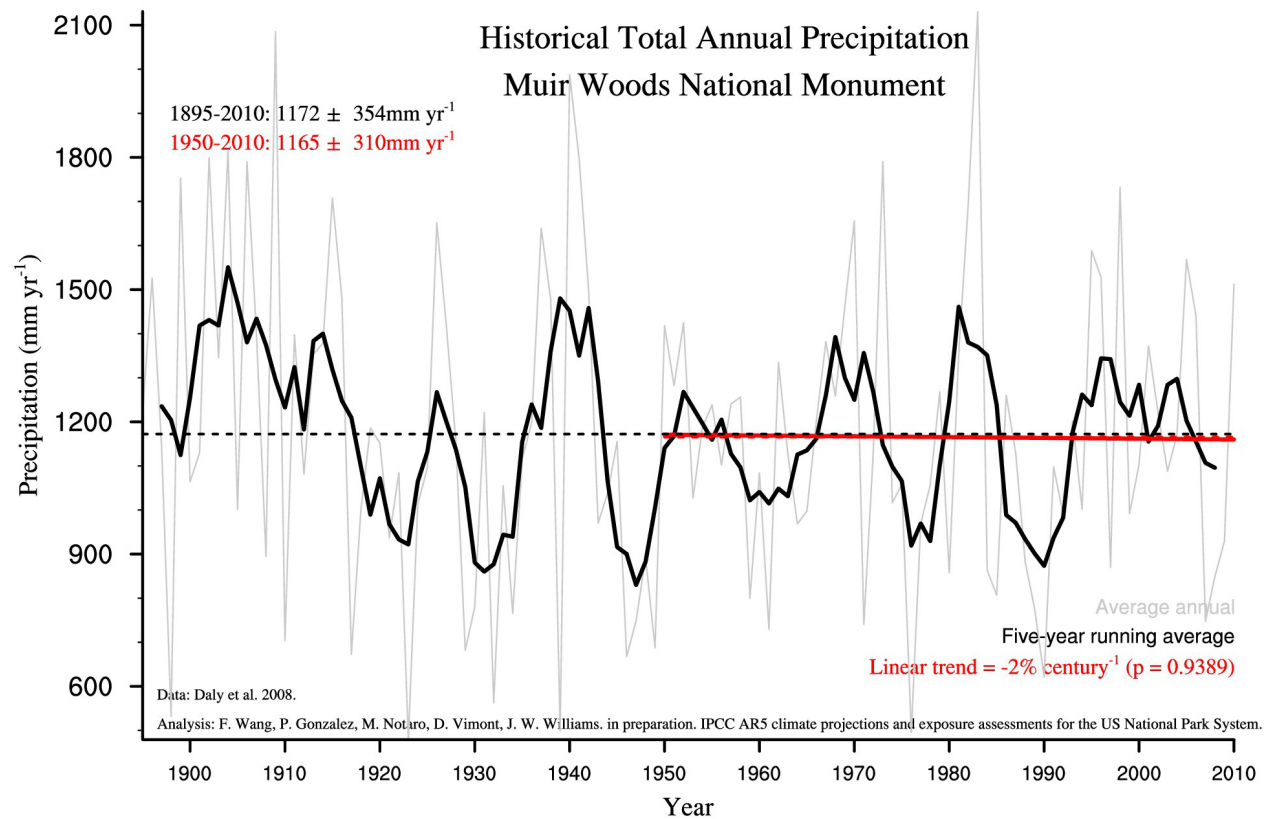


Table 2. Golden Gate National Recreation Area. Historical average temperatures and temperature trends of the area within the legislative boundary. SD = standard deviation, SE = standard error, sig. = statistical significance, * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	°C		°C century ⁻¹			°C century ⁻¹		
Annual	13.8	0.5	0.9	0.2	***	1.4	0.5	*
December-February	10.2	0.8	0.8	0.3	**	1.2	0.5	*
March-May	13	0.9	0.8	0.3	**	2	0.7	*
June-August	16.8	0.5	0.8	0.2	***	1.8	0.6	**
September-November	15.4	0.7	0.9	0.2	***	0.7	0.4	
January	9.7	1	1	0.3	**	2.2	0.7	**
February	11	1.1	0.8	0.3	*	1	0.7	
March	11.9	1.2	0.9	0.4	*	2.7	0.9	**
April	12.8	1.1	0.5	0.3		1.4	0.9	
May	14.2	1.1	1.1	0.3	***	1.9	0.7	*
June	15.9	0.9	0.6	0.3	*	1.8	0.7	*
July	17	0.7	0.6	0.2	**	1.7	0.7	*
August	17.4	0.7	1.2	0.3	***	1.9	0.7	**
September	17.6	1	1.2	0.3	***	0.7	0.8	
October	16.1	0.9	1.1	0.3	***	0.9	0.7	
November	12.6	1.1	0.5	0.3		0.5	0.7	
December	9.8	1.2	0.8	0.3	*	0.5	0.8	

