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CARIBBEAN CLIMATE SCENARIOS FOR THE CARIBBEAN: LIMITATIONS AND NEEDS FOR BIODIVERSITY STUDIES

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ABSTRACT: The extent of climate baseline data, climate information and climate scenarios which are readily available for related biodiversity studies and the capacity for undertaking these studies in the Caribbean were investigated. A list of the databases available is given. Although adequate capacity and some information exist, there are gaps to be filled. Information is inadequate because of the limited baseline data, the course resolution of the global and even the regional models. Steps to fill the gaps are discussed. Information for biodiversity studies includes knowledge of climate threshold values, geographical distribution. Some of this information can be provided by statistical downscaling but the process requires daily data of good quality and long duration. These however infrequently exist. The material for this paper comes from the Implementation of the Climate Change and Biodiversity in the Insular Caribbean (CCBIC) Project which is being conducted by the Caribbean Natural Resources Institute (CANARI).

Keywords: climate change, biodiversity, Caribbean, modeling

1. Introduction

> "At the global level, human activities have caused and will continue to cause a loss in biodiversity through, *inter alia,* land-use and land-cover change; soil and water pollution and degradation (including desertification), and air pollution; diversion of water to intensively managed ecosystems and urban systems; habitat fragmentation; selective exploitation of species; the introduction of non-native species; and stratospheric ozone depletion. The current rate of biodiversity loss is greater than the natural background rate of extinction. A critical question … is how much might climate change (natural or human-induced) enhance or inhibit these losses in biodiversity?" (Gitay *et al.,* 2002).

This question is being addressed by implementation of the *Climate Change and Biodiversity in the Insular Caribbean (CCBIC) Project.* The project is executed by The Caribbean Natural Resources Institute (CANARI). One of the first steps, recognized by the CCBIC Steering Committee at its inaugural meeting in Trinidad in March 2007, was the establishment of Scenario and Modelling Working Group (WG I). The task of WGI was to provide "a summary of the state of knowledge and expertise for the development of climate change scenarios and models in support of the identification and assessment of expected impacts of global climate change on Caribbean coastal and marine biodiversity, identifying the gaps in our knowledge, expertise, and capacities, and the measures that must be undertaken to fill these gaps" (CCBIC Guidance to Working Group Leaders).

To address the task of WGI, 5 key problems were considered:

1. What baseline climate information and existing climate databases do we have for the Caribbean? This is a necessary starting point in any climate study.

2. What research has been done on climate variability and climate change in the Caribbean, and what has been learned? How are climate change scenarios developed and what are the climate change scenarios for the Caribbean? To generate scenarios of future climate, it is necessary to know the climate processes at work and processes that change climate. Models that simulate climate and climate change have to be evaluated to determine if they capture actual climate processes and changes. This will assist in determining the validity of the scenarios generated.

3. What is our present manpower and equipment capacity? This will determine the manpower and equipment needs.

4. What more do we need to know about climate change, especially as it relates to biodiversity and how can these needs be achieved?

5. What climate models are best suited for addressing climate change and biodiversity?

These problems are the subject of the following 5 sections, sections 2 to 6. Section 7 contains concluding remarks.

2. Baseline Data and Climate

The focus of this section was to summarize the baseline climate information and databases for the Caribbean region. Note that particular emphasis was paid to the English-speaking Caribbean and Cuba. Several sources of climate data [for example, precipitation (intensity and duration), temperature (daily maximum and minimum), wind speed, direction, radiation, relative humidity among others] exist for the Caribbean region. The climate parameters contained in these datasets vary with some datasets containing more parameters than others. In addition, some data sets contain unprocessed data whereas other datasets contain processed data. These datasets and their availability are summarized below.

■ Caribbean Institute for Meteorology & Hydrology (CIMH)

CIMH maintains a climatology database that contains data recorded at stations maintained by National Meteorological Services (NMS) that are members of the Caribbean Meteorological Organization (CMO) [Anguilla, Antigua & Barbuda, Barbados, St. Lucia, St. Vincent & the Grenadines, Dominica, Guyana, Grenada, Trinidad & Tobago, Jamaica, St. Kitts & Nevis, Belize, the British Virgin Islands, the Cayman Islands, Montserrat, and the Turks and Caicos Islands] as well as other stations in these countries deemed to provide data of good quality that meets WMO specified standards. CIMH performs quality assurance checks on the data prior to making it available to the public.

Parameters contained in the CIMH database include daily temperature, pressure, relative humidity, precipitation, cloud, and wind speed and direction. In several cases, the data sets are incomplete due to instrument failure and failure of the NHS to forward the data to CIMH. In some cases, the NMSs have a more comprehensive data base than CIMH, however, much of this data is in notebooks and has not been converted to electronic form. A proposal to support rescuing much of the hard copy data from the various NMSs has been circulated to various funding agencies. Data contained in the database is available at no cost for academic applications; however, there is a charge to commercial customers. Data contained in the CIMH monthly summaries is available directly from CIMH in hard copy form (1972-2004). These datasets are currently being scanned and posted to the CIMH webpage (**http://www.cimh.edu.bb**). A list of stations currently stored at CIMH is available at **http://www.cimh.edu.bb/datainv.htm**. In addition, data can be obtained directly from NMSs who may have data for stations not present in the CIMH data base. Electronic data at most NMSs in the Caribbean are stored in CLICOM and/or CLIDATA.

