Decrease in the summer rainfall of the southern United States coast and the Caribbean due to climate change

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ABSTRACT

Simulations from the North American Regional Climate Change Assessment Program (NARCAPP) Geophysical Fluid Dynamics Laboratory (GFDL) AM2.1 timeslice experiment, for current climate (1971-2000) and future climate (2041-2070), were compared and contrasted to assess how May through October accumulated rainfall is responding to climate change along the southern United States coast and in the Caribbean under the Intergovernmental Panel on Climate Change (IPCC) A2 emissions scenario (a scenario of relatively high emissions increase). The simulations were done on a global domain at a horizontal resolution of roughly 50 km.

There is an overall decrease of about 200 mm (30 percent) in the May through October rainfall in the region of the southern United States coast and the Caribbean. The absolute decrease is larger in the regions that receive the most rain. However, proportionally, the decrease is larger in the regions that receive the least rain. For the subregion of Florida, rainfall time series indicate a delay of the region's late wet period in the future climate. This shift needs to be further examined to determine its significance and underlying physical processes. Florida also received less rainfall in future climate, but the standard deviation of the early and late wet periods was found to be larger. This is in accord with the findings of the IPCC of an increase in global extremes as a result of climate change. In a future study, the time series for four other subregions will be analyzed.

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1. Introduction

In a changing climate, what happens to the typical summer rainfall season of the southern United States coast and the Caribbean? According to Rauscher et al. (2008), both climate models and observations indicate that summer rainfall in Central America is decreasing. As a part of the Caribbean, Central America has been called the “hotspot” of climate change in the subtropics (Rauscher et al., 2008). According to Magaña et al. (1999), Ashby et al. (2005), and Stephenson et al. (2008), the summer rainfall season in most of the Caribbean follows a distinctly bimodal distribution pattern: increased rainfall from May through early July, a period of relatively drier weather in late July and early August called the midsummer drought (MSD), and increased rainfall again from late August through October. The start of the rainy season in the Caribbean is generally marked by the northward movement of the North Atlantic subtropical high (NASH). The NASH remains north throughout the summer rainy season from May through October, with a slight shift south and then back north during the MSD period (Ashby et al., 2005).

For most of the Caribbean, most climate models indicate less summer rainfall under climate change. For example, using the World Climate Research Programme’s (WCRP’s) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, Rauscher et al. (2008) found a 25% reduction in Central America summertime rainfall between the twentieth and twenty-first century simulations, with the greatest reduction experienced in June and July. Rauscher et al. (2008) conjecture that this reduction is the result of an intensification, an earlier onset, and a longer persistence of the conditions necessary for the MSD, leading to drier summers.

Agriculture and hydropower generation, major economic activities for most countries of the Caribbean, are extremely sensitive to the seasonal rainfall cycle (Magaña et al., 1999). Changing rainfall patterns can have a big negative impact on planted crops (Ashby et al., 2005). In a mostly poor region like the Caribbean, where potable water is already scarce in many neighborhoods, a reduction in the summer rainfall is only likely to worsen an already bad situation in many countries.

The MSD tends to be more prominent over Central America and southern Mexico (Magaña et al., 1999). The exact causes for the MSD still remain unknown, though there are many conjectures (Rauscher et al., 2008). One suggestion by Magaña et al. (1999) is that increased cloud cover during late spring and early summer leads to cooler sea surface temperatures (SSTs) in the eastern equatorial Pacific, which leads to less evaporation, which helps produce the MSD. Less cloud cover during MSD leads to warmer SSTs, allowing rainfall to come back in the fall. According to Rauscher et al. (2008), although the exact causes for the MSD are not yet fully known, SST anomalies in the equatorial Pacific do have a weak effect on the MSD. For example, during warm El Niño-Southern Oscillation (ENSO) events, prior to mature El Niño years, less rainfall occurs on the Pacific coast of Central America from July through October, while rainfall increases during cold ENSO events.

This study analyzes simulations from the North American Regional Climate Change Assessment Program (NARCAPP) Geophysical Fluid Dynamics Laboratory (GFDL) AM2.1 timeslice experiment, which was run globally in Atmospheric Model Intercomparison Project

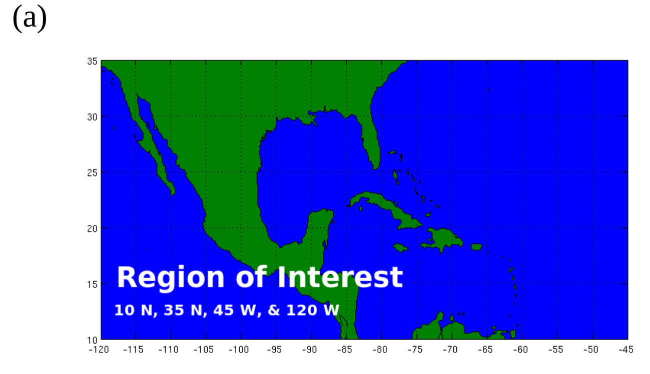
(AMIP) mode, at a relatively high horizontal resolution of roughly 50 km (each grid point is 0.5^{o} latitude by 0.625^{o} longitude). The simulations were made for current climate (1968-2000) and for future climate (2038-2070). For the AM2-LM2 model architecture, the atmospheric model, known as AM2, includes a new dynamical core, a prognostic cloud scheme, and a multispecies aerosol climatology, as well as physics components from previous models used at GFDL; the land model, known as LM2, includes soil sensible and latent heat storage, groundwater storage, and stomatal resistance (Anderson et al., 2004). For the current climate, AM2 and LM2 were run using observed SSTs and sea ice extend from the Hadley Centre Sea Ice and Sea Surface Temperature data set #1 (HadISST1). For the simulations of future climate, SSTs and sea ice extent were determined by offsetting the HadISST1 data set with changes from the mean and trend from the GFDL‘s coupled Atmosphere-Ocean model (CM2.1) simulations of future climate based on the Special Report on Emission Scenarios (SRES) A2 scenario (a scenario of relatively emissions increase). Strengths of AM2-LM2 include its good representation of precipitation movement and distribution (Anderson et al., 2004). A cold bias in surface and tropospheric temperature, weak tropical cyclone activity, and weak tropical intraseasonal activity associated with the Madden-Julian Oscillation (MJO) are a few of the problems associated with AM2-LM2 (Anderson et al., 2004).

