The State of the Jamaican Climate 2015

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List of Abbreviations

Abbreviation	Meaning
AMO	Atlantic Multi-Decadal Oscillation
AR5	IPCC Fifth Assessment Report
ASO	August-September-October
CariSAM	The Caribbean Society for Agricultural Meteorology
CARIWIG	Caribbean Weather Impacts Generator
C-ARK	Coastal Community Enterprises: Adaptation, Resilience & Knowledge
CCCCC	Caribbean Community Climate Change Centre
CCCMA	Canadian Centre for Climate Modelling and Analysis
CCID	Caribbean Climate Impacts Database
CCORAL	Caribbean Climate Online Risk and Adaptation Tool
CDD	Consecutive Dry Days
CDEMA	Caribbean Disaster Emergency Management Agency
CDERA	Caribbean Disaster Emergency Response Agency
CDM	Comprehensive Disaster Management
CIDA	Canadian International Development Agency
CIF	Climate Investment Fund
Climpag	Climate Impacts on Agriculture
CMIP5	Coupled Models Intercomparison Project 5
C-ROADS World Climate	Climate Simulation Model
CRU	Climatic Research Unit
CSEC	Caribbean Secondary Education Certificate
CSGM	Climate Studies Group, Mona
CWD	Consecutive Wet Days
DFID	Department for International Development
DJFMA	December-January-February-March-April
DSSAT	Decision Support System for Agrotechnology Transfer
DTR	Daily Temperature Range
ENSO	El Niño-Southern Oscillation
EOC	End-of-Century
ESCI	Emerging and Sustainable Cities Initiative
ET0 Map	Drought and Evapotranspiration Map
FAO	Food and Agriculture Organization of the United Nations
FMA	February-March-April
GCM	General/Global Climate Model
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	Greenhouse Gas
GIA	Global Isostatic Adjustment
GIS	Geographic Information System
GMSL	Global Mean Sea Level
GOJ	Government of Jamaica
GSL	Growing Season Length
HEC-GeoHMS	The Geospatial Hydrologic Modeling Extension
HEC-HMS	The Hydrologic Modeling System
HIV	Human Immunodeficiency Virus
ICDIMP	Improving Climate Data and Information Management Project
ICTP	International Centre for Theoretical Physics
IDB	Inter-American Development Bank
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute
JCAL Tours Jamaica	Jamaica Co-operative Automobile and Limousine Tours Ltd.
JMD	Jamaican Dollar
JJA	June-July-August
KMA	Kingston Metropolitan Area
KNMI	Koninklijk Nederlands Meteorologisch Instituut (Dutch: Royal Netherlands Meteorological Institute)

KSA	Kingston and St. Andrew
KWH	Kilowatt-hour
LAI	Leaf Area Index
LIDAR	Light Detection and Ranging
LMI	Lifetime Maximum Intensity
mgd	Million Imperial Gallons
MGI	Mona GeoInformatics
MJ	May-June
MJJ	May-June-July
MOSAICC	Modelling System for Agricultural Impacts of Climate Change
MSD	Mid-summer Drought
MSL	Mean Sea Level
MWLECC	Ministry of Water, Land, Environment and Climate Change
NAH	North Atlantic High
NASA	National Aeronautics and Space Administration
NCAR	National Centre for Atmospheric Research
NCEP	National Centre for Environmental Prediction
NDJ	November-December-January
NDVI	Normalized Difference Vegetation Index
NEPA	National Environment and Planning Agency
NMIA	Norman Manley International Airport
NOAA	National Oceanic and Atmospheric Administration
NOAA NDBC	National Data Buoy Centre - NOAA
NRCA	Natural Resources Conservation Authority
NSWMA	National Solid Waste Management Authority
NWC	National Water Commission
ODPEM	Office of Disaster Preparedness and Emergency Management
OTEC	Ocean Thermal Energy conversions
PAR	Photosynthetically Active Radiation
PATH Programme	Programme for Advancement Through Health and Education
PCAC	Portmore Citizens Advisory Council
PIOJ	Planning Institute of Jamaica
PPCR	The Pilot Program for Climate Resilience
PPE	Perturbed Physics Experiment
PRCPTOT	Annual Total Precipitation
PRECIS	Providing Regional Climates for Impacts Studies
PRI	Photochemical Reflectance Index
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
ReCORD	Regional Climate Observations Database
RegCM4	Regional Climate Model developed at the ICTP
RH	Relative Humidity
SDII	Simple Daily Intensity Index
SDSM	Statistical Downscaling Model
SFCA	Special Fishery Conservation Area
SIA	Sangster International Airport
SIDS	Small Island Developing State
SimCLIM	ArcGIS-based Climate Simulation Model
SLR	Sea Level Rise
SMASH	Simple Model for Advection Storms and Hurricanes
SON	September-October-November
SPCR	Strategic Program for Climate Resilience
SRES	Special Report on Emission Scenarios
SRS	Spectral Reflectance Sensors
SST	Sea Surface temperatures
TNn	Coolest Minimum Temperatures
TOPEX	NASA's satellite
TR20	Nights warmer than 20°C
TXx	Warmest Maximum Temperatures
UDC	Urban Development Corporation
UNEP	United Nations Environment Programme
WAD	Wave Attenuation Device
WAMIS	World AgroMeteorological Information Service
WEAP	Water Evaluation and Planning System
WMU	Watershed Management Units

Executive Overview

There is growing recognition that climate data and information specific to Jamaica are required for planning purposes. The recognition is evident both in the number of requests for climate data being made of entities that are custodians or producers of such data, as well as in the growing amount of climate data, research and information focused on the Caribbean and Jamaica that is being generated. The Investment Project 1 – Improving Climate Data and Information Management Project (ICDIMP) – of Jamaica's Pilot Programme for Climate Resilience (PPCR), financed by the Climate Investments Fund (CIF) and administered by the World Bank, targets improving the quality and use of climate-related data and information for effective planning and action at local and national levels. The preparation of the 2015 *State of the Jamaican Climate* Report is consistent with Outcome 14 (Climate Change Adaptation and Hazard Risk Reduction) of the Vision 2030 Jamaica National Development Plan.

This report attempts to provide a concise overview of what is available and known about Jamaica's climate via a survey of available literature complemented by analysis. The report is intended as a first reference point with respect to climate information for Jamaica and is geared at, in particular but not exclusively, decision makers. It is not meant to replace the sources of literatures it references but rather to point to them especially when further detail is required. One of the documents heavily cited in this document is the document which it updates, namely the *State of the Jamaican Climate 2012* (SOJC 2012). In **Chapter 1** the additions which distinguish the *State of the Jamaican Climate 2015* from SOJC2012 are outlined, including an emphasis on the provision of sub-country level projections at higher resolutions than have previously been available; the use of the Intergovernmental Panel on Climate Change's (IPCC's) most recent climate scenarios; and the provision of climate vulnerability profiles for selected towns and cities. **Chapter 2** summarises the methodologies and data employed including the ensemble of model projections used to provide country level future projections (over 20 global climate models) and sub-country projections (2 regional climate models). The data now available is substantial and this is indicative of the advances made with respect to provision of data for use in decision making.

Within the context of decision making, there are three ***Take Away*** messages from this *State of the Climate 2015* report.

MESSAGE 1: TAKE A GOOD LOOK AROUND – THE PATTERNS OF CLIMATE ALREADY PROVIDE A BASIS FOR DECISION MAKING!

The mean annual variation for a number of climate variables is provided in **Chapter 3** as determined from the latest and most comprehensive observation datasets that could be obtained. Data are used to define dry and wet seasons, dry and cool periods, and months for peak hurricane activity, solar radiation, wave heights and wind strength. Mean spatial patterns (for example the west and east being wetter than the dry north and south coasts) are also presented. These mean patterns should be considered as the baseline information for consideration when climate is being taken into account in decision making and development planning. These mean patterns of climate represent a guide for, among other things, resource allocation and spending, contingency and event planning, and are a first guess of the climate bounds for those sectors where climate magnitudes and frequencies are/should be significant considerations.

MESSAGE 2: TAKE A GOOD LOOK AGAIN – THE PRESENT CLIMATE MUST BE BORNE IN MIND IN DECISION MAKING!

An analysis of the available historical climate data suggests that Jamaican climate is changing – as evidenced by long term trends and variations on timescales ranging from seasonal through decadal and

even longer. These variations are driven by global climatic phenomenon and by climate change. For example, rainfall amounts in the dry or wet seasons are strongly conditioned by the occurrence of an El Niño event, while mean temperatures have been rising at a rate of 0.16 °C/ decade. The ways in which Jamaican climate is known to vary and the ways in which climate change is already manifesting itself are captured in **Chapter 4** and summarized in the table at the end of this Executive Summary. Since some of the variations are predictable months in advance (for example, those due to El Niño) while others are pushing expected variability to the boundaries of what we are used to (for example, the changes in temperature extremes due to climate change) there is a need to account for them in decision making. How some of the observed changes in climate have been or will impact critical sectors and areas of life in Jamaica are detailed in tables in **Chapter 6**.

MESSAGE 3: TAKE A GOOD LOOK AHEAD – THE PROJECTIONS OF FUTURE CLIMATE MAKE THE INCLUSION OF CLIMATE INFORMATION A NECESSITY FOR DECISION MAKING!

Global and regional climate models run using future scenarios of greenhouse gas emissions provide some consensus about how Jamaica's climate is likely to change in the near future and for time slices through to the end of the century. The projections are provided in **Chapter 5** and also summarized in the table at the end of this Executive Summary. What is striking about the projections are the magnitude, rate and frequency of the changes projected in Jamaican climate under the scenarios that best represent the global trajectory in terms of greenhouse gas emissions. Again, bearing in mind the likely impacts outlined in **Chapter 6** and that these may be magnified many times over under the unprecedented changes projected, there is clear need for inclusion of climate information such as that provided in this report in the processes of decision making. Some tools to facilitate decision making given the climate information provided are captured in **Chapter 8.** Examples of how present and future climate vulnerabilities can be defined and accounted for in Jamaican communities of varying scales are provided in **Chapter 7.**

All the documents reviewed in the process of producing this State of the Jamaican Climate 2015 are listed in **Chapter 9**.

The process of producing this document has also highlighted some gaps still existent in the science of Jamaican climate. These include (i) inadequate climate observation station coverage over the island in general and glaring gaps in (among other places) St. Ann and Portland; (ii) the need for more ensembles of regional models run using the RCP scenarios to provide sub-island data; (iii) the need for more targeted research on climate impacts on some understudied sectors including education, the private sector and biodiversity; and (iv) processes for translating the science into real plans and then into actions.

Climate Trends and Projections for Jamaica at a Glance

Historical Trend[1]	Projection[2]
TEMPERATURES	
» Maximum and mean, minimum temperatures show upward (linear) trend. » Minimum temperatures are increasing faster (~0.27 °C/decade) than maximum temperatures (~0.06 °C/decade). Mean temperatures increasing at a rate of 0.16 °C/decade. » Increases in temperature are consistent with global rates. » Daily temperature range has decreased.	» Min, max and mean temperatures increase irrespective of scenario through the end of the century. » The mean temperature increase (in °C) from the GCMs will be 0.49°–0.57°C by the 2020s; 0.65-0.84 °C by the 2030s, 0.85°-1.80°C by the 2050s and 0.82-3.09 °C for 2081-2100 with respect to a 1986-2005 baseline over all four RCPs. » RCMs suggest higher magnitude increases for the downscaled grid boxes – up to 4 °C by end of century. » Temperature increases across all seasons of the year. » Coastal regions show slightly smaller increases than interior regions. » Mean daily maximum temperature each month at the Norman Manley International Airport station is expected to increase by 0.8-1.3°C (1-2-2.0°C) across all RCPs by early (mid) century. » The annual frequency of warm days in any given month at the Norman Manley International Airport station may increase by 2-12 (4-19) days across all RCPs by early (mid) century.
RAINFALL	
» Significant year-to-year variability due to the influence of phenomenon like the El Niño Southern Oscillation (ENSO). » Insignificant upward trend » Strong decadal signal. With wet anomalies in the 1960s, early 1980s, late 1990s and mid to late 2000s. Dry anomalies in the late 1970s, mid and late 1980s and post 2010. » Four rainfall zones. » Interior, West and Coasts co-vary on decadal time scale. The East is least well correlated with other rainfall zones. » Intensity and occurrence of extreme rainfall events increasing between 1940-2010.	» GCMs suggest that mid 2020s will see 0 to 2 % less rainfall in the annual mean. The 2030s will be up to 4% drier, the 2050s up to 10% drier, while by the end of the century the country as a whole may be up to 21% drier for the most severe RCP scenario (RCP8.5). » The GCMs suggest that change in summer rainfall is the primary driver of the drying trend. » Dry season rainfall generally shows small increases or no change » RCM projections reflect the onset of a drying trend from the mid-2030s which continues through to the end of the century. » There is some spatial variation (across the country and even within Blocks) with the south and east showing greater decreases than the north and west. » The decreases are higher for the grid boxes in the RCM than for the GCM projections for the entire country.
SEA LEVELS	
» A regional rate of increase of 0.18 ± 0.01 mm/year between 1950 and 2010. » Higher rate of increase in later years: up to 3.2 mm/year between 1993 and 2010. » Caribbean Sea level changes are near the global mean. » SLR at Port Royal, Jamaica ~ 1.66 mm/year.	» For the Caribbean, the combined range for projected SLR spans 0.26-0.82 m by 2100 relative to 1986-2005 levels. The range is 0.17-0.38 for 2046 – 2065. Other recent studies suggest an upper limit for the Caribbean of up to 1.5 m under RCP8.5 » For Jamaica, mean projected SLR over all RCPs for the north coast is 0.58 - 0.87 m by the end of the century. Maximum rise is 1.04 m. SLR rates are similar for the south coast.
HURRICANES	
» Dramatic increase in frequency and duration of Atlantic hurricanes since 1995. » Increase in category 4 and 5 hurricanes; rainfall intensity, associated peak wind intensities, mean rainfall for same period. » South more susceptible to hurricane influence.	» No change or slight decrease in frequency of hurricanes. » Shift toward stronger storms by the end of the century as measured by maximum wind speed increases of +2 to +11%. » +20% to +30% increase in rainfall rates for the model hurricane's inner core. Smaller increase (~10%) at radii of 200 km or larger. » An 80% increase in the frequency of Saffir-Simpson category 4 and 5 Atlantic hurricanes over the next 80 years using the A1B scenario.

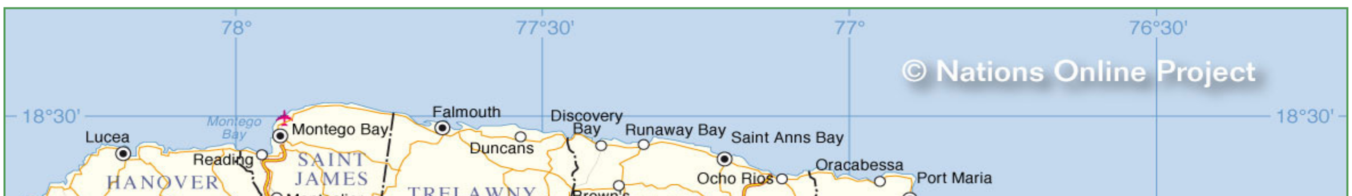
1 Historical trends are based on observations made over 1961-2010.
2 GCM-generated projections are relative to a 1986-2005 baseline, RCM-generated projections are relative to a 1961-1990 baseline.

1. Rationale & Background

1.1. Jamaica

Jamaica is the third largest island in the Caribbean Sea with a total landmass of 10,991 square kilometres. The island is centred on latitude 18°15' N and longitude 77°20' W. It is approximately 145 kilometres south of the island of Cuba. Jamaica is elongated along west-northwest to east-northeast alignment, roughly 230 kilometres long and 80 kilometres wide at its broadest point. The island's exclusive economic zone is approximately 25 times the size of its landmass. Jamaica has several rugged mountain ranges, with the highest point, the Blue Mountain Peak, soaring over 2,256 metres (7,402 feet). About sixty percent of the island's bedrock is white limestone; twenty five percent is volcanic and cretaceous, ten percent alluvial and five percent yellow limestone. More than 120 rivers flow from the mountains to the coast. There are fourteen parishes in Jamaica, with Kingston being the capital of the country. The coastline is approximately 1,022 kilometres. The climate of Jamaica is mainly tropical with the most important climatic influences being the Northeast Trade Winds and the island's orographic features (mainly the central ridge of mountains and hills). **– Jamaica's Initial National Communication to the United Nations Framework Convention on Climate Change (GOJ 2001).**

Figure 1. Map of Jamaica. Inset shows Jamaica's location within the Caribbean.



1.2. Pilot Programme for Climate Resilience

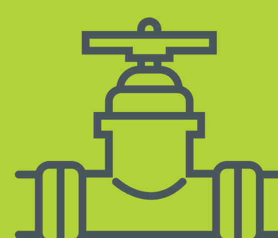
The purpose of the Pilot Programme for Climate Resilience (PPCR) is to help developing countries to integrate climate resilience into development planning and offer additional funding to support public and private sector investments for implementation. Donor countries including Australia, Canada, Denmark, Germany, Japan, Spain, and the United Kingdom have pledged USD 1.3 billion in funding for pilot programmes currently being implemented in 18 developing and under-developed countries including Jamaica that demonstrate a high vulnerability to climate change. Jamaica features in both the Regional and National Tracks of the PPCR.

Jamaica's PPCR was administered in two phases. The first phase of the project resulted in the development of a *Strategic Plan for Climate Resilience* (SPCR) in 2011. The SPCR has been developed to help Jamaica with climate adaptation. It is also aligned to Vision 2030 Jamaica National Development plan and addresses and builds on gaps that have been identified during the first phase, also making the implementation process easier. Several investment projects were formed from the 2011 SPCR:

INVESTMENT PROJECT 1: Improving Climate Data and Information Management Project (ICDIMP)

INVESTMENT PROJECTS 2 & 3: Adaptation Programme and Financing Mechanism (APFM), implemented by the Climate Change Division (CCD), Ministry of Economic Growth and Job Creation

INVESTMENT PROJECT 4: Building Resilience in the Fisheries Sector (approval and implementation expected in 2018)



PRIVATE SECTOR WATER PROJECT: Financing Water Adaptation in Jamaica's New Urban Housing Sector

The Investment Project 1 – Improving Climate Data and Information Management Project (ICDIMP) – of Jamaica's PPCR, financed by the Climate Investments Fund (CIF) and administered through the World Bank, is aimed at improving the quality and use of climate-related data and information for effective planning and action at local and national levels. In keeping with Outcome 14 (Climate Change Adaptation and Hazard Risk Reduction) of Vision 2030 Jamaica National Development Plan and with the Growth Inducement Strategy, this project will allow climate change considerations to be integrated into Jamaica's future national planning for climate resilience, thus enhancing the thrust towards long-term transformational change in the country. Jamaica also features in the Regional PPCR for the Caribbean, in which the University of the West Indies acquired a high-performance computing system that allowed for some of the climate scenarios presented in this document.

The objectives of the State of the Jamaican Climate 2015 Report are to provide current climate information that may be used to inform resilience building efforts at the country and sub-country level and allow for improved sector-based assessments for climate resilient planning and decision-making. To this effect, this document provides:

a. A comprehensive review of Jamaica's climatology.
b. An analysis of the dominant drivers of the mean climate and climate variability patterns.
c. An examination of variability on seasonal, interannual and decadal scales as well as the long-term climate change signal.
d. Future climate scenarios generated from global climate models and high-resolution regional climate models.
e. A focused summarising of known sector-specific climate change impacts.
f. Climate profiles for selected geographical regions.
g. Suggested climate tools and resources that may help in understanding the effects of climate change and assist decision makers and policy makers in viewing projects through the lens of climate change.

1.3. About this Document

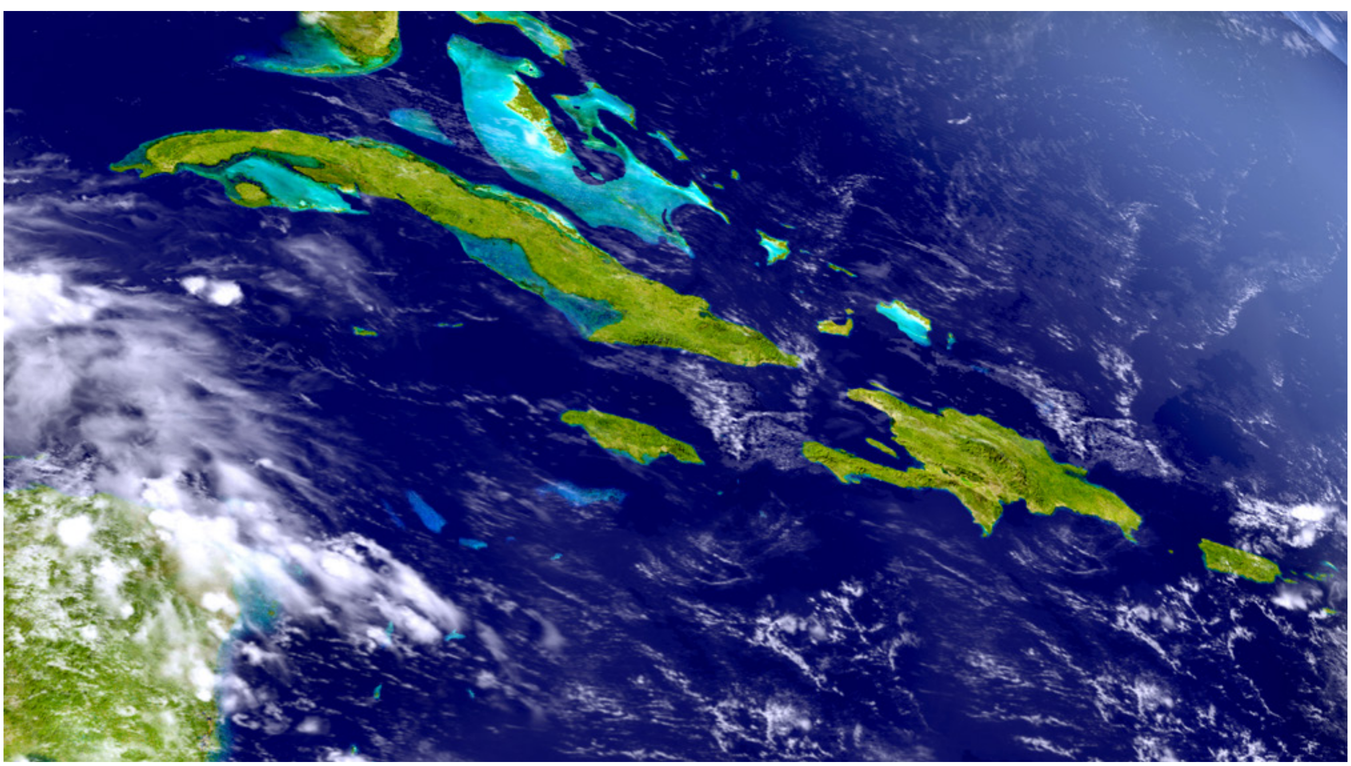
In accordance with Component 2 of the ICDIMP, this report outlines in detail updates to observed variability and future climate scenarios for Jamaica since 2012. This report is a companion to both the State of the Jamaican Climate 2012 (CSGM, 2012) and the Third National Communication on Climate Change (GOJ, 2016), both of which have been published within the last five years. That is, this report does not replace the information in the latter two reports but rather builds on it through the incorporation of significant new knowledge generated since the publication of both referenced reports and the inclusion of new sections.

Five important new additions to this report include: (i) the provision of sub-country level projections at higher resolutions and the use of the Intergovernmental Panel on Climate Change's (IPCC's) most recent climate scenarios (see Section 2.3.1) (ii) the incorporation of updated information on the climatology, trends and projections of tropical storms, hurricanes and sea levels using new datasets, analyses and climate tools; (iii) the provision of climate vulnerability profiles for seven selected towns and cities; (iv) an expanded section summarizing likely sector impacts drawn from literature reviews; and (v) a provision of a list of climate tools and resources which may be useful for decision making and/or for understanding the influence of climate change. In addition to the above, every attempt has been made to update any maps and tables previously offered in the State of the Jamaican Climate 2012 (CSGM 2012) which are provided again in this document with additional data collected in the intervening years or with data from new research published since then.

Table 1 outlines the structure of the State of the Jamaican Climate 2015 technical report.

Table 1: An outline and description of each chapter.

	TITLE	SUMMARY
Chapter 1	Rationale & Background	Provides the rationale and describes the structure of the document.
Chapter 2	Data & Resources	A description of data sources, methodologies, and resources used in generating trend profiles for analysis.
Chapter 3	Climatology	An analysis of climate norms for a variety of climate variables as compiled from a variety of data sources.
Chapter 4	Observed Variability, Trends & Extremes	Description of variability and trends in climate variables based on station and grid data for Jamaica.
Chapter 5	Climate Projections	Local and regional projections generated from global climate models (GCMs) and regional climate models (RCMs).
Chapter 6	Sector Impacts	A comprehensive list of climate change impacts on key sectors
Chapter 7	Climate Profiles	A climate vulnerability profile of key geographical areas.
Chapter 8	Climate Tools & Resources	A comprehensive list of useful climate tools and resources for select sectors, and a description of recent ReCORD updates.
Chapter 9	References	References used in the compilation of the document.



2. Data and Methodologies

2.1. Approach

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

LITERATURE REVIEW. A literature review was conducted of authoritative works and recent studies on climate change and climate variability for Jamaica and the Caribbean region. The authoritative works whose results are utilized in this document include the State of the Jamaican Climate 2012 (CSGM, 2012), the Near-Term Climate Scenarios for Jamaica (CSGM, 2014), the Second and Third National Communications and Biennial Update Report submissions under the United Nations Framework Convention on Climate Change (GOJ, 2016), the Jamaica: Future Climate Changes (CSGM, 2016) report produced during the development of Jamaica's Third National Communications, the IPCC's Fifth Assessment Report (IPCC, 2013) and other reports and studies produced by the Intergovernmental Panel on Climate Change (IPCC), Caribbean Community Climate Change Centre (CCCCC), and Climate Studies Group Mona (CSGM).

HISTORICAL DATA ANALYSIS. Available historical observed data were used to both characterise the climatology of relevant variables describing the climate of Jamaica as at 2015 and examine variability and trends on the same climate variables as well as sea level rise, tropical storms and hurricanes and climate extremes. The literature review was also used to complement the descriptions of the climatology and the historical climate variability. Data from a variety of sources are used including from the Meteorological Service of Jamaica. The data employed are listed in the following subsection (section 2.2). The analysis was organised by variable analysed using tables, graphs, and diagrams for Jamaica as a whole, for specific stations and climatic zones accounting for Eastern, Western, Central and Coastal regions of Jamaica. The latter regions approximate the rainfall zones of Jamaica (see section 3.3).

PROJECTIONS OF FUTURE CLIMATE. Climate projections for Jamaica are obtained from the outputs of a suite of global climate models (GCMs), from two regional climate models (RCMs), and from the use of statistical downscaling techniques. Future trends in climate and variability are produced for Jamaica over four future time slices: 2020's (2020-2029), 2030's (2030-2039), 2050's (2050-2059), and end of the century (2080-2099). For the GCM data, it is country scale projections that are generated using the representative concentration pathway scenarios or RCPs (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) consistent with the IPCC's Fifth Assessment Report. RCPs are explained in section 2.3.1. Comparisons to past trends are made where appropriate. For the RCM analyses, data are extracted from 2 RCMs – one with a 25 km grid resolution covering Jamaica and using a perturbed physics ensemble (see section 2.3), and second with a 20-km grid resolution running RCP4.5. The same future time slices are reported on. Whereas the coarser resolution RCM data are used to capture mean climate changes for Jamaica divided into four rainfall zones and to illustrate sub-island variations on plotted maps, the 20-km data are only used to extract projection data for seven selected geographic regions. Projections of extreme indices are also derived from rainfall and temperature data for at least two stations with long-term time series, using statistical downscaling techniques and GCM data.

In producing the future projections, the data were analysed to provide as best as possible a picture of the state of the climate for Jamaica at the country and sub-country (~20-25 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.

IMPACT TABLES, VULNERABILITY PROFILES & MAPS. The likely impacts of climate variability and change on key sectors were summarized from an extensive literature review and presented in tabular form. Sectors addressed under the PPCR initiative were targeted (water, agriculture, tourism, health, human settlements, and coastal resources) but the tables of impacts were not limited to these sectors. The impacts tables were also a feature of the previous State of the Jamaican Climate report but they have been expanded on and updated with new research in this version. In addition to the impacts tables, this study also presents climate vulnerability profiles for seven selected geographic areas, as drawn from previously conducted studies. The geographic regions are Portmore (an area of interest for infrastructural development and disaster mitigation), Negril, Montego Bay and Ocho Rios (areas of interest for tourism), and Black River, Rio Minho and Bluefields.

2.2. Data Sources

As noted above, multiple sources are used in compiling the narrative of this report. Table 2 below shows the primary climate data sources which are relied upon to produce the climatologies and analyses of past and future climatic trends. The respective usage made of each source is also shown.

Table 2: Data sources used in the compilation of historical climatologies and future projections.

Historical Data				
Temperature	Climatology + Historical Trends	Station data	Monthly data for stations across the island with less than 20% missing data and reporting between 1971-2015.	Meteorological Service of Jamaica
	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
Rainfall	Climatology + Historical Trends	Station data	Monthly data for stations across the island with less than 20% missing data and reporting between 1971-2015.	Meteorological Service of Jamaica
	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
Sea Levels	Trends	Gauge data	As reported in literature	Various sources
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 "Atlas". Only a single realization from each of over 20 models is used. All models are weighed equally, where model realizations differing only in model parametre 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	CMIP5 model data accessed through SIMCLIM2013	SIMCLIM2013 software: http://www.climsystems.com/simclim/
Hurricanes			As reported in literature.	Various sources.

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

2.3. Obtaining Future Projections from Models

2.3.1. EMISSION SCENARIOS

It is largely 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 range of Representative Concentration Pathways (RCPs), namely RCP2.6. RCP4.5, RCP6.0 and RCP8.5. See Information Box 1. However, one RCM was run multiple times using the A1B Special Report Emission Scenario (SRES) (Nakicenovic et al. 2000), while the other RCM was run once using one RCP. As is explained later, more sub-island scale data is currently available for a future Jamaica 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, in terms of carbon dioxide concentrations and global temperature change the SRES A1B is comparable to RCP6.0 by century's end and RCP8.5 through midcentury. 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). By 2100, carbon dioxide concentrations for both scenarios are very similar (over 600 ppm) as is the mean global temperature anomaly (just under 3 ^{o}C). In this document, then, 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 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 therefore RCP2.6. RCP4.5, RCP6.0 and RCP8.5 (Figure 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 SRES. Of the 4 RCPs, many do not believe RCP2.6 or 4.5 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).

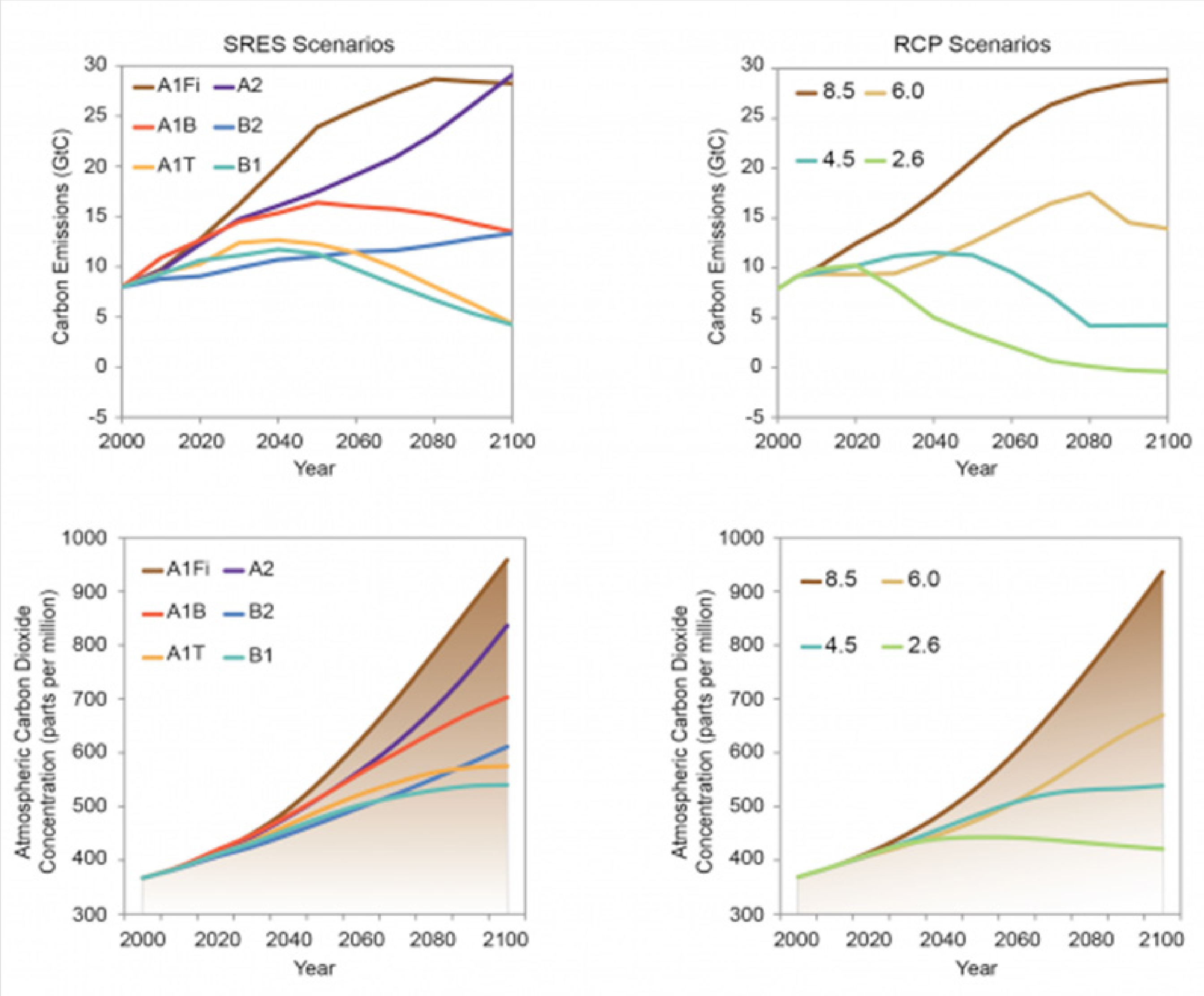


Figure 2: Two families of scenarios commonly used for future climate projections: the Special Report on Emission Scenarios (SRES, left) and the Representative Concentration Pathways (RCP, right). The SRES scenarios are named by family (A1, A2, B1, and B2), where each family is designed around a set of 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.

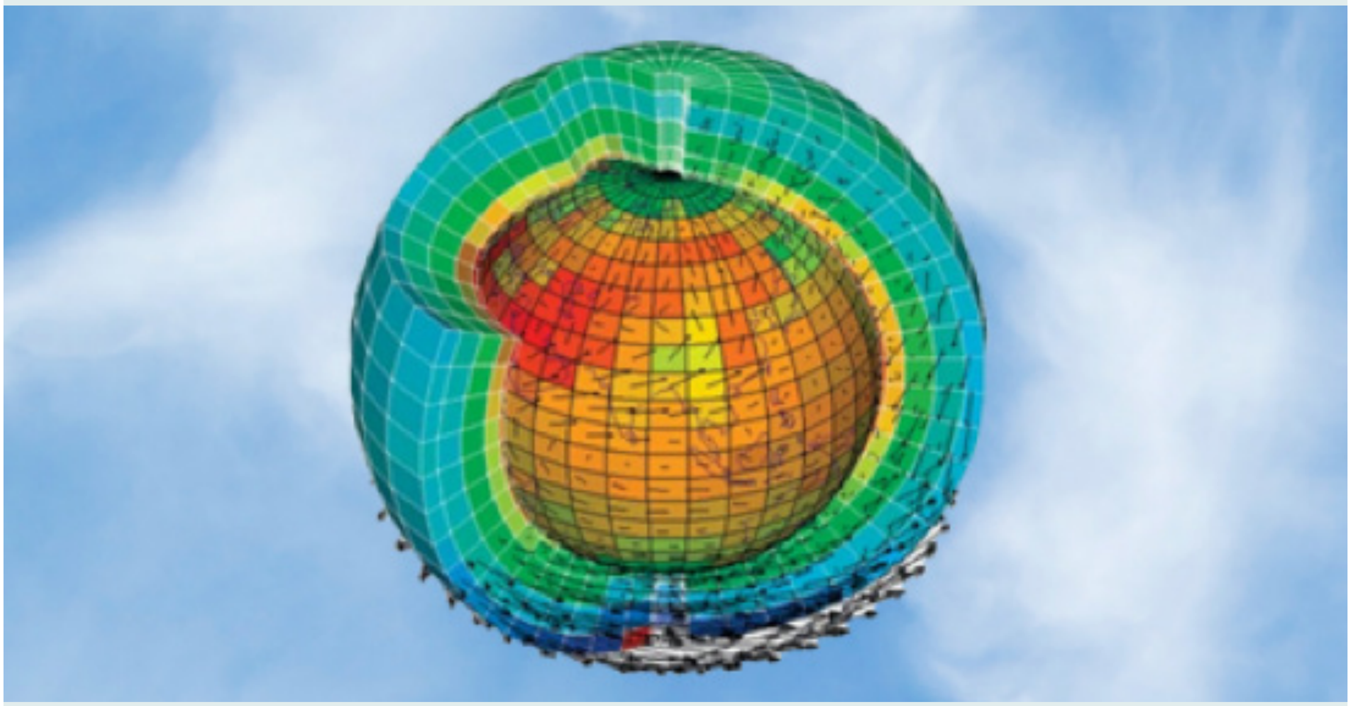
2.3.2. GCMS AND RCMS

Data from both Global Circulation Models (GCMs) and Regional Climate Models (RCMs) are used in this study. See Information Box 2.

Information Box 2

What's the Difference between GCMs and RCMs?

Global Climate Models (GCMs) 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 Jamaica versus the grid spacing of the GCMs on which data are reported means that Jamaica is 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 Jamaica'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 Jamaica 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 in excess of 20 GCMs were analyzed and projected annual change extracted for the GCM grid boxes over Jamaica. It is a single country average which is generated from the GCM data. This provides a context within which to interpret other sub-country scale projections derived from the RCM. Projections through the end of the century are generated, and values are averaged over the 2020s, 2030s, 2050s and the end-of-century. Extraction was done for the four RCPs. The projections are presented in Figures and summary Tables.

Available dynamically downscaled data for Jamaica were obtained from two RCMs – the PRECIS (Providing Regional Climates for Impact Studies) model (Jones et al. 2004) run at a resolution of 25 km and the RegCM4.3.5 model (Giorgi et al. 2014) run at a resolution of 20 km. Table 3 summarizes key characteristics of each RCM and the experiments performed.

Table 3: Summary of RCM characteristics and experimental setups.

	PRECIS	**RegCM**
Resolution	0.22°x0.22° or ~ 25 km	20 km
Grid boxes over Jamaica	26	51
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.	» A hydrostatic, compressible, sigma-p vertical coordinate model run on a Arakawa B-grid » Grell convection scheme
Forcing GCM	HadGM	CNRM
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.	1 simulation using RCP 4.5
Validation for the Caribbean	Campbell et al. (2011) and Taylor et al. (2013)	Martinez-Castro et al. (2016)
Reference	Hadley Centre (UK) http://www.metoffice.gov.uk/precis/intro	International Centre for Theoretical Physics https://www.ictp.it/research/esp/models/regcm4.aspx

Although, the PRECIS model runs are premised on the SRESA1B scenario, its results are reported on because of the availability of an ensemble of up to 6 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. The PPE captures some major sources of modelling uncertainty by running each member using identical climate forcings. 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. Since as noted previously, the SRES A1B mirror RCP 8.5 through the first three time slices and RCP6.0 by end of century, the projections from the PRECIS model reported on in this document represent future projections from an ensemble of simulations run using a high emissions scenario.

Figure 3 shows how Jamaica is 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 this data was extracted for all 26 grid boxes shown in Figure 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 Jamaica divided into four blocks roughly coinciding with the island's four rainfall zones (see section 3.3). The grid boxes comprising each block (rainfall zone) are given in Table 4. If the reader is interested in projections for a particular grid box, the reader is referred to the appendices of the report entitled Jamaica: Future Climate Projections (CSGM 2016) prepared during the development of Jamaica's Third National Communications as well as to the **ReCORD** tool discussed in Chapter 8 of this State of the Jamaican Climate 2015 report.

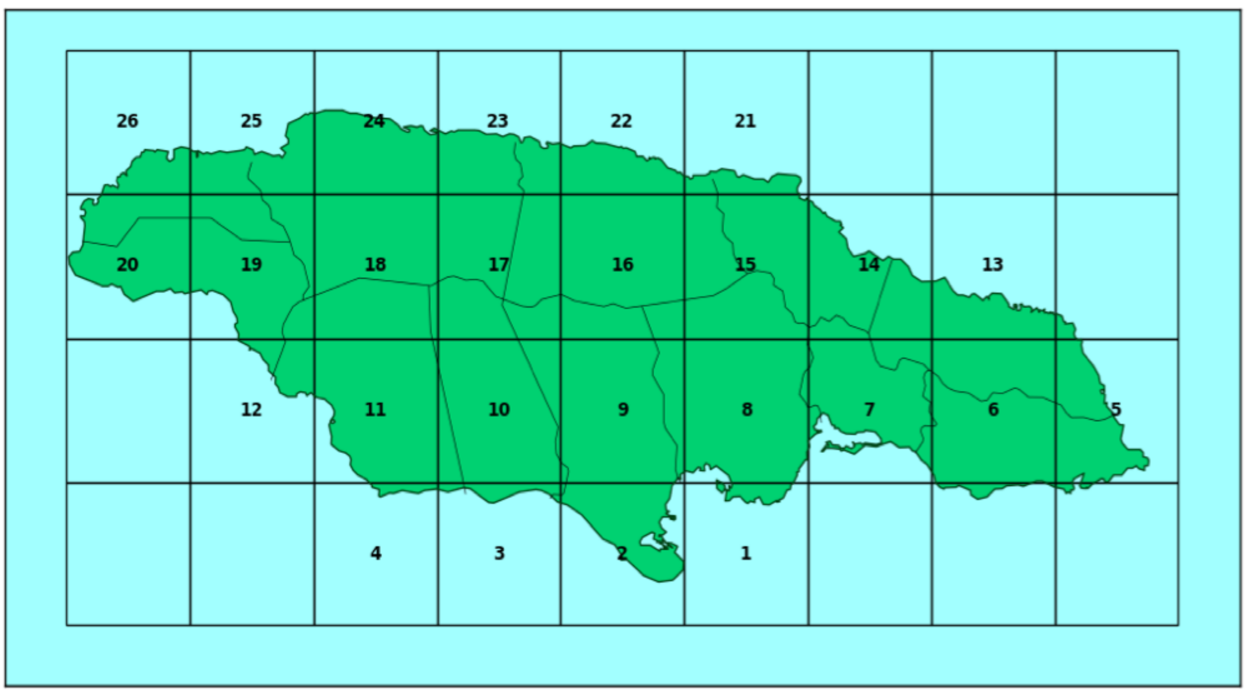


Figure 3: PRECIS 25-km grid box representation over the island of Jamaica.

Table 4: Reporting blocks and grid box coordinates categorized by region. See figure 3 for grid boxes.

Block	Grid Box No.	Block	Grid Box No.
West	11, 19, 20, 26, 25	Coasts	1, 2, 3, 4, 12, 21, 22, 23, 24
East	5, 13, 14	Interior	6, 7, 8, 9, 10, 15, 16, 17, 18

Figure 4 shows how Jamaica is represented by the RegCM model with its finer resolution. Again the volume of data precludes presentation of tables of projections for all grid boxes from this model. Additionally, however, because only one model run is available at this finer resolution (as opposed to the range of futures offered by an ensemble) and for a lower emissions scenario (RCP 4.5), the user is encouraged to bear these limitations in mind when interpreting and using the results from this model. There is an ongoing effort to expand the ensemble of runs at this resolution to include additional forcing GCMs and other RCPs. Given these considerations only data extracted for grid boxes covering six geographical regions, are presented four of which are also profiled later in this document with respect to their climate vulnerability. Table 5 maps the grid boxes to the geographic locations. Again, the reader is encouraged to bear in mind that the future data from the RegCM model that are presented represent change under a more moderate emissions scenario than for the PRECIS RCM results.

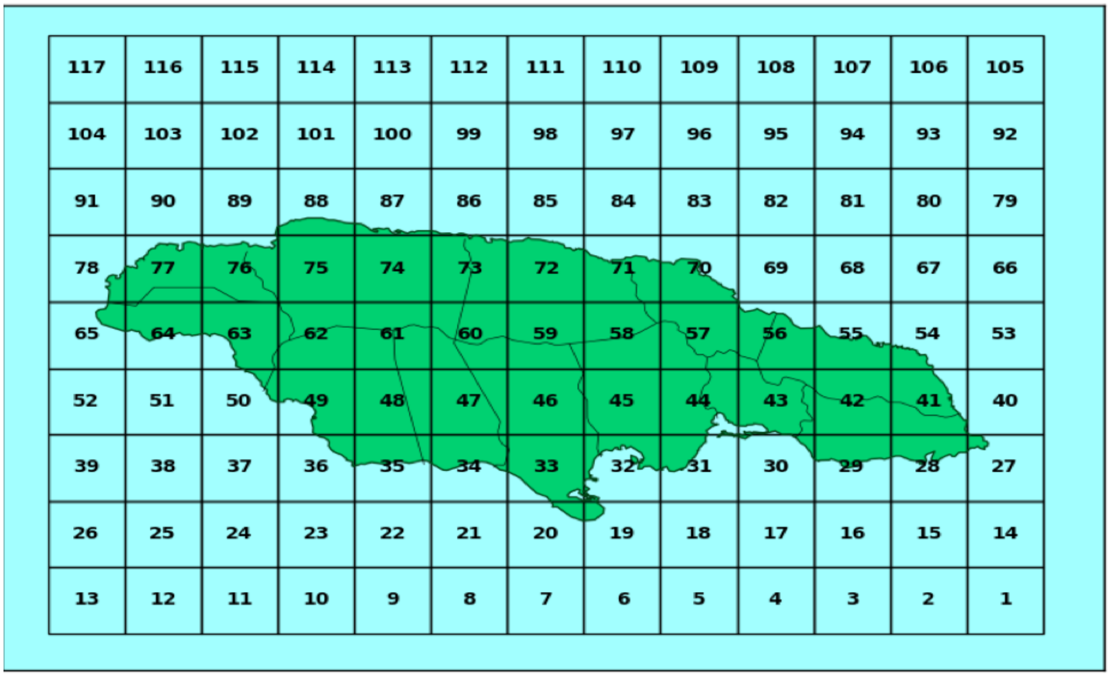


Figure 4: RegCM4.3.5 20-km grid box representation over the island of Jamaica.

Table 5: Reporting blocks and grid box coordinates categorized by region. See figure 4 for grid boxes.

Grid box numbers	Cities/ Municipalities	Parish
28	Morant Bay (East)	St. Mary
43	Kingston (Southeast)	Kingston and St. Andrew
44	Portmore (Southeast)	St. Catherine
65	Negril (West)	Westmoreland
71	Ocho Rios (North)	St. Ann
88	Montego Bay (Northwest)	St. James

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 which relates large-scale climate variables (called predictors, like relative humidity and wind velocity) to regional or local variables (called predictands, like rainfall and temperature). The large-scale output of a GCM simulation is then fed into the model to estimate local or regional characteristics like 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 tool SDSM developed at Loughborough University in the United Kingdom are reported on. 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.