■ Caribbean Climate Interactive Database (CCID)

The CCID database consists of daily and monthly station data for various Caribbean islands in the period 1935 to 2000. The variables available are minimum temperature, maximum temperature and precipitation. The raw data or time series of monthly averages, climatologies, standard deviations, and anomalies may be viewed and saved. In addition correlations and scatterplots of variables may also be obtained. The data is available free of cost and can be obtained by sending a request to Dr. Michael Taylor in the Department of Physics, University of the West Indies, Mona at **michael.taylor@uwimona.edu.jm**.

■ Universidad Nacional Autonoma de Mexico (UNAM)

UNAM provides monthly temperature (maximum and minimum) and precipitation data on a 0.5° x 0.5° grid that extends from 140° to 59° Longitude W and from 4.75° to 45.25° Latitude N. The data time series extends from 1901 to 2002. Sources of the data used to develop the gridded dataset are daily station precipitation and temperature from CLICOM (for Mexico) and the Global Historical Climatology Network (GHCN). Given the sizes of the islands of the eastern Caribbean, the grid resolution is quite coarse. In addition, the quality of the gridded data relies on the spatial locations of the sources of data, the interpolation methods used to develop the grid, and the quality assurance methods employed at the measurement locations. More information is available at **http://iridl.ldeo.columbia.edu/SOURCES/.UNAM/.gridded/.monthly/.v0705/.dataset_documentation.html**.

■ Climate Research Unit (CRU)

The Climate Research Unit (CRU) at the University of East Anglia is one of the most popular sources of global climatic data and is often cited in major publications on climate. The CRU provides monthly data at several grid resolutions with the highest resolution being on a 0.5° x 0.5° grid that includes the Caribbean. The data time series extends from 1901 to 2000.

Climate parameters available from CRU include temperature (maximum, minimum, mean, and range), precipitation, wet days, water vapour, and cloud. More information on CRU is available at **http://www.cru.uea.ac.uk/**.

■ Climate Prediction Center (CPC) Global Climate Data and Maps

The Climate Prediction Center Global Climate Data and Maps contains maps and time series for precipitation and surface temperatures for Africa, Asia, Europe, South and Central America, Mexico, Caribbean, Australia, and New Zealand. CPC monitors weather and climate in real time with the aid of satellite animations, conventional rain gauge observations and global analyses of the atmospheric state. CPC also has available time series of accumulated actual daily precipitation and accumulated normal precipitation both of which are available on a daily basis and can be viewed on 5° x 5° grids over the Americas. CPC also provides weekly maps of total precipitation and temperature (maximum and minimum) as well as departures from the norm. Monthly and 3-month maps are also available. CPC provides observed precipitation time series showing observed versus actual for selected cities around the world for the last 30, 90 and 365 days. CPC provides observed temperature time series showing observed versus actual for selected cities around the world for the last 30, 90 and 365 days. More information on CPC is available from **http://www.cpc.noaa.gov/products/monitoring_and_data/restworld.shtml**.

■ International Research Institute for Climate and Society (IRI)
IRI/LDEO Climate Data Library has available over 300 datasets from a range of earth science disciplines and climate related topics. The data includes the NCEP reanalysis database, outputs from IPCC assessment models, NCEP Climate Forecast System, and NCEP CPC constructed analog sea surface temperature forecasts among others. Information summarizing the contents of the IRI/LDEO Climate Library is available at **http://iridl.ldeo.columbia.edu** and **http://iridl.ldeo.columbia.edu/SOURCES**.

■ National Centers for Environmental Protection (NECP) Operational Analysis
NCEP provides a range of climate data products to the public. The global products dataset includes precipitation and temperature which are updated twice daily. In addition to these products, NCEP also provides reanalysis data 4 times per day for a range of meteorology parameters. For more information go to **http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis2.html**.

■ Global Climate Observation System (GCOS)
GCOS is intended to be a long-term operational system. GCOS addresses the total climate system including physical, chemical and biological properties as well as its atmospheric, oceanic, terrestrial, hydrologic, and cryospheric components. GCOS provides comprehensive operations required for monitoring the climate system, detecting and attributing climate change, assessing inputs of, and supporting adaptation to, climate variability and change, applications to national economic development, research to improve understanding, modeling and prediction of the climate system. More information on GCOS is available at **http://www.wmo.ch/pages/prog/ gcos/index.php**.

■ Cuba's Climate Data
A database of precipitation, maximum and minimum temperature, relative humidity and wind speed and direction exists for 68 stations on Cuba. These stations have in general at least 30 years of daily and tri-hourly data with some stations having time series that go back 100 years. (See the Attachment for an illustration of precipitation and temperature anomalies over approximately 100

years). Most stations have not been moved from their original location and those that were moved have had correction factors applied to the data to account for the relocation. All of the meteorological data for Cuba has been digitized and a quality control process implemented to minimize errors. In addition to the measurement of standard meteorological parameters, specialized meteorological stations exist that provide solar radiation, upper-air agro-meteorological, air quality and pollution data. The Center of Climate is in charge of storing and processing all the climate data and has the necessary software and hardware resources to deal with this task efficiently. More information on climate data and climate studies in Cuba can be obtained at **http://www.met.int.inf.cu**.

