National Park Service
U.S. Department of the Interior

Left to right: The White House, National Mall, Washington Monument, Tidal Basin, and Jefferson Memorial (photo P. Gonzalez)

Climate Change and Impacts for the National Parks of Washington, DC, USA

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Introduction

Greenhouse gas emissions from vehicles, power plants, deforestation, and other human activities have increased temperatures around the world and changed other climate factors in the 20th and early 21st centuries (IPCC 2007a). Field measurements show that climate change is fundamentally altering ecosystems by shifting biomes, contributing to species extinctions, and causing numerous other changes (IPCC 2007b). To assist National Parks in Washington, the capital of the United States, to integrate climate change into resource management, this report presents results of original analyses of historical and projected climate change and a summary of published scientific findings on impacts related to climate change. This report covers an area that includes 27 national parks, including all National Park Service land in the District of Columbia (DC) and nearby parks in Maryland and Virginia:

Arlington House, the Robert E. Lee Memorial
Carter G. Woodson Home National Historic Site
Clara Barton National Historic Site
Constitution Gardens
Ford's Theatre National Historic Site
Fort Washington Park
Franklin Delano Roosevelt Memorial
Frederick Douglass National Historic Site
George Washington Memorial Parkway
Greenbelt Park
Korean War Veterans Memorial
Lincoln Memorial
Lyndon Baines Johnson Memorial Grove on the Potomac
Martin Luther King, Jr. Memorial
Mary McLeod Bethune Council House National Historic Site
National Capital Parks
National Mall
Pennsylvania Avenue National Historic Site
Piscataway Park
Rock Creek Park
Theodore Roosevelt Island Park
Thomas Jefferson Memorial
Vietnam Veterans Memorial
Washington Monument
White House
Wolf Trap National Park for the Performing Arts
World War II Memorial.

The results also apply to sections of Chesapeake and Ohio Canal National Historical Park and the Potomac Heritage National Scenic Trail in the District of Columbia, although the entire areas of those parks are the subjects of separate reports.

Historical Climate Changes

From 1901 to 2002, mean annual temperature increased across the mid-Atlantic region of the United States (Figure 1; Gonzalez et al. 2010) and showed a statistically significant increase in the three 50 x 50 km pixels that include the national parks of the Washington, DC area (Figure 2, Table 1). From 1946 to 2012, temperature at the Washington National Airport weather station also showed a statistically significant increase (Figure 2; data from National Oceanic and Atmospheric Administration [NOAA]).

From 1901 to 2002, total annual precipitation increased in the mid-Atlantic region (Figure 3; Gonzalez et al. 2010), the Washington, DC area, and, from 1946 to 2012, at Washington National Airport (Figure 4, Table 1, data from National Oceanic and Atmospheric Administration), although the precipitation trends were not statistically significant.

While climate change has increased the frequency of heat waves, hurricanes, and other extreme events in some parts of the world (IPCC 2012), NOAA analyses of weather station data show no statistically significant 20th century trends of extreme events in the northeastern United States attributable to climate change (Kunkel et al. 2013). It is not definitively determined whether or not recent changes in North Atlantic hurricanes, which can reach Washington, DC, are due to climate change (IPCC 2012).

Historical Impacts

Analyses of tidal gauge measurements around the world have detected a statistically significant rise in global sea level and analyses of potential causal factors attribute the rise to human climate change (Church and White 2006, IPCC 2007a). Mean sea level at the NOAA tidal gauge on the southwest Washington waterfront shows a statistically significant rise from 1931 to 2013 (Figure 5).

Analyses of Audubon Christmas Bird Count data across the United States, including the mid-Atlantic region, has detected a shift of winter ranges of a set of 254 bird species northward at an average rate of 0.5 ± 2.4 km y^{-1} from 1975 to 2004, attributable to climate change and not other factors (La Sorte and Thompson 2007).

Research on cherry tree blooming in Washington, DC and Baltimore, Maryland has detected

20th century phenology changes that are consistent with, but not statistically attributed to, human climate change. Smithsonian Institution analyses show a statistically significant advance of cherry tree blooming by seven days from 1970 to 1999 (Abu-Asab et al. 2001). This is consistent with warmer temperatures caused by climate change. Analysis of cherry blossom records from the past 1200 years in Japan also shows that cherry trees are blooming earlier as spring temperatures have warmed (Primack et al. 2009).

Monitoring of forest plots at the Smithsonian Environmental Research Center, just east of Washington, DC on Chesapeake Bay, found an increase in tree growth between 1987 and 2009, consistent with, but not formally attributed to, increased atmospheric carbon dioxide and warmer temperatures due to climate change (McMahon et al. 2010).

Future Climate Projections

The Intergovernmental Panel on Climate Change (IPCC) has coordinated research groups to project possible future climates under defined greenhouse gas emissions scenarios (IPCC 2007a). The three main IPCC greenhouse gas emissions scenarios are B1 (lower emissions), A1B (medium emissions), and A2 (higher emissions). Actual global emissions are on a path above IPCC emissions scenario A2 (Le Quéré et al. 2012, Raupach et al. 2007).

For the three main IPCC emissions scenarios, general circulation models (GCMs) of the atmosphere project an increase in 21st century temperature three to five times the amount of historical 20th century warming in the Washington, DC area (Table 1). Precipitation could increase under all three emissions scenarios (Table 1).

Spatial analyses of the Washington, DC area, using climate projections for IPCC emissions scenario A2 downscaled to 4 x 4 km pixels (data from Conservation International <http://futureclimates.conservation.org>, method of Tabor and Williams [2010]) show projected patterns of climate that may occur if we do not reduce greenhouse gas emissions. Mean annual temperature could increase 4.2 ± 0.9° C by 2100 AD (Figure 6). The temperature projections of the 18 GCMs are generally in close agreement, with a coefficient of variation (the standard deviation as a fraction of the mean) of 0.21, indicating that the temperature uncertainty is approximately one-fifth of the mean, although uncertainty is higher around Washington than much of the surrounding area (Figure 7).

The GCMs show an average 7 ± 6% increase in precipitation under IPCC emissions scenario A2 (Figure 8), with 15 of 18 GCMs projecting increases (Figure 9). Taken together, the temperature and precipitation projections from the 18 GCMs form a cloud of potential future climates (Figure 10). The ensemble mean reflects the central tendency of the projections, but the uncertainty of any projection of the future is large.

Projections indicate potential changes in the frequency of extreme temperature and precipitation events. Modeling under emissions scenario A2 projects 18 to 21 more days with a maximum temperature > 35ºC, between the periods 1980-2000 and 2041-2070 and an increase of 15 to 18% in the number of days with precipitation > 2.5 cm (Kunkel et al. 2013).

