

Climate Change Trends, Impacts, and Vulnerabilities, Great Smoky Mountains National Park, USA

Patrick Gonzalez

Natural Resource Stewardship and Science, U.S. National Park Service, Washington, DC

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Climate Trends for the Area within Park Boundaries

- Analyses of temperature data downscaled to 800 m spatial resolution (Daly et al. 2008, Wang et al., in preparation) show no statistically significant changes in the period 1950-2010 (Table 1, Figure 1). While temperatures have increased across most of the world, the southeastern U.S. is an anomaly due to the cooling effect of increased precipitation, El Niño, and other factors (Portmann et al. 2009).
- Analysis of temperature data downscaled to 30 m spatial resolution (Lesser and Fridley 2015) shows no increase in temperature in the period 1980-2011 except for an increase in spring minimum temperature.
- Average annual temperature changes have been higher in the western half of the park (Figure 2).
- Precipitation increased in the period 1950-2010 but the rates have not been statistically significant (Table 2, Figure 3).
- Precipitation changes have been highest in the central mountain ridge of the park (Figure 4).
- If the world does not reduce emissions from power plants, cars, and deforestation by 40-70%, models project substantial warming (Table 3) and changes in precipitation (Table 4). Figure 5).
- For average annual precipitation, the climate models show broad agreement on projections increases (Figure 5).
- Projections under the highest emissions scenario project 10-20 more days per year with a maximum temperature >35°C (95°F.) and an increase in 20-year storms (a storm with more precipitation than any other storm in 20 years) to once every 5-6 years (Walsh et al. 2014).

Historical Change Detected and Attributed to Climate Change

- Analyses of Audubon Christmas Bird Count data across the United States, including counts in the park, 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 and not other factors (La Sorte and Thompson 2007).

Future Vulnerabilities

Forests

- Under the highest emissions scenario, climate change could shift the ranges of numerous tree species northward, reducing potential densities of red maple (*Acer rubrum*) and white oak (*Quercus alba*) (Iverson et al. 2008).
- Under a medium emissions scenario, suitable habitat for red spruce (*Picea rubens*) may contract at lower and higher elevations, with the range losses exacerbated if air pollution increases (Koo et al. 2015).
- Climate change could shift the potential ranges of a group of 35 eastern forest species northward out of the park, reducing the combined potential ranges by two-fifths under a low emissions scenario and by half under a high emissions scenario (Zolkos et al. 2015).
- Under a high emissions scenario, fire frequencies could increase slightly by 2100 (Moritz et al. 2012). In the past, wildfire favored oaks and pines, which tolerate drier conditions (Flatley et al. 2015).
- Under continued climate change, longer growing seasons may increase the risk of southern pine beetle outbreaks, increasing forest mortality (McNulty et al. 2013).
- Under continued climate change, increasing winter temperatures may exacerbate hemlock woolly adelgid infestation and increase mortality of hemlock trees (Dukes et al. 2009).
- Under a high emissions scenario, the region could become more favorable to the growth of the invasive plants kudzu (*Pueraria lobata*) and privet (*Ligustrum sinense*) (Bradley et al. 2010).
- Experimental increases of atmospheric carbon dioxide in a North Carolina forest indicate that climate change could increase the growth and toxicity of poison ivy (Mohan et al. 2006).

Air Pollution

- Increased ammonia emissions under a range of climate change scenarios could increase nitrogen deposition by 2050 above critical loads for sensitive ecosystems in the park (Ellis et al. 2013).
- Future emissions reductions would reduce particulate (PM_{2.5}) and surface ozone (O₃) concentrations in the park, even with the increased temperatures of climate change (Val Martin et al. 2015).