Table 3. Golden Gate National Recreation Area. Historical average precipitation totals and precipitation trends of the area within the legislative boundary. SD = standard deviation, SE = standard error, sig. = statistical significance, * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	mm y ⁻¹		% century ⁻¹			% century ⁻¹		
Annual	838	303	1	9		7	25	
December-February	469	212	3	13		17	31	
March-May	192	107	-5	16		17	41	
June-August	12	10	2	28		-53	75	
September-November	175	115	3	19		-31	51	
January	177	122	-22	19		-47	45	
February	151	115	5	20		91	52	
March	122	91	-14	22		14	54	
April	49	36	19	22		-25	47	
May	21	28	-19	32		142	88	
June	7	7	-22	35		-43	92	
July	2	4	61	94		-67	254	
August	3	6	75	61		-75	136	
September	10	11	-107	52	*	-122	121	
October	47	40	5	25		-21	71	
November	118	95	13	25		-29	70	
December	133	92	28	22		26	67	

Table 4. Fort Point National Historic Site. Historical average temperatures and temperature trends of the area within the park boundary. SD = standard deviation, SE = standard error, sig. = statistical significance, * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	°C		°C century ⁻¹			°C century ⁻¹		
Annual	13.8	0.6	0.9	0.2	**	1.6	0.6	*
December-February	10.8	0.8	1	0.3	***	1.4	0.5	*
March-May	13.3	0.9	0.8	0.3	*	2	0.8	*
June-August	15.9	0.6	0.7	0.3	*	2.3	0.8	**
September-November	15.2	0.7	1	0.2	***	0.7	0.5	
January	10.2	1	1.1	0.3	***	2.2	0.7	**
February	11.9	1.1	0.8	0.3	*	1.1	0.7	
March	12.7	1.2	0.8	0.4	*	2.6	0.9	**
April	13.1	1.1	0.5	0.3		1.5	0.9	
May	14.1	1.1	1	0.3	**	1.7	0.8	*
June	15.3	0.9	0.4	0.3		1.9	0.8	*
July	16.1	0.8	0.4	0.3		2.2	0.8	*
August	16.5	0.8	1.2	0.3	***	2.6	0.9	**
September	16.8	1	1.2	0.3	***	0.7	0.8	
October	15.8	0.8	1.2	0.3	***	0.8	0.7	
November	13.1	1.1	0.6	0.3	*	0.6	0.6	
December	10.3	1.2	1.1	0.4	**	0.7	0.8	

Table 5. Fort Point National Historic Site. Historical average precipitation totals and precipitation trends of the area within the park boundary. SD = standard deviation, SE = standard error, sig. = statistical significance, * $P \leq 0.05$, ** $P \leq 0.01$, * $P \leq 0.001$.**

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	mm y ⁻¹		% century ⁻¹			% century ⁻¹		
Annual	609	225	9	9		19	27	
December-February	329	154	13	13		32	32	
March-May	142	83	2	16		24	44	
June-August	8	8	6	33		-61	84	
September-November	136	93	8	20		-21	54	
January	126	87	-9	20		-27	47	
February	111	87	16	20		109	54	
March	94	69	-3	21		21	55	
April	32	26	29	24		-16	51	
May	16	22	-24	34		141	97	
June	4	5	-18	41		-39	106	
July	1	3	54	128		-149	352	
August	3	6	62	69		-81	152	
September	9	11	-121	52	*	-122	119	
October	33	30	9	27		-11	76	
November	95	79	23	25		-16	71	
December	86	57	37	22		33	66	

Table 6. Muir Woods National Monument. Historical average temperatures and temperature trends of the area within the park boundary. SD = standard deviation, SE = standard error, sig. = statistical significance, * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	°C		°C century ⁻¹			°C century ⁻¹		
Annual	14	0.5	1	0.2	***	1.3	0.5	*
December-February	9.8	0.8	1	0.3	***	1.1	0.5	*
March-May	13.2	0.9	1.1	0.3	***	1.9	0.8	*
June-August	17.4	0.5	0.8	0.2	***	1.7	0.5	**
September-November	15.6	0.7	1.1	0.2	***	0.6	0.5	
January	9.2	1.1	1.2	0.4	**	2.1	0.7	**
February	10.9	1.1	1	0.4	**	0.8	0.8	
March	11.9	1.2	1.1	0.4	**	2.5	0.9	**
April	13.1	1.2	0.7	0.3	*	1.2	0.9	
May	14.7	1.1	1.3	0.3	***	1.9	0.7	*
June	16.7	0.9	0.7	0.3	*	1.6	0.7	*
July	17.5	0.7	0.6	0.2	*	1.5	0.7	*
August	17.9	0.7	1.3	0.3	***	2	0.7	**
September	17.9	1.1	1.3	0.4	***	0.6	0.8	
October	16.3	0.9	1.2	0.3	***	0.8	0.7	
November	12.5	1.2	0.7	0.3	*	0.4	0.7	
December	9.4	1.3	1	0.4	**	0.3	0.9	