Statistical downscaling can provide site specific information that is critical for many climate change impact studies.

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, the analyses with Norman Manley's rainfall, maximum temperature and minimum temperature 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 are 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. SIMCLIM

SimCLIM 2013 is a versatile software package used to supply climate data and information to facilitate informed impact risk analysis and adaptation assessments by the end user. The software allows the users to generate spatial representations of future climate variability in climate scenarios at the global, regional and local scales. Datasets are generated from the IPCC's CMIP5 suite of GCMs. However, the user also has the option of inputting their own datasets which they can then manipulate.

This report makes use of SimCLIM to project sea level rise (SLR) for Jamaica for time slices in the future. To enable robust coastal vulnerability and adaptation assessment, sea-level change scenarios should integrate factors at global, regional and local levels in an internally consistent fashion. SimCLIM accomplishes this task in its sea-level scenario generator which is contained within its larger integrated modelling system. Projections are given for three distinct levels of climate sensitivity: low sensitivity, medium sensitivity and high sensitivity. Climate sensitivity is defined as a measure of the strengths of feedback mechanisms of the climate system at a particular time to changes in atmospheric CO_2 concentrations therefore low sensitivity indicates a small effect to the surrounding climate with radiative forcing, while high sensitivity projections indicate trends with a much more affected climate system. GCMs have different sensitivities (therefore, different representations of the climate system and its feedbacks) and hence different GCMs produce different results for the same GHG emission scenarios. The model projections in SimCLIM are partitioned according to climate sensitivity. More information may be accessed at www.climsystems.com/**simclim.**

For the purposes of this document, SimCLIM 2013 is used to generate sea level rise (SLR) projections for two points located off the northern and southern coast of Jamaica. The SLR projections are generated for time slices noted previously using the mean value from the full ensemble of CMIP5 GCMs for low, medium and high sensitivities, and for RCP2.6, RCP4.5, RCP6.0 and RCP8.5. The future trend diagrams presented are, however, presented only for medium sensitivity.

2.3.5. PRESENTING THE DATA

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

3. Climatology

3.1. Introduction

In this chapter, the climatology - the average monthly values over the course of a year or the annual cycle - of several climate variables are presented. In most cases, island averages are given or the averages for select stations where data of sufficient length and quality are available. The climatology establishes the baseline to which future change (for example, as deduced from GCMs and RCMs) is added to produce a future climate scenario. Climatology is also indicative of the 'mean' against which year to year or longer-term variations are examined.

3.2. Temperature

Surface temperature in Jamaica is controlled largely by the variation in solar insolation, the earth's orbit of the sun (with its axis tilted at a nearly fixed angle of 23.5º to the plane of its orbit) gives rise to variations in temperatures. The temperature climatologies calculated for nine stations are shown in Figure 5. Tables 6-8 gives the average mean, maximum and minimum temperatures by month for each station and a Jamaica mean for each temperature variable found from averaging the values for the nine stations. There is in general less available temperature data than rainfall for the country.

The temperature climatology across Jamaica is unimodal with peak temperatures occurring during the summer months from June to September and coolest temperatures occurring from December through March. The annual range of mean monthly temperatures is small (~ 3 ^{o}C). For Jamaica mean values range between approximately 24 ^{o}C and 27 ^{o}C, although figure 5 shows that mean maximum (day time) temperatures can reach as high as 33^{o}C during the warmest months for some locations, while mean minimum (night time) temperatures can be as low as 19^{o}C during coolest months.

Jamaica's topography and size allows for some latitudinal variation in mean monthly temperatures as indicated by the differences between the climatological plots for the nine stations. Of the stations analyzed, Norman Manley International Airport (south coast) was in the mean found to be the warmest while Mason River (interior regions) was found to be the coolest (Table 4). There is also the strong suggestion that the interior of the island is markedly cooler (by up to 0.6^{o}C) than the coast perhaps due to the associated rise in elevation. Occasional surges of cooler air from continental North America from October through early April during the passage of cold fronts contribute to minimum temperatures that can fall below 20 degrees, particularly for northern portions of the island.

Occasional surges of cooler air from continental North America from October through early April during the passage of cold fronts contribute to minimum temperatures that can fall below 20 degrees, particularly for northern portions of the island.

Table 6: Table showing mean temperature climatologies for nine meteorological sites across Jamaica. Data averaged over varying periods for each station. Units (°C).
Data source: Meteorological Service of Jamaica.

Station	Years Averaged	Altitude (metres)	Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			Lat (°N)	Long (°W)												
Bodles	1987-2015	36.0	17.93	77.14	24.8	24.9	25.3	26.2	26.9	27.7	27.8	28.0	27.8	27.4	26.2	25.8
Discovery Bay Marine Laboratory	1992-2009	10.0	18.47	77.42	24.8	24.8	25.0	26.0	26.6	27.4	27.6	26.8	27.8	27.3	26.4	24.5
Duckenfield	2000-2015	17.0	17.92	76.26	24.8	24.9	25.1	25.8	26.6	27.5	27.7	27.7	27.3	26.8	26.2	25.5
Frome	1996-2016	20.0	18.29	78.15	25.1	24.9	25.5	26.3	27.0	27.7	27.8	28.0	27.9	27.5	26.9	25.8
Norman Manley	1992-2015	2.7	17.93	76.78	27.0	26.9	27.1	27.8	28.5	29.3	29.5	29.5	29.3	28.7	28.2	27.4
Mason River	1978-2015	703.0	18.20	77.26	21.0	20.7	21.3	21.8	22.3	23.1	23.3	23.5	23.0	23.1	22.3	21.7
Passley Gardens	2000-2015	36.0	18.20	76.49	24.7	24.7	25.0	25.8	26.6	27.5	27.6	27.7	27.5	27.0	25.9	25.5
Sangster	1992-2015	9.0	18.50	77.92	25.9	25.9	26.4	27.3	27.9	28.7	29.0	29.1	28.7	28.2	27.5	26.5
Worthy Park	1973-2015	374.0	18.14	77.15	21.7	21.9	22.5	23.4	24.3	24.9	25.0	25.1	25.1	24.6	23.6	22.4
Jamaica					24.4	24.4	24.8	25.6	26.3	27.1	27.3	27.3	27.2	26.7	25.9	25.0

Table 7: Table showing minimum temperature climatologies for nine meteorological sites across Jamaica. Data averaged over varying periods for each station. Units (°C).
Data source: Meteorological Service of Jamaica.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bodles	18.6	19.0	19.5	20.6	21.7	22.7	22.2	22.4	22.4	22.2	20.5	20.3
Discovery Bay Marine Laboratory	21.6	21.4	21.5	22.6	23.1	24.0	24.1	24.1	24.2	23.9	23.4	22.5
Duckenfield	20.9	20.7	20.7	21.5	22.5	23.9	23.8	23.5	22.8	22.5	22.3	21.5
Frome	19.4	19.0	19.5	20.6	21.7	22.4	22.2	22.5	22.5	22.3	21.8	20.3
Manley	22.9	22.9	23.3	24.2	25.1	26.0	25.9	25.9	25.7	25.2	24.4	23.5
Mason River	15.7	15.0	15.3	15.5	16.4	17.3	17.3	17.6	17.2	18.0	17.3	16.9
Passley Gardens	21.2	20.7	20.8	21.7	22.6	23.8	23.7	23.6	23.2	22.8	22.2	21.8
Sangster	22.1	21.9	22.4	23.3	23.8	24.5	24.7	24.8	24.5	24.2	23.8	22.8
Worthy Park	15.9	15.7	16.2	17.3	18.6	19.3	19.1	19.3	19.3	19.1	18.3	16.8
Jamaica	19.8	19.6	19.9	20.8	21.7	22.7	22.6	22.6	22.4	22.2	21.6	20.7

Table 8: Table showing maximum temperature climatologies for nine meteorological sites across Jamaica. Data averaged over varying periods for each station. Units (°C).
Data source: Meteorological Service of Jamaica.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bodles	31.0	30.9	31.1	31.8	32.2	32.8	33.5	33.6	33.2	32.5	31.9	31.3
Discovery Bay Marine Laboratory	28.0	28.3	28.5	29.4	30.0	30.8	31.1	29.6	31.5	30.7	29.5	26.5
Duckenfield	28.8	29.1	29.4	30.1	30.6	31.2	31.6	31.9	31.7	31.1	30.2	29.4
Frome	30.9	30.9	31.5	32.0	32.3	32.9	33.3	33.5	33.3	32.7	32.0	31.4
Manley	31.0	30.8	30.9	31.5	31.9	32.6	33.1	33.0	32.8	32.3	32.0	31.4
Mason River	26.3	26.5	27.2	28.1	28.3	28.8	29.3	29.4	28.8	28.2	27.4	26.6
Passley Gardens	28.3	28.8	29.2	29.9	30.5	31.2	31.4	31.8	31.9	31.2	29.7	29.1
Sangster	29.6	29.9	30.4	31.3	31.9	33.0	33.2	33.3	32.9	32.2	31.1	30.1
Worthy Park	27.6	28.0	28.9	29.6	30.0	30.5	31.0	31.0	30.8	30.0	28.9	28.0
Jamaica	29.1	29.2	29.7	30.4	30.9	31.5	31.9	31.9	31.9	31.2	30.3	29.3

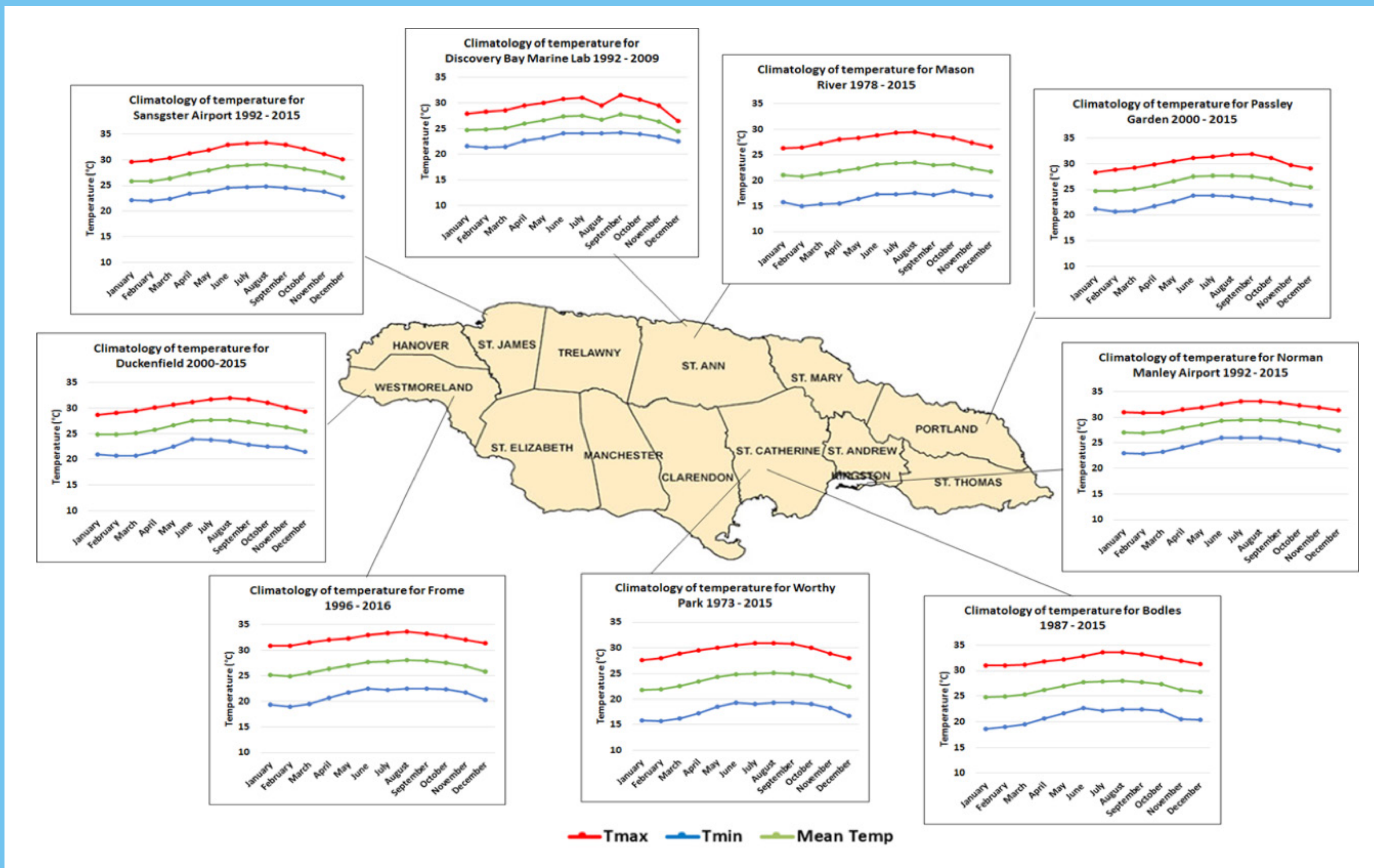


Figure 5: Temperature climatologies of nine meteorological sites across Jamaica. Maximum temperatures are shown in red, mean temperatures in green and minimum temperatures in blue. Data averaged over varying periods for each station. *Data source: Meteorological Service of Jamaica.*

3.3. Rainfall

The annual cycle of rainfall for Jamaica (averaged over the entire island) reflects a bimodal pattern (Figure 6). The bimodal pattern is typical for most of the countries in the northwest Caribbean and is a result of an interplay between the large scale climatic modulators of the Intra-Americas region, including the North Atlantic subtropical High (Azores high), the trade winds, vertical shear in the Caribbean basin, and the Atlantic warm pool. See Information Box 3. In tandem, the large-scale influences condition the region to be conducive to rain during boreal summer and dry during the cooler winter months. For Jamaica, this translates into a dry season spanning December-March and a rainy season spanning April-November which can be divided into an early rainfall season (April-June) and a late rainfall season (September–November). A mid-summer minimum in July (termed the midsummer drought or MSD) separates the early and late wet seasons. Jamaica receives most of its rainfall during the late rainfall season, with May and October being the rainiest months, while February and March are the driest months of the year. Figure 6 also shows that although in general the October peak is higher than the one occurring in May, in more recent times (see the 1980-2009 climatology) the opposite is true.

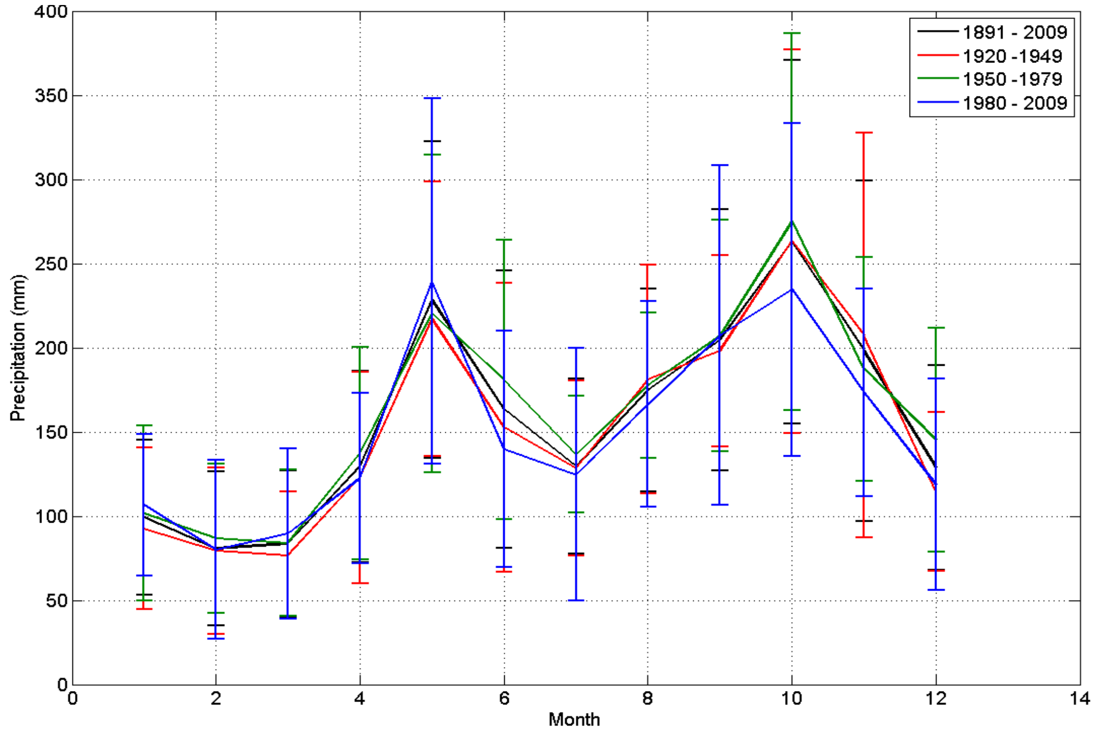


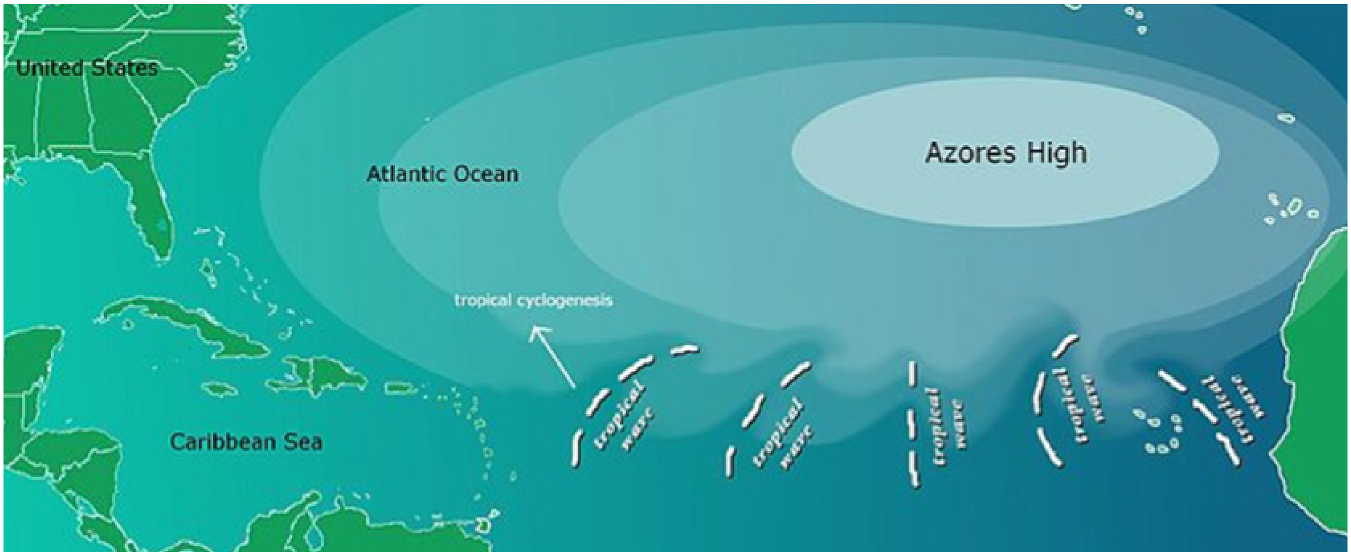
Figure 6: Rainfall climatology in mm for Jamaica as determined from the All-Jamaica rainfall index of the Meteorological Service of Jamaica. Climatologies are shown for four averaging periods: 1891-2009; 1920-1949; 1950-1979; and 1980-2009. Bars indicate standard deviations.
Source: Meteorological Service of Jamaica.

A mid-summer minimum in July (termed the midsummer drought or MSD) separates the early and late wet seasons. Jamaica receives most of its rainfall during the late rainfall season, with May and October being the rainiest months, while February and March are the driest months of the year.

The bimodal pattern depicted in Figure 6 and the relative timing of the associated peaks are also evident in the rainfall climatologies for all parishes (averaging over available selected stations in a parish) (Table 9). However, unlike the other parishes, Portland receives its maximum rainfall in November and next highest rainfall totals during the dry season months of December and January. This latter observation points to the fact that Jamaica is large enough that its topographical variations can modify the background climatological pattern determined by the large-scale drivers. That is, the location, height and orientation of Jamaica's topographical features (for example, the mountainous interior and coastal plains) with respect to the prevailing trades causes differences in rainfall amounts and the timing of rainfall peaks over various parts of the island.

Table 9: Table showing mean monthly rainfall received per parish (millimetres). Mean calculated by averaging all stations in the parish. Mean is for 1971-2000.
Source: Meteorological Service Jamaica.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Hanover	94	109	104	153	309	283	234	269	292	300	141	90
Westmoreland	70	80	88	139	274	216	220	274	254	254	136	74
Manchester	61	64	91	168	235	115	92	164	203	257	141	58
St. Elizabeth	66	78	99	175	262	127	131	205	229	263	124	60
Clarendon	45	40	56	68	139	94	57	113	171	209	111	49
St. Catherine	53	55	61	91	156	110	85	129	172	188	115	62
Trelawny	92	83	61	89	141	93	76	106	137	160	121	116
St. James	67	59	60	95	189	161	125	161	222	200	114	96
St. Ann	106	82	71	93	158	95	67	96	103	169	168	117
St. Mary	181	136	108	141	148	117	82	125	141	170	260	209
Portland	346	264	209	263	292	206	170	244	243	361	475	366
St. Thomas	94	81	68	92	162	170	120	180	255	287	217	116
K&SA	70	72	67	93	152	98	65	147	206	241	160	79
Jamaica	103	93	88	128	201	145	117	170	202	235	176	115



Information Box 3

Why is October usually wet and February usually dry?

The rainfall pattern for the Caribbean is largely conditioned by the North Atlantic High (NAH) pressure system which is a large subtropical semi-permanent centre of high atmospheric pressure typically found south of the Azores in the Atlantic Ocean between 30º N and 35º N. During northern hemisphere winter the NAH is southernmost with strong easterly trades on its equatorial flank. Coupled with a strong trade inversion, cold sea surface temperatures (SSTs) and reduced atmospheric humidity, the region is generally at its driest. Precipitation during boreal winter months is therefore generally only due to the passage of mid-latitude cold fronts which pass far south.

THE WAVES ARE THEMSELVES A SOURCE OF CONVECTION AND CAN DEVELOP INTO DEPRESSIONS, STORMS AND HURRICANES UNDER THE CONDUCIVE CONDITIONS THAT NOW EXIST.

With the onset of boreal spring, the NAH moves northward, the trade wind intensity decreases, vertical shear is diminished and the Caribbean Sea becomes warmer due to the appearance of the north tropical Atlantic warm pool. The result is that the southern flank of the NAH becomes convergent and the region is conducive to convective development. The primary source of rainfall in boreal summer comes from the passage of easterly tropical waves which begin traversing the Atlantic Ocean in June after leaving the west coast of Africa. The waves are themselves a source of convection and can develop into depressions, storms and hurricanes under the conducive conditions that now exist. Around July, a temporary retreat of the NAH equatorward is associated with an unfavorable atmospheric environment, diminished rainfall and the occurrence of the MSD. Enhanced precipitation follows the return of the NAH to the north and the passage of the Inter Tropical Convergent Zone (ITCZ) northward.

The cessation of easterly waves around November and the trek of the NAH south again at the end of the year mark the end of the rainy season and the re-emergence of the dry season.

Figure 7 shows the distribution of mean annual rainfall and highlights the variation in annual rainfall amounts across the island. The mountainous interior generally receives rainfall in excess of 1700 mm annually, while the north and south coasts are significantly drier, with the plains of the south coast being the driest region (1000 mm or less). Rainfall maxima occur on the west and east of the island, with highest rainfall amounts (up to 5000 mm or more) occurring over far eastern Jamaica (Portland), likely due to a convergence of mountain and sea breezes.

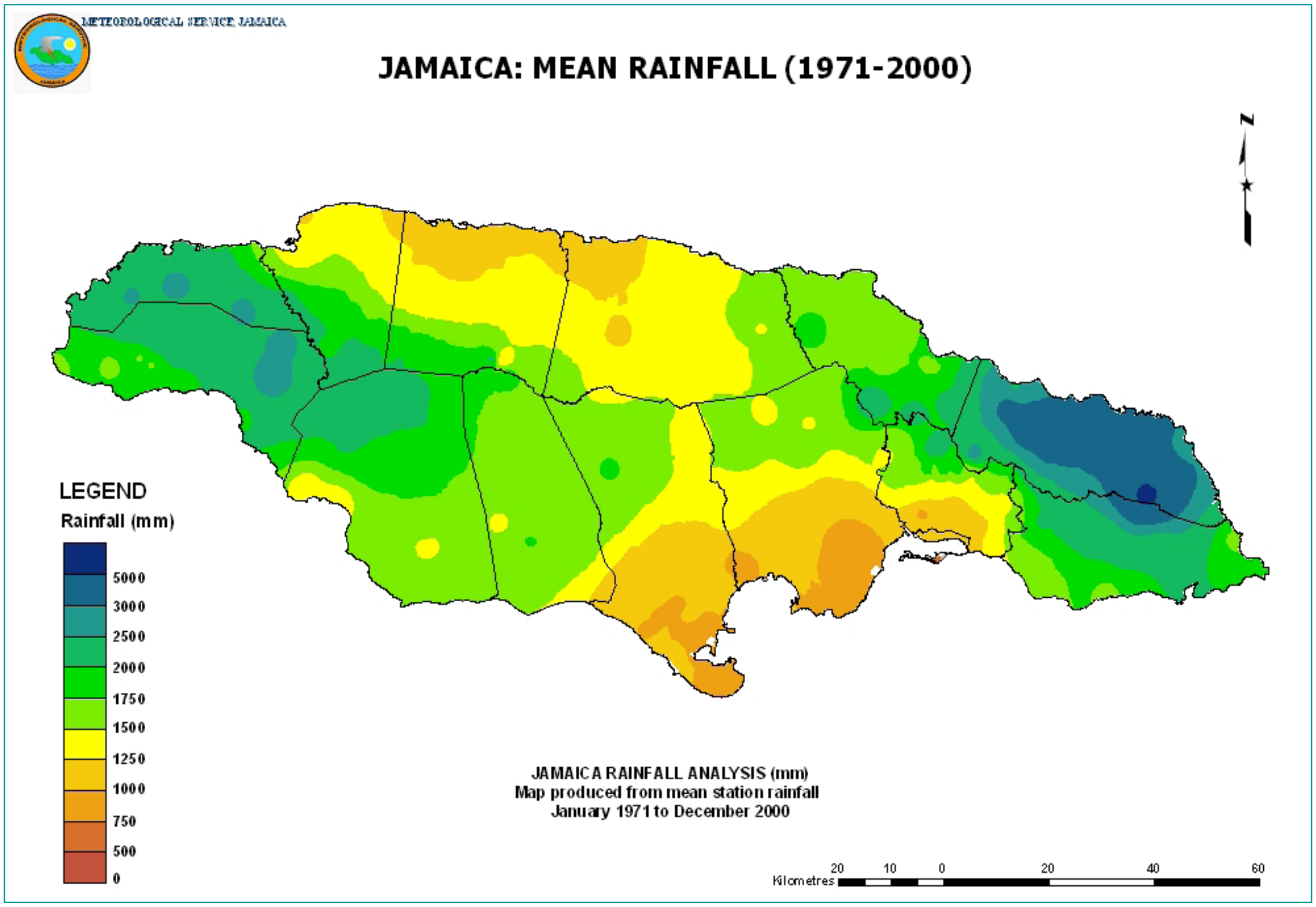


Figure 7: Distribution of mean annual rainfall for Jamaica (in millimetres). Averaging period is 1971-2000.
Source: Meteorological Service of Jamaica.

When cluster analysis is done using rainfall data from 129 stations across the island with sufficient long term data, four rainfall zones emerge. Cluster analysis highlights sub-regions with similar patterns of variability. The bold lines in Figure 8 show the best guess delineation of the four rainfall zones premised on the co-varying stations and the mean rainfall map shown in Figure 7. The four zones identified are: the Interior (Zone 1) which largely encompasses Jamaica's mountainous interior; the East (Zone 2) which covers the rainfall maximum in Portland; the West (Zone 3) covering western Jamaica; and the Coasts (Zone 4) containing the dry north and south coasts. The rainfall zones are not limited to parish boundaries. As an aside, the figure also highlights the glaring gaps in Jamaica's meteorological data coverage with some parishes e.g. St. Ann having inadequate stations to capture its climatic variations.

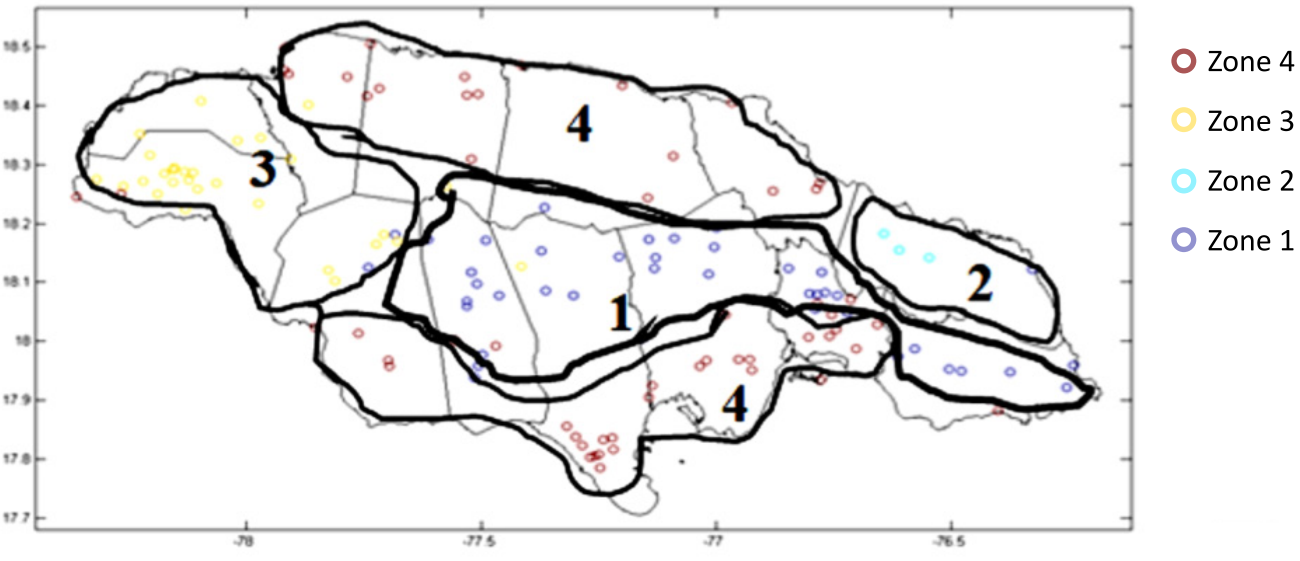


Figure 8: Meteorological stations that cluster together with respect to rainfall variability and the four rainfall zones they fall in. Bold lines show the rough delineation of the four zones which are called the Interior zone or Zone 1 (dark blue), the East zone or Zone 2 (cyan), the West zone or Zone 3 (yellow), and the Coastal zone or Zone 4 (red). *Data Source: Meteorological Service of Jamaica.*

Figure 9 shows the annual cycle associated with each rainfall zone derived by averaging over the stations within the zone. The all-island climatology (purple dotted line) is also shown. Table 10 gives the mean monthly values. Table 11 shows how the rainfall for each zone is distributed across the traditional rainfall seasons. The following things are noted:

» The characteristic bimodal pattern seen in the all-island index is reflected in the rainfall climatology for three of the four rainfall zones.

» The Interior (zone1) and Coasts (zone 4) follow the all island climatology closely with an early season peak in May but with the late season peak and mid-summer minimum occurring one month earlier in September and June respectively. The Interior also has higher rainfall totals than the Coasts which represent the driest of all the rainfall zones.

» Rainfall in the West (zone 3) peaks in May and September-October and has the least pronounced mid-summer rainfall minimum. The West also shows least variability from month to month and receives the most rainfall of all zones excepting the East (zone 2).

» The East (zone 2) deviates the most from the all-island climatology with highest rainfall occurs in November (and comparable totals in December and January), and a secondary peak in April-May. Like the other zones, the mid-summer minimum first appears in June. The East also receives the highest amounts of rainfall year-round – at all times exceeding the average rainfall of any of the other three zones.

» Both the Interior and the Coasts receive most rainfall during the late rainfall season (August-November). The West receives comparable amounts during the dry and late wet seasons, while the East receives most of its rainfall during the traditional dry season (Table 8).

In general, the climatological mean, annual, and monthly rainfall across Jamaica is a complex function of fixed factors including the topography and shape of the country, as well as the annual cycle of regional-scale oceanic and atmospheric factors.

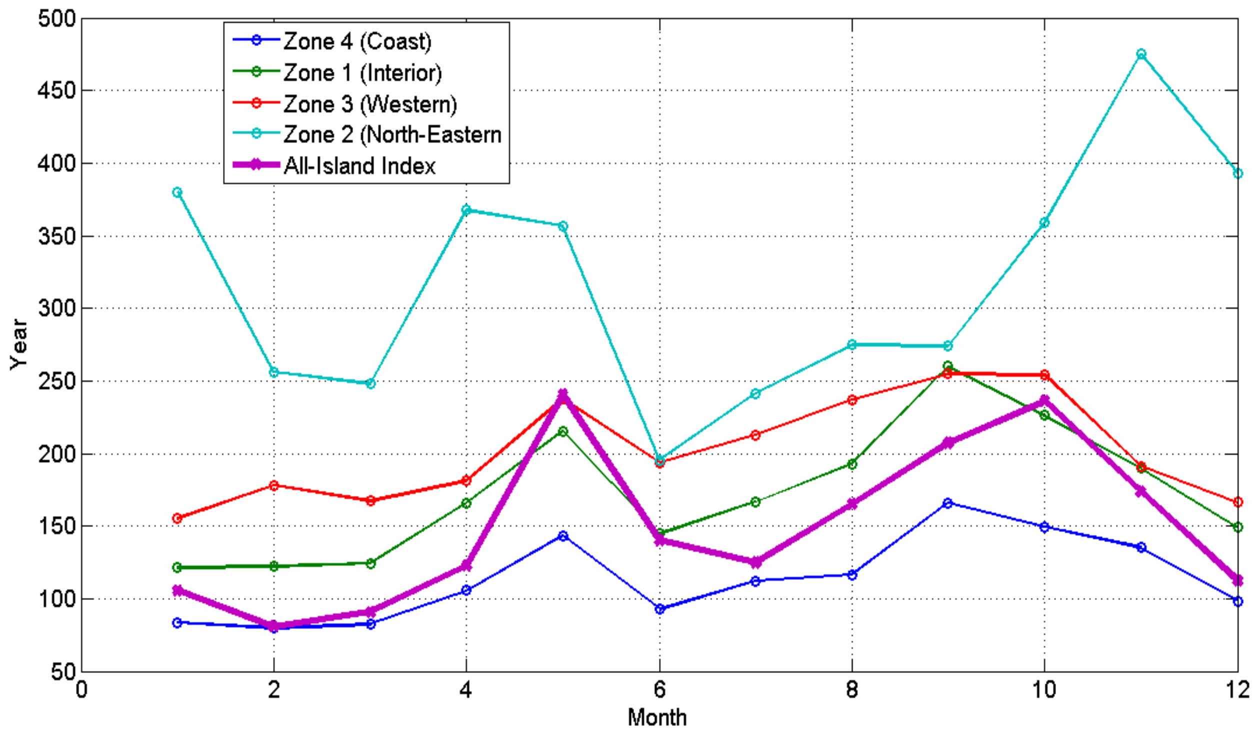


Figure 9: Climatologies of the four rainfall zones for the years 1981-2010. Colours are as follows: Interior (zone 1) – green; East (zone 2) – cyan; West (zone 3) – red; Coasts (zone 4) - navy blue and the All-Island Index (purple). The All island index is averaged over the years 1891-2009 (purple line). *Data Source: Meteorological Service of Jamaica.*

Table 10: Average annual rainfall values (in millimetres) over the period 1981-2010 for the four rainfall zones compared to the all-island average.

MONTH	ZONE 1	ZONE 2	ZONE 3	ZONE 4	COUNTRY
January	121.41	380.12	155.02	83.66	105.63
February	122.32	255.93	178.29	79.76	81.00
March	124.44	247.81	167.26	82.51	90.78
April	166.09	367.56	181.19	105.52	122.50
May	215.35	356.92	237.49	143.39	240.53
June	144.60	195.58	193.85	92.89	140.16
July	166.60	241.27	212.72	112.42	124.78
August	193.00	274.76	237.09	116.74	165.23
September	259.98	274.04	254.63	165.89	207.28
October	226.18	359.04	254.02	149.36	236.16
November	189.88	475.26	191.29	135.18	173.85
December	149.15	392.95	166.25	98.41	112.68

Table 11: Table showing total rainfall (mm) for a year for zone, along with station average total (mm) and percentage (%) rainfall for three seasons of the year, DJFMA (December-January-February-March-April), MJ (May-June), ASON (August-September-October-November).

Zone	Total Mean Rainfall (mm)	DJFMA		MJ		ASON	
		Total (mm)	Percentage (%)	Total (mm)	Percentage (%)	Total (mm)	Percentage (%)
Interior (Zone 1)	1826.8	627.5	34.3	311.2	17.0	743.4	40.7
East (Zone 2)	3840.7	1635.8	42.6	568.3	14.8	1391.9	36.2
West (Zone 3)	2139.2	776.3	36.3	372.0	17.3	808.5	37.8
Coasts (Zone 4)	1218.7	419.3	34.4	207.5	17.1	492.3	40.4

3.4. Hurricanes

The North Atlantic (the Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico) hurricane season runs from June 1 to November 30. This coincides with the period when the Caribbean Sea is most conducive to convective activity (see again Information Box 3) and with Jamaica's rainfall season. This however does not preclude storm or hurricane activity in May. The peak of the North Atlantic season is from mid-August to late October as seen in Figure 10, although a deadly hurricane may occur at any time during the season.

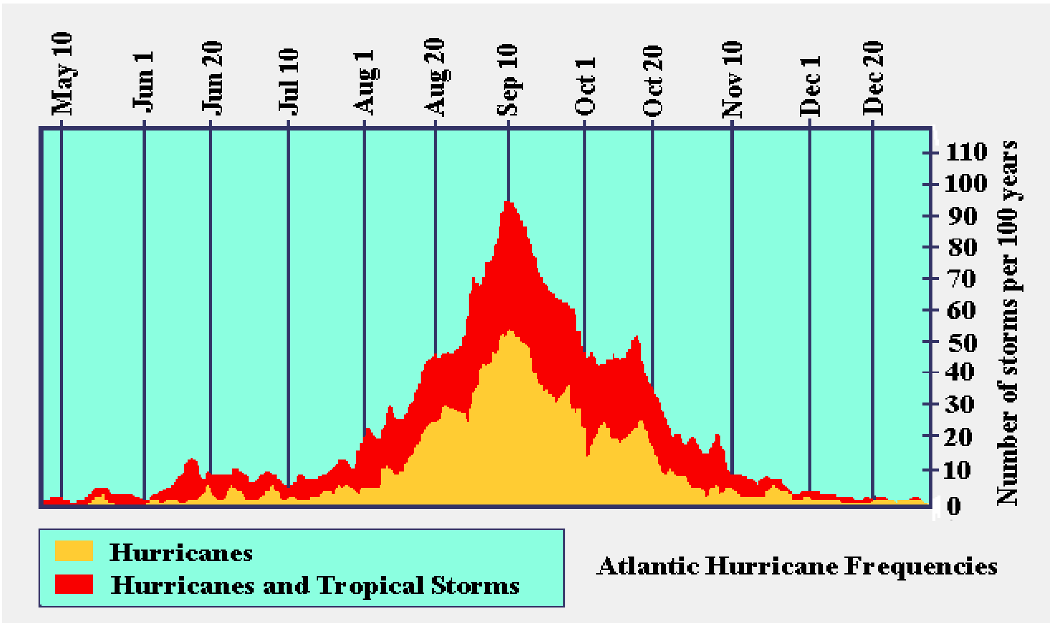


Figure 10: Data Hurricane frequency for the Atlantic Ocean hurricane season.
Source: NOAA.

Table 12 shows the number of storms and hurricanes by category passing within 200 km of Jamaica over the period 1842-2016. The Table suggests that in the mean, the frequency of tropical storm and hurricane activity in the proximity of Jamaica peaks between August and October. The most active months are August (29 storms and hurricanes) and September (25 storms and hurricanes) while the least active months are May (1 event) and June (7 storms and hurricanes). When the categories are considered separately, hurricane activity near Jamaica peaks in August, while tropical storm activity peaks in September.

Table 12: Number of tropical storms and hurricanes passing within 200 km of Jamaica over the period 1845-2015 sorted by month. Hurricanes are also categorized by storm strength.
Data source: NOAA reconstructed Hurricane Reanalysis database.

Month	Number of Storms						
	TS	H1	H2	H3	H4	H5	Total
May	1						1
June	1	1					2
July	3	-			1		4
Aug	7	8	3	4	2	1	25
Sept	14	3	2		1	1	21
Oct	6	4	2				12
Nov	4	1	1	1			7

3.5. Other Variables

3.5.1. WIND

Winds in Jamaica are a combination of the prevailing winds, sea breezes and mountain and valley winds which arise as a result of heating and cooling in valleys. The strongest influence is the prevailing trade winds from the East or North East associated with the North Atlantic High (NAH) (Information Box 3). In the mean, wind strengths vary inversely with rainfall. Therefore, during the driest months (when the island is under the influence of the NAH, for example, January-April and July) wind speeds are largest while during the wettest months, wind speeds are smaller. This is generally reflected in Figure 11 which shows the wind speed climatology for Norman Manley International Airport based on data collected over the period 2011-2012. This does not preclude very large wind speeds occurring when a tropical system is passing near or over Jamaica.

Wind mapping campaigns (Amarakoon and Chen, 2001, 2002) show that winds are strongest in Portland, St. Thomas, Manchester and St. Elizabeth (see also Figure 12). The extremes of annual wind speed at 30m for each parish as determined from one such wind mapping exercise are given in Table 13. The data also confirm the four above mentioned parishes as those with strongest mean winds.

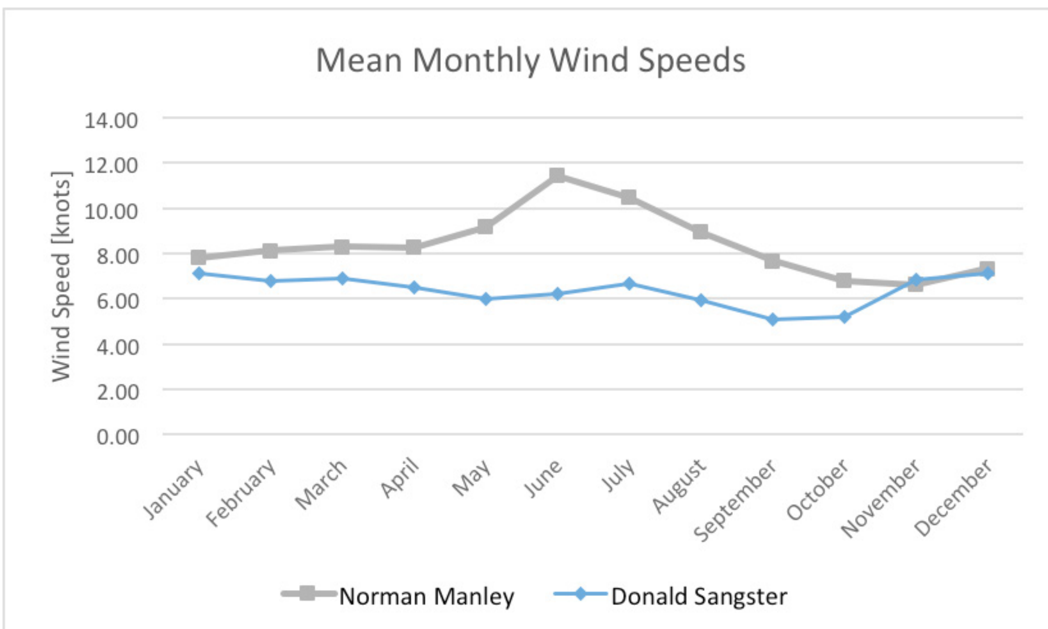


Figure 11: Wind speed climatology of Jamaica based on data collected at a) the Norman Manley International Airport and b) the Donald Sangster International Airport on an hourly basis for January 1998 to December 2016.

Table 13: Extremes of annual mean wind speed for each parish, taken at 30 metres.
Source: Amarakoon et al. (2001).

PARISH	WIND SPEED (m/s)
Portland	1.49 – 9.40
St. Thomas	1.48 – 8.69
Manchester	2.64 – 8.39
St. Elizabeth	1.61 -8.24
St. Catherine	2.18 – 7.18
Westmoreland	2.61 – 6.95
St. James	2.09 – 6.67
St. Ann	2.39 – 6.40
Clarendon	2.67 – 6.01
St. Mary	2.67 – 6.26
Hanover	2.53 – 5.95
St. Andrew	2.30 – 5.52
Kingston	2.71 – 5.61
Trelawny	3.44 – 4.67

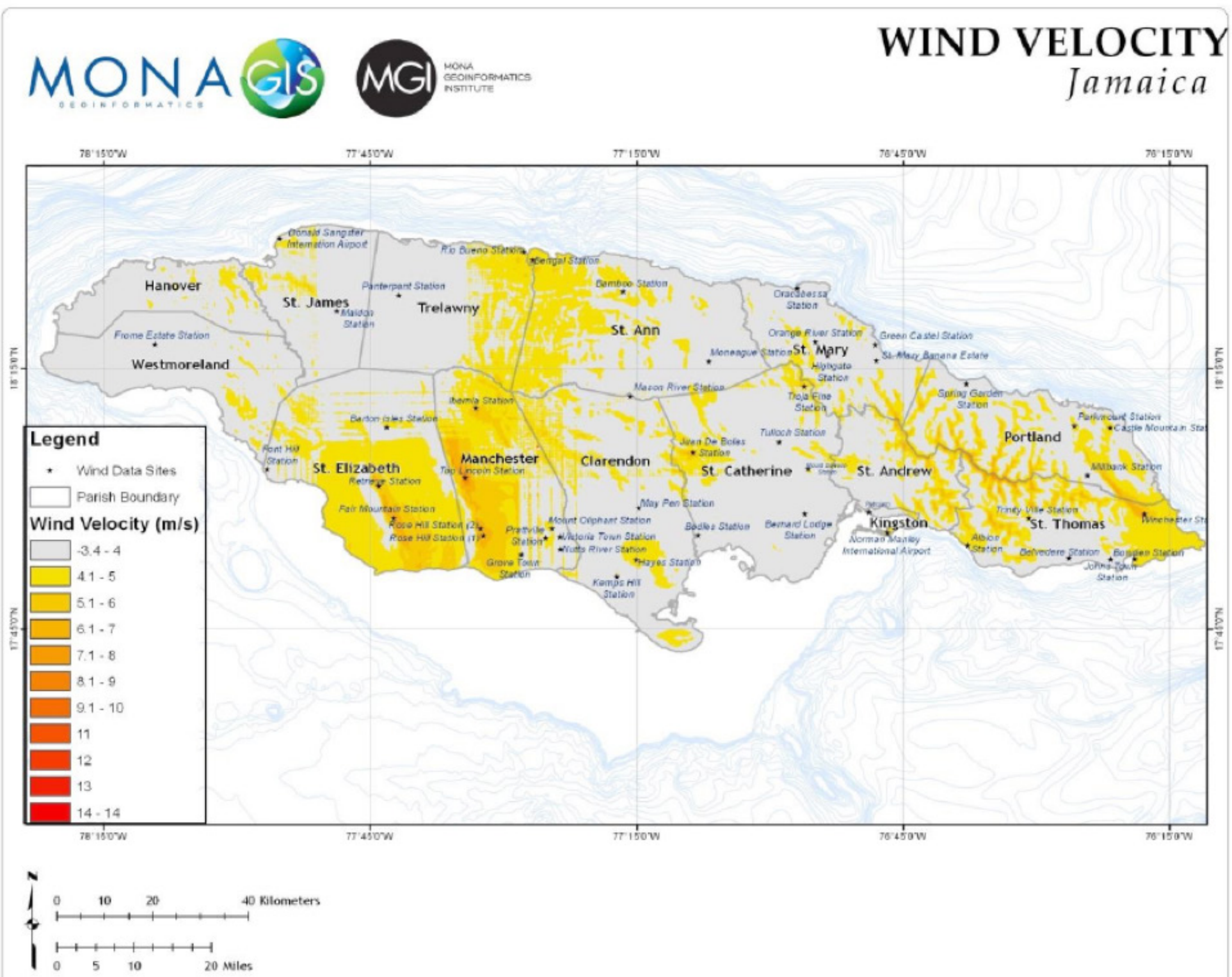


Figure 12: Variation of wind speeds across Jamaica. Source: Mona GeoInformatics Institute.