Projected Vulnerabilities

Analyses of climate projections and modeling of ecosystem and infrastructure changes indicate potential vulnerabilities of species, ecosystems, and other resources if we do not reduce our greenhouse gas emissions. Climate change could shift the ranges of numerous tree species northward, reducing potential densities in Washington, DC of red maple (*Acer rubrum*), tulip tree (*Liriodendron tuliperfia*), and white oak (*Quercus alba*) (Iverson et al. 2008). Modeling indicates that additional warming could advance peak bloom of Tidal Basin cherry trees by a week (emissions scenario A1B) to a month (emissions scenario A2) by the end of the century (Chung et al. 2011). Modeling of the range of the invasive species kudzu (*Pueraria lobata*) indicates a potential increase in the Washington, DC area (Bradley et al. 2010). Experimental increases of atmospheric carbon dioxide in a North Carolina forest (Mohan et al. 2006) indicate that climate change could increase the growth and toxicity of poison ivy (*Toxicodendron radicans*), a species common in Rock Creek Park. Modeling of damage to buildings in Washington, DC from a sea level rise projection of 10 cm by 2100 generates a damage estimate of $2 billion from flooding of over 60 buildings, 10 km of roads, and 3 km of Metro rail lines (Ayyub et al. 2012).

Table 1. Climate and sea level for the area that includes the national parks of Washington, DC (Mitchell and Jones 2005, IPCC 2007a, Gonzalez et al. 2010). Historical results from analyses of the 50 km x 50 km pixels that include the parks, the weather station at Washington National Airport, and the tidal gauge on the southwest Washington waterfront. Standard error (SE) for historical trends; standard deviation (SD) for other variables. Future projections from spatial analyses of the 50 x 50 km and 4 x 4 km pixels that include the parks (data Conservation International, method of Tabor and Williams [2010]) and from NOAA (Parris et al. 2012).

	mean	SD/SE	units
Historical			
temperature 1901-2002 annual average (area)	12.6	0.7	ºC
temperature 1901-2002 linear trend (area) [SE]	0.8	0.2	ºC century^{-1}
temperature 1946-2012 annual average (station)	14.4	0.7	ºC
temperature 1946-2012 linear trend (station) [SE]	1.6	0.4	ºC century^{-1}
precipitation 1901-2002 annual average (area)	1050	130	mm y^{-1}
precipitation 1901-2002 linear trend (area) [SE]	-0.6	4	% century^{-1}
precipitation 1946-2012 annual average (station)	1000	190	mm y^{-1}
precipitation 1946-2012 linear trend (station) [SE]	3	18	% century^{-1}
sea level 1931-2013 linear trend [SE]	31	1	cm century^{-1}
Projected			
IPCC B1 scenario (lower emissions)			
temperature 1990-2100 annual average	2.5	0.9	ºC century^{-1}
precipitation 1990-2100 annual average	7	6	% century^{-1}
sea level 1992-2100 [SD/SE not given]	50	-	cm century^{-1}
IPCC A1B scenario (medium emissions)			
temperature 1990-2100 annual average	3.6	0.9	ºC century^{-1}
precipitation 1990-2100 annual average	7	6	% century^{-1}
IPCC A2 scenario (higher emissions)			
temperature 1990-2100 annual average	4.2	0.9	ºC century^{-1}
precipitation 1990-2100 annual average	7	6	% century^{-1}
sea level 1992-2100 [SD/SE not given]	200	-	cm century^{-1}

Figure 1.

