1. INTRODUCTION

1.1. CONTEXT

The very climate that has for decades underpinned the economies of many Caribbean territories is now proving to be their greatest area of vulnerability. This is in large part due to significant economic dependence upon climate sensitive sectors, like tourism and agriculture, in the face of a changing climate regime. There are, however, several other factors that further contribute to regional climate sensitivity and a heightened vulnerability to climate variations and change. These include limited coastal plains for siting major towns, cities and zones of economic activities (due to the small sizes and/or complex terrain of most Caribbean territories); a strong dependence on rainfall for water; and limited capabilities for hazard forecasting. For much of the Caribbean, there has been an expectation that the climate must follow anticipated and accustomed patterns, and as a result, planning related to both quality of life and economic development is strongly premised on these 'normal' patterns of climate. This is true even when the region experiences 'anomalous' climate phenomena, i.e., even variations from the 'normal' are expected to occur within bounds of familiarity.

Recent years, however, have seemingly brought the emergence of climatic conditions that are not only unfamiliar, but also unprecedented. This has been seen in such phenomena as rising sea levels, more prolonged region-wide droughts, increased heavy rainfall and flooding events, and greater numbers of very hot days and nights in a year. It is not just the magnitude of the change that has proven challenging (e.g., the intensity of the rainfall events leading to flooding, or the length of the droughts), but also the frequency of extreme event occurrence. Such is the case when the region is impacted by a climate extreme even before it has managed to recover from another. Projections of future Caribbean climates indicate that changes already seen are likely to continue and further intensify, exposing the region to an increasing number of extreme climatic events. The Caribbean is, therefore, projected to keep facing the challenges that accompany the adjustment to climate change, for example, from more frequent and/or intense tropical storms and hurricanes.

The 2017 hurricane season provided valuable insight into what the Caribbean might face in the future under climate change. Far surpassing any upper limits of devastation in prior experience, the 2017 hurricane season was among the deadliest on record, and the costliest to date - estimated at over US$350 billion globally (Seria 2018). According to the Caribbean Development Bank (CDB), several of its Borrowing Member Countries (BMCs)[4], shown in Figure 1.1, were affected by the hurricanes of September 2017. Hurricanes Irma and Maria, in particular, challenged prior concepts of familiarity and preparedness, both in terms of the record-breaking speed with which they attained category 5 status, and their relentless onslaught upon the region. The damage caused by these hurricanes led to substantial loss of life, widespread infrastructural damage, destruction of crops and livestock, diminished standards of living, and loss of livelihoods. Recovery from that most devastating of seasons is still proving to be a challenge for the scope of regional experience, and perhaps regional economic power as well. (It is noted that the challenge posed to the region by recurrent hazards of unprecedented nature was being played out even as this document was being finalized. The 2019 hurricane season proved to also be record breaking with Hurricane Dorian (category 5) causing significant devastation in the Bahamas (ECLAC 2019).

4 CDB BMCs: Anguilla, Antigua and Barbuda, Bahamas, Barbados, Belize, British Virgin Islands, Cayman Islands, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, St Kitts and Nevis, St Lucia, St Vincent and the Grenadines, Suriname, Trinidad and Tobago, and Turks and Caicos Islands