Other Vulnerabilities

- Analyses of the potential distributions of 213 mammal species under a temperature increase of 3.8°C by 2100 project a possible loss of eight species and influx of 29 species into the park (Burns et al. 2003). Species vulnerable to local disappearance include the red squirrel (*Tamiasciurus hudsonicus*), southern red-back vole (*Clethrionomys gapperi*) and the endangered northern flying squirrel (*Glaucomys sabrinus*). Twelve of the potential new species are rodents.
- Drought conditions can increase ranavirus infection rates among salamanders (Sutton et al. 2014).
- Projected changes in rainfall timing and amount, potential evapotranspiration, and other factors may alter river and stream hydrology and reduce water availability (Ingram et al. 2013).
- Continued warming of water temperatures could threaten coldwater fish (TWRA 2009).
- Under high emissions, hotter temperatures may shift the range for the endangered Indiana Bat (*Myotis sodalis*) northward away from the park due to a loss of suitable summer climate for maternity colonies (Loeb and Winters 2013).

Table 1. Historical average temperatures and temperature trends of the area within the boundaries of Great Smoky Mountains National Park (data Daly et al. 2008; analysis Wang et al. in preparation). 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	10.8	0.5	-0.4	0.2		0.1	0.5	
December-February	1.8	1.5	-0.5	0.6		-0.8	1.5	
March-May	10.3	0.8	-0.4	0.2		0.2	0.6	
June-August	19.6	0.6	-0.2	0.2		0.4	0.6	
September-November	11.6	1	-0.4	0.3		0.6	0.7	
January	0.7	2.8	-1.7	0.9		-1.8	2.7	
February	2.2	2	0.1	0.8		-1	2.1	
March	6.1	1.8	-0.6	0.6		1.6	1.3	
April	10.3	1.3	0.2	0.4		-0.1	1	
May	14.6	1.5	-0.6	0.3		-0.8	0.9	
June	18.4	0.9	-0.5	0.4		0.2	0.8	
July	20.4	0.9	-0.1	0.3		0.2	0.7	
August	19.8	0.8	-0.1	0.2		0.8	0.7	
September	16.9	1	-0.9	0.4	*	-0.1	0.9	
October	11.3	1.7	-0.5	0.5		-0.3	1.2	
November	6.5	1.8	0.2	0.4		2.2	1.4	
December	2.3	2.2	-0.3	0.6		-0.1	1.5	

Table 2. Historical average precipitation totals and precipitation trends of the area within the boundaries of Great Smoky Mountains National Park (data Daly et al. 2008; analysis Wang et al. in preparation). 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	1652	237	2	4		4	11	
December-February	432	111	3	7		-12	20	
March-May	447	107	1	7		-7	20	
June-August	428	99	-13	7		11	14	
September-November	346	91	28	8	***	34	18	
January	155	61	11	12		-4	30	
February	138	53	-6	11		-39	32	
March	166	71	-12	11		-53	36	
April	129	53	-4	10		-4	25	
May	152	48	22	11		45	30	
June	152	58	-9	11		23	25	
July	151	59	-12	10		6	22	
August	126	51	-17	11		3	36	
September	124	55	29	13	*	62	29	
October	93	49	6	14		4	35	
November	129	38	45	12	***	29	21	
December	138	58	-4	13		-3	32	

Table 3. Projected temperature increases (°C), 2000 to 2100, for the area within Great Smoky Mountains National Park boundaries, from the average of all available general circulation model projections used for IPCC (2013) (analysis Wang et al. in preparation). 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	1.5	0.6	2.6	0.7	3	0.7	4.6	0.9
December-February	1.3	0.7	2.2	0.8	2.5	0.8	3.8	1
March-May	1.4	0.6	2.3	1.1	2.8	0.6	4.1	1.2
June-August	1.6	0.6	2.8	0.8	3.3	0.8	5.1	1.1
September-November	1.6	0.8	3	1.6	3.3	0.9	5.4	1.9
January	1.2	0.8	2.2	0.9	2.4	0.7	3.7	1.2
February	1.1	0.8	2	0.9	2.3	1	3.6	0.9
March	1.2	0.7	1.9	1.2	2.4	0.7	3.4	1.3
April	1.5	0.6	2.4	1.1	2.9	0.7	4.2	1.2
May	1.4	0.6	2.5	1.1	3.1	0.6	4.6	1.3
June	1.6	0.5	2.7	1	3.2	0.7	4.9	1.2
July	1.6	0.6	2.7	0.8	3.3	0.9	5	1.1
August	1.7	0.8	3	0.9	3.4	1.1	5.3	1.3
September	1.7	0.9	3.2	1.4	3.6	1.1	5.6	1.8
October	1.7	0.9	3.2	1.7	3.5	1.1	5.6	2.1
November	1.4	0.8	2.8	1.7	2.9	0.8	4.8	1.9
December	1.5	0.9	2.5	1.7	2.7	1.1	4.1	1.8

