Forecast: Climate Change Impacts on Texas Water

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The Changing Climate of South Texas 1900-2100: A Challenge “Come and Take It”

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Abstract

Models suggest that subtropical locations will mainly be negatively impacted by twentieth-century global-warming-related climate change. The existing semi-arid subtropical South Texas climate, already problematic, is likely to become considerably more so by the end of this century. This could prove to be the region's greatest challenge since its first human inhabitants arrived ten or so millennia ago. Our new book, The Changing Climate of South Texas 1900-2100: Problems and Prospects, Impacts and Implications (Norwine and John, eds., December 2007), the work of leading scientists and engineers, was prepared to provide citizens and leaders with knowledge in the form of a readable state-of-the-science assessment of what we know and where we are headed. Our job as we saw it was to describe and explain this new regional challenge to the best of our ability. We hope and believe that this work offers a “come and take it” challenge to other climate-vulnerable regions, i.e., as an example to build and improve on.
The Changing Climate of South Texas 1900-2100

Problems and Prospects
Impacts and Implications

Jim Norwine and Kuruvilla John, editors
ACKNOWLEDGEMENTS

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CREST-RESSACA: Research on Environmental Sustainability of Semi-Acid Coastal Areas

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Changes in Temperature, Sea Level and Northern Hemisphere Snow Cover

(a) Global average temperature

(b) Global average sea level

(c) Northern Hemisphere snow cover
Future projections based upon climate model simulations for various scenarios. The orange line is the solution for constant green house gases from the year 2000. Scenario A1F1 is a business as usual scenario, while B1 is a case where the emissions are leveled at 2050. (IPCC 2007 Working Group I Summary for Policy Makers)
Climates of the Earth (Thornthwaite, 1931)
Me Before 65 Million Years Ago:

ROAR! I am Lord of the World (forever)!

SQUEAK! Excuse me!
One Fine Day 65 Million Years Ago:
35 Million Years Ago

Generalized climate zones of North America during a) late Eocene to early Oligocene; b) late Oligocene to early Miocene
1 Million Years Ago

Generalized climatic zones representing a composite of Pleistocene glacial conditions in North America
Why our South Texas climate is “different”: Two of the three great divides get hitched right here.

The North Pole

The High-Latitude, Polar or Frigid (Aristotle) Realm

-60N S

The Temperate (Seasonal) Belt

K

-30N S

Subtropical Divide

The Tropical, Frost-Free or Torrid (Aristotle) Zone

Y

E

T

Equator

D

W

The Tropical, Frost-Free or Torrid (Aristotle) Zone

R

E

-30S

Subtropical Divide

Y

The Temperate (Seasonal) Belt

T

-60N S

Subtropical Divide

The High-Latitude, Polar or Frigid (Aristotle) Realm

The South Pole
Corpus Christi

Red = deficiency
Green = surplus

PE = 111.8
P = 67.7
S.M.U. = 1.5 + 1.3 + 0.7 = 3.5
D = 44.2
S = 0

No Annual Surplus
### Table 1. South Texas Regional Temperatures: 1900-2000

<table>
<thead>
<tr>
<th>Period</th>
<th>Region</th>
<th>Mean Daily Minimum (°C)</th>
<th>Mean Daily Maximum (°C)</th>
<th>Mean Daily Mean (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Entire Twentieth Century: 1900-2000</strong></td>
<td>Southern South Texas</td>
<td>22.0</td>
<td>28.2</td>
<td>15.8</td>
</tr>
<tr>
<td></td>
<td>Eastern South Texas</td>
<td>21.9</td>
<td>27.8</td>
<td>16.1</td>
</tr>
<tr>
<td></td>
<td>Western South Texas</td>
<td>21.2</td>
<td>28.0</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>Southern South Texas</td>
<td>23.6</td>
<td>28.9</td>
<td>17.6</td>
</tr>
<tr>
<td><strong>1931-1965 versus 1966-2000</strong></td>
<td>South Texas combined</td>
<td>22.3/22.0</td>
<td>28.5/28.2</td>
<td>16.1/15.9</td>
</tr>
<tr>
<td></td>
<td>Eastern South Texas</td>
<td>22.3/21.9</td>
<td>28.2/27.9</td>
<td>16.1/15.8</td>
</tr>
<tr>
<td></td>
<td>Western South Texas</td>
<td>21.3/21.1</td>
<td>28.2/27.9</td>
<td>14.4/14.3</td>
</tr>
<tr>
<td></td>
<td>Southern South Texas</td>
<td>23.3/23.1</td>
<td>29.8/28.7</td>
<td>17.7/17.5</td>
</tr>
</tbody>
</table>