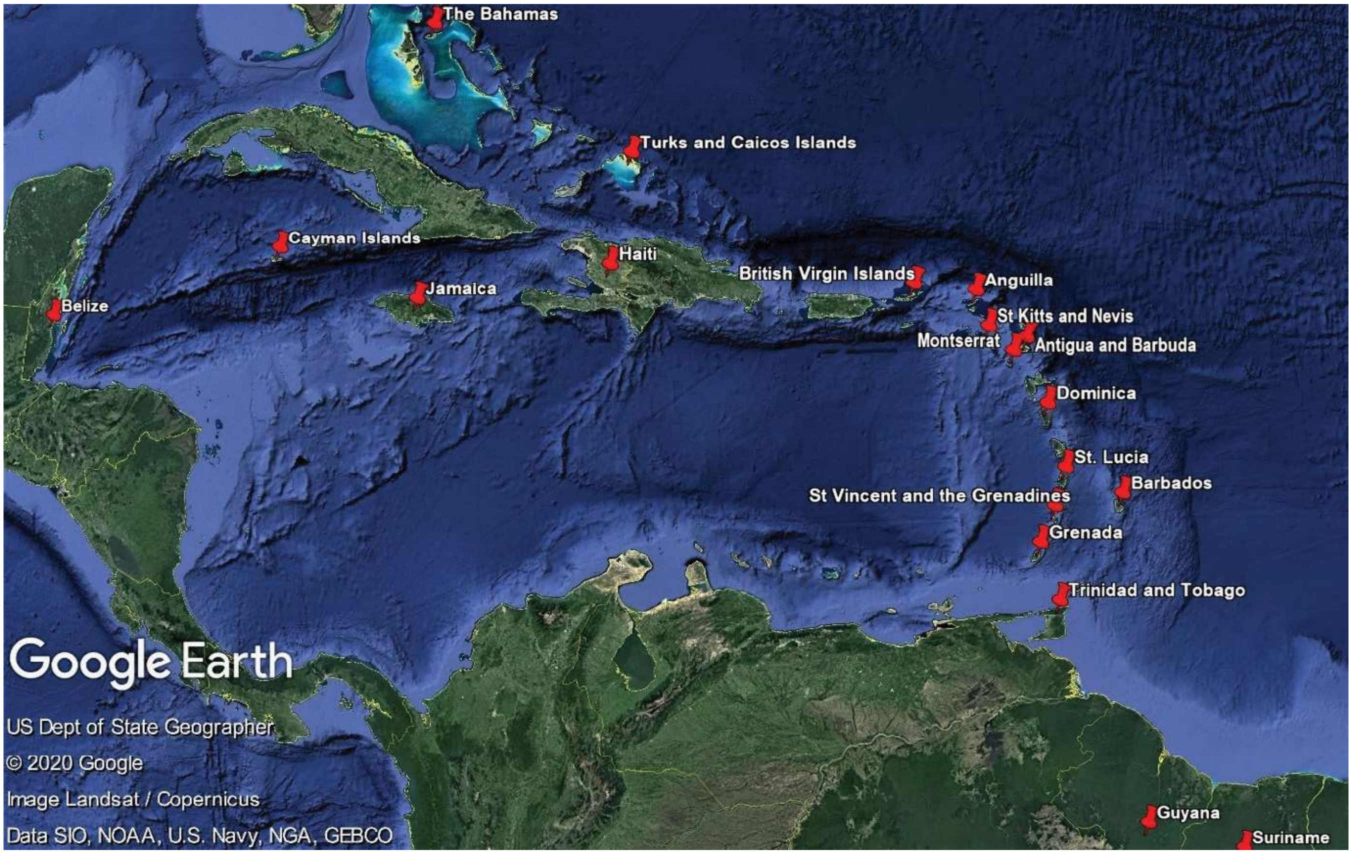

Figure 1.1: Map of the Caribbean showing CDB BMCs (Source: Google Earth 2020)

Given recent experiences and future projections, it seems clear that the Caribbean can no longer afford the cost of the catastrophic consequences of climate change, nor can it afford not to respond to climate change. Therefore, regional efforts aimed at augmenting climate resilience are necessary given that the Caribbean's vulnerability to climate variability and change is projected to only increase. Such resilience will require a multi-faceted, strategic, and sustainable approach which will only be possible with the support of decision-makers in government and industry.

This document serves as a contribution to the regional resilience building effort through the provision of historical and future climate information for use by regional decision-makers. In order to mainstream climate variability and change into regional planning and decision-making, it is necessary to have an understanding of: (i) the baseline or mean climate of the region, (ii) how that climate has changed in the recent past and how it is projected to change in the future, (iii) how those changes are expected to have an impact at local levels, and (iv) potential measures that have already been implemented or will be required to reduce vulnerability to climate change. This document, compiled under the auspices of the State of the Caribbean Climate (SOCC) Project, provides the climate-related information decisionmakers will need as they seek to proactively plan and effectively respond to a changing climate.

1.2. THE STATE OF THE CARIBBEAN CLIMATE PROJECT

The CDB has long been cognizant of the need for increased knowledge about climate change and its effects. In 2017, the organisation provided a grant of 445,056 euros to The University of the West Indies (UWI), Mona through financing from the European Union (EU), to implement the Project "State of the Caribbean Climate Report: Information for Resilience Building". Funding for the project came as a result of a 2014 agreement with the EU for the CDB to execute projects within the African Caribbean Pacific (ACP)[5]-EU Natural Disaster Risk Management

5 The African, Caribbean and Pacific Group of States is now called The Organisation of African, Caribbean and Pacific States (OACPs).

(NDRM) Programme in the CARIFORUM states[6]. The main objective of the five-year NDRM Programme is "to contribute to reducing the vulnerability to long term impacts of natural hazards, including the potential impacts of climate change, thereby achieving regional and national sustainable development and poverty reduction goals in the CARIFORUM States." (Jambou 2015).

The State of the Caribbean Climate Project contributes to the goals of the NDRM Programme by seeking to increase awareness about, and use of, updated and reliable climate data in CDB BMCs. The Climate Studies Group, Mona (CSGM), within the Department of Physics at The UWI, is directly responsible for technical implementation of the project across its three main components listed below:

Preparation of the "State of the Caribbean Climate Report". This is intended to be a comprehensive 'first-stop' reference report that details the state of knowledge of climate variability and change at the time of its compilation. This report is expected to become the premise for actionable recommendations to improve the region's resilience across all levels and sectors. Two validation workshops for targeted end-users, one in Jamaica and one in St. Lucia, formed part of the report finalization process. Section 1.3 presents further details on the report.

Conducting interactive "Climate SMART Series" workshops. These were targeted at key governmental representatives within BMCs of the CDB as well as relevant regional organisations. The workshops focussed on: (a) building knowledge and awareness of climate change and its impacts on climate-sensitive sectors, and (b) guiding the BMCs to effectively use the data in the State of the Caribbean Climate Report to assess the effects of climate variability and change on specific sectors, and integrate climate data into development planning and strategies.

Development of an online platform. This will permanently host content relating to the State of the Caribbean Climate Report. The platform will also host workshop materials, and other relevant climate resources, thereby increasing the reach and capacity-building potential of the Project.

In the delivery of the State of the Caribbean Climate Report the CSGM partnered with the Caribbean Institute for Meteorology and Hydrology (CIMH) to produce two chapters (see the author listing in the front material). This report has also significantly benefitted from collaborative dynamical downscaling modelling work done with the Cuban Instituto de Meteorología (INSMET) under the auspices of the Caribbean Climate Modellers Consortium.

6 Caribbean Forum of African, Caribbean and Pacific States.

1.3. ABOUT THIS DOCUMENT

The State of the Caribbean Climate Report (hereafter SOCC Report) contains updated and reliable climate data for the Caribbean region, including observed climate variability and trends, recent extreme climatic events and impacts, a compilation of potential impacts of climate change for climate sensitive sectors, and an examination of the value of climate information. The report is geared towards increasing decision-makers' basic understanding of climate variability and change, facilitating evidence-based planning and policy, and implementing prioritised actions tailored to respond to climatic threats as well as sector-specific sensitivity contexts. Ultimately, this SOCC Report is expected to be used to support disaster risk reduction, facilitate the formation of climate change adaptation strategic plans, and aid work programme development, all of which will contribute to the increased resilience of vulnerable Caribbean countries and communities.