Table 7. Muir Woods National Monument. Historical average precipitation totals and precipitation trends of the area within the park boundary. SD = standard deviation, SE = standard error, sig. = statistical significance, * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	mm y ⁻¹		% century ⁻¹			% century ⁻¹		
Annual	1134	371	-7	9		-2	21	1134
December-February	598	263	-5	13		4	31	598
March-May	271	148	-15	16		7	40	271
June-August	16	14	20	27		-47	74	16
September-November	258	166	-7	19		-23	50	258
January	226	153	-31	19		-70	44	226
February	204	146	-8	21		64	49	204
March	178	143	-26	23		-1	53	178
April	60	40	15	23		-35	47	60
May	32	41	-14	30		138	79	32
June	9	10	-7	36		-35	103	9
July	3	7	69	78		-11	206	3
August	5	7	76	48		-92	104	5
September	15	18	-111	43	*	-63	114	15
October	57	48	6	25		-26	73	57
November	185	141	-2	24		-19	65	185
December	158	110	34	23		40	74	158

Figure 9.

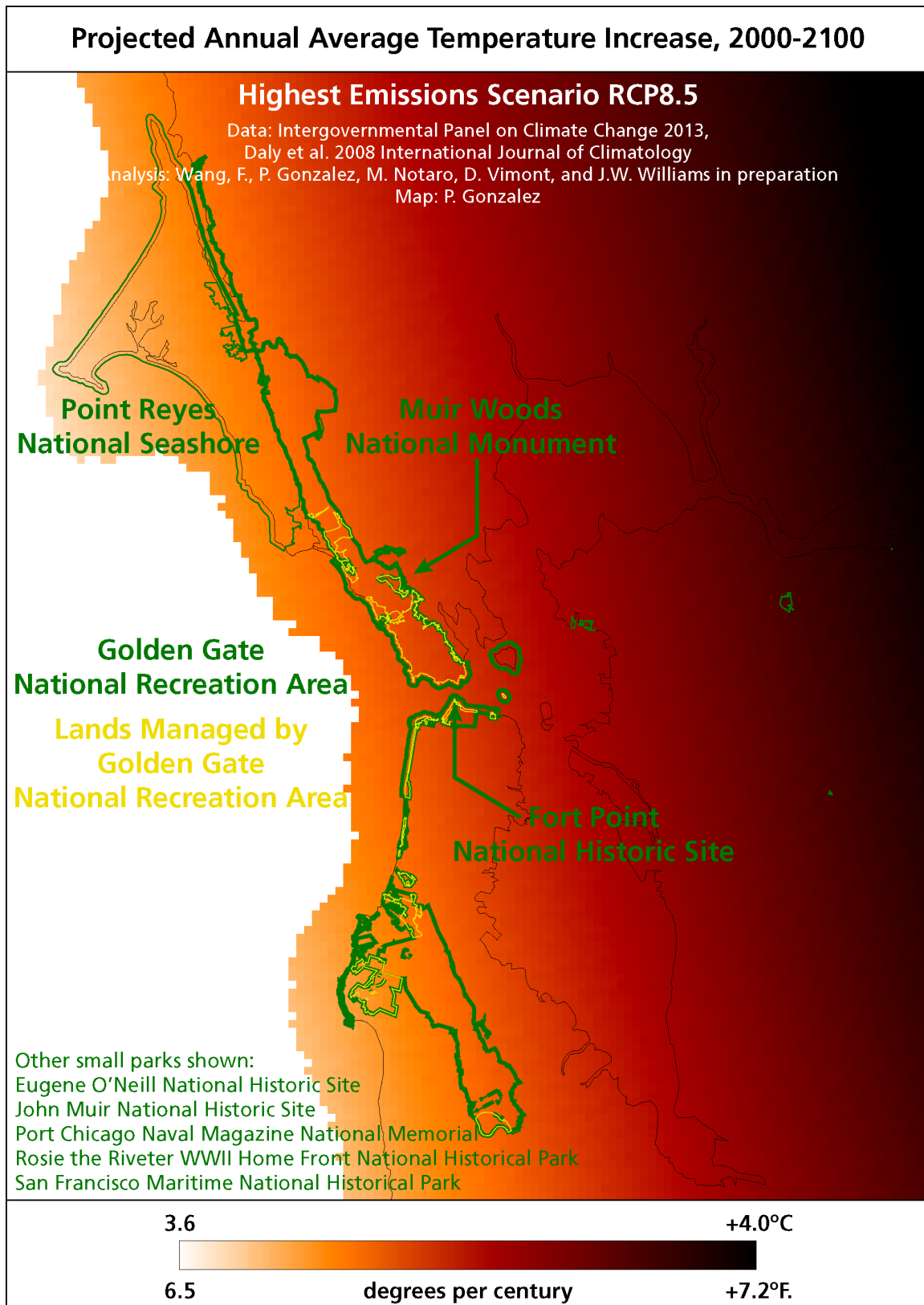


Figure 10.

