Climate Change Trends, Impacts, and Vulnerabilities,

Great Sand Dunes National Park and Preserve, Colorado

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January 29, 2016

Climate Trends for the Area within Park and Preserve Boundaries

- Average annual temperature increased in the park and the preserve in the period 1950-2010, but the rates were not statistically significant (Tables 1, 2; Figure 1).
- Total annual precipitation increased at statistically significant rates in the park and the preserve in the period 1950-2010 (Tables 1, 2, Figure 2).
- Historical rates of temperature and precipitation increase were greater at higher elevations, mainly in the Preserve (Figures 3, 4).
- If the world does not reduce emissions from power plants, cars, and deforestation by 40-70%, models project substantial warming and changes in precipitation (Tables 1, 2; Figure 5).
- For projected average annual precipitation, climate models do not agree, with the average of all models projecting an increase, but many individual models projecting decreases (Figure 5).
- Even if precipitation increases, temperature increases may overcome any cooling effects of increased precipitation, leading to increased evapotranspiration and overall aridity.
- Under the highest emissions scenario, climate models project an increase in 20-year storms (a storm with more precipitation than any other storm in 20 years) to once every 6-10 years (Walsh et al. 2014).

Historical Impacts in the Region Attributed to Human Climate Change

- **Physical changes** Analyses of data from weather stations and snow courses across the western United States have detected statistically significant physical changes in the 20th century and attributed these to climate change. The changes include decreased snowpack (Barnett et al. 2008; Pierce et al. 2008), decreased ratio of snow to rain (Pierce et al. 2008), and earlier spring stream flow (Barnett et al. 2008) from 1950 to 1999 and earlier spring warmth from 1950 to 2005 (Ault et al. 2011).
- **Wildfire** Multivariate analysis of wildfire across the western U.S. from 1916 to 2003 indicates that climate was the dominant factor determining how much land burned, even during periods of active fire suppression (Littell et al. 2009).

- **Bark beetles and tree mortality** Climate change has caused bark beetle outbreaks, including in southern Colorado, leading to the most extensive tree mortality across western North America in the last 125 years (Raffa et al. 2008).
- **Bird range shifts** Analyses of Audubon Christmas Bird Count data across the United States, including counts in southern Colorado, 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 in the Region

- **Stream flow** Under all emissions scenarios, reduced snowfall and rainfall and increased temperature could reduce the flow of springs, streams, and rivers (Garfin et al. 2014).
- **Wildfire** Under high emissions, fire frequencies could increase up to 25% by 2100 (Moritz et al. 2012).
- **Tree dieback** In areas experiencing drought, aridity and beetle infestations increase the vulnerability of piñon pines (*Pinus edulis*) and other tree species to dieback (Breshears et al. 2005).
- **Biome shifts** Alpine, sub-alpine, and mid-elevation forest and woodland biomes are moderately vulnerable to upslope shifts due to climate change (Gonzalez et al. 2010), exacerbated by habitat fragmentation (Eigenbrod et al. 2015).
- **Invasive species** Under high emissions, the region of the park and preserve would provide suitable habitat for the invasive species leafy spurge (*Euphorbia esula*) and spotted knapweed (*Centaurea biebersteinii*) (Bradley et al. 2009).
- **Fish** In New Mexico, south of the park, research on the Rio Grande sucker (*Catostomus plebeius*), a fish found in the park, indicates that the species is vulnerable to reduced genetic diversity if dry conditions reduce the number of wet reaches of intermittent streams (Turner et al. 2015).
- **Ptarmigan** In Rocky Mountain National Park, north of the park and preserve, warmer temperatures advanced white-tailed ptarmigan (*Lagopus leucurus*) hatching 15 days between 1975 and 1999 and reduced population growth rates, while future warming under the highest emissions scenarios could substantially reduce population sizes (Wang et al. 2002).
- **Pika** Modeling of American pika (*Ochotona princeps*) habitat in the western U.S., based on field occurrences, indicates that the species is vulnerable to habitat loss caused by upslope

shifting under climate change (Calkins et al. 2012, Galbreath et al. 2009). Analyses of pika in the park, preserve, and other locations, however, indicate that current locations of pika at a fine scale are not strictly related to climate, which makes future projections of pika ranges uncertain (Castillo et al. 2014, Erb et al. 2011, 2014, Jeffress et al. 2013).