Although general assessment reports for the Caribbean do exist, there are often limitations to their access and use, particularly in the following ways: (a) many exist in peer-reviewed literature and are not readily accessible by decision-makers, (b) they are unsuited for policy-makers due to their technical scope, (c) the projections used tend to rely on general circulation models that do not provide sufficiently detailed data and information at spatial scales required by small Caribbean islands, (d) climate variability is not taken into account, and (e) existing climate change projections at the regional level are not based on the most recent science. The SOCC Report seeks to address these limitations.

Despite the fact that there have been significant improvements in the collection and availability of climate data over the last ten years, the data do not often play a critical role in planning and decision-making processes. In some cases, this is due to limitations in (i) understanding and awareness of climate variability and change as it relates to the Caribbean region, and (ii) knowledge of how and where to access climate information and data for the Caribbean. Furthermore, while many Caribbean policymakers have a strong interest in climate change issues, the perception is that such matters are often presented in an overly academic and technical manner, which discourages attempts at both understanding and using the information. The SOCC Project is an attempt to provide tools for bridging these gaps. One goal of the project is to increase basic knowledge and understanding of recent and future climate variability and change in the Caribbean region, in the hope that doing so will yield evidence-based policy and investment actions. In particular, the SOCC Report attempts to do this by amalgamating all current Caribbean region-specific climate-related information for a non-scientific audience. Table 1.1 outlines the structure of the report.

Table 1.1: Structure of the State of the Caribbean Climate Report

CHAPTER	TITLE	SUMMARY
CHAPTER 1	INTRODUCTION	Caribbean context and State of the Caribbean Climate Project.
CHAPTER 2	DATA AND METHODOLOGIES	Methods and sources of data collection.
CHAPTER 3	RAINFALL AND TEMPERATURE	Defining climatology, extremes, and trends.
CHAPTER 4	SEA LEVEL RISE, DROUGHTS & FLOODS, HURRICANES	Historical variability or long-term trends.
CHAPTER 5	CLIMATE SCENARIOS AND PROJECTIONS	Caribbean climate in the future using regional climate models and statistical downscaling.
CHAPTER 6	CLIMATE EXTREMES AND EARLY WARNING	A description of extreme climatic events and the current regional early warning information for improved preparedness to such events.
CHAPTER 7	IMPACTS OF CLIMATE CHANGE ON THE CARIBBEAN	A compilation of potential impacts of climate change for relevant sectors in the Caribbean with references.
CHAPTER 8	ADDING VALUE TO CLIMATE INFORMATION THROUGH SERVICES	Caribbean approach to climate services at national and regional levels.
CHAPTER 9	CONCLUSIONS AND RECOMMENDATIONS	Summary of key report findings and recommendations for the way forward.
CHAPTER 10	REFERENCES	A list of all the references (by chapter) used in the preparation of this document.
APPENDIX 1	CLIMATE RESOURCES	A comprehensive review of credible climate tools, reports, and articles on Caribbean climate.

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2. DATA & METHODOLOGIES

2.1. APPROACH

The general approach taken in compiling this document is as follows:

Literature Review. A literature review was conducted of authoritative works and recent studies on climate change and climate variability for the Caribbean region. These included national reports such as the State of the Jamaican Climate 2015 (CSGM 2017), National Communication submissions from Non-Annex I Parties and Biennial Update Report submissions under the United Nations Framework Convention on Climate Change (UNFCCC), the Fifth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC 2013), and other reports and studies produced by the IPCC, Caribbean Community Climate Change Centre (CCCCC), Caribbean Institute for Meteorology and Hydrology, and the Climate Studies Group, Mona. The literature review guided the preparation of, and provided content for, the sections of this report.

Historical Data Analysis. The climate data products used in this work are listed in Table 2.1. Available historical observed data are used to both characterise the climatology of selected climate variables and examine variability and trends for the same climate variables. Variability and trends in sea level rise and the occurrence of tropical storms, hurricanes, and other climate extremes were also examined. The literature review was used to complement the descriptions of the climatology and historical climate variability. Data from a variety of sources were used. The data sources employed are further described in the following subsection (Section 2.2). The analysis of the data is organised by variable and done using tables, graphs, and diagrams with specific emphasis on CDB member states and for the Caribbean as a whole. Data are also presented for climatic zones premised on six rainfall zones identified in the Caribbean (see Section 3.1). The climatic zones group countries within the Caribbean with similar rainfall climatological patterns.

Projections of Future Climate. Climate projections for the Caribbean region were obtained from the outputs of a suite of global climate models (GCMs), two regional climate models (RCMs), and statistical downscaling techniques. Future trends in climate and variability were produced for the Caribbean over three future time slices: 2020s (2020-2029), 2050s (2050-2059), and end of the century (2091-2100) with respect to a historical baseline. For GCM data, country scale projections were generated using representative concentration pathway scenarios or RCPs (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) consistent with the IPCC's Fifth Assessment Report (AR5). RCPs are explained in Section 2.3.

Comparisons to past trends are shown, where appropriate. For RCM analyses, data were extracted from the PRECIS (Providing Regional Climates for Impact Studies) RCM, with 25 km grid resolution covering respective rainfall zones consisting of CDB member states and using a perturbed physics ensemble (see Section 2.3). Similar future time slices were reported on. Whereas the coarser resolution GCM data were used to capture mean climate changes for the Caribbean divided into six rainfall zones, the RCM data were only used to extract projection data for selected geographic regions. Projections of extreme indices were also derived from rainfall and temperature data obtained from stations with long-term time series using statistical downscaling techniques and GCM data.

In producing future projections, the data are analysed to provide, as best as possible, a picture of the state of the climate of the Caribbean at the regional, country, and sub-country (~25 km) levels for the near-term to end-of-century. Again, the literature review was used to provide complementary pictures of the future with respect to other climatic variables, for example, with respect to sea level rise and future tropical storms and hurricanes.