### Table 2. South Texas Regional Precipitation: 1900-2000

<table>
<thead>
<tr>
<th>Period</th>
<th>Region</th>
<th>Mean Annual (mm)</th>
<th>Mean Summer (mm)</th>
<th>Mean Winter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Entire Twentieth Century: 1900 to 2000</strong></td>
<td>South Texas Combined</td>
<td>660</td>
<td>411.5</td>
<td>247.1</td>
</tr>
<tr>
<td></td>
<td>Eastern South Texas</td>
<td>761.6</td>
<td>462.7</td>
<td>299.3</td>
</tr>
<tr>
<td></td>
<td>Western South Texas</td>
<td>592.6</td>
<td>377.5</td>
<td>214</td>
</tr>
<tr>
<td></td>
<td>Southern South Texas</td>
<td>625.7</td>
<td>396.1</td>
<td>228.2</td>
</tr>
<tr>
<td><strong>1931 to 1965 vs 1966 to 2000</strong></td>
<td>South Texas Combined</td>
<td>622/710**</td>
<td>389/451**</td>
<td>233/262**</td>
</tr>
<tr>
<td></td>
<td>Eastern South Texas</td>
<td>714/837**</td>
<td>429/529**</td>
<td>287/313**</td>
</tr>
<tr>
<td></td>
<td>Western South Texas</td>
<td>572/633**</td>
<td>373/397</td>
<td>198/224**</td>
</tr>
<tr>
<td></td>
<td>Southern South Texas</td>
<td>579/669**</td>
<td>366/429**</td>
<td>214/248**</td>
</tr>
</tbody>
</table>
Reconstructed June Parmer Drought Sensitivity Index (PSDI) for South Texas plotted annually from 1698 to 1980, and smoothed with a low-pass filter passing variance with a frequency of greater than about eight years (Stahle and Cleaveland, 1988)
(a) Mean annual temperature, (b) mean annual minimum temperature, and (c) mean annual maximum temperature of South Texas during 1931 to 2001. Twenty-one stations: Eastern: Alice, Beeville, Corpus Christi, Falfurrias, Goliad, Kingsville and Victoria; Western: Brackettville, Carrizo Springs, Dilley, Eagle Pass, Encinal, San Antonio and Uvalde; Lower Valley: Brownsville, Harlingen, McAllen, Port Isabel, Raymondville, Rio Grande City, and Weslaco.
(a) Mean annual total precipitation, (b) mean annual summer precipitation, and (c) mean annual winter precipitation of South Texas during 1931 to 2001. Summer includes precipitation from April to September and winter indicates October to March.
“Let’s go over to Celsius’s place. I hear it’s only 36° over there.”
Doubled CO2 Impact on Houston Temperatures

- **Days Above 100 F (~38 C)**
  - Yesterday's Climate: 47
  - Doubled CO2: 111

- **Days Below Freezing**
  - Yesterday's Climate: 1.3
  - Doubled CO2: 1.4

- **Days Above 95 F (~35 C)**
  - Yesterday's Climate: 25
  - Doubled CO2: 86

- **Days where Minimum Temperature above 80 F (~27 C)**
  - Yesterday's Climate: 1
  - Doubled CO2: 86
Table 2: Average Climate Water Budget in Corpus Christi, TX using NOAA Model, 270.0 mm Storage at Field Capacity and Linear Declining Availability of Soil Moisture