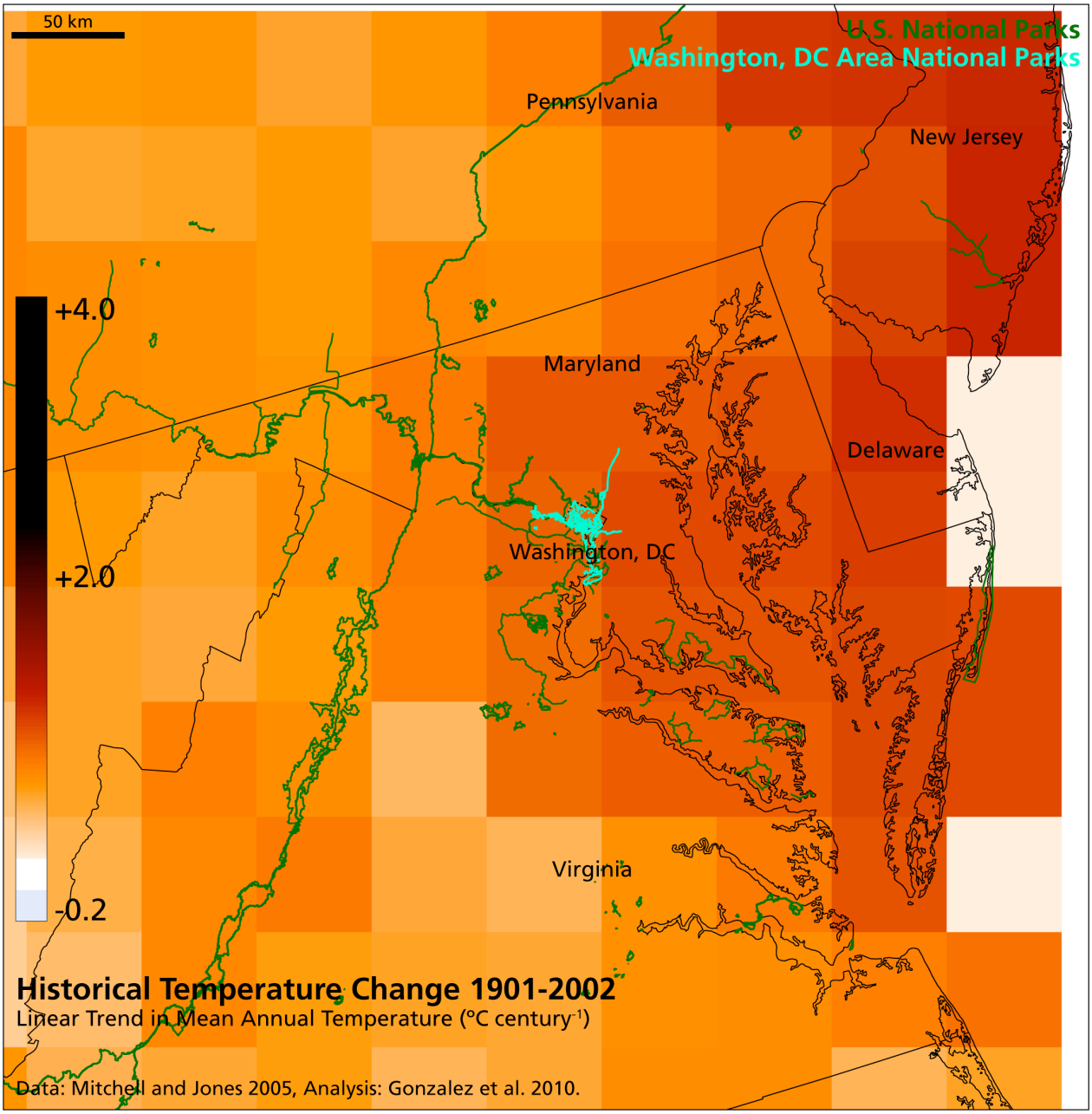

50 km
U.S. National Parks
Washington, DC Area National Parks
Pennsylvania
New Jersey
Maryland
Delaware
Washington, DC
Virginia
+4.0
+2.0
-0.2
Historical Temperature Change 1901-2002
Linear Trend in Mean Annual Temperature (°C century-1)
Data: Mitchell and Jones 2005, Analysis: Gonzalez et al. 2010.

Figure 2.

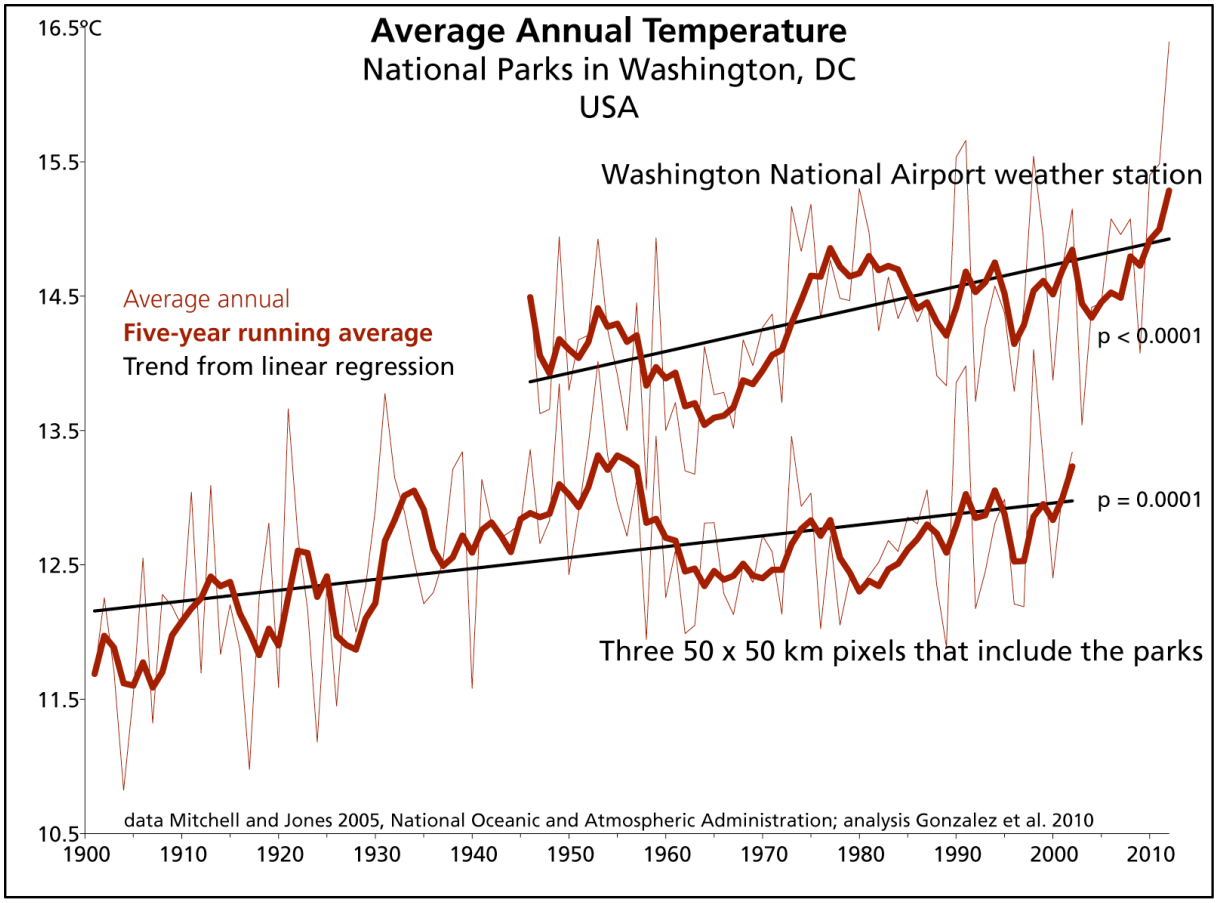

Average Annual Temperature
National Parks in Washington, DC
USA
16.5ºC
15.5
14.5
13.5
12.5
11.5
10.5
Washington National Airport weather station
Average annual
Five-year running average
Trend from linear regression
p < 0.0001
p = 0.0001
Three 50 x 50 km pixels that include the parks
data Mitchell and Jones 2005, National Oceanic and Atmospheric Administration; analysis Gonzalez et al. 2010
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

Figure 3.