Table 4. Projected precipitation increases (%), 2000 to 2100, for the area within Great Smoky Mountains National Park boundaries, from the average of all available general circulation model projections used for IPCC (2013) (analysis Wang et al. in preparation). 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	6	6	7	5	7	7	10	9
December-February	3	8	6	10	6	12	10	13
March-May	8	9	8	9	8	9	12	11
June-August	7	10	7	10	7	12	7	13
September-November	4	8	5	8	7	10	9	11
January	2	12	5	14	5	16	9	16
February	4	11	7	15	8	16	11	17
March	7	11	8	11	7	15	15	15
April	12	16	13	14	12	15	15	16
May	5	13	5	13	5	15	5	15
June	8	15	8	13	11	16	4	16
July	7	11	6	14	4	14	7	14
August	6	11	7	12	7	14	12	16
September	10	12	13	15	14	17	17	21
October	3	16	2	14	5	19	7	17
November	0	12	1	13	1	12	3	15
December	5	12	8	15	7	14	12	16

Figure 1. Historical annual average temperature for the area within park boundaries. 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).

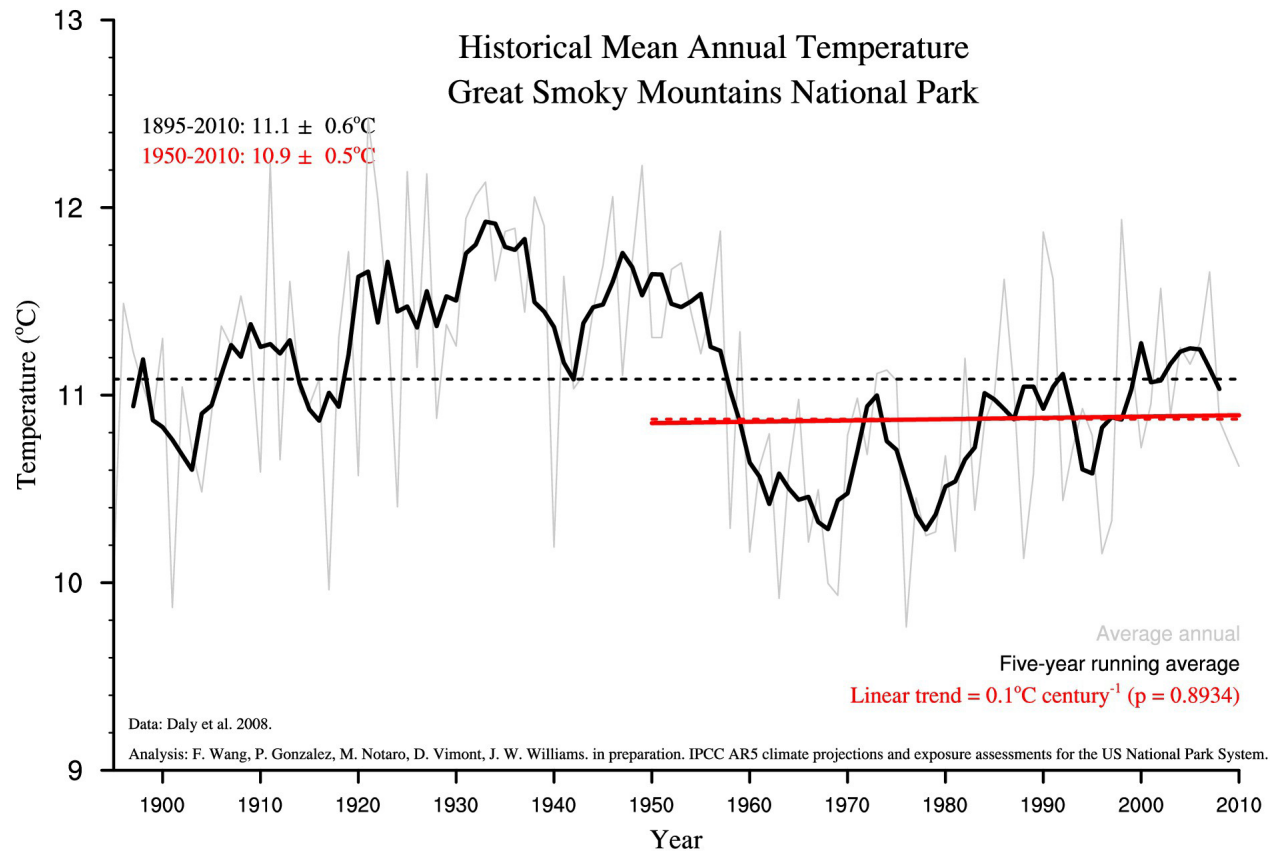


Figure 2.

