Future Climate Change Scenarios for Big Bend National Park, Texas

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Big Bend National Park, Texas, is one of the largest but least visited National Parks in the United States. This study assesses the impact of global climate change on the park, using a statistical downscaling technique to produce future climate change predictions at weather stations in the park, based on the National Center for Atmospheric Research Community System Climate Model. Temperature predictions for 2000 - 2099 for low, medium, and high greenhouse gas emission scenarios are presented. Results suggest that the park will warm in line with the global average, between 1 and 4 ^{o}C, but that the seasonal temperature range will decrease by as much as 2 ^{o}C, and the geographic temperature range increase by as much as 1 ^{o}C.
Key Words: Big Bend National Park, Climate change, Downscaling.

Introduction

Big Bend National Park is one of the largest but least visited National Parks in the United States. It covers approximately 3000 km^2 and has approximately 300,000 visitors a year. Elevations range from approximately 500 to 2500 meters above sea level. It is located in Brewster County, Texas, in the southwest of the state, bordering Mexico (Figure 1). It is an area of contrasts, with river, desert, and mountain environments. In line with all National Parks, the purpose of Big Bend is to preserve and protect physical and cultural resources, and provide recreational and educational opportunities (National Park Service 2007a).

Global climate change is a much publicized issue. The global average temperature increased over the last century by approximately 0.5 ^{o}C, with at least some of the warming due to human activities. Predictions of global average temperature change for this century range from approximately 1 to 6 ^{o}C, the range due to a variety of possible greenhouse gas emission scenarios and climate models (Albritton *et al* 2001).

Regionally, temperature and other variables will vary with climate change. Many parts of the United States may be vulnerable to these changes, including National Parks. These changes could affect the natural environment and tourism, through changes in landscapes, vegetation, or general weather conditions. Climate change studies have been carried out in some of the major National Parks, and the park service is taking an active role in addressing climate change (National Park Service 2007b).

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In order to start to answer how changes in climate might affect Big Bend National Park, this study attempts to create local future climate change scenarios for Big Bend National Park, based on global climate model simulations.

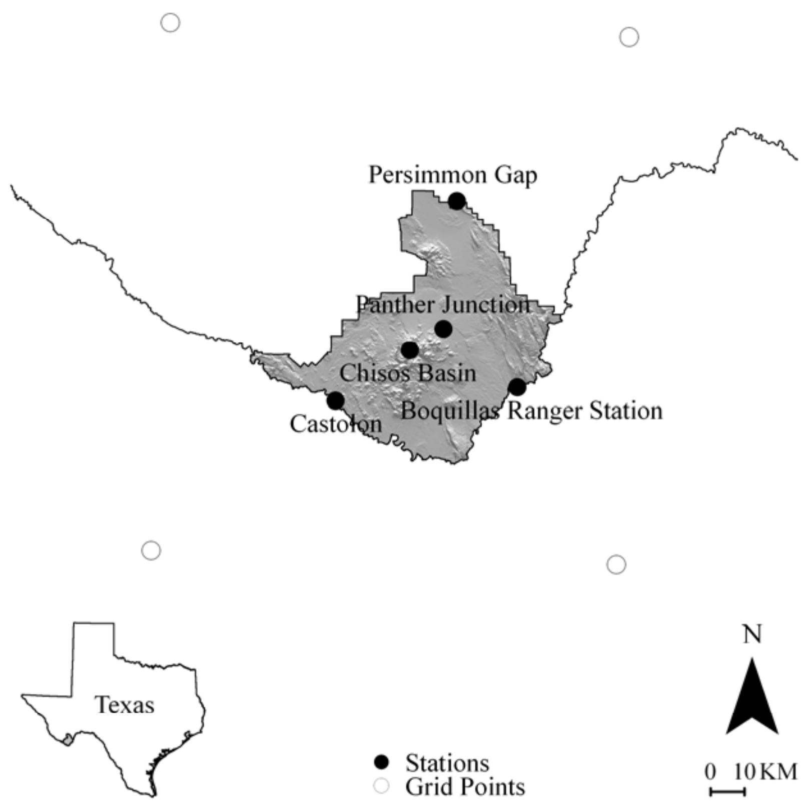

Figure 1. Location of Big Bend National Park, Texas, weather stations and global climate model grid points used in this study.