This study analyzes the GFDL AM2.1 simulations for the summer rainy months of May through October, for 1971 to 2000 and for 2041 to 2070, to assess summer rainfall changes in the southern United States coast and the Caribbean under the Intergovernmental Panel on Climate Change (IPCC) A2 emissions scenario. This study also compares the GFDL AM2.1 to actual rainfall observations to get a sense of how accurate the simulations are for our region of interest.

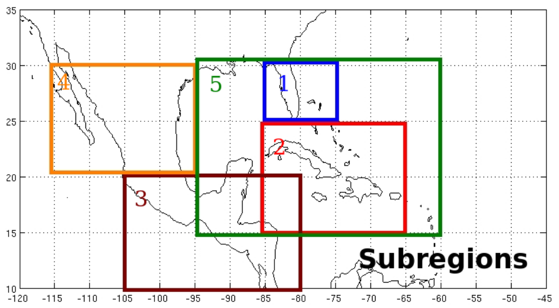
Our methodology is explained in Section 2, our results are presented and analyzed/discussed in Section 3, and Section 4 briefly summarizes our findings and conclusions. This study will become a part of the author’s University of Miami graduate work.

2. Methods

FIGURE 2.1 - a) Region of interest, and b) Subregions used for time series analysis



(b)



This study compares and contrasts GFDL AM2.1 simulation for current climate (1971-2000) and future climate (2041-2070) for the closed quadrilateral formed by the lines of 10^{o} N, 35^{o} N, 45^{o} W, and 120^{o} W (Fig. 2.1a) to assess how much the model projects that summer rainfall along the southern United States coast and in the Caribbean will decrease as a result of projected climate change. The GFDL AM2.1 model, briefly described in Section 1 of this paper, was run at a horizontal resolution of roughly 50 km. The region's rainy months of May through October are examined here. First, the average May through October accumulated rainfall for the current climate (1971-2000) and the future climate (2041-2070) is plotted for each grid point to see how much the accumulated summer rainfall may be changing in the different regions of the Caribbean, and how the spatial distribution of accumulated summer rainfall may also be changing. The same procedure is also repeated for the early wet period (May-June), the MSD (July-August), and the late wet period (September-October). Then, absolute differences and percent differences (future minus current) plots/maps were created for whole rainy season, early wet period, MSD, and late wet period.

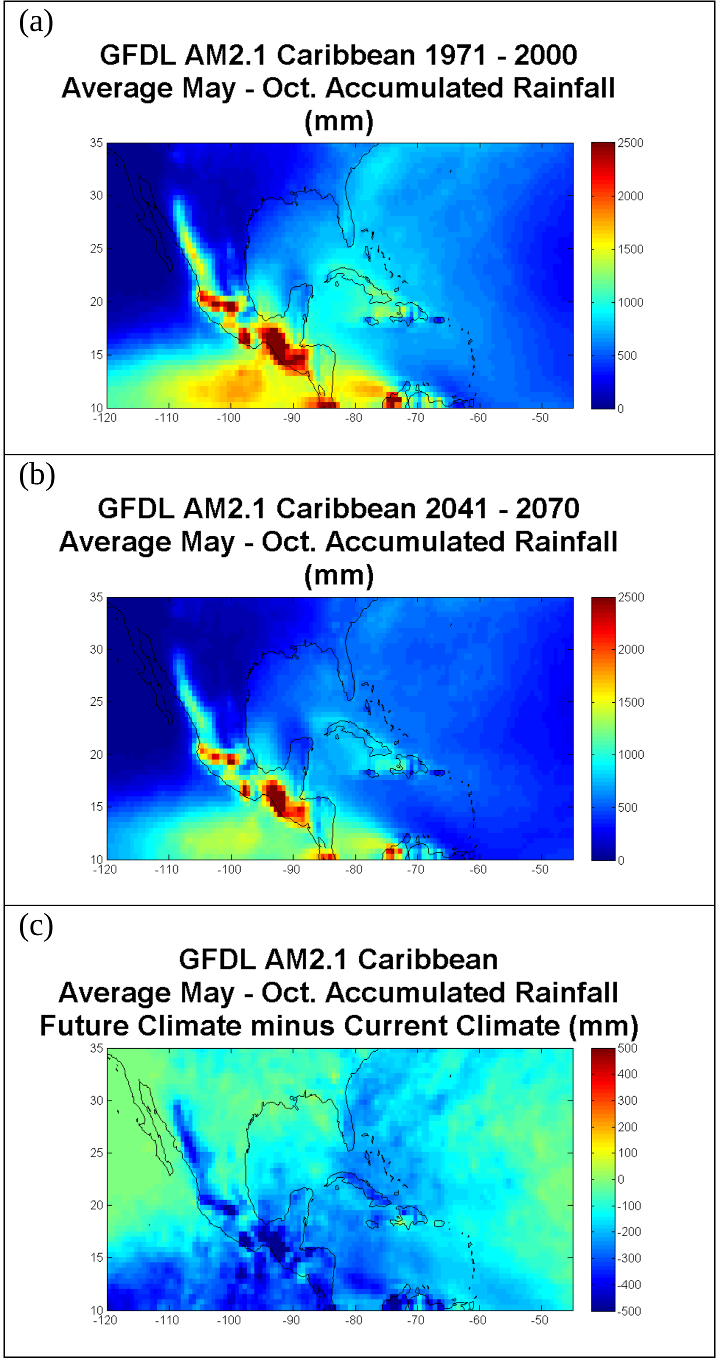
Based on the results of those plots, we then divide the Caribbean into five different subregions (Fig. 2.1b) with the aim of creating time series plots to analyze how these subregions have varied over time in the model simulations and to assess the potential impacts of climate change and climate variability. Time series plots of the (regionally-averaged) 8-day May 1st thru October 31st and 5-day annual accumulated rainfall and standard deviation are presented here for subregion #1 (Florida). The other four subregions will be analyzed at a later time. For the annual time series, February 29th has been subtracted from leap years. We also perform quick simplified t-tests on the May – October time series for Florida to obtain the level of significance of the changes between current and future climate.