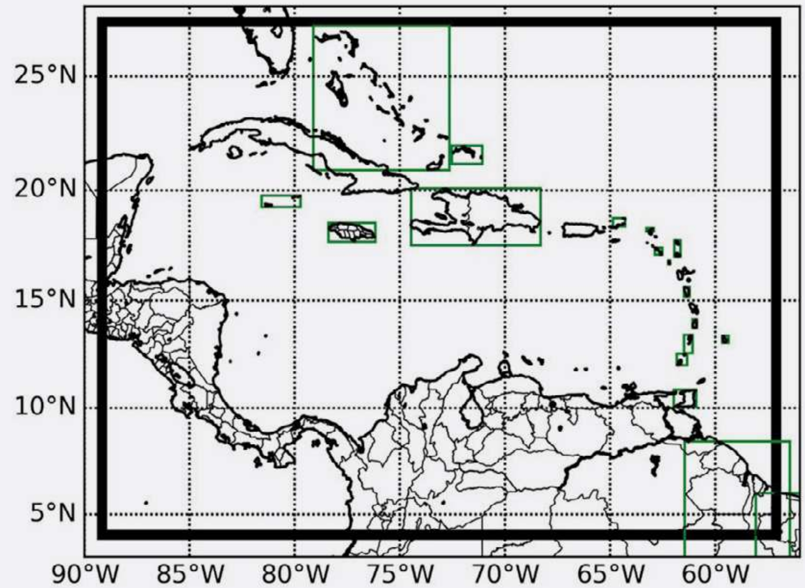


Figure 2.1: Representation of the Caribbean. CDB member states are shown in green boxes.

Impact Tables, Vulnerability Profiles, and Maps. The likely impacts of climate variability and change on key sectors are summarized from an extensive literature review and presented in tabular form. Sectors addressed under other CDB initiatives were targeted (water, agriculture, tourism, health, human settlements, and coastal resources). Also presented are impacts tables for crosscutting themes such as poverty, society, gender, and development

2.2. DATA SOURCES

As noted above, multiple sources are used in compiling the narrative of this report. Table 2.1 shows the primary climate data sources which are relied upon to produce the climatologies, and the general analyses of past and future climatic trends for which they are used. Links to each source are also shown.

Table 2.1: Data sources used in the compilation of historical climatologies and future projections

HISTORICAL DATA				
Temperature	Climatology + Historical Trends	Station data	» CAROGEN Monthly data for stations across the Caribbean region. Data availability varies from country to country. Stations are listed in Table 3.2.	» Observed weather station data from Caribbean Institute for Meteorology and Hydrology: Retrieved from http://carogen.cimh.edu.bb/
		Gridded Dataset	» University of Delaware (UDel): Monthly global gridded high resolution (0.5°) station (land) data for air temperature from 1900-2014.	» University of Delaware, Center for Climatic Research; Willmott et al. (2014): Retrieved from Global Precipitation Archive
	Trends	Gridded Dataset	» CRU TS 3.24: fully interpolated dataset with high resolution (0.5°). Monthly gridded fields based on monthly observational data, which are calculated from daily or sub-daily data by National Meteorological Services and other external agents.	» University of East Anglia Climatic Research Unit; Harris et al. (2014): Retrieved from KNMI Climate Explorer http://climexp.knmi.nl/plot_atlas_form.py
			» IRI Climate and Society Map Room Tool used to present an approximate timescale decomposition of the Caribbean region's precipitation and air temperature time series for the twentieth century.	» Columbia University International Research Institute for climate and society; Map Room: Retrieved from from http://iridl.ldeo.columbia.edu/maproom/
Rainfall	Climatology + Historical Trends	Station data	» CAROGEN Monthly data for stations across the Caribbean region. Data availability varies from country to country. Stations listed in Table 3.2.	» Observed weather station data from Caribbean Institute for Meteorology and Hydrology: Retrieved from http://carogen.cimh.edu.bb/
		Gridded Dataset	» University of Delaware (UD): Monthly global gridded high resolution (0.5°) station (land) data for rainfall from 1900-2014.	» University of Delaware, Center for Climatic Research; Willmott et al. (2014): Retrieved from Global Precipitation Archive
	Trends	Gridded Dataset	» CRU TS 3.24: Fully interpolated dataset with high resolution (0.5°). Monthly gridded fields based on monthly observational data, which are calculated from daily or sub-daily data by National Meteorological Services and other external agents. Based on analysis of several individual weather station records in the Caribbean.	» University of East Anglia Climatic Research Unit; Harris et al. (2014): Retrieved from KNMI Climate Explorer http://climexp.knmi.nl/plot_atlas_form.py
			» IRI Climate and Society Map Room Tool used to present an approximate decomposition of the Caribbean region's precipitation anomaly time series for the twentieth century.	» Columbia University International Research Institute for climate and society; Map Room: Retrieved from http://iridl.ldeo.columbia.edu/maproom/
Sea Levels	Trends	Gauge data	» As reported in literature	» Various sources