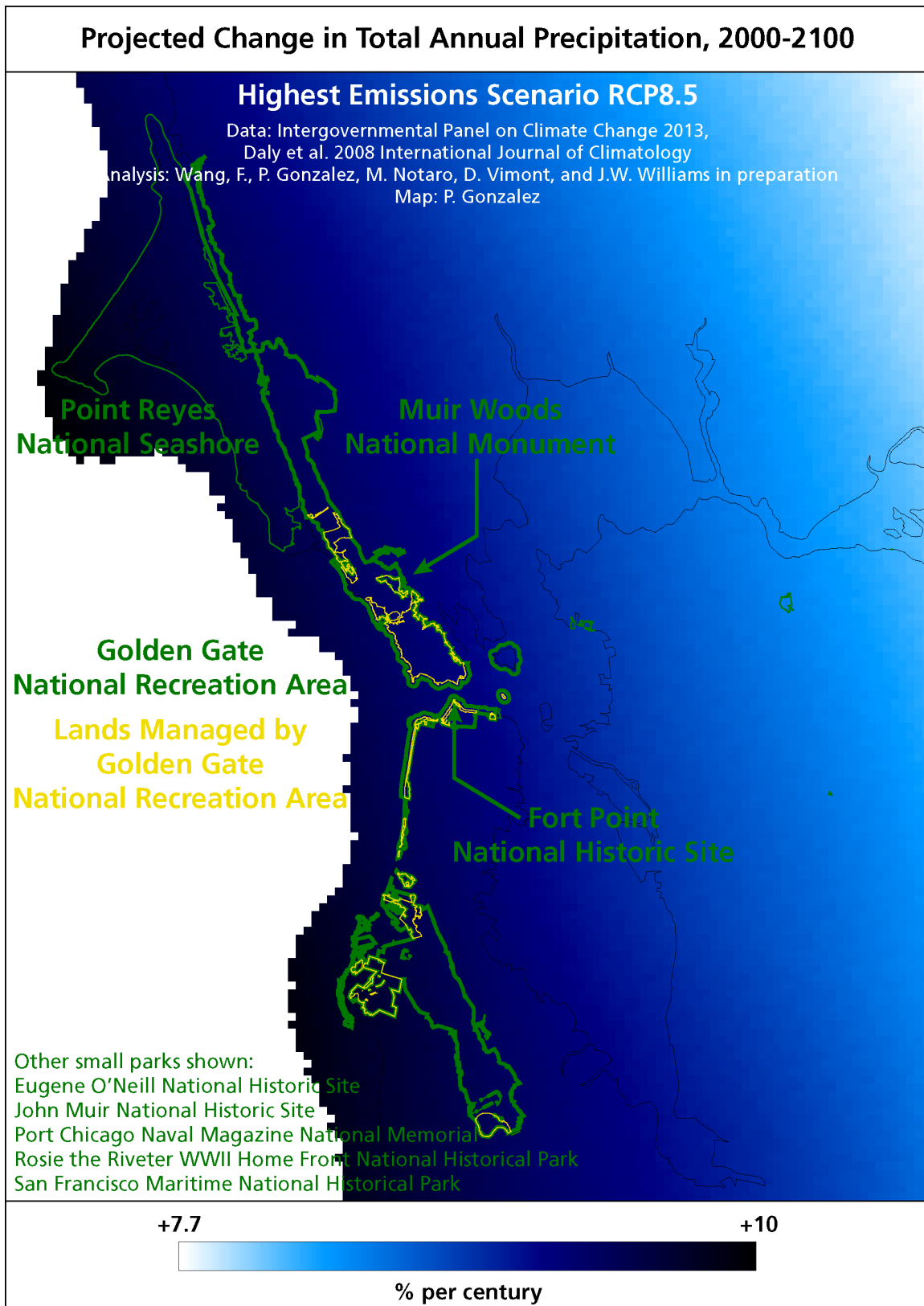


Figure 11. Golden Gate National Recreation Area. Projections of future climate for the area within the legislative boundary. Each small dot is the output of a single climate model. The large color dots are the average values for the four IPCC emissions scenarios. The lines are the standard deviations of each average value. (Data: IPCC 2013, Daly et al. 2008; Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