Lastly, we compare the GFDL AM2.1 1971-2000 average May – October rainfall to observations. For observations, we used the National Centers for Environmental Prediction (NCEP) North American Regional Reanalysis (NARR). We create NARR plots for 1979-2000 and for 1979-2007. NARR data prior to 1979 is not currently available. Although the GFDL time span of 1971-2000 is not exactly matched, we consider that, in the average and in climate time scales, the 1979-2000 and the 1979-2007 rainfall plots should be a reasonably good estimate of the 1971-2000 observations. We chose 1979-2000 because it is within our 1971-2000 period of interest, and 1979-2007 because it is a longer-running mean.

3. Results and discussion

a. Whole rainy season

FIGURE 3.1 - Whole rainy season: a) Current climate, b) Future climate, c) Absolute changes, and d) Percent differences



(a)

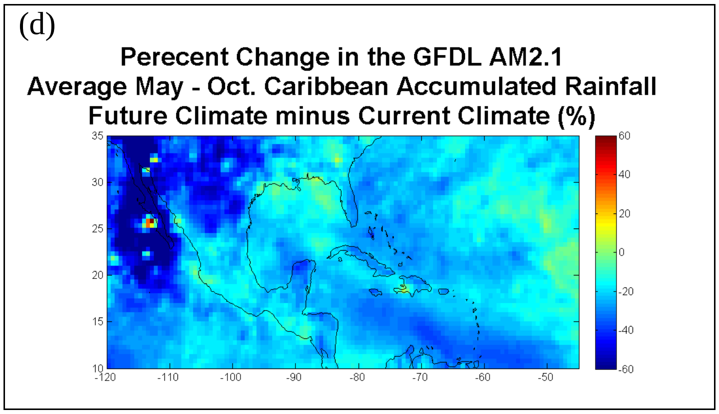
GFDL AM2.1 Caribbean 1971 - 2000
Average May - Oct. Accumulated Rainfall
(mm)

(b)

GFDL AM2.1 Caribbean 2041 - 2070
Average May - Oct. Accumulated Rainfall
(mm)

(c)

GFDL AM2.1 Caribbean
Average May - Oct. Accumulated Rainfall
Future Climate minus Current Climate (mm)