Background

The Big Bend region is part of the Chihuahuan Desert. The Chihuahuan is the largest of the North American deserts and covers parts of Mexico, Texas, and New Mexico. It results from the rainshadow effect of the Sierra Madre, Occidental and Oriental that block moisture from the Pacific and Atlantic respectively (Laity 2002). There is a wide variety of flora and fauna in the desert. Big Bend National Park has river floodplain, shrub desert, sotol and grassland, and woodland. There are many species of mammals, reptiles, and birds (Maxwell 2001, Swanson 2001, Tyler 2003, Wauer and Fleming 2002).

Texas has as range of climates, ranging from humid subtropical to arid. Temperature decreases generally south to north with latitude, from approximately 13 to 23 oC, and precipitation decrease generally east to west with distance from the Gulf of Mexico, from approximately 25 to 147 cm. Trans-Pecos Texas has some of the highest temperatures and lowest rates of precipitation. Precipitation is greatest in summer and results mostly from convective storms (Bomar 1995, Russell 1945, Schmidt 1995).

Paleoclimate reconstruction of Texas climate suggests that the climate the last glacial period was cooler and drier, and that this transitioned over the last 10,000 years to warmer and drier conditions (Stahle and Cleaveland 1995). In Big Bend, evidence suggests that during the last glacial the area would have been dominated by woodland at higher elevations and savanna at lower elevations. By 5,000 years ago, this had changed to the modern pattern of vegetation. Although temperatures showed a cooling trend over the last century in most of Texas, parts of West Texas warmed (Elias 1997, Griffiths 1995).

Global climate model simulations of future climate suggest increases in temperature and precipitation. The greatest temperature increases are expected to be in the Northern Hemisphere and at high latitudes. Daily and seasonal temperature ranges are predicted to decrease. Precipitation changes are more complex, and less understood. Some areas will experience increases and some areas decreases, although it is likely that extreme events will increase (Albritton et al 2001).

Future predictions suggest climate change will affect Texas in many of the same ways. The state is predicted to warm in line with the global average, and precipitation will changes in a complex way, increasing in some parts of the state and decreasing in others, most likely increasing in the east and remaining the same or decreasing in the west (Griffiths 1995, Mellilo et al 2001, North 1995).

Climate change in Big Bend National Park, would be expected to follow many of these patterns. However, desert and mountain climates are some of the most complex and variable, in terms of both temperature and precipitation, so the response to climate change may also be complex (Barry 1992, Warner 2004, Whiteman 2000).

This study will assess this issue, by providing some specific climate predictions at individual weather stations in the park, at a much better resolution that a global climate model would provide. In the process the study will also assess how well the climate model in question simulates the climate of each station. It is hoped that the National Park Service and other scientists may be able to use this information to begin plan for the future in the park, and to consider what effects any changes in temperature or precipitation may have.

Data

The data for this study are monthly mean temperature in oC and total precipitation in cm, taken from weather stations (National Climatic Data Center 2007) and from climate simulations from the Community Climate System Model (CCSM) (National Center for Atmospheric Research 2007).

The weather station data are for 5 stations located in Big Bend National Park, Boquillas Ranger Station, Castolon, Chisos Basin, Panther Junction, and Persimmon Gap. The climate model data are for the closest 4 grid points surrounding the park, to the northwest, northeast, southwest, and southeast (Figure 1).

The weather stations have various periods of record, the longest beginning in 1947, the shortest in 1982. They are at various elevations, the lowest 566 meters, and the highest 1615 meters above sea level. The grid points have a single period, 1870 - 2099, which consists of simulations of historic (1870 - 1999) and future (2000 - 2099) climate. They too are at various elevations, the lowest 190 meters, and the highest 1217 meters above sea level. These elevations represent a smoothed surface topography used in the model (Table 1).

The climate model simulations are ensemble means, the average of multiple model runs with different initial conditions. The historic simulation is based on historic levels of greenhouse gases, the future simulations are based on several possible future greenhouse gas emission scenarios, all of which lead to different levels of radiative forcing and changes in climate. The simulations used here are run using the Special Report on Emission Scenarios (SRES) scenarios B1, A1B, and A2 used by the Intergovernmental Panel on Climate Change (IPCC), that produce low, medium, and high global temperature changes respectively, in the range 1 to 4 oC over the next century.

Table 1. Location and period of record for weather stations and global climate model grid points. Latitude and longitude are in degrees and minutes, elevation is in meters.