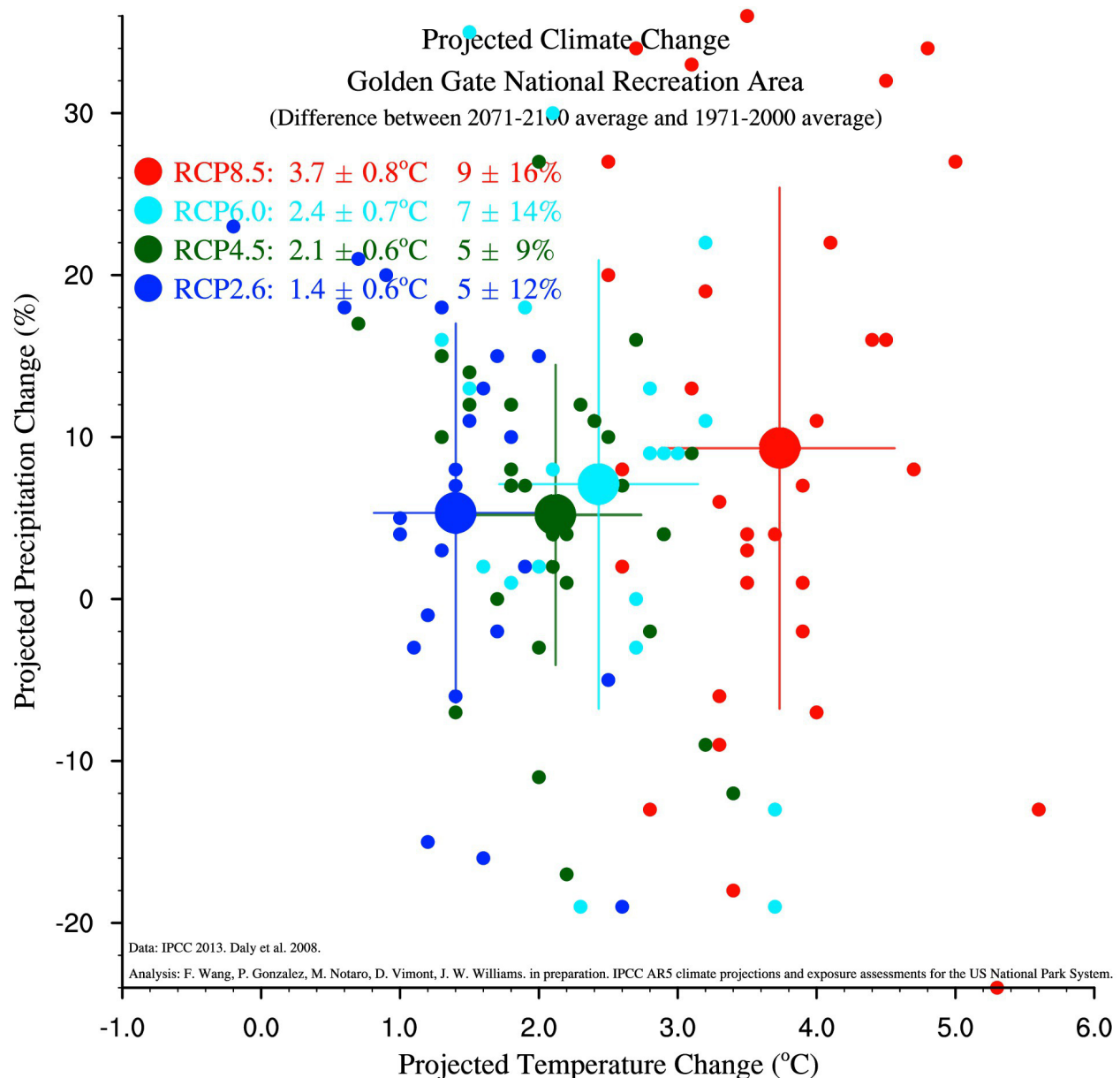


Figure 12. Fort Point National Historic Site. Projections of future climate for the area within the park boundary. Each small dot is the output of a single climate model. The large color dots are the average values for the four IPCC emissions scenarios. The lines are the standard deviations of each average value. (Data: IPCC 2013, Daly et al. 2008; Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