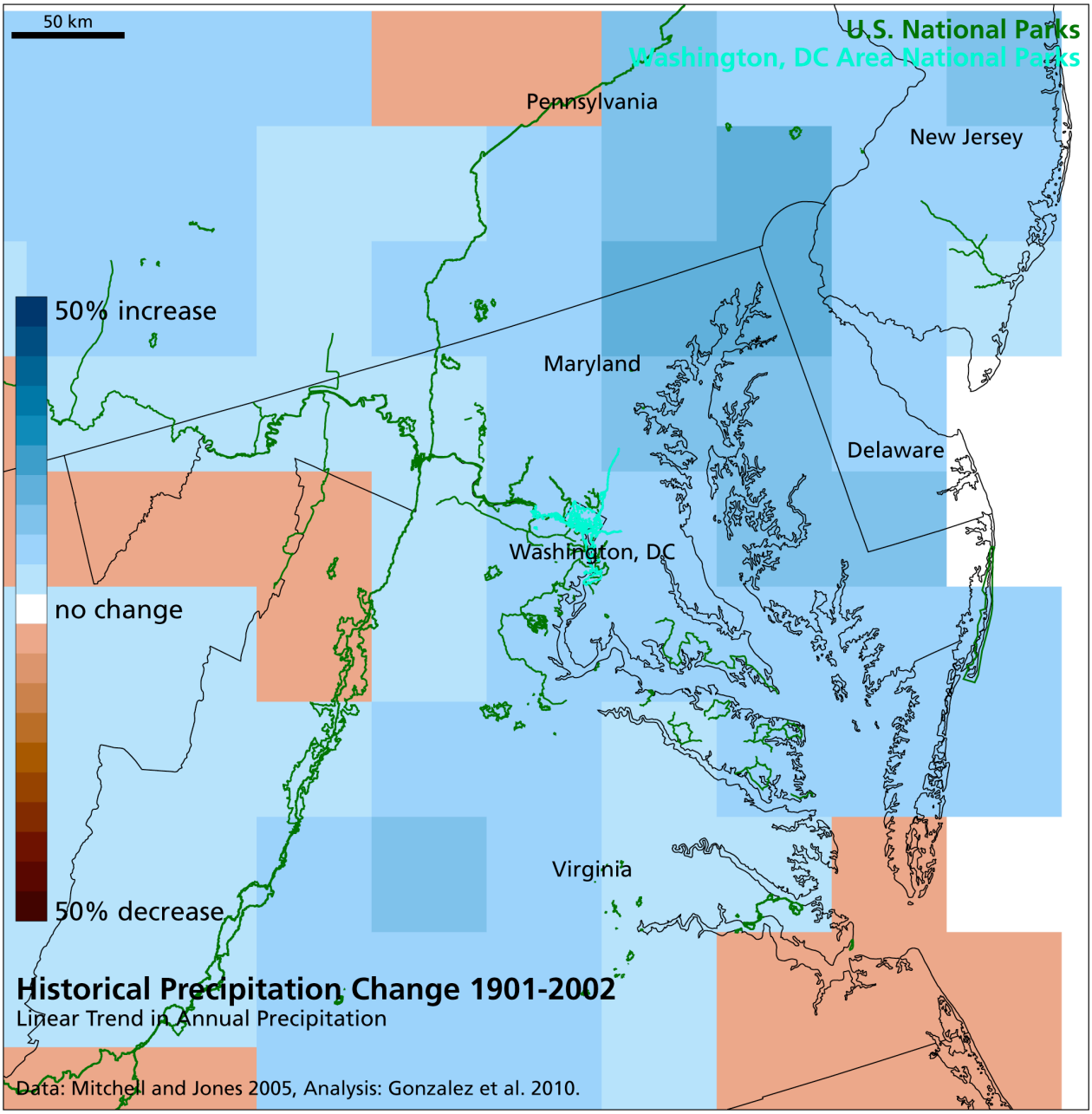

50 km
U.S. National Parks
Washington, DC Area National Parks
Pennsylvania
New Jersey
50% increase
Maryland
Delaware
Washington, DC
no change
Virginia
50% decrease
Historical Precipitation Change 1901-2002
Linear Trend in Annual Precipitation
Data: Mitchell and Jones 2005, Analysis: Gonzalez et al. 2010.

Figure 4.

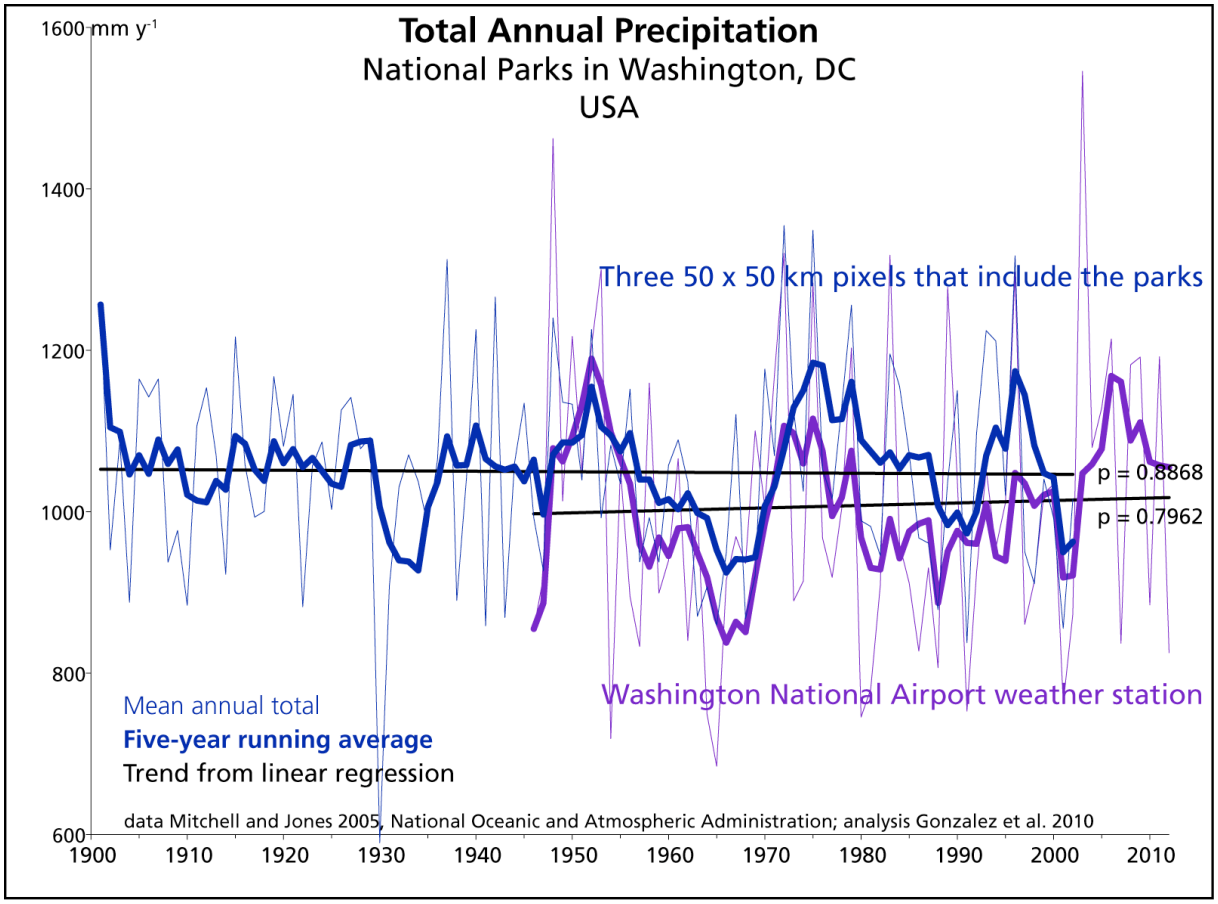

Total Annual Precipitation
National Parks in Washington, DC
USA
1600 mm y-1
1400
1200
1000
800
600
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Three 50 x 50 km pixels that include the parks
p = 0.8868
p = 0.7962
Washington National Airport weather station
Mean annual total
Five-year running average
Trend from linear regression
data Mitchell and Jones 2005, National Oceanic and Atmospheric Administration; analysis Gonzalez et al. 2010

Figure 5.