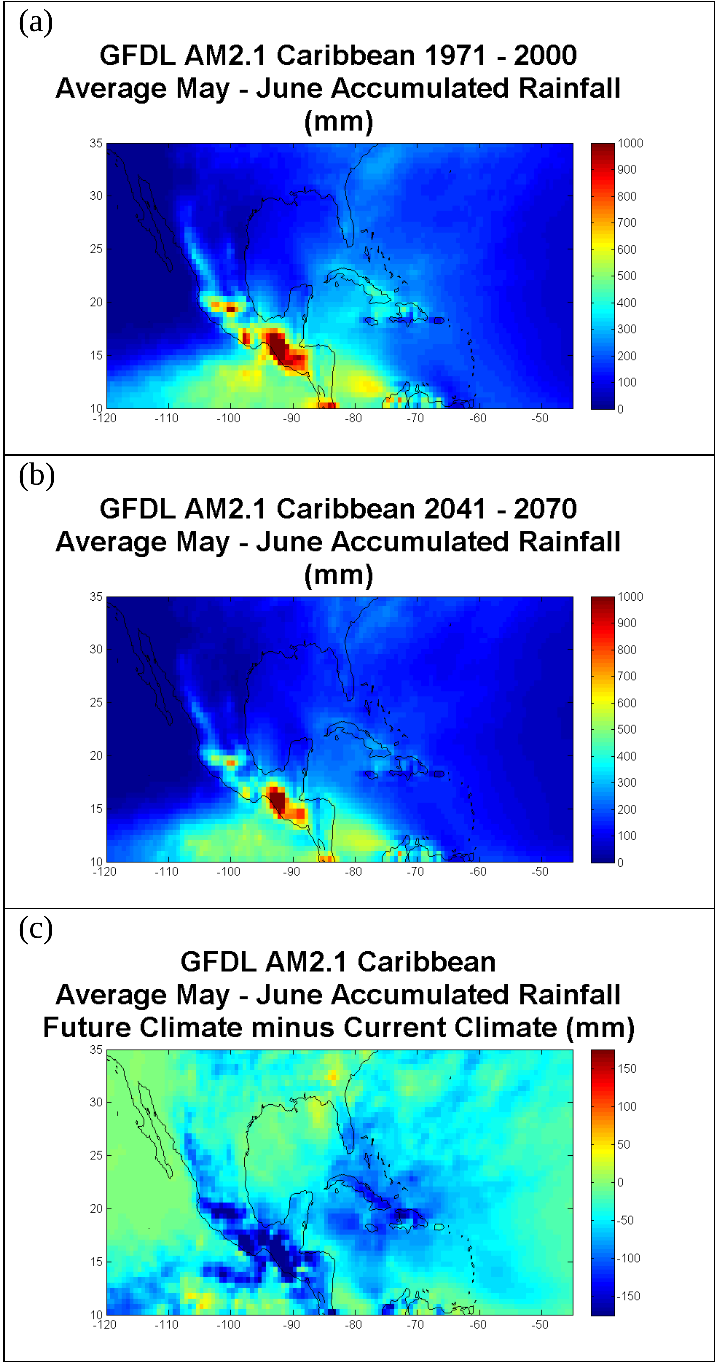


The model simulates the average 1971-2000 May - October accumulated rainfall fairly well, with maximum precipitation over Central America and western Mexico, and a somewhat drier northwestern region (Fig. 3.1a). There is some orographic effect over the mountain ranges and rough terrain in the western part of the country of Mexico (Fig. 3.1a). Also, in the current climate, the eastern Pacific seems to be considerably drier compared to other regions. It is interesting to note the large accumulated rainfall amounts over the Pacific Ocean near Central America. The western Atlantic Ocean also receives large amounts of warm season rain according to the 1971-2000 model simulations (Fig. 3.1a) and the dry part of the eastern Caribbean expands slightly westward in the future climate (Fig. 3.1b). Also, in the future climate, there is less of a contrast of rainfall over the oceans on either sides of Central America.

As shown in Figs. 3.1c and 3.1d, there is an overall decrease of about 200 mm or 30 percent in the May through October accumulated rainfall for the region. The absolute decrease is larger in the regions that receive the most rain (i.e., Central America and western Mexico). However, proportionally the decrease is larger in the regions that usually receive the least rain – the northwestern part of our region of interest (Fig. 3.1d). While the overall decrease is about 30 percent, in the northwest this increases to more than 60 percent. Notice the small spot of large percentage increase near the northwestern part of Mexico. This feature is unusual and comparable in size to the model's grid scale: it may or may not be significant. Given that this anomaly is on the limit of what the model can resolve; we will consider it insignificant in this paper.

b. Early wet period

FIGURE 3.2 - Early wet period: a) Current climate, b) Future climate, c) Absolute changes, and d) Percent differences



(a)

GFDL AM2.1 Caribbean 1971 - 2000
Average May - June Accumulated Rainfall
(mm)

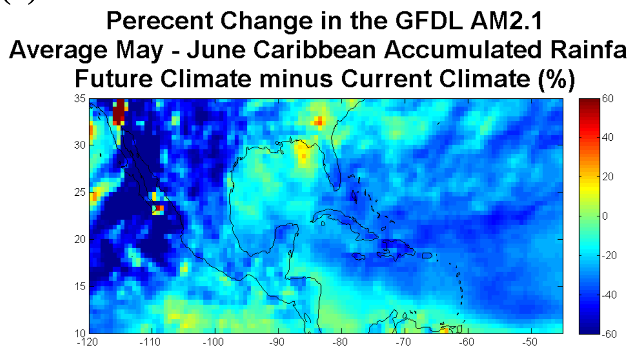
(b)

GFDL AM2.1 Caribbean 2041 - 2070
Average May - June Accumulated Rainfall
(mm)

(c)

GFDL AM2.1 Caribbean
Average May - June Accumulated Rainfall
Future Climate minus Current Climate (mm)

(d)