Data Source	Latitude	Longitude	Elevation	Record
Stations				
Boquillas	29 ^{o} 11' N	102 ^{o} 58 ' W	566	1980 - Present
Castolon	29 ^{o} 8 ' N	103 ^{o} 31 ' W	661	1980 - Present
Chisos	29 ^{o} 16 ' N	103 ^{o} 18 ' W	1615	1947 - Present
Panther	29 ^{o} 20 ' N	103 ^{o} 12 ' W	1140	1955 - Present
Persimmon	29 ^{o} 40 ' N	103 ^{o} 10 ' W	873	1982 - Present
Grid Points				
Northwest	30 ^{o} 7 ' N	102 ^{o} 40 ' W	1217	1870 - 2099
Northeast	28 ^{o} 43 ' N	104 ^{o} 36 ' W	190	1870 - 2099
Southwest	28 ^{o} 43 ' N	102 ^{o} 40 ' W	418	1870 - 2099
Southeast	30 ^{o} 7 ' N	104 ^{o} 36 ' W	576	1870 - 2099

Method

Global climate model simulations like those used here provide good generalizations of the Earth's climate. Although resolution is constantly improving, the models cannot at present provide detailed regional simulations of climate change. Also, models do not always include all aspects of the climate system, and parameterize, or average, atmospheric phenomena that are smaller than their gird resolution. For this reason, separate, higher resolution models and statistical techniques have been used to downscale global climate model simulations (Leung et al 2002).

The CCSM model used here includes atmosphere, ocean, sea ice, and land components and has a resolution of approximately 1.5^{o} of latitude and longitude. But even at this resolution, it cannot provide detailed climate change information for an area the size of a National Park.

In order to downscale the model simulations a regional climate model or statistical technique is needed. Many have been developed. There are several statistical approaches, including regression, weather generator, and weather pattern techniques. All rely on the assumption that relationships in variables between observed conditions at weather stations and model grid points will stay the same under future climates (Wilby and Wigley 1997). These approaches have their origins in weather forecasting techniques such as model output statistics (Klein 1982, Wilks 2005).

The method used here is a statistical regression based technique called Climate Prediction by Model Statistics (CPMS). It has been used previously to simulate regional climate change in various regions across the United States, but not in the southwestern United States (Karl et al 1990, Easterling 1999).

The method is based on developing regression equations that relate free atmosphere variables from climate model grid points to surface variables at weather stations of interest. The equations are typically built using historic weather station data and historic reanalysis data. Principal components of free atmosphere variables are typically used to cut down the number of independent variables.

Once the equations are developed, they are applied to the future climate model output, to predict future climate at the weather stations. The approach has been used to predict temperature and precipitation, but has shown considerably more skill predicting temperature, although this is most likely due to less accurate simulation of precipitation in climate models in general.

Here a simplified version of CPMS is used. Because both historic and future simulations were available from the CCSM model, the historic simulation was used in place of reanalysis data. And since the same surface variables to be predicted at the weather stations of interested were available from the CCSM model, they were used as well as free atmosphere variables. Two approaches were taken, the first was closest to the original technique, and used multiple regression analysis between free atmosphere variables in the model (temperature, precipitation flux, pressure, water vapor content, northerly wind stress, and easterly wind stress) and surface variables in the historic data (temperature and precipitation). The second used simple regression between surface variables in the both model and historic data. The second approach produced equal or better results and was simpler, so was favored here.

Also, rather than use the closest global climate model grid point to each station to develop regression equations, all surrounding grid points were included in a stepwise multiple regression, and those that made a significant contribution were used. This way all useful climate information from the climate model grid points in the region is used.

The steps of the analysis, then, were as follows. First, multiple regression analysis was carried out using the monthly data, between the surface variables, temperature and precipitation, at each weather station and the same variables at the surrounding climate model grid points. This produced one equation for each station, using historic weather station data and the historic climate model simulation. Given the short periods of record at several of the weather stations, and in order to use a common time period for each station, ten years of data, 1980 - 1989 were used.

Second, the regression equations were applied to the climate model simulation for the period 1990 - 1999, to validate the technique and see if it could historic temperature and precipitation. Third, the regression equations were applied to the future climate model simulations, low, medium, and high, to predict, future temperature and precipitation, for the period 2000 - 2099.

Results

The regression equation parameters and r square values for temperature are given in table 2. The r square values are all high, above 0.9, and all equations use southern climate model grid points as independent variables. Precipitation results are not given here, due to low r square values, below 0.4, that suggest that neither the climate model, or downscaled output would be meaningful or useful for this region.