HISTORICAL DATA				
Sea Surface Temperature	Trends	Gridded Dataset	» NOAA/OAR/ESRL PSD V2 High Resolution 0.25° monthly dataset	» National Oceanic and Atmospheric Administration (NOAA), Earth System Research laboratory; Optimum Interpolation (OI) SST V2: Retrieved from https://www.esrl.noaa.gov/psd/
Hurricanes	Historical Trends		» Atlantic hurricane reanalysis project of the National Oceanic and Atmospheric Administration	» Observed storm data available from: http://www.aoml.noaa.gov/hrd/data_sub/re_anal.html
FUTURE DATA*				
Temperature & Rainfall	GCM Data	Gridded Dataset	» CMIP5 (IPCC AR5 Atlas subset)- This is the dataset used in the IPCC WG1 AR5 Annex I "Climate Change Atlas". » Only a single realization from each of over 20 models is used. » All models are weighted equally, where model realizations differing only in model parameter settings are treated as different models.	» Retrieved from KNMI Climate Explorer: http://climexp.knmi.nl/plot_atlas_form.py
	RCM Data	Gridded Dataset	» PRECIS Perturbed Physics experiments performed for the Caribbean. » Dynamical Downscaling using the RegCM4.3.5 Model.	» Perturbed physics data available from the Caribbean Community Climate Change Centre: http://www.caribbeanclimate.bz/general/clearinghouse-search-tool.html
Sea Levels	GCM Data	Gridded Dataset	» Ensemble mean and 95% percentile of 21 CMIP5 models. Data taken for projections to the end of century (2100). Data relative to 1986-2005.	» Model data: Retrieved from Integrated Climate Data Center: http://icdc.cen.uni-hamburg.de/las/getUI.do
Hurricanes			» As reported in literature.	» Various sources.

*Additional information on model data is provided in Section 2.3.2.

2.3. OBTAINING FUTURE PROJECTIONS FROM MODELS

2.3.1. EMISSION SCENARIOS

It is largely Representative Concentration Pathway (RCP) based future data that are reported on in this document. The GCMs from which data were extracted for use in this study were run using the full range of RCPs, namely RCP2.6, RCP4.5, RCP6.0 and RCP8.5 (see Box 2.1). However, the PRECIS RCM was run multiple times using the A1B Special Report Emission Scenario (SRES) (Nakicenovic et al. 2000). As will be explained later, more sub-island scale data are currently available for a future Caribbean for the RCM run using the SRES scenario (6 possible futures), hence its use. The statistical downscaling also relied on the output of a GCM run using RCP2.6, 4.5, and 8.5.

With respect to comparability between the two sets of scenarios used in this document, the SRES A1B is comparable to RCP6.0 in carbon dioxide concentrations and global temperature change by century's end and RCP8.5 through mid-century. Both RCP6.0 and the A1B scenarios are marked by an increase in carbon dioxide emissions through to (A1B) or after (RCP6.0) mid-century, followed by a decrease approaching 2100 (see Figure 2.2). By 2100, carbon dioxide concentrations for both scenarios are very similar (over 600 ppm) as is the mean global temperature anomaly (just under 3 °C). In this document, the RCM data reported on using the A1B scenario are representative of a high emissions (or worst case) future scenario for the first three time slices and a medium-high emissions scenario for the end of century time slice.

INFORMATION BOX 2.1

SO WHAT IS A SCENARIO?

In distinguishing between SRES and RCP scenarios, it is noted that SRES scenarios (reported on in the IPCC's Fourth Assessment Report (IPCC 2007)) represent plausible storylines of how a future world will look. The SRES scenarios explore pathways of future greenhouse gas emissions, derived from self-consistent sets of assumptions about energy use, population growth, economic development, and other factors. They however explicitly exclude any global policy to reduce emissions to avoid climate change. SRES scenarios are grouped into families (e.g. A1, B1, A1B, etc.) according to the similarities in their storylines. In this document data from one RCM run using the A1B scenario are reported on. The A1B scenario is characterized by an increase in carbon dioxide emissions through mid-century followed by a decrease. A1B is often seen as a compromise between the A2 (high emissions) and B1 (lower emissions) scenarios.

In the IPCC's Fifth Assessment Report (AR5) (IPCC 2013), however, outcomes of climate simulations use new scenarios referred to as *"Representative Concentration Pathways"* (RCPs) (van Vuuren et al. 2011). These RCPs represent a larger set of mitigation scenarios and were selected to have different targets in terms of radiative forcing (cumulative measure of human emissions of greenhouse gases from all sources expressed in Watts per square metre) of the atmosphere at 2100. They are therefore defined by their total radiative forcing pathway and level by 2100: RCP2.6. RCP4.5, RCP6.0 and RCP8.5 (Figure 2.2). The four RCPs include one mitigation scenario leading to a very low forcing level (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6), and one scenario with very high greenhouse gas emissions (RCP8.5).The RCP scenarios are also considered plausible and illustrative, and do not have probabilities attached to them.

In comparing the SRES and RCP scenarios it is noted that whereas the SRES scenarios resulted from specific socio-economic scenarios from storylines about future demographic and economic development, regionalization, energy production and use, technology, agriculture, forestry and land use (IPCC 2000), the RCPs are new scenarios that specify concentrations and corresponding emissions, but not directly based on socio-economic storylines like the SRES scenarios. The RCPs can thus represent a range of 21st century climate policies, as compared with the no-climate policy of the Special Report on Emissions Scenarios (SRES). Of the 4 RCPs, many do not believe RCP2.6 or RCP4.5 are feasible without considerable and concerted global action cause, and that the world is currently on an emission pathway equivalent to RCP6.0 or higher (Meinshausen et al. 2015).

The four RCPs include one mitigation scenario leading to a very low forcing level, two stabilization scenarios, and one scenario with very high greenhouse gas emissions