3.5.2. SIGNIFICANT WAVE HEIGHT

Very little information exists about marine variables relevant for Jamaica. Figure 13 shows the climatology of Jamaica's significant wave height, wind speed, period, and wave direction deduced from 15 years of data from two weather buoys – 42058 (yellow) and 42057 (blue) - located southwest of Kingston and Negril, respectively. Significant wave height is the average height of the highest one third of the waves and should not be confused with the vertical distance between the crest and the trough otherwise known as the wave height. Significant wave height varies between 0.7-2.3 m and generally mirrors the wind speed pattern. Highest waves occur when wind speeds are strongest which are in the drier months of the year. The range for the dominant period is 5-7 s and again is generally strongest when surface winds are strongest.

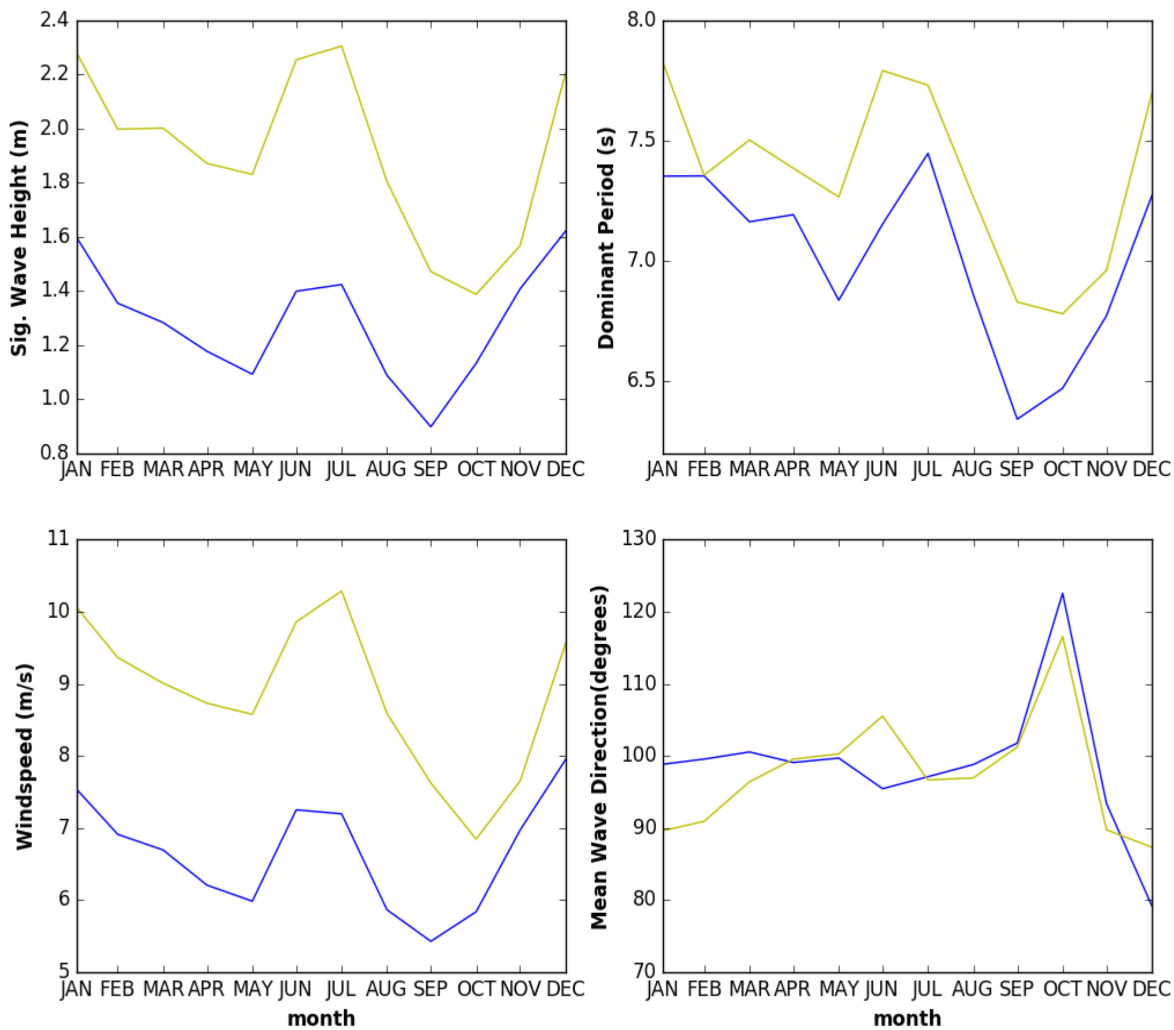


Figure 13: Climatology of Jamaica's significant wave height, wind speed, period, and wave direction for two weather stations – 42058 (yellow) and 42057 (blue).
Source: NOAA NDBC.

3.5.3. SOLAR RADIATION

Solar radiation data taken between 1978 and 1987 for 12 stations throughout Jamaica (Chen, 1994) are provided in Table 14. The data generally suggest a peak in solar radiation in June-July and a minimum in January. Average radiation for Jamaica from the data is calculated to be about 0.005 MegaWatt-hour/ m^2. Figure 14 maps the average annual solar irradiation over the period 1999-2013 for Jamaica. Highest irradiation occurs on the flat coastal plains, while smallest amounts occur in eastern Jamaica over high mountain regions.

Table 14: Mean daily global radiation in $MJ/m^2/day$ at several radiation stations in Jamaica. See notes (i) and (ii) below. To convert from $MJ/m^2/day$ to Kilowatt-hour (KWH), divide ($MJ/m^2/day$) by 3.6. *Source: Solar radiation map for Jamaica (1994).*

STATION	PARISH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Alcan	Manchester	14.6	15.1	18.0	18.9	-9.9	19.6	20.4	-9.9	-9.9	16.7	15.6	15.1
Allsides	Trelawny	13.1	13.7	17.4	17.3	17.5	22.0	17.7	17.7	16.3	14.8	13.3	14.8
Black River	St. Elizabeth	16.2	17.1	18.6	18.8	20.9	26.1	24.6	25.4	18.7	16.5	16.1	14.5
Bodles	St. Catherine	15.2	16.8	19.5	21.5	21.2	19.7	20.8	20.4	19.0	18.0	16.2	15.5
Discovery Bay	St. Ann	12.9	14.9	19.6	21.3	21.0	21.1	21.6	18.6	18.7	16.0	14.1	12.9
Duckensfield	St. Thomas	16.5	15.8	21.1	22.9	21.9	22.4	22.3	21.1	21.4	17.6	18.4	16.4
Manley	Kingston	15.9	18.0	20.3	20.7	20.0	19.5	19.9	21.4	19.0	17.3	15.8	15.4
Mona	St. Andrew	14.4	17.0	19.5	19.5	20.0	20.5	19.5	18.7	17.8	15.4	15.7	15.2
Negril	Westmoreland	15.8	17.5	18.4	19.7	18.4	19.9	18.7	17.8	18.6	16.1	15.2	14.7
Orange River	St. Mary	15.9	13.0	13.0	18.7	18.0	19.0	17.9	19.5	17.8	15.9	16.1	15.5
Sangster	Montego Bay	14.5	15.5	19.0	20.9	20.6	20.0	20.5	19.3	16.8	15.9	14.9	13.8
Smithfield	Hanover	13.1	15.6	20.7	22.3	19.8	17.2	17.2	17.2	17.1	16.1	12.2	13.2
	Notes:	(i) -9.9 denotes missing values (ii) High values for Black River in June, July and August are questionable.											

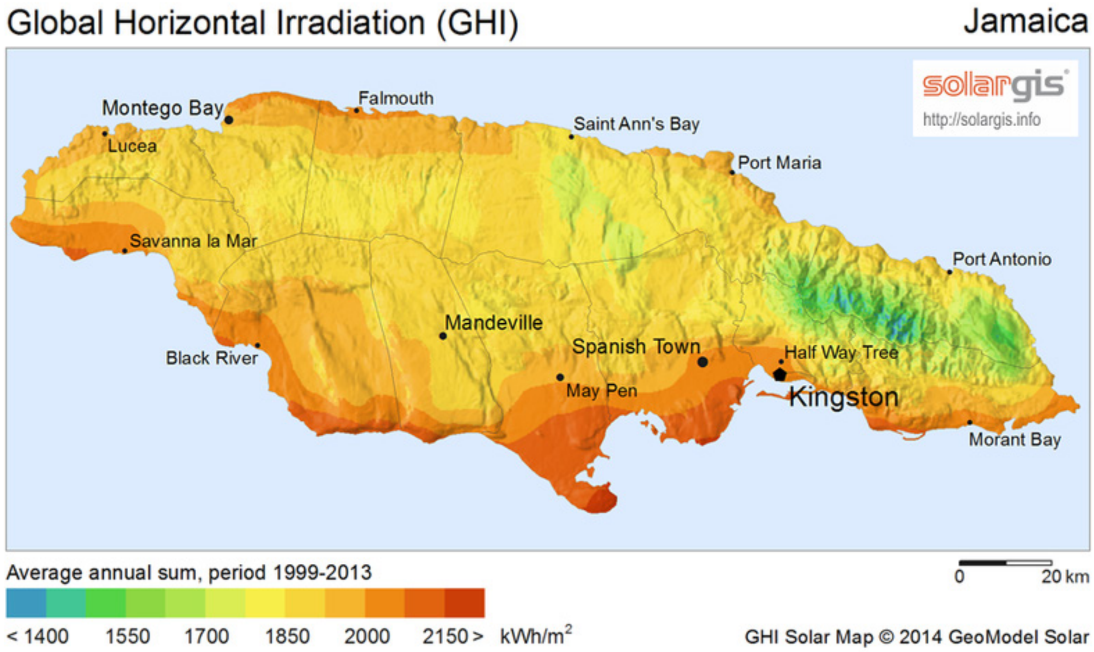


Figure 14: Solar Radiation Map: Global Horizontal Irradiation Map of Jamaica.
Source: SolarGIS.

3.5.4. RELATIVE HUMIDITY, SUNSHINE HOURS, AND EVAPORATION

As noted in the State of the Jamaican Climate 2012, the lack of data hampers the extent to which analysis of other meteorological variables is possible, particularly with respect to their spatial variation. Values for Percentage Relative Humidity, Sunshine Hours, and Evaporation for the Norman Manley and Sangster International Airports are given in Table 15.

Relative humidity does not vary significantly throughout the year. Average humidity at the airport stations is higher during morning hours, ranging from 72-80%, and lower in the afternoon at 59-65%. Afternoon showers are the major cause of most of the daily variation, therefore the highest values are recorded during the cooler morning hours near dawn, which is followed by a decrease through to early afternoon when temperatures are highest.

Sunshine hours vary little throughout the year, ranging between seven and nine hours per day. There are more sunlight hours in the dry season and less in the main rainy season, with this being directly related to cloudiness. Spatial variations in sunshine hours are usually quite small, though there are differences between coastal and inland stations. Mean sunshine in mountainous areas tends to be less than six hours per day, caused mainly by the persistence of clouds, while in coastal areas it is near eight hours per day (GOJ, 2000).

Evaporation tends to be a function of both temperatures and available moisture. For both stations, the values peak during the months approaching July, therefore approaching the month of highest mean temperatures, but following the onset of the rainy season (May).

Table 15: Mean monthly and annual observed values for Relative Humidity, Sunshine Hours and Evaporation for the Norman Manley and Donald Sangster International Airports (SIA) for the period 1997-2016.

	NORMAN MANLEY INTERNATIONAL AIRPORT			
	Relative Humidity (%)		Evaporation (mm)	Sunshine Hours (hrs)
	7am	1pm		
January	76.28	60.28	5.33	10.45
February	75.92	61.00	5.97	10.89
March	74.84	61.60	6.78	10.79
April	73.28	62.54	7.05	11.12
May	73.38	64.71	7.15	10.47
June	72.09	63.91	8.20	9.95
July	71.88	62.71	7.83	10.48
August	73.54	64.96	7.05	10.40
September	75.04	65.96	6.63	9.89
October	77.32	66.92	5.70	9.80
November	76.88	63.48	5.28	10.22
December	77.08	61.16	5.18	10.24
Annual	74.79	63.27	6.51	10.39
SANGSTER INTERNATIONAL AIRPORT				
January	82.92	73.04	4.66	7.77
February	81.83	71.17	5.20	8.40
March	80.17	70.88	6.21	8.55
April	78.92	71.13	6.78	9.08
May	78.29	73.33	6.47	8.32
June	77.92	72.17	6.48	8.13
July	78.33	70.88	6.84	8.79
August	80.25	72.04	6.53	8.12
September	80.71	73.25	5.47	7.41
October	83.17	75.96	4.92	7.35
November	83.87	74.30	4.83	7.70
December	84.13	73.83	4.40	7.63
Annual	80.88	72.66	5.73	8.10

4. Observed Variability, Trends, and Extremes

4.1. Temperatures

CRU gridded data for Jamaica (Figure 15) show a warming trend for the country for maximum, minimum and mean temperatures. For the period 1950-2014, minimum temperatures are, however, observed to be increasing at a faster rate (~0.27 °C/decade) than maximum temperatures (~0.06 °C/decade). This suggests that the daily temperature range is decreasing. Mean temperatures are increasing at a rate of 0.16 °C/decade over the same period. Using data for the airport stations the trend in the mean temperature is estimated at ~0.10 °C/decade.

The values for Jamaica are similar to the global and regional estimates of temperature increase. Global mean surface temperatures have increased by 0.85 °C ± 0.20 °C from 1880-2012 (IPCC, 2013). The annual mean of daytime temperatures for the Caribbean region also shows a significant increase of 0.19 °C/decade over the period 1961-2010 (Stephenson et al., 2014). This is, however, smaller than the increase in mean nighttime temperatures (0.28 °C/decade). Like Jamaica, then, the results for the Caribbean also suggest a decrease in the mean annual daily temperature range over the period.

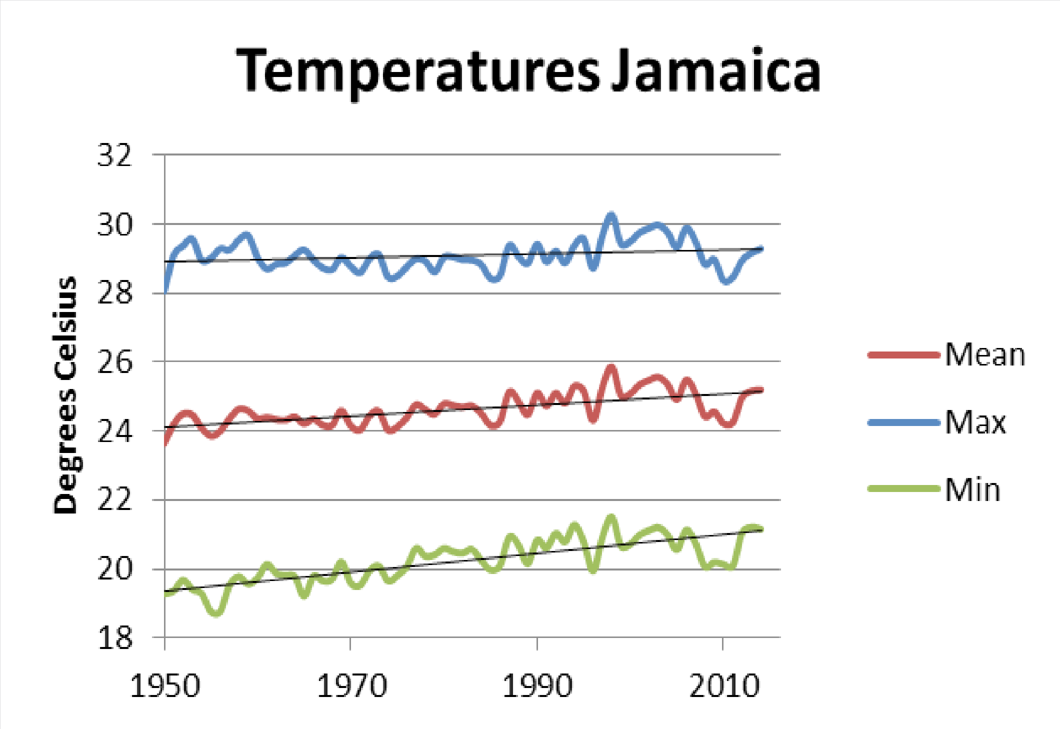
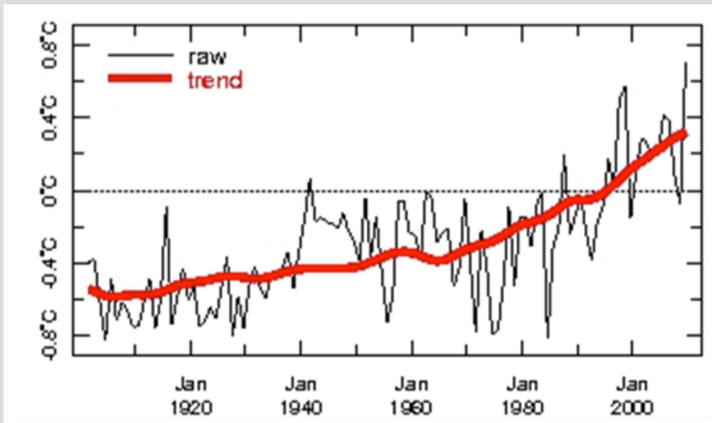


Figure 15: Annual maximum, minimum and mean temperatures for Jamaica 1950-2015. The linear trend lines are inserted. Data source: CRU TS3.24.

Figure 15 also shows that for the Jamaican temperature time series it is the linear trend that dominates. The dominance of the global warming signal in the historical temperature data is also true for the entire Caribbean where the linear trend accounts for approximately half of the variability seen (Figure 16). Figures 15 and 16 also show evidence of decadal variability (groups of years which are warmer or colder) and significant interannual variability (swings between one year and another). These two timescales of variations, however, account for much less of the explained variance in the temperature time series.



Trend	54%
Decadal	17%
Inter-Annual	29%

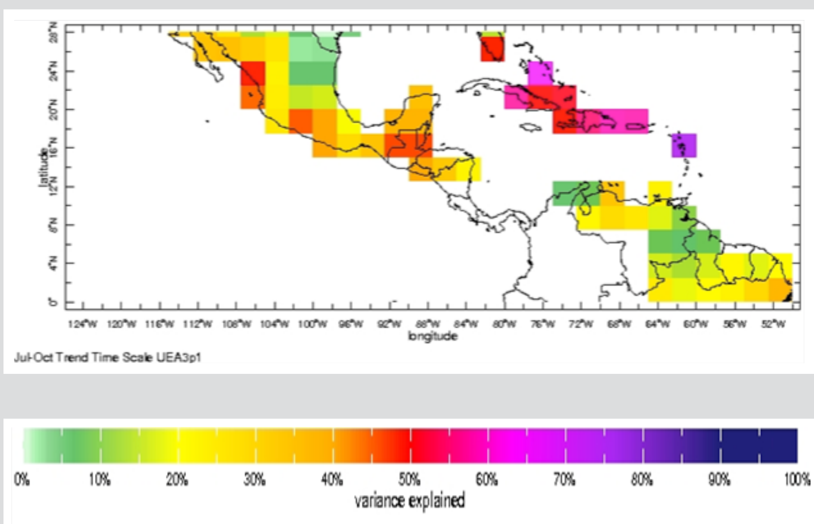


Figure 16: (a) Average July-October temperature anomalies over the Caribbean from the late 1800s with trend line imposed. Box Inset: Percentage of variance explained by trend line, decadal variations > 10 years, interannual (year-to-year) variations. (b) Percentage variance in July-October temperature anomalies (from late 1800s) accounted for by the 'global warming' trend line for grid boxes over the Caribbean. Data source: Climate Research Unit (CRU). Acknowledgements: IRI Map Room.

Five extreme temperature indices were calculated for the temperature stations (Figure 17) - Donald Sangster International Airport, Discovery Bay, Worthy Park, Bodles, Tulloch, Norman Manley International Airport, and Duckenfield- using data for the period 1992 to 2011. The following trends are noted. The daily temperature range (DTR) has increased at most sites analyzed, with the exception of decreases in Discovery Bay and at the Norman Manley International Airport. The opposite is true for growing season length (GSL) which has decreased at most sites except for Discovery Bay and at the Norman Manley International Airport. The number of nights warmer than 20°C (TR20) has also increased at all stations except the far eastern one. The warmest maximum temperatures (TXx) has risen at four of the six stations and the coolest minimum temperatures (TNn) has also risen at four of the six stations (Figure 17).

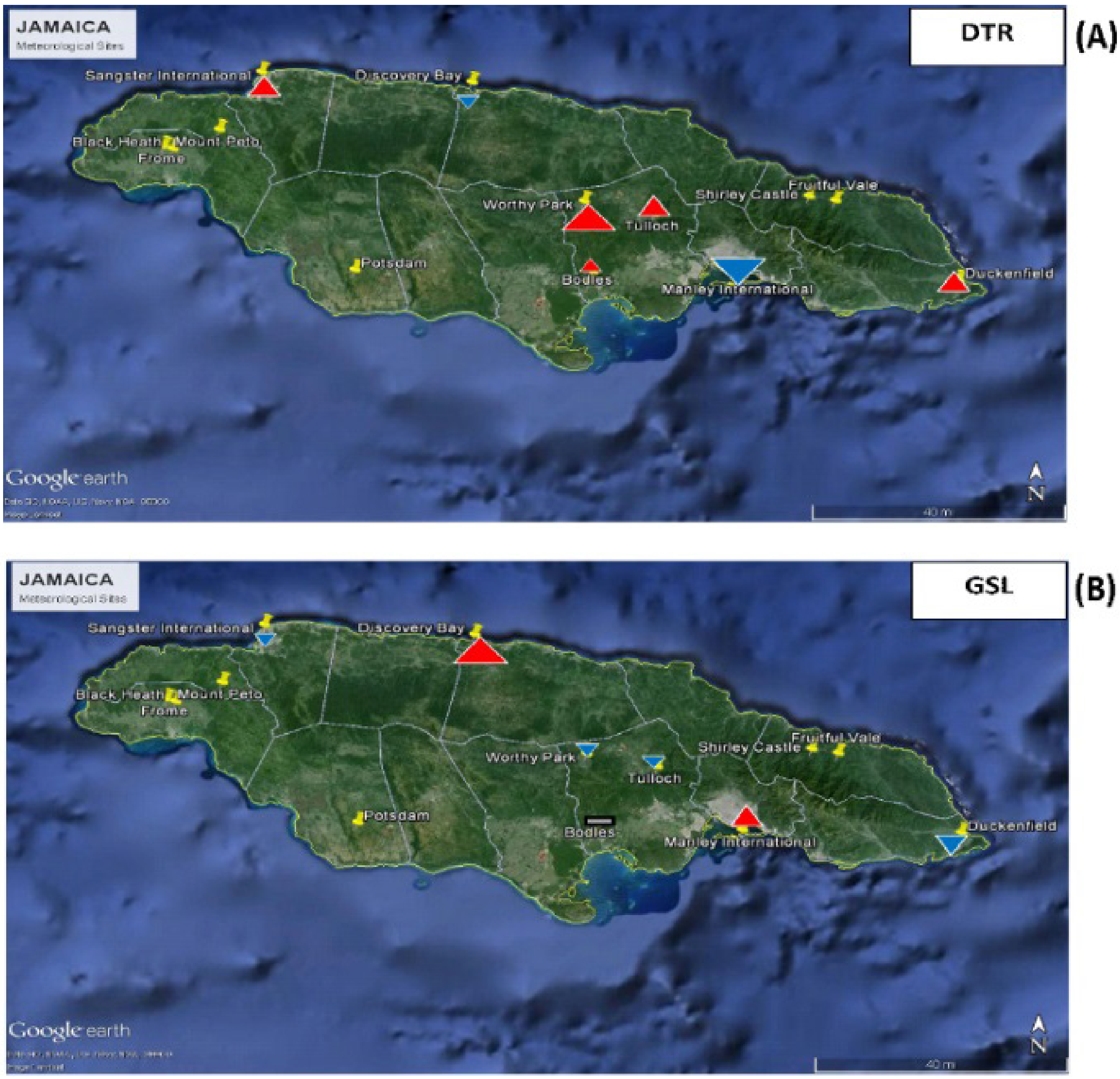


Figure 17 (above and next page): Trends in selected historical temperature extremes for stations located at Donald Sangster International Airport, Discovery Bay, Worthy Park, Bodles, Tulloch, Norman Manley International Airport, and Duckenfield. Figure shows (a) daily temperature range (DTR) (b) growing season length (GSL) (c) nights warmer than 20°C (TR20) (d) coolest minimum temperatures (TNn) (e) warmest maximum temperatures (TXx). Direction of the arrow indicates positive (upward) or negative (downward) trend. The size of arrow indicates the magnitude relative to the largest trend in each panel.


JAMAICA
Meteorological Sites
TR20
Sangster International
Discovery Bay
Black Heath
Mount Peto
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Shirley Castle
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4.2. Rainfall

Unlike the temperature time series where the linear trend dominates, it is interannual variability which accounts for most of the variability seen in the Jamaican rainfall record. The annual rainfall anomaly from 1880 to present for Jamaica using the All Jamaica rainfall index is plotted in Figure 18. The record is dominated by year to year fluctuations (also evident in the smoothed time series using a 13-month running mean) such that when a linear trend is fitted it is not statistically significant. That is, over the entire period Jamaica is not getting wetter or drier with respect to mean annual rainfall. Wavelet power spectrum analysis confirms peaks in the Jamaican rainfall time series at 3 years, 9 years, 13-14 years and 21 years. The first peak is particularly prevalent since the mid-1990s suggesting increased short-term variability (therefore, it swings between wet and dry conditions) in the recent past. The presence of a strong interannual (versus linear) signal in the rainfall time series is true for most of the Caribbean (Figure 19) and is in large part due to the El Niño/La Niña phenomenon which is a significant driver of interannual climate variability in the Caribbean. Information Box 4 provides more details about how an El Niño is known to affect Caribbean rainfall patterns. It is likely the El Niño phenomenon which has resulted in the recent increase in variability observed since the late 1990s, as from that time to present, there have been at least eight moderate or strong El Niño (5) and La Niña (3) events.

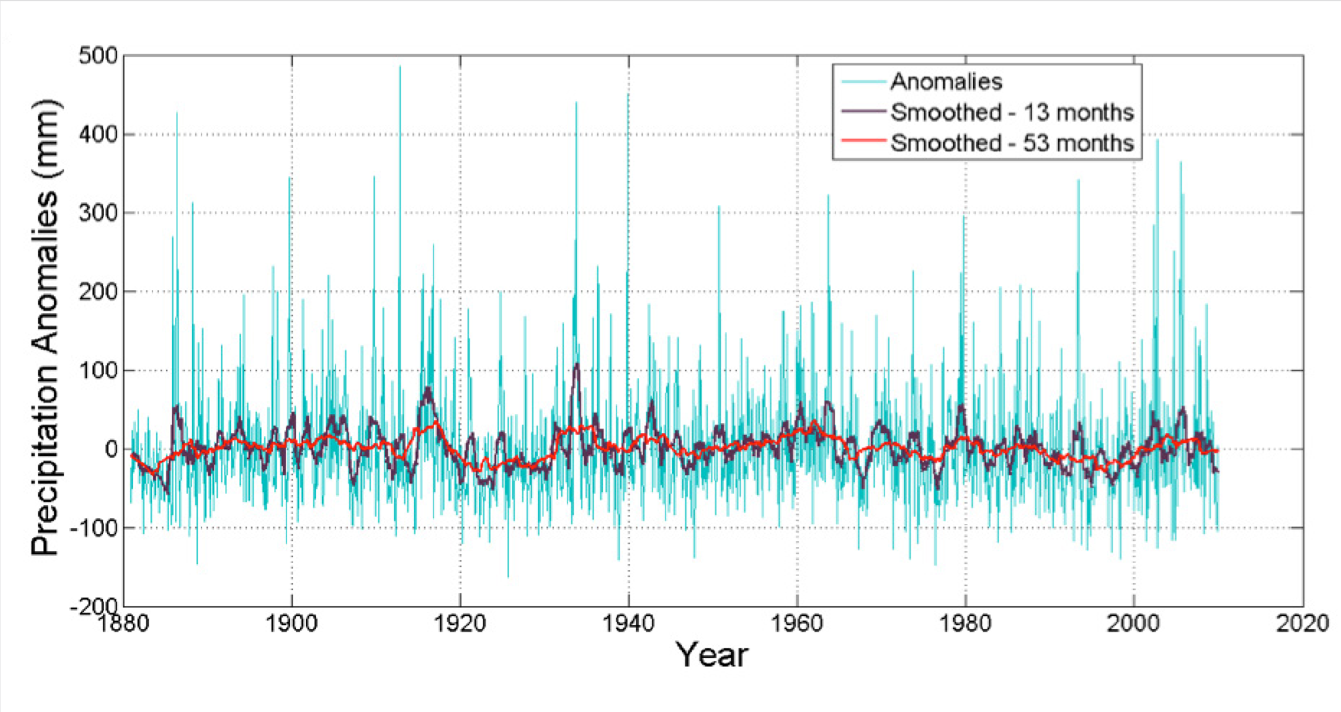


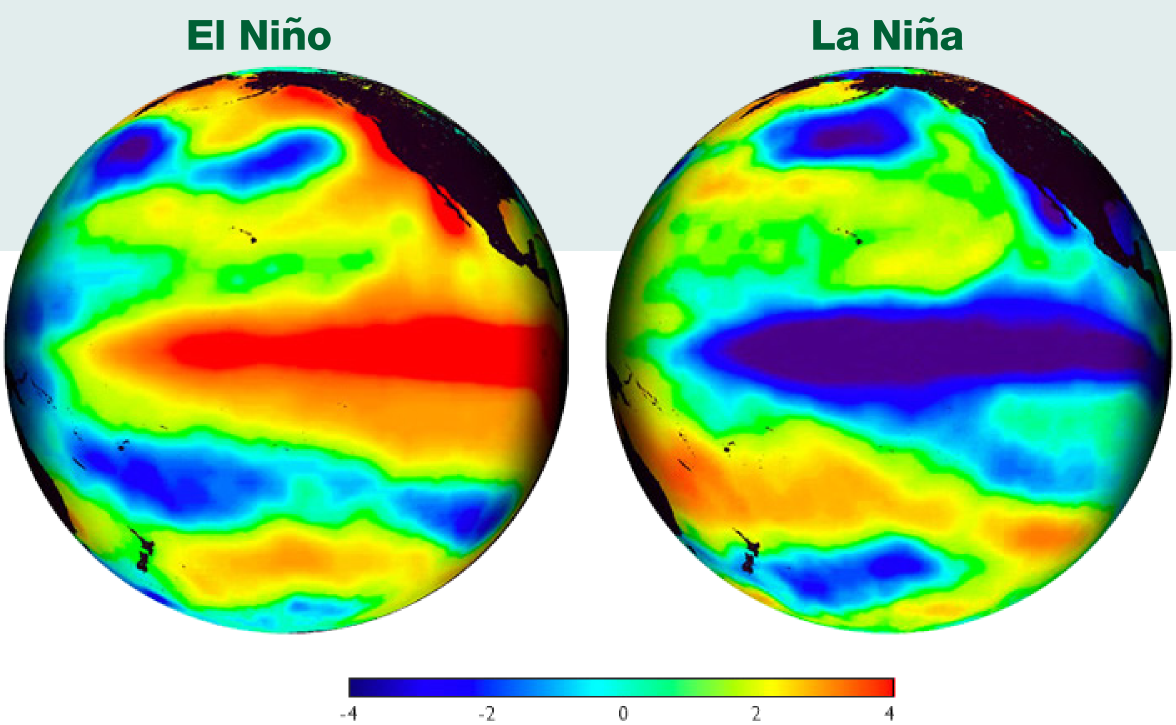
Figure 18: Anomaly time series (blue) of All Jamaica rainfall index. Dark blue and red lines show respectively the smoothed index using running means of 13 and 53 months respectively to highlight interannual and decadal variability. Anomalies are with respect to a climatology calculated using the entire period. Units are mm.

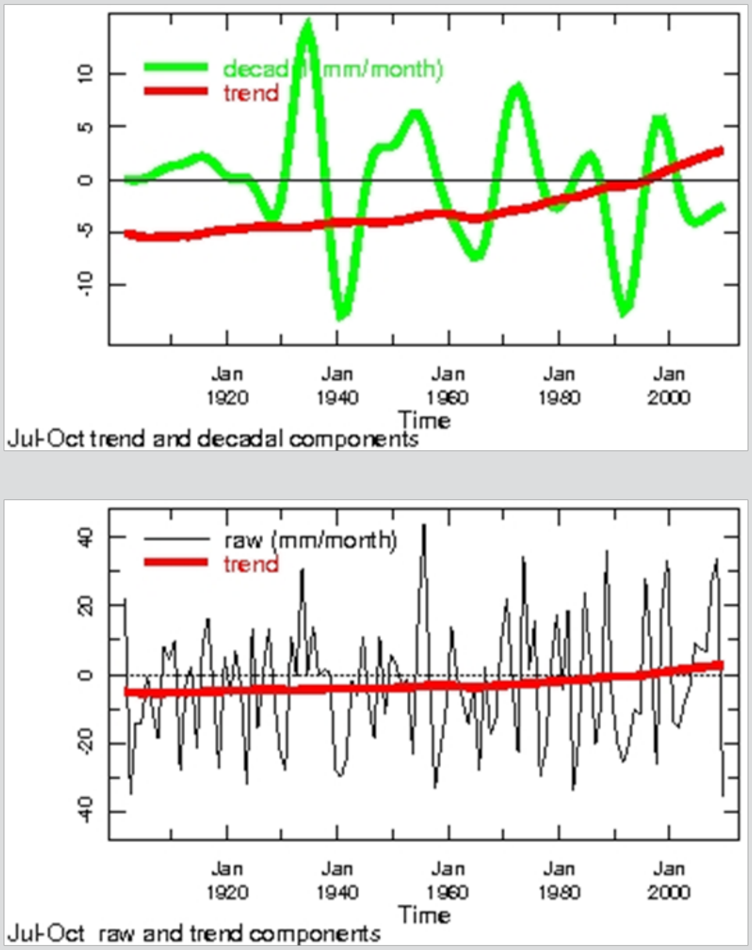
Information Box 4

What does the El Niño event mean for the Caribbean?

El Niño conditions refer to periods when the eastern Pacific Ocean off the coast of Peru and Ecuador is abnormally warm. La Niña refers to the opposite conditions when the eastern Pacific Ocean is abnormally cold. When an El Niño starts it tends to last for about a year, peaking in December and dying out during the following spring. El Niño events tend to occur every 3 to 5 years, though increases in the frequency, severity and duration of events have been noted since the 1970s. Further increases in frequency are also projected under climate change.

During an El Niño event, the Caribbean tends to be drier and hotter than usual in the mean, and particularly during the late wet season from August through November. There is also a tendency for reduced hurricane activity. Recent meteorological droughts occurring over the Caribbean in 2010 and 2014-15 coincide with El Niño events. However, during the early rainfall season (May to July) in the year after an El Niño (the El Niño + 1 year), the Caribbean tends to be wetter than usual. The El Niño impact on the Caribbean dry period (January to March) is to induce opposite signals over the north and south Caribbean i.e. with strong drying in the southern Caribbean, but a transitioning to wetter conditions over Jamaica and countries further north. In general, a La Niña event produces the opposite conditions in both the late wet season (i.e. wetter conditions) and the dry season (i.e. produces a drier north Caribbean). The low-level zonal component of the wind that flows over the Caribbean Sea is also associated with rainfall conditions in the north Caribbean. A westerly (easterly) anomaly decreases the low-level jet creating a wetter (drier) north Caribbean. The low-level jet is strongly controlled by sea surface temperature (SST) gradients between the Pacific and Atlantic which are in turn modulated by El Niño/La Niña events.





Trend	1%
Decadal	8%
Inter-Annual	88%

Figure 19: (a) Average July-October rainfall anomalies over the Caribbean from the late 1800s with trend line imposed. (b)Trend and decadal components of the average July-October rainfall anomalies over the Caribbean from the late 1800s. Data source: CRU data. Acknowledgements: IRI Map Room.

Figure 18 also shows decadal variance in the Jamaican rainfall series as illustrated by the 53-month running mean. It is the decadal periodicities (13 and 20 years) that are strongest in the wavelet analysis of the all Jamaica rainfall index. Since the 1950s Jamaica has experienced wet periods (groups of years) in the 1960s, early 1980s, late 1990s and mid to late 2000s. Dry anomalies are evident in the late 1970s, mid and late 1980s and post 2010. Some of the decadal swings may be accounted for by swings in phase of the Atlantic Multidecadal Oscillation (AMO).

Figure 20 shows the smoothed rainfall anomalies for Jamaica's four rainfall zones. All zones show strong decadal variation. The Interior (zone 1), West (zone 3) and Coasts (zone 4) co-vary on a similar decadal time scale, with the 1970s, 1985-88, and 1999-2001 being dry, and the 1990s generally being wetter. Table 16 shows that variability across zones 1, 3 and 4 are indeed strongly correlated suggesting that rainfall in these zones may be conditioned by the same large-scale forcings such as the AMO. The East (zone 2), however, was largely dry between 1985 and 1995, but wet from 1995 through 2005 and is not significantly correlated with the other rainfall zones. The driving forces for zone 2 are not fully understood.

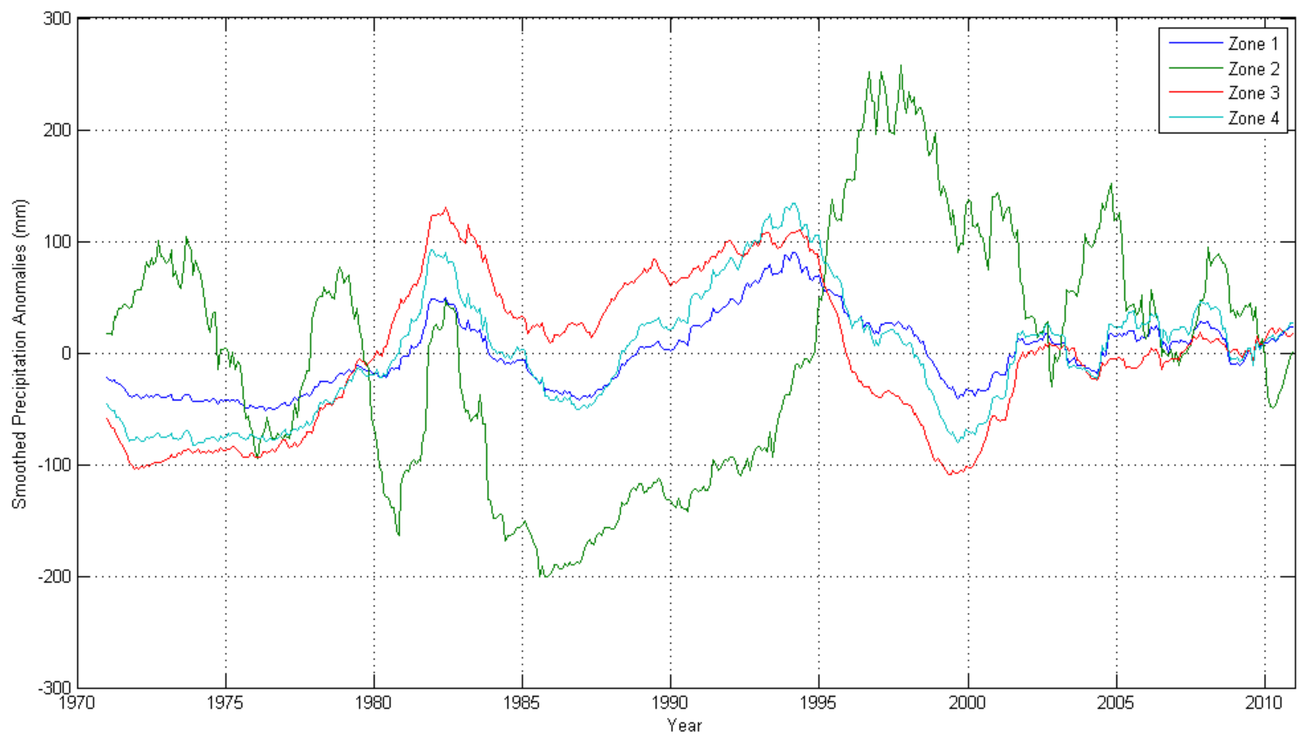


Figure 20: All smoothing was done at a 24-month running mean. Anomalies were determined relative to the base period 1970-2010.

Table 16: Correlation between Jamaica's rainfall zones. Bold numbers are statistically significant at the 95% level.

	ZONE 1	ZONE 2	ZONE 3	ZONE 4
Zone 1	1.000	0.244	0.754	0.966
Zone 2	0.244	1.000	-0.055	0.363
Zone 3	0.754	-0.055	1.000	0.675
Zone 4	0.966	0.363	0.675	1.000

Ten indices representing rainfall extremes were computed using daily station data for thirteen stations across the island (at least 2 per rainfall zone). Table 17 shows the average trend calculated on the basis of using all nine stations. Figures 21 and 22 show the station trends for eight of the indices.

In general, for the island as a whole, the intensity and occurrence of extreme rainfall events have been increasing over the seventy-year period 1940-2010. The trend is positive and increasing for all indices of extreme rainfall when averaged over the nine stations. There are positive trends with respect to annual total wet-day precipitation (PRCPTOT), annual total precipitation on the wettest days on record (R95 and R99), monthly maximum one and five-day precipitation (RX1 and RX5) and the proportion of rainfall intensity to rainfall occurrence (SDII). The averaged indices indicate a decrease in consecutive dry days.

Figures 21 and 22 show some sub-island distinctions. The plotted stations suggest that the entire island (as represented by the plotted stations) has experienced a positive (though small) rise in annual total precipitation (PRCPTOT). The largest relative trend is evident in the East (zone 2) stations. There is a distinction between the north and west versus the south and interior stations with respect to dry spells or consecutive dry days (CDD). The former regions reflect a decrease in consecutive dry days while the latter indicate relatively larger increases (Figure 21c). The situation almost reverses when consecutive wet days (CWD) or the length of wet spells are considered. The occurrence of heavy rainfall events (R10 and R20) has also increased across most stations with largest magnitude trends in the northwest, central and southeast (not shown). In general, largest changes in most rainfall indices have occurred in Westmoreland and Portland to the extreme west and east of the island.

Table 17: Table showing mean trend values for rainfall extreme indices.

INDEX	DEFINITION	TREND	UNITS
CDD	Annual maximum number of consecutive dry days	-1.5	Days
CWD	Annual maximum number of consecutive wet days	0.2	Days
PRCPTOT	Annual Total Precipitation	71.3	Mm
R10mm	Annual count of days when rainfall above 10 mm	1.2	Days
R20mm	Annual count of days when rainfall above 20 mm	1.0	Days
R95P	Very wet days	18.9	Mm
R99P	Extreme wet days	6.2	Mm
SDII	Simple daily intensity index	0.4	mm/day
RX1	Maximum 1-day precipitation	4.4	Mm
RX5	Maximum 5-day precipitation	10.5	Mm

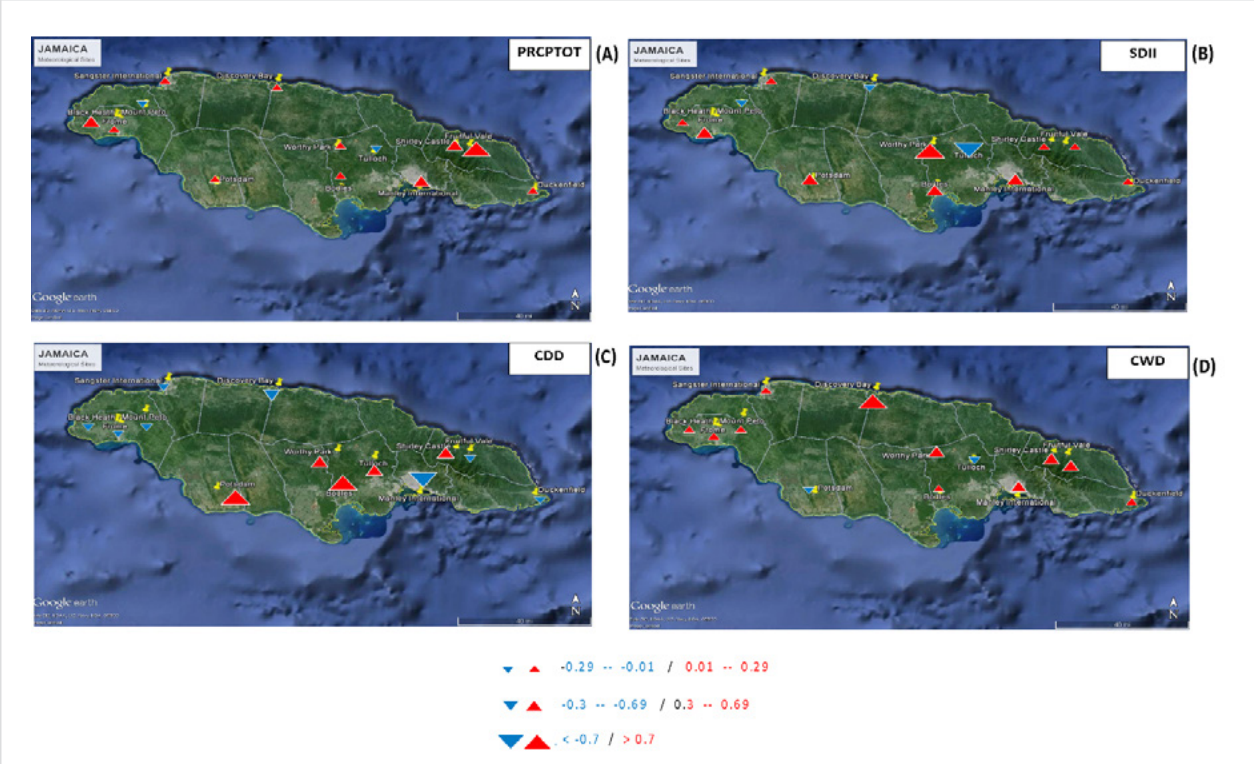


Figure 21: Trends in selected historical rainfall extremes across Jamaica for (A) Annual Total Precipitation (PRCPTOT), (B) Simple Daily Intensity Index (SDII), (C) Consecutive Dry Days (CDD) and (D) Consecutive Wet Days (CWD).