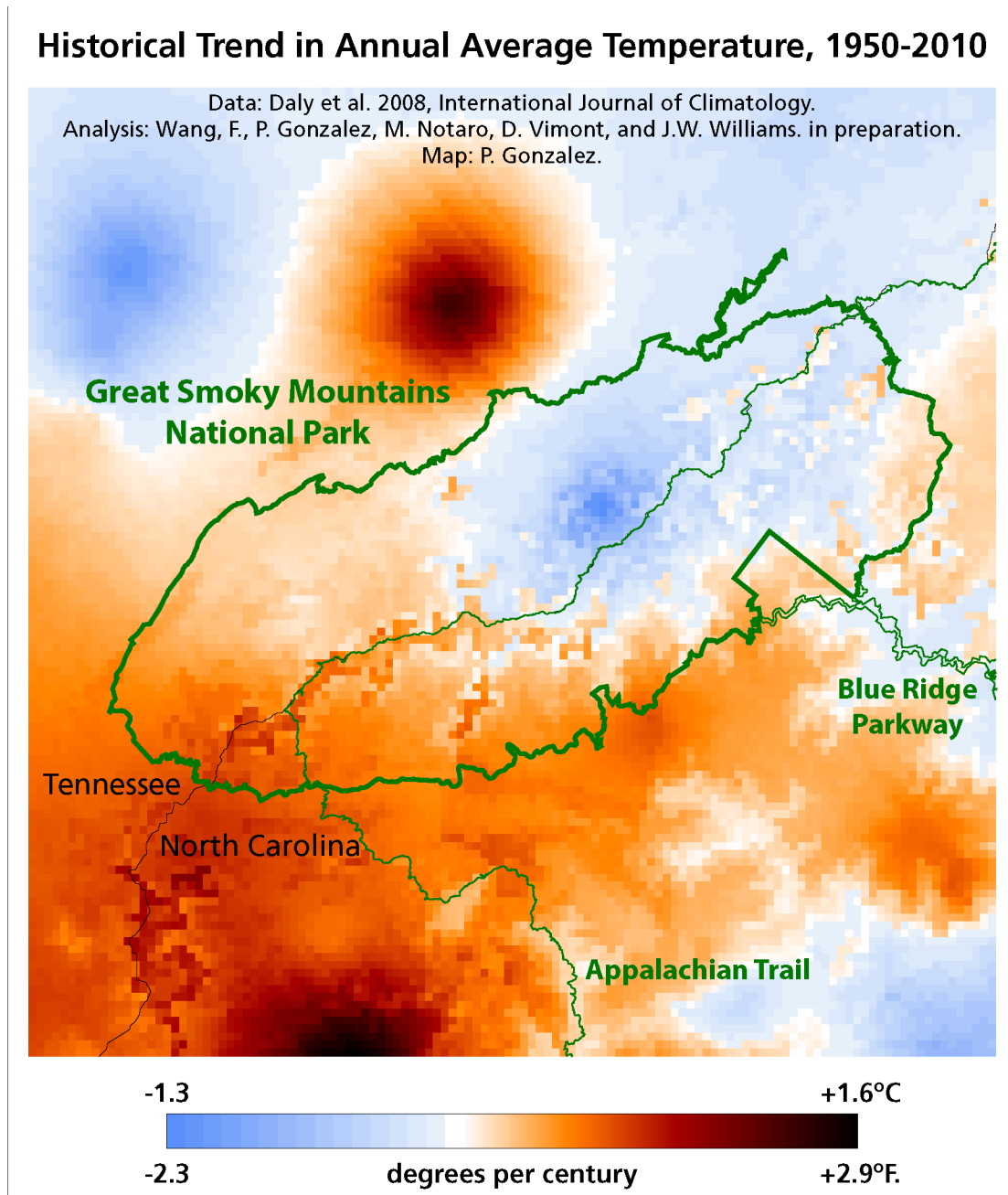


Figure 3. Historical annual total precipitation for the area within park boundaries. Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

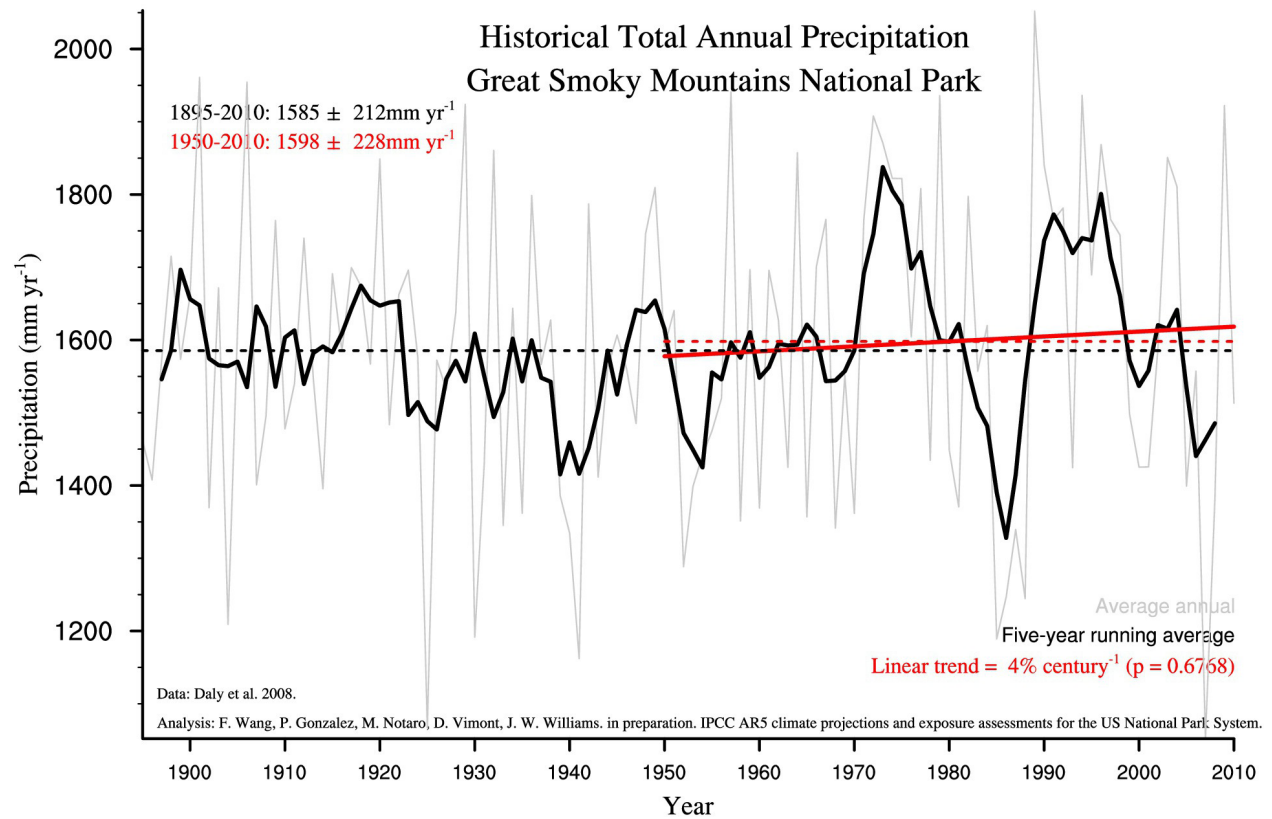


Figure 4.