- **Marmots** In western Colorado, the date of yellow-bellied marmot (*Marmota flaviventris*) emergence from hibernation advanced 38 days from 1976 to 1999 as temperatures increased (Inouye et al. 2000). Under future climate change, the species may be vulnerable to mismatch of food availability and the timing of the end of hibernation.
- **Bison** Analysis of 22 bison herds, including the San Luis Valley herd that lives in a park inholding, indicate that hotter and drier conditions may reduce forage quality and animal weight (Craine 2013).

Table 1. Great Sand Dunes National Park. 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 1950-2010. 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).

	1950-2010	**2000-2100**
Historical		
temperature	+0.7 ± 0.6°C per century (1.3 ± 1.1°F.)	
precipitation	+40 ± 17% per century	
Projected (compared to 1971-2000)		
Reduced emissions (IPCC RCP2.6)		
temperature		+1.6 ± 0.8°C per century (+3 ± 1.4°F.)
precipitation		+5 ± 8% per century
Low emissions (IPCC RCP4.5)		
temperature		+2.8 ± 0.8°C per century (+5 ± 1.4°F.)
precipitation		+4 ± 6% per century
High emissions (IPCC RCP6.0)		
temperature		+3.2 ± 0.9°C per century (+6 ± 1.6°F.)
precipitation		+3 ± 9% per century
Highest emissions (IPCC RCP8.5)		
temperature		+5.1 ± 1.1°C per century (+9 ± 2°F.)
precipitation		+2 ± 11% per century

Table 2. Great Sand Dunes National Preserve. 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 1950-2010. 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).

	1950-2010	**2000-2100**
Historical		
temperature	+1 ± 0.7°C per century (1.3 ± 1.1°F.)	
precipitation	+54 ± 19% per century	
Projected (compared to 1971-2000)		
Reduced emissions (IPCC RCP2.6)		
temperature		+1.6 ± 0.8°C per century (+3 ± 1.4°F.)
precipitation		+5 ± 8% per century
Low emissions (IPCC RCP4.5)		
temperature		+2.8 ± 0.8°C per century (+5 ± 1.4°F.)
precipitation		+4 ± 7% per century
High emissions (IPCC RCP6.0)		
temperature		+3.2 ± 0.9°C per century (+6 ± 1.6°F.)
precipitation		+3 ± 9% per century
Highest emissions (IPCC RCP8.5)		
temperature		+5.1 ± 1.1°C per century (+9 ± 2°F.)
precipitation		+2 ± 11% per century

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).