3. Average Behaviour or Climatology

The Caribbean climate has been concisely described by Taylor and Alfaro (2005). It can be broadly characterized as dry winter/wet summer with orography and elevation being significant modifiers on the sub regional scale. The dominant synoptic influence is the North Atlantic subtropical high (NAH). During the winter the NAH is southernmost with strong easterly trades on its equatorial flank. Coupled with a strong trade inversion, a cold sea surface temperature (SST) and reduced atmospheric humidity, the region generally is at its driest during the winter. Precipitation during this period is due to the passage of mid-latitude cold fronts. With the onset of the spring, the NAH moves northward, the trade wind intensity decreases, the sea becomes warmer and the southern flank of the NAH becomes convergent. Concurrently easterly waves traverse the Atlantic from the coast of Africa into the Caribbean. Easterly waves frequently mature into storms and hurricanes under warm sea surface temperatures and low vertical wind shear generally within a 10°N-20°N latitudinal band referred to as the *main development region*. They represent the primary rainfall source and their onset in June and demise in November roughly coincides with the mean Caribbean rainy season. Around July a temporary retreat of the NAH equatorward is associated with diminished rainfall known as the mid-summer drought. Enhanced precipitation follows the return of the NAH and the passage of the Inter Tropical Convergent Zone (ITCZ) northward. The passage of cold fronts from mid-latitudes is responsible for much of the rainfall in the dry season (December to March). Air temperature tends to follow the sun, or more precisely the variation in solar insolation. Below about 15°N, this variation results in a bi-modal temperature peak. The timing of the processes are illustrated graphically for Jamaica in Figure 1, and for Trinidad and Tobago in Figure 2.

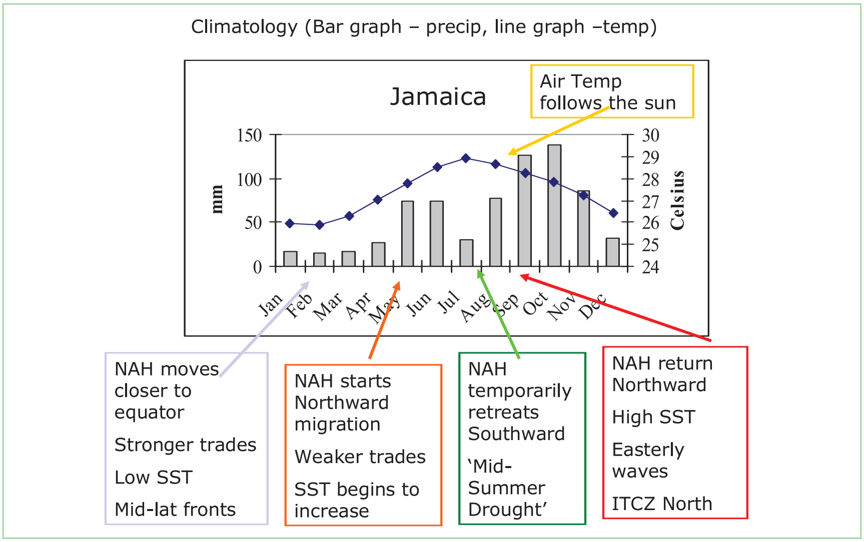

FIGURE 1

The timing of climatology processes for Jamaica (NAH refers to North Atlantic High pressure system; SST, Sea Surface Temperature; ITCZ, Inter-tropical Convergence Zone)

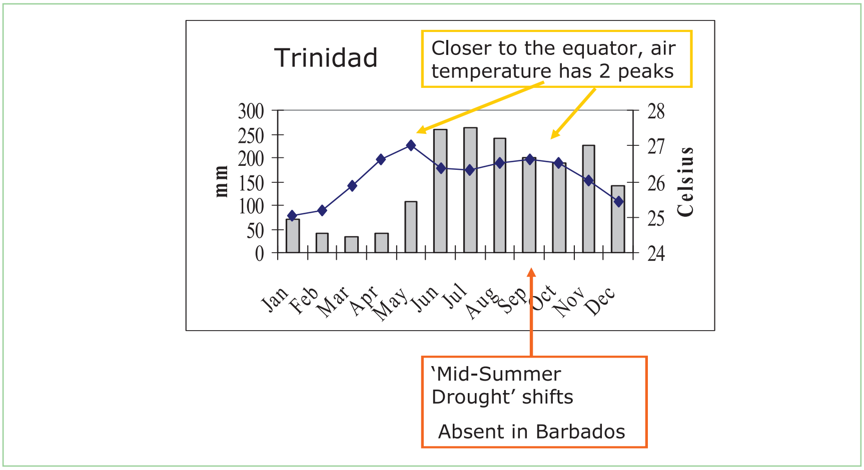

FIGURE 2

The climatology for Trinidad, same as for Jamaica but the Mid-Summer Drought occurs later and 2 peaks in air temperature are evident

For small islands, differences in size, shape, topography and orientation with respect to the trade wind influence the amount of rainfall received by the various islands. Cuba, Jamaica, Hispaniola and Puerto Rico, the larger and more mountainous islands of the Greater Antilles, receive heavier rainfall at higher elevations, with a rain-shadow effect on their southern coasts that are distinctively arid. The smaller islands to the East tend to receive less rainfall, with Barbados and Trinidad in the South receiving more rainfall than the rest. The dry belt of the Caribbean is found over the south-western islands of the Netherlands Antilles.

4. Climate Variability and Climate Change

4.1 Climate Trends

■ Temperature and Precipitation

Global temperatures have increased by about 0.74°C (0.56°C to 0.92°C) since the 19th century (IPCC, 2007). There has been a warming trend globally with minimum temperatures increasing at a higher rate than maximum from 1950-2001 (Alexander *et al.*, 2006). An increasing trend in both variables is also observed for the Caribbean region by Peterson *et al.* (2002). They used ten global climate indices to examine changes in extremes in Caribbean climate from 1950 to 2000. They found that the difference between the highest and lowest temperature for the year is decreasing but is not significant at the 10% significance level. Temperatures falling at or above the 90th percentile are increasing while those at or below the 10th percentile are decreasing (both significant at the 1% significance level). These results indicate that the region has experienced some warming over the past fifty years. Thus there is a general warming trend with the number of very warm days and nights increasing, while the number of very cool days and nights has been steadily decreasing over the same time period.