The results are of the analysis are summarized here at the annual and seasonal scale. Seasons are defined as winter (December, January, February), spring (March, April, May), summer (June, July, August), and fall (September, October, November). Results are given in tables 3 through 7.

At the annual scale, the results show that the downscaling approach is able to predict historic means and standard deviations relatively accurately, typically to within a half a degree for means and a degree for standard deviations. Means are typically overestimated, and standard deviations are typically underestimated. At the seasonal scale, the same patterns are apparent, although there is less accuracy and more variation, and in summer, means are underpredicted and standard deviations overpredicted in contrast to the general pattern.

Predictions also vary spatially. Means are reproduced better at the higher elevation mountain stations, Chisos Basin and Panther Junction, but standard deviations better at the lower elevation, desert floor stations, Boquillas Ranger Station, Castolon, and Panther Junction.

The annual results suggest that Big Bend National Park will warm between 1 and 4^{o}C over the course of this century, depending on the greenhouse gas emission scenario. Temperature variability also increases.

Seasonally, the most warming is predicted to take place in the fall, and the least in the summer, a decrease in seasonal temperature range of as much as 2°C. Temperature is also predicted to increase more at the lower elevation stations, and less at the higher elevation stations, an increase in the geographic temperature range of as much as 1°C.

Table 2. Regression equations for stations. The coefficient of determination is abbreviated to r^2, the regression intercept to a, and the regression coefficients to b.

Station	r^2	a	NW b	NE b	SW b	SE b
Boquillas	0.95	7.385			1.664	-0.783
Castolon	0.949	7.787			1.621	-0.744
Chisos	0.923	6.426			1.361	-0.722
Panther	0.937	6.474			1.386	-0.616
Persimmon	0.951	4.727			0.900	

Table 3. Observed and predicted annual temperatures for the historic period, and low, medium, and high climate change scenarios. Temperatures are in degrees Celsius. Means and standard deviations are for the periods 1990 - 1999 and 2090 - 2099, and trends are for the period 2000 - 2099.

Statistic	Boquillas	Castolon	Chisos	Panther	Persimmon
Mean					
Observed	21.3	22.3	16.5	18.7	19.5
Predicted	21.5	21.9	16.5	18.9	20.0
Low	22.5	22.9	17.2	19.8	21.1
Medium	23.1	23.5	17.7	20.3	21.6
High	23.4	23.8	17.9	20.6	22.0
Standard Deviation					
Observed	0.4	0.8	0.6	1.1	0.2
Predicted	0.5	0.5	0.4	0.4	0.5
Low	0.5	0.2	0.1	0.2	0.2
Medium	0.8	0.6	0.3	0.5	0.6
High	1.3	1.6	0.9	1.2	1.5
Trend					
Low	1.2	1.2	0.9	1.0	1.2
Medium	2.5	2.5	1.8	2.2	2.5
High	4.2	4.1	3.1	3.6	4.1

Table 4. Observed and predicted winter temperature results for the historic period, and low, medium, and high climate change scenarios. Temperatures are in degrees Celsius. Means and standard deviations are for the periods 1990 - 1999 and 2090 - 2099, and trends are for the period 2000 - 2099.

Statistic	Boquillas	Castolon	Chisos	Panther	Persimmon
Mean					
Observed	11.4	12.4	9.3	10.3	10.6
Predicted	11.8	12.2	9.4	10.4	10.2
Low	12.7	13.1	10.1	11.2	11.2
Medium	13.2	13.7	10.5	11.7	11.8
High	13.7	14.1	10.8	12.1	12.3
Standard Deviation					
Observed	0.7	0.9	1.1	1.4	0.8
Predicted	0.7	0.7	0.5	0.6	0.7
Low	0.6	0.4	0.2	0.3	0.5
Medium	0.9	0.8	0.4	0.6	0.9
High	1.3	1.7	0.9	1.3	1.8
Trend					
Low	1.2	1.2	0.8	1.0	1.3
Medium	2.6	2.6	1.9	2.3	2.7
High	4.1	4.1	3.0	3.6	4.2

Table 5. Observed and predicted spring temperature results for the historic period, and low, medium, and high climate change scenarios. Temperatures are in degrees Celsius. Means and standard deviations are for the periods 1990 - 1999 and 2090 - 2099, and trends are for the period 2000 - 2099.