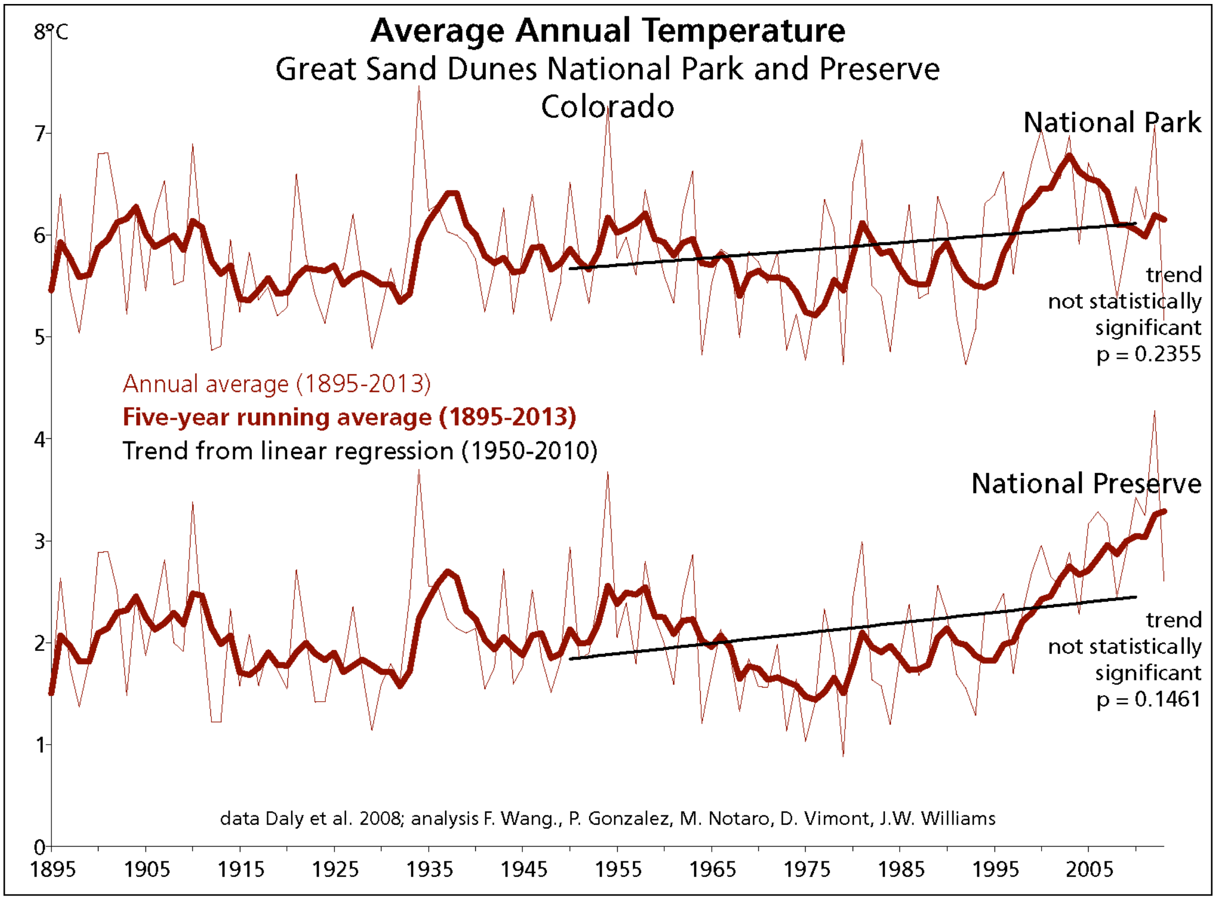


Figure 2. Historical annual total precipitation for the area within park boundaries. Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