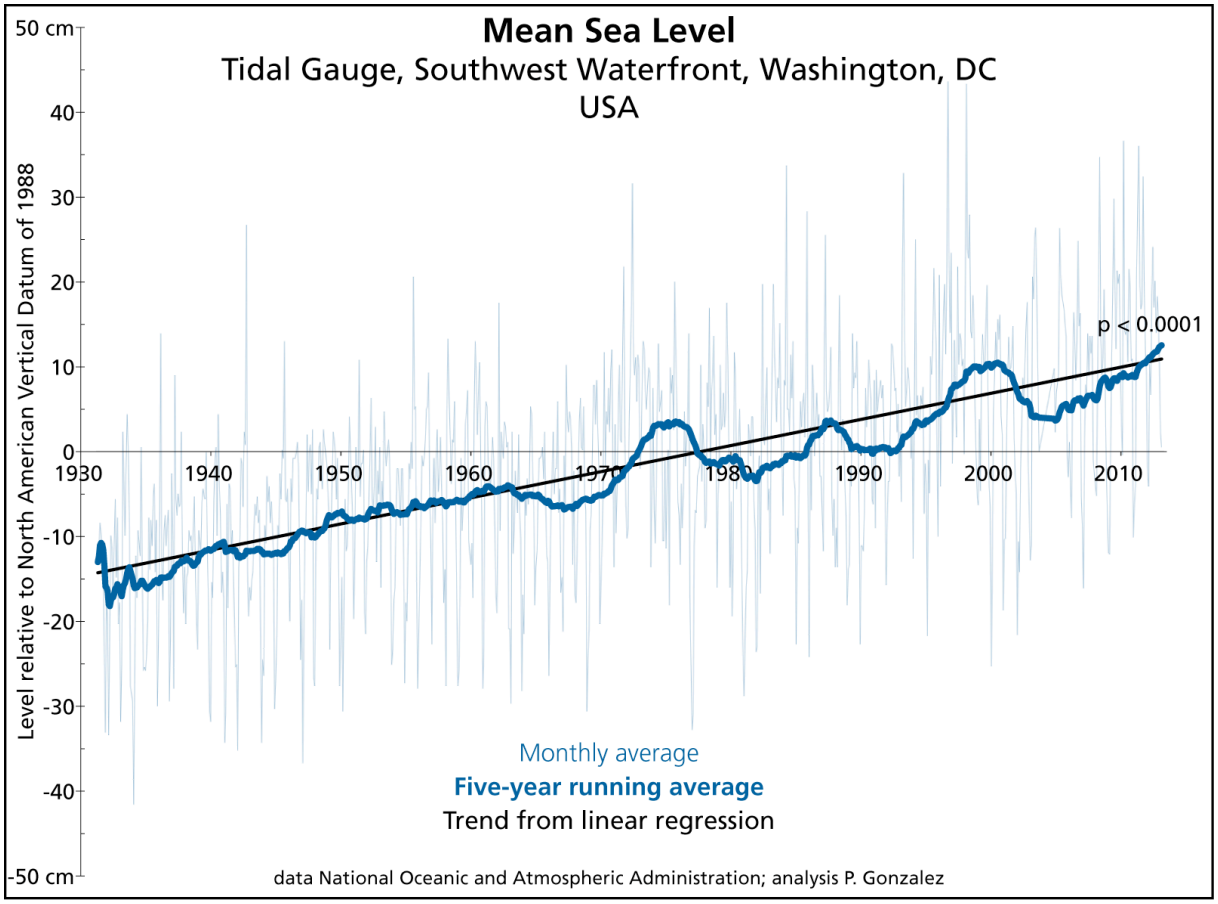

Mean Sea Level
Tidal Gauge, Southwest Waterfront, Washington, DC
USA
Level relative to North American Vertical Datum of 1988
50 cm
40
30
20
10
0
-10
-20
-30
-40
-50 cm
1930
1940
1950
1960
1970
1980
1990
2000
2010
p < 0.0001
Monthly average
Five-year running average
Trend from linear regression
data National Oceanic and Atmospheric Administration; analysis P. Gonzalez

Figure 6.