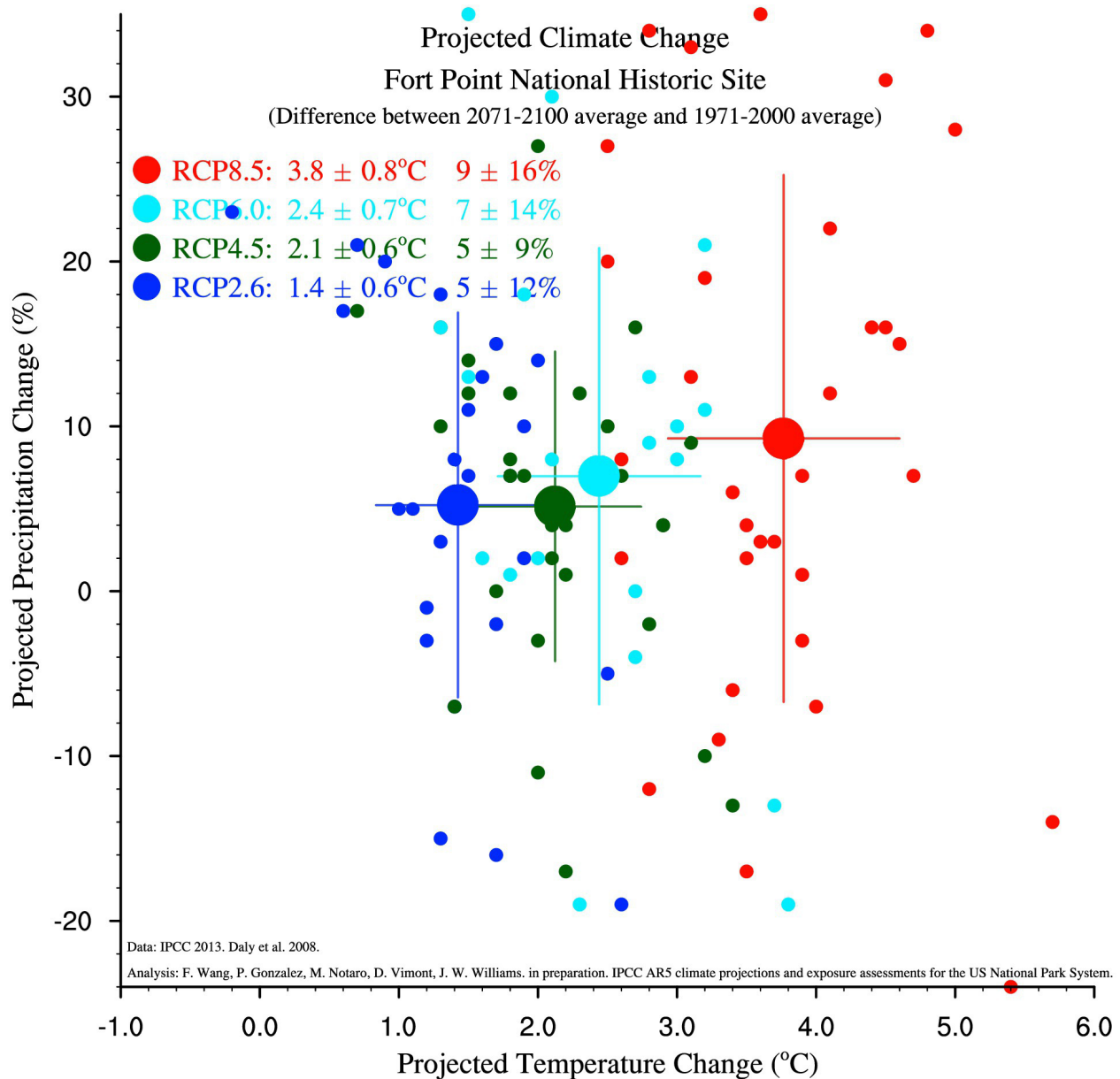


Figure 13. Muir Woods National Monument. Projections of future climate for the area within the park boundary. Each small dot is the output of a single climate model. The large color dots are the average values for the four IPCC emissions scenarios. The lines are the standard deviations of each average value. (Data: IPCC 2013, Daly et al. 2008; Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