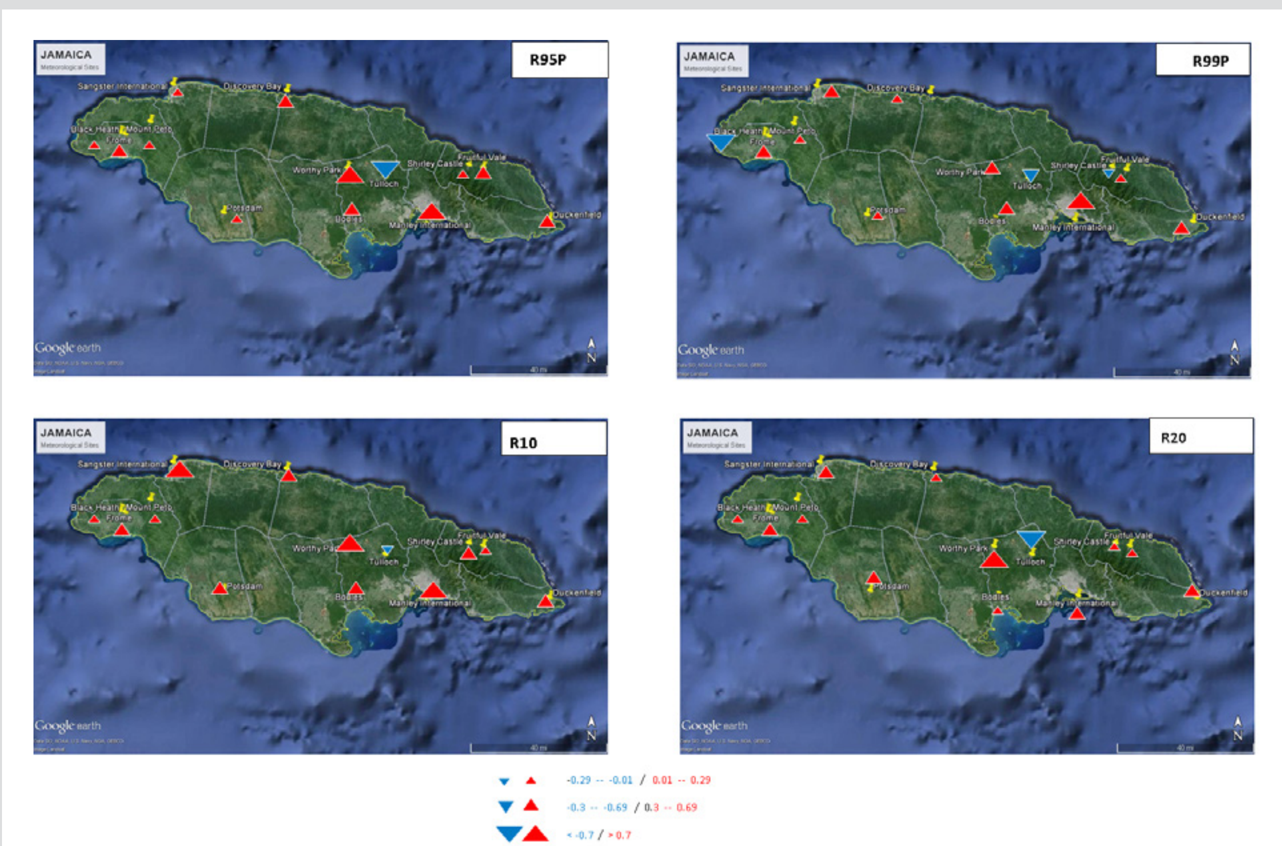


Figure 22: Trends in selected historical rainfall extremes across Jamaica for (A) Very Wet Days (R95P), (B) Extreme Wet Days (R99P), (C) Annual count of days when rainfall above 10 mm (R10) and (D) Annual count of days when rainfall above 20 mm (R20).

4.3. Hurricanes

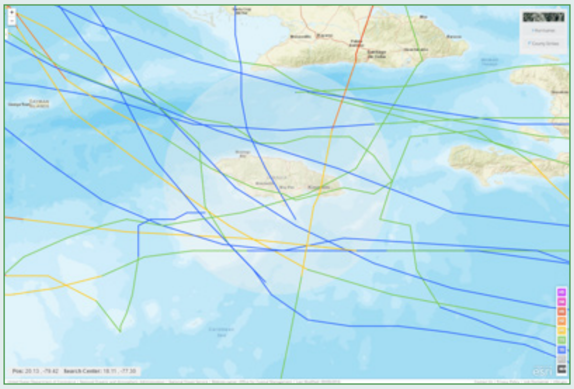
Most measures of Atlantic hurricane activity show a substantial increase since the early 1980s when high-quality satellite data became available (Bell et al., 2012; Bender et al., 2010; Emanuel, 2007; Landsea and Franklin, 2013). These include measures of intensity, frequency, and duration as well as the number of strongest (Category 4 and 5) storms. There is little consensus, however, that the increases in hurricane activity are attributable primarily to global warming. The El Niño-Southern Oscillation (ENSO) phenomenon also plays a significant role in modulating hurricane activity in the North Atlantic from year to year. During an El Niño vertical shear is strong across the Caribbean basin resulting in fewer Atlantic hurricanes. The opposite is true for La Niña. El Niño and La Niña also influence where the Atlantic hurricanes form. For example, during El Niño (La Niña) events fewer (more) hurricanes and major hurricanes develop in the deep Tropics from African easterly waves.

Figure 23 shows the historical paths of tropical storms and, depressions (panel a) and hurricanes (panel b) that passed within 200 km of Jamaica (panel b) between 1950 and 2015. The panels show that Jamaica was impacted by 10 hurricanes during that period. The temporal distribution of the 10 hurricanes indicates one each in the 1960's and 1970's, 2 in the 1950's and 2 in the 1980's, and 4 since the 2000's. Panel (a) indicates that Jamaica was impacted by an equally large number of tropical storms over the same time period.

The panels also show that the preferred path of hurricanes that impact Jamaica is from the southeast to northwest, with the majority approaching from south of the island. This makes the south coast of Jamaica more susceptible to highest wind, rain and surge events associated with hurricane passage. This susceptibility is captured in Tables 18-21 and Figure 25. For these tables and figure, Jamaica was divided into the 23 grid boxes shown in Figure 24. Table 15 then shows the number of times a grid box was impacted by a hurricane (including category) over the period 1950-2014, as determined by a count of the number of hurricanes whose centre passed within 50, 100, 150 and 200 km of the centre of the grid box. Figure 25 maps the probability that a storm centre will pass within 50 km of a grid box. The centre and northern regions of the islands (grid boxes 1 -14) experience marginally fewer storm centres than those in the south (grid boxes 15 – 23). This is also reflected in the probability map. South-eastern Jamaica (grid boxes 20-23) and the southernmost tip of Jamaica (grid box 23) in comparison have the highest impact count and the highest probability of influence.

It is also noted that the majority of the storms or hurricanes impacting the island of Jamaica are of categories 3 and 4 strength (Tables 18-21). This likely reflects the downstream position of Jamaica relative to the main development region of hurricanes in the tropical Atlantic east of the Lesser Antilles. Jamaica seems to be hardly impacted by a category 2 hurricane, whilst category 4 storms have the greatest impact on the island in terms of grid boxes impacted.

a)



b)

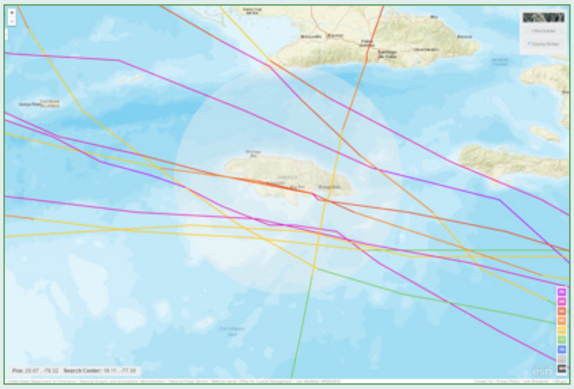


Figure 23: (a) All hurricanes impacting the Caribbean basin between 1950 and 2015. (b) Tropical Depressions and Tropical Storms. Source: http://coast.noaa.gov/hurricanes/.

Tables 18-21: Total number of hurricanes (by category) passing within 50-km, 100-km, 150-km and 200-km Jamaica from 1950 to 2015. Impact on grid boxes previously defined are shown.

	50-km																						
	Grid Box																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Category 1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	1	1	1
Category 2	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Category 3	1	2	2	0	0	0	1	2	2	2	2	1	1	1	2	2	2	1	1	1	1	1	1
Category 4	0	0	0	1	1	1	0	0	0	0	0	1	2	1	1	0	0	1	1	1	1	1	3
Category 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of Hurricanes Impacting Grid Box	2	2	2	1	1	1	2	2	2	2	2	2	4	3	3	2	2	2	3	3	3	4	5

	100-km																						
	Grid Box																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Category 1	2	0	0	0	1	1	2	2	1	0	1	1	1	1	3	3	4	3	3	2	2	2	4
Category 2	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	1	1	0
Category 3	2	2	2	1	2	1	2	2	2	1	1	2	1	1	2	1	1	1	1	1	1	1	1
Category 4	2	2	1	2	2	2	2	3	3	4	4	4	2	1	2	3	4	4	4	3	3	3	3
Category 5	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	1	1	0
Number of Hurricanes Impacting Grid Box	6	4	3	3	5	5	6	7	6	5	6	7	6	5	7	7	9	8	8	8	8	8	8

	150-km																						
	Grid Box																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Category 1	5	5	5	4	3	2	5	5	4	4	4	4	3	3	5	4	4	4	4	4	5	5	4
Category 2	0	0	0	0	1	1	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1	1	0
Category 3	2	2	3	2	1	1	2	1	2	2	1	1	1	1	1	1	2	1	1	1	1	1	2
Category 4	3	4	4	5	5	4	3	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4
Category 5	0	0	0	0	0	1	0	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0
Number of Hurricanes Impacting Grid Box	10	11	12	11	10	9	10	10	10	10	11	11	10	10	10	9	10	10	10	11	12	12	10

	200-km																						
	Grid Box																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Category 1	7	6	6	6	5	5	6	6	6	6	5	4	6	8	6	6	5	4	4	6	7	8	4
Category 2	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	0	0	1
Category 3	2	1	2	2	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	2	1
Category 4	7	6	6	5	5	5	6	7	7	5	5	5	4	4	5	6	5	5	4	4	4	4	5
Category 5	0	0	0	1	1	1	0	0	0	1	1	1	1	1	0	0	1	1	1	1	1	1	1
Number of Hurricanes Impacting Grid Box	17	14	14	14	12	12	13	14	14	13	12	11	13	14	13	14	13	12	11	13	13	15	12

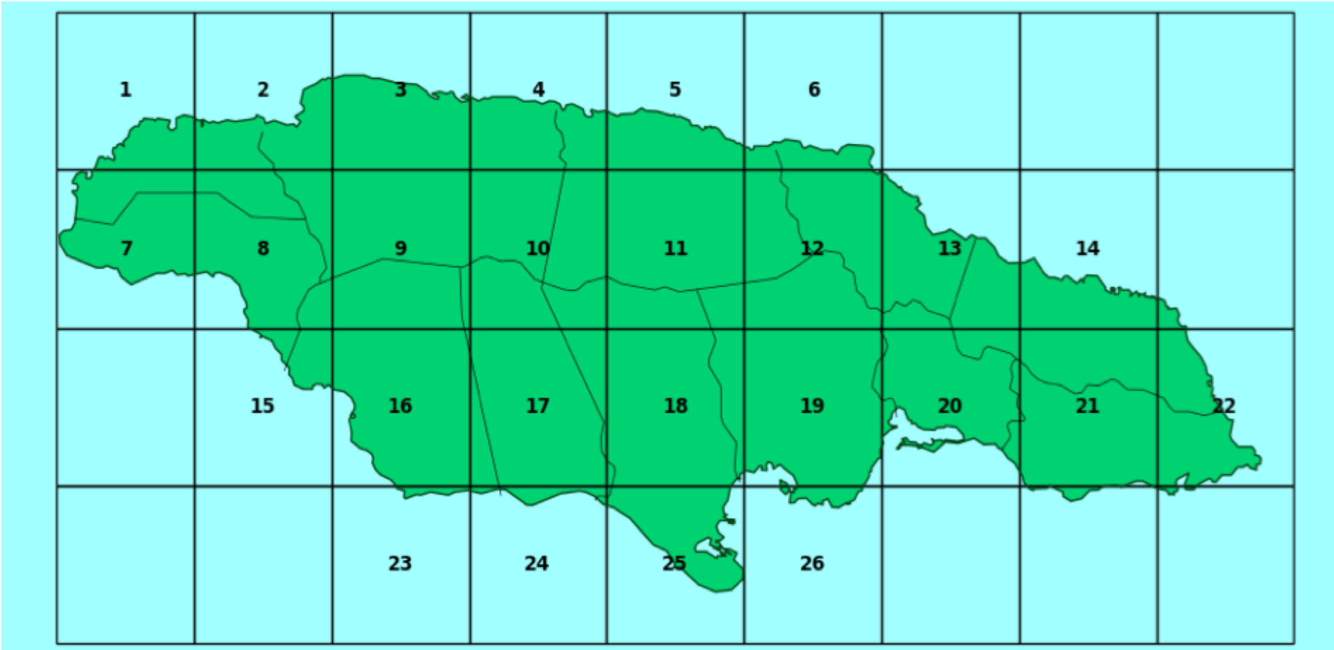


Figure 24: The 23 Grid locations used to determine hurricanes passing Jamaica within a radius of 100km.

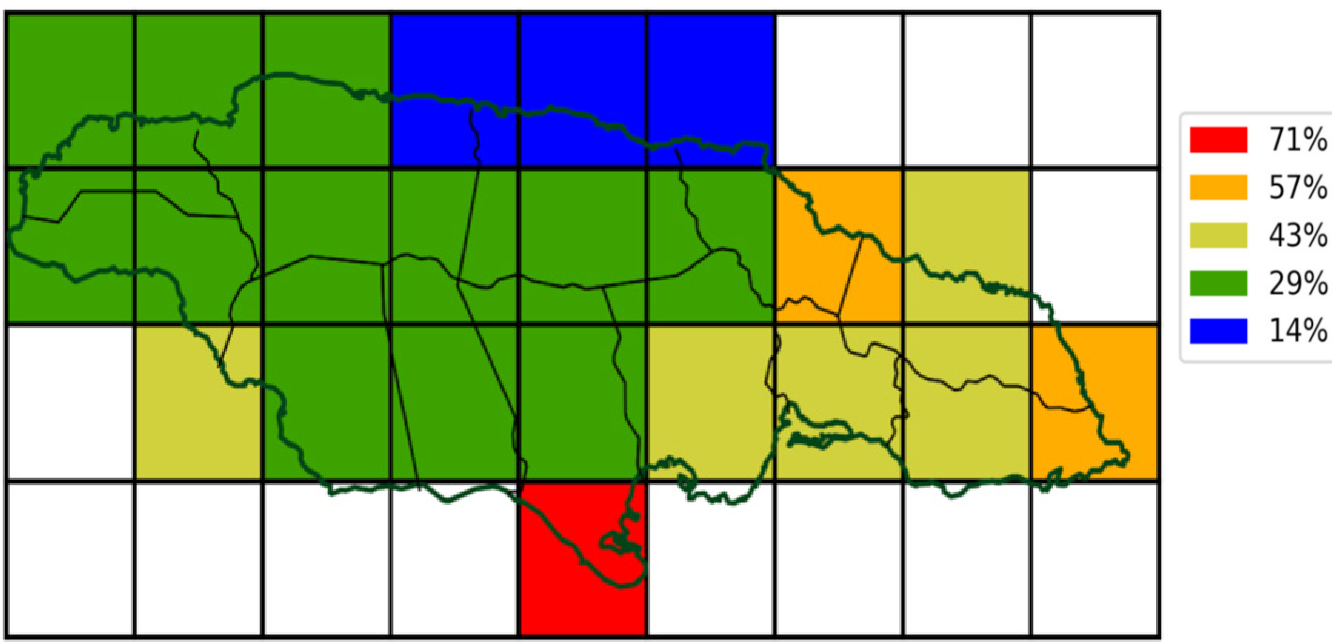


Figure 25: Map of Jamaica showing the probability of a hurricane passing within 50km of a grid box based on 66 years (1950 – 2015) of historical data.

4.4. Droughts and Floods

A meteorological drought is a period of well-below-normal precipitation that spans a few months to a few years. The Standardized Precipitation Index (SPI) allows for the determination of the rarity of drought events (or anomalously wet events) on a variety of time scales. For SPI analysis, positive values above +1 indicate wetter than normal whilst those below -1 indicate drier than normal. Values below -2 are considered to be extremely dry, and above +2 to be extremely wet. SPI analyses were done for the time series representing the rainfall zones using data up to 2012.

For SPI-12 (not shown) representing interannual variability, the Interior (zone 1), West (zone 3) and Coasts (zone 4) again co-vary, with significant drying in the early to mid-1970's. All zones experienced severe droughts centred on the year 2000, and again in 2010 i.e. these were two recent all-Island droughts. There are other periods (for example, early 1980s) when the coast and interior experience drought conditions which are not seen in the west. The east (Zone 2) is noted again as seemingly having a different underlying forcing mechanism which resulted in a prolonged dry period from 1985-1995, while the other three zones experience varying degrees of wet and dry. All four zones display more interannual swings between extreme conditions i.e. more flood and droughts since the 2000s as opposed to the decades before.

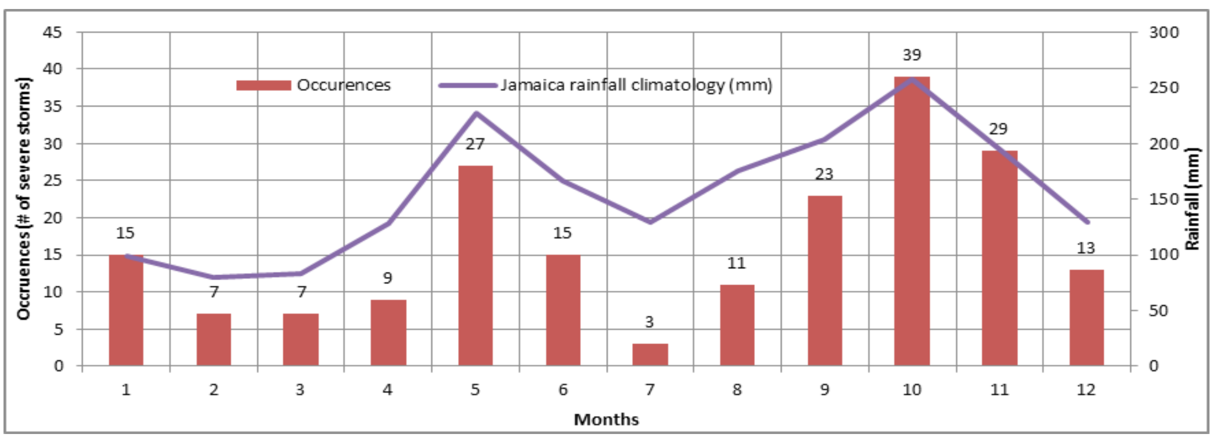
Table 22 shows that the number of drought occurrences for each zone for both SPI-3 (seasonal or 3-month drought) and SPI-12 (year long drought) over the period 1970-2012. The number of seasonal droughts is expectedly greater than the number of year-long drought periods. The middle of the island represented by the interior and coastal zones (zones 1 and 4) is far more prone to short-term drought than the western or eastern ends. The coastal areas (zone 4) have been far more prone to year-long drought occurrence than the rest of the island.

Table 22: The number of dry periods as determined by SPI3 and SPI12 in each rainfall zone.

SPI	Number of Dry Periods			
	Interior (zone 1)	East (zone 2)	West (zone 3)	Coasts (zone 4)
3	34	23	25	36
12	6	6	5	11

Burgess et al. (2015) and Taylor et al. (2014) offer a comprehensive analysis of floods in Jamaica over the period 1850-2010. Flood occurrences in Jamaica have a bimodal pattern (Figure 26) which mirrors that of the rainfall climatology previously shown in Chapter 3, with a minor peak in April-May-June (27% of occurrences) and a maximum in September-October-November (39%). Not surprisingly, the mean monthly distribution of floods is statistically correlated with the mean rainfall climatology suggesting that any changes in the mean rainfall regime will likely be accompanied by changes in the frequency of severe floods. Figure 26 also shows an increasing trend in flood occurrences over the last century to present with the period between 2000 and 2010 being the most intense decade on record with 35 flood events.

Spectral analysis of the annual occurrences of severe floods reveals 30 and 9-year cycles as well as minor 3 and 6-year cycles suggesting large-scale controls of floods possibly by the Atlantic Multi-decadal Oscillation (AMO) and ENSO events. Hurricanes, depressions and waves account for 46% of all the devastating flood events in Jamaica while storms and troughs account for 21%. Rainfall events of one and two days durations of rainfall dominate (67%) of the occurrence of severe events.



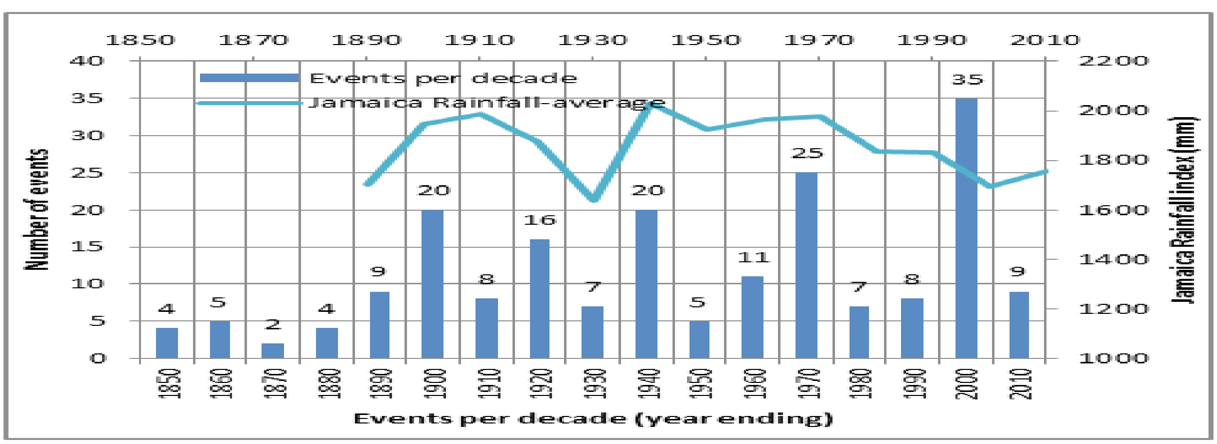


Figure 26: Severe flood climatology for Jamaica for the period 1850 to 2010 for 198 events (top). Occurrences of severe flood events per decade for the period 1850 to 2010 with decadal mean Jamaica Rainfall index (mm). Source: Burgess et al. (2015).

4.5. Sea Levels

Global mean sea levels (GMSL) continue to show a sustained increase (Figure 27) with sea level rates almost doubling from 1.7 mm/year to 3.1 mm/year through the 20th century (Table 23). Recent studies such as Yi et al. (2015) highlight the increasing risk of accelerated sea level rise with sustained increases in global and regional temperatures, with some regions of the globe recording a rate of increase of 4.5 ± 0.4 mm/year from 2010-2014. Recent satellite altimetry measurements also indicate a global rate of 3.3 ± 0.4 mm/year from 1993 to 2016. In 2015, sea level anomalies achieved a record high of approximately 80 mm above the 1993 average because of a very strong El Niño (Merrifield et al., 2016).

Recent studies such as Yi et al. (2015) highlight the increasing risk of accelerated sea level rise with sustained increases in global and regional temperatures, with some regions of the globe recording a rate of increase of 4.5 ± 0.4 mm/year from 2010-2014.

Trends within the Caribbean closely follow the global trend. Tables 24 and 25 give sea level trends in the Caribbean basin as measured from tide gauge data. In comparison, current satellite altimetry measurements show that Caribbean trends are approximately 2.5 ± 0.4 mm/year, which is consistent with the trends deduced from measurements by Torres and Tsimplis (2013) (Table 25). In more recent years, the region has seen larger increases in sea levels due to the influence of warmer El Niños (Blunden et al., 2016). During the 2015 El Niño, sea level changes within the Caribbean reached a maximum of 11.3 cm above the mean sea level.

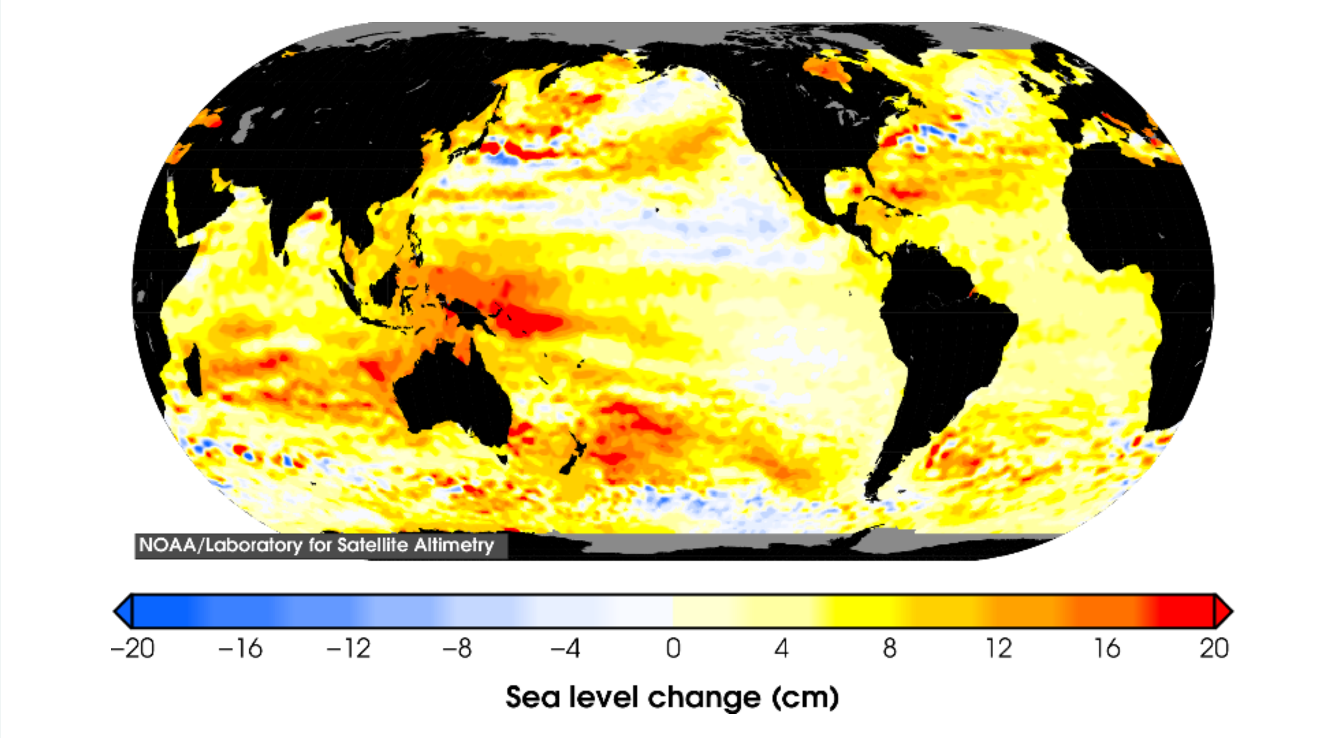


Figure 27: Total sea level rise (in cm) relative to the mean sea level averaged over 1993-2014. Source: NOAA/Laboratory for Satellite Altimetry.

Table 23: Rates and absolute changes in global mean sea level from 1901 to 2014.

PERIOD	RATE (MM/YEAR)	TOTAL SEA LEVEL RISE (M)	REFERENCE
1901 - 1990	1.5 ± 0.5	-	IPCC (2013)
1901 - 2010	1.7 ± 0.2	0.19 ± 0.02	
1971 - 2010	2.0 ± 0.2	-	
1993 - 2012	3.2 ± 0.4	-	
2005 – 2014	3.1 ± 0.4	-	Yi et al. (2015)

Sea levels measured at Port Royal, Jamaica, indicate an increase which has been estimated at 1.66 mm/year over a 17.8-year span.

Sea levels measured at Port Royal, Jamaica, indicate an increase which has been estimated at 1.66 mm/year over a 17.8-year span (Table 25). Satellite altimetry data from the TOPEX/Poseidon-2 experiments averaged over the Jamaican coasts also confirm a substantial increase in sea surface heights since 1950. Sea surface height data, however, remain inconsistent and limited for the coastal regions of Jamaica. There have been a number of studies on coastal erosion and storm surge mapping for areas such as Long Bay, Negril (for example, Robinson et al., 2012) and Kingston. Though these studies do not focus on measuring the contribution of global warming to coastal recession rates, Robinson et al. (2012) maintain that sea level rise plays a significant role in the sustained increases in shoreline recession rates seen along Long Bay, Negril. Interannual sea-level variability also accounts for a significant part (approximately one-third) of the total sea-level variability. Palanisamy et al. (2012) observe that interannual sea-level variability in the north Caribbean is higher than for the southern Caribbean and strongly correlated with El Niño.

Table 24: Mean rate of sea level rise averaged over the Caribbean basin.

PERIOD	RATE (MM/YEAR)	INFORMATION SOURCE
1950 - 2009	**1.8 ± 0.1**	**Palanisamy et al. (2012)**
1993 - 2010	**1.7 ± 1.3**	**Torres and Tsimplis (2013)**
1993 - 2010	**2.5± 1.3**	**Torres and Tsimplis (2013), after correction for Global Isostatic Adjustment (GIA)**

Table 25: Tide gauge observed sea-level trends for stations across the Caribbean region.
Adapted from Torres and Tsimplis (2013).

	COUNTRY	SPAN YEARS	% OF DATA	TREND	MONTHS	GAUGE CORRECTED
Puerto Limon	Costa Rica	20.3	95.1	1.76±0.8	216	2.16±0.9
Cristobal	Panama	101.7	86.9	1.96±0.1	566	2.86±0.2
Cartagena	Colombia	44	90	5.36±0.3	463	5.46±0.3
Amuay	Venezuela	33	93.4	0.26±0.5	370	0.26±0.5
Cumana	Venezuela	29	98.6	0.96±0.5	331	0.76±0.6
Lime Tree	US Virgin Islands	32.2	81.9	1.86±0.5	316	1.56±0.5
Magueyes	Puerto Rico	55	96.2	1.36±0.2	635	1.06±0.2
P. Prince	Haiti	12.7	100	10.76±1.5	144	12.26±1.5
Guantanamo	Cuba	34.6	89.9	1.76±0.4	258	2.56±0.6
Port Royal	**Jamaica**	**17.8**	**99.5**	**1.66±1.6**	**212**	**1.36±1.6**
Cabo Cruz	Cuba	10	90	2.26±2.8	108	2.16±2.8
South Sound	Cayman	20.8	87.6	1.76±1.5	219	1.26±1.5
North Sound	Cayman	27.7	89.2	2.76±0.9	296	2.26±0.9
C. San Antonio	Cuba	38.3	76.7	0.86±0.5	353	0.36±0.5
Santo Tomas	Mexico	20	85.4	2.06±1.3	205	1.76±1.3
Puerto Cortes	Honduras	20.9	98	8.66±0.6	224	8.86±0.7
Puerto Castilla	Honduras	13.3	100	3.16±1.3	160	3.26±1.3

5. Climate Scenarios and Projections

5.1. Introduction

Climate projections for Jamaica are provided by climatic variable from a suite of GCMs, two RCMs and from statistical downscaling (see again chapter 2). The use of each of these sources represents a refinement of scale. That is, the GCMs first provide country scale projections therefore they provide a mean climate change profile for Jamaica as a whole over the range of RCPs and for four time slices. In comparison, the RCMs provide sub-island details. The PRECIS 25 km simulations give a range of future projections under a high emissions scenario or for a worst-case scenario (see again chapter 2). Because of the number of grid boxes available, the data presented are summarised over Jamaica's four rainfall zones. However, the reader is encouraged to check out the ReCORD tool (see chapter 8 on Climate Resources) if projections from the PRECIS RCM for a specific grid box shown in Figure 3 are required. The 20 km RegCM run is also used to provide future projections but for a medium emissions scenario and only over the grid boxes corresponding to the six selected towns and cities noted in Chapter 2. It is noted that all six of these grid boxes lie along the coast, and therefore they all fall within Jamaica's rainfall zone 4. These projections are an example of sub-zonal variations. Finally, statistical downscaling provides future projections of temperature and rainfall extremes using data from the weather station located at the Norman Manley International Airport.

The future projections of this chapter are presented as maps, plots and tables. A summary of the GCM, RCM and statistically downscaled results are provided in narrative form at the beginning of the sections for temperature and rainfall projections.

Irrespective of the model used or scenario examined, Jamaica continues the warming trend seen in the historical data through to the end of the century.

5.2. Temperature

Irrespective of the model used or scenario examined, Jamaica continues the warming trend seen in the historical data through to the end of the century. Major points to note about the future temperatures relative to a model baseline are outlined below. Refer to Section 3.2 (page 17) for observed changes from historical baseline.

» The GCMs suggest that the range of the mean temperature increase (°C) over all four RCPs will be 0.49°–0.57°C by the 2020s; 0.65-0.84 °C by the 2030s, 0.85°-1.80°C by the 2050s and 0.82-3.09 °C for 2081-2100 with respect to a 1986-2005 model baseline.

» Increases will be of the same approximate magnitude for maximum and minimum temperatures. Projected changes for minimum annual temperature are 0.48°-0.57°C by the 2020’s, 0.86°-1.53°C by the 2050’s, and 0.82°-3.10°C by the end-of-century. Projected changes for maximum annual temperature are 0.49°-0.58°C by the 2020’s, 0.86°-1.53°C by the 2050’s, and 0.82°-3.12°C by the end-of-century.

» The RCM ensemble using the high emissions scenario suggests increases of up to 4.0 °C for the high emissions (A1B) scenario for the sub-island regions by the end of the century. This is in general higher than the values projected by the GCMs (including for RCP4.5). This is expected since the GCM average results across the entire country. Table 26 below summarises the range of mean annual temperature increase seen across the gird boxes comprising each of the four sub-island rainfall zones.

Table 26: Range of temperature change across the grid boxes covering Jamaica’s four rainfall zones from an RCM ensemble running the A1B scenario. See again Figure 3 for grid boxes and Table 3 for grid boxes in each zone.

		WEST	COASTS	INTERIOR	EAST
Tmean	2020s	1.23 – 1.32	1.18 – 1.31	1.17 – 1.36	1.22 – 1.30
	2030s	2.04 – 2.79	1.48 – 2.83	1.83 – 2.26	1.92 – 2.06
	2050s	2.77 – 2.96	2.11 – 2.98	2.51 – 3.12	2.65 – 2.85
	EOC	3.40 – 3.69	2.76 – 3.62	3.12 – 3.90	3.22 – 3.48
Tmin	2020s	1.35 – 1.47	0.92 – 1.12	1.21 – 1.47	1.23 – 1.35
	2030s	2.13 – 2.88	-	1.88 – 2.39	1.92 – 2.10
	2050s	2.55 – 3.06	-	2.52 – 3.20	2.58 – 2.84
	EOC	3.35 – 3.92	-	3.24 – 4.04	3.22 – 3.56
Tmax	2020s	1.16 – 1.24	0.99 – 1.64	1.15 – 1.32	1.21 – 1.28
	2030s	1.89 – 3.39	-	1.84 – 2.28	1.93 – 2.08
	2050s	2.47 – 3.58	-	2.53 – 3.17	2.67 – 2.88
	EOC	3.29 – 4.19	-	3.32 – 4.03	3.42 – 3.67

» There is some spatial variation (across the country and even within Blocks) with coastal regions and eastern Jamaica generally showing slightly smaller increases in temperature variables than interior regions and western Jamaica.

» August-September-October (ASO) has slightly higher values of temperature change than other times of the year.

» Results for the six selected boxes covering major cities or towns similarly reflect increases in temperatures through the end of the century. The south coast grid box over Portmore shows slightly greater warming than the other five grid boxes. Greatest warming is observed for the late wet season (August-September-October) and the dry season (November-December).

» Mean daily maximum temperature each month at the Norman Manley International Airport station is expected to increase by 0.8-1.3°C (1.2-2.0°C) across all RCPs by early century (mid-

century). Warming of daily minimum temperatures is anticipated to be greater: 1.2-1.7°C (1.7-3.6°C) by early century (mid-century).

» The maximum daily maximum temperature each month is expected to increase by 0.5-1.3°C (1.1-2.0°C) across all RCPs by early century (mid-century) at the Norman Manley International Airport station. The minimum daily minimum temperature each month is also expected to increase by 1.1-1.8°C (1.4-2.4°C) by early century (mid-century).[1]

» The annual frequency of warm days/nights (days when the maximum/minimum temperature is greater than the 90th percentile) in any given month at the Norman Manley International Airport station may increase by 2-12 (4-19) days across all RCPs by early century (midcentury). The annual frequency of cool days/nights (days when the maximum/minimum temperature is less than the 10th percentile) in any given month is expected to decrease particularly for the traditionally cooler month of January-March by up to 6 days (7 days) by early century (mid-century).

5.2.1. GCMS

Tables 27–29 show the range of projected changes for minimum, mean, and maximum annual temperatures with respect to a 1986-2005 baseline period from the suite of GCMs. The projections are illustrated as time series in Figure 28.

1 The change in the lowest minimum temperature identified for January was up to 11.8° and is excluded from the reported range due to its magnitude and implications.

Table 27: Mean annual absolute temperature change for Jamaica with respect to 1986-2005. Change shown for four RCP scenarios. *Source: AR5 CMIP5 subset, KNMI Climate Explorer.*

	Tmean											
	2020's			2030's			2050's			End of century		
Averaged over	2020-2029			2030-2039			2050-2059			2081-2100		
	min	mean	max	min	mean	max	min	mean	max	min	mean	max
rcp26	0.30	0.53	0.93	0.43	0.68	1.17	0.43	0.86	1.52	0.09	0.82	1.67
rcp45	0.20	0.53	0.89	0.34	0.73	1.18	0.54	1.10	1.80	0.84	1.54	2.55
rcp60	0.28	0.49	0.77	0.44	0.65	1.12	0.72	1.00	1.69	1.15	1.86	2.91
rcp85	0.25	0.57	0.93	0.46	0.84	1.37	0.91	1.52	2.32	2.10	3.09	4.49
Range of mean:	0.49 to 0.57			0.65 to 0.84			0.85 to 1.80			0.82 to 3.09		

Table 28: Mean annual minimum temperature change for Jamaica with respect to 1986-2005. Change shown for four RCP scenarios.
Source: AR5 CMIP5 subset, KNMI Climate Explorer.

	Tmin											
	2020's			2030's			2050's			End of century		
Averaged over	2020-2029			2030-2039			2050-2059			2081-2100		
	min	mean	max	min	mean	max	min	mean	max	min	mean	max
rcp26	0.31	0.53	0.96	0.43	0.68	1.20	0.43	0.86	1.55	0.04	0.82	1.69
rcp45	0.19	0.53	0.89	0.33	0.72	1.19	0.53	1.10	1.79	0.79	1.54	2.53
rcp60	0.25	0.48	0.79	0.39	0.65	1.14	0.72	0.99	1.73	1.09	1.86	2.96
rcp85	0.31	0.57	0.98	0.44	0.84	1.44	0.89	1.53	2.39	2.07	3.10	4.55
Range of mean:	0.48 to 0.57			0.65 to 0.84			0.86 to 1.53			0.82 to 3.10		

Table 29: Mean annual maximum temperature change for Jamaica with respect to 1986-2005. Change shown for four RCP scenarios.
Source: AR5 CMIP5 subset, KNMI Climate Explorer.

	Tmax											
	2020's			2030's			2050's			End of century		
Averaged over	2020-2029			2030-2039			2050-2059			2081-2100		
	min	mean	max	min	mean	max	min	mean	max	min	mean	max
rcp26	0.30	0.53	0.89	0.40	0.68	1.14	0.44	0.86	1.50	0.13	0.82	1.64
rcp45	0.21	0.53	0.88	0.35	0.73	1.19	0.55	1.12	1.84	0.88	1.56	2.58
rcp60	0.32	0.49	0.73	0.48	0.65	1.08	0.73	1.00	1.63	1.19	1.86	2.84
rcp85	0.34	0.58	0.90	0.47	0.85	1.27	0.93	1.53	2.31	2.13	3.12	4.37
Range of mean:	0.49 to 0.58			0.65 to 0.85			0.86 to 1.53			0.82 to 3.12		

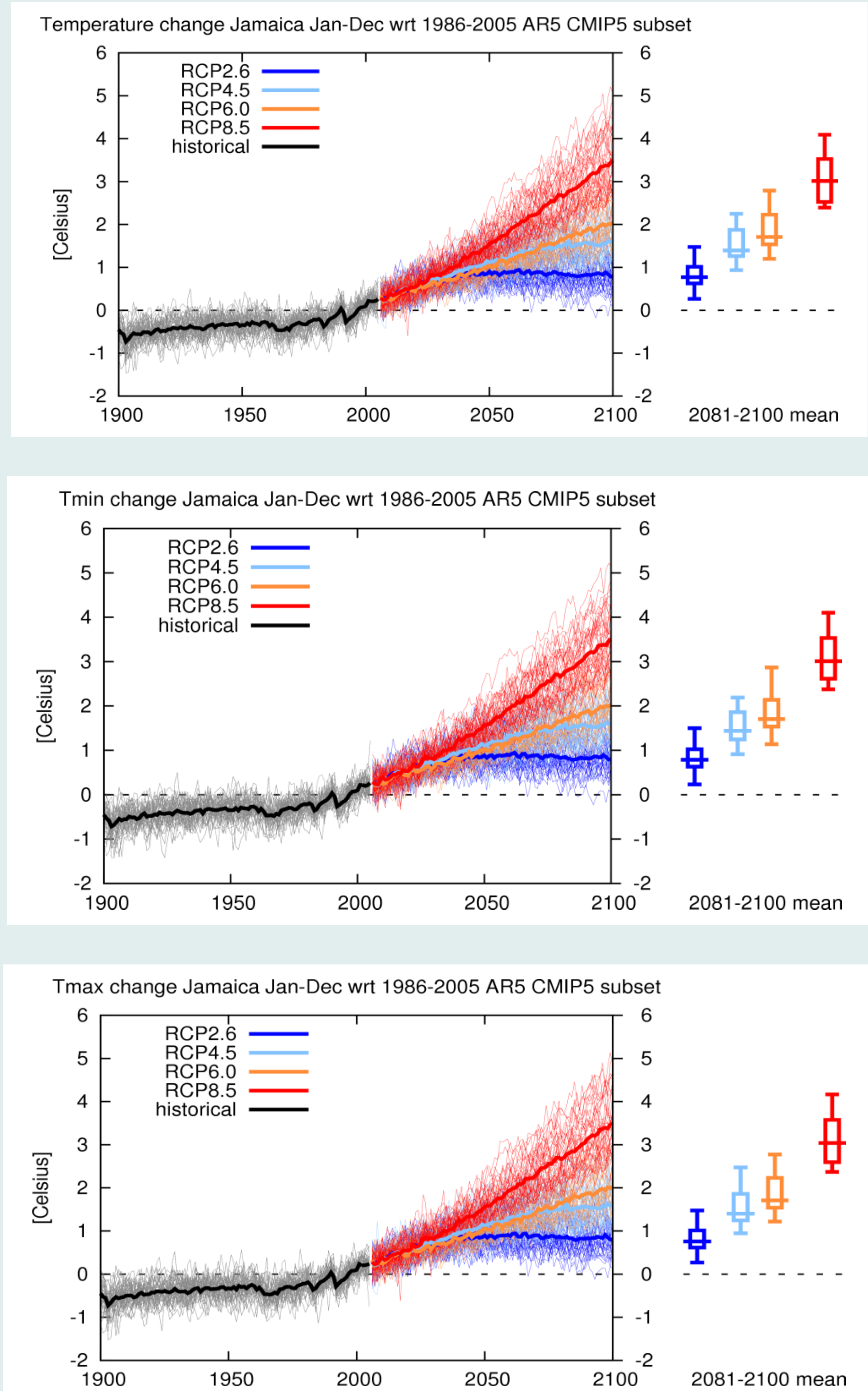


Figure 28: (a) Mean annual temperature change (°C) (b) Mean annual minimum temperature change (°C) (c) Mean annual maximum temperature change (°C) for Jamaica with respect to 1986-2005 AR5 CMIP5 subset. On the left, for each scenario one line per model is shown plus the multi-model mean, on the right percentiles of the whole dataset: the box extends from 25% to 75%, the whiskers from 5% to 95% and the horizontal line denotes the median (50%).

5.2.1. RCMS

Projections for the four rainfall zones are provided in Tables 30-41. A summary map showing absolute change per grid box of annual Mean Temperatures is given in Figure 29. Tables 42-44 show projections for the grid boxes over the five selected cities or towns.