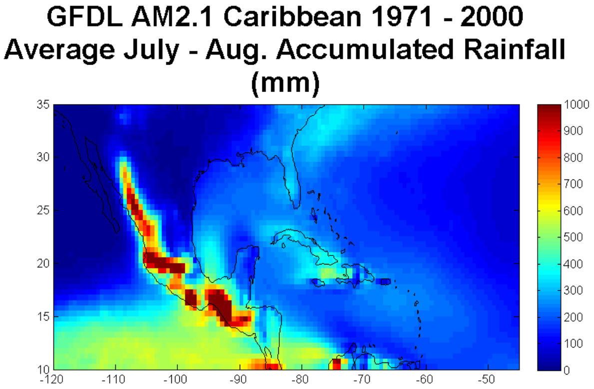


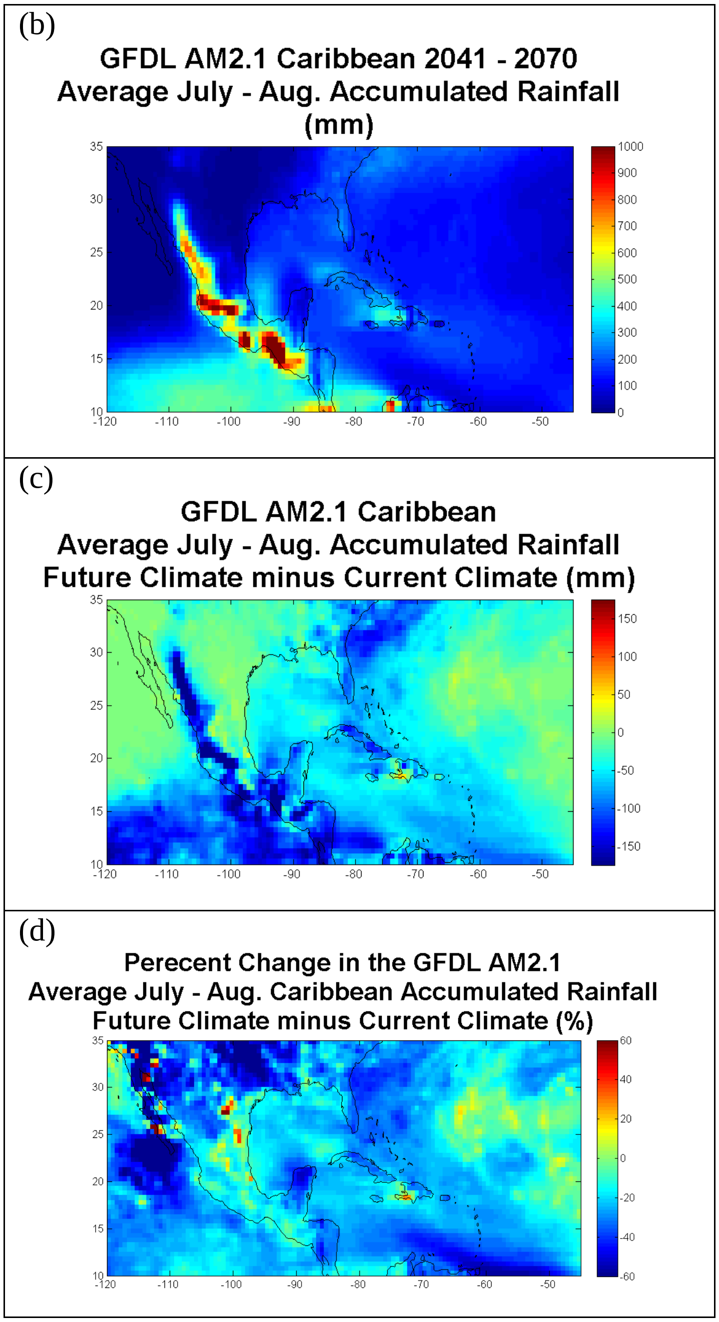
Comparing Figs. 3.2a and 3.2b, we can clearly observe a westward expansion of the dry region on the eastern part of our region of interest. Again, the region with the most rainfall receives the largest decrease (Fig. 3.2c) but proportionally the relatively drier northwest experiences the largest percentage decrease in accumulated rainfall (Fig. 3.2d). There again are small spots of large percentage increases in areas of decreases, which likewise appear anomalous, and will be ignored. It is interesting to note the areas of increase rainfall at the southern edge of our region of interest, the Gulf of Mexico, and the state of Georgia (Figs. 3.2c and 3.2d).

c. Midsummer drought

FIGURE 3.3 - Midsummer drought: a) Current climate, b) Future climate, c) Absolute changes, and d) Percent differences

(a)