Two of the precipitation indices used by Peterson *et al.* (2002) showed significant changes, the greatest 5 days rainfall total is increasing (10% significance level) while the number of consecutive dry days has decreased (1% significant level). However the results may not take into account differing behaviour in precipitation in the North and South Caribbean. Using several observed data sets, Neelin *et al.* (2008) noted a modest but statistically significant drying trend for the Caribbean's summer period in recent decades.

Studies carried out in Cuba have demonstrated the existence of important climate variations in the country and in the region (Naranjo and Centella ,1998; Lapinel *et al.,* 2002 and Álvarez, 2006). Major trends in the increase of annual mean temperature of 0.5°C and an increase in the frequency of impact of extreme climate events, such as, intense rains and severe local storms, characterize the climate of the second half of the 20th century in Cuba**.** The frequency of drought events has also increased significantly, while the hurricanes that affect Cuba show a secular tendency to reduction. It has been demonstrated that these variations are consistent with the increase in the atmospheric circulation in the region and with the increase in the influence of El Niño Southern Oscillation (ENSO) event, which plays an important role as a forcing element of climate variability in Cuba. Cuba's climate behaviour during the last 4 decades is consistent and suggests the existence of an important variation since the 1970s.

■ Hurricanes

Analysis of observed Tropical cyclones in the Caribbean and wider north Atlantic Basin show a dramatic increase since 1995. This increase however has been attributed to the region being in the positive (warm) phase of a multidecadal signal and not necessarily due to global warming (Goldenburg *et al.*, 2001). Results per year obtained from Goldenburg *et al.* have shown that during the negative (cold) phase of the oscillation the average number of hurricanes in the Caribbean Sea was 0.5 per year with a dramatic increase to 1.7 per year during the positive phase. While attempts have been made to link warmer SSTs with this increase in numbers, these have proven to be inconclusive, (Peilke *et al.*, 2005). In a study to further examine the proposed link between global warming and tropical cyclone frequency, Webster *et al.*, (2005) found that while SSTs in tropical oceans have increased by approximately 0.5°C between 1970 and 2004 only the North Atlantic Ocean (NATL) shows a statistically significant increase in the total number of hurricanes experienced since 1995. In an analysis of the frequency and duration for the same time period no significant trends were noted for ocean basins except for the NATL which showed an increasing trend significant at the 99% confidence level. Webster *et al.*, (2005) also noted an almost doubling of the Category 4 and 5 hurricanes in the same time period for all ocean basins. While the number of intense hurricanes has been rising, the maximum intensity of hurricanes has remained fairly constant over the 35 year period examined.

4.2 Future Climate Scenarios - IPCC Projections

■ Temperature and Precipitation

IPCC Scenarios of temperature change and percentage precipitation change between 1980 to 1999 and 2080 to 2099 for the Caribbean are based on the coordinated set of climate model simulations archived at the Program for Climate Model Diagnosis and Intercomparison (see **http://www-pcmdi.llnl.gov/**) PCMDI; subsequently called the multi-model dataset or MMD (Christensen *et al.*, 2007). The results of the analysis using A1B Special Report Emission Scenario - SRES (Nakićenović and Swart, 2000) are summarised in Table 1 (Christensen *et* *al.*, 2007). A small value of T (column 8 for temperature and column 14 for precipitation) implies a large signal-to-noise ratio and it can be seen that, in general, the signal-to-noise ratio is greater for temperature than for precipitation change, so that the temperature results are more significant. The probability of extreme warm seasons is 100% (column 15) in all cases and the scenarios of warming are all very significant by the end of the century.

TABLE 1

Regional average of Caribbean (CAR) temperature and precipitation projections from a set of 21 global models in the MMD for the A1B scenario. The mean temperature and precipitation responses are first averaged for each model over all available realisations of the 1980 to 1999 period from the 20th Century Climate in Coupled Models (20C3M) simulations and the 2080 to 2099 period of A1B. Computing the difference between these two periods, the table shows the minimum, maximum, median (50%), and 25 and 75% quartile values among the 21 models, for temperature (°C) and precipitation (%) change. Regions in which the middle half (25-75%) of this distribution is all of the same sign in the precipitation response are coloured light brown for decreasing precipitation. T years (yrs) are measures of the signal-to-noise ratios for these 20-year mean responses. They are estimates of the times for emergence of a clearly discernible signal. The frequency (%) of extremely warm, wet and dry seasons, averaged over the models, is also presented. Values are only shown when at least 14 out of the 21 models agree on an increase (bold) or a decrease in the extremes. A value of 5% indicates no change, as this is the nominal value for the control period by construction (from Christensen *et al.*, 2007).