(a) Calibrated data for doubled CO₂ Condition

<table>
<thead>
<tr>
<th>MO</th>
<th>TEMP</th>
<th>APE</th>
<th>PREC</th>
<th>ST</th>
<th>AE</th>
<th>DEF</th>
<th>SURF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>16.6</td>
<td>24.</td>
<td>30.</td>
<td>33.</td>
<td>24.</td>
<td>0.</td>
<td>0.</td>
</tr>
<tr>
<td>Feb</td>
<td>18.4</td>
<td>33.</td>
<td>36.</td>
<td>36.</td>
<td>33.</td>
<td>0.</td>
<td>0.</td>
</tr>
<tr>
<td>Mar</td>
<td>22.0</td>
<td>72.</td>
<td>38.</td>
<td>32.</td>
<td>42.</td>
<td>30.</td>
<td>0.</td>
</tr>
<tr>
<td>Apr</td>
<td>24.6</td>
<td>111.</td>
<td>42.</td>
<td>25.</td>
<td>49.</td>
<td>62.</td>
<td>0.</td>
</tr>
<tr>
<td>May</td>
<td>29.6</td>
<td>186.</td>
<td>81.</td>
<td>17.</td>
<td>89.</td>
<td>97.</td>
<td>0.</td>
</tr>
<tr>
<td>Jun</td>
<td>32.1</td>
<td>201.</td>
<td>71.</td>
<td>10.</td>
<td>77.</td>
<td>124.</td>
<td>0.</td>
</tr>
<tr>
<td>Jul</td>
<td>32.5</td>
<td>207.</td>
<td>66.</td>
<td>6.</td>
<td>50.</td>
<td>157.</td>
<td>0.</td>
</tr>
<tr>
<td>Aug</td>
<td>33.0</td>
<td>202.</td>
<td>51.</td>
<td>3.</td>
<td>53.</td>
<td>149.</td>
<td>0.</td>
</tr>
<tr>
<td>Sep</td>
<td>31.6</td>
<td>175.</td>
<td>92.</td>
<td>2.</td>
<td>93.</td>
<td>82.</td>
<td>0.</td>
</tr>
<tr>
<td>Oct</td>
<td>26.9</td>
<td>136.</td>
<td>76.</td>
<td>2.</td>
<td>76.</td>
<td>60.</td>
<td>0.</td>
</tr>
<tr>
<td>Nov</td>
<td>21.5</td>
<td>58.</td>
<td>45.</td>
<td>2.</td>
<td>45.</td>
<td>13.</td>
<td>0.</td>
</tr>
<tr>
<td>Dec</td>
<td>15.7</td>
<td>19.</td>
<td>45.</td>
<td>27.</td>
<td>19.</td>
<td>0.</td>
<td>0.</td>
</tr>
<tr>
<td>YEARLY TOTALS</td>
<td>1424</td>
<td>651</td>
<td>651</td>
<td>773</td>
<td>0.</td>
<td></td>
<td></td>
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</tbody>
</table>

(b) Average Current Data

<table>
<thead>
<tr>
<th>MO</th>
<th>TEMP</th>
<th>APE</th>
<th>PREC</th>
<th>ST</th>
<th>AE</th>
<th>DEF</th>
<th>SURF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>13.2</td>
<td>20</td>
<td>39</td>
<td>39</td>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Feb</td>
<td>15.1</td>
<td>28</td>
<td>36</td>
<td>45</td>
<td>28</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mar</td>
<td>18.4</td>
<td>54</td>
<td>39</td>
<td>45</td>
<td>42</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Apr</td>
<td>23.1</td>
<td>91</td>
<td>43</td>
<td>38</td>
<td>50</td>
<td>41</td>
<td>0</td>
</tr>
<tr>
<td>May</td>
<td>25.3</td>
<td>140</td>
<td>82</td>
<td>31</td>
<td>59</td>
<td>51</td>
<td>0</td>
</tr>
<tr>
<td>Jun</td>
<td>28.1</td>
<td>172</td>
<td>72</td>
<td>21</td>
<td>82</td>
<td>90</td>
<td>0</td>
</tr>
<tr>
<td>Jul</td>
<td>29.1</td>
<td>185</td>
<td>48</td>
<td>13</td>
<td>57</td>
<td>123</td>
<td>0</td>
</tr>
<tr>
<td>Aug</td>
<td>29.6</td>
<td>180</td>
<td>52</td>
<td>8</td>
<td>57</td>
<td>123</td>
<td>0</td>
</tr>
<tr>
<td>Sep</td>
<td>27.5</td>
<td>147</td>
<td>52</td>
<td>6</td>
<td>93</td>
<td>54</td>
<td>0</td>
</tr>
<tr>
<td>Oct</td>
<td>23.0</td>
<td>92</td>
<td>76</td>
<td>6</td>
<td>77</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Nov</td>
<td>17.9</td>
<td>44</td>
<td>46</td>
<td>9</td>
<td>43</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Dec</td>
<td>13.8</td>
<td>23</td>
<td>43</td>
<td>30</td>
<td>23</td>
<td>0</td>
<td>0</td>
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<tr>
<td>YEARLY TOTALS</td>
<td>1176</td>
<td>659</td>
<td>661</td>
<td>515</td>
<td>0</td>
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<td></td>
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</tbody>
</table>