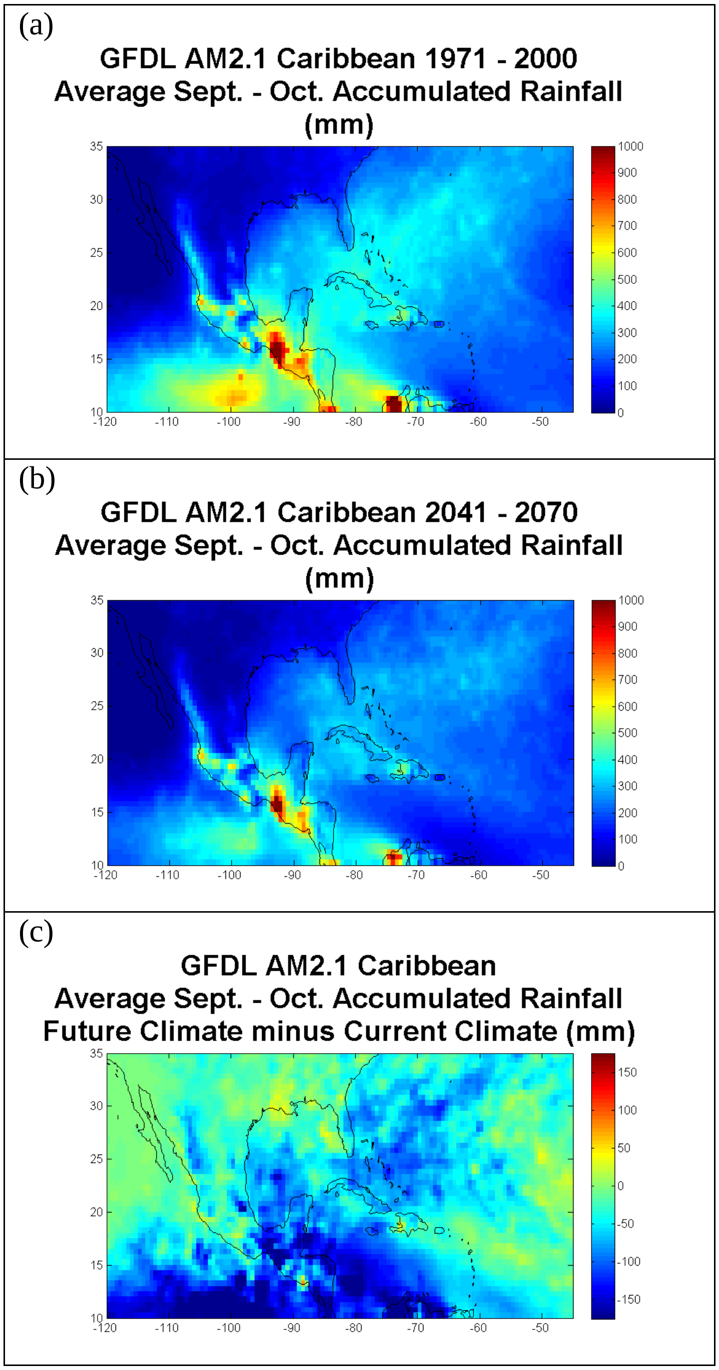


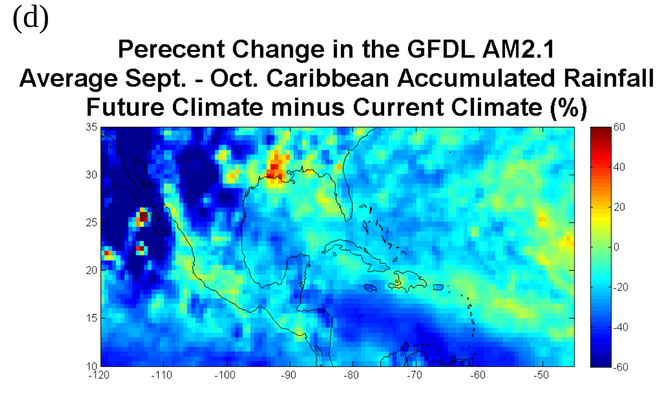
A general decrease in MSD rainfall is observed throughout the region (Figs. 3.3c and d), with the largest relative decreases in the Yucatan Peninsula, the southeastern Caribbean seas, the United States, and the eastern Pacific (Fig. 3.3d). Comparing Fig. 3.3a to Fig. 3.3b, and observing Figs. 3.3c and 3.3d, there is substantial increase in July-August rainfall in the eastern portion of the region in the future climate. The country of Mexico also has several spots of substantial increase spread throughout, and southern Haiti also experiences substantial increase in the future climate. There again are small spots of unrealistically large percent increases on the region’s northwest, which should be discarded as insignificant, for the purpose of this study.

Comparing Figs. 3.2a and 3.3a, it is interesting to note the high rainfall amounts in the current climate during July-August in western Mexico. This July-August increase also occurs in the future climate (Figs. 3.2b and 3.3b).

d. Late wet period

FIGURE 3.4 – Late wet period: a) Current climate, b) Future climate, c) Absolute changes, and d) Percent differences



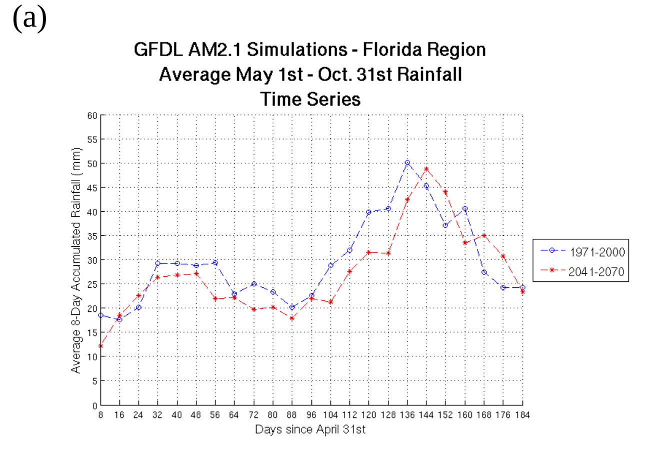

(d)

Perecent Change in the GFDL AM2.1 Average Sept. - Oct. Caribbean Accumulated Rainfall Future Climate minus Current Climate (%)