Tables 30-33: Projected absolute changes in mean temperature by season and for annual average (°C) for the 2020's, 2030's, 2050's and 2080's relative to the 1961-1990 baseline. Data presented for the mean value of a six-member ensemble. Range shown is over all the grid boxes in the zone (see Table 2). *Source: PRECIS RCM perturbed physics ensemble run for A1B scenario.*

Table 30: West (Zone 3)				
	2020's	**2030's**	**2050's**	**2080's**
NDJ	1.23 – 1.41	2.06 – 2.22	2.59 – 2.85	3.10 – 3.58
FMA	0.99 – 1.28	1.96 – 2.10	2.47 – 2.86	3.04 – 3.63
MJJ	1.14 – 1.25	1.98 – 2.24	2.77 – 3.08	3.27 – 3.76
ASO	1.29 – 1.38	2.14 – 2.40	2.88 – 3.10	3.53 – 3.80
ANNUAL	1.23 – 1.32	2.04 – 2.79	2.77 – 2.96	3.40 – 3.69

Table 31: Coasts (Zone 4)				
	2020's	**2030's**	**2050's**	**2080's**
NDJ	1.17 – 1.40	1.20 – 2.18	1.63 – 2.89	2.21 – 3.54
FMA	1.19 – 1.27	1.35 – 2.02	1.93 – 2.83	2.62 – 3.49
MJJ	1.14 – 1.22	1.67 – 2.49	2.47 – 3.32	3.20 – 3.95
ASO	1.22 – 1.37	1.71 – 2.63	2.42 – 3.17	3.04 – 3.81
ANNUAL	1.18 – 1.31	1.48 – 2.83	2.11 – 2.98	2.76 – 3.62

Table 32: Interior (Zone 1)				
	2020's	**2030's**	**2050's**	**2080's**
NDJ	1.21 – 1.43	1.87 – 2.25	2.49 – 3.00	3.05 – 3.73
FMA	1.18 – 1.32	1.81 – 2.09	2.49 – 2.88	3.19 – 3.74
MJJ	1.09 – 1.28	1.79 – 2.25	2.50 – 3.20	3.15 – 4.05
ASO	1.19 – 1.47	1.86 – 2.49	2.55 – 3.39	3.11 – 4.12
ANNUAL	1.17 – 1.36	1.83 – 2.26	2.51 – 3.12	3.12 – 3.90

Table 33: East (Zone 2)				
	2020's	**2030's**	**2050's**	**2080's**
NDJ	1.26 – 1.32	1.94 – 2.06	2.61 – 2.77	3.13 – 3.34
FMA	1.22 – 1.27	1.86 – 1.95	2.57 - 2.70	3.20 – 3.38
MJJ	1.14 – 1.21	1.87 – 2.02	2.65 – 2.86	3.27 – 3.55
ASO	1.28 – 1.38	2.00 – 2.21	2.76 – 3.04	3.30 – 3.64
ANNUAL	1.22 – 1.30	1.92 – 2.06	2.65 – 2.85	3.22 – 3.48

Tables 34-37: Projected absolute changes in maximum temperature by season and for annual average (°C) for the 2020's, 2030's, 2050's and 2080's relative to the 1961-1990 baseline. Data presented for the mean value of a six-member ensemble. Range shown is over all the grid boxes in the zone (see Table 2). *Source: PRECIS RCM perturbed physics ensemble run for A1B scenario.*

Table 34: West (Zone 3)				
	2020's	**2030's**	**2050's**	**2080's**
NDJ	1.05 – 1.13	1.73 – 2.24	2.23 – 3.01	2.83 – 3.61
FMA	0.80 – 1.12	1.63 – 2.47	2.12 – 3.39	2.68 – 3.93
MJJ	1.14 – 1.40	1.96 – 2.88	2.66 – 4.06	3.33 – 4.69
ASO	1.14 – 1.36	2.25 – 2.86	2.87 – 3.85	3.77 – 4.54
ANNUAL	1.16 – 1.24	1.89 – 3.39	2.47 – 3.58	3.29 – 4.19

Table 35: Coasts (Zone 4)				
	2020's	**2030's**	**2050's**	**2080's**
NDJ	0.96 – 1.23	1.94 – 2.67	2.63 – 3.63	3.21 – 4.18
FMA	0.73 – 1.14	1.82 – 3.21	2.34 – 4.51	2.93 – 5.04
MJJ	1.23 – 1.53	2.24 – 3.88	3.04 – 5.56	3.84 – 6.33
ASO	1.24 – 1.51	2.53 – 3.64	3.37 – 5.04	4.03 – 5.63
ANNUAL	1.15 – 1.31	2.16 – 4.51	2.87 – 4.68	3.64 – 5.25

Table 36: Interior (Zone 1)				
	2020's	**2030's**	**2050's**	**2080's**
NDJ	1.09 – 1.16	1.75 – 2.05	2.37 – 2.83	3.09 – 3.56
FMA	1.04 – 1.14	1.68 – 1.92	2.25 – 2.55	3.08 – 3.37
MJJ	1.17 – 1.52	1.93 – 2.48	2.71 - 3.58	3.56 – 4.59
ASO	1.28 – 1.59	1.98 – 2.71	2.77 – 3.73	3.54 – 4.76
ANNUAL	1.15 – 1.32	1.84 – 2.28	2.53 – 3.17	3.32 – 4.03

Table 37: East (Zone 2)				
	2020's	**2030's**	**2050's**	**2080's**
NDJ	1.11 – 1.13	1.82 – 1.93	2.48 – 2.64	3.13 – 3.33
FMA	1.05 – 1.08	1.69 – 1.77	2.28 – 2.37	3.03 – 3.17
MJJ	1.26 – 1.37	2.04 – 2.21	2.89 – 3.16	3.75 – 4.07
ASO	1.42 – 1.53	2.17 – 2.42	3.04 – 3.35	3.76 – 4.12
ANNUAL	1.21 – 1.28	1.93 – 2.08	2.67 – 2.88	3.42 – 3.67

Tables 38-41: Projected absolute changes in minimum temperature by season and for annual average (°C) for the 2020's, 2030's, 2050's and 2080's relative to the 1961-1990 baseline. Data presented for mean value of a six-member ensemble. Range shown is over all the grid boxes in the zone (see Table 2). *Source: PRECIS RCM perturbed physics ensemble run for A1B scenario.*

Table 38: West (Zone 3)

	2020's	2030's	2050's	2080's
NDJ	1.25 – 1.41	1.74 – 2.32	2.31 – 2.84	3.11 – 3.71
FMA	1.24 – 1.48	1.80 – 2.28	2.44 – 3.01	3.21 – 3.90
MJJ	1.38 – 1.48	2.03 – 2.42	2.73 – 3.21	3.49 – 4.08
ASO	1.46 – 1.59	2.03 – 2.45	2.72 – 3.22	3.52 – 4.06
ANNUAL	1.35 – 1.47	2.13 – 2.88	2.55 – 3.06	3.35 – 3.92

Table 39: Coast (Zone 4)

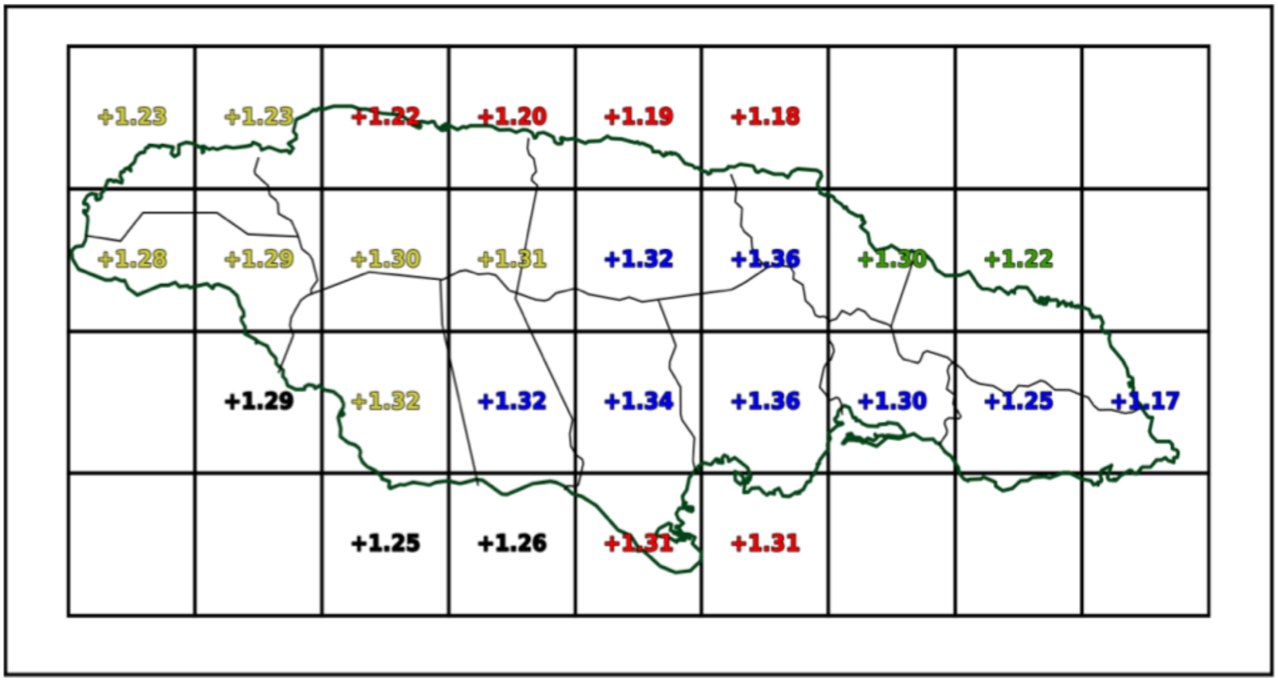
	2020's	2030's	2050's	2080's
NDJ	1.13 – 1.31	0.16 – 2.19	0.20 – 2.93	1.17 – 3.68
FMA	1.17 – 1.38	0.42 – 2.18	0.52 – 2.94	1.49 – 3.66
MJJ	1.22 – 1.37	0.72 – 2.23	0.92 – 2.95	1.95 – 3.64
ASO	1.31 – 1.45	0.63 – 2.29	0.83 – 3.07	1.79 – 3.74
ANNUAL	1.21 – 1.37	0.48 – 2.22	0.62 – 2.97	1.60 – 3.68

Table 40: Interior (Zone 1)

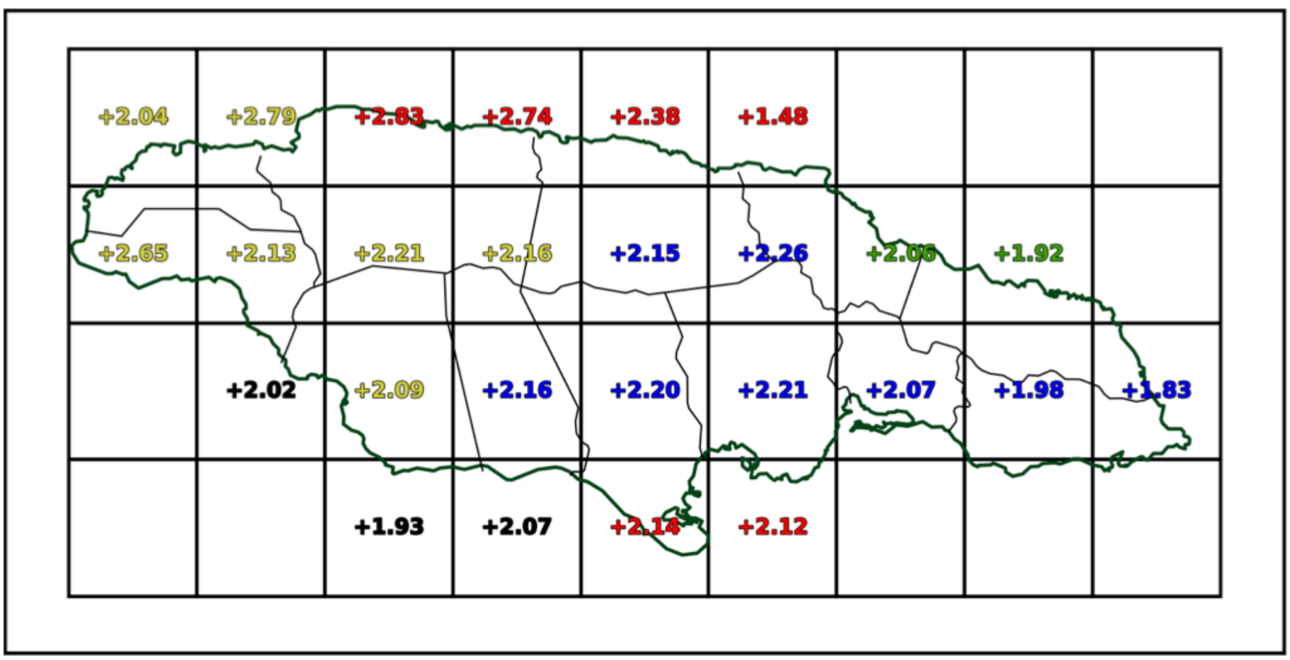
	2020's	2030's	2050's	2080's
NDJ	1.17 – 1.38	1.81 – 2.17	2.42 – 2.90	3.17 – 3.82
FMA	1.21 – 1.47	1.89 – 2.28	2.57 – 3.08	3.29 – 3.91
MJJ	1.17 – 1.48	1.88 – 2.48	2.50 – 3.29	3.22 – 4.17
ASO	1.27 – 1.64	1.93 – 2.64	2.59 – 3.55	3.27 – 4.34
ANNUAL	1.21 – 1.47	1.88 – 2.39	2.52 – 3.20	3.24 – 4.04

Table 41: East (Zone 2)

	2020's	2030's	2050's	2080's
NDJ	1.18 – 1.25	1.85 – 1.95	2.47 – 2.62	3.15 – 3.35
FMA	1.21 – 1.32	1.90 – 2.05	2.60 – 2.79	3.22 – 3.49
MJJ	1.21 – 1.34	1.92 – 2.16	2.57 – 2.88	3.21 – 3.64
ASO	1.32 – 1.48	1.98 – 2.24	2.69 – 3.05	3.29 – 3.75
ANNUAL	1.23 – 1.35	1.92 – 2.10	2.58 – 2.84	3.22 – 3.56

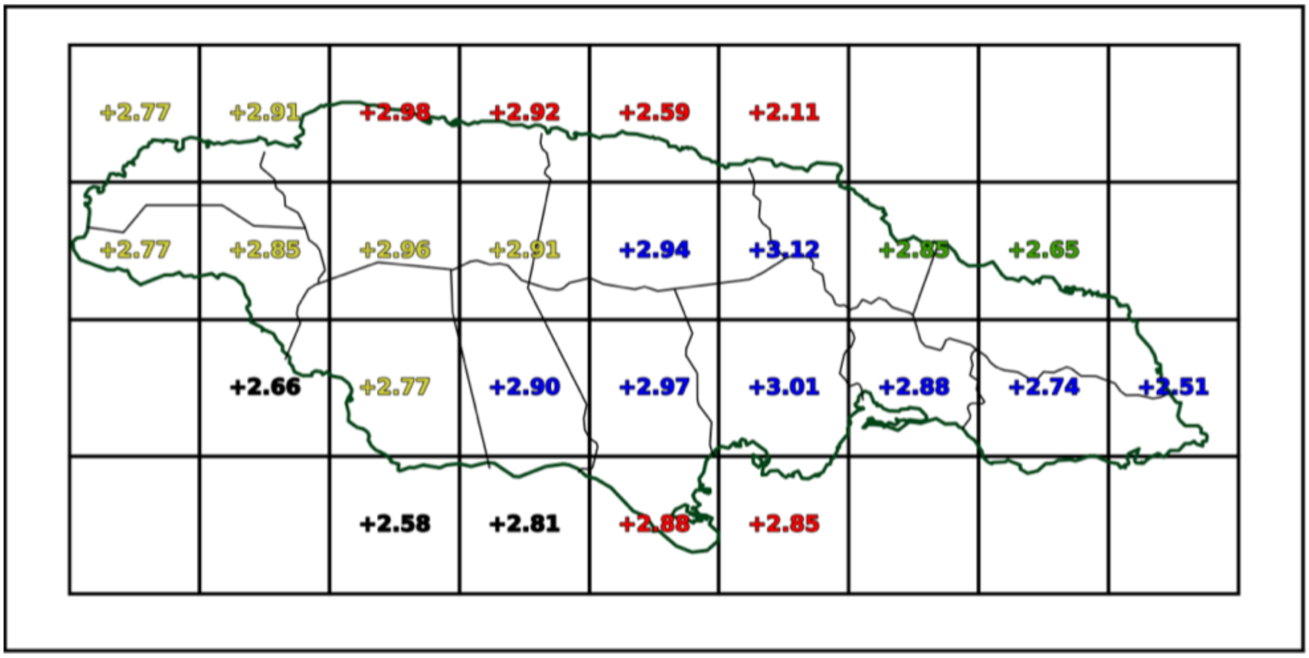


2020s

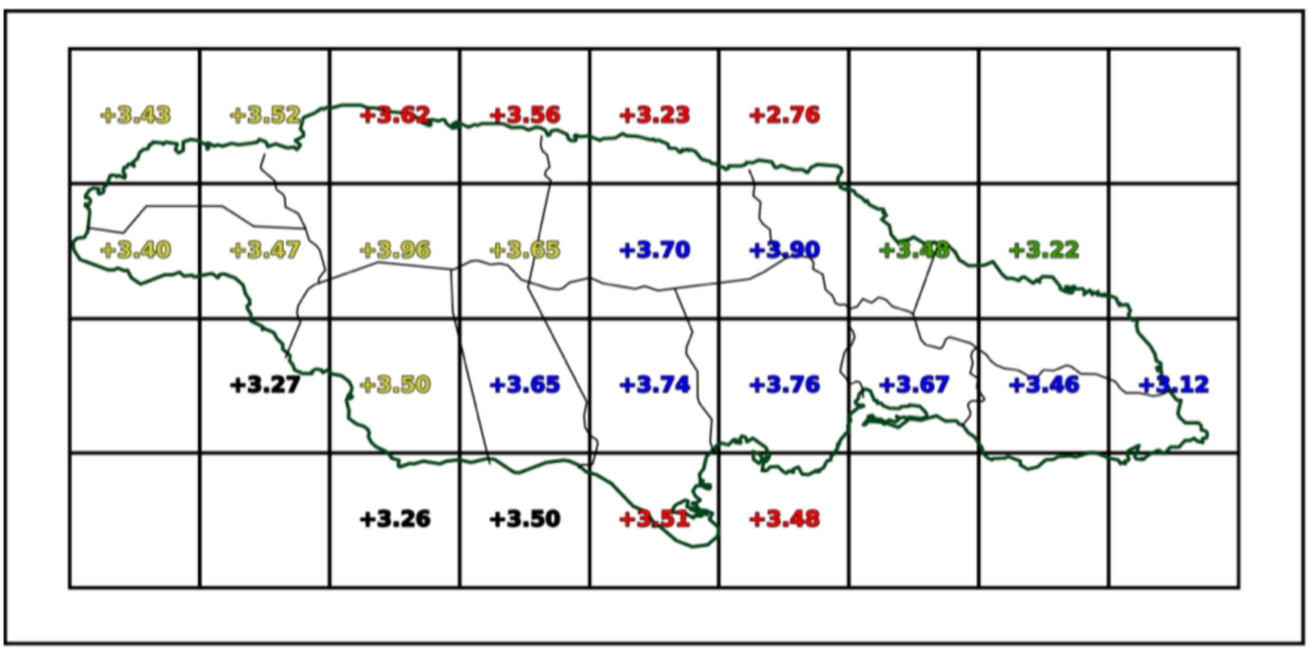


2030s

Figure 29a: Summary map showing absolute change per grid box of annual Mean Temperature (◦C) for the 2020's (top panel) and 2030s (bottom panel).
Source: PRECIS RCM PPE.



2050s



End of Century

Figure 29b: Summary map showing absolute change per grid box of annual Mean Temperature (◦C) for the 2050's (top panel) and end of century (2080-2098) (bottom panel).
Source: PRECIS RCM PPE.

Table 42: Projected absolute changes in mean temperature by season and for annual average (°C) for the 2020's, 2050's and end-of-century relative to the 1961-1990 baseline
Source: RegCM run for RCP4.5 scenario.

CHANGE IN MEAN TEMPERATURE (◦C) (20'S)						
GRID BOX	**GRID 28**	**GRID 43**	**GRID 44**	**GRID 65**	**GRID 71**	**GRID 88**
NDJ	0.82	0.79	0.80	0.78	0.75	0.81
FMA	0.65	0.67	0.80	0.67	0.69	0.68
MJJ	0.61	0.62	0.56	0.62	0.58	0.61
ASO	0.63	0.61	0.70	0.62	0.62	0.65
ANN	0.68	0.67	0.72	0.67	0.66	0.69
CHANGE IN MEAN TEMPERATURE (◦C) (50'S)						
GRID BOX	**GRID 28**	**GRID 43**	**GRID 44**	**GRID 65**	**GRID 71**	**GRID 88**
NDJ	1.14	1.16	1.23	1.15	1.22	1.15
FMA	1.16	1.16	1.18	1.19	1.14	1.18
MJJ	1.09	1.12	1.22	1.10	1.13	1.11
ASO	1.21	1.18	1.23	1.20	1.21	1.23
ANN	1.15	1.16	1.21	1.16	1.18	1.17
CHANGE IN MEAN TEMPERATURE (◦C) (EOC)						
GRID BOX	**GRID 28**	**GRID 43**	**GRID 44**	**GRID 65**	**GRID 71**	**GRID 88**
NDJ	1.65	1.68	1.74	1.64	1.72	1.65
FMA	1.38	1.40	1.39	1.40	1.43	1.39
MJJ	1.42	1.45	1.55	1.44	1.50	1.46
ASO	1.48	1.47	1.49	1.46	1.49	1.48
ANN	1.48	1.50	1.55	1.48	1.54	1.49

Table 43: Projected absolute changes in minimum temperature by season and for annual average (°C) for the 2020's, 2050's and end-of-century relative to the 1961-1990 baseline
Source: RegCM run for RCP4.5 scenario.

CHANGE IN MINIMUM TEMPERATURE (◦C) (20'S)						
GRID BOX	GRID 28	GRID 43	GRID 44	GRID 65	GRID 71	GRID 88
NDJ	0.84	0.78	0.77	0.80	0.69	0.82
FMA	0.69	0.69	0.77	0.69	0.65	0.68
MJJ	0.60	0.63	0.73	0.59	0.81	0.62
ASO	0.64	0.58	0.60	0.65	0.53	0.70
ANN	0.69	0.67	0.72	0.68	0.67	0.70
CHANGE IN MINIMUM TEMPERATURE (◦C) (50'S)						
GRID BOX	GRID 28	GRID 43	GRID 44	GRID 65	GRID 71	GRID 88
NDJ	1.15	1.16	1.23	1.15	1.28	1.13
FMA	1.15	1.16	1.34	1.21	1.36	1.20
MJJ	1.08	1.09	1.12	1.10	1.17	1.13
ASO	1.22	1.16	1.20	1.24	1.19	1.28
ANN	1.15	1.14	1.22	1.18	1.25	1.19
CHANGE IN MINIMUM TEMPERATURE (◦C) (EOC)						
GRID BOX	GRID 28	GRID 43	GRID 44	GRID 65	GRID 71	GRID 88
NDJ	1.67	1.71	1.81	1.62	1.81	1.61
FMA	1.35	1.40	1.52	1.39	1.64	1.40
MJJ	1.42	1.42	1.59	1.43	1.64	1.49
ASO	1.50	1.45	1.43	1.49	1.44	1.49
ANN	1.49	1.50	1.59	1.48	1.64	1.50

Table 44: Projected absolute changes in maximum temperature by season and for annual average (°C) for the 2020's, 2050's and end-of-century relative to the 1961-1990 baseline
Source: RegCM run for RCP4.5 scenario.

CHANGE IN MAXIMUM TEMPERATURE (◦C) (20'S)						
GRID BOX	**GRID 28**	**GRID 43**	**GRID 44**	**GRID 65**	**GRID 71**	**GRID 88**
NDJ	0.76	0.75	0.84	0.75	0.93	0.80
FMA	0.61	0.63	0.79	0.64	0.83	0.68
MJJ	0.62	0.62	0.44	0.63	0.33	0.60
ASO	0.62	0.63	0.87	0.61	0.82	0.61
ANN	0.65	0.66	0.74	0.66	0.73	0.67
CHANGE IN MAXIMUM TEMPERATURE (◦C) (50'S)						
GRID BOX	**GRID 28**	**GRID 43**	**GRID 44**	**GRID 65**	**GRID 71**	**GRID 88**
NDJ	1.14	1.16	1.28	1.16	1.19	1.17
FMA	1.13	1.11	0.96	1.16	0.92	1.17
MJJ	1.09	1.15	1.43	1.11	1.20	1.09
ASO	1.21	1.21	1.35	1.19	1.30	1.20
ANN	1.14	1.16	1.26	1.15	1.15	1.16
CHANGE IN MAXIMUM TEMPERATURE (◦C) (EOC)						
GRID BOX	**GRID 28**	**GRID 43**	**GRID 44**	**GRID 65**	**GRID 71**	**GRID 88**
NDJ	1.62	1.60	1.68	1.65	1.68	1.69
FMA	1.41	1.40	1.26	1.39	1.27	1.36
MJJ	1.42	1.46	1.59	1.44	1.42	1.44
ASO	1.47	1.47	1.67	1.45	1.64	1.47
ANN	1.48	1.49	1.55	1.48	1.50	1.49

5.2.1. STATISTICAL DOWNSCALING

Figure 30: Projections of mean and extreme daily maximum temperature for the Norman Manley International Airport Weather Station for 2016-2035 and 2036-75. (A+D) Mean daily maximum temperature; (B+E) Maximum daily maximum temperature; (C+F) Warm day frequency per decade.

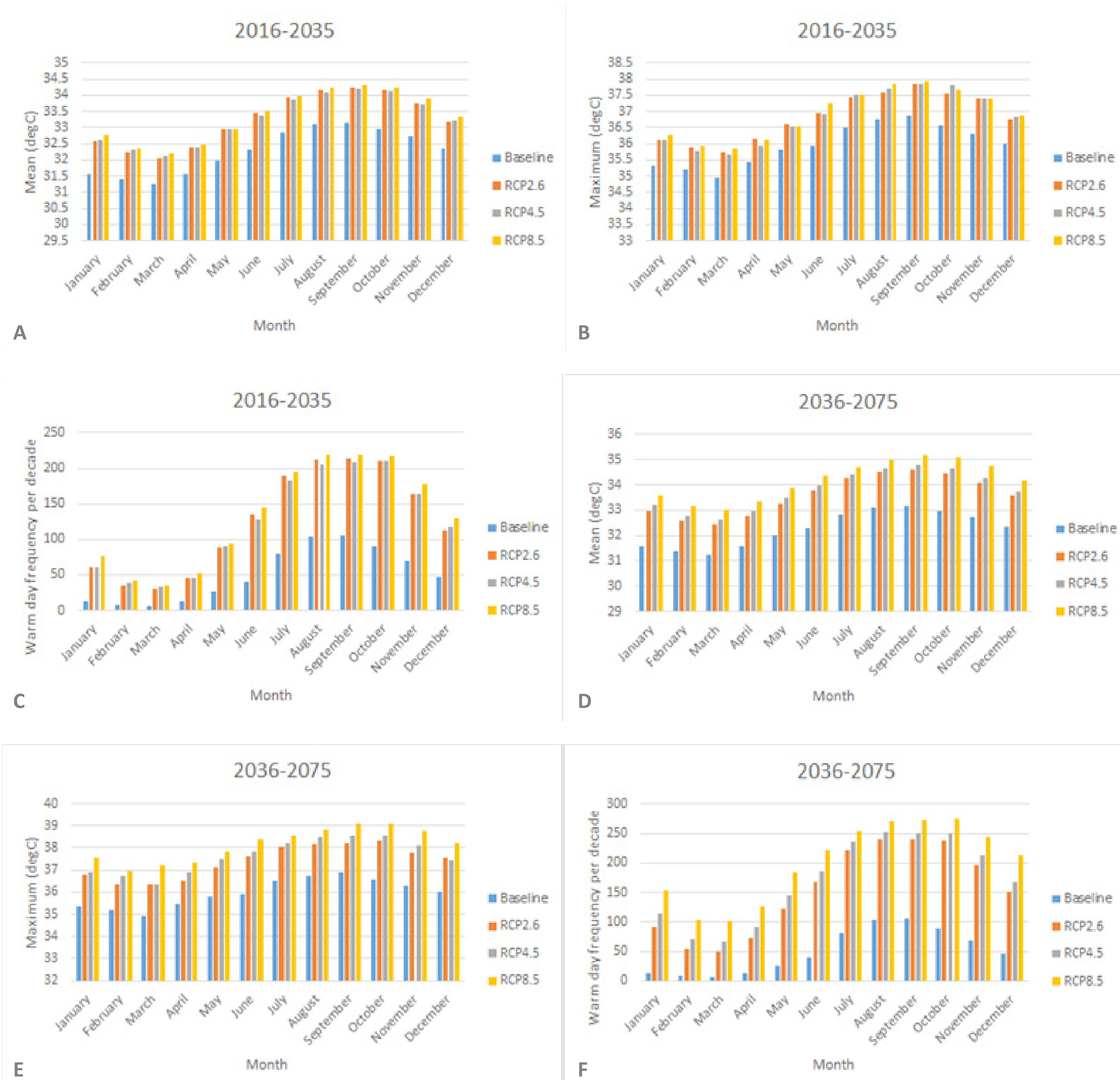


Figure 31: Projections of mean and extreme daily minimum temperature for the Norman Manley International Airport Weather Station for 2016-2035 and 2036-75. (A+D) Mean daily minimum temperature; (B+E) Minimum daily minimum temperature; (C+F) Cool night frequency per decade.

5.3. Rainfall

The following are noted about the future rainfall changes for Jamaica from the GCMs, RCMs and statistical downscaling.

- From the GCMs, the results suggest that a drying trend sets in from as early as the mid-2020s with 0 to 2% less rainfall in the annual mean. The 2030s will be up to 4% drier, the 2050s up to 10% drier, while by the end of the century the country as a whole may be up to 21% drier for the most severe RCP scenario (RCP8.5).
- The GCMs suggest that change in rainfall during the late rainfall season is the primary driver of the drying trend noted. By the mid-2030s late season rainfall has decreased by 1-3%, while by the end of the century the mean decrease is 2-20%.
- Dry season rainfall generally shows small increases or no change. Mean increases are consistently between 1-4% across all time slices examined. Given the small amounts of rainfall received during the dry season, the increases are not enough to offset the overall drying pattern.
- RCM projections reflect the onset of a drying trend from the mid-2030s which continues into the 2050s and through the end of the century.
- The percentage decreases (over the grid boxes) for annual rainfall in the defined Blocks are as summarised below.

Table 45: Range of percentage annual rainfall change across the grid boxes comprising the four rainfall zones. Changes are relative to a 1986-2005 model baseline. See Figure 1 for grid boxes and Table 2 for grid boxes in each zone.

	2020s	2030s	2050s	End of Century (2081-2100)
West	2.44 – 4.50	-10.11 – 34.37	-5.70 – 9.95	-13.23 – 6.09
East	-4.17 – -1.77	-13.91 – -8.82	-19.38 – -14.73	-28.09 – -22.91
Interior	-4.64 – 2.58	-24.84 – -3.89	-25.25 – -2.16	-37.03 – -9.70
Coasts	-18.44 – -6.97	-29.86 – -5.00	-31.24 – -1.26	-43.28 – -4.34

- There is some spatial variation (across the country and even within Blocks) with the south and east showing greater decreases than the north and west for each time slice.
- Results for the six selected boxes covering major cities or towns show a decrease in annual rainfall for all grids except grid box 88 (Montego Bay) beginning in the 2020s and through the end of century. Grid box 88 alternates between decrease and increase and then back to decrease for the three time slices for which data are presented. The dry season (February-April) is notable because it has the largest projected increase in rainfall of all seasons for both the 2050's and end of century. It is however noted again that rainfall amounts during this period are small and

The GCMs suggest that change in rainfall during the late rainfall season is the primary driver of the drying trend noted. By the mid-2030s late season rainfall has decreased by 1-3%, while by the end of the century the mean decrease is 2–20%

the larger percentages may not indicate large magnitude increases (therefore not enough to offset decreased rainfall in the rainfall seasons). Grid boxes 28 and 43 (Morant Bay and Kingston) representing the southeast of Jamaica have the highest projected decrease in annual rainfall for all time slices. This is consistent with the spatial variation seen in the RCM ensemble suite.

» At the Norman Manley International Airport station, statistical downscaling suggests strong increases in mean daily rainfall for June of up to 57% (48%) and December of up to 108% (68%) by the 2020s (2050s) across all RCPs.

» At the Norman Manley International Airport station statistical downscaling suggests increases in maximum 5-day rainfall amounts for June of up to 65% (77%) and December up to 186% (155%) by early century (mid-century). Decreases for September-October of up to 35% are also indicated for early century.

» At the Norman Manley International station statistical downscaling suggests that increases in maximum dry spell length are largest for March up to 7 (7) days and October up to 10 (11) days across all RCPs by the 2020s (2050s).

5.3.1. GCMS

Tables 46-48 show the range of projected changes for annual, late rainfall season, and dry season rainfall with respect to a 1986-2005 baseline period from the suite of GCMs. The projections are illustrated as time series in Figure 32.

Table 46: Mean percentage change in rainfall for Jamaica with respect to 1986-2005. Changes are shown for the four RCP scenarios.
Source: AR5 CMIP5 subset, KNMI Climate Change Atlas.

	Annual Rainfall											
	2020's			2030's			2050's			End of century		
Averaged over	2020-2029			2030-2039			2050-2059			2081-2100		
	min	mean	max	min	mean	max	min	mean	max	min	mean	Max
rcp26	-10.70	-0.02	15.02	-11.39	-0.15	17.33	-13.57	-0.36	20.74	-38.16	-0.45	14.00
rcp45	-16.8	-3.11	10.30	-19.91	-3.76	12.75	-40.34	-6.10	23.56	-42.84	-7.47	25.20
rcp60	-14.67	-1.84	11.31	-19.36	-2.67	12.23	-18.98	-2.66	18.82	-46.27	-8.85	15.83
rcp85	-25.01	-1.95	26.01	-20.55	-3.84	17.58	-37.77	-8.52	30.57	-69.60	-21.02	24.29
Range of mean:	-3.11 to -0.02			-3.84 to -0.15			-8.52 to -0.36			-21.02 to -0.45		

Table 47: Mean percentage change in late season (August-November) rainfall for Jamaica with respect to 1986-2005. Changes are shown for the four RCP scenarios.
Source: AR5 CMIP5 subset, KNMI Climate Change Atlas.

	Late Rainfall Season											
	2020's			2030's			2050's			End of century		
Averaged over	2020-2029			2030-2039			2050-2059			2081-2100		
	Min	mean	max	min	mean	max	min	mean	max	min	mean	max
rcp26	-16.8 3	-0.84	23.73	-16.87	-1.01	24.26	-19.74	-0.53	25.44	-39.40	-1.57	16.44
rcp45	-20.54	-2.15	11.33	-28.80	-3.86	18.27	-45.99	-4.28	35.91	-41.47	-7.19	32.31
rcp60	-15.47	-2.69	10.57	-26.58	-2.81	15.25	-23.47	-3.19	24.90	-49.10	-8.96	20.85
rcp85	-15.19	-0.84	23.63	-14.92	-2.73	17.87	-48.21	-7.73	40.82	-75.08	-19.91	40.16
Range of mean:	-2.15 to -0.84			-3.86 to -1.01			-7.73 to -0.53			-19.91 to -1.57		

Table 48: Mean percentage change in dry season (January -March) rainfall for Jamaica with respect to 1986-2005. Changes are shown for four RCP scenarios.
Source: AR5 CMIP5 subset, KNMI Climate Change Atlas.

	Dry Season Rainfall											
	2020's			2030's			2050's			End of century		
Averaged over	2020-2029			2030-2039			2050-2059			2081-2100		
	min	mean	max	min	mean	max	min	mean	max	min	mean	max
rcp26	-15.25	2.74	22.54	-17.02	3.38	27.89	-17.44	3.11	28.12	-26.06	2.94	23.37
rcp45	-36.47	-0.46	41.23	-34.74	0.79	51.99	-32.85	1.10	39.88	-37.59	1.05	41.00
rcp60	-22.84	4.32	27.29	-18.97	4.26	28.91	-18.07	1.93	24.31	-30.93	-1.00	21.04
rcp85	-32.92	1.23	42.45	-26.20	-0.45	36.07	-28.35	0.12	30.98	-52.07	-9.15	36.41
Range of mean:	-0.46 to 4.32			-0.45 to 4.26			0.12 to 3.11			-9.15 to 2.94		

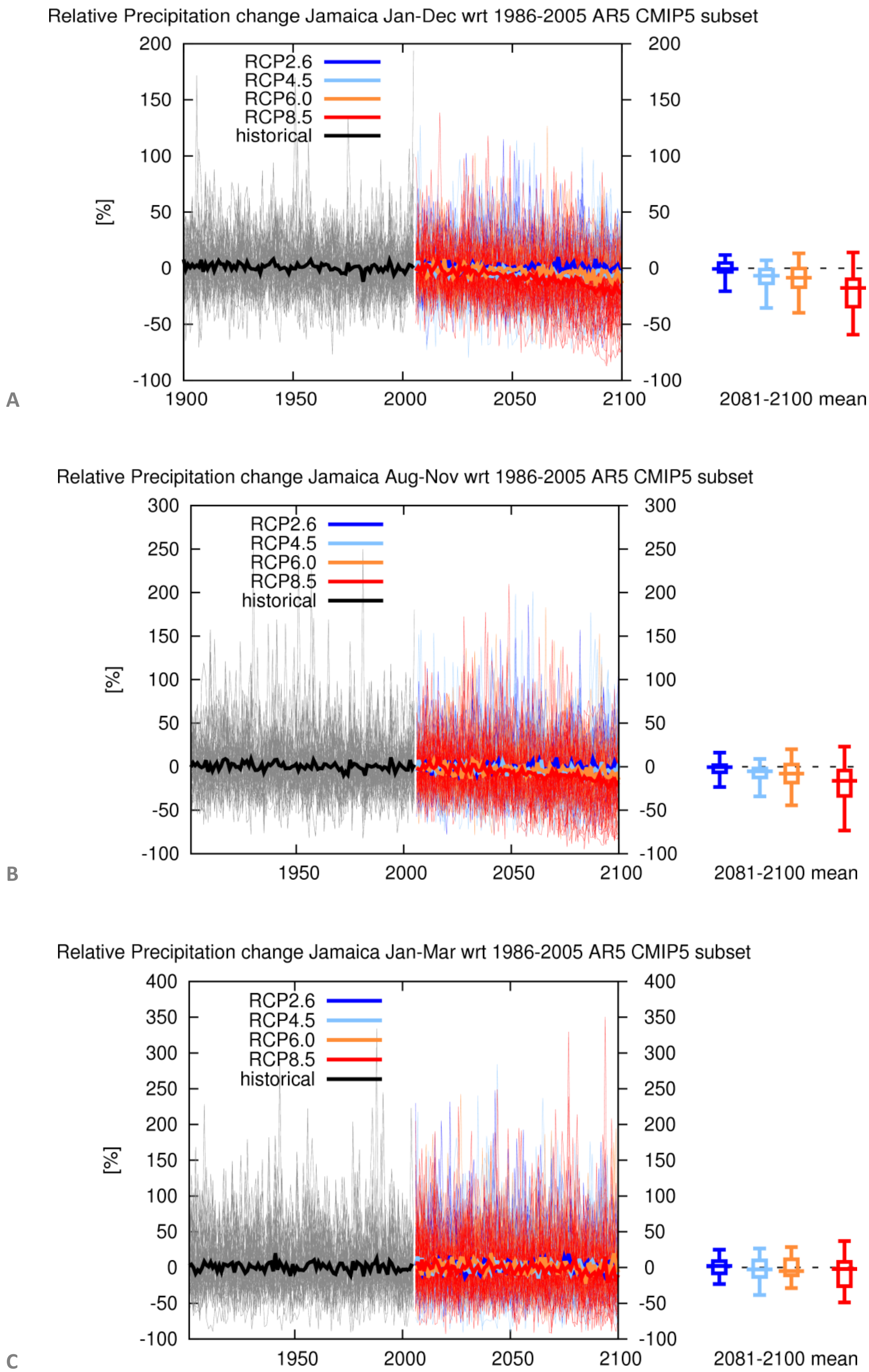


Figure 32: (a) Relative Annual Precipitation change (%) (b) Relative August-November Precipitation change (%) (c) Relative January-March Precipitation change (%) for Jamaica with respect to 1986-2005 AR5 CMIP5 subset. On the left, for each scenario one line per model is shown plus the multi-model mean, on the right percentiles of the whole dataset: the box extends from 25% to 75%, the whiskers from 5% to 95% and the horizontal line denotes the median (50%).

5.3.1. RCMs

Projections for the four rainfall zones are provided in Tables 49-52. A summary map showing percentage change per grid box of annual rainfall is given in Figure 33. Table 53 shows projections for grid boxes over the five selected cities or towns.

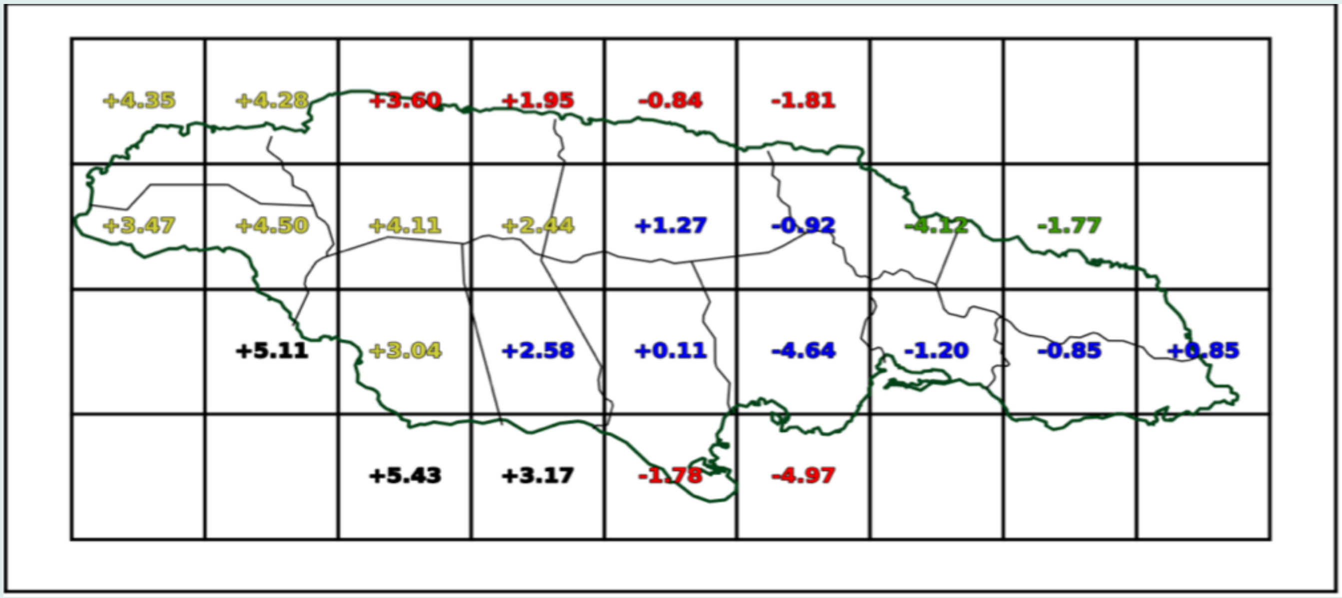
Table 49-52: Projected percentage changes in rainfall by season and for annual average (°C) for the 2020's, 2030's, 2050's and 2080's relative to the 1961-1990 baseline. Data presented for the mean value of a six-member ensemble. Range shown is over all the grid boxes in the zone (see Table 2). *Source: PRECIS RCM perturbed physics ensemble run for A1B scenario.*

TABLE 49: WEST (ZONE 3)				
	2020's	2030's	2050's	2080's
NDJ	3.27 – 16.13	2.15 – 26.56	1.63 – 29.71	7.10 – 35.10
FMA	1.12 – 28.36	-5.89 – 28.23	16.12 – 39.86	-1.09 – 36.23
MJJ	4.21 – 17.09	-11.84 – 12.77	-8.54 – 17.59	-29.46 – 4.98
ASO	-12.90 – 7.01	-25.13 – -3.17	-20.92 – 4.13	-26.92 – -0.29
ANNUAL	2.44 – 4.50	-10.11 – 34.37	-5.70 – 9.95	-13.23 – 6.09

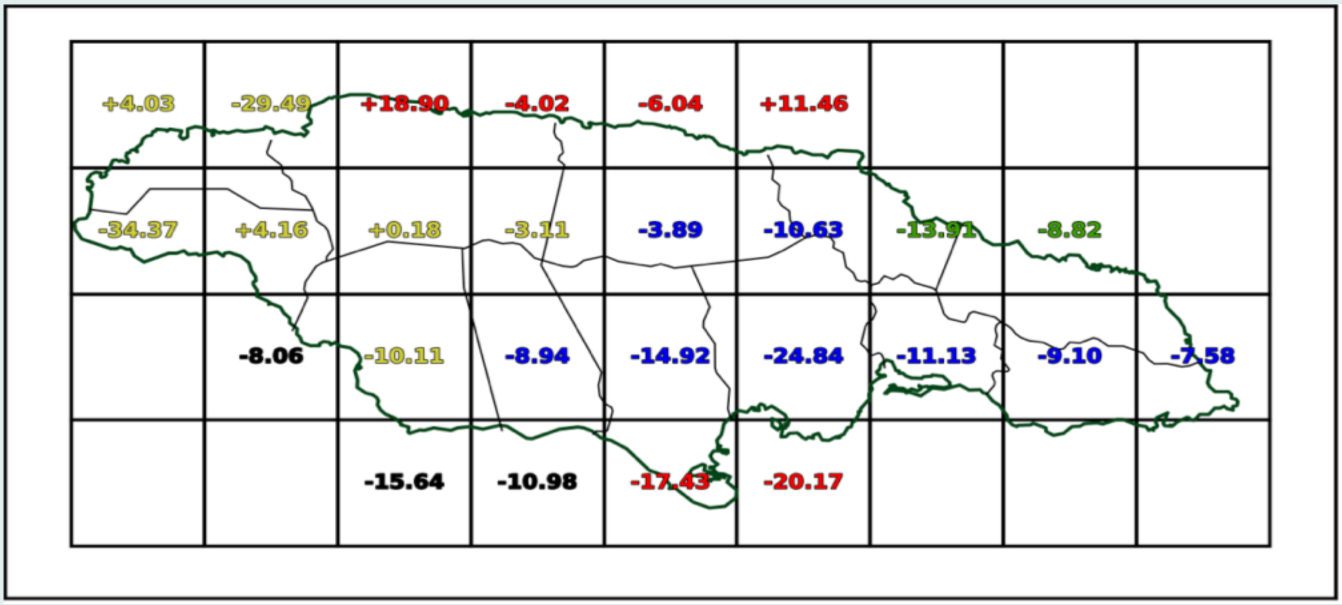
TABLE 50: COASTS (ZONE 4)				
	2020's	2030's	2050's	2080's
NDJ	-74.87 – -18.22	-54.09 – -16.02	-63.50 – -33.28	-73.82 – -38.74
FMA	-80.52 – -4.63	-22.48 – -4.40	-26.71 – -0.67	-21.62 – 0.01
MJJ	-65.86 – -22.68	-48.18 – -11.94	-56.18 – -13.76	-65.23 – -19.47
ASO	-77.43 – -21.33	-73.87 – -24.72	-71.52 – -22.95	-76.62 – -23.65
ANNUAL	-18.44 – -6.97	-29.86 – -5.00	-31.24 – -1.26	-43.28 – -4.34

TABLE 51: INTERIOR (ZONE 1)				
	2020's	2030's	2050's	2080's
NDJ	-1.80 – 6.65	-10.18 – 11.04	-16.04 – 12.14	-21.75 – 11.08
FMA	9.73 – 27.32	-4.80 – 20.24	6.29 – 28.33	2.41 – 24.08
MJJ	0.10 – 14.38	-22.96 – -2.88	-20.61 – 0.14	-48.77 – -23.15
ASO	-20.45 – -8.68	-40.03 – -16.01	-42.70 – -15.73	-51.16 – -21.86
ANNUAL	-4.64 – 2.58	-24.84 – -3.89	-25.25 – -2.16	-37.03 – -9.70

TABLE 52: EAST (ZONE 2)				
	2020's	2030's	2050's	2080's
NDJ	-2.39 – 0.15	-9.43 – -5.28	-18.40 –14.16	-18.57 - -13.88
FMA	3.49 – 6.99	0.78 – 5.91	1.46 - 8.24	1.84 – 7.40
MJJ	6.07 – 7.94	-9.80 – -7.03	-11.86 – -11.61	-37.60 – -32.81
ASO	-17.78 – -14.43	-29.90 – -22.58	-36.56 – -29.79	-45.65 – -39.55
ANNUAL	-4.17 – -1.77	-13.91 – -8.82	-19.38 – -14.73	-28.09 – -22.91