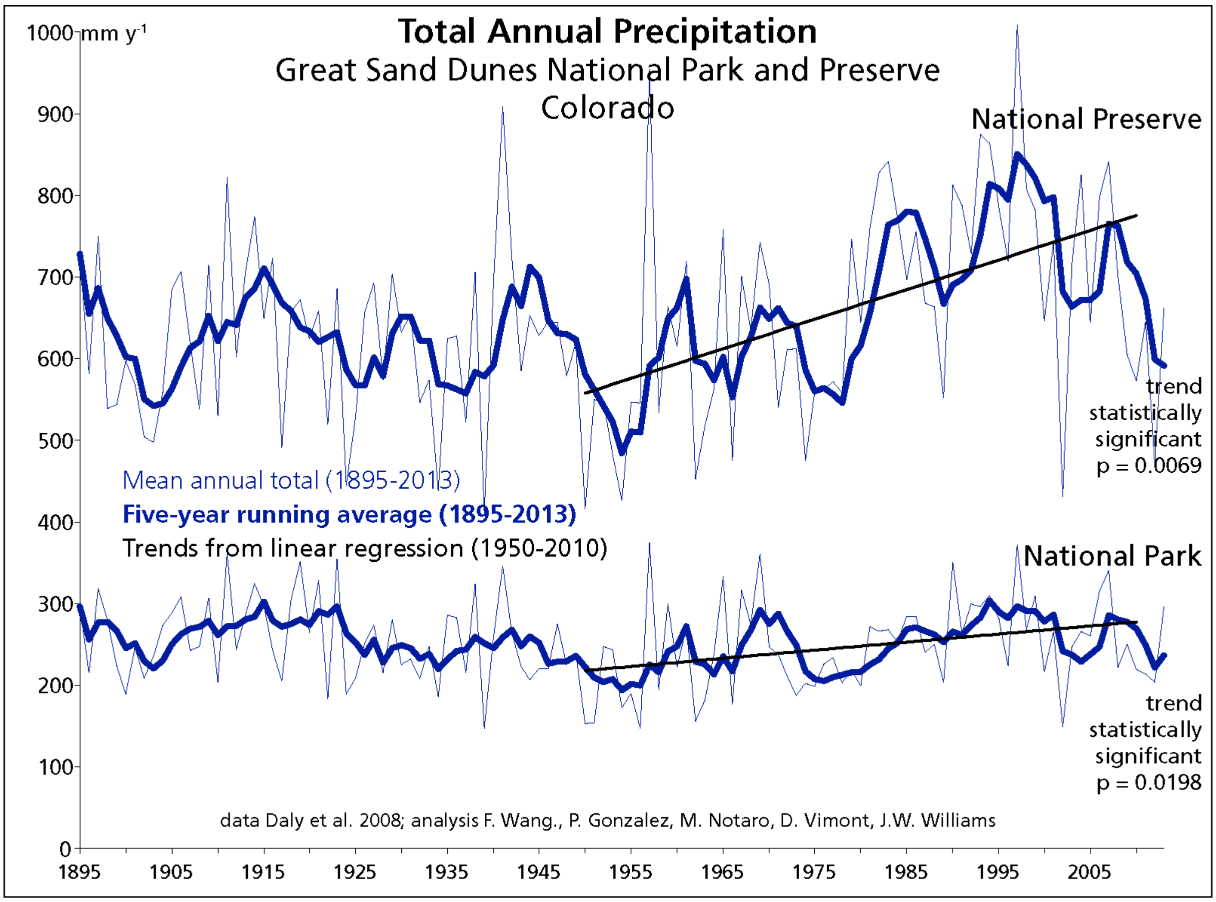


Figure 3.