Current Portential Evapotranspiration
Table 4: Differences in Water Budget Factors Between Doubled CO₂ [(a) in Tables 1-3] and Average Current Data [(b) in Tables 1-3]

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>AP</th>
<th>Prec.</th>
<th>Deficit</th>
<th>Surplus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual:</td>
<td>Brownsville</td>
<td>25°54.3’</td>
<td>261</td>
<td>-12</td>
<td>262</td>
</tr>
<tr>
<td></td>
<td>Corpus Christi</td>
<td>28°2.4’</td>
<td>248</td>
<td>-8</td>
<td>258</td>
</tr>
<tr>
<td></td>
<td>Laredo</td>
<td>27°30.4’</td>
<td>237</td>
<td>-5</td>
<td>240</td>
</tr>
<tr>
<td>Summer:</td>
<td>Brownsville</td>
<td>25°54.3’</td>
<td>68</td>
<td>-6</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Corpus Christi</td>
<td>28°2.4’</td>
<td>73</td>
<td>-4</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>Laredo</td>
<td>27°30.4’</td>
<td>61</td>
<td>-3</td>
<td>64</td>
</tr>
<tr>
<td>Winter:</td>
<td>Brownsville</td>
<td>25°54.3’</td>
<td>17</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Corpus Christi</td>
<td>28°2.4’</td>
<td>5</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Laredo</td>
<td>27°30.4’</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 5: Moisture Index Analysis

<table>
<thead>
<tr>
<th>Location</th>
<th>Im = 100[(P/PE) - 1]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 × CO₂</td>
</tr>
<tr>
<td></td>
<td>P</td>
</tr>
<tr>
<td>Brownsville</td>
<td>554</td>
</tr>
<tr>
<td>Corpus Christi</td>
<td>651</td>
</tr>
<tr>
<td>Laredo</td>
<td>499</td>
</tr>
</tbody>
</table>
South Texas future climate: temperature change over the year (a) 2025, (b) 2050 and (c) 2100. Calculations by C. Tebaldi, NCAR, 2006.
South Texas future climate: precipitation change (mm) over the year (a) 2025, (b) 2050, and (c) 2100. Calculations by C. Tebaldi, NCAR, 2006
South Texas future climate: precipitation change (%) over the year (a) 2025, (b) 2050, and (c) 2100. Calculations by C. Tebaldi, NCAR, 2006
Moisture regions of the US: percent (Thornthwaite, 1931, 1933, and 1948)
Inundation of Mustang Island. The amounts of sea-level rise depicted here (darker gray color) are expected in 100 years when combining local subsidence estimates with the lower and upper ranges of global sea level rise projections presented in the IPCC (2007) report. This map was created using aerial photography draped on a high-resolution, lidar-derived digital elevation model. Lidar data acquisition and processing were performed by the Bureau of Economic Geology, the University of Texas at Austin in 2005.
Perspective view of inundation of the Corpus Christi Bay area by sea level rise. These scenarios are reflective of polar ice sheet melting and destabilization triggered by global warming. Topographic relief is vertically exaggerated six times.
Inundation of land if the level of the sea were to rise 6 m above present level. Lighter gray shows the present bays and lagoons and the darker gray depicts inundated areas. This scenario is reflective of polar ice sheet melting and destabilization triggered by global warming during the next one hundred years resulting in sea level rise rates of 10 mm/yr or more for centuries. Constant redistribution of sediments by waves and currents during sea level rise would tend to smooth the shoreline, but that process is not reflected in this map.
Number of grid cells exceeding eight-hour ozone standard for base case and each temperature perturbed case.
Number of eight-hour ozone exceedences for base case and each temperature perturbed case
The baseline (1987 to 2002) average potential and actual monthly evapotranspiration and the predicted change when the temperature in each month is raised by 4°C.
Average monthly recharge for the baseline and year 2100 conditions
The impact of increasing temperature on soil moisture
Monthly PET estimate with temperature increases of 1 ºC, 2 ºC, 3 ºC and 4 ºC. PET 2000 was calculated based on US National Climatic Data from 1970-2000.