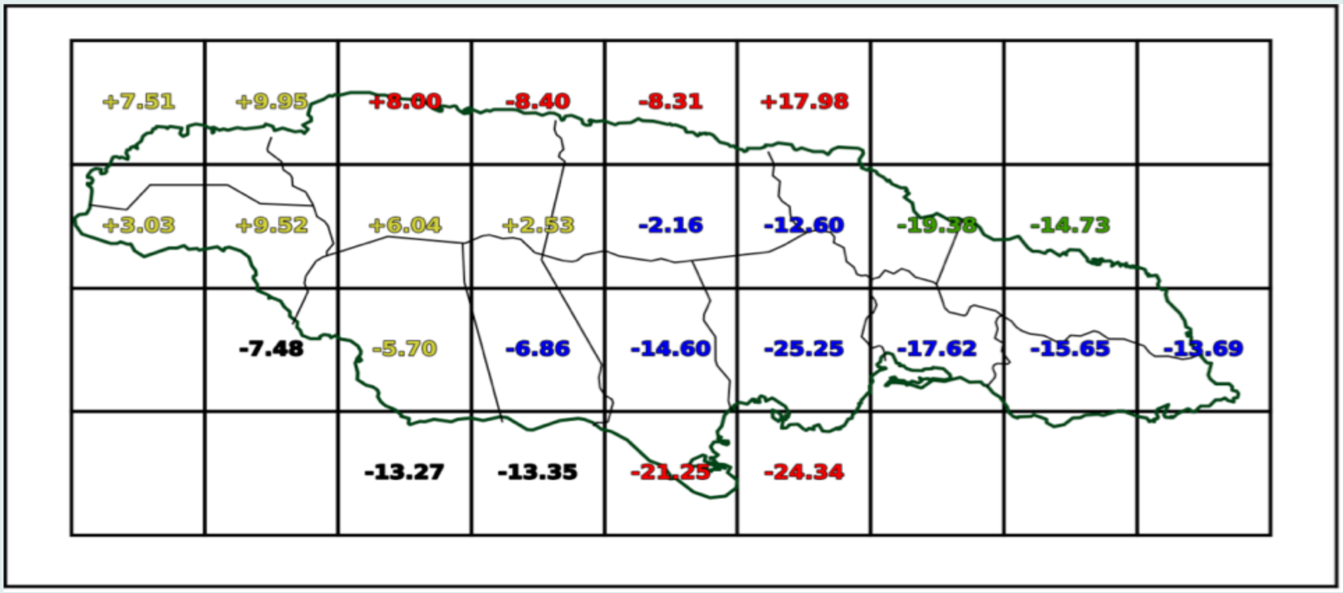


2020s

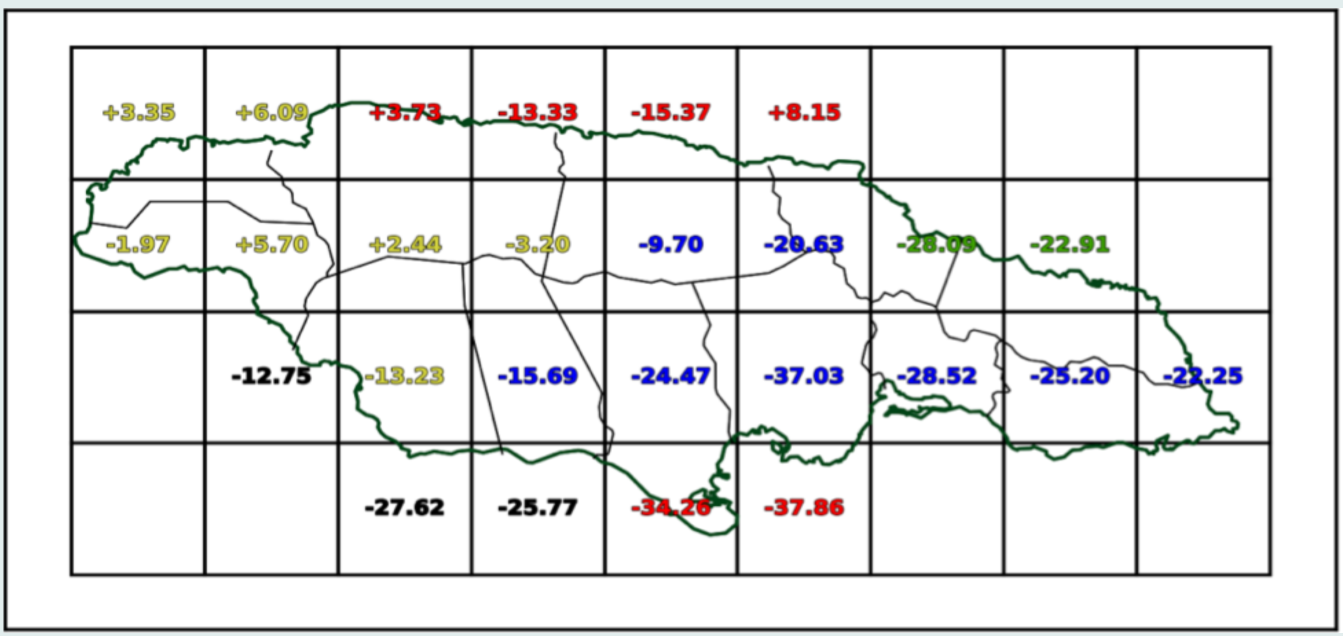


2030s

Figure 33a: Summary map showing percentage change per grid box of annual rainfall for the 2020's (top panel) and 2030s (bottom panel). Colours indicate different rainfall zones: zone 1/Interior regions (blue), zone 2/Eastern Jamaica (green), zone 3 /Western Jamaica (yellow), zone 4/Coastal regions (red). *Source: PRECIS RCM PPE.*



2050s



End of Century

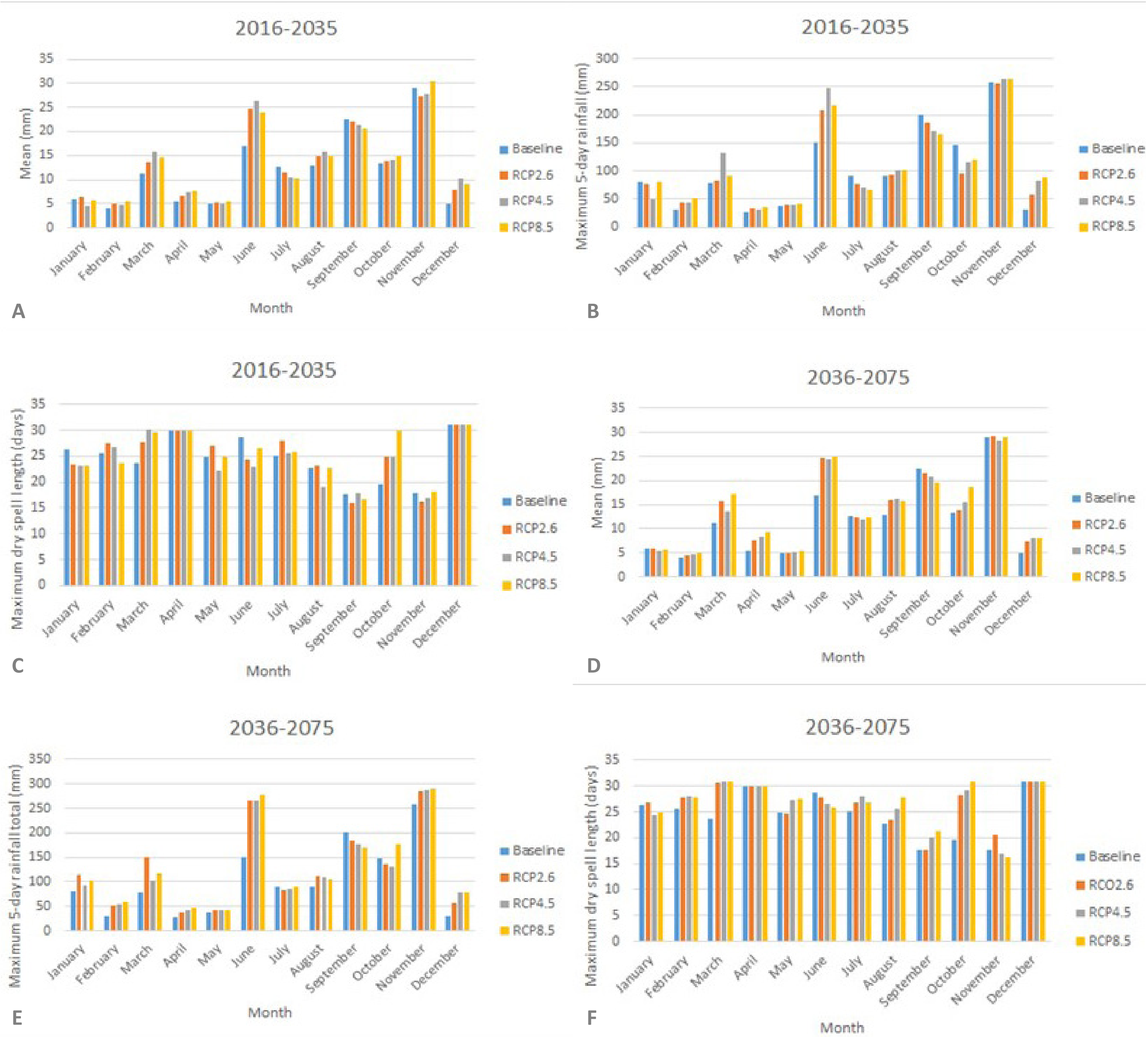
Figure 33b: Summary map showing percentage change per grid box of annual rainfall for the 2050's (top panel) and end of century (2075-2098) (bottom panel).). Colours indicate different rainfall zones: zone 1/Interior regions (blue), zone 2/Eastern Jamaica (green), zone 3 /Western Jamaica (yellow), zone 4/Coastal regions (red).
Source: PRECIS RCM PPE.

Table 53: Projected percentage changes in rainfall by season and for annual average for the 2020's, 2050's and end-of-century relative to the 1961-1990 baseline
Source: RegCM run for RCP4.5 scenario.

PERCENTAGE CHANGE IN PRECIPITATION (%) (20'S)						
GRID BOX	GRID 28	GRID 43	GRID 44	GRID 65	GRID 71	GRID 88
NDJ	9.20	16.73	2.48	-7.30	3.68	3.17
FMA	-13.17	-25.82	-8.06	-17.05	9.95	-7.66
MJJ	4.70	45.37	14.76	21.97	-3.40	21.03
ASO	-12.20	-24.10	-15.49	-6.50	-2.32	-6.40
ANN	-5.30	-8.03	-4.59	-1.11	-0.30	2.41
PERCENTAGE CHANGE IN PRECIPITATION (%) (50'S)						
GRID BOX	GRID 28	GRID 43	GRID 44	GRID 65	GRID 71	GRID 88
NDJ	-8.06	-18.44	2.79	-1.45	1.62	-2.19
FMA	20.86	24.15	21.57	20.55	25.36	32.38
MJJ	-33.21	-33.68	-5.17	-21.68	-5.59	-12.60
ASO	-12.47	-17.11	-11.11	-4.21	-13.71	-4.31
ANN	-15.38	-17.84	-4.12	-5.79	-3.67	-2.98
PERCENTAGE CHANGE IN PRECIPITATION (%) (EOC)						
GRID BOX	GRID 28	GRID 43	GRID 44	GRID 65	GRID 71	GRID 88
NDJ	9.47	3.51	-5.21	9.45	-1.97	10.35
FMA	9.11	14.43	20.63	23.57	10.43	36.67
MJJ	-23.77	-39.32	-11.27	-12.00	-8.70	-4.38
ASO	-24.73	-15.12	-8.98	-6.56	-6.06	-6.03
ANN	-18.38	-14.68	-5.88	-2.52	-4.33	1.31

5.3.1. RAINFALL EXTREMES

Figure 34. Projections of mean and extreme daily rainfall for the Norman Manley International Airport Weather Station. (A+D) Mean daily rainfall; (B+E) maximum number of consecutive dry days.



5.4. Sea Levels

The first three rows of Table 54 provide a range of estimates for end-of-century sea level rise globally and in the Caribbean Sea under a number of SRES scenarios. The values are taken from the IPCC's Fourth Assessment Report (IPCC 2017). The combined range over all scenarios spans 0.18 m to approximately 0.5 m by 2100 relative to 1980-1999 levels. The future rise in the Caribbean is not significantly different from the projected global rise.

Table 54: Projected changes in temperature per grid box by 2090s from a regional climate mode.
Source: IPCC (2007).

Scenario	Global Mean Sea Level Rise by 2100 relative to 1980 – 1999	Caribbean Mean Sea Level Rise by 2100 relative to 1980 – 1999 (± 0.05m relative to global mean)
IPCC B1	0.18 – 0.38	0.13 – 0.43
IPCC A1B	0.21 – 0.48	0.16 – 0.53
IPCC A2	0.23 – 0.51	0.18 – 0.56
Rahmstorf, 2007	Up to 1.4m	Up to 1.45 m
Perrette et al., 2013		Up to 1.50 m

Since the IPCC's Fourth Assessment Report, however, a number of other studies (Rahmstorf, 2007; Rignot and Kanargaratnam, 2006; Horton et al., 2008) including the IPCC's Fifth Assessment Report (IPCC 2013) suggest that the upper bound for the global estimates in Table 54 are conservative and could be up to 0.98 m, with a rate during 2081–2100 of 8 to16 mm/year. Diagrams from Perrette et al. (2013) indicate the same kind of underestimation for the Caribbean Sea and suggest a higher upper bound of up to 1.5 m for the region by the end of the century. The IPCC's Fifth Assessment Report does not, however, provide projections for the Caribbean separate from that for the Global mean. Nonetheless, the same assumption of SLR being similar for the region as for the globe may be taken. Projections for the globe under the four RCPs from the IPCC's Fifth Assessment Report are shown in Table 55. Through mid-century, the mean increase is similar for all RCPs. Distinctions in projected values arise toward the end of the century.

By mid-century, the projected largest rise in the mean is 0.39-0.40 m across both coasts. By the end of the century, the projected largest rise in the mean across both coasts is 0.87-0.90 m. The highest sensitivity models indicate a rise of just over 1 m for RCP8.5.

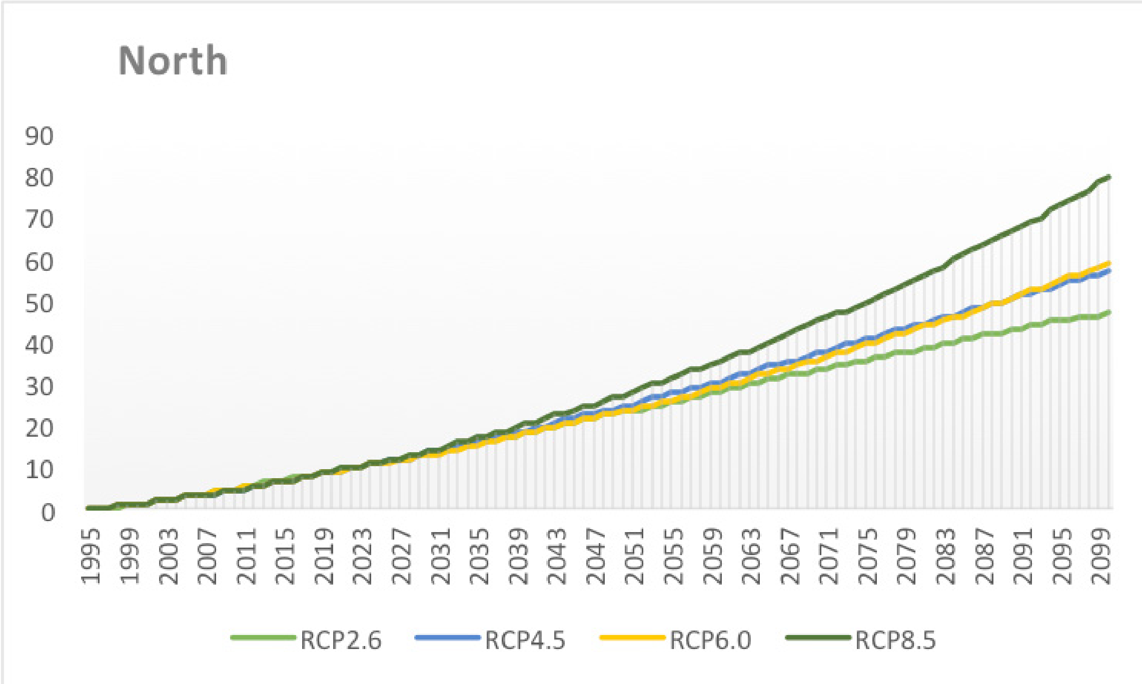
Projections for SLR for the north coast versus the south coast of Jamaica are extracted from the ensemble of models available in SIMCLIM (see again Section 2) and are summarised in Table 56 and shown for medium sensitivity models in Figure 35. Generally, the difference between north and south coast is approximately 0.01 m (1 cm). By mid-century, the projected largest rise in the mean is 0.39-0.40 m across both coasts. By the end of the century, the projected largest rise in the mean across both coasts is 0.87-0.90 m. The highest sensitivity models indicate a rise of just over 1 m for RCP8.5.

Table 55: Projected increases in global mean sea level rise (m). Projections are relative to 1986-2005. IPCC (2013).

	2046 – 2065		2081– 2100	
Scenario	**Mean**	**Likely range**	**Mean**	**Likely range**
RCP2.6	0.24	0.17 – 0.32	0.40	0.26 – 0.55
RCP4.5	0.26	0.19 – 0.33	0.47	0.32 – 0.63
RCP6.0	0.25	0.18 – 0.32	0.48	0.33 – 0.63
RCP8.5	0.30	0.22 – 0.38	0.63	0.45 – 0.82

Table 56: Projected increases in mean sea level rise (m) for the north and south coasts of Jamaica. Range is the lowest projection under low sensitivity conditions to the highest annual projection under high sensitivity during the period. Projections relative to 1986-2005.

SEA LEVEL RISE (m) NORTH COAST (-77.076W, 18.8605N)								
Centred on	**2025**		**2035**		**2055**		**End of century**	
Averaged over	**2020-2029**		**2030-2039**		**2050-2059**		**2080-2100**	
	Mean	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
RCP2.6	**0.13**	**0.11 – 0.17**	**0.20**	**0.17 – 0.22**	**0.33**	**0.30 – 0.36**	**0.58**	**0.51 – 0.65**
RCP4.5	**0.13**	**0.11 – 0.17**	**0.20**	**0.17 – 0.22**	**0.35**	**0.31 – 0.39**	**0.66**	**0.58 – 0.76**
RCP6.0	**0.13**	**0.11 – 0.17**	**0.20**	**0.17 – 0.22**	**0.33**	**0.30 – 0.37**	**0.67**	**0.57 – 0.78**
RCP8.5	**0.14**	**0.11 – 0.17**	**0.21**	**0.18 – 0.25**	**0.39**	**0.34 – 0.44**	**0.87**	**0.72 – 1.04**
SEA LEVEL RISE (m) SOUTH COAST (-77.157W, 17.142N)								
Centreed on	**2025**		**2035**		**2055**		**End of century**	
Averaged over	**2020-2029**		**2030-2039**		**2050-2059**		**2080-2100**	
	Mean	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
RCP2.6	**0.14**	**0.11 – 0.17**	**0.20**	**0.18 – 0.23**	**0.34**	**0.31 – 0.37**	**0.60**	**0.53 – 0.67**
RCP4.5	**0.14**	**0.11 – 0.17**	**0.20**	**0.18 – 0.23**	**0.36**	**0.32 – 0.40**	**0.68**	**0.59 – 0.78**
RCP6.0	**0.14**	**0.11 – 0.17**	**0.20**	**0.18 – 0.23**	**0.43**	**0.31 – 0.39**	**0.69**	**0.58 – 0.80**
RCP8.5	**0.15**	**0.12 – 0.18**	**0.22**	**0.19 – 0.25**	**0.40**	**0.35 – 0.45**	**0.90**	**0.74 – 1.08**



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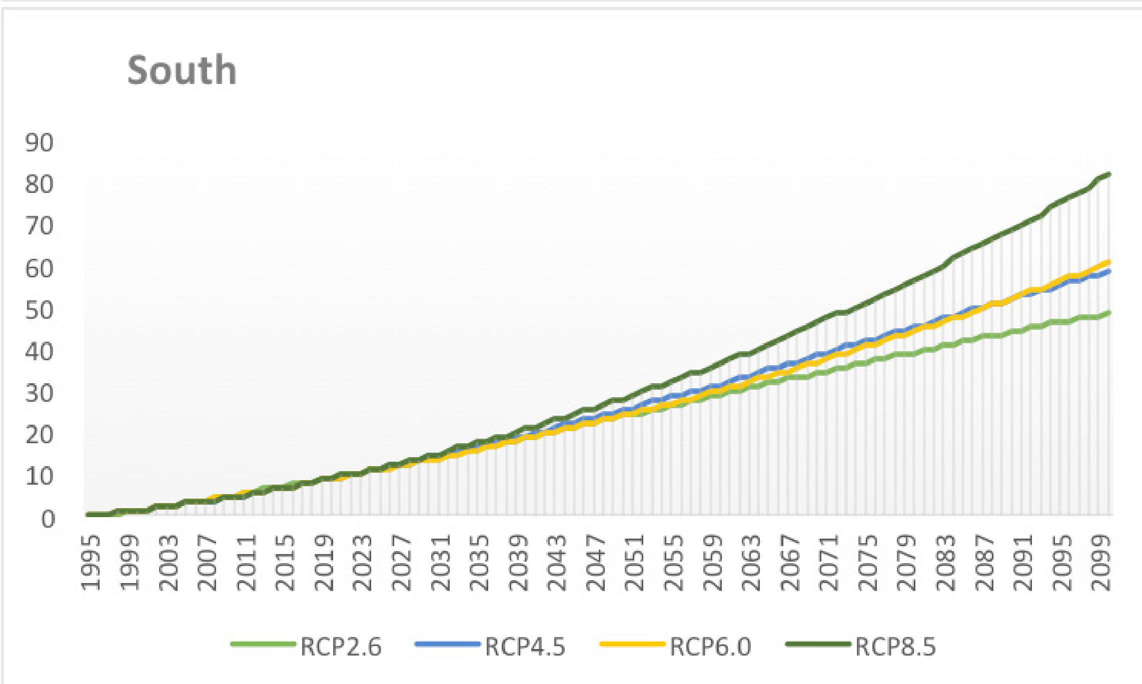


B

Figure 35: Sea level rise projections under RCP2.6, RCP4.5, RCP6.0 and RCP8.5 for a) a point (-77.076°W, 18.8605°N) off the Northern coast of Jamaica; b) a point (-77.157°W, 17.142°N) off the Southern coast of Jamaica.

5.4.1. SEA LEVEL EXTREMES

Adapted from IPCC (2013)

Higher mean sea levels can significantly decrease the return period for exceeding given threshold levels. Hunter (2012) determined the factor by which the frequency of sea levels exceeding a given height would be increased for a mean sea level rise of 0.5 m for a network of 198 tide gauges covering much of the globe. The AR5 repeats the calculations using regional sea level projections and their uncertainty under the RCP4.5 scenario. The multiplication factor depends exponentially on the inverse of the Gumbel scale parameter (a factor which describes the statistics of sea level extremes caused by the combination of tides and storm surges) (Coles and Tawn, 1990). The scale parameter is generally large where tides and/ or storm surges are large, leading to a small multiplication factor, and vice versa. Figure 36 shows that a 0.5 m MSL rise would *likely* result in the frequency of sea level extremes increasing by an order of magnitude or more in some regions. The multiplication factors are found to be slightly higher, in general, when accounting for regional MSL projections. In regions having higher regional projections of mean sea level, the multiplication factor is higher, whereas in regions having lower regional projections of mean sea level the multiplication factor is lower.

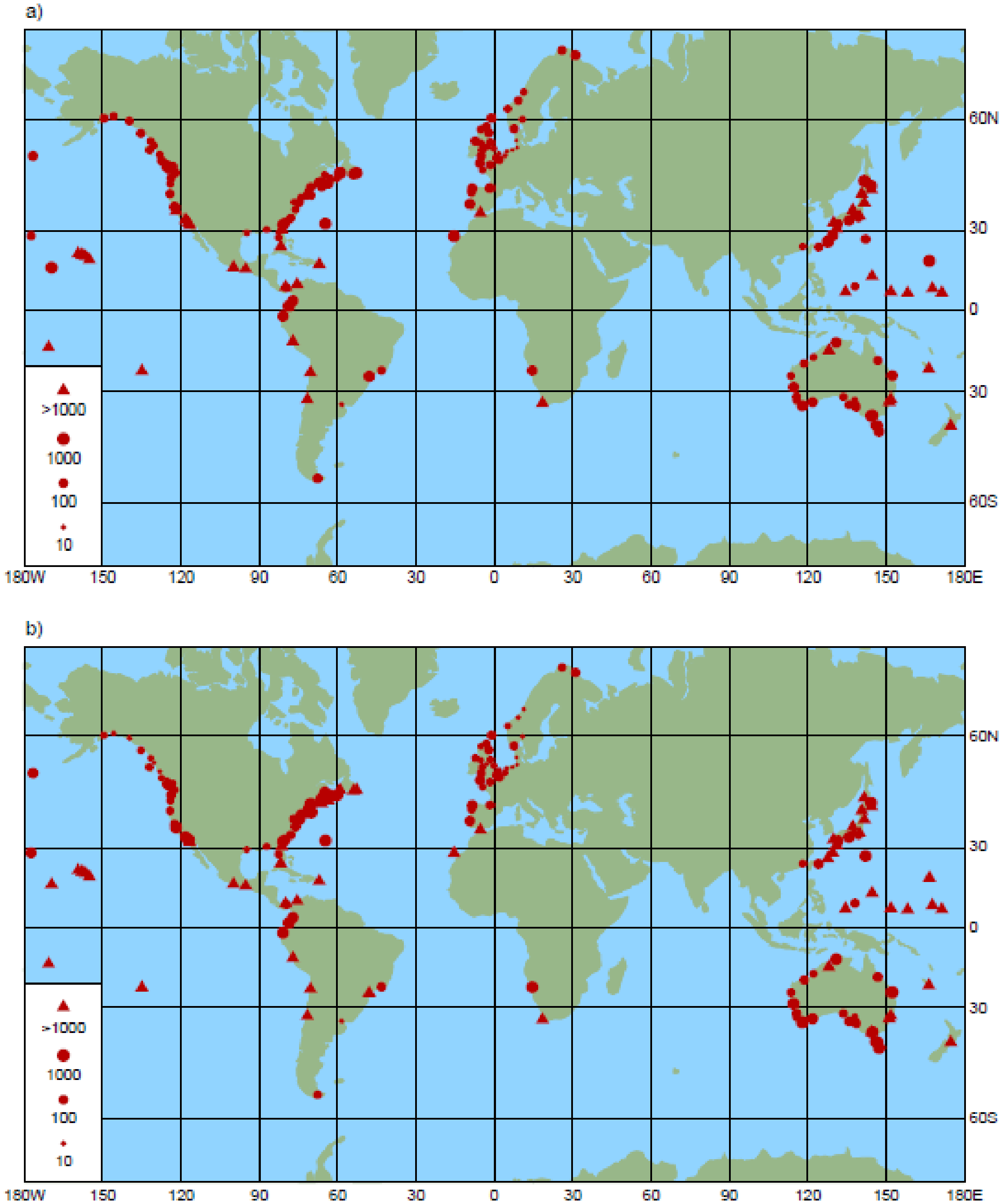


Figure 36: The estimated multiplication factor (shown at tide gauge locations by red circles and triangles), by which the frequency of flooding events of a given height increase for (a) a mean sea level rise of 0.5 m (b) using regional projections of mean sea level for the RCP4.5 scenario. The Gumbel scale parameters are generally large in regions of large tides and/or surges resulting in a small multiplication factor and vice versa.
Source: IPCC (2013).

5.5. Hurricanes

The IPCC Special Report on Extremes (IPCC 2012) offers five summary statements with respect to projections of future hurricane under global warming which are of relevance to Jamaica. They are reiterated below as major conclusions and supported with additional information (where available) specific for the Atlantic basin.

Conclusion 1: There is low confidence in projections of changes in tropical cyclone genesis, location, tracks, duration, or areas of impact.

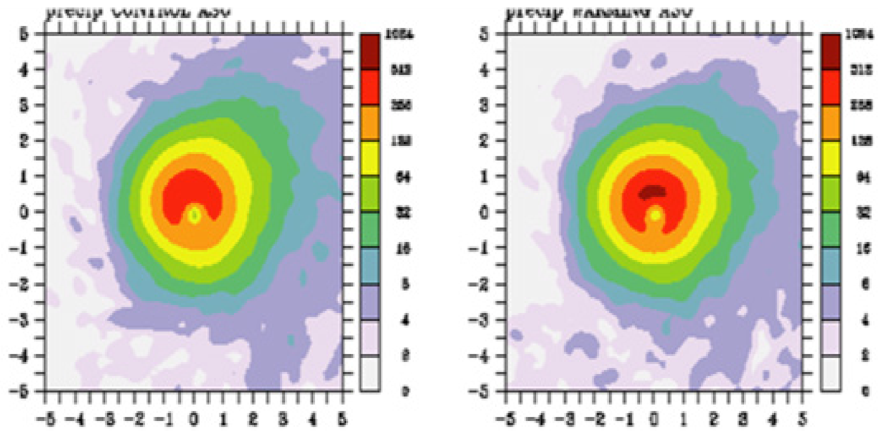
Tropical cyclone genesis and track variability is modulated in most regions by known modes of atmosphere–ocean variability. The details of the relationships vary by region (for example, El Niño events tend to suppress Atlantic storm genesis and development). The accurate modelling, then, of tropical cyclone activity fundamentally depends on the model's ability to reproduce these modes of variability to produce reliable projections of the behavior of these modes of variability (for example, ENSO) under global warming, as well as on a good understanding of their physical links with tropical cyclones. At present, there is still uncertainty in the model's ability to project these behaviors.

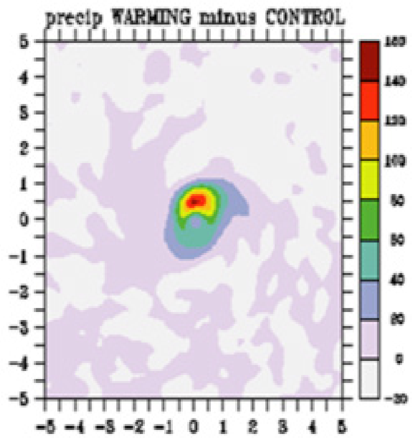
Conclusion 2: Based on the level of consistency among models, and physical reasoning, it is likely that tropical cyclone related rainfall rates will increase with greenhouse warming.

Observed changes in rainfall associated with tropical cyclones have not been clearly established. However, as water vapor in the tropics increases, there is an expectation for increased heavy rainfall associated with tropical cyclones. Models in which tropical cyclone precipitation rates have been examined are highly consistent in projecting increased rainfall within the area near the tropical cyclone centre under 21st-century warming, with increases of 3 to 37% (Knutson et al., 2010). Typical projected increases are near 20% within 100 km of storm centres (see Figure 37). More recent work premised on RCP 4.5 suggest that rainfall rates increase robustly for the CMIP3 and CMIP5 scenarios (Knutson et al. 2013). For the late-twenty-first-century, the increase amounts to +20% to +30% in the model hurricane's inner core, with a smaller increase (~10%) at radii of 200 km or larger.

Conclusion 3: It is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged.

Hurricane research done at NOAA's GFDL laboratory using regional models projects that Atlantic hurricane and tropical storms are **substantially reduced in number,** for the average 21st-century climate change projected by current models, but will have **higher rainfall rates**, particularly near the storm centre. http://www.gfdl.noaa.gov/global-warming-and-hurricaneshttp://www.gfdl.noaa.gov/global-warming-and-hurricanes





Avg. Rainfall Rate Increases:
50 km radius: +37%
100 km radius: +23%
150 km radius: +17%
400 km radius: +10%

Figure 37: Rainfall rates (mm/day) associated with simulated tropical storms in a) a present climate b) warm climate c) warm minus present climate. Average warming is 1.72 °C. From Knutson et al. (2010).

Conclusion 4: An increase in mean tropical cyclone maximum wind speed is likely, although increases may not occur in all tropical regions.

Assessments of projections by Knutson et al. (2010), Bender et al. (2010) and statistical-dynamical models (Emanuel, 2007) are consistent greenhouse warming causes tropical cyclone intensity to shift toward stronger storms by the end of the 21st century as measured by maximum wind speed increases by +2 to +11%.

Conclusion 5: While it is likely that overall global frequency will either decrease or remain essentially unchanged, it is more likely than not that the frequency of the most intense storms will increase substantially in some ocean basins.

The downscaling experiments of Bender et al. (2010) project a 28% reduction in the overall frequency of Atlantic storms and an 80% increase in the frequency of Saffir-Simpson category 4 and 5 Atlantic hurricanes over the next 80 years using the A1B scenario. Downscaled projections using CMIP5 multi-model scenarios (RCP4.5) as input (Knutson et al. 2013) still show increases in category 4 and 5 storm frequency, but these are only marginally significant for the early 21st century (+45%) or the late 21st century (+40%) using CMIP5 scenarios.

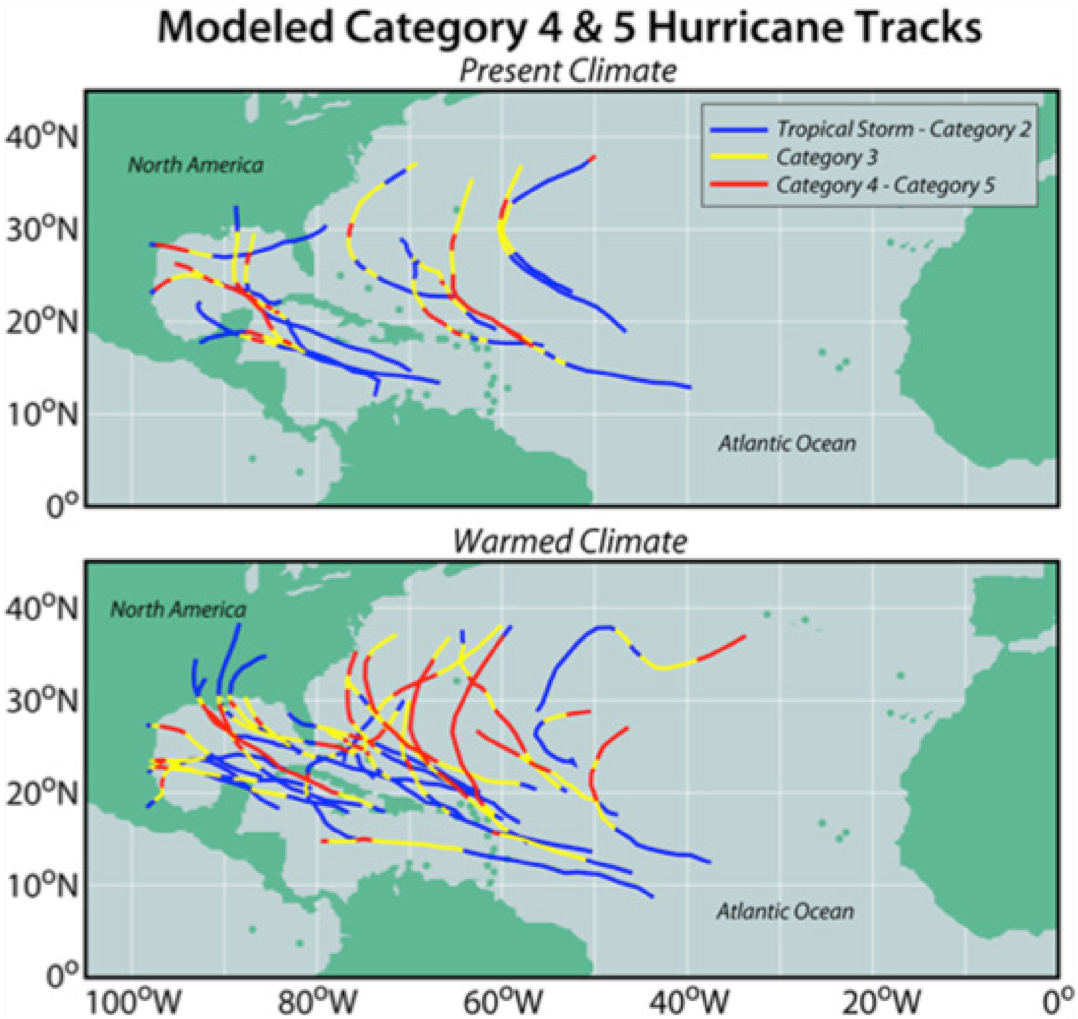


Figure 38: Late 21st century warming projections of category 4 and 5 hurricanes in the Atlantic. Average of 18 CMIP3 models.
Source: Bender et al. (2010).

The uncertainty evident in the 5 conclusions suggests that at the very least Jamaica should contemplate a future where tropical storm/hurricane genesis, frequency and tracks are similar to what has been experienced in the very recent past (last two decades), but intensities (rainfall rates and wind speeds) are increased.

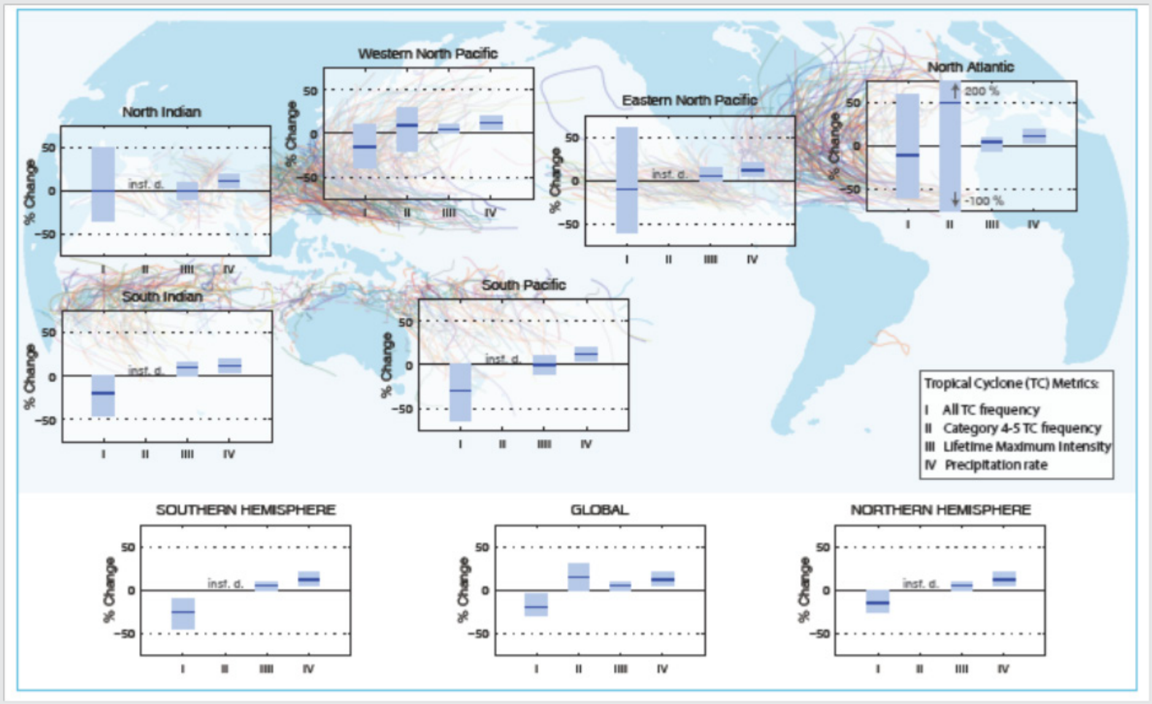


Figure 39: IPCC AR5 Summary Diagram

General consensus assessment of the numerical experiments described in IPCC (2013) Supplementary Material Tables 14.SM.1 to 14.SM.4. All values represent expected percent change in the average over period 2081–2100 relative to 2000–2019, under an A1B-like scenario, based on expert judgement after subjective normalization of the model projections. Four metrics were considered: the percent change in (I) the total annual frequency of tropical storms, (II) the annual frequency of Category 4 and 5 storms, (III) the mean Lifetime Maximum Intensity (LMI; the maximum intensity achieved during a storm's lifetime) and (IV) the precipitation rate within 200 km of storm centre at the time of LMI. For each metric plotted, the solid blue line is the best guess of the expected percent change, and the coloured bar provides the 67% (likely) confidence interval for this value (note that this interval ranges across –100% to +200% for the annual frequency of Category 4 and 5 storms in the North Atlantic). Where a metric is not plotted, there are insufficient data (denoted 'insf. d.') available to complete an assessment. A randomly drawn (and coloured) selection of historical storm tracks are underlain to identify regions of tropical cyclone activity.

6. Sector Impacts

6.1. Introduction

Vision 2030 Jamaica is a national development plan that aims to make Jamaica a first world country by the year 2030. Its national vision statement is to make "Jamaica, the place of choice to live, work, raise families and do business." It has four national goals, but Goal 4 of Vision 2030 is focused on Jamaica having a healthy natural environment, through sustainable urban and rural development, the sustainable use of natural resources and hazard risk reduction and adaptation to climate change. There is, therefore, recognition that climate change presents immense risks which can threaten and even derail Vision 2030. Jamaica as a small island developing state is very vulnerable to climate extremes including very warm temperatures, floods and droughts, intense hurricanes, and rising sea levels. In the future, the vulnerability increases due to the projected changes in both the magnitude and frequency of recurrence of these threats. Jamaica's climate sensitivity is across all sectors and if not accounted for in planning will continue to limit Jamaica's development.

This chapter details in tabular form ways in which climate impacts a number of key economic sectors and important thematic areas identified by Vision 2030 as relevant to the Jamaican way of life and to national development. The Tables are drawn from an extensive review of the literature and are presented with full references. The information in the tables is not meant to be seen as all-inclusive but rather as a starting point for further research for those who are interested. The following section presents a one paragraph summary of some of the main points highlighted in each table with reference back to Vision 2030. The chapter also includes simple graphical representations of the sector impact by climate variable.

6.1.1. TABLE SUMMARIES

DEVELOPMENT

Climate change is a developmental issue and has the potential to derail Vision 2030 efforts. The persistent and increasing threat of climate impacts as suggested by projections of increasing temperatures, extreme events and sea level rise will severely impact the local economy, workers' productivity and critical infrastructure located along the coast. In particular, with respect to infrastructural development, Vision 2030 in part premises national development on an *expansion and improvement of systems for land transport, including roads, rail and public transport, inland and overseas air transport and service.* The continuous development of coastal infrastructure for housing settlements and road networks increases the country's vulnerability to the impacts of climate change due to the challenges posed by sea level rise. See Table 57 for further details.

EDUCATION

Vision 2030 promises *that every Jamaican child by 2030 will have the best learning environment and leave high school passing 5 CSEC subjects including English, Mathematics and a foreign language.* Climate change may impact the success of these commitments as extreme temperatures affect concentration and student productivity. More frequent extreme events will further damage school infrastructure, reduce classroom time and the time needed for guided assistance for success in subjects like Mathematics and Science subjects. See Table 58 for further details.

GENDER

Gender is a social construct influencing roles and responsibilities of men and women. In Jamaica, women are more vulnerable to climate change than their male counterparts due to their socioeconomic circumstances and the social roles that they are expected to fulfil as women (caregiving and mothering). See Table 59 for further details.

SECURITY

Vision 2030 promises that *by the year 2030 every Jamaican will live in a safe community and the security forces will have modern and effective ways of maintaining law and order*. Climate change is a local national security issue because it exacerbates local vulnerabilities and developmental issues. Increasing temperatures, sea level rise and more frequent storms can lead to increased incidence of violence or protests due to competition for scarce resources and little relief from harsher environmental conditions. Increased civil unrest due to environmental stress may pose a threat to socioeconomic stability and would likely place a heavy burden on security forces. See Table 60 for further information.

AGRICULTURE

Agriculture is one of the most important economic sectors in Jamaica, employing over 180,000 farmers, and a 6.8% share in Gross Domestic Product (JAMPRO, 2017; RADA, 2017). It is also one of the most climate sensitive sectors. Vision 2030 *aims to improve the agricultural sector by increasing the local farmers' productivity by providing access to the best technology and sustaining a healthy natural environment*. Projected increases in temperatures and an overall decline in mean rainfall particularly in the traditional growing seasons as well as longer drought periods and more frequent extreme events will result in crop losses and lower productivity. In the Caribbean, livestock is traditionally managed in pastures without water and shade; and in broilers without any cooling aids. Extreme temperatures, droughts and other climate variables may result in (among other things) heat stress in livestock, resulting in declines in egg, milk and meat quantity and quality. See Tables 61 and 62 for further details.

MARINE AND TERRESTRIAL BIODIVERSITY

Vision 2030 reports that by the year 2030, all Jamaicans should live in a healthy and beautiful natural environment with clean air, water, rich forests and an abundance of plants and animals. This will be achieved by efforts including promoting the use of technologies that will not harm the environment. Climate change in conjunction with poor environmental practices threatens biodiversity. Increasing temperature, sea level rise and heavy rainfall events will impact on coral reefs, sea turtle nesting and sea grasses. See Table 63 for further information.

POVERTY

Vision 2030 promises include providing social protection to the most vulnerable and marginalized including those living in poverty, by ensuring that the Government provides these families with opportunities to make a good living and ensuring that welfare and assistance reach the most needy. In 2015, the International Monetary Fund estimated that 20% of Jamaica's population was living in poverty and that the extensive 2014 drought that continued in 2015 was a contributing factor to limiting poverty reduction prospects. Harsher climate conditions (for example, extreme temperatures) are likely to affect poorer communities the most and extreme events are likely to increase incidents of human trafficking within these communities. See Table 64 for further information.

TOURISM

Tourism is a major income earner for the Jamaican economy, generating USD2.2 billion in 2015 and USD1.4 billion in 2016 (STATIN, 2015; WTTC, 2017). At present, Jamaica's tourism brand is predominantly premised on sun, sea and sand. Vision 2030 envisions that *by the year 2030, Jamaica will have a wider choice of tourist attractions in safe and secure resort areas and that all hotels will be operated in harmony with the natural environment*. Climate change will directly impact the tourism sector through impact on tourist arrivals, increased incidents of beach erosion and through the degradation of both the natural environment and near shore water quality (for example, through sargussum events). Tourism infrastructure is also vulnerable to sea level rise and hurricanes and increasing temperatures will lead to heat related illnesses among workers and guests and higher operational costs for cooling aids. See Table 65 for further information.

HEALTH

Vision 2030 promises a health care system that is affordable and accessible to everybody. It also hopes to improve the monitoring and controlling of diseases in the population and ensuring that health services respond quickly to those in need of them. Climate change is likely to impact this commitment as increasing temperatures may affect the reproductive patterns of both men and women, and the emergence of vector borne diseases. Longer drought conditions and the potential for food insecurity may likely to lead to increased incidence of malnutrition within the population. See Table 66 for further information.

SOCIETY

Jamaican society is inherently vulnerable to the impacts of climate change. Most of the population lives within coastal and mountainous areas, and are therefore prone to displacement because of climate impacts such as sea level rise and land slippage. Climatic patterns also continue to guide our work and recreational lives through its impact on key quality of life indicators e.g. health, water availability and food security. Table 67 refers to the various ways in which climate change affects youth, livelihoods and productivity of the population.

FRESHWATER RESOURCES

Vision 2030 promises to ensure satisfactory water supply and sanitation services by strengthening the systems for storage, treatment and distribution of water, and proper disposal of wastewater. Water in Jamaica is sourced mainly from groundwater sources which contribute (84%) to local water supply. They are recharged by rainfall. Climate change is likely to affect the delivery of this Vision 2030 commitment because water quality and availability is subjected to climatic conditions. Increasing temperature and extreme events will increase evaporation and sedimentation of water. Furthermore, the proximity of basins to the coast is likely to increase saltwater intrusion into local water supply. See Table 68 for further information.

ENERGY

Vision 2030 aspires to develop and use new sources of energy such as renewable and natural gas and promote and improve energy conservation and efficiency in government, businesses and households. Climate impacts have the potential to challenge this outcome. Extreme temperatures will likely increase energy costs for cooling aids and sea level rise is likely to affect coastal power stations. See Table 69 for further information.

STORM SURGES AND COASTAL SETTLEMENTS

Vision 2030 plans to improve design of settlements and facilities to withstand the impacts of climate change. Continued coastal development, which sometimes involves the removal of natural barriers such as mangroves and coral reefs, for roads, bridges and human settlements increases vulnerability to sea level rise and storm surges. See Table 70 for further information.