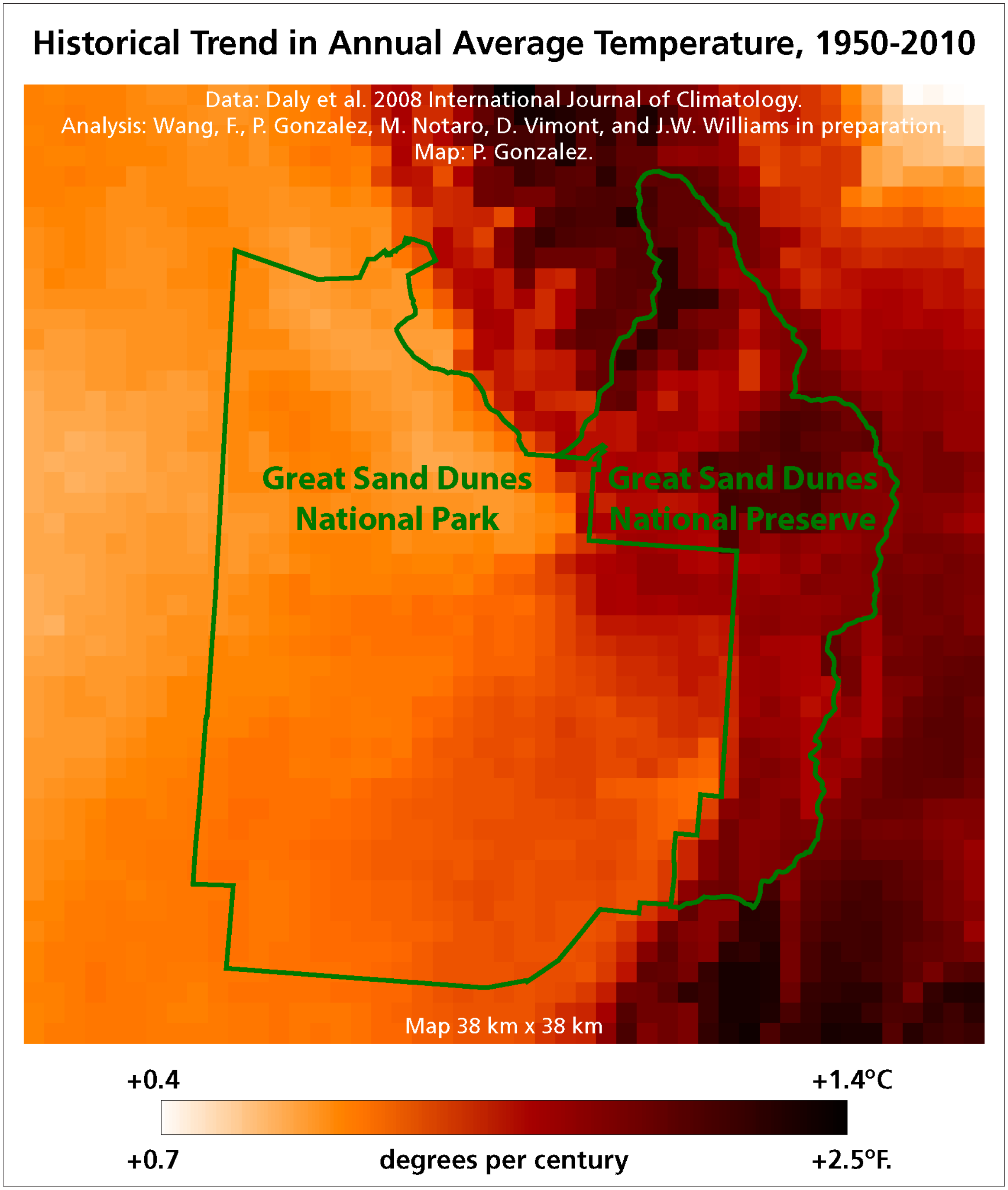

Historical Trend in Annual Average Temperature, 1950-2010
Data: Daly et al. 2008 International Journal of Climatology.
Analysis: Wang, F., P. Gonzalez, M. Notaro, D. Vimont, and J.W. Williams in preparation.
Map: P. Gonzalez.
Great Sand Dunes National Park
Great Sand Dunes National Preserve
Map 38 km x 38 km
+0.4
+1.4°C
+0.7
degrees per century
+2.5°F.

Figure 4.