	Temperature Response (°C)							Precipitation Response (%)						Extreme Seasons (%)		
Region[a]	Season	Min	25	50	75	Max	T yrs	Min	25	50	75	Max	T yrs	Warm	Wet	Dry
CAR	DJF	1.4	1.8	2.1	2.4	3.2	10	-21	-11	-6	0	10		100	2	
	MAM	1.3	1.8	2.2	2.4	3.2	10	-28	-20	-13	-6	6	>100	100	3	18
10N,85W	JJA	1.3	1.8	2.0	2.4	3.2	10	-57	-35	-20	-6	8	60	100	2	40
to	SON	1.6	1.9	2.0	2.5	3.4	10	-38	-18	-6	1	19		100		22
25N,60W	Annual	1.4	1.8	2.0	2.4	3.2	10	-39	-19	-12	-3	11	60	100	3	39

Table 1 shows that the MMD-simulated annual temperature increases at the end of the 21st century range from 1.4°C to 3.2°C with a median of 2.0°C, somewhat below the global average. Fifty percent of the models give values differing from the median by only ±0.4°C. There were no noticeable differences in monthly changes. According to Table 1, most models project decreases in annual precipitation and a few increases, varying from –39 to +11%, with a median of –12%. Figure 3 (Christensen *et al.*, 2007) shows that the annual mean decrease is spread across the entire region (left panels). In December, January and February (DJF), some areas of increases are noted (middle panels) and in June, July and August (JJA), the region-wide decrease is enhanced, especially in the region of the Greater Antilles, where the model consensus is also strong (right panels).

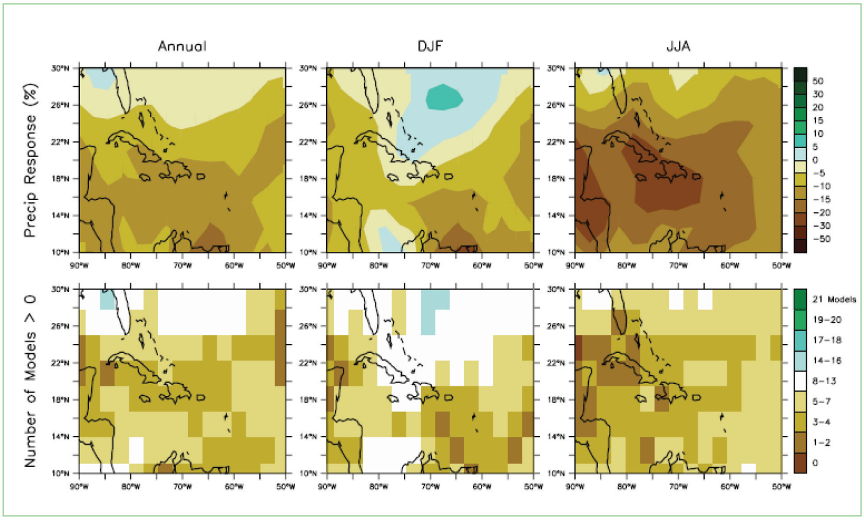

FIGURE 3
Precipitation changes over the Caribbean from the MMD-A1B simulations.
Top row: Annual mean, DJF and JJA fractional precipitation change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Bottom row: number of models out of 21 that project increases in precipitation (From Christensen *et al.*, 2007).

Sea Level Rise

Global sea level is projected to rise between the present (1980–1999) and the end of this century (2090–2099) by 0.35 m (0.23 to 0.47 m) for the A1B scenario (IPCC, 2007). Due to ocean density and circulation changes, the distribution will not be uniform. However, large deviations among models make estimates of distribution across the Caribbean uncertain. The range of uncertainty cannot be reliably quantified due to the limited set of models addressing the problem . The changes in the Caribbean are expected to be near the global mean. This is in agreement with observed trends in sea level rise from 1950 to 2000, when the rise in the Caribbean appeared to be near the global mean (Church *et al.*, 2004),

Hurricanes

In an experiment with a high resolution global 20-km grid atmospheric model, Oouchi *et al.*, (2006). was able to generate tropical cyclones that begin to approximate real storms. The model was run in time slice experiments for a present-day 10-year period and a 10-year period at the end of the 21st century for the A1B scenario to examine changes in tropical cyclones. In that study, tropical cyclone frequency decreased 30% globally, but increased about 34% in the North Atlantic. The strongest tropical cyclones with extreme surface winds increased in number while weaker storms decreased. The tracks were not appreciably altered, and maximum peak wind speeds in future simulated tropical cyclones increased by about 14% in that model, although statistically significant increases were not found in all basins (Meehl *et al.*, 2007). However, these regional changes are largely dependent on the spatial pattern of future simulated SST changes (Yoshimura *et al.*, 2006) which are uncertain.

4.3 IPCC 4th Assessment Summary

The summary below (Christensen *et al.*, 2007) is based on the SRES A1B scenario which gives an average global increase in temperature of 2.8° C over the present century. If all developed countries were to cut greenhouse gas emissions at the rate now proposed by the United Kingdom and France (approximately 50% by 2050 and 80% thereafter), then the global temperature increase would be limited to just under 2° C.

> "Sea levels are likely[1] to continue to rise on average during the century around the small islands of the Caribbean Sea …. Models indicate that the rise will not be geographically uniform but large deviations among models make regional estimates across the Caribbean … uncertain. Note: Based on the personal judgement of the CANARI Working Group I, the increase will probably follow the global average. All Caribbean … islands are very likely to warm during this century. The warming is likely to be somewhat smaller than the global annual mean warming in all seasons. Summer rainfall in the Caribbean is likely to decrease in the vicinity of the Greater Antilles but changes elsewhere and in winter are uncertain. Note: On-going analysis of precipitation changes by the Climate Studies Group Mona warrants upgrading the 'likely' decrease of precipitation in the greater Antilles to 'very likely'. It is likely that intense tropical cyclone activity will increase (but tracks and the global distribution are uncertain)."

