

Climate Change Trends and Vulnerability of the Colorado River and Rainbow Bridge National Monument

Patrick Gonzalez

Natural Resource Stewardship and Science, National Park Service, Washington, DC

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Historical Climate

From 1901 to 2002, mean annual temperature increased across North America (Figure 1; Gonzalez et al. 2010) and showed a statistically significant increase in the area that includes Rainbow Bridge National Monument (NM) (Figure 2, Table 1). At Glen Canyon Dam, the mean annual freezing elevation has increased 2000 m from the 1950s to today (Figure 3, Kunkel et al. 2013). From 1901 to 2002, precipitation increased across most of North America (Figure 4; Gonzalez et al. 2010), although it showed no statistically significant trend in the Glen Canyon area (Figure 5, Table 1). Analyses of causal factors attribute 20th century warming and precipitation changes to greenhouse gas emissions from vehicles, power plants, deforestation, and other human activities (Intergovernmental Panel on Climate Change (IPCC) 2007, Bonfils et al. 2008).

Projected Climate

The Intergovernmental Panel on Climate Change (IPCC) has coordinated research groups to project possible future climates under defined greenhouse gas emissions scenarios (IPCC 2007). 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, projected 21st century temperature in the Rainbow Bridge area could increase three to five times the amount of historical 20th century warming (Table 1, Mitchell and Jones 2005, Gonzalez et al. 2010). On average, general circulation models (GCMs) of the atmosphere project a slight increase in precipitation in the Rainbow Bridge area under the three emissions scenarios, although 10 out of 18 GCMs project decreases in precipitation under emissions scenario A2 (Figure 6; historical average from Mitchell and Jones 2005, Hijmans et al. 2005; projections from IPCC 2007, Tabor and Williams 2010, Conservation International; analysis by P. Gonzalez).

Projections indicate potential changes in the frequency of extreme temperature and precipitation events. Modeling under emissions scenario A2 projects 20 to 25 more days with a maximum temperature $> 35^{\circ}\text{C}$, 25-30 fewer days with a minimum temperature $< 0^{\circ}\text{C}$, and 10-15 more consecutive days with precipitation < 3 cm between the periods 1980-2000 and 2041-2070 (Kunkel et al. 2013).

Colorado River

The water level of Lake Powell is currently 30 m lower than the level of top of the dam, but 15 m higher than the level in 2005, which was the lowest since the filling of the reservoir after the completion of the dam in 1966 <<http://www.usbr.gov/uc/crsp>>. Reconstruction of what natural flow of the Colorado River would be at Lees Ferry, Arizona, indicates that river flow in 2004 was approximately at the 1906-2004 average, but that the river has experienced much lower flows for decades at a time in the period 800-2000 AD (Figure 7, Meko et al. 2007).

Modeling under emissions scenarios B1 and A2 projects decreases in runoff of 10 to 30% by the end of the 21st century (Barnett and Pierce 2009) and a 50% chance that live storage in Lakes Mead and Powell could be gone by 2021, due to human use and climate change (Barnett and Pierce 2008). Modeling under emissions scenarios B1, A1B, and A2 projects a 9% decrease in mean natural flow at Lees Ferry by 2060 (Bureau of Reclamation 2012).

Table 1. Historical and projected climate (mean $\pm$ standard deviation (SD)) trends for the area that includes Rainbow Bridge NM (Mitchell and Jones 2005, IPCC 2007, Gonzalez et al. 2010). Historical climate and climate projections for IPCC emissions scenarios B1 and A1B are calculated for the 50 x 50 km pixel that includes the park (Gonzalez et al. 2010). Climate under emissions scenario A2 is calculated for the 4 x 4 km pixels that include the park (data from Conservation International using method of Tabor and Williams (2010)).

	mean	SD	units
Historical (1901-2002)			
temperature annual average	10.6	0.8	°C
temperature linear trend	1.0	2.5	°C century ⁻¹
precipitation annual average	250	60	mm y ⁻¹
precipitation linear trend	8	83	% century ⁻¹
Projected (1990-2100)			
IPCC B1 scenario (lower emissions)			
temperature change in annual average	3.0	1.1	°C century ⁻¹
precipitation change in annual average	1	27	% century ⁻¹
IPCC A1B scenario (medium emissions)			
temperature change in annual average	3.9	1.1	°C century ⁻¹
precipitation change in annual average	7	27	% century ⁻¹
IPCC A2 scenario (higher emissions)			
temperature change in annual average	4.8	1.1	°C century ⁻¹
precipitation change in annual average	4	27	% century ⁻¹

Figure 1.