6.2. Climate Impacts at a Glance

Figure 40: Illustrating how sea level rise affects different sectors of society

Figure 41: Illustrating the impacts of extreme events on sectors of society

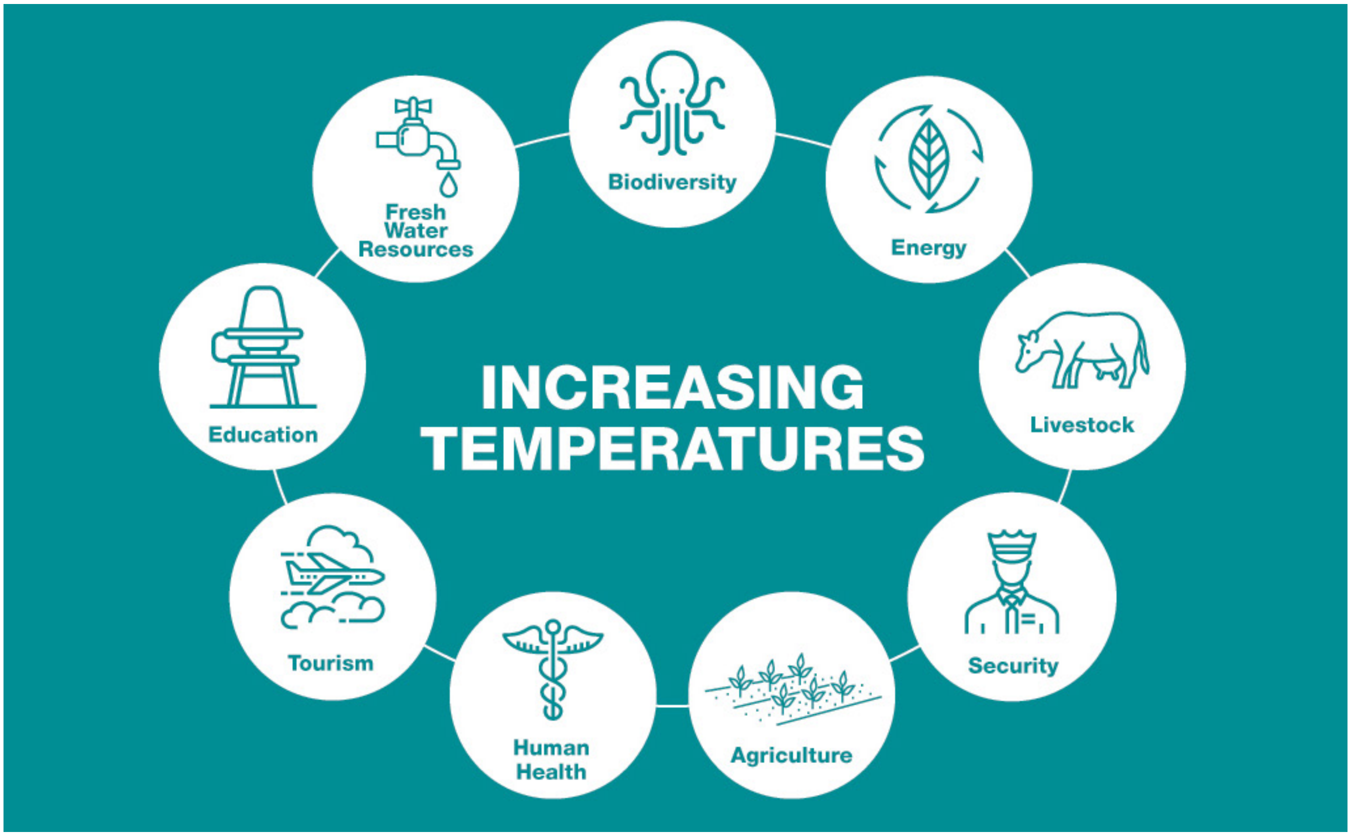


Figure 42: Illustrating the impacts of increasing temperatures on the different sectors

Figure 43: Illustrating the impact of droughts on different sectors of society.

Table 57: Impact of Climate Change on Development

DEVELOPMENT	
CLIMATE CHANGE VARIABLE/EXTREME EVENTS	**IMPACTS**
Increasing Temperature	**Decline in population health and associated economic losses**. Extreme temperatures are associated with the emergence of vector borne diseases such as the Chikungunya virus. This virus which is from the same mosquito (Aedes egypti) responsible for dengue fever; malaria severely impacted Jamaica's economy in 2014. It was estimated that 60% of the local population was affected, with a loss of productive time for recovery (5-10 days) and an economic loss of JMD30 million (37). **Extreme temperatures and workers' productivity.** Increasing temperatures has the potential to threaten social and economic development in the country. This is due to the correlation with body temperature, work performance and alertness (14, p.1). This has implications for outdoor workers such as sportspeople, farmers, manual laborers and indoor workers and students in classrooms without cooling aids. Higher temperatures can lead to low productivity. This is due to the fact that heat exposure can affect physical and mental capacity and lead to heat exhaustion or heat stroke in extreme cases.
Storm Surges / Sea Level Rise	**Increased incidents of sea level rise may displace coastal communities**. Increased incidents of sea level rise and storm surges would lead to displacement of 25% of Jamaicans who inhabit coastal areas (14, p.391). Areas like Portmore, which is a drained low lying coastal area (170,000 pop) would be at risk from flooding (29, p.67). Inundation of coastal areas, settlements, loss of life and property are also features of continual coastal development which exacerbate risks from these events (32, p.2). **Coastal erosion could destroy economically critical infrastructure** (ports, tourism centres, airports, road networks, since 90% of Jamaica's GDP is earned along the coastal zone (14, p.390). This could result in massive economic losses for the country (25, p.29).
Storms, Hurricanes, Droughts Tropical Cyclones, Floods	**Frequency of extreme events has implications for freshwater availability**. With a rise in the occurrence of extreme events, freshwater may be less available or it may be contaminated which will increase the susceptibility, especially of some remote and rural communities, to infectious diseases that have minimal public health care infrastructure (25, p.35). **Improper land use/development in watershed/flood-prone areas increase vulnerabilities to landslides and floods (29, p.67).** **A deterioration in social and economic circumstances might arise from adverse impacts of climate change on patterns of employment, population mobility, wealth distribution and limited resettlement prospects (25, p.35).**

DEVELOPMENT	
CLIMATE CHANGE VARIABLE/EXTREME EVENTS	IMPACTS
Storms, Hurricanes, Tropical Cyclones	**The unpredictability of climate change may affect insurance sector's ability to calculate risk**. Weather and climate are "core business" for the insurance industry. Insurers underwrite weather-related catastrophes by calculating and pricing risks and then meeting claims when they arise. Therefore, an unpredictable climate has the potential to reduce the sector's capacity to calculate and price this weather-related risk (38, p.1). The role of insurance in underwriting weather-related risk is an important component of the national economy. Any reduction in the industry's ability to underwrite weather-related risk will have serious ramifications for vulnerable countries (like Jamaica) where climate and weather risk is greatest (38, p.1). **The unpredictability of climate change is forcing insurers to develop adaptation strategies which includes putting a price on current and future risks** (39). **Banking sector would be affected by the adverse impacts of extreme climatic events**. Banks will be affected by climate change mostly indirectly to the extent that general economic activity is affected (20, p.11). It is estimated that up to 5% of market capitalization could be at risk from the consequences of climate change (40, p.11). The effects of climate change on banking companies would be direct (for example, through extreme events that put facilities at risk or indirect (through imposed regulations or shifts in social preferences) (40, p.11).

Table 58: Impacts of Climate Change on Education

EDUCATION	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	**IMPACTS**
Droughts	Increases in water shortages result in declines in water quality, leading to an increase in water borne diseases (such as dengue fever and malaria), resulting in a decline in children's school attendance and health. Children in female headed households in rural areas are particularly affected (5, p.20). Children spend more time with labour/time intensive water carrying responsibilities at home rather than attending school (5, p.8).
Hurricanes/Storms	Infrastructural damage forces the closure of schools and shortens the school term, reducing the numbers of days students attend classes. Hurricanes affect schools by damaging infrastructure, power lines and forcing the closure of many schools, as exemplified in the aftermath of Hurricane Ivan in Jamaica, where 1000 schools were damaged affecting 204,000 students. (7, p.6). Hurricanes affect performance of students in standardized examinations in Mathematics and science based subjects such as Biology, Chemistry and Physics. This is because the number of hurricanes occurring during the year increases the likelihood that school days and number of days of classroom time for guided teaching, practicing problems and laboratory experiments are reduced (7, p.4). Performance in standardized examinations for Humanities subjects such as French, Geography and Spanish, however are not affected by the passage of a hurricane (7, p.4). Worsening post-disaster socioeconomic circumstances negatively affect school attendance. After the passage of disasters some people become worse off economically, so they may remove children from schools and put them to work to reduce economic burden and increase family income (7, p.8).
Increasing temperature	Increasing temperature can disrupt the learning process. This is because of the correlation with body temperature, work performance and alertness, which has implications for students in classrooms without cooling aids (8, 9). Higher temperatures can lead to lower productivity. This is due to the fact that heat exposure can affect physical and mental capacity and lead to exhaustion or heat strokes in extreme cases. There is the potential threat of increasing temperature on youth and their educational development. Reading speed, reading comprehension and multiplication performance of schoolchildren could be affected by temperatures of 27-30 degrees.

Table 59: Impacts of Climate Change on Gender

GENDER	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	**IMPACTS**
Hurricanes, Floods, Tropical Storms	**Women's socioeconomic circumstances are worsened during the times of disasters.** Women comprise half of the population but represent 70% of the population living below the poverty line (4, p.7). This makes them more vulnerable to disasters since they experience higher rates of poverty and unemployment than men (4, p.14). These vulnerabilities are expanded in times of disasters when their risks are increased. This is manifested through higher levels of poverty, extensive responsibilities in caring for others, domestic violence and further fulfilment of duties considered "women's work" (4, p.10). **Gender bias in education**. In rural areas in Jamaica, there is a gender bias in the education of girls and boys, as boys are more likely to be removed from school than girls to assist with recovery efforts after disasters and to work on the farm (5, p.8). **Women and girls who are displaced from home are more vulnerable to sexual violence and sexually transmitted diseases in shelters than their male counterparts**. These women face several risks including the outbreak of diseases, especially when shelters are overcrowded, and have inadequate and poor sanitation facilities (4, p.14). **HIV rates increase among women in times of disasters, especially among those who engage in transactional sex as a survival strategy (6).** **Human trafficking increases in the event of a disaster disproportionately affecting women and girls**.85% of whom are at risk of being trafficked for sexual exploitation, while 25% of men and boys are trafficked for forced labor (2, p.11). **Women's mortality increases when disasters occur**. Many women sacrifice themselves during disaster when their own traditional caregiving roles hamper their own rescue efforts (4, p.3). This also reflects women's social exclusion because they are less able than men to run, and have behavioral restrictions that limit their mobility in the face of risk especially since their voices often do not carry as much weight as men's in their households. On the other hand, men suffer higher mortality rates because they take more risks trying to save themselves and their families (3). **Women and girls are particularly vulnerable in post disaster situations**. This is because they lack land and other assets that could help them cope. Therefore, they are more likely to face food shortages, sexual harassment, unwanted pregnancies and vulnerability to diseases and could be forced to drop out of school or marry earlier (3). **Rural women's socioeconomic circumstances affect their abilities to respond and recover from disasters.** As a group, they have lower incomes because job opportunities are more limited in rural areas. Many rural women experience various forms of inequality, related to their gender roles in the household, restricted access to credit to finance micro-businesses and more limited support services (2, p.10). **Greater loss of income for women in rural areas due to breakdown in road infrastructure.** Women in rural areas also experience greater income losses than their male counterparts from the breakdown of road infrastructure after the passage of a disaster due to their role in market vending and their dependence on road transportation, which would affect their food and livelihood security (5, p.8). **Women will experience lower resilience after disasters given weaker socio-economic and lower asset holdings; men are seen as being better able "to come back to their income streams after disaster" (5, p.8).**

GENDER	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	**IMPACTS**
Droughts	**Women in drought affected areas have time consuming water carrying responsibilities which limits ability to earn and diversify her income**. Women and children have the main responsibility for securing water supplies daily from springs or other sources, a lot of commuting time/ work is spent performing these duties This has implications for how they use their time which can be considerable because of the distances they have to travel to get water (5, p.20).

Table 60: Impact of Climate Change on Security

SECURITY	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	**IMPACTS**
Sea Level Rise	**Increased vulnerability of coastal populations and infrastructure through rising seas, beach erosion and under-resourced emergency response agencies makes them extremely vulnerable to climate change (10).** **Relief efforts of military services in the Caribbean may be hampered by sea level rise.** Caribbean operational and training facilities of the military service that launch relief efforts are highly vulnerable to sea level rise because many of them are located along the coast, so sea level rise and more intense storms can lead to destructive inundation and erosion of coastal facilities. It can also impact on clean water supplies and lead to an increase in maintenance costs of these coastal facilities (11). **Regional counterdrug trafficking efforts may be hampered by sea level rise because of the location of these facilities to coastal areas**. This deterioration in facilities will impact on military readiness and their capacity to continue in the American led counterdrug trafficking fight in the region since Caribbean security facilities often serve as launching pads for maritime patrols and interdiction operations (11). **Caribbean economic pillars are climate sensitive.** Caribbean islands are particularly vulnerable because of the inextricable link between its key economic activities, tourism and agriculture, and their heavy reliance on extremely climate sensitive areas such as seas, beaches and ports, which are subjected to climate change impacts such as beach erosion, sea level rise and port degradation (11). In Jamaica, 90% of Gross Domestic Product is produced within the coastal zone (14, p.391).

SECURITY	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	**IMPACTS**
Hurricanes, Storms	**Increasing storms and hurricanes can damage critical infrastructure**. An increase in extreme events can lead to the destruction of critical infrastructure of ports and roadways, which is disastrous for many island nations, and will inevitably disrupt their economic progress for many years (10). **More intense tropical storms increase search and rescue efforts of the Caribbean military**. The Caribbean military forces in support of regional bodies like (Caribbean Disaster Emergency Management Agency) CDEMA can expect an increase in requirements for search and rescue efforts and recovery operations in the wake of more intense tropical storms (10). **Military resources will be stretched beyond capacity to respond to distressed communities**. The military will not only have to build their respective capacities (training and equipment) to assist distressed communities but will also have to work with other defence organizations like the Inter-American Defense Board to pool resources, share best practices and hone specialties (10). As storms become more frequent and severe, the capabilities of Caribbean military and coast guard service organizations to provide relief and law and order to overwhelmed civilian response organizations will be undermined (11).
	Storms can lead to increased migration. There is a possibility of increased migration of residents from extremely fragile Caribbean nations like Haiti into neighboring countries like the Dominican Republic due to an extreme event (10)
	Greater risk to public safety with more frequent climate extremes. Longer periods of drought that result in dry loose earth increase chances of flooding and landslides across vulnerable areas. This can have consequential impacts on security especially when national disaster and security responses are unprepared (11).
Storms	**More frequent extreme events increase threats to livelihood security**: Extreme events such as hurricanes can lead to destruction of commercial infrastructure particularly along the coast leading to job losses (2, p.11) Farming is among the most vulnerable groups. Eighty percent of Jamaica's rural population is involved in agriculture (small farming, fishing and livestock rearing). They are also among the poorest (75% of them rely on government aided Programme for Advancement Through Health and Education (PATH programme) and are extremely sensitive to climate change because of the loss of income caused by climate change which leads to crop loss and lower yields (5, p.17). Household workers in Jamaica are very vulnerable to climate change because extreme events such as hurricanes can lead to destruction of their workplaces (homes) and job losses for their employers (2, p.11).
Droughts	**Droughts can exacerbate civil unrest due to limitations in water resources**. Longer dry periods especially pose a distinct challenge for governments which will have to invest more heavily in water management systems and infrastructural improvements to keep this most critical resource flowing. If they don't, civil and even military public servants may find themselves handing out emergency packages to the most affected citizens (12).

SECURITY	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	**IMPACTS**
Increasing temperatures	**Increasing temperature could result in heightened aggression.** There is a positive correlation between increasing temperature, body temperature changes and the production of adrenaline and testosterone hormones (flight and fright hormone). As a result, there may be increase in domestic and physical altercations (13).

Table 61: Impact of Climate Change on Agriculture & Fisheries

AGRICULTURE & FISHERIES	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	**IMPACTS**
Increasing temperatures	**Extreme temperatures can lead to growths in agricultural pest populations**. Increasing temperatures lead to an increase in the population of Beet Army Pest Worm, an agricultural pest which thrives in harsh conditions wreaking havoc on escallion and onion crops. In 2012, farmers lost JMD140 million worth of crop damages (28). **Rising temperatures are expected to result in reduced yield and growth of weeds, pests, bacteria and diseases** (27, p.26). **Sargasso seaweed affecting fisheries.** The sargassum seaweed may continue to clog propellers and prevent access to fish catch for local fishermen (24). **Citrus and root crops will continue to be affected by changes in temperature and precipitation (26, p.18).**
Decreased precipitation	**Threatens local agriculture, which demands 75% of local water supply (25, p. 29).** Soil degradation and loss of fertility due to droughts (25, p.34). **More severe drought conditions will affect local food security**. With projected decreases in precipitation up to 40% and up to 2.8°C rise in temperature expected by 2080s, many domestic crops will be under stress and food security will be threatened (14, p.262). **Higher water and production costs for local food production (28, p.19).**
Sea level rise	**Sea level intrusion in coastal agricultural areas and salinization of water supply (27, p.27).** In Jamaica, some wells have been abandoned due to increased salinity and others produce water unsuitable for agricultural use (29, p.74).
Storms, Hurricanes and Floods	**Passage of extreme events incurs losses of agricultural assets, livestock, crops and agricultural infrastructure (14, p. 264).** Especially severe for standing export crops (like banana, sugar cane, coffee) (14, p.265). Increased flooding will lead to inundation of production fields (27, p.27). Increased precipitation and flooding also leads to more favorable conditions for crop disease (25, p.34). **Increased food costs, increased costs of insurance and higher rates for capital cost loans (30, p.6).**

AGRICULTURE & FISHERIES	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	IMPACTS
Rainfall Patterns	**Unreliable/unpredictable rainfall patterns would affect product distribution, distribution and quality** (25, p.34).

Table 62: Impacts of Climate Change on Livestock

LIVESTOCK	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	**IMPACTS**
Increasing temperatures	**Increasing temperatures for poultry can affect reproduction rate, breast meat and egg quality:** Chickens especially inside broilers, are finding it increasingly difficult to cope with heat stress conditions. The adverse effects of high temperature increase with age and may result in lower quality of breast meat yield, carcass quality and high mortality (15, p.171). High temperatures also affect reproduction rate among chickens (20). Hot environments impair production which affects egg yield, weight and quality (19).
Increasing temperatures (cont'd)	**High temperatures affect growth rate and susceptibility of young goats and sheep to many diseases.** Heat stress has a direct effect on feed intake, growth rate and reproductive performance (16, 45). It also suppresses the immune system and increases animal susceptibility to many diseases. **Heat stress in early and late gestation can cause a decrease in lamb birth weight (17, p.8).** **Rising temperatures affect behavioral patterns in goats and sheep**. Amidst rising temperatures, some of the behavioral patterns observed among sheep include roaming pastures looking for shade, increased water consumption and consuming less feed to maintain body temperature (17, p.2; 46.
	Increasing temperatures can affect milk quality: Heat stress directly and indirectly reduces the ability of the cow to lactate to its full potential. This affects the yield and composition of milk. Heat stress can also adversely affect the rate of conception among the herd, pregnancy and calf birth weight (18, p.11).
Drought	**Drought conditions can affect birth weight and litter size among sheep**. During the dry season, there is an 11% reduction in litter size, birth and weaning weight among hair sheep. This is due to the decreased availability of forage in the dry season as compared to the rainy season. Therefore, lambs born in dry season had heavier birth weight than those born in wet season because they were conceived during the wet season when ewes had higher quality of pasture, with higher protein forages and concentrate supplement. Animal performance is heavily dependent on the availability of forage and its nutritional value (17, p.8).
	Longer periods of drought may lead to a large-scale loss of cattle (27, p.26).

LIVESTOCK	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	**IMPACTS**
Hurricanes, Storms	**More frequent extreme events can increase livestock mortality**. Increasing frequency of storms and its associated effects of floodwater and high winds has the potential to increase the mortality among livestock (poultry, cattle, small ruminants) on a large scale (22). The passage of Tropical Storm Gustav led to livestock losses valued at USD16 million (21).

Table 63: Impact of Climate Change on Marine and Terrestrial Biodiversity

MARINE & TERRESTRIAL DIVERSITY	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	IMPACTS
Increasing temperature	**Northern migration of Caribbean coral reefs and commercially viable fish stock.** Rising sea surface temperatures are leading to the migration of Caribbean grazers like parrotfish and rabbitfish to more temperate seas. These fish species can now be found in areas such as the Mediterranean Seas, Japan and Australia feeding on sea grasses and kelp forests. Caribbean coral reefs have also followed these fish populations and are replacing the sea grasses and kelp forests (23). **Sargassum seaweed affects marine life**. Ocean acidification and increasing sea surface temperatures has led to the presence of the Atlantic Sargassum seaweed in the Caribbean region. This seaweed threatens coastal ecosystems by smothering sea grass beds, coral reefs and mangroves. It also threatens endangered species such as sea turtles by drowning and entangling them (24). **Increasing temperatures will affect sea turtle populations.** Rising temperatures are projected to affect reproduction of sea turtles since sex is determined by temperature (26, p.15). **An increase in sea surface temperature of 1.0 degree Celsius will lead to coral reef bleaching**. Bleaching reduces the ability of corals to withstand impacts of extreme events and also leads to habitat loss for reef fish and their eventual decline (25, p.36). **Sea grass decline**. Sea grasses are also sensitive to thermal discharges and can only accept temperatures up to 2–3 degrees Celsius above summer temperatures (25, p.36).
Increasing temperatures and Decreasing precipitation	**Changes in temperature and precipitation will affect the frequency and extent of forest fires (26, p.18).** **Citrus and root crops highly sensitive to changes in temperature and precipitation (26, p.18).**
Sea level rise	**Sea level rise leads to a decrease in sea turtle nesting**. Beach erosion as a result of 0.5-metre sea level rise in the Caribbean is projected to cause a decrease in sea turtle nesting habitats by up to 35% (25, p.35). **Storm surges and sea level rise could increase the salinity of estuaries and fresh water aquifers (25, p.36).** **Degraded wetlands have a reduced capability to act as natural filters & buffering systems for shorelines and coral reefs against severe events such as flooding (25, p.36).** **Mangrove vegetation will migrate landward in response to changing ecological conditions brought on by inland movement of the sea and salt water intrusion into coastal waterway**s **(27, p.46).**

MARINE & TERRESTRIAL DIVERSITY	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	IMPACTS
Heavy Rainfall	**Sea grasses currently face threats from sedimentation, direct dredge and fill activities and wastewater discharge.** Increased storm events, flooding or high intensity rainfall, attributed to climate change, could magnify this effect by increasing the volume of polluted runoff from upstream sources (25, p.36).

Table 64: Impacts of Climate Change on Poverty

POVERTY	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	IMPACTS
Increasing temperature	**Severity of heat waves likely to increase human mortality among the urban poor**. It is anticipated that an increased frequency or severity of heat waves in the Caribbean would cause an increase in human mortality especially among (urban) poor communities without access to cooling aids like air conditioners or refrigerators (25, p.35).
Droughts	**Droughts increases (especially) low income communities' vulnerability to disease infection.** Households in low income communities with no running water are more at risk of dengue fever and infectious diseases, than those with piped water supply since water storage becomes necessary (36, p.43). During water shortages in some communities, diseases spread because of poor infrastructure, waste disposal issues and lack of access to clean water sources (28, p.15). **Malnutrition resulting from disturbances in food distribution and production could also occur (25, p.34).** **Increased vulnerability of the elderly poor.** The elderly poor in rural areas may face serious health threats from the lack of water or adequate sanitation associated with climate change impacts. These health issues will place a greater strain on care givers (who tend to be female) in the household and community (27, p.20).
Storms, Tropical cyclones, Hurricanes	**Flooding and landslides lead to population displacement because of vulnerabilities of settlements in floodplains** (29, p.67). **Poor housing quality increases residents' vulnerability to the ravages of extreme events** (1, p.148). **Heavy rainfall affects the health and sanitation of some communities without proper toilet facilities.** Flooded pit latrines, during storms release waste directly into the rivers which some residents use. This has led to an increase in diseases associated with water sanitation and poor hygiene practices (28, p.15). **Passage of extreme events lead to increased incidence of human trafficking in low income communities.** Human displacement due to extreme events such as hurricanes, floods and droughts increases the risk of human trafficking, especially in those communities facing chronic poverty and lack of security. Children are particularly vulnerable to trafficking (2, p.11).

Table 65: Impacts of Climate Change on Tourism

TOURISM	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	IMPACTS
Sea Level Rise	**Beaches respond to sea level rise by retreating inland at approximately 100 times the rate of sea level rise (26, p.13).**
Increasing Temperature	**Sargassum blooms compromise quality of local tourism product:** Increasing sea surface temperature has led to the presence of the Sargassum seaweed covering white sandy beaches and discoloring near shore waters in many coastal areas (including hotel facilities) and emitting a pungent odor across the Caribbean region, including Jamaica. This compromises the scenic beauty of the local tourism product (24). **Temperature extremes can lead to increased incidence of heat stress and other heat related illnesses.** In extreme cases, it can become fatal. Heat stress remains a concern with higher temperatures for tourists and outdoor workers (31, p.18) Heat storage of built structures, leads to 'heat island effect' (31, p.18). This leads to additional operating costs for cooling aids (27, p.87). **Sea surface temperature increases of at least 1.0 degree Celsius will lead to coral reef bleaching** (26, p.14). Note: No base temperature was given for the 1.0 degree rise. These reefs contribute to Jamaica's tourism product through diving and fishing tours. They are also critical sources of beach sand (32, p.6).
Sea Level Rise	**Beaches respond to sea level rise by retreating inland at approximately 100 times the rate of sea level rise** (26, p.13).
Increasing Temperature	**Sargassum blooms compromise quality of local tourism product:** Increasing sea surface temperature has led to the presence of the Sargassum seaweed covering white sandy beaches and discoloring near shore waters in many coastal areas (including hotel facilities) and emitting a pungent odor across the Caribbean region, including Jamaica. This compromises the scenic beauty of the local tourism product (24). **Temperature extremes can lead to increased incidence of heat stress and other heat related illnesses.** In extreme cases, it can become fatal. Heat stress remains a concern with higher temperatures for tourists and outdoor workers (31, p.18) Heat storage of built structures, leads to 'heat island effect' (31, p.18). This leads to additional operating costs for cooling aids (27, p.87). **Sea surface temperature increases of at least 1.0 degree Celsius will lead to coral reef bleaching** (26, p.14). Note: No base temperature was given for the 1.0 degree rise. These reefs contribute to Jamaica's tourism product through diving and fishing tours. They are also critical sources of beach sand (32, p.6).
Heavy Rainfall	**Adverse rainfall /weather conditions could lead to cancellation of reservations or displacement of visitors which would incur massive losses in revenue (25, p.29).**

TOURISM	
CLIMATE CHANGE VARIABLE/ EXTREME EVENT	IMPACTS
Hurricanes/Storms	**Increased infrastructural damage, additional emergency preparedness requirements and business interruptions, including in the tourist industry, due to floods, coastal inundation and extreme events (27, p.87).** Tropical storms and hurricanes appear to be the dominant factor influencing beach erosion (26, p.14).

Table 66: Impacts of Climate Change on Human Health

HEALTH	
CLIMATE CHANGE VARIABLES &EXTREME EVENTS	**IMPACTS**
Droughts	**Food shortages as a result of drought conditions, may lead to malnutrition.** Studies have shown that food shortages lead to the necessary importation of foreign goods, which includes affordably priced carbohydrate and sodium laden foods that contribute to obesity and other forms of malnutrition (28) **Prolonged droughts and water storage promote disease infection.** Storage of water in drums during droughts provides favorable conditions for the breeding of vectors and transmission of infectious diseases (14, p.12).
Increasing temperature	**Increasing temperature may lead to reproductive problems for both men and women.** Heat exposure may lead to reproductive problems in men, due to the relationship with repeatedly raising testicular temperature by 3-5 degrees and decreasing sperm count (28). Exposure of pregnant females to increasing temperatures could lead to hypothermia, which may result in high incidence of embryo deaths and malformation of head and the central nervous system (28).
	With extreme temperatures diabetic persons increase demand for water use more so than non-diabetics (35). Studies have shown that diabetics urinate more often, increasing water usage for hygiene and sanitation.
	Higher temperatures also speed the life cycle of the Aedes Aegypti mosquito and the disease organisms they harbor and make adult mosquitoes bite more often (31, p.79). A 2-3 degree Celsius rise in temperature results in shorter incubation period for the virus and can lead to a three-fold increase in dengue fever transmission. The chances of dengue hemorrhagic fever could also be increased (14, p.12). Note: Chikungunya and Zika viruses are caused by the same mosquito.
	Warmer temperatures provide favorable conditions for RED TIDE (blooms of toxic algae) which can increase incidence of human shellfish poisoning (31, p.25).
Increasing Temperature and Humidity, Sahara dust due to droughts in Africa	**Increasing temperature and humidity increases respiratory problems.** Increased incidence of acute asthma, bronchitis and respiratory allergies are to be expected as a result of increasing temperature, dust, humidity and wetter conditions respectively (31, p.80). Air pollution which results in the inhalation of suspended particulate matter from fossil fuel emissions, waste incineration, etc., will lead to respiratory diseases (31, p.19).

HEALTH	
CLIMATE CHANGE VARIABLES &EXTREME EVENTS	**IMPACTS**
Increasing Temperature and Humidity	**High temperatures and humidity stress the body's ability to cool itself.** This heat stress can lead to increased incidence of heat related illnesses like heat strokes, cramps (31, p.18). **Incidences of diarrheal diseases and cerebrovascular (strokes) are also susceptible to heat stress.** Strokes are among the leading causes of deaths in Jamaica (14, p.12). The heat island effect exacerbates the impact of increased temperatures (31, p.18).
Storms, Floods, Tropical Cyclones and Hurricanes	**More frequent extreme events have public health consequences.** Examples of public health impacts include lack of potable water, loss of food production, population displacement, loss of livelihood security (31, p.19). There may also be fatal injuries, for instance, deaths by drowning (27, p.62). Possible increase in incidence of mental cases, malnutrition, increases in infectious diseases (water, rodent and vector borne) (31, p.19).
Heavy Rainfall	**Incidents of leptospirosis may increase with heavier rainfall.** Humans are infected through exposure to water /soil contaminated by infected animals usually during heavy rainfall and has been associated with wading and swimming in untreated open water (31, p.79). **Heavy rains can have public health consequences**. Heavy rains contaminate watersheds by transporting human and animal faecal products and other wastes into groundwater. (31, p.25). Heavy rainfall also affects the health and sanitation of some communities without proper toilet facilities (water closets). Flooded pit latrines release waste directly into the rivers. This solid waste then threatens the health of people in the communities and especially the health of children who use the river for bathing purposes. This has led to an increase in diseases associated with water sanitation and poor hygiene practices (28, p.15). Lack of potable water and poor sanitation also increases the likelihood of infection (14, p.12).

Table 67: Impacts of Climate Change on Society

SOCIETY	
CLIMATE CHANGE VARIABLE/EXTREME EVENT	IMPACT
Hurricanes/Tropical Storms/Heavy rainfall/ Flooding	**Extreme events increase the vulnerability of unattached youth to risky behavior**. The Caribbean region has a big pool of unattached youth (youth not in school and not at work). With high levels of unemployment and low levels of skills and education they are vulnerable to climate change. Climate change presents challenges with the loss of homes and livelihoods which could increase the likelihood of this group engaging in transactional sex as a survival strategy (14, p.11).
	Increase in stress and familial conflicts in rural areas associated with crop loss and damages after an extreme event. Agricultural areas, which are extremely vulnerable to climate change, will experience an increase in stress associated with crop loss and damages and loss of livelihoods after the passage of an extreme event. This affects family life because there is a higher tendency for increasing familial conflicts and relational breakdowns associated with climate change impacts. This is because men and women are exposed to greater stress and feelings of being unable to cope due to their expected responsibilities for family and for supporting food and income security (27, p.8). **Increased flooding will lead to inundation of production fields (27, p.27).** **Rainfall extremes (droughts, floods) are associated with the spread of waterborne diseases, due to a lack of potable water and sanitation issues,** possibly leading to lack of productivity (28, p.15).
Increasing temperature	**Fisher folk livelihoods threatened by increasing temperatures**. The majority of Jamaica's coastal communities depend on coastal resources for their livelihood. In particular, reef fisheries are of major importance in the Jamaican food chain as the island's fringing reefs provide a livelihood for artisanal fisheries. Coral reefs are already facing impacts from climate change, which are thereby affecting reef fisheries (25, p.34). **Extreme temperatures likely to affect household resources**. Temperature increases could lead to the spread of dengue fever and other vector borne diseases (14, p.12). Households consisting of disabled or ill members are considered more vulnerable since this affects the number of people available for productive labour and puts a strain on household resources (36,p.43).

Table 68: Impacts of Climate Change on Freshwater Resources

FRESHWATER RESOURCES	
CLIMATE CHANGE VARIABLE/EXTREME EVENT	IMPACT
Sea Level Rise	**Groundwater quality continues to be and will be further affected by the proximity of some basins to the coast (29, p.74).** **Sea water intrusion has resulted in the loss of 100 million cubic metres of groundwater (10% of local supply) annually (29, p.74).**
Heavy Rainfall /Storms	**More extreme events affect water quality**. Some water catchment areas are prone to flooding and exposed to the risk of debris and sediment flows (29, p.67).
Droughts	**Drought affects sanitation due to lack of water for hygienic purposes, thereby affecting the transmission of disease (25, p.30).** **Scarcity of freshwater sources could limit Jamaica's social and economic development**. It would affect local sectors which include agriculture and domestic usage which account for 75% and 17% respectively of local water demand (25, p.29). **Irrigated agriculture depends on 85% of local water supply (29, p.83).** **Longer drought periods will lead to water shortages, a decline in food availability and a need for food importation**. Hunger and malnutrition may increase (14, p.12).
Increasing Temperature	**Increasing temperature leads to more evaporation** (29, p.30). Evaporation leads to a greater pathogen density in the water and this could result in a lack of potable water (14,p.12).

Table 69: Impact of Climate Change on Energy Supply and Distribution

ENERGY SUPPLY & DISTRIBUTION	
CLIMATE CHANGE VARIABLE/EXTREME EVENT	IMPACT
Increasing Temperature	**Extreme temperatures increase energy demand for cooling aids**. Heat stress in buildings and in cars would increase pressure on electricity and fuel demand for cooling aids like fans and air conditioning units (33). Less favorable for the harnessing of solar energy. With photovoltaic solar voltage and power decrease with increased temperature (33). **Increased sea surface temperatures will increase the efficiency of Ocean Thermal Energy conversions (OTEC) systems (34).**
Sea level Rise	**Impending sea level rise may impact coastal power plants**. A 1-2m sea level rise is expected within the Caribbean region by 2100 (33). Sea level rise could greatly impact critical infrastructure which is located near the coastline (14, p.391). Many power plants are located near the coastline to discharge waste heat.
Hurricanes, Storms	**More intense hurricane and storm events may damage energy infrastructure**. Damage to on and off shore wind turbines. Damage to power lines, substations and other , etc(33).
Inadequate rainfall	**Inadequate rainfall and drought conditions place greater demand for electricity**. Inadequate rainfall will negatively affect river flows and decrease hydropower (33).

Table 70: Sea Level Rise and Storm Surge Impacts on Coastal Infrastructure and Settlements

SEA LEVEL RISE AND STORM SURGE IMPACTS ON COASTAL INFRASTRUCTURE AND SETTLEMENTS
IMPACTS
Storm surges associated with hurricanes and tropical storms can lead to the inundation of low lying coastal areas by high tides with coastal swells (29, p.67). Permanent inundation could occur in some areas (14, p.391). A large percentage of Jamaica's population (25%) is concentrated near to the coastline, thus a rise in sea level will cause a displacement of coastal settlements (14, p.391).
Critical infrastructures like port facilities, tourism centres and dense population centres are located within Jamaica's coastal zone. The coastal zone of Jamaica is thus very susceptible to sea level rise, which would cause increased beach erosion rates and higher incidences of coastal flooding (2, p.391). Sea level rise and storm surges will impact these critical infrastructures economically since it is reported that 90% of GDP is produced within the coastal zone (14, p.391).
Sea level rise is also expected to exacerbate coastal erosion, resulting in damage or increased loss of coastal ecosystems, threatening property and infrastructure located in coastal areas and resulting in salt water intrusion of underground coastal aquifers (27, p.43). Damages to road networks and bridges, during the passage of Hurricane Nicole resulted in losses totaling JMD14 billion (16). Coastal erosion along the Palisadoes Spit has caused flooding and deposited sand and debris on the road access to the Norman Manley International Airport rendering it impassable (25, p.36).
Additional information: The First National Communication indicated that the IPCC in 1990 estimated that the cost to protect Jamaica from one metre of sea level rise would be USD462 million (14, p.391). Continued coastal development is very likely to exacerbate risk of loss of life and property due to storms and sea level rise (32, p.2).

7. Climate Vulnerability Profiles

7.1. Introduction

In recent years, there has been a steady rise in the number of studies profiling Jamaican communities and their vulnerabilities with respect to climate. In this chapter, the vulnerability profiles for seven Jamaican communities are summarized from the range of environmental assessments that now exist in the public domain. The communities chosen are diverse in terms of location, demographics, biodiversity, and economic activities. The profiles are meant to illustrate (i) the amount of existing detailed information on which decision making can be premised, and (ii) the scales at which this information exists (from small rural town to major urban population centres) and therefore the scales at which decision making must take place. (iii) the kinds of recommendations that already exist for building community resilience to climate change.

Profiles for seven communities are provided: Bluefield (Westmoreland), Negril (Westmoreland), Rio Minho (Clarendon), Ocho Rios (St. Ann), Black River (St. Elizabeth), Montego Bay (St. James), Portmore (St. Catherine). The information in each profile is adapted directly from the studies listed in the References Chapter and specifically Section 9.7.

7.2. Bluefields

Bluefields is a small coastal community in Westmoreland, Jamaica. There is a great deal of biodiversity in the area, and efforts to implement ecotourism and protect this biodiversity are being led by the Bluefields Bay Fisherman's Friendly Society and the Bluefields Eco-tourism Community Group. The Bluefields Bay Special Fishery Conservation Area (SFCA) was designated on July 28, 2009, and covers approximately 1347 hectares. It is managed by the Bluefields Bay Fisherman's Friendly Society and is one of two SFCAs in Westmoreland. The beaches in the area have been maintained in a sustainable way in coordination with turtle rescue programmes that are funded by a number of international projects, particularly from the UK government, such as CARIBSAVE.

LOCAL GOVERNANCE AND STRUCTURE

The Westmoreland Municipal Corporation governs over the community of Bluefields. The Municipal Corporation is responsible for all local governance, including development and facilitation of community involvement. The Corporation has adapted a Strategic Planning approach to its activities so as to improve efficiency, service and communication to the communities within the parish.

BUSINESS/LIVELIHOODS/INDUSTRIES

The primary drivers of the economy of the community are fishing, agriculture and tourism. As a coastal community, residents engage in large scale fishing and related activities, such as fish processing, pot stick cutting and boat building. Agriculture is also an important activity in the area, due to the rich soil. It is also a small, but growing tourist destination, and both local and international tourists frequent the beaches and nature parks in the community.

PUBLIC INFRASTRUCTURE

Notable public infrastructure includes:

- » Boat dockyard and jetty;
- » Post Office;
- » Police Station; and
- » Schools and community centres, some of which are converted to relief shelters in times of emergency. For example: Mearnsville Primary School (relief shelter); Belmont Academy High School; Bluefields Basic School; Cave Basic School; Mc-Alpine Basic School; and Robins River Basic School
- » Small businesses:
    - 10 craft shops
    - 15 guest houses,
    - 10 villas and 1 hotel
    - 5 agricultural vending kiosks
    - Peter Tosh memorial monument

ASSESSMENT OF WATER AVAILABILITY AND SUPPLY

Bluefields currently experiences extended periods without rainfall. Many households in Westmoreland do not have access to running water and rely solely on rainwater catchments. During these periods, their options include either traveling to Beeston Springs on their own to fill drums of water, or they pay private trucking services to deliver water to their empty catchments. In the event of an emergency, the government provides water to households by truck. Lack of piped water poses a challenge for farmers as well.

HISTORICAL AND PROJECTED CLIMATE

See profile on **Negril** for assessment of a nearby site.

CLIMATE RELATED HAZARDS

The community has experienced longer dry spells and droughts over time, resulting in a lack of water resources for home or farming use. Residents have reported that rainfall patterns and seasons have become less predictable, which hinders the largely rain-fed agriculture of the area. Direct hurricane damage has been relatively frequent in the area, with some residents reporting one to three occurrences of damage in the last ten years. The dry season in Bluefields occurs in December-May, and no droughts have been experienced in the community since 2012.

The location of the community makes it susceptible to climate hazards. There is high risk to infrastructure and economic activity due to erosion, storm surges, and sea level rise, among other impacts of climate change. Particularly vulnerable settlements are:

» Coastal settlements at risk of storm surges, sea level rise and flooding, for example, Belmont, Creek, Blacks Bay, Farm Community, Sandals White House, and the districts between Cave and Ferris Cross.

» Hillside settlements at risk of rainfall triggered erosion and landslides, for example, Belmont, River Top, Brighton, Auldayr, Cave Mountain, Cave Hill, McAlpine, Mearnsville and Red Gate.

Despite prolonged erosion in many areas, the beaches in Bluefields showed an increase in width between 2011 and 2012. However, the marine ecosystems, such as coral reefs and mangroves, are susceptible to storm activity and rising temperatures. This may result in future loss of biodiversity and ecosystem services provided by these systems. In addition, coral reefs and fish stocks have declined in health in recent decades, leading to a decline in economic activity among fish-dependent residents and areas.

Unsustainable environmental management practices have led to increased vulnerability of the community. These include:

» Use of gullies and waterways as dumping sites, blocking drainage and increasing flood risk

» Slash and burn practices reduce plant cover on hillsides and increase likelihood of landslides

» Poor waste management leads to contamination of water resources

» Poor disposal of collected water leads to proliferation of vector-borne diseases

In the past decade, infrastructure and other physical assets have been damaged by climate extremes. Economic impacts have been heavy, as severe weather has decreased productivity of farmers, fishermen and tourism related activities. There has also been loss of physical property related to these livelihoods, such as tools and boats. There has been damage to natural resources and ecosystems in the area due to increased storm intensity, which has also damaged roads and other infrastructure. Erosion has been of great concern in the area, with storm surges and strong waves reducing sand cover and increasing rock exposure along beaches.

RESPONSE AND RESILIENCE BUILDING INITIATIVES

The CARIBSAVE led Climate Change, Coastal Community Enterprises: Adaptation, Resilience & Knowledge (C-ARK) project produced a compilation of the Bluefields Climate Adaptation goals, strategy and actions with the participation of the community in 2015. Six major goals for building climate resilience were identified. To:

» Increase public awareness and communication of climate change and its community impacts.

» Engage in and encourage activities that aid in habitat restoration and natural resource preservation.

» Minimise or prevent damage or loss of property from flooding or inundation resulting from heavier storm events, sea level rise and other adverse climate impacts.

» Enhance current livelihood strategies and create livelihoods and opportunities that put less strain on the use of local natural resources.

» Strengthen community partnerships to reduce vulnerability.

» Establish early warning systems and an emergency response plan for the community.

Development of the plan was spearheaded by the Bluefields Bay Community Association, along with CARIBSAVE. The plan is to be implemented and monitored by key groups in the community.

7.3. Negril

Negril is located in western Westmorland and spans 408 km² of coastline. Key features of the area are well drained inland karstic white limestone, coastal hard reef limestone, hilly terrain with peaks of up to 250km, the Great Morass covering approximately 2,400 hectares bordered by coral reefs, and approximately 12 km of white coral sand beach. There are two rivers running through the community, the North and South Negril Rivers, in addition to canals running through the Great Morass (see Figure 43).

There is a sand barrier that separates the 9 km stretch of beach into Long Bay in the north and Bloody Bay in the south, which are both coastal borders of the ecologically important inland morass. The Great Morass is the second largest freshwater wetland in Jamaica and makes up one-fifth of the island's wetlands. It is an important habitat for migratory birds and a number of endemic keystone species. The morass is also important as a source of ground water recharge, flood control, nutrient retention, shoreline stabilization, and climate control through air quality improvement. Offshore, there are seagrass beds and a coral reef system that protect the shoreline from storm surges and erosion, and serve as habitat for ecologically and economically important wildlife.

DEMOGRAPHIC PATTERN AND TRENDS

In 1996, the population of Westmoreland was 135,600, of which 51% was female and 49% male. The population of Negril was estimated in 2011 to be 11,176, reflecting a 15% increase in the decade since 2001 (Table 71). The gender proportion is similar to that of the rest of Westmoreland, with 52% females and 48% males. The majority of the population is between 15 and 64 years of age, while the minority of residents is over 65.

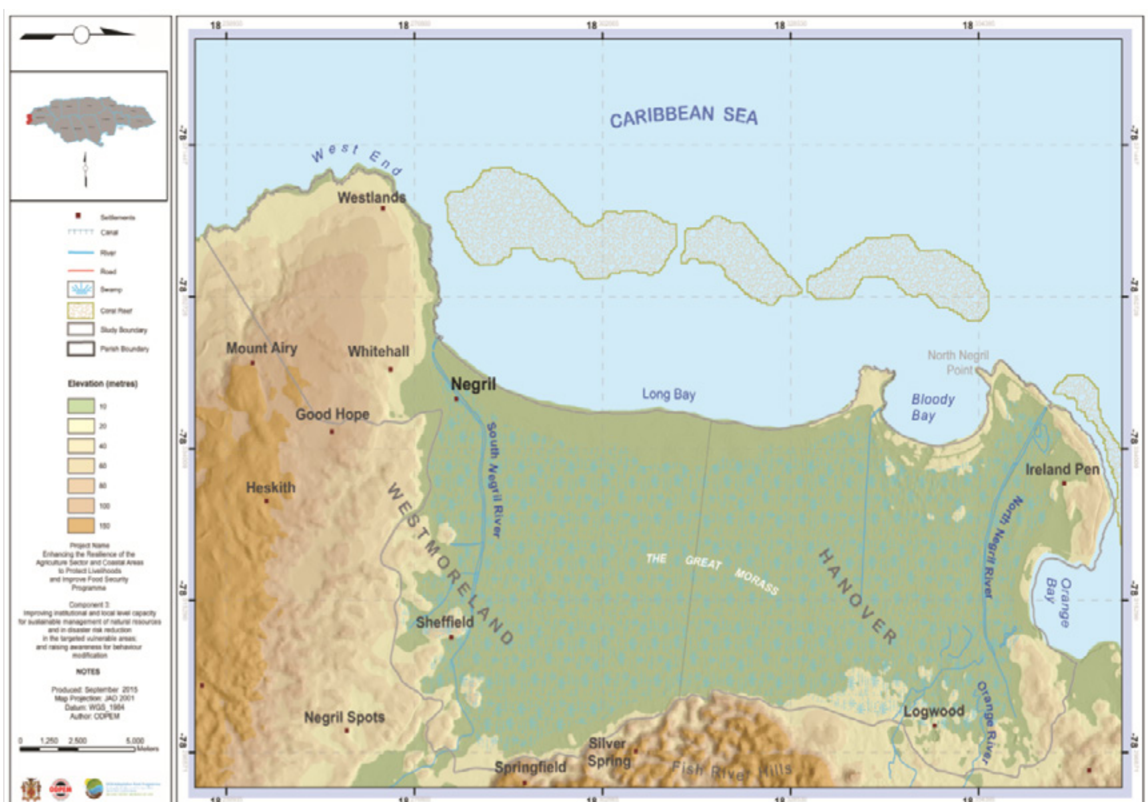


Figure 44: Map of Negril showing geographical features (ODPEM 2015).