[1] In the IPCC Summary for Policymakers, the following terms have been used to indicate the assessed likelihood, using expert judgement, of an outcome or a result: Virtually certain > 99% probability of occurrence, Extremely likely > 95%, Very likely > 90%, Likely > 66%, More likely than not > 50%, Unlikely < 33%, Very unlikely < 10%, Extremely unlikely < 5%

5. Present Capacity

This section deals mainly with the manpower and equipment capacity of three institutions, Caribbean Institute of Meteorolgoy and Hydrology (CIMH), Climate Studies Group Mona (CSGM) and Instituto de Meteorologia (INSMET). Other institutions involved in climate change research in the regions are the Caribbean Community Climate Change Centre (CCCCC) and the Joint Institute for Caribbean Climate Studies (JICCS). CSGM has been collaborating on climate variability and climate change projects with CIMH since 1995, and with ISMET since 2000. Collaboration on climate change has strengthened with CCCCC as the facilitator. Taken together there is a core group of researchers and technical staff, backed up by research students capable of conducting climate change research in the region. However since these institutions deal mainly with atmospheric modeling, there is a need for expertise in ocean and land surface interaction.

6. Gaps and Bridging Them

6.1 Gaps

Significant strides have been made with respect to gaining an understanding of Caribbean climate variability and change, and efforts have begun with respect to generating region specific scenarios of future climate. Yet, gaps still remain which must be bridged, particularly if interdisciplinary efforts are to materialize. Some of the gaps are as identified below.

■ The Data Deficit

Determining the mechanisms that control Caribbean climate whether through statistical analyses or modelling requires good quality climate data of significant temporal length, and from all territories across the Caribbean region. For example, statistical downscaling – a technique well suited for the development of scenarios for the biodiversity sector – requires long time series of daily station data for the location being studied. The summary of Section 2 suggests that datasets and data reserves exist for and within the Caribbean region. However there a number of deficits, including:

- The need to increase the density of stations for which quality controlled historical data is available.
- The need for daily station data of sufficient temporal length (30 years or more) to enable scenario generation via statistical means.
- The need to expand the number of climatic variables captured by the historical data. The current emphasis is on a minimum dataset of precipitation,

maximum and minimum temperature. This may not be sufficient for the generation of scenarios of relevance to other sectors for example, the biodiversity sector.
- The need to ensure easy access to the existing data stores, for legitimate users for example, researchers.
- The need to ensure that data currently being recorded meet adopted global and regional standards so that the identified data deficiencies with respect to present day historical data are not the deficiencies of the future generation.
- The need to capture secondary or derived information (for example, climate indices or data ranges or deviations) for storage alongside the primary data.
- The need to expand data offerings to include SST and variables such as soil moisture, concentration of atmospheric constituents, etc.

Whereas some territories, for example Cuba, have been successful at amassing reasonably long time series of station data for multiple variables and multiple stations this is not the case throughout the entire region. In many territories additional data exist which could supplement existing databases, but in non-traditional archives (for example, records of sugar plantations, agricultural and hydrological bodies) and in non-digitized forms, and are therefore yet to be captured. There is at present no coordinated region-wide data capture effort in spite of a growing sense of urgency about the deterioration of the media on which some the data is currently captured.

6.2 Capacity Constraints

■ Human Capacity

The Caribbean region is not devoid of the human capacity to undertake the tasks associated with generating climate change scenarios. Highly qualified meteorologists, and climate researchers with sufficient knowledge of methodologies to assess and produce relevant analyses exist within the region at institutions such as the CIMH, at a few meteorological offices and at regional and local universities. The number of interdisciplinary and multinational research projects carried out at these institutions and others within the region attest to this capacity. Yet there are constraints. In particular, the very recent interdisciplinary emphasis of climate change research means that the pool of professionals who can either straddle the disciplines being combined (for example, meteorology and the biosciences), or with skills to effectively assess and/or examine vulnerability or adaptation, is small (though growing). Consequently there is often a need to hire consultants from outside the region to do such evaluations and assessments. Unfortunately, the experience of the region is that such experts leave their results but not their methodologies, and therefore do not facilitate a transfer of knowledge. It is also to be noted that an aging cadre of professionals in the meteorological institutions of the region remains a problem.

Technical Constraints

Technical capacity varies across the region. The infrastructure to support meteorological measurements, climatic analysis, dynamical modeling, and scenario generation exists throughout the region, though not necessarily uniformly so. Institutions such as CIMH, IMSMET, UWI and UPR- Mayaguez are noteworthy for their technical infrastructure which, though not adequate, is sufficient for many tasks. Yet a survey of the region suggests some common constraints. In spite of a growing awareness about the importance of data collection, the high cost of purchase, maintenance and calibration of meteorological instruments has resulted in a gradual deterioration of the meteorological network. When replacement instruments do not exist, or must wait on grant or government funding to be obtained, or inappropriate substitutions are made in the absence of the genuine instrument, the climate database suffers. Additionally, the use that modern meteorology makes of new computer resources means that the meteorological services and institutions conducting related meteorological activities, as well as research entities exploring climate variability and change, require high performance computers and massive data storage systems. These are necessary to generate useful and high quality information for forecasting purposes and for the research community. At this moment, most territories benefit from useful meteorological information from a variety of sources, including regional weather forecasting and some detailed mesoscale information. Outside of a few territories, however, (for example, Puerto Rico) it is impossible to give a detailed local forecast using currently installed capacity.