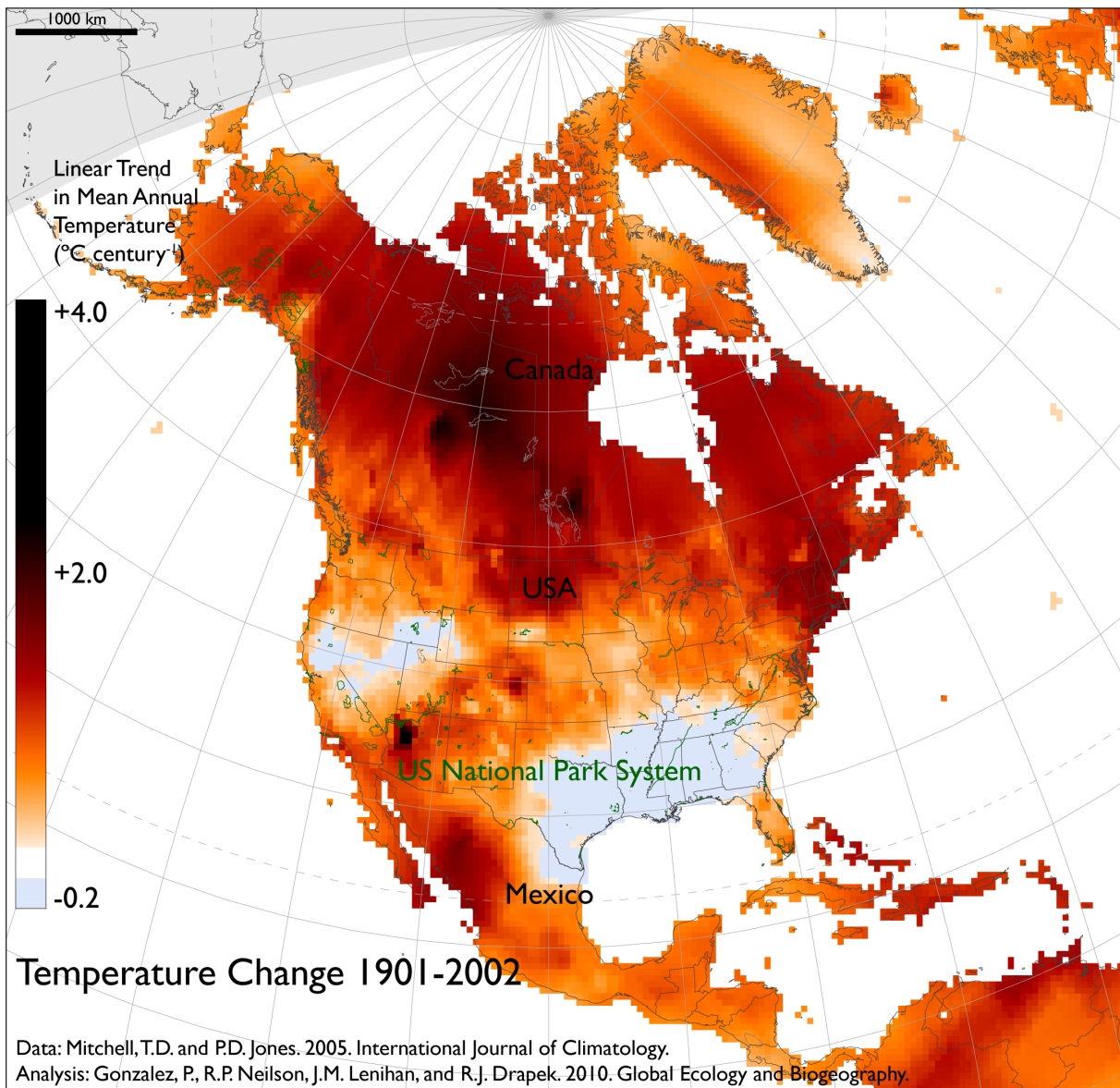


Figure 2.