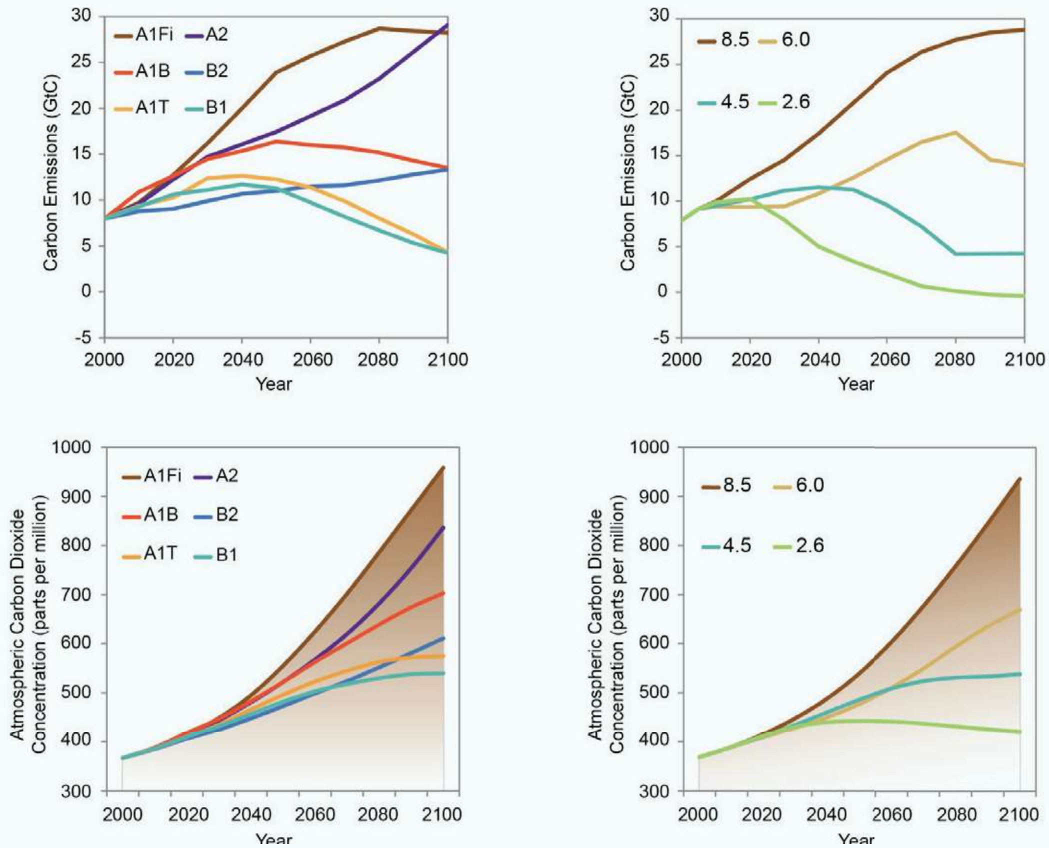


Figure 2.2: Two families of scenarios commonly used for future climate projections: the Special Report on Emission Scenarios (SRES, left) and the Representative Concentration Pathways (RCP, right). The SRES scenarios are named by family (A1, A2, B1, and B2), where each family is designed around a set of consistent assumptions: for example, a world that is more integrated or more divided. The RCP scenarios are simply numbered according to the change in radiative forcing (from +2.6 to +8.5 watts per square metre) that results by 2100. This figure compares SRES and RCP annual carbon emissions (top), carbon dioxide equivalent levels in the atmosphere (bottom).

Figure source: Climate Change Impacts in the United States: The Third National Climate Assessment.

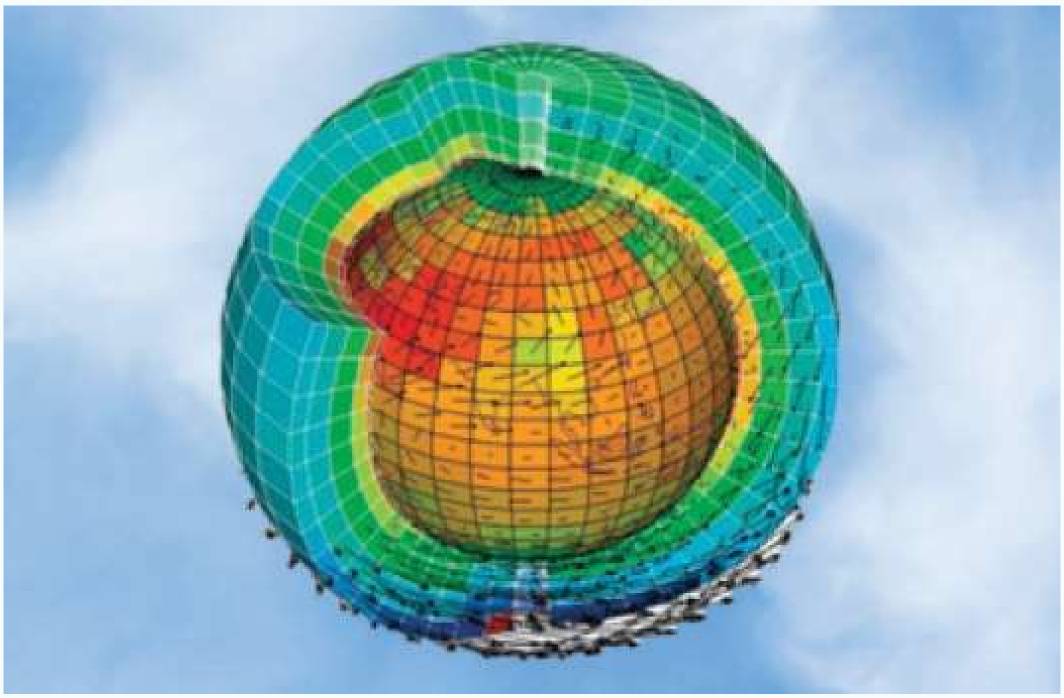
2.3.2. GCMS AND RCMS

Data from both Global Circulation Models (GCMs) and Regional Climate Models (RCMs) are used in this study (see Box 2.2).

INFORMATION BOX 2.2

WHAT'S THE DIFFERENCE BETWEEN GCMS AND RCMS?

Climate Models are useful tools for providing future climate information. GCMs are mathematical representations of the physical and dynamical processes in the atmosphere, ocean, cryosphere and land surfaces. Their physical consistency and skill at representing current and past climates make them useful for simulating future climates under differing scenarios of increasing greenhouse gas concentrations. (See the previous section for the discussion on scenarios.)