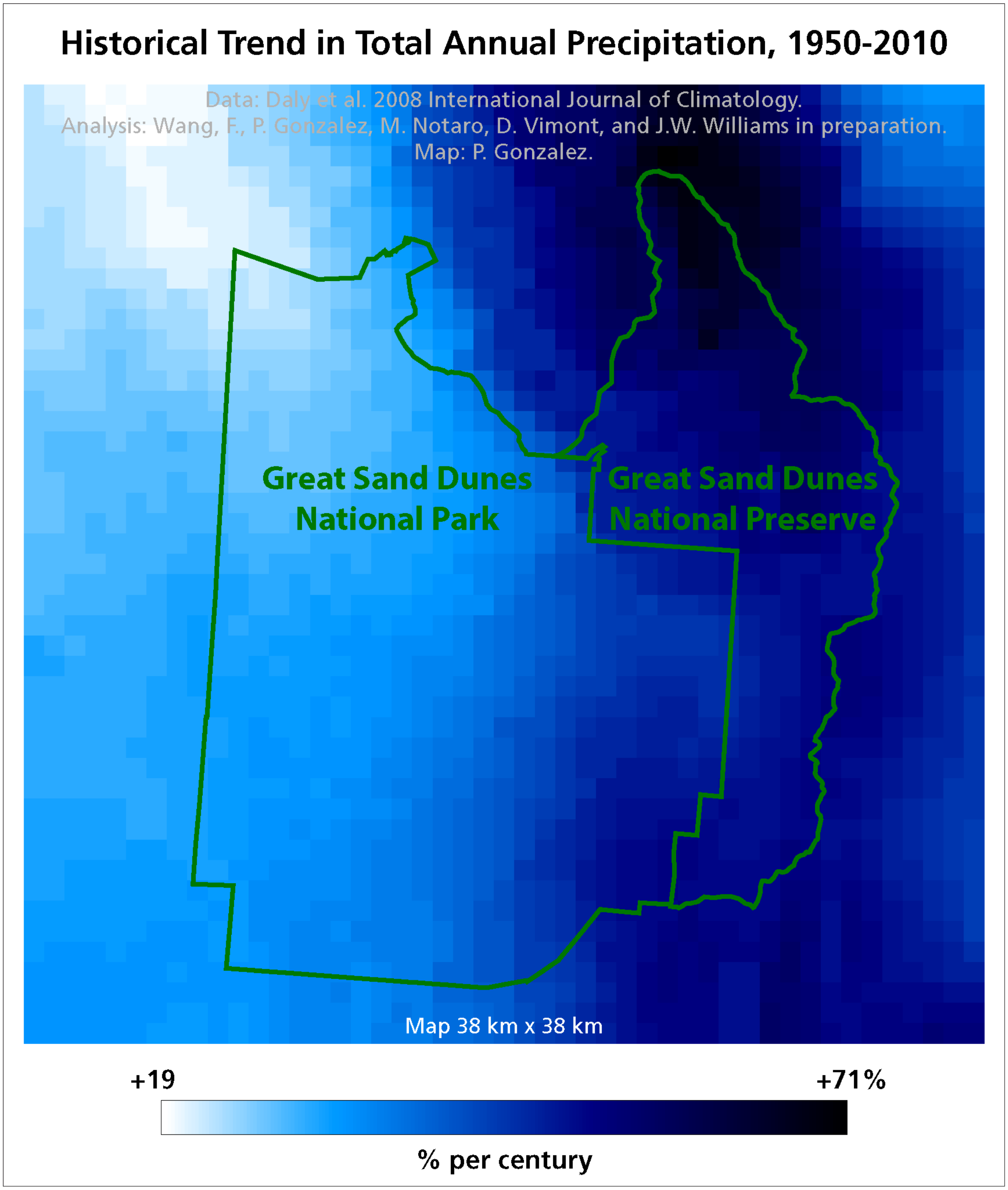
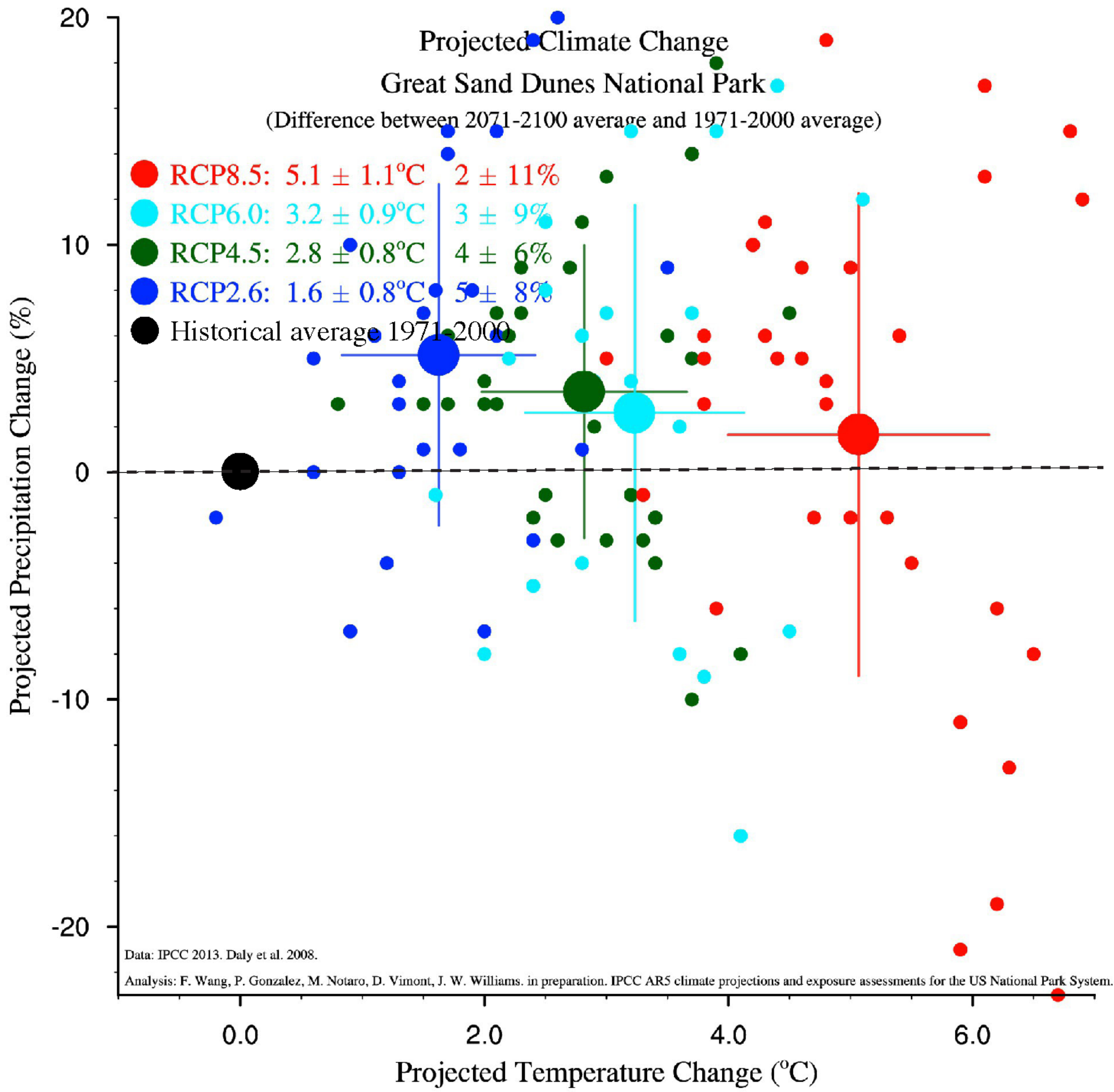