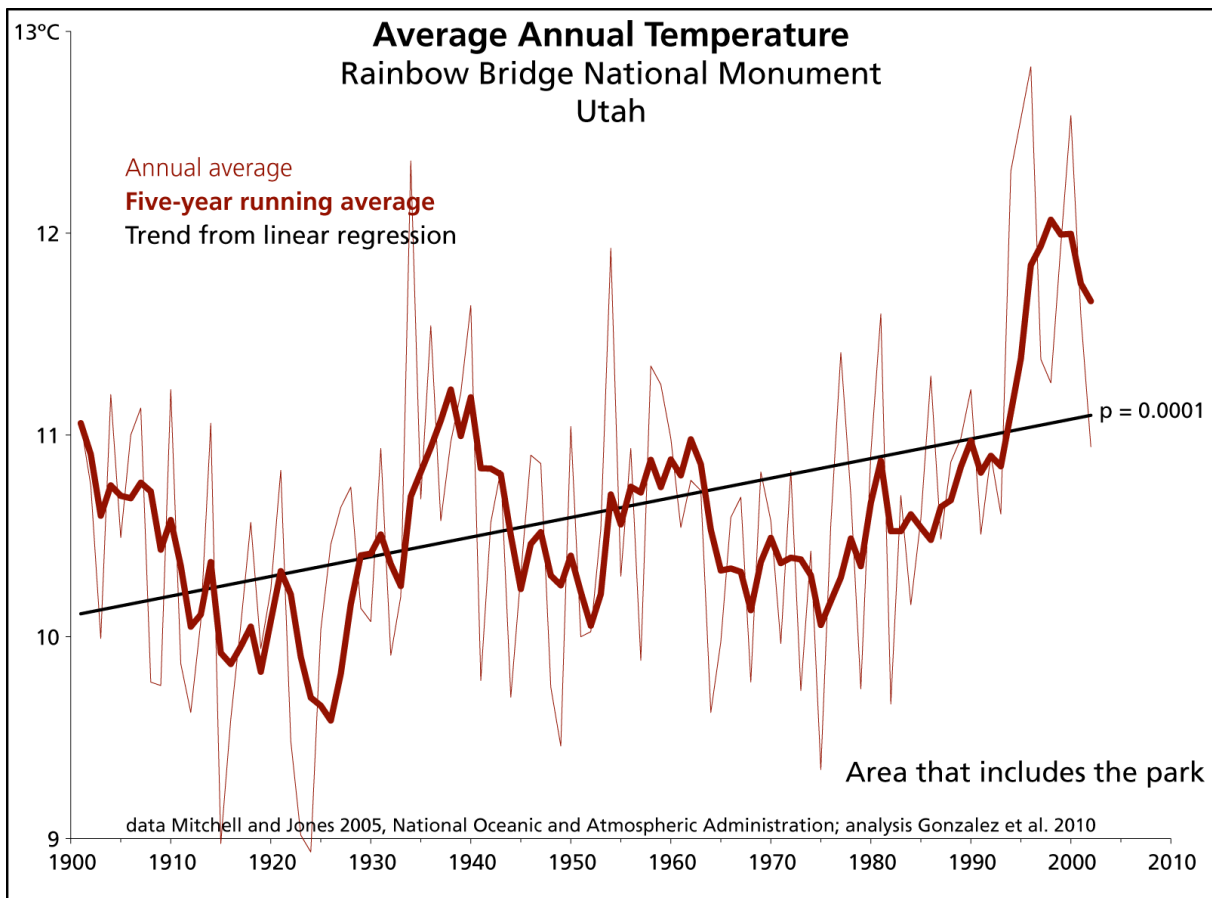


Figure 3.

Mean annual freezing elevation above Glen Canyon Dam. Red = above 1970-2000 average, Blue = below 1970-2000 average, black = 10-year running average (data Western Regional Climate Center, analysis and graph Kunkel et al. 2013).