Statistic	Boquillas	Castolon	Chisos	Panther	Persimmon
Mean					
Observed	22.0	23.2	17.1	19.4	20.4
Predicted	22.5	22.9	17.3	19.8	20.8
Low	23.6	24.0	18.1	20.7	21.8
Medium	24.3	24.6	18.6	21.3	22.5
High	24.6	24.9	18.8	21.5	22.7
Standard Deviation					
Observed	0.9	0.8	1.0	1.3	0.8
Predicted	0.5	0.5	0.4	0.5	0.5
Low	0.7	0.7	0.5	0.6	0.6
Medium	0.9	0.9	0.7	0.8	0.8
High	1.4	1.4	1.0	1.2	1.2
Trend					
Low	1.4	1.3	1.0	1.2	1.3
Medium	2.3	2.3	1.7	2.0	2.3
High	4.4	4.3	3.3	3.8	3.9

Table 6. Observed and predicted summer temperature results for the historic period, and low, medium, and high climate change scenarios. Temperatures are in degrees Celsius. Means and standard deviations are for the periods 1990 - 1999 and 2090 - 2099, and trends are for the period 2000 - 2099.

Statistic	Boquillas	Castolon	Chisos	Panther	Persimmon
Mean					
Observed	30.7	31.3	23.3	26.7	29.0
Predicted	30.2	30.5	22.8	26.4	28.6
Low	31.0	31.3	23.4	27.1	29.4
Medium	31.4	31.6	23.7	27.5	29.8
High	31.7	32.0	23.9	27.7	30.1
Standard Deviation					
Observed	0.6	1.0	0.5	1.3	0.8
Predicted	0.9	0.9	0.7	0.8	0.9
Low	0.8	0.8	0.6	0.7	0.6
Medium	1.0	0.9	0.7	0.8	0.9
High	1.2	1.2	0.9	1.1	1.2
Trend					
Low	0.7	0.7	0.6	0.6	0.7
Medium	1.9	1.9	1.4	1.7	2.0
High	3.2	3.2	2.3	2.8	3.3

Table 7. Observed and predicted fall temperature results for the historic period, and low, medium, and high climate change scenarios. Temperatures are in degrees Celsius. Means and standard deviations are for the periods 1990 - 1999 and 2090 - 2099, and trends are for the period 2000 - 2099.

Statistic	Boquillas	Castolon	Chisos	Panther	Persimmon
Mean					
Observed	21.2	22.3	16.5	18.7	19.4
Predicted	21.5	21.9	16.4	18.9	20.5
Low	22.9	23.3	17.4	20.1	21.9
Medium	23.5	23.9	17.9	20.7	22.5
High	23.9	24.3	18.2	21.0	22.9
Standard Deviation					
Observed	1.1	1.4	0.9	1.7	1.0
Predicted	0.5	0.5	0.4	0.5	0.6
Low	0.7	0.7	0.5	0.6	0.6
Medium	1.1	1.1	0.8	0.9	1.0
High	1.6	1.6	1.2	1.4	1.6
Trend					
Low	1.5	1.5	1.1	1.3	1.5
Medium	3.2	3.1	2.3	2.8	3.1
High	5.1	5.1	3.7	4.4	5.1

Conclusions

This study has presented a statistical method to downscale future climate predictions from global climate models, to a regional scale, at specific weather stations, and a case study for Big Bend National Park, Texas. Regional downscaling has been carried out for many parts of the United States, but this method has not before been applied to a National Park, desert, or mountainous region.

In this study, results suggest that temperatures will warm in Big Bend National Park in line with the global average over the course of this century as predicted by most climate models, but that the change will vary seasonally and geographically, with a decreased temporal and increased spatial temperature range. Unfortunately, the technique used was not able to produce useful precipitation results. This may be a problem with climate model simulations of desert or mountain climates, the downscaling approach, or the local, convective nature of much of the precipitation in the region.

Interestingly, the downscaling method used here not only increases the resolution of the original climate model predictions, it also suggests slightly less warming, and differences in warming at different elevations, a pattern that is not evident in the model. Therefore, based on this study, this downscaling methods does add detail and new information to climate predictions from global climate models.

Climate changes are likely to affect all National Parks. Regional downscaling of global climate model output provides one approach for studying how these changes might affect different parks in different parts of the country. Although Big Bend is not one of the most visited national parks, it is one of the most unique and varied parks and the results of this study suggest that its response to climate change is also going to be varied.

Hopefully, the information provided here is a first step to considering the effects of climate change on Big Bend National Park, and will be useful to the park service and other scientists interested in its future.

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