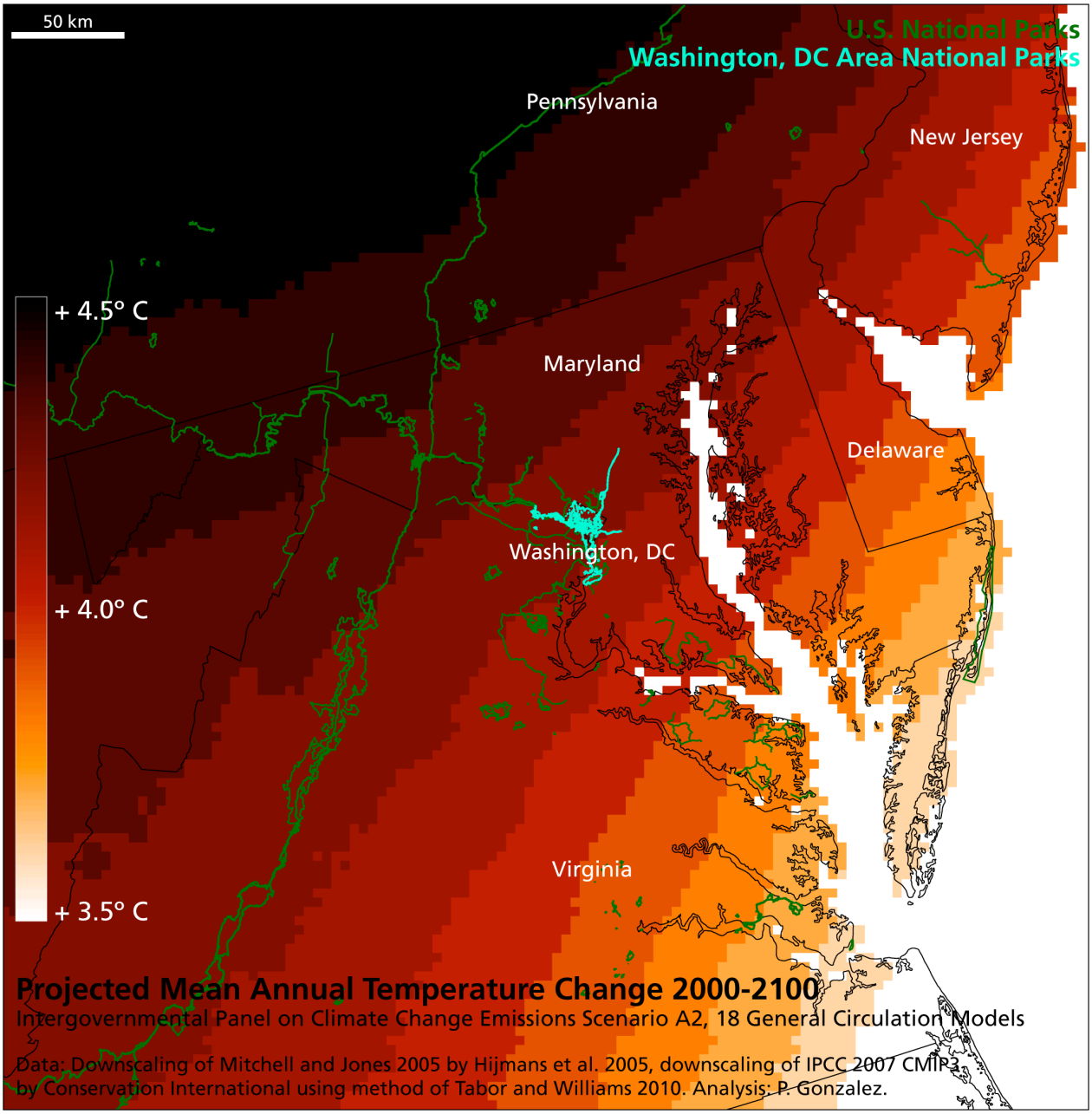

50 km
U.S. National Parks
Washington, DC Area National Parks
Pennsylvania
New Jersey
+ 4.5° C
Maryland
Delaware
Washington, DC
+ 4.0° C
Virginia
+ 3.5° C
Projected Mean Annual Temperature Change 2000-2100
Intergovernmental Panel on Climate Change Emissions Scenario A2, 18 General Circulation Models
Data: Downscaling of Mitchell and Jones 2005 by Hijmans et al. 2005, downscaling of IPCC 2007 CMIP3
by Conservation International using method of Tabor and Williams 2010. Analysis: P. Gonzalez.

Figure 7.

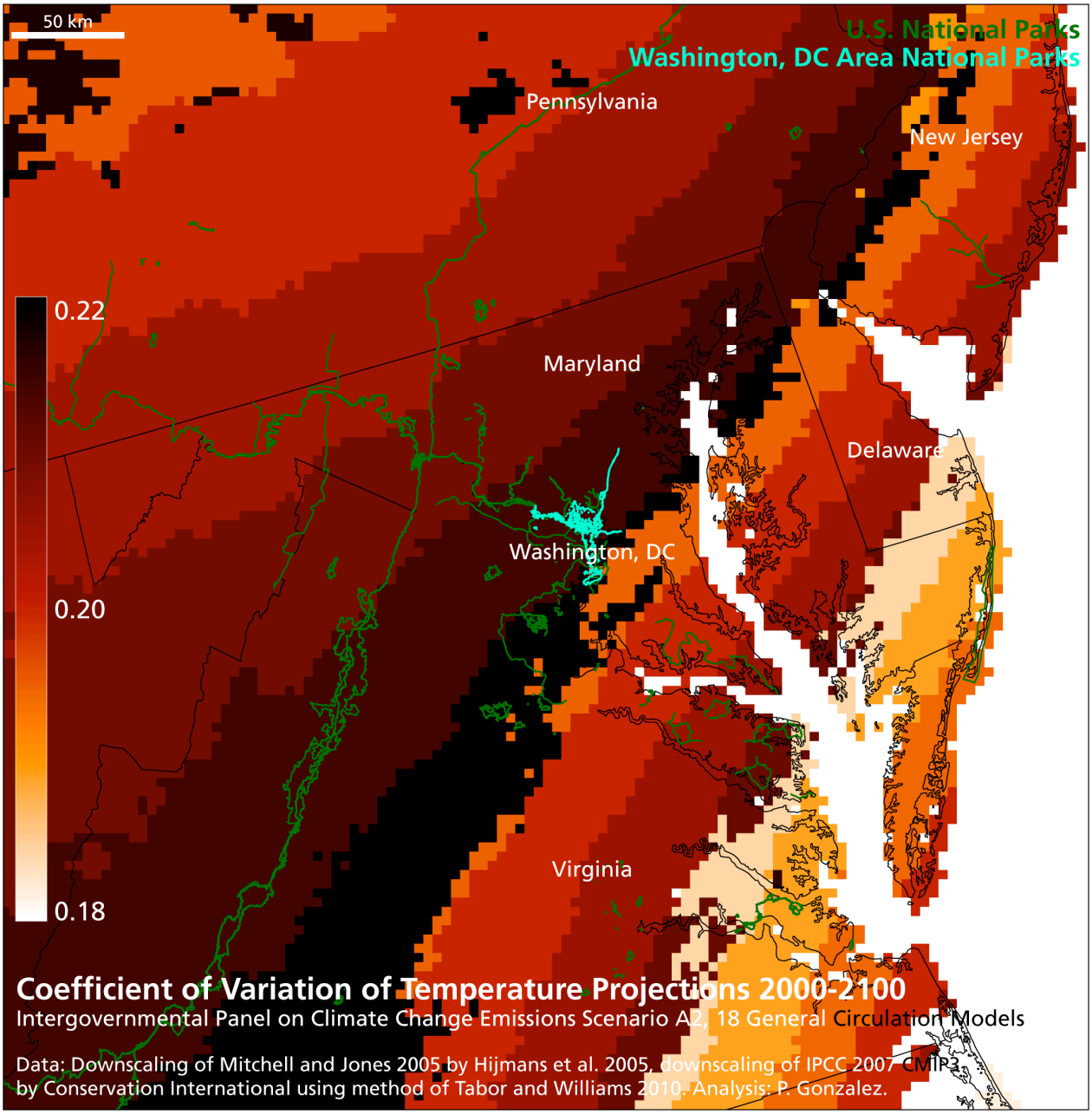

50 km
U.S. National Parks
Washington, DC Area National Parks
Pennsylvania
New Jersey
Maryland
Delaware
Washington, DC
Virginia
0.22
0.20
0.18
Coefficient of Variation of Temperature Projections 2000-2100
Intergovernmental Panel on Climate Change Emissions Scenario A2, 18 General Circulation Models
Data: Downscaling of Mitchell and Jones 2005 by Hijmans et al. 2005, downscaling of IPCC 2007 CMIP3
by Conservation International using method of Tabor and Williams 2010. Analysis: P. Gonzalez.