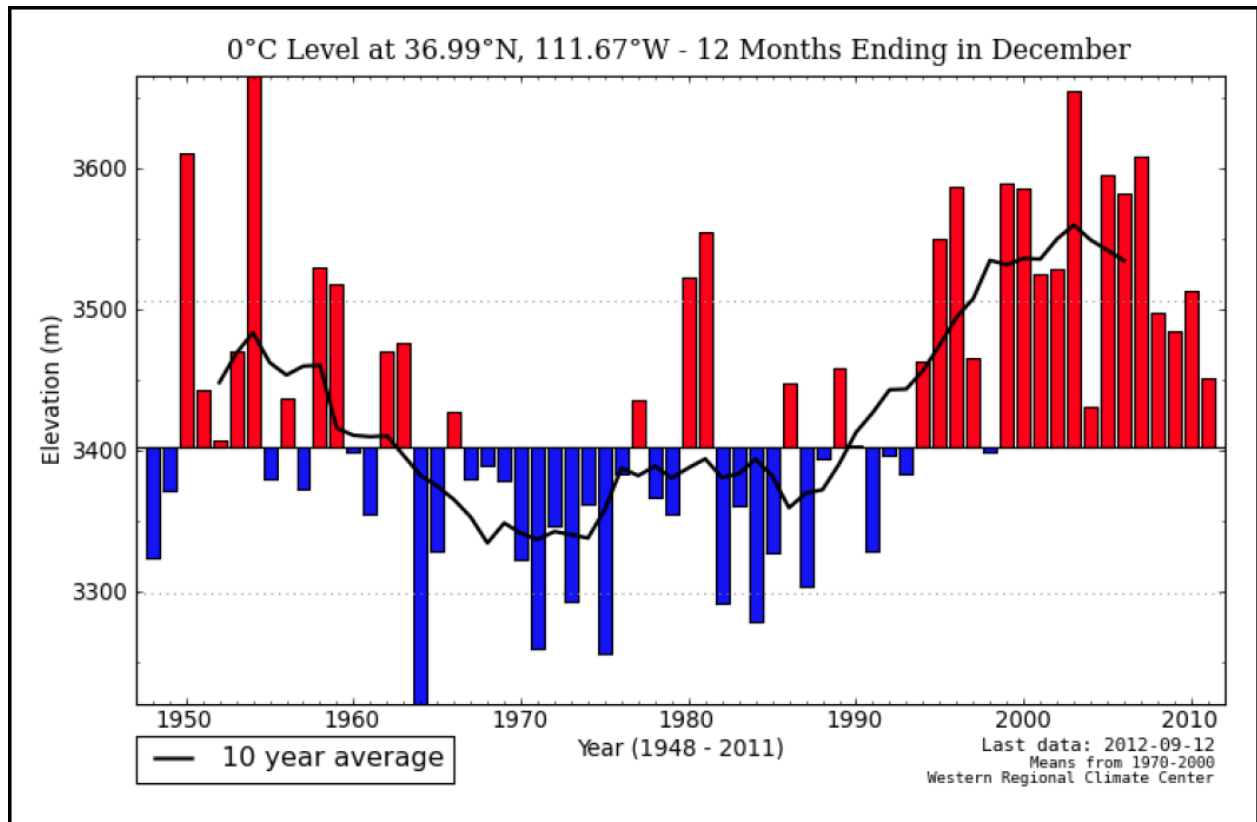


Figure 4.