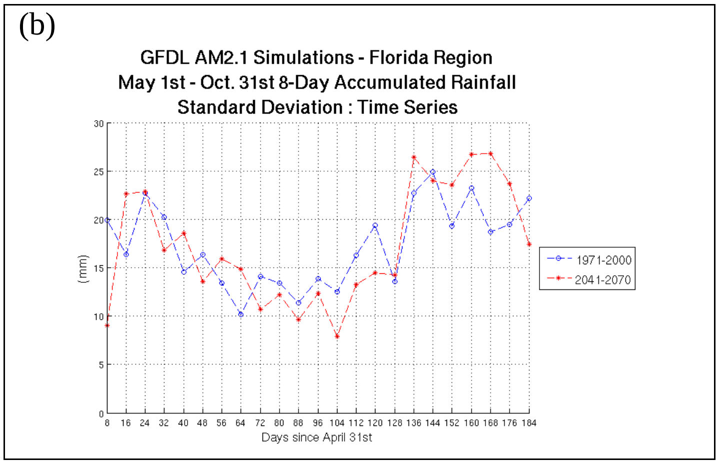
For both the current and future climate simulations, September-October seems to be the wettest period of the warm rainfall season, but the Central America precipitation maximum seems to receive considerable less rainfall in September-October (Figs. 3.2a,b, 3.3a,b, and 3.4a,b). There is an overall decrease in the whole region in the future climate, but there is a fairly big region of considerable increase centered over the state of Louisiana (Fig. 3.4b). In Fig. 3.4b, there is also some substantial increase on the eastern part of the region of interest, the Gulf of Mexico, and western Mexico/northwestern Central America, and the largest percentage decrease occurs over the ocean in the northeastern Pacific waters and through the southern Caribbean oceanic areas (Figs 3.4c,d). Large positive anomalies can again be observed in the northeastern Pacific Ocean on Fig 3.4d.

e. Florida time series

FIGURE 3.5 – Subregion #1 (Florida) rainy season time series: a) 8-day accumulated rainfall, and b) 8-day standard deviation

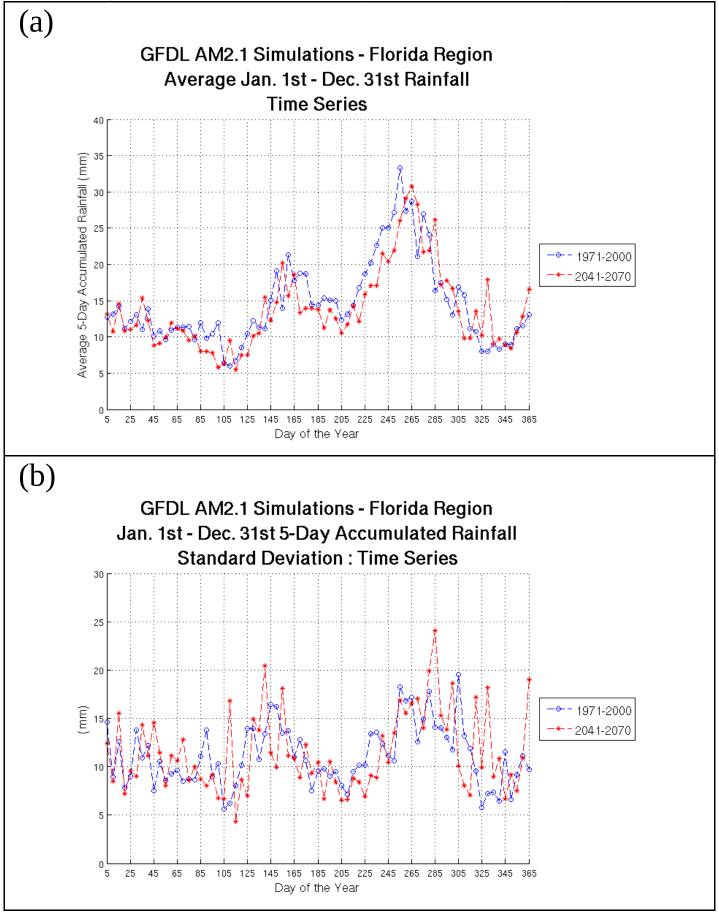

(a)

GFDL AM2.1 Simulations - Florida Region Average May 1st - Oct. 31st Rainfall Time Series



GFDL AM2.1 Simulations - Florida Region
May 1st - Oct. 31st 8-Day Accumulated Rainfall
Standard Deviation : Time Series

FIGURE 3.6 – Subregion #1 (Florida) annual time series:
a) 5-day accumulated rainfall, and b) 5-day standard deviation



GFDL AM2.1 Simulations - Florida Region
Average Jan. 1st - Dec. 31st Rainfall
Time Series

GFDL AM2.1 Simulations - Florida Region
Jan. 1st - Dec. 31st 5-Day Accumulated Rainfall
Standard Deviation : Time Series

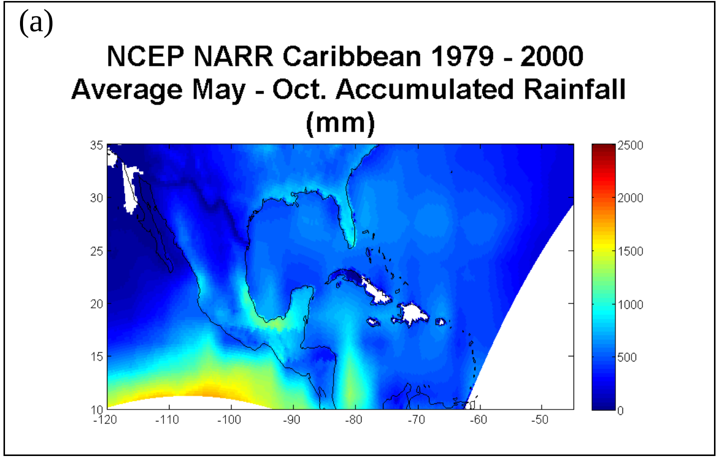
From Figs. 3.5a and 3.6a, one can observe that, in the model simulations, the regional early wet period for the region of Florida, defined as subregion #1 in Fig. 2.1b, is from mid April to early July, and the MSD occurs in mid to late July, with the largest drying occurring toward late July. The late wet period for Florida in the GFDL AM2.1 model is from early August to late November, and it peaks around mid September (Figs. 3.5a and 3.6a).