Figure 8.

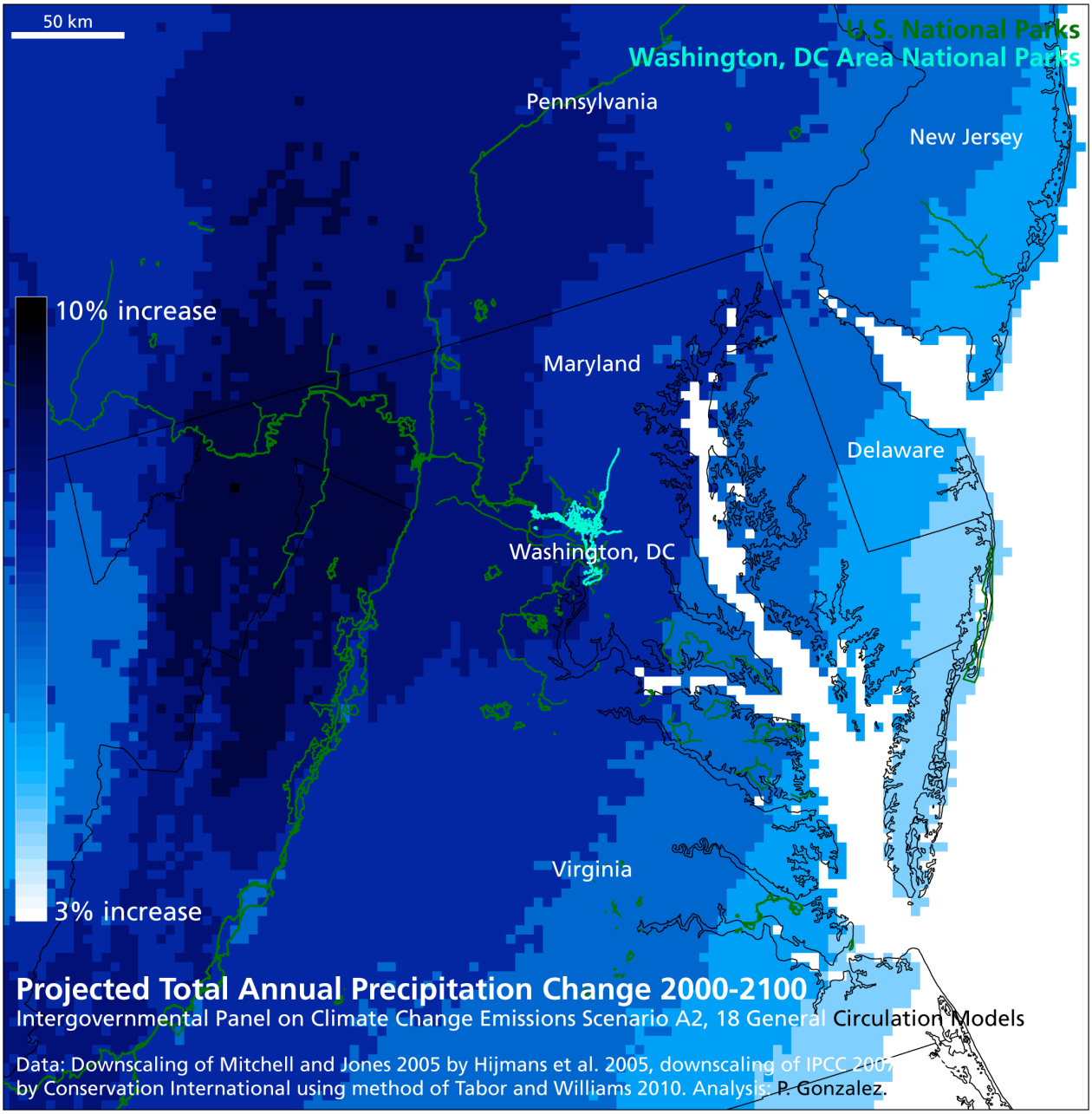

50 km
U.S. National Parks
Washington, DC Area National Parks
Pennsylvania
New Jersey
10% increase
Maryland
Delaware
Washington, DC
Virginia
3% increase
Projected Total Annual Precipitation Change 2000-2100
Intergovernmental Panel on Climate Change Emissions Scenario A2, 18 General Circulation Models
Data: Downscaling of Mitchell and Jones 2005 by Hijmans et al. 2005, downscaling of IPCC 2007,
by Conservation International using method of Tabor and Williams 2010. Analysis: P. Gonzalez.

Figure 9.