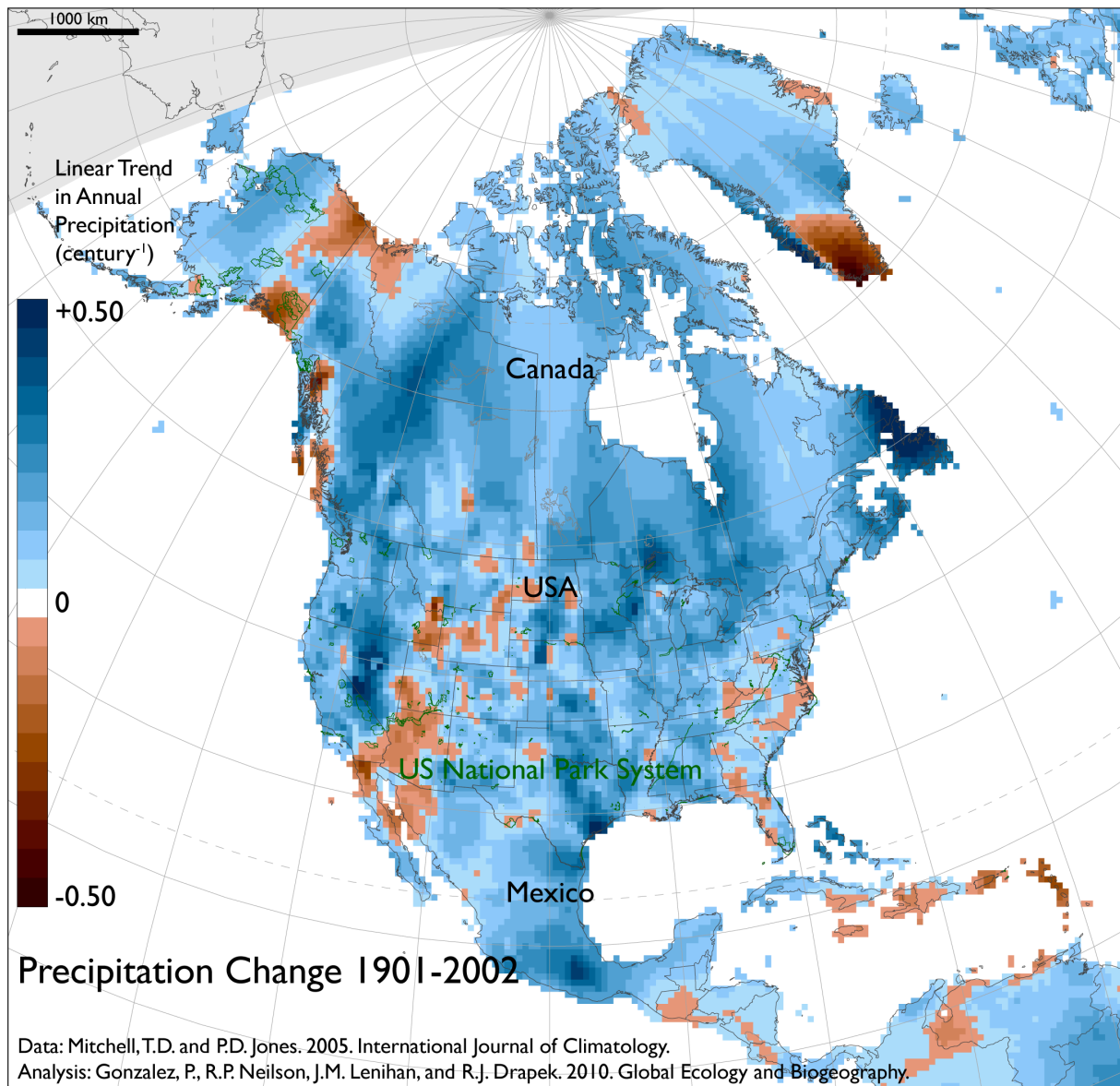


Figure 5.