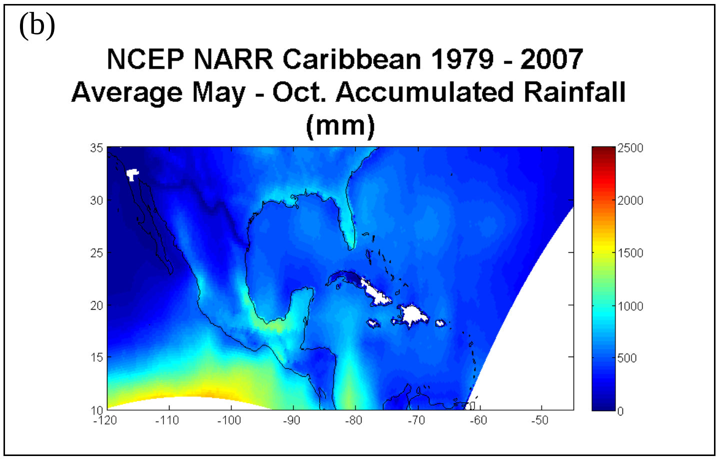
According to the model simulations, the late wet period is the time of the year when the Florida region receives the most rainfall (Fig. 3.6a). It is interesting to note how the model simulates a phase delay, of approximately 8 days, of the late wet period in the future climate (Figs. 3.5a and 3.6b). Note that, for subregion #1 (Florida), the actual length, shape, and magnitude of the late wet period do not actually change much between current climate and future climate, but that, in the future climate, the starting time and ending time of the late wet period are shifted to a later time. A simple t-test (see Appendix A) revealed little statistical significance for this shift, a result of the large standard deviation during the late wet period, but this delay can also be observed in the standard deviation time series plots (Figs. 3.5b and 3.6b). Note that the phase delay in the standard deviation time series can be more clearly observed in Fig. 3.6b. More research needs to be done to determine if this shift is a real signal in the GFDL AM2.1 simulations, and to understand the physical basis.

As it can be observed from Figs. 3.5 and 3.6, the model's rainfall standard deviation is positively correlated with rainfall amount (i.e., the times with more accumulated rainfall have the larger standard deviations). Although during the region's early wet period and late wet period, there is slightly less accumulated rainfall in the future climate compared to the current climate (Figs. 3.5a and 3.6a), the rainfall standard deviation is overall larger during the early wet period and late wet period in the future climate (Figs. 3.5b and 3.6b). This is consistent with the IPCC findings of an overall global increase in extreme events (Committee on Environment and Natural Resources 2008).

f. Comparison with observations

FIGURE 3.7 – NCEP NARR summer rainfall: a) 1979-2000, and b) 1979-2007





Figs. 3.7a and b are derived from the National Centers for Environmental Prediction (NCEP) North American Regional Reanalysis (NARR). For purposes of this comparison, we assume that Figs. 3.7a and b are good representations of the actual average 1971-2000 rainfall. For a brief discussion of this assumption, please see Section 2. Comparing Fig. 3.1a with Fig. 3.7, one can see that the GFDL AM2.1 model does a fairly good job at simulating the May – October accumulated rainfall amounts and general distribution in our region of interest. However, regional accumulated precipitation contours do not match exactly, and the model simulations have too much precipitation over Central America and the western part of Mexico. Precipitation over the ocean on both sides of Central America is simulated fairly well by the GFDL AM2.1 model.

4. Conclusions

Simulations from the GFDL AM2.1 timeslice experiment for current climate (1971-2000) and for future climate (2041-2070) were compared and contrasted. For our region of interest, the model was found to simulate the overall distribution of May – October rainfall fairly well, although it simulates too much rainfall generally and especially over western Mexico and Central America (Figs. 3.1a and 3.7). An overall decrease in the May through October rainfall for the region of the southern United States coast and the Caribbean was found (Fig. 3.1). For the subregion of Florida, rainfall time series indicated a delay of 8 days in the region’s late wet period in the future climate (Figs. 3.5a and 3.6a). This phase shift needs to be further examined to determine its significance and physical basis. In general, Florida receives less summer rainfall in the future climate (Figs. 3.5a and 3.6a), but the standard deviation of Florida’s early wet period and late wet period was found to be larger in the future climate (Figs. 3.5b and 3.6b). This is consistent with the IPCC findings of a global increase in extremes (Committee on Environment and Natural Resources 2008).

As future work, time series for four other subregions will be analyzed (Fig. 2.1b). More in-depth comparisons with observations will be done. Comparisons with the simulations from GFDL Atmosphere-Ocean General Circulation Model (AOGCM), which has a coarser resolution, will also be done. The increase in rainfall standard deviation, that occurs between current climate and future climate, will also be further investigated. A special focus will be on analysis of the dry period (November-April). This research will become a part of the author’s

University of Miami graduate work, and an abstract has been submitted for consideration to the American Meteorology Society’s 2010 Conference on Climate Variability and Change.

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Appendix A: A t-test of the differences between current and future climate (Florida time series)

Model: GFDL AM2.1 Time: May thru October Current climate: 1971 – 2000 Future climate: 2041 – 2070 Region: subregion #1 (Florida) Null hypothesis: both current and future time series are the same