6.3 Knowledge Needs

Finally, as previously suggested, Sections 3 and 4 point to a vastly improved understanding of regional dynamics and a growing understanding of climate change and its likely manifestation in the Caribbean region. Yet the increased understanding highlights some knowledge gaps - pointing to areas that require better understanding. These include a need for:

- Further understanding of Caribbean climate variability, particularly on the sub-seasonal, seasonal, interannual (outside of El Niño variations) and decadal scales. Phenomena such as the low level jet, dry season dynamics, easterly wave dynamics and interactions require further examination. This is needed to provide context for examining future change within the region;

- Investigation of local or sub-regional climates and climate gradations within individual territories and how these will likely be altered by climate change;
- Further application of regional modelling techniques (dynamical and statistical), particularly with respect to downscaling climate change results for sub-regions, territories, cities, towns, and station sites;
- Dialogue between climate researchers and scientists within the biodiversity sector (for example) in order to jointly set foci, priorities, and an agenda of needs and deliverables. This would include the quantifying of climatic variables, scales, and thresholds which would be needed for analysis of the impact of climate change on the sector. For example, measurement of changes in oxygen levels in the water, or in the composition of gases in the atmosphere (ozone, methane) seem necessary for biodiversity studies but are not currently routinely done;
- Better understanding of sea level rise estimations due to global warming and the implications this will have for Caribbean coastlines especially during extreme events;
- More region specific information/studies on deforestation, flooding, and the role of climate in determining such things as human settlements and international commerce; and
- Clearer understanding of the usefulness of the various types of climate data currently being archived for modelling biodiversity impacts, as well as the limitations and boundaries within which the data can/should be used.

Admittedly, some of this knowledge may already be in existence, particularly in the archives of governmental and non-governmental organizations, in the form of consultancy reports and commissioned studies done over the years. Their inaccessibility, the lack of knowledge about their whereabouts or existence, and the absence of central bibliographic databases do nothing to fill the knowledge needs of the region.

6.4 Filling the Gaps

The following represent steps which could/should be taken to fill the identified gaps. In some cases the steps represent major efforts which would involve multi-national collaboration, while in other cases the steps could be undertaken by a single territory or institution. Identification of funding to carry out the proposed solutions remains a vexing issue for the region as a whole. Recommendations for each section include:

Data

1. Putting in place mechanisms (protocols and agreements for sharing, online facilities, etc.) to facilitate the sharing of data located in existing archives and databases scattered throughout the Caribbean.
2. Putting in place structures/programs to capture data that is not yet digitized and not yet available for use by researchers.
3. Putting in place programmes, infrastructure, and instrumentation to enable and/or support the capture of new data.
4. Subjecting existing data to rigorous quality control techniques in order to build a climate database for use by other sectors.
5. Acquiring useful datasets from sources outside the Caribbean, for example, detailed bathymetric maps of the Caribbean region.
6. Creating additional databases (where possible) of variables deemed necessary for interdisciplinary work, for example, soil moisture, SST, etc.

Capacity – Human and Technical

7. Investing in postgraduate training with an emphasis on Caribbean climate variability and change, numerical modelling of climate, and the modeling of climate change impact on various sectors including biodiversity, agriculture, tourism, water and coastal zones.
8. Supporting student exchanges within and outside of the region.
9. Support for staff education and training (especially for existing staff at meteorological services) in numeric and impact modelling, interpretation of results, analysis methods for climate change etc.
10. Acquiring equipment and software to support climate research at existing organizations and institutions with track records for doing the same. This would include massive storage devices, beowolf clusters (for numerical model runs), high speed intranet, radar networks, satellite images, software licenses and professional packages (for example, Fortran, Matlab, GIS and professional Linux), high speed intranet, radar networks, satellite images, licenses and professional packages.
11. Updating meteorological infrastructure to ensure recording of quality data. This would include acquisition of automatic stations and calibration equipment for basic meteorological instruments for example thermometers, barometers, etc. as well as the acquisition of specific meteorological instruments, for example, buoys, mareographs, and gradient towers to study the turbulent layer and the wind properties near the ground level, solar radiometers and UV sensors, to study the solar potential of our region, etc.

Knowledge

12. Developing online mechanisms for storing and disseminating information for example, a web-page compendium for use as a clearing house document for information.
13. Developing a Caribbean climate atlas.
14. Facilitating dialogue between climate researchers and scientists of other sectors such as biodiversity, in order to establish priorities, needs and deliverables for climate change studies.
15. Supporting graduate student research and cross disciplinary training.

7. Climate Models, Generation of Climate Scenarios

Scenarios can be generated using Atmospheric Global Climate Models (GCM), Coupled Atmospheric-Ocean Global Climate Models (AOGCM) which give coarse results over a large grid (~ 4° latitude x 4° longitute), and Regional Models, which have a smaller scale of approximately 50km. These models are referred to as dynamic models since they utilize the dynamic processes that affect climate. Current temperature, pressure, relative humidity and winds are used as inputs into these models and many atmospheric parameters, computed and stepped forward in time, are produced as outputs. Another technique used for generating the scenarios is called statistical downscaling. The aim of statistical downscaling is to generate the climate scenarios for a small region or even a point such as a weather station, using the output of a dynamic model for a larger region; hence the term downscaling. The process consists of generating and validating regression equations that relate the climate parameters to be downscaled for the small region, called predictands, with climate predictors, such as surface temperatures, pressure and vertical velocity, which are available from data sets, such as the National Centre for Environmental Prediction (NCEP) re-analysis dataset (Kalnay *et al.*, 1996). These regression equations are then employed to find scenarios of future climate for the small region by using future values of the predictors generated by the dynamic model (reproduced from Chen *et al.*, 2006). All models must be validated by comparing their simulation of current or past climate with current or past climate data.

General Circulation models can be used to study climate change in the Caribbean region as a whole. For finer resolution, for example, studying an individual island, a regional model with resolutions of 25 to 50 km would be required. For studies of smaller areas, for example, biodiversity around a station, statistical downscaling would have to be used. The statistical method however requires an input of a long time series of daily data, preferably of at least 30 years duration, but it has been know to be used with as short as 15 years of data.