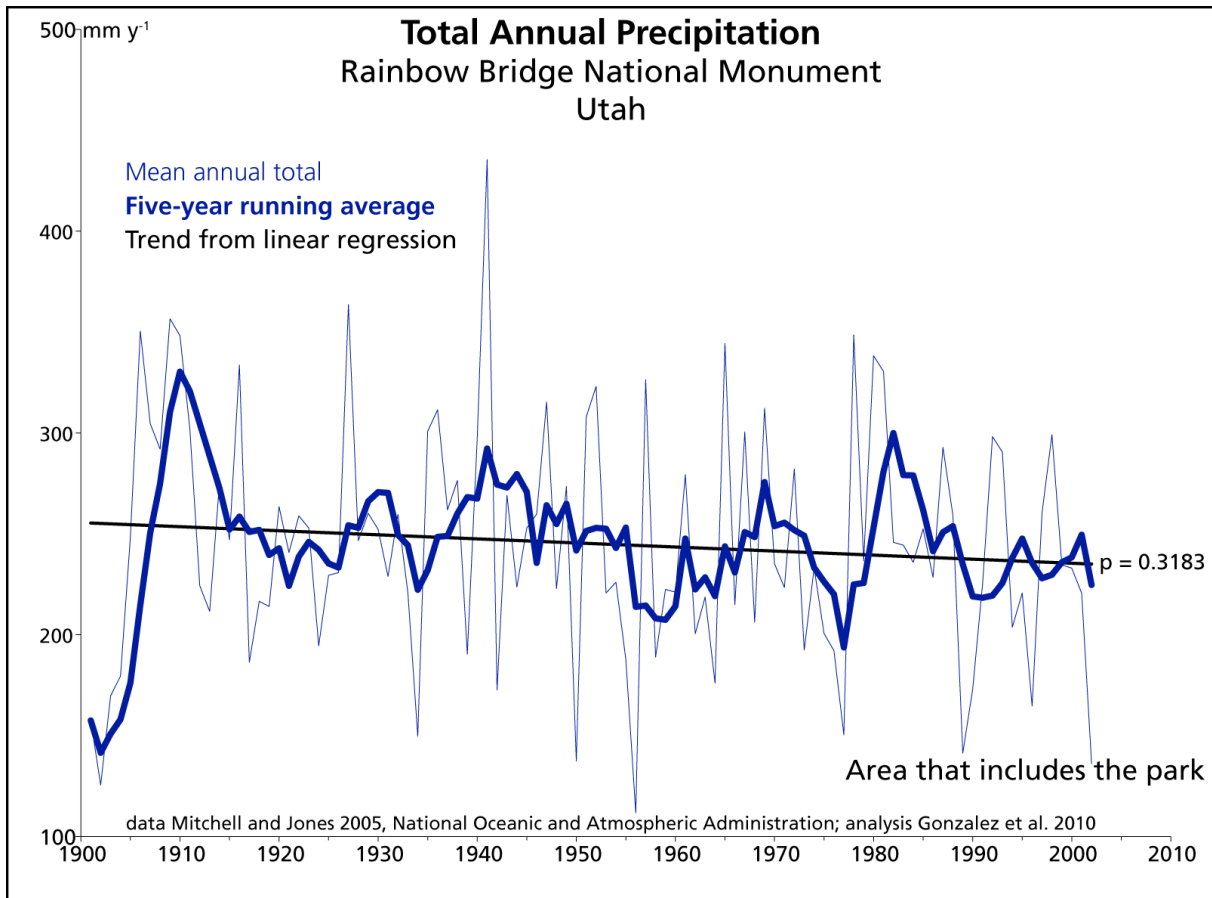


Figure 6.