Historical Trend in Total Annual Precipitation, 1950-2010
Data: Daly et al. 2008 International Journal of Climatology.
Analysis: Wang, F., P. Gonzalez, M. Notaro, D. Vimont, and J.W. Williams in preparation.
Map: P. Gonzalez.
Great Sand Dunes National Park
Great Sand Dunes National Preserve
Map 38 km x 38 km
+19
+71%
% per century

Figure 5. Projections of future climate for the area within Great Sand Dunes National Park boundaries. Projections for Great Sand Dunes National Preserve are similar. 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. (Data: IPCC 2013, Daly et al. 2008; Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).



References

Ault, T.R., A.K. Macalady, G.T. Pederson, J.L. Betancourt, and M.D. Schwartz. 2011. Northern Hemisphere modes of variability and the timing of spring in western North America. Journal of Climate 24: 4003-4014.

Barnett, T.P., D.W. Pierce, H.G. Hidalgo, C. Bonfils, B.D. Santer, T. Das, G. Bala, A.W. Wood, T. Nozawa, A.A. Mirin, D.R. Cayan, and M.D. Dettinger. 2008. Human-induced changes in the hydrology of the western United States. Science 319: 1080-1083.

Bradley, B.A., M. Oppenheimer, and D.S. Wilcove. 2009. Climate change and plant invasions: restoration opportunities ahead? Global Change Biology 15: 1511-1521.

Breshears, D.D., N.S. Cobb, P.M. Rich, K.P. Price, C.D. Allen, R.G. Balice, W.H. Romme, J.H. Kastens, M.L. Floyd, J. Belnap, J.J. Anderson, O.B. Myers, and C.W. Meyer. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences of the USA 102: 15 144-15 148.