Because information for biodiversity studies includes knowledge of climate threshold values and geographical distribution, statistical downscaling may be a method of choice due to its site specific nature. This method is versatile in terms of the parameterization and generation of future climate. Say, for example, that vegetation growth rate was related to relative humidity. In the first place, independent of generating scenarios, a long time series would allow for better correlation between vegetation and relative humidity. Then by statistical downscaling, scenarios of a time series of relative humidity could be obtained for sometime in the future, and this in turn could be used to develop scenarios of growth rate.

In addition, for purposes of downscaling a properly designed statistical method may in actuality be more reliable than a regional method using a single model. This is because the convention in obtaining the most reliable scenario from dynamic models is to use the average scenario from a number of models. So if the values of future predictors to be used in a statistical downscaling model could be obtained by averaging these values from outputs of several GCM's, the scenario generated by the statistical model would be more reliable than that obtained by a single regional model using inputs from a single GCM. The main limitation would be the uncertainty that the regression equations developed between the predictors and predicted in the present climate would remain the same in the future climate. However the likelihood of this is quite good since we know most of the atmospheric physics and chemistry involved, and there is not much room left for surprises.

8. Concluding Remarks

This report has established that, although Caribbean Institutions are able to analyze and generate climate change scenarios, gaps in our ability to do so exist. Section 5 lists the needs and suggests pathways for bridging the gaps. Some solutions are not expensive, such as inter-disciplinary collaboration, exchange of personnel and training. Others require more funding, notably in computer accessories. Invariably the question will be asked whether or not the efforts to bridge the gaps are worthwhile. The scenarios generated by more affluent countries are global (and regional for their own needs). It will inevitably be the task of Caribbean countries to produce their own regional scenarios, and the quality of the scenarios generated will depend on the capability, so that efforts must be made to increase it. There are questions that need to be answered concerning changes in Caribbean biodiversity, as reported by the other 2 working groups in the *CCBIC* project, which require more data gathering and model runs.

The question will also be asked 'What if global warming can be limited and eventually reversed will efforts be in vain?' In the first place, the world is already committed to increases (less than 2°C) over the century due to the long life time of greenhouse gases in the atmosphere and the 'long' memory of the ocean even if GHG emission conditions were stabilized. In the second place there are many advantages to be gained, outside of global warming concerns. Increased capacity in climate studies will lead to better forecasting of daily weather and of seasonal changes, such as drought and floods. Crop models and climate models could be combined to predict crop yields. Again, models could be run to determine the effects of deforestation, or better yet, the effects for re-forestation. So that filling the gaps in our capability to study and generate future climate will not be in vain.

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Attachment

Precipitation and Temperature at Casablanca station, Cuba, 1909 - 2000/2

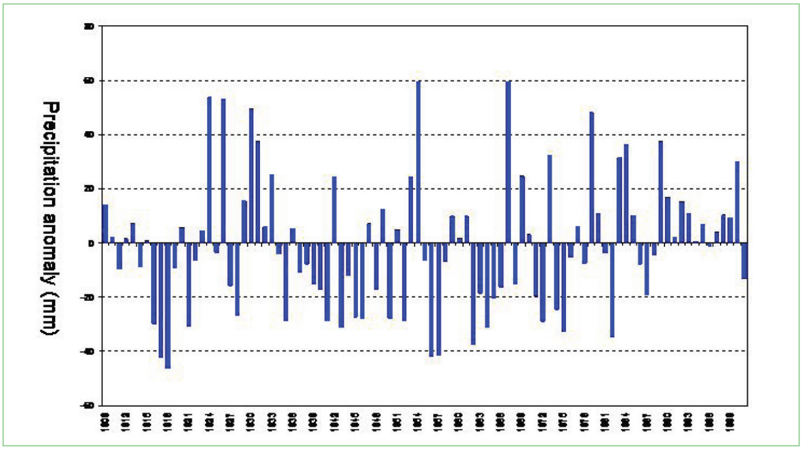

FIGURE A1
Precipitation anomaly at Casablanca station, Cuba, 1909 - 2000.

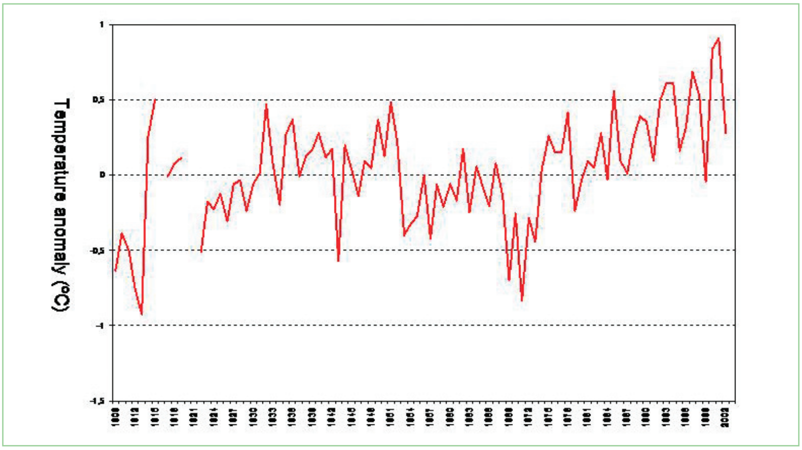

FIGURE A2
Temperature anomaly at Casablanca station, Cuba, 1909 - 2002.