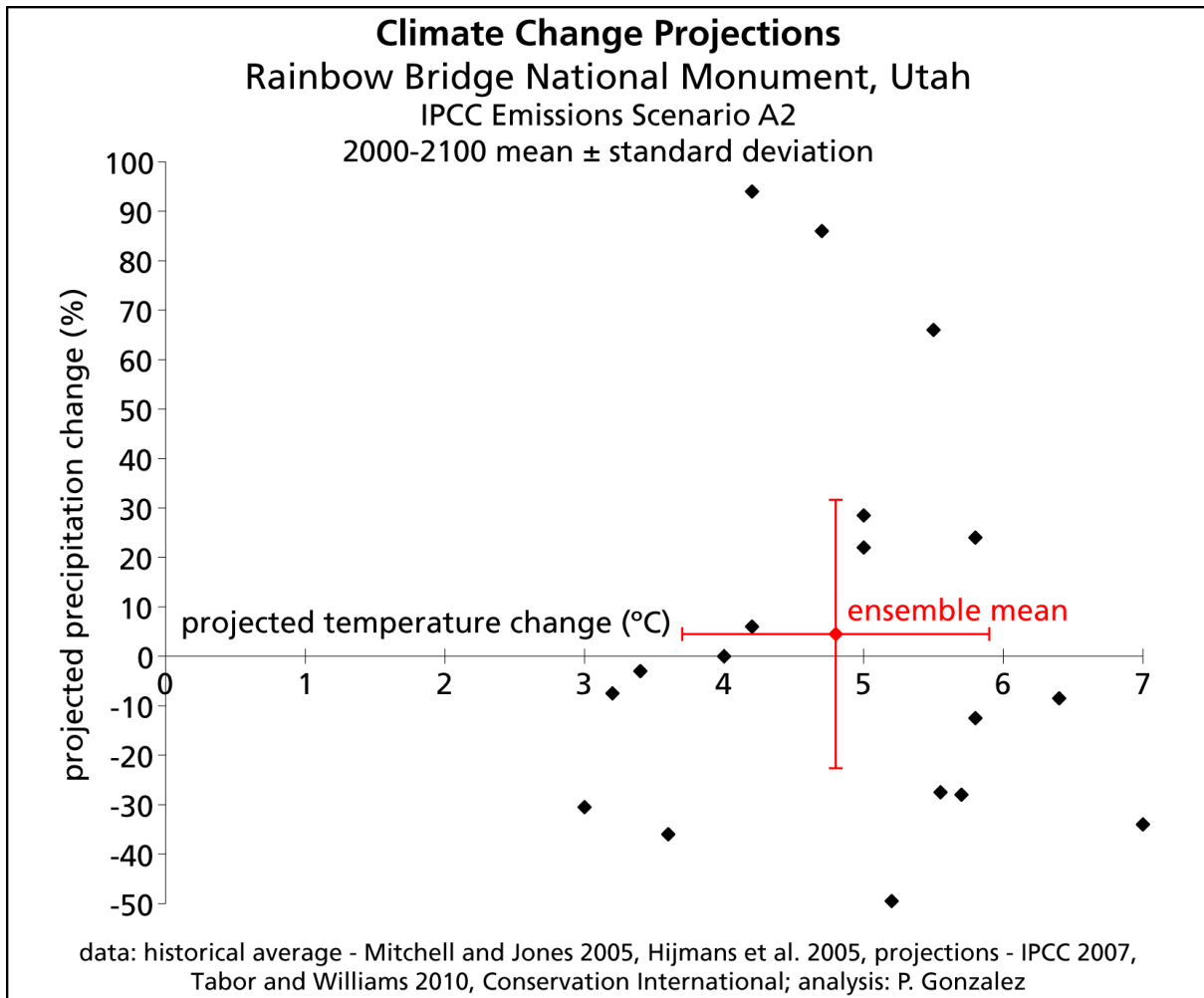
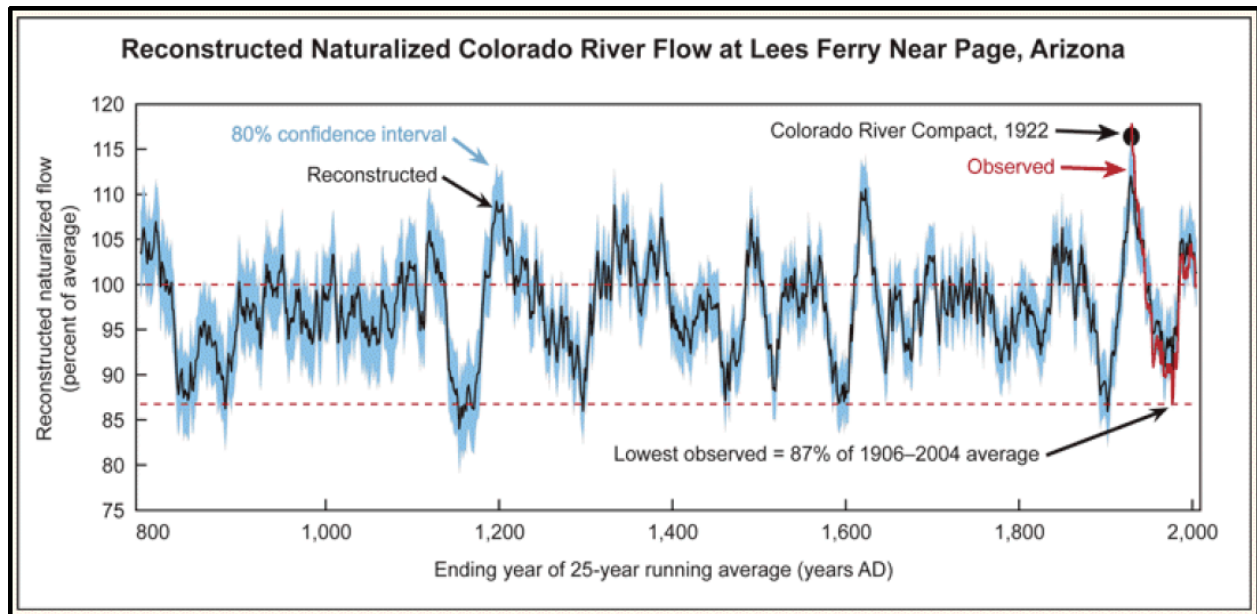


Figure 7.

Reconstruction of what natural Colorado River flow would be at Lees Ferry, Arizona, from analysis of tree rings and gauge station measurements, relative to 1906-2004 average. Black = reconstruction, Red = historical measurements (data Meko et al. 2007, graph Z. Guido, University of Arizona).



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