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annua l Total (inches)</th>
<th>PET Change %</th>
</tr>
</thead>
<tbody>
<tr>
<td>P (in.)</td>
<td>1.2</td>
<td>1.3</td>
<td>0.95</td>
<td>1.36</td>
<td>2.51</td>
<td>2.49</td>
<td>1.7</td>
<td>2.31</td>
<td>4</td>
<td>2.76</td>
<td>0.95</td>
<td>1.01</td>
<td>22.61</td>
<td></td>
</tr>
<tr>
<td>PET+1C</td>
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Green Parakeet range change 1976 to 2004
Black-tailed Gnatcatcher range change in Texas
1912 to 2004
Green Jay range change in Texas 1912 to 2004
Things change.
Not all change is benign or beneficial: much is "bad".
Bad change can be endured, even made "good".
If.

Dear Reader: By now you know that you hold in your hand a "global warming" book mostly lacking in policies or prescriptions. There is a place for advocacy but this is not that place. The singular reason-to-be of The Changing Climate of South Texas 1900 to 2100 was to provide citizens and leaders with knowledge; knowledge in the form of a readable, state-of-the-science assessment of what we know and where we are headed. We hope you agree that, although this volume lacks elements we wish could have included such the social implications of our current climate scenarios, an important and urgent purpose has been accomplished.

The Changing Climate of South Texas 1900 to 2100 was the work of leading scholarly authorities, to whom we are deeply grateful. As you have read their chapters, you have found that they explained that the existing semi-arid, subtropical climate, which is already "problematic," is very likely to become considerably more so by the end of this century. In 2100, South Texas will be warmer, perhaps very much warmer. It will probably be more moisture-variable, with both more intense storms and more and longer droughts. Paradoxically it may be both rainier as a consequence of influences such as heightened El Ninos and/or tropical disturbances, and yet also drier in terms of average soil moisture due to increased evaporation rates. The potential magnitude and shock of this change was illustrated in Chapter Two with an idea that at first blush seems hyperbolic: "Imagine Corpus Christi moved to Laredo by the year 2100." In fact, while that prospect might prove an exaggeration in one sense - one hundred years may not be long enough to shift the climate of Corpus Christi from subhumid to semi-desert - it is probably too moderate in other ways. After all, Laredo will not have to deal with the very real threat of sea-level rise.

Our expert contributors have also shown that the potential regional impacts and implications of such changes will, with exceptions, tend to be unfavorable for most natural and human economies and ecologies. South Texas is in this sense a microcosm of planetary patterns. While some regions, communities, and systems will benefit from a warmer world, most will not. However, our region is also different. This is not the American midwest or western Europe, areas of comparable size but better situated for a variety of reasons to deal with and adapt to climate change. Like the subarctic zone of Alaska, subtropical South Texas faces special challenges due to a combination of physical and human geography factors. Among these the following are noteworthy: rapid population growth; economic underdevelopment; unique but vulnerable ecology; significant but vulnerable agriculture; and limited water supplies. Then there are the three great overarching realities of coastal location, the existing semi-desert to subhumid climate, and, finally, the subtropical location itself.

The result of all this is a regional challenge which we believe is the greatest test South Texas has faced since its first human inhabitants arrived ten or so millennia ago. Our job was to describe and explain that challenge to the best of our ability. It is up to the present and next generation of citizens and leaders to "come and take it." We are confident that they, you, will do so.

Thank you for your interest and attention. Vaya con Dios.
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