Global Climate Models (GCMs) have relatively coarse resolutions relative to the scale of required information because of the computational requirements to model the entire globe. Unfortunately, the size of the Caribbean islands versus the grid spacing of the GCMs on which data are reported means that some islands are represented by at most a few grid boxes. There is therefore a need for downscaling techniques to provide more detailed information on a sub-country level. The additional information which the downscaling techniques provide do not however devalue the information provided by the GCMs especially since (1) to a large extent the Caribbean's climate is driven by large-scale phenomenon (2) the downscaling techniques themselves are driven by the GCM outputs, and (3) at present the GCMs are the best source of future information on some phenomena, for example, hurricanes. Dynamical downscaling employs a regional climate model (RCM) driven at its boundaries by the outputs of the GCMs. Like GCMs, the RCMs rely on mathematical representations of the physical processes, but are restricted to a much smaller geographical domain (the Caribbean in this case). The restriction enables the production of data of much higher resolution (typically < 100 km).

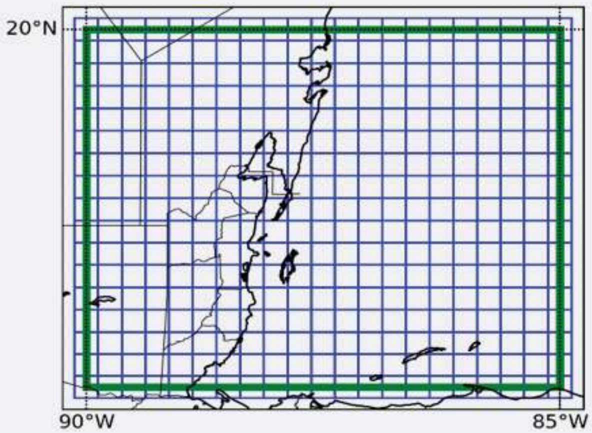
GCM projections of rainfall and temperature characteristics for the Caribbean were extracted from the subset of CMIP5 (Coupled Models Intercomparison Project 5) models used to develop the regional atlas of projections presented as a part of the IPCC's Fifth Assessment Report (AR5) (IPCC 2013). Data from more than 20 GCMs are analysed and projected annual change extracted for the GCM grid boxes over the Caribbean islands. The average for each zone containing CDB states is generated from the GCM data. This analysis provides a context within which to interpret other subzone and country scale projections derived from the RCM. Save for sea level rise (SLR), projections through the end of the century are generated, and values were averaged over the 2020s, 2050s, and end-of-century (EOC) as previously noted. Extraction was done for four RCPs. SLR projections are generated for the Caribbean as a whole and the six defined zones. The projections are presented in figures and summary tables in Chapter 5.

Available dynamically downscaled data for CDB member states are obtained from the PRECIS RCM – the PRECIS model (Jones et al. 2004) run at a resolution of 25 km. Table 2.2 summarizes key characteristics of the RCM and the experiments performed.

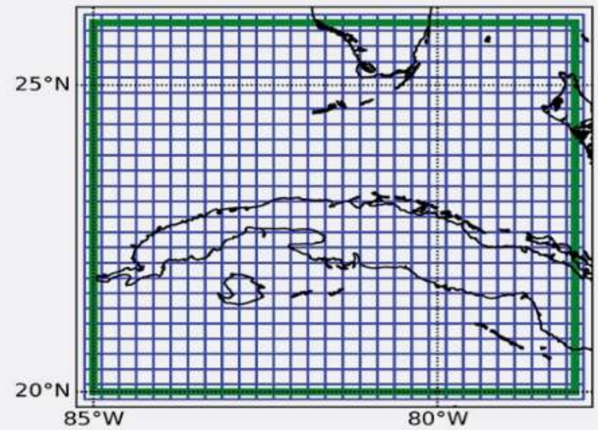
Table 2.2: Summary of RCM characteristics and experimental setups.

	PRECIS
RESOLUTION	0.22°x0.22° or ~ 25 km
KEY FEATURES	» Hydrostatic primitive equations grid point model. » 19 levels in the vertical. » Dynamical flow, the atmospheric sulphur cycle, clouds and precipitation, radiative processes, the land surface and the deep soil are all described in the model.
FORCING GCM	HadGM
AVAILABLE ENSEMBLE	6 members through the 2050s and 3 members for end of century projections using a perturbed physics approach. All ensemble members simulate SRES A1B.
VALIDATION FOR THE CARIBBEAN	Campbell et al. (2011) and Taylor et al. (2013)
REFERENCE	Hadley Centre (UK) http://www.metoffice.gov.uk/precis/intro

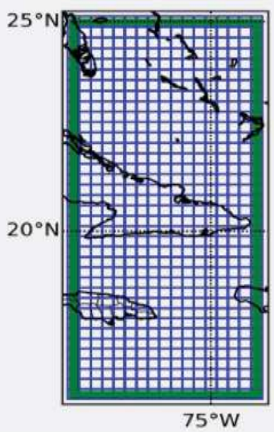
Although the PRECIS model runs are premised on the SRES A1B scenario, its results are reported because of the availability of an ensemble of up to six members from the Hadley Centre's Perturbed Physics Experiments (PPEs). PPEs are designed by varying uncertain parameters in the model's representation of important physical and dynamical processes. They capture major sources of modelling uncertainty by running each member using identical climate forcing and the methodology is an alternative to using different driving GCMs developed at different modelling centres around the world to create a multi-model ensemble. The range of climate futures projected by the Hadley Centre's PPE is considered equivalent to or greater than those based on the CMIP multi-model ensemble. As noted previously, the SRES A1B mirrors RCP 8.5 through the first three time slices and RCP6.0 by end of century. Therefore, the projections from the PRECIS model that are reported in this document represent future projections from an ensemble of simulations run using a high emissions scenario.