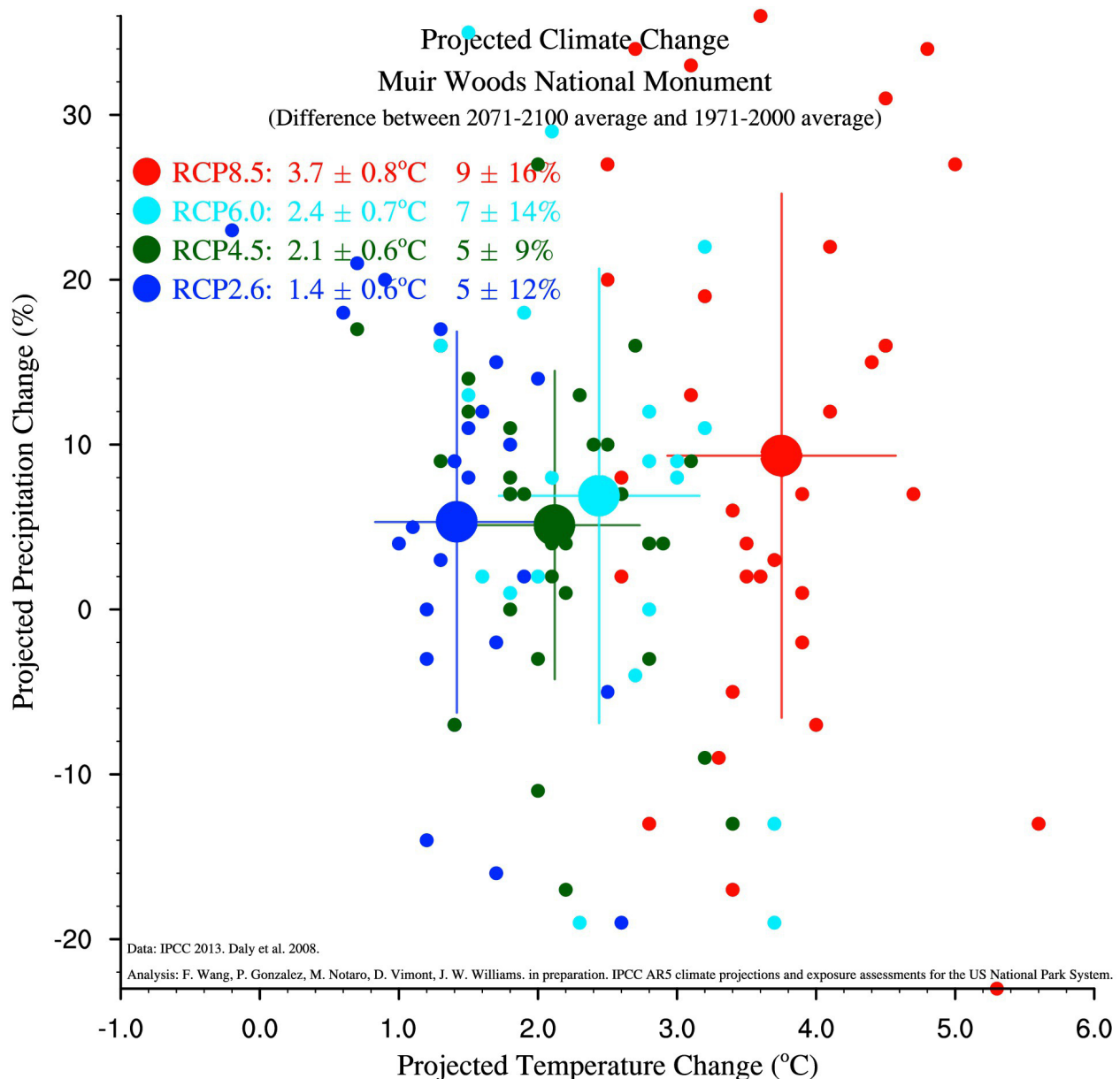


Table 8. Golden Gate National Recreation Area. Projected temperature increases (°C), 2000 to 2100, for the area within the legislative boundary, from the average of all general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	1.4	0.6	2.1	0.6	2.4	0.7	3.7	0.8
December-February	1.4	0.5	2	0.6	2.2	0.7	3.4	0.8
March-May	1.3	0.6	1.8	0.6	2.2	0.6	3.3	0.8
June-August	1.4	0.7	2.2	0.8	2.6	0.8	3.9	0.9
September-November	1.5	0.7	2.4	0.9	2.7	0.8	4.3	1.2
January	1.4	0.5	2	0.6	2.3	0.7	3.5	0.8
February	1.3	0.6	1.9	0.6	2.2	0.6	3.3	0.7
March	1.3	0.7	1.8	0.6	2.1	0.7	3.2	0.9
April	1.3	0.5	1.7	0.6	2.2	0.6	3.2	0.8
May	1.3	0.6	1.9	0.6	2.3	0.7	3.4	0.8
June	1.4	0.8	2.1	0.9	2.4	0.9	3.7	1
July	1.4	0.8	2.2	0.8	2.6	0.9	3.9	1
August	1.5	0.7	2.4	0.7	2.8	0.8	4.2	0.9
September	1.7	0.8	2.6	0.8	2.9	1	4.5	1.1
October	1.5	0.8	2.5	1	2.7	0.9	4.4	1.3
November	1.4	0.6	2.3	1.1	2.5	0.8	4	1.4
December	1.4	0.5	2.1	0.9	2.2	0.8	3.6	1.1

Table 9. Golden Gate National Recreation Area. Projected precipitation changes (%), 2000 to 2100, for the area within the legislative boundary, from the average of all general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	5	12	5	9	7	14	9	16
December-February	7	15	11	14	13	19	19	22
March-May	7	16	2	21	2	12	2	26
June-August	24	35	31	63	12	37	40	78
September-November	-2	14	-6	24	-6	20	-12	23
January	9	20	14	20	12	22	23	26
February	7	22	15	24	19	31	27	38
March	7	20	4	20	8	16	9	24
April	8	25	0	25	-6	20	-6	38
May	14	37	2	50	-7	29	-12	48
June	8	35	-7	36	-13	31	-8	44
July	99	220	146	240	142	224	186	311
August	67	112	96	148	51	88	112	146
September	10	63	10	69	4	41	21	82
October	7	32	-8	26	-2	34	-16	32
November	-6	13	-7	28	-9	18	-14	29
December	6	23	4	23	13	25	9	24