Calkins, M.T., E.A. Beever, K.G. Boykin, J.K. Frey, and M.C. Andersen. 2012. Not-so-splendid isolation: Modeling climate-mediated range collapse of a montane mammal *Ochotona princeps* across numerous ecoregions. Ecography 35: 780-791.

Castillo, J.A., C.W. Epps, A.R. Davis, and S.A. Cushman. 2014, Landscape effects on gene flow for a climate-sensitive montane species, the American pika. Molecular Ecology 23: 843-856.

Craine, J.M. 2013. Long-term climate sensitivity of grazer performance: A cross-site study. PLoS ONE 8: e67065. doi:10.1371/journal.pone.0067065.

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.

Eigenbrod, F., P. Gonzalez, J. Dash, and I. Steyl. 2015. Vulnerability of ecosystems to climate change moderated by habitat intactness. Global Change Biology 21: 275-286.

Erb, L.P., C. Ray, and R. Guralnick. 2011. On the generality of a climate-mediated shift in the distribution of the American pika (*Ochotona princeps*). Ecology 92: 1730-1735.

Erb, L.P., C. Ray, and R. Guralnick. 2014. Determinants of pika population density vs. occupancy in the Southern Rocky Mountains. Ecological Applications 24: 429-435.

Galbreath, KE., D.J. Hafner, and K.R. Zamudio. 2009. When cold is better: Climate-driven elevation shifts yield complex patterns of diversification and demography in an alpine specialist (American pika, *Ochotona princeps*). Evolution 63: 2848-2863.

Garfin, G., G. Franco, H. Blanco, A. Comrie, P. Gonzalez, T. Piechota, R. Smyth, and R. Waskom. 2014. Southwest. In Melillo, J.M., T.C. Richmond, and G.W. Yohe (Eds.) 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, Washington, DC.

Gonzalez, P., R.P. Neilson, J.M. Lenihan, and R.J. Drapek. 2010. Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. Global Ecology and Biogeography 19: 755-768.

Inouye, D.W., B. Barr, K.B. Armitage, and B.D. Inouye. 2000. Climate change is affecting altitudinal migrants and hibernating species. Proceedings of the National Academy of Sciences of the USA. 97: 1630-1633.

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013: The Physical Science Basis. Cambridge University Press, Cambridge, UK.

Jeffress, M.R., T.J. Rodhouse, C. Ray, S. Wolff, and C.W. Epps. 2013. The idiosyncrasies of place: Geographic variation in the climate–distribution relationships of the American pika. Ecological Applications 23: 864-878.

La Sorte, F.A. and F.R. Thompson. 2007. Poleward shifts in winter ranges of North American birds. Ecology 88: 1803-1812.

Littell, J.S., D. McKenzie, D.L. Peterson, and A.L. Westerling. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. Ecological Applications 19: 1003-1021.

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.

Pierce, D.W., T.P., Barnett, H.G. Hidalgo. T. Das, C. Bonfils, B.D. Santer, G. Bala, M.D. Dettinger, D.R. Cayan, A. Mirin, A.W. Wood, and T. Nozawa. 2008. Attribution of declining western U.S. snowpack to human effects. Journal of Climate 21: 6425-6444.

Raffa, K.F., B.H. Aukema, B.J. Bentz, A.L. Carroll, J.A. Hicke, M.G. Turner, and W.H. Romme. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: The dynamics of bark beetle eruptions. BioScience 58: 501-517.

Turner, T.F., M.J. Osborne, M.V. McPhee, and C.G. Kruse. 2015. High and dry: intermittent watersheds provide a test case for genetic response of desert fishes to climate change. Conservation Genetics 16: 399-410.

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.

Wang, G.M., N.T. Hobbs, K.M. Giesen, H. Galbraith, D.S. Ojima, and C.E. Braun. 2002. Relationships between climate and population dynamics of white-tailed ptarmigan Lagopus leucurus in Rocky Mountain National Park, Colorado, USA. Climate Research 23: 81-87.