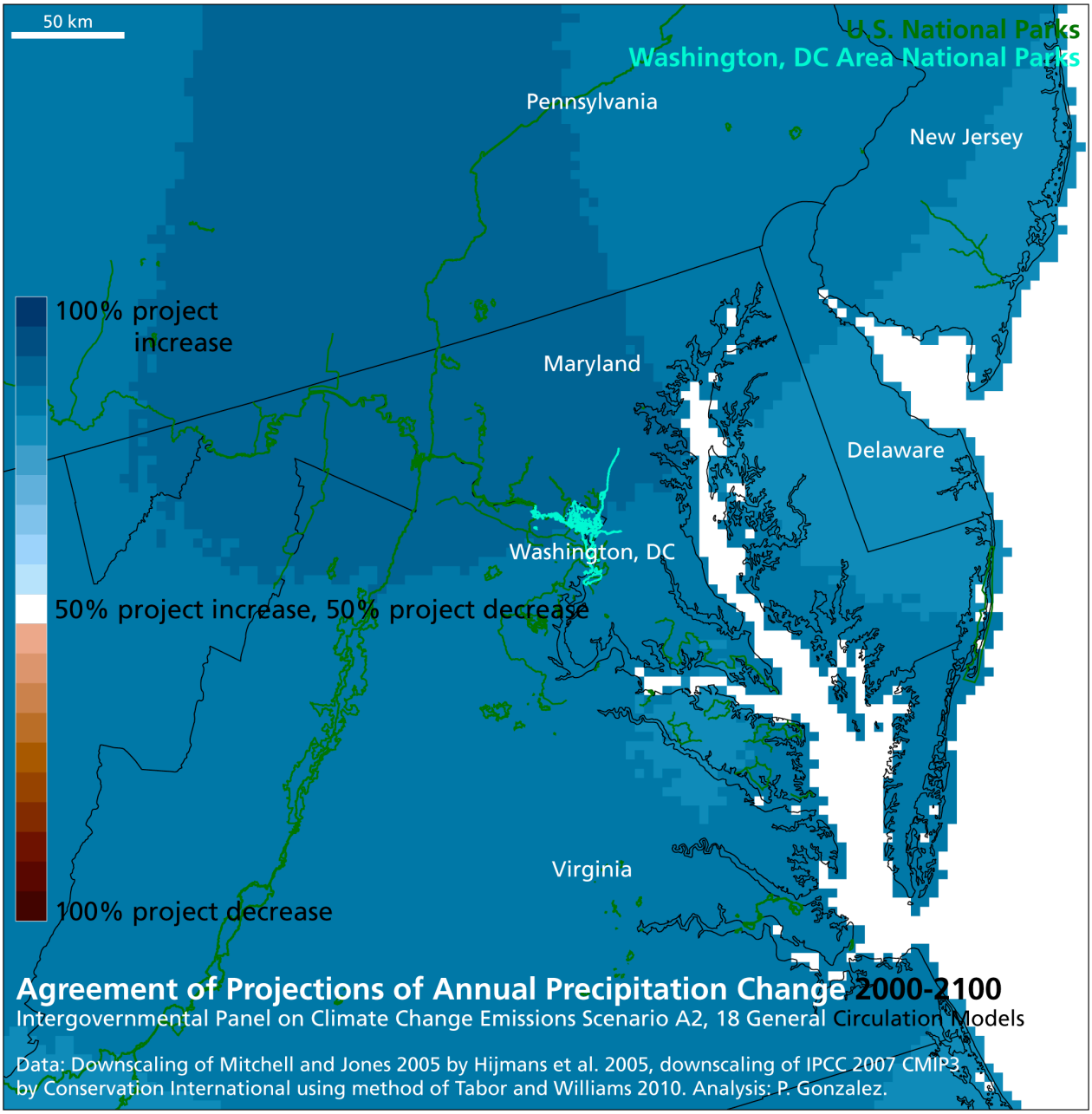
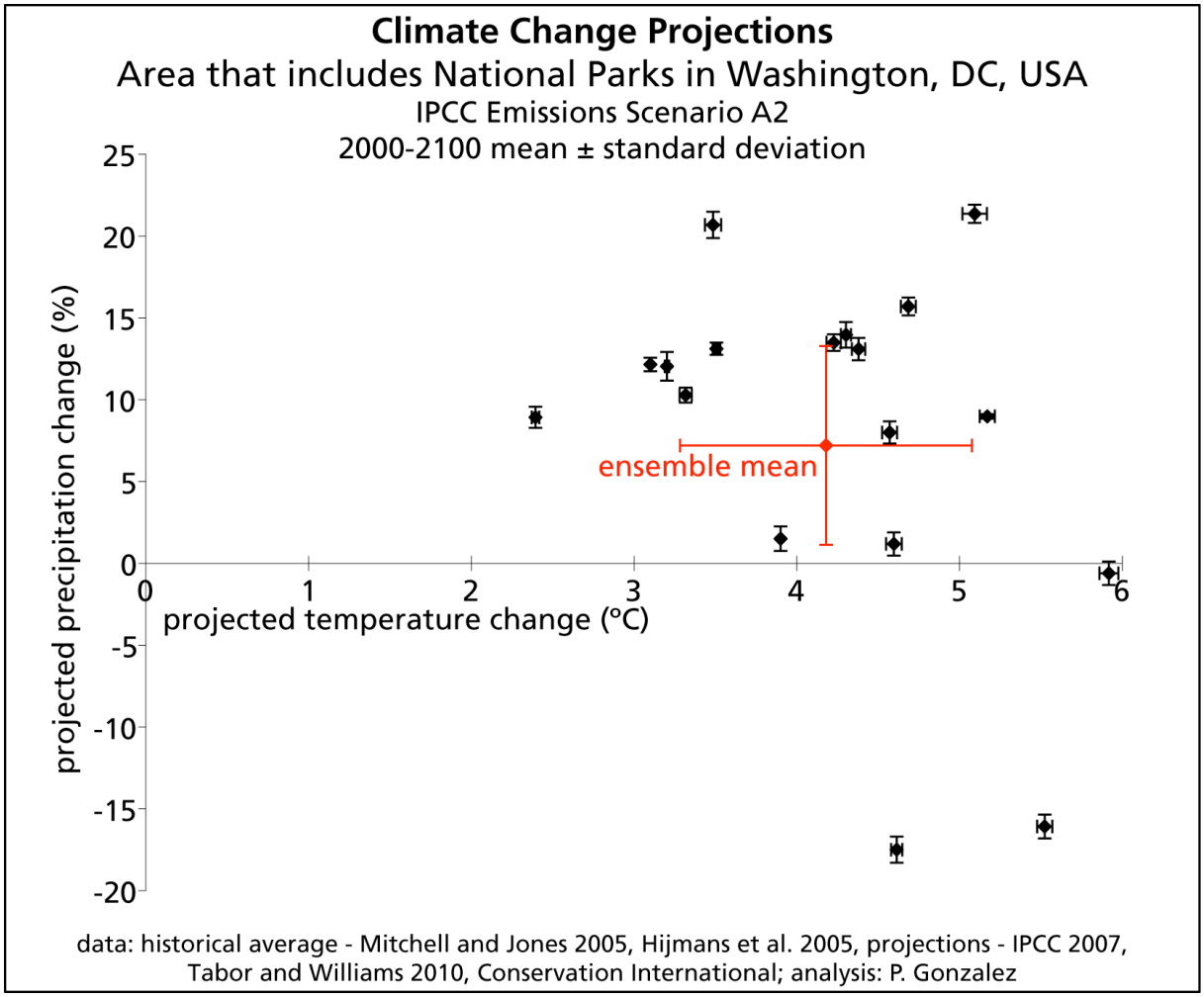

50 km
U.S. National Parks
Washington, DC Area National Parks
Pennsylvania
New Jersey
100% project increase
Maryland
Delaware
Washington, DC
50% project increase, 50% project decrease
Virginia
100% project decrease
Agreement of Projections of Annual Precipitation Change 2000-2100
Intergovernmental Panel on Climate Change Emissions Scenario A2, 18 General Circulation Models
Data: Downscaling of Mitchell and Jones 2005 by Hijmans et al. 2005, downscaling of IPCC 2007 CMIP3
by Conservation International using method of Tabor and Williams 2010. Analysis: P. Gonzalez.

Figure 10.


Climate Change Projections
Area that includes National Parks in Washington, DC, USA
IPCC Emissions Scenario A2
2000-2100 mean ± standard deviation
projected precipitation change (%)
projected temperature change (°C)
ensemble mean
25
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
data: historical average - Mitchell and Jones 2005, Hijmans et al. 2005, projections - IPCC 2007,
Tabor and Williams 2010, Conservation International; analysis: P. Gonzalez

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