Table 10. Fort Point National Historic Site. Projected temperature increases (°C), 2000 to 2100, for the area within the park boundary, from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	1.4	0.6	2.1	0.6	2.5	0.7	3.8	0.8
December-February	1.4	0.5	2	0.6	2.2	0.7	3.5	0.8
March-May	1.3	0.6	1.8	0.6	2.2	0.6	3.3	0.8
June-August	1.4	0.8	2.2	0.8	2.6	0.8	4	0.9
September-November	1.6	0.7	2.5	0.9	2.7	0.9	4.3	1.2
January	1.4	0.6	2	0.6	2.3	0.7	3.5	0.8
February	1.3	0.6	1.9	0.6	2.2	0.6	3.3	0.8
March	1.3	0.7	1.8	0.6	2.2	0.7	3.2	0.9
April	1.3	0.5	1.7	0.6	2.2	0.6	3.2	0.8
May	1.3	0.6	1.9	0.7	2.3	0.7	3.5	0.9
June	1.4	0.8	2.1	0.9	2.5	0.9	3.8	1
July	1.4	0.8	2.2	0.8	2.6	0.9	3.9	1
August	1.5	0.7	2.4	0.7	2.8	0.8	4.2	0.9
September	1.7	0.8	2.6	0.8	2.9	1	4.5	1.2
October	1.5	0.8	2.5	1.1	2.7	0.9	4.5	1.3
November	1.4	0.6	2.3	1.2	2.6	0.8	4	1.4
December	1.4	0.5	2.1	0.9	2.2	0.8	3.6	1.2

Table 11. Fort Point National Historic Site. Projected precipitation changes (%), 2000 to 2100, for the area within the park boundary, from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	5	12	5	9	7	14	9	16
December-February	7	15	10	14	13	19	19	22
March-May	7	16	2	21	2	12	1	26
June-August	23	35	31	63	11	35	39	77
September-November	-2	15	-6	24	-6	20	-12	23
January	9	20	14	20	12	22	23	26
February	7	23	15	24	19	31	27	38
March	7	20	4	20	8	17	8	24
April	8	25	-1	25	-6	20	-6	37
May	13	37	2	49	-7	29	-12	48
June	7	34	-6	37	-14	30	-9	43
July	98	231	142	244	140	223	184	318
August	66	112	96	150	50	87	110	145
September	11	64	10	69	4	42	21	83
October	8	32	-8	26	-1	35	-16	33
November	-6	13	-7	28	-9	18	-14	29
December	6	23	4	23	13	25	9	24

Table 12. Muir Woods National Monument. Projected temperature increases (°C), 2000 to 2100, for the area within the park boundary, from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	1.4	0.6	2.1	0.6	2.5	0.7	3.8	0.8
December-February	1.4	0.5	2	0.6	2.2	0.7	3.4	0.8
March-May	1.3	0.6	1.8	0.6	2.2	0.6	3.3	0.8
June-August	1.4	0.7	2.2	0.8	2.6	0.8	4	0.9
September-November	1.5	0.7	2.4	0.9	2.7	0.8	4.3	1.2
January	1.4	0.6	2	0.6	2.3	0.7	3.5	0.8
February	1.3	0.6	1.9	0.6	2.2	0.6	3.3	0.7
March	1.3	0.7	1.8	0.6	2.2	0.7	3.2	0.9
April	1.3	0.5	1.7	0.6	2.2	0.6	3.2	0.8
May	1.3	0.6	1.9	0.7	2.3	0.7	3.4	0.8
June	1.4	0.8	2.1	0.9	2.5	0.9	3.7	1
July	1.4	0.8	2.2	0.8	2.7	0.9	3.9	1
August	1.5	0.7	2.4	0.7	2.8	0.8	4.2	0.9
September	1.7	0.8	2.6	0.8	2.9	1	4.5	1.1
October	1.5	0.8	2.5	1	2.7	0.9	4.4	1.3
November	1.4	0.6	2.3	1.1	2.5	0.8	4	1.4
December	1.4	0.5	2.1	0.9	2.2	0.7	3.6	1.1

Table 13. Muir Woods National Monument. Projected precipitation changes (%), 2000 to 2100, for the area within the park boundary, from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	5	12	5	9	7	14	9	16
December-February	7	15	10	14	13	19	19	22
March-May	7	16	2	20	2	12	2	26
June-August	23	35	30	62	12	36	38	77
September-November	-2	14	-6	24	-6	19	-12	24
January	9	20	14	20	12	22	23	26
February	7	22	14	24	19	30	27	37
March	7	20	4	20	8	16	8	24
April	8	25	0	25	-6	20	-6	37
May	14	37	2	49	-8	29	-11	48
June	7	35	-7	37	-14	31	-9	44
July	108	252	154	260	157	253	199	342
August	66	114	92	139	51	88	108	144
September	10	61	10	68	4	41	20	82
October	7	32	-8	26	-2	34	-16	32
November	-6	13	-6	28	-9	18	-13	29
December	6	23	4	23	13	25	9	24

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