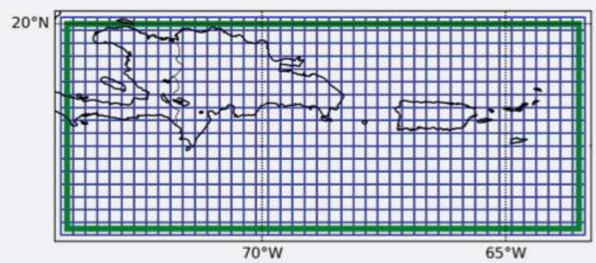
PRECIS 25-km grid box representation over zone 1



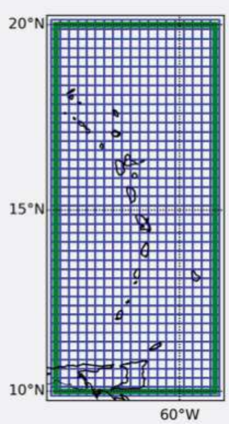
PRECIS 25-km grid box representation over zone 2



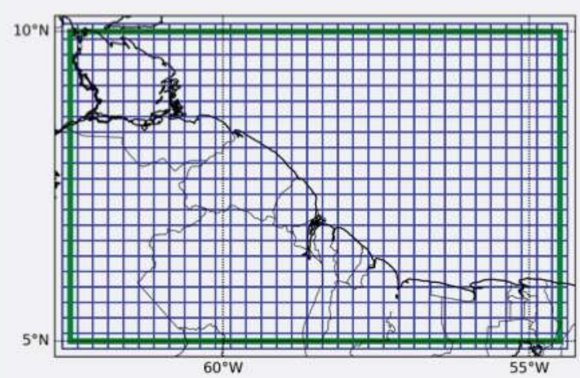
PRECIS 25-km grid box representation over zone 3



PRECIS 25-km grid box representation over zone 4



PRECIS 25-km grid box representation over zone 5



PRECIS 25-km grid box representation over zone 6

Figure 2.3: PRECIS 25-km grid box representation over six Caribbean rainfall zones.

Figures 2.3 shows how the rainfall zones in the Caribbean are represented by the PRECIS RCM. Future data for temperature (mean, maximum, and minimum) and rainfall for each grid box are extracted for the available ensemble of perturbations. The mean, minimum, and maximum change on seasonal and annual time scales for each variable and for each future time slice are then determined. However, though these data were extracted for all grid boxes for each CDB member state shown in Figure 2.3, the volume of data precluded the presentation of tables of projections for each grid box. Instead, only maps showing the mean projected changes across the perturbation ensemble are presented. Additionally, mean, minimum and maximum changes are presented in tables for the Caribbean divided into six blocks, roughly coinciding with the region's six rainfall zones (see Section 3.1).

2.3.3. SDSM

Statistical downscaling is a second means of obtaining downscaled information. It is premised on the view that the climate of a location is influenced by two types of factors: the large-scale climatic state and the regional/ local features (such as topography, land-sea distribution, and land use). The approach first determines a statistical model that relates large-scale climate variables (called predictors, such as relative humidity and wind velocity) to regional or local variables (called predictands, such as rainfall and temperature). The large-scale output of a GCM simulation is then fed into the model to estimate future local or regional characteristics, such as station rainfall and temperature. Statistical downscaling can provide site-specific information that is critical for many climate change impact studies. A guidance document on how climate scenarios may be developed from this approach is available at http://www.ipcc-data.org/guidelines/dgm_no2_v1_09_2004.pdf.

In this document, results obtained using the Statistical DownScaling Model (SDSM) developed at Loughborough University in the United Kingdom are reported. SDSM is a freely available software tool that facilitates rapid development of multiple low cost, single-site scenarios of daily weather and surface variables under present and future climate forcings (http://co-public.lboro.ac.uk/cocwd/SDSM/sdsmmain.html). The model is a combination of a weather generator approach and a transfer function model. A weather generator allows the generation of a number of synthetic present or future weather series given observed or model predictors. The transfer function approach establishes a mathematical relationship between local scale predictands and large-scale predictors. In SDSM, the transfer function is obtained using linear regression.

Predictors on daily time-steps and for a grid box closest to the study area are obtained from two datasets: (1) the NCEP Reanalysis for 1961-2005, and (2) the CanESM2, a coupled GCM developed by the Canadian Centre for Climate Modelling and Analysis (CCCMA) of Environment Canada for a historical period 1961-2005 and for a continuous 2006-2100 for RCP2.6, 4.5 and 8.5. Correlation analysis, partial correlation analysis, and scatter plots are used to identify a useful subset of predictors from the original suite of 26 predictors. A mathematical relationship is then created between the predictand and predictor subset in a process known as model calibration. These first steps are executed using the first half of the available data. All the analyses with observed data are constrained by the availability of data and their overlap with the span of the predictor dataset (1961-2005). For example, analyses using rainfall, maximum temperature and minimum temperature data measured at Jamaica's Norman Manley International Airport could only be conducted for 1993-2005, with the first half of the data used for model calibration. Annual models are created for temperature and seasonal models were created for rainfall. The stochastic component of SDSM is used to generate 20 simulations of weather series using the mathematical model established in the previous step, with observed predictors over the second half of the data used as inputs. These series are averaged and can be compared with the observation data set using a number of metrics to validate the model. Once the models are identified as reliable representations of historical climate, they are fed with data from the CanESM2 model to generate future weather series for analysis. The periods examined are 2016-2035 and 2036-2075.

2.3.4. PRESENTING THE DATA

In presenting the future projection data, absolute change is provided for most variables, for example temperature, while percentage change is presented for rainfall. For temperature and rainfall, the data are averaged over three-month seasons: November-January (NDJ), February-April (FMA), May-July (MJJ) and August-October (ASO), which are roughly consistent with the Caribbean dry season (December-April) and wet season (May- November) (Taylor et al. 2002). The mean annual change