Historical Trend in Total Annual Precipitation, 1950-2010

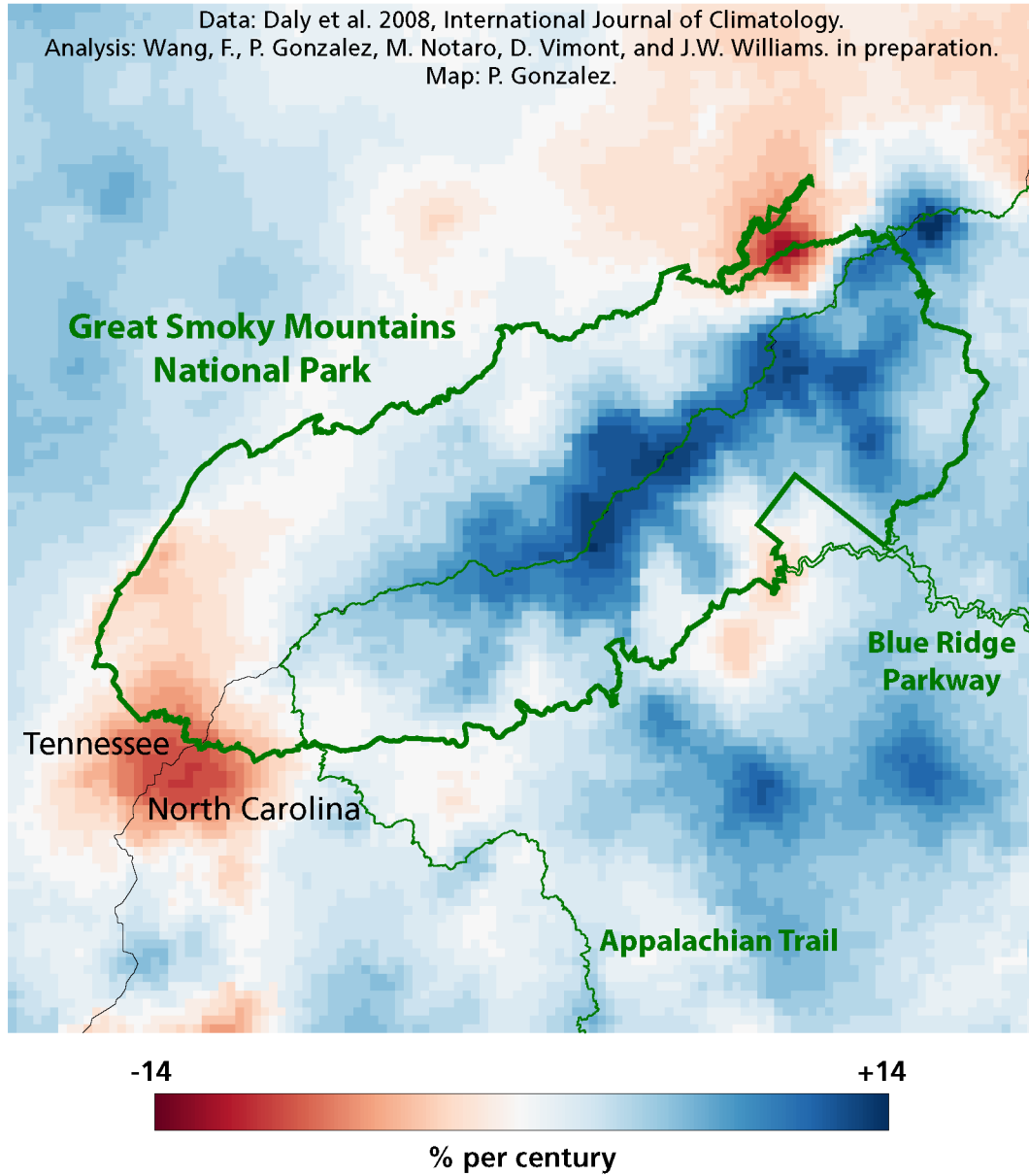
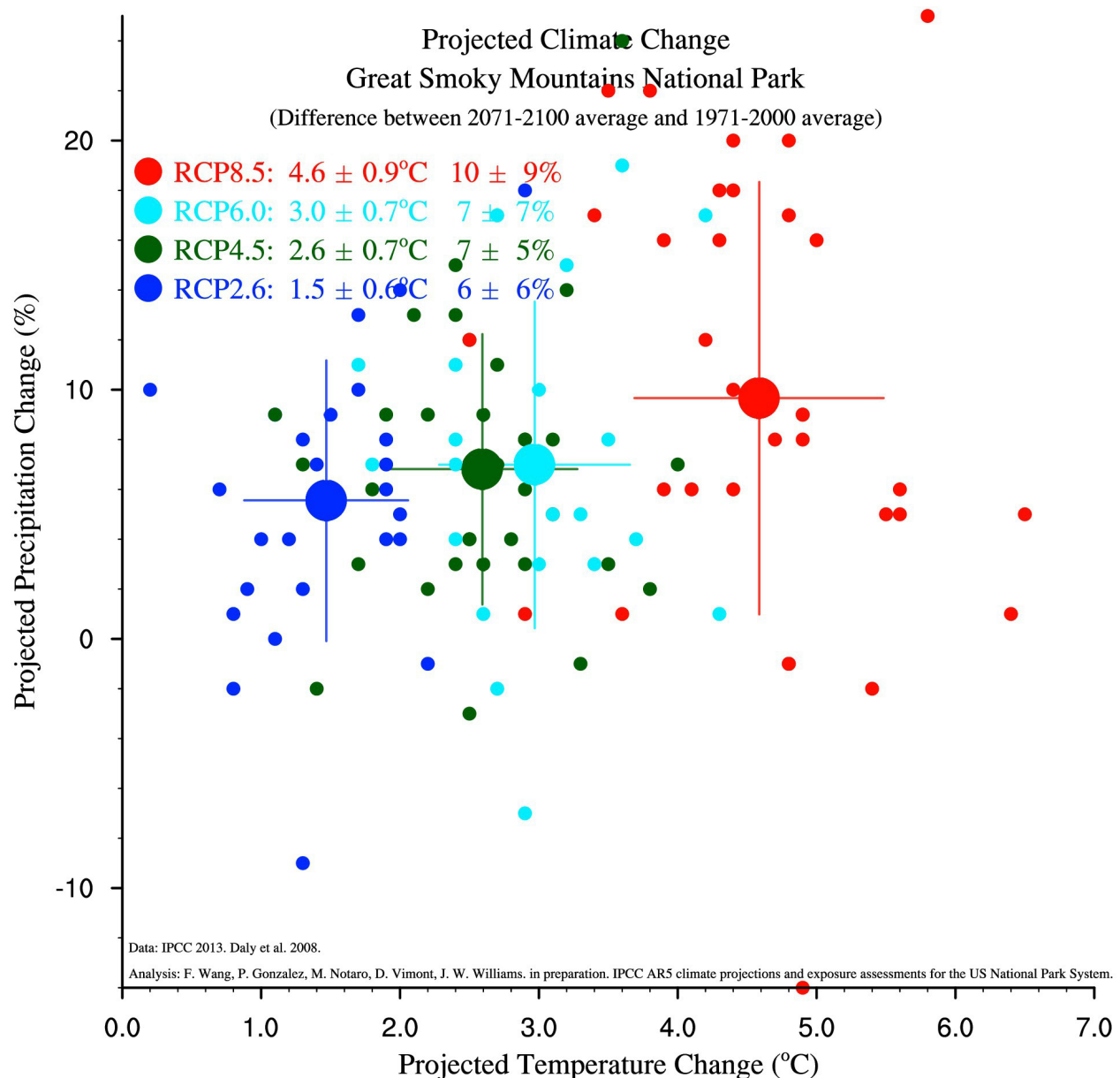


Figure 5. Projections of future climate for the area within park boundaries. Each small dot is the output of a single climate model. The large color dots are the average values for the four IPCC emissions scenarios. The lines are the standard deviations of each average value. (Data: IPCC 2013, Daly et al. 2008; Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).



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