LOCAL GOVERNANCE AND STRUCTURE

The Westmoreland Municipal Corporation governs over the community of Negril, and is led by its Mayor. The employment rate for Negril is high due to tourism as the economic base. The area presents a development challenge, and is home to the Negril/Green Island Area Planning Authority, the UDC, and the NRCA, all having specific mandates for managing the land resources. The Negril area is a significant contribution to the property tax revenue stream. The NWC has within recent years implemented a central sewerage system and potable water supply schemes. The Westmoreland Municipal Corporation deals with development issues concerning the provision of water within the parish, and is guided by development orders and plans. Plans are sent across agencies for proper guidance and enforcement.

Table 71: Population structure of Negril in 2011.

Gender	Age Cohort			Total Population 2011 Census
	0-14	15-64	65 and Over	
Male	1,529	4,018	251	5,798
Female	1,530	3,570	278	5,378
Total	3,059	7,588	529	11,176

BUSINESS/LIVELIHOODS AND INDUSTRIES

The economy of Negril is dominated by tourism. Tourist resorts are highly frequent in the area and provide approximately 9,712 jobs directly via the accommodation sector. It is the third largest tourist area in the island, and many of these facilities cater to both locals and foreigners staying for long or short periods.

The other major source of income for communities in the area is agriculture, including both farming and fishing. Fishing is an important livelihood in the coastal community, with approximately 400 fishermen and 120 vessels registered in the area. However, fishing activity has declined over the years. Farming is the dominant land use activity in the Great Morass. This includes cultivation of crops and rearing of livestock. Crops cultivated in the area include cabbage, broccoli, callaloo and sweet potato, as well as banana and sugarcane to the east and south. Cattle farming is done on a small scale, primarily in the Sheffield and Negril Spots communities.

AN ASSESSMENT OF WATER AVAILABILITY AND SUPPLY

The main water sources are the South Negril River that runs through several small communities including Whitehall and Sheffield, and the Logwood Treatment Plant. The Logwood plant gets its 3.2 million gallons per day capacity from the Blue Hole and Fish River springs. This, however, is a split resource between Lucea and Negril. There is currently a lack of water within this parish that stems from development. However, the NWC has implemented a central sewerage system and potable water supply schemes.

HISTORICAL AND PROJECTED CLIMATE

The climate of the area is subtropical. Rainfall is variable, but peaks between May and October exceeding 180 mm. Highest mean daily temperatures have been recorded in July and August exceeding 29^{o}C, and lowest temperatures have occurred in March, often reaching 22^{o}C. Relative humidity is around the Jamaican mean, ranging from 65% to 85%.

Trends in observed climate have shown:

- Increase in temperature at a rate of 0.41^{o}C per decade over the period 1973-2008, particularly in JJA
- Decreased rainfall of 18% per decade over the period 1973-2008. This trend may, however, have been skewed by anomalously high rainfall in the early 1980s.
- Wind speed observations from nearby Montego Bay indicate a decreasing trend, though not statistically significant.
- Relative humidity slightly increased in nearby Montego Bay by 1.0-1.5% per decade, but this trend is only significant in annual and SON data.
- Local sea levels have risen by approximately 0.9 mm/year

Trends in RCM projected climate indicate:

- Increase in mean temperatures by 3.6-3.8^{o}C by the 2080s under the A2 scenario, with marginally more warming in JJA and SON than the other seasons
- Changes of -11 to +17% in mean rainfall by the 2080s, with a general mean trend towards drying. Changes in seasonality of rainfall vary based on the driving GCMs, but there is a consensus on overall annual drying.
- Small decreases in mean annual wind speeds of approximately -0.1 ms^{-2} by the 2080s.

CLIMATE RELATED HAZARDS

Negril is highly susceptible to climate hazards due to its coastal location and low-lying topography. It is particularly vulnerable to water based hazards and coastal erosion, which have significantly affected infrastructure and livelihoods.

- Coastal erosion has occurred at a noticeable rate in Negril at a rate of between 0.2 and 1.4 m/year in Long Bay and 0.2 and 0.8 m/yr in Bloody Bay. Over the past 45 years, Long Bay has receded by 62.6 m.
- Erosion was greatest between 2003 and 2009 following impact by Hurricanes Ivan (2004), Wilma (2004) and Dean (2007). This was followed by accretion over the period 2009 – 2013, during which storm activity was minimal.
- Notable hurricane damage also occurred during the passage of Hurricane Mitch in 1998, which damaged both infrastructure and environment, with storm surges at a height of 13-17m along West End and Long Bay, and loss of 10 m^3 of beach sand along with reefs and wildlife.
- Many flood events have impacted Negril, particularly those that occurred in 1990, 1997 and 2002. In 1990, there was heavy damage to infrastructure, and recession was hindered by blocked drains. In 1997, damaged pipelines resulted in flooding that delayed commuters in Sheffield. In 2002, Tropical Storm Isidore caused heavy flooding in Negril, resulting in flood waters carving trenches across major roadways.
- The economic implications of extreme climate events such as strong winds and flooding are far reaching for the communities within the area. They not only damage physical assets and utilities, but also cause cancellation or displacement of tourists and events and loss of public investments.
- Negril Coral Reef Park, which is an educational park and ecotourism site, is highly vulnerable to extreme weather conditions such as rough seas and high winds.
- Without the presence of breakwaters by 2100, a 25-year storm surge event is projected to reach elevations of 1.42 m, and a 100-year event could reach 1.64 m. This will likely result in inundation of farm lands in the Great Morass.

Figure 45: Map showing impacts of 25-year storm surge event (light blue) and future storm surge event under projected sea level rise for the year 2025, Negril.
Source: ODPEM 2015

RESPONSE AND RESILIENCE BUILDING INITIATIVES

» The GOJ/Adaptation Fund Programme "Enhancing the Resilience of the Agriculture Sector and Coastal Areas to Protect Livelihoods and improve Food Security Project/Programme" had a goal "to increase livelihoods security of the population in the targeted communities and to increase the climate resilience of sections of the Negril coastline, which will also contribute to increased security of livelihoods". The project had three components that resulted in an assessment of the vulnerability of Negril and development of a strategic plan for the area. These were:

- Increasing the climate resilience of the Negril Coastline
- Enhancing climate resilience of the agricultural sector by improving water and land management in select communities.
- Improving institutional and local level capacity for sustainable management of natural resources and disaster risk reduction in the targeted vulnerable areas; raising awareness for behaviour modification

» With the help of the CARIBSAVE partnership, a SLR Adaptation Plan was developed for the community of Negril to address the threat of sea level rise. The objectives of the proposal were to:

- Undertake information assessment and analysis (GPS surveys, LIDAR) and build high resolution GIS for the Negril Area (Phase 1).

- Review management of beach and coral reefs (for example, Negril Marine Park) to incorporate projected changes in SLR, water temperature and ocean acidification (Phase 1).
- Produce communication outputs (leaflet, poster, and film) to raise awareness throughout Jamaica of the threat of SLR and to improve public understanding of the science behind the development of SLR Adaptation Plans (Phase 2).
- Characterise, review and prioritise SLR issues in Negril and develop a report on the state of the science, policy, and regulatory environment (Phase 3).
- Review and evaluate SLR management strategies proposed for Negril and other vulnerable coastal areas, and identify potential models for Jamaica/Negril (Phase 3).
- Develop recommendations for comprehensive SLR adaptation planning including management strategies, soft and hard engineering options and regulatory revisions. The plan will embrace the principles of Integrated Coastal Zone Management (Phase 4).
- Implementation of SLR Adaptation Plan (Phase 5).
- Monitoring and evaluation of implementation to quantify effectiveness and inform necessary adjustments (Phase 5).

» In 2009, the project to ensure Negril's continued marketability as a tourist destination got underway with the installation of wave attenuation devices (WADs) in a barrier design 45 metres offshore and parallel to Villa Lido on the north side of Long Bay, Negril. This was done as a Government of Jamaica/ European Union/ United Nations Environment Programme (UNEP) Climate Change Adaptation and Disaster Risk Reduction Project (Climate Change Adaptation Project). Almost two years following the installation, after several climatic events, over 23 metres of stabilised beach now exists along the property. In addition, 200 metres north and south of the WAD array have benefitted with over four metres of new, stabilised beach being formed. The other phases of the initiative carried out between 2013 and 2015 included:

- Planting 1500 sq. metres of seagrass
- Testing of shorelock on 250 metres of beach; binding the sand particles with a special organic compound to slow erosion
- The installation of mooring buoys within the marine park
- The use of temperature gauges/data loggers to help monitoring and analysis as well as drafting a marine park management plan.

7.4. Rio Minho

The Rio Minho watershed comprises 859 square kilometres of the southern parish of Clarendon, of which 633 square kilometres is covered by the catchment area. The three WMUs of the hydrological basin provide the main surface water supply for Clarendon are centred around the Rio Minho river, which is 92.8 kilometres long and is Jamaica's longest river. The river originates in the limestone mountains at the centre of the island and runs south to the fertile alluvial plains. In the upper watershed, dendritic drainage results in smaller streams feeding into the larger water body. Erosion and drainage occurs more easily in soils originating from conglomerate, shale and igneous rock, whereas in limestone areas internal drainage is slower. Drainage is also slower in the lower watershed drainage. Figure 46 shows the longitudinal profile and hydraulic properties of the basin.

POPULATION AND DEMOGRAPHIC PATTERN

Clarendon has over 200,000 residents of which approximately 60,000 live in the 16 communities of May Pen, one of the larger settlements along the Rio Minho. The parish is predominantly male with the percentage ratio of males per 100 females being 102 as of 2011, a 0.1% increase from 2001. The majority of the population falls within the age ranges of under 15, and 30-64 years; with 27 % between the ages of 15-29 and 8 % in the group of 65 and over.

LOCAL GOVERNANCE AND STRUCTURE

The Municipal Corporation of Clarendon is headed by a mayor who chairs with the help of the Deputy Mayor and elected councillors for each of the sections of the parish. The Municipal Corporation overseas the development, managing and maintaining of infrastructure and public facilities such as parochial roads, water supplies, drains and gullies, pars, transportation centres etc. The municipal office is fully staffed to achieve its mandate, with positions ranging from disaster coordinator to finance and planning specialists. These functionalities and corresponding departments work in partnership with non-government and governmental agencies to ensure the proper operation of the parish.

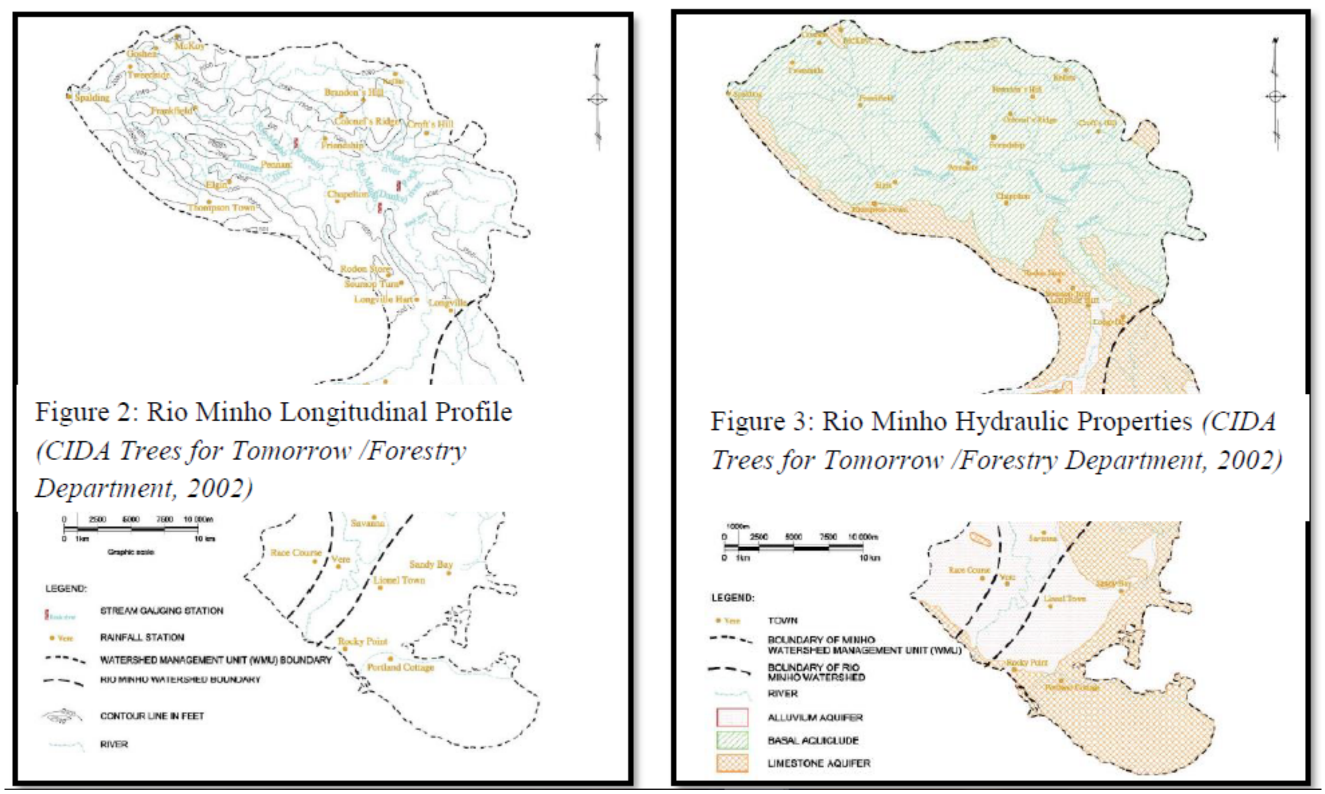


Figure 2: Rio Minho Longitudinal Profile *(CIDA Trees for Tomorrow /Forestry Department, 2002)*

Figure 3: Rio Minho Hydraulic Properties *(CIDA Trees for Tomorrow /Forestry Department, 2002)*

Figure 46: The longitudinal profiles of the Rio Minho and its major tributaries as well as its hydraulic properties**.**
Source: Birthwright, 2016.

BUSINESS/LIVELIHOODS/INDUSTRIES

Local communities depend on a number of land use practices in the Rio Minho watershed to support their livelihoods. Quarrying and mining are important industries due to the high concentration of bauxite, crushed limestone, and alluvial sand and gravel. Agriculture is also widely practiced, with small and large-scale farms raising livestock, as well as producing crops such as banana, cocoa, coffee and sugarcane for both local sale and export. However, the area is considered a high priority watershed according to established WMU classification (CADI, 1999) due to its unsustainability as a base for agriculture and other land use practices. Coastal communities depend heavily on fishing. Electricity and cooking gas are accessible to all communities within the watershed. Whereas solid waste is consistently collected by the National Solid Waste Management Authority (NSWMA), poor water supply has led to dependence in many areas on latrines and toilets that do not link to official sewage collection systems. Many residents also continue to use traditional fuels such as kerosene and charcoal, and garbage disposal methods such as burning and dumping.

ASSESSMENT OF WATER AVAILABILITY AND SUPPLY

The Rio Minho WMU is mainly fed by rainfall, and is therefore a major source of groundwater, surface water and direct rainwater. Annual abstraction can reach 400 million cubic metres (MCM), which is primarily used in agriculture, domestic water supply, and bauxite refinement. Though pollutants such as sediment, waste and fertiliser have recently contaminated much of the groundwater supply, it is still the source of 80% of the watershed's total water supply. Much of this groundwater is from limestone and alluvial aquifers in the lower watershed. Surface water is primarily from the Rio Minho, which is the largest river in the watershed and the longest river on the island. Though the residents may purchase water from the National Water Commission (NWC) or private trucking companies, most utilize water from rivers and streams, private catchment, and public standpipes.

HISTORICAL AND PROJECTED CLIMATE

Climate data for the Rio Minho watershed area are very limited. Information for the area can be assessed based on two stations, Bodles and Hampshire.

» At both stations, there is a summer peak in temperature occurring in July and August and reaching between 33 and 35 ^{o}C. Minimum temperatures at Hampshire are often lower than Bodles, and can plunge to 17^{o}C in February-March. Diurnal temperature range at both stations is approximately 10^{o}C.

» Rainfall is bimodal, peaking in May and September. Mean monthly rainfall is higher in the hilly areas towards the centre of the island, and does not exceed 195 mm. Rainfall is lowest during December-February.

» Relative humidity is highest during months of greatest rainfall and lowest during the dry season.

Trends in projected climate for the grid boxes over the watershed are:

» Mean annual temperatures are likely to increase by the end of the century. The range of change is projected to be within 3.2 - 4.6^{o}C depending on scenario, and may be faster on the western side of the watershed.

» Overall drying is expected to occur in the area within a range of 36 – 58%, and is again projected to be greatest on the western side. Drying will likely be more intense during the late wet season (ASO).

» Mean annual relative humidity may decrease by up to 5.5% by the end of the century across the watershed.

CLIMATE RELATED HAZARDS

Most roads in the Rio Minho watershed do not have adequate drainage in place to allow for discharge of flood waters, resulting in flooding of major roadways, bank slips and erosion. Flood prone areas in the region of the watershed start at Alley and spreads to both sides of the river the more the water level rises. As the rainfall periods increase based on the 10 -100 year projection from the Rio Minho Floodplain Mapping Report 2006, areas including Lionel Town, Hunter village, Portland Cottage and some emergency shelters will be affected by floods. This gives rise to changes in the emergency plans to account for the future projections.

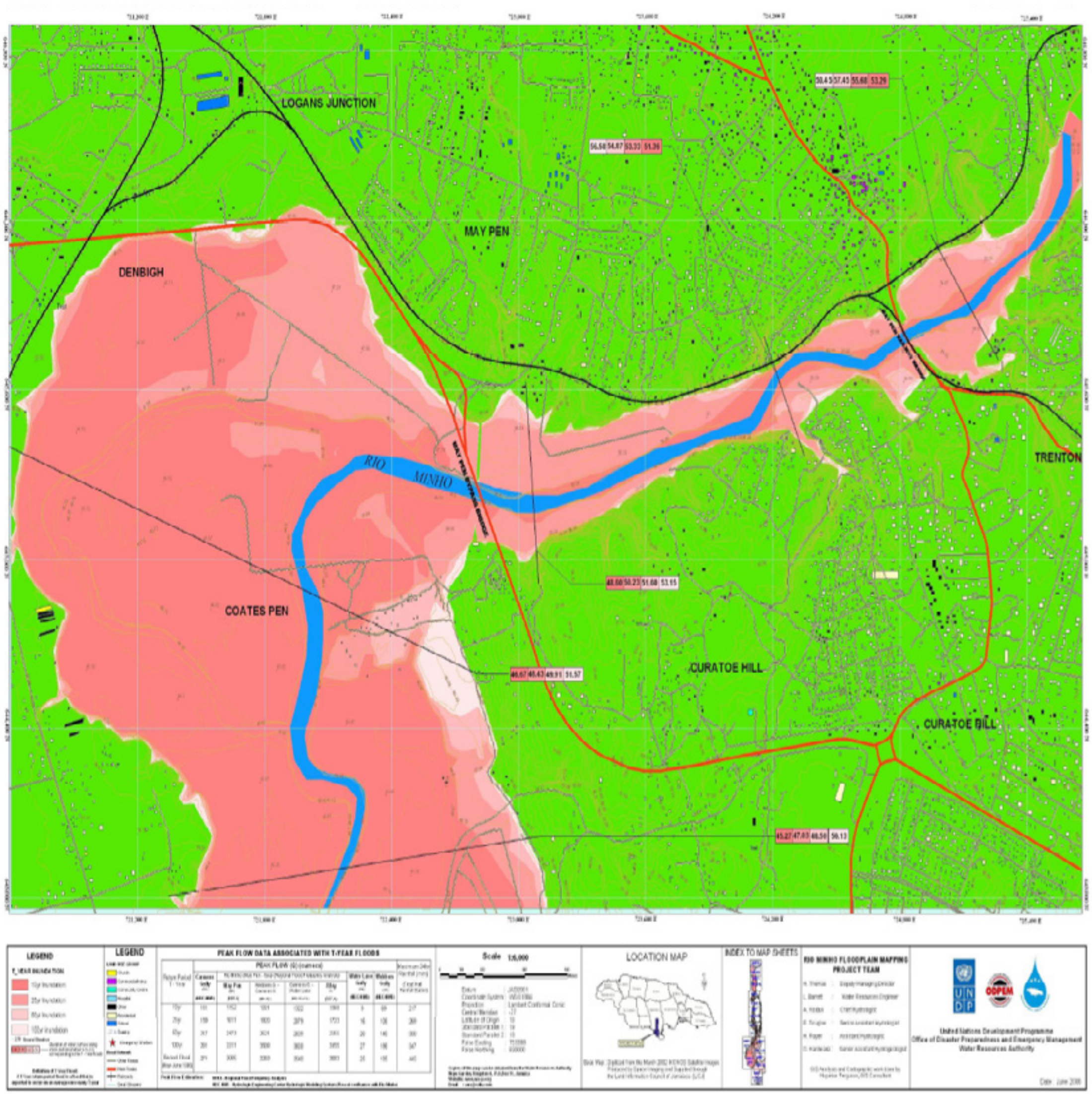


Figure 47: Rio Minho floodplain map for May Pen showing flood extents of the 10, 25, 50, and 100-year return period floods. Colour intensity goes from darker to lighter as time period increases.
Source: ODPEM 2006.

Sea level Rise and storms will also cause:

» Saline intrusion of freshwater aquifers, which will reduce the freshwater available to coastal ecosystems. Increased salinity of irrigation water will also impact agriculture.

» Storm activity hinders water supply services by causing damage to water storage and distribution systems. Distribution infrastructure can also be damaged by landslides and erosion occurring in degraded areas.

RESPONSE AND RESILIENCE BUILDING INITIATIVES

- The 2012 programme 'Enhancing the Resilience of the Agriculture Sector and Coastal Areas to Protect Livelihoods and Improve Food Security' was launched by the Jamaica Adaptation Fund Programme with the goal of maintaining the food security and livelihoods of those most vulnerable by enhancing agriculture through land and water management, coastal protection, and climate change adaptation capacity. The project was implemented by the Planning Institute of Jamaica (PIOJ), National Environment and Planning Agency (NEPA), Ministry of Agriculture and Fisheries and Ministry of Tourism, and ended in March 2016. The infrastructure put in place through the "ridge to reef" system included contour ridges along hillsides, micro dams and rainwater harvesting for irrigation, water-user groups (WUGs) in farming communities for managing irrigation assets, and training in disaster rick reduction climate smart agriculture.
- The SPCR funded 'Rapid Characterization of the Upper Rio Minho Watershed', implemented in 2013, had the goal of characterising the Rio Minho watershed, understanding its climate, and developing necessary monitoring strategies and baseline information for the work of the SPCR. It was implemented by the PIOJ. Recommended climate change interventions coming out of the project included climate resilient cropping systems, rainwater harvesting and water re-use, artificial recharge of the limestone aquifer, and contour planting for slope stabilization.
- The 'Adaptation Program and Financing Mechanisms' programme was a 2015 investment operation funded by the PPCR. It was an extension of the 'Rapid Characterization of the Upper Rio Minho Watershed', and has the goal of assessing implementation of interventions in sample communities within the Upper Rio Minho Watershed. The executing agency is the Ministry of Economic Growth and Job Creation with coordination from the Planning Institute of Jamaica (PIOJ). The climate focussed infrastructure planned for implementation include rehabilitation of rainwater ponds, rainwater harvesting, construction of check dams and greenhouses, installation of aquaponics systems, and retrofitting agricultural storage and processing facilities.

7.5. Ocho Rios

Ocho Rios lies on the northern coast of Jamaica, positioned 18°24'08" North (latitude), 77°06'17" West (longitude). It is a rural centre situated to the north of St. Ann. The coastal areas are located on immature Pleistocene gravel fan, established by the continuous accumulation of sediments transported by the north-flowing water courses, specifically the catchments of the Milford River and Turtle River. These also serve as drainage systems for rainfall runoff and dislodged sediments. A fault scarp separates the low-lying deposits of the Ocho Rios fan and the upland limestone exposures to the south. South of Ocho Rios is bedrock that is composed of marl and limestone remains, and is the site of a number of communities, including Breadnut Hill, Harrison Town, Great Pond, Milford, Snow Hill and Shaw Park. The Coastal Group limestone provides the home for the major population centres within the district.

DEMOGRAPHIC PATTERN AND TRENDS

Ocho Rios was once a fishing village, but now caters to tourists. As of 2001, St. Ann had a population of 165,758. Ocho Rios, which is the most inhabited town centre in the parish, had a total of 15,769 individuals living there at the time. This represented a little less than 10% share of the entire parish population. A 5.13% annual average growth rate was observed during the period from 1991 to 2001, an estimated gain of 5,300 individuals, second only to Portmore in St. Catherine.

Residential settlements are concentrated within the town boundaries of Ocho Rios. South of the town, communities follow a linear progression, with clusters in some areas like Parry Town and Pimento Walk. Residents of the high and middle-income class in these areas generally reside in condominiums, apartments and larger family homes. Residential areas are not centralized, and as such can be found throughout Ocho Rios. Further south of the town, areas become more densely populated and housing facilities differ. These communities are dominated by middle income earners, and are generally known for their shops and informal activities.

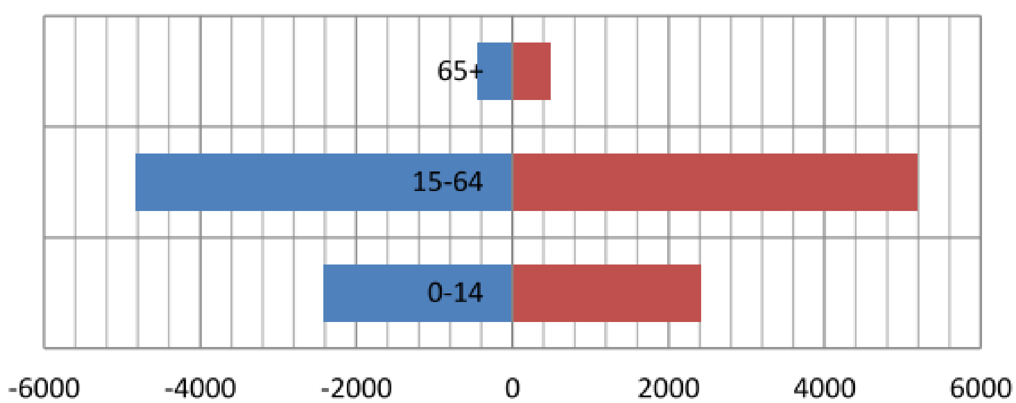
Demographics according to age and gender: According to the census 2011 the population of black river was 5352 where men are still the dominants settlers as was found in the 2001 census. Figure 48 shows the age sex pyramid of Ocho Rios. Of the steady population growth since 1991, females represent the larger proportion.

LOCAL GOVERNANCE AND STRUCTURE

The parish of St. Ann has four constituencies, of which Ocho Rios is located in the Northeastern constituency. The needs of the citizens within the communities are addressed by the St. Ann Municipal Corporation. It is composed of sixteen divisions and each is represented by a councillor. After a local government election is held, the councillors choose from among themselves a chairman and a deputy. These are the individuals who receive the title of Mayor and Deputy Mayor of St. Ann.

TRANSPORTATION

Public transportation in the Ocho Rios community is primarily provided by taxis. In addition to this, most residents own their own vehicles. Tourists are generally transported by private contractors such as JUTA Jamaica Tours and Jamaica Co-operative Automobile and Limousine Tours Ltd. (JCAL tours Jamaica). There are four primary routes used to access Ocho Rios: Ocho Rios bypass, Fern Gully Main Road, Milford road and Main Street. Whenever there is a heavy downpour, Fern Gully Main Road and Milford Road act as a water transport system for a large quantity of water and debris, making the roads impassable. Ocho Rios bypass and Main Street are also affected by these waters when there is heavy rainfall.



	0-14	15-64	65+
Males	-2408	-4810	-426
Females	2421	5188	478

Figure 48: Age sex pyramid for Ocho Rios.
Source: ODPEM 2011.

BUSINESS/LIVELIHOODS/INDUSTRIES

Tourism is the driving force for Ocho Rios' economy, as it is the second most important tourist destination in the island. The town is dominated by tourism related facilities such as hotels, restaurants, plazas and several types of attractions. The meeting point of Milford Road and the north coast highway is where most of these establishments are condensed. Land is hardly used for agricultural purposes in Ocho Rios as shown in Figure 49. Both formal and informal businesses thrive in this area. The pier has a dual function, as it is the point of contact for exports as well as a docking facility for cruise ships.

WATER AVAILABILITY AND SUPPLY

The Bogue treatment plant supplies Ocho Rios with water on a day to day basis. The town of Ocho Rios consumes 2 million gallons per day (gpd), which is just 28% of the total generation at Bogue. This plant is possibly Jamaica's most efficient plant due to its head of 380ft. This plant operates solely based on gravity and supplies all nearby communities. White River, which supplies Exchange and areas close by, is the only local water source that uses pumps. The latter station, however, has a major issue in that there is no stand-by generator, making it susceptible to power outages. During Hurricane Dean in August 2007, Bogue was within the 20% of water suppliers that held firm after the passage, proving its soundness.

Minor supplies also come from less robust water networks at Snow Hill and Shaw Park. These systems have an estimated capacity of 300,000 gpd, and supply communities in close proximity, such as Parry Town and Pimento Walk. Turbidity becomes an issue for these facilities once there are heavy rains due to surface run-off. Contrarily, Shaw Park is not vulnerable to turbidity issues because it has a spring source. This system supplies communities like Harrison Town, Great Pond and parts of Milford.

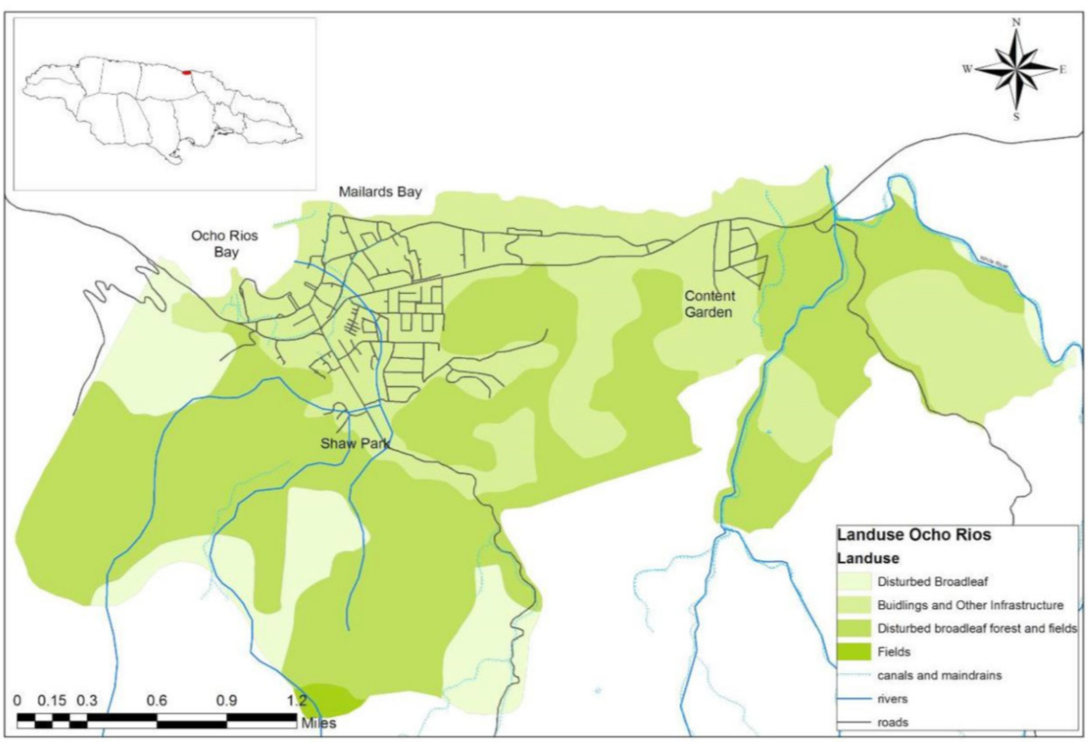


Figure 4.4 Land Use Map for Ocho Rios
Source: Ministry of Agriculture, Forestry Department

Figure 49: Land Use Map for Ocho Rios.
Source: ODPEM 2011.

HISTORICAL AND PROJECTED CLIMATE

Trends in historical climate:

» Temperature data from the nearby Discovery Bay weather station indicate that the area is warmest in August and September, during which mean monthly temperatures approach 28°C. Minimum temperatures of 25°C and below occur during January and February.

» There is an early peak in rainfall in May and a late peak beginning in September, exceeding 130 mm. The town of Ocho Rios is located in a relatively dry portion of the north coast, which is driest during the winter months centred around December.

» Mean daily global solar radiation peaks in July and dims December-January.

Trends in projected climate:

» Mean annual temperature change for the RCM grid box over Ocho Rios indicates a projected increase in temperature of 2.07 – 2.64°C by end of century. Greatest warming is likely to occur during MJJ and least in NDJ.

» The proportion of warm days and nights is projected to increase, while cool days and nights decrease.

» Overall drying is likely for the area within a range of 47.8 – 63.9% annually. Greatest drying is projected to occur during the dry season (NDJ).

» Decrease in relative humidity is projected to be less severe than other parts of the island, with a maximum loss in annual mean relative humidity of 0.6%.

CLIMATE RELATED HAZARDS

The greatest risk to Ocho Rios comes from the impact of storms surges, flooding and seismic activity. Jamaica, due to its geographical location within the Atlantic hurricane belt, is plagued with storms of varying categories. Despite these storms approaching from the south, Ocho Rios is still impacted by their effects.

» Sea facing cliffs and bluffs protect most households from storm surges. However, businesses and resorts are at moderate risk from surges due to their location along the coast. This vulnerability is paramount, as the livelihoods of citizens are heavily dependent on tourism.

» The fishing village and its resources in this locale are at great risk because of its open nature, which makes it a perfect target for wave run-up. Most fishermen do not reside within this coastal area, and as such the physical infrastructure within this area is minimal.

» Critical infrastructure such as fire stations, communication towers, electrical supply, and the NWC sewage treatment plant are also vulnerable in varying degrees to storm run-off, flooding, strong winds and storm surges.

» Clogged drains and over flowing river banks make the frequency of riverine flooding in Ocho Rios high.

» An alluivial fan created by two major rivers provides the foundation for Ocho Rios. Flooding due to water logging, topography, and frequency and intensity of rainfall is prevalent in this area. This flooding causes landslides that are amplified by improper management of land, particularly clearing of land for fuel, agriculture and informal settlements. Debris from these landslides forms the basis of Ocho Rios' most identifiable hazard, which is debris flow. The greatest impact comes from those landslides that occur in the upper catchment locations, as this debris has nowhere to go but downhill and thus destroys infrastructure in its path.

» Drains within the densely-populated areas do not meet the demand passage of storm water flow or debris.

» Landslides do not seem to be much of an issue presently. However, care should still be taken given the precedent set by historical heavy debris flow events that occurred during 1995 and 2008. This debris flow was due in part to old escarpments and weak rock strata along gullies.

» High flow rates of flood waters result in high debris flow due to the removal of barriers, roadways and minimal vegetation.

RESPONSE AND RESILIENCE BUILDING INITIATIVES

» The Office of Disaster and Preparedness and Emergency Management (ODPEM) works together with the St. Ann Municipal Corporation through the Parish Disaster Committee and coordinator on all matters relating to disaster risk management, and coordination of disaster relief begins with ODPEM after an event. The town has a clearly defined Disaster Plan that outlines the duties of all agencies and sub-committees. There are many challenges and shortcomings to the disaster risk management system in the town, but measures are being implemented to help mitigate these issues.

» The Ocho Rios Zonal Committee is a group of 10 members supported by ODPEM and the St. Ann Parish Disaster Committee and Coordinator that provides public education for various groups, including churches and police youth groups. It also provides response and support during disasters. However, lack of participation is a major issue for this group.

7.6. Black River

Black River lies on the south-western coast of Jamaica, positioned 18°15′ North (latitude), 77°56′ West (longitude), with geology consisting of limestone bedrock of Eocene-Miocene age overlain by quaternary/superficial deposits including alluvium, beach/marine sand and marsh and peat deposits. Black River lies within Lower Morass, within close proximity to the current mouth of the Black River basin, one of Jamaica's longest recorded rivers. The Black River is joined by the YS River in the Lower Morass, making it the largest swamp environment in the Caribbean covering 14,085 acres.

Black River was once famous for its commercial, economic and trans-shipment centre. In 1999, the Jamaica National Heritage Trust designated Black River as a Protected National Heritage District. Tourists frequent these areas for the safari tours via motor boats to observe the diverse flora and fauna of the area, particularly native crocodiles. It was declared a Ramsar site in in 1997 because of the diverse ecosystem formed by the combination of marshlands, estuaries and mangrove swamps. Recent draining of swamps in order to gain agricultural and tourism benefits has resulted in the decline of the crocodile population. Floodwaters in this area are regulated by the Morass during severe rainfall events.

DEMOGRAPHIC PATTERN AND TRENDS

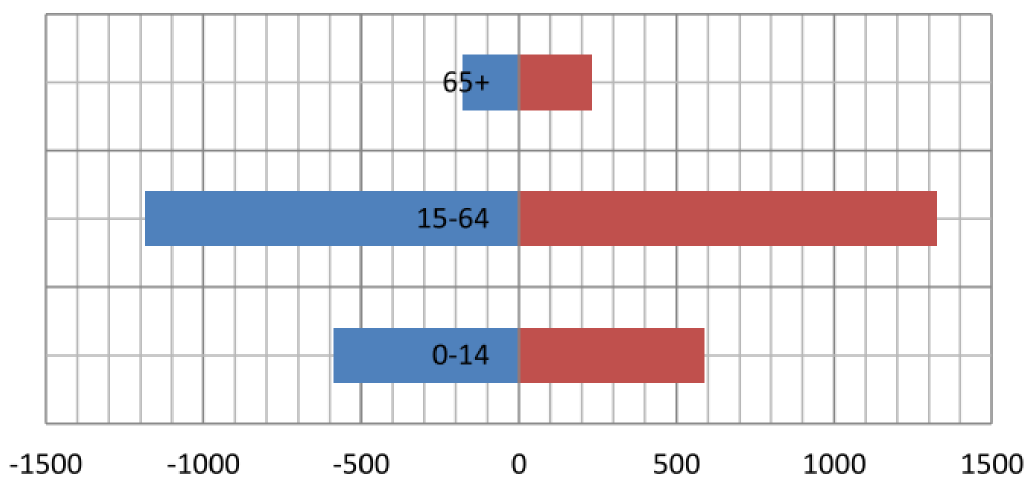
Once a commercial port, Black River now relies heavily on tourism and agriculture. The parish of St. Elizabeth had a population of 145,023 in 2001. Black River, as one of four main town centres in the parish, had a declining population of 4,095 individuals or 2.8% of the entire parish population. A 2.5% decrease in population size was observed during the period from 1991 to 2001. In the parish of St. Elizabeth, 97.4% of residents have achieved primary school education, 50.5% secondary and 8.1% tertiary. This relatively high level of education is reflective of high disaster awareness and preparedness, which has been found to be the case in Black River. The most prevalent chronic illnesses occurring in the parish are hypertension, arthritis, diabetes and asthma, which can all be exacerbated during a disaster.

Settlements are concentrated on the outskirts of the town boundaries. Generally, they are constructed from block and steel or a combination of wood and other materials. Newly built homes are built to meet the criteria of National Housing Trust and National Housing Development Corporation. Residents are generally middle-income earners. Within the town centre, residential areas are clustered and mainly run north to south along major travel routes.

Demographics according to age and gender: According to the 2011 census, the population of Black River was characterized by 1,943 males and 2,146 females, of which approximately 1327 are 15 years or older. Figure 50 shows the age sex pyramid of Black River. Of the decline in population since 1991, females represent the larger proportion. Most individuals are of working age, though there are a growing number of dependents. There are a relatively small number of elderly residents, and a large number of children. Most households are headed by females, many of whom are single-parents.

LOCAL GOVERNANCE AND STRUCTURE

The parish of St. Elizabeth has four constituencies, namely St. Elizabeth South-Eastern, North-Western, North-Eastern and South-Western. The needs of the citizens within the communities are addressed by the St. Elizabeth Municipal Corporation, and the Mayor. It is composed of fifteen divisions and each is represented by a counselor. Among other leadership positions in the Municipal Corporation is the Parish Disaster Coordinator, who coordinates disaster preparedness and relief.



	0-14	15-64	65+
Males	-585	-1183	-175
Females	587	1327	232

Figure 50: Age sex pyramid for Black River.
Source: ODPEM 2011.

BUSINESS/LIVELIHOODS/INDUSTRIES

Commercial activity in the town is centred in Lower Works, and extends south and west, reaching the coast. There is a range of activities that contribute to the economy of the town, including agriculture, tourism, banking, commerce and public administration. The primary income source, however, is retail and services in the commercial centre. The town serves as a hub for market produce in the area, though few crop farms are located within Black River proper. Eco-tourism has recently been taken on as an important venture, and the historical and ecological significance of Black River makes it a popular choice for short and long stay in both traditional hotels and guest houses. The town is bordered by the morass, as shown in Figure 51, which is a high traffic site for river based tours and other attractions. The major roads in Black River are High Street and North Street, and the river is crossed by a large bridge.

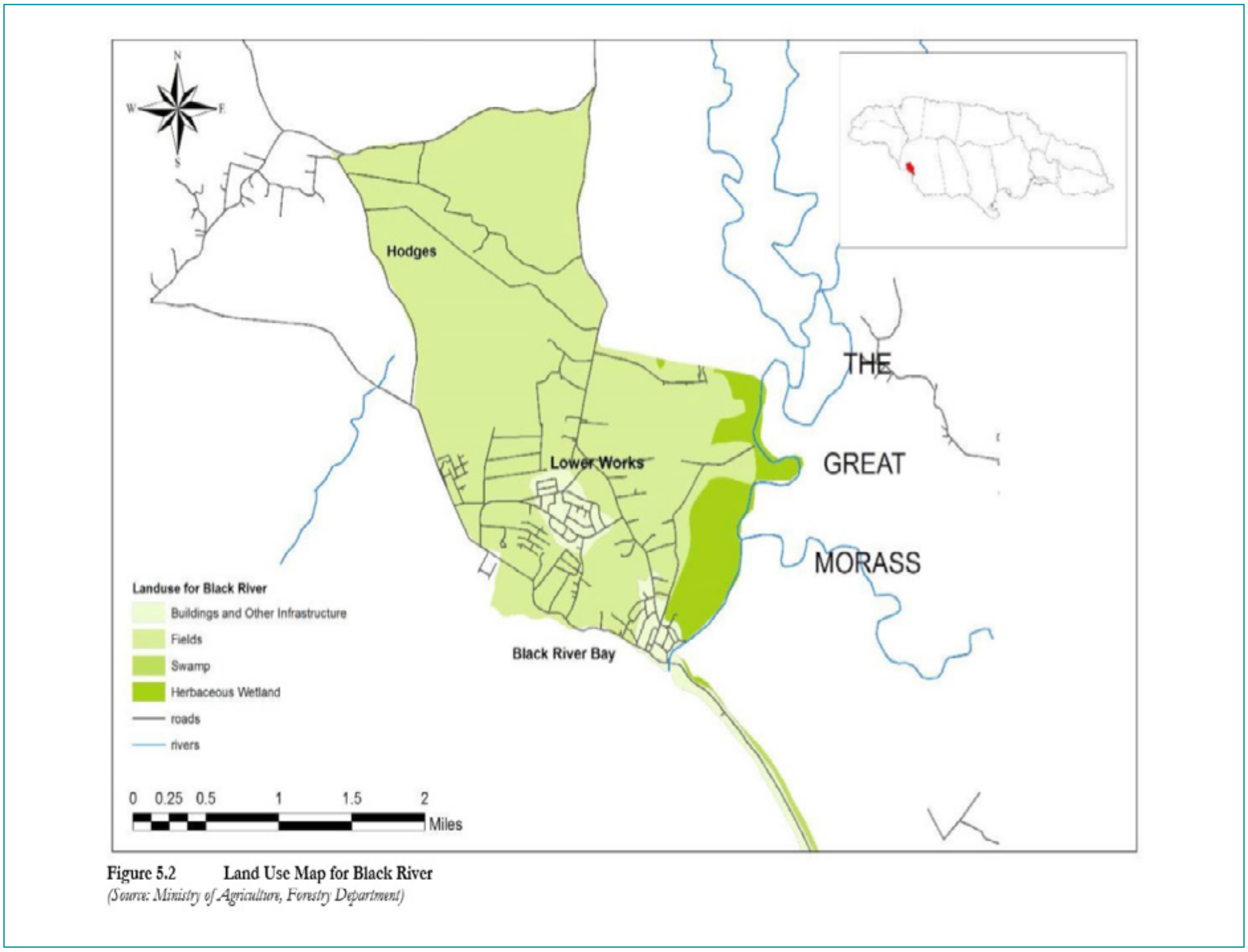


Figure 51: Land use map of Black River.
Source: ODPEM 2011.

WATER AVAILABILITY AND SUPPLY

A well north-west of sandy ground in close proximity of the end of Black River bypass treatment plant supplies Black River with water on a day to day basis. It is housed in a concrete structure protecting it against flooding and natural hazard interruptions. Similar to the smaller system that supplies Ocho Rios, this system does not need to worry about turbidity during heavy rainfall. The lack of disruption in the piping network during heavy rainfall is proof of the systems robustness.

HISTORICAL AND PROJECTED CLIMATE

Historical climate has not been well documented for Black River. Observations for Black River are specified, but other noted observations are for St. Elizabeth. Observations include the following:

- Lack of temperature stations in the parish prevented an accurate temperature analysis.
- Rainfall follows the bimodal pattern expected for Jamaica. Peaks occur in May and October, with a midsummer dry spell in July and the dry season beginning in December.
- Mean solar radiation in Black River is at a maximum in June-August, and a minimum in December.
- Wind speed in St. Elizabeth is typically high, and is among the strongest across the island. Trends for the island have shown an increase since 1960.

Trends in projected climate up to the end of the century are as follows:

- Mean annual temperature will likely increase by 3.5 – 4.7^{o}C by the end of the century, occurring most rapidly in June-October. Projections indicate an increase in the number of hot nights and days, and a decrease in cool days and nights.
- Mean annual rainfall is projected to decrease by 38 – 58% by the end of the century, with greatest drying occurring in September. Projections also indicate a decrease in consecutive wet days in western parishes, and an increase in intense rainfall events.
- Relative humidity is projected to decrease by up to 6% annually, with greatest seasonal change occurring in the summer months.
- Wind speed is projected to decrease across the island, and sunshine hours to increase.

CLIMATE RELATED HAZARDS

- Coastal businesses along High Street have been impacted by storm surges frequently in the past. The passage of Tropical Storm Nicole in 2010 resulted in overtopping and, in some sections, destruction of sea walls. There was no flooding in low-lying areas, despite rive in river volume.
- The presence of the Lower Morass prevents riverine flooding, but the area is highly susceptible to rainfall flooding due to canals and sinkholes being blocked by debris and construction.
- Landslides are infrequent due to elevation and soil type of the town. However, they may occur in areas with white limestone based soil, and along faults or rock discontinuities. The low bearing capacity of the morass may lead to liquefaction, erosion, or settling.
- Much of High Street and many coastal homes are vulnerable to strong winds because of construction specifications.
- Damage to critical infrastructure from storm surges tends to be minimal, but there is still some vulnerability to flooding and strong winds.
- Many of the environmental resources of Black River are both vulnerable and protective in the event of a disaster. The habitats of crocodiles are likely to be disturbed or destroyed by heavy winds and flooding, which can also kill crocodiles by increasing sedimentation in the river. Mangroves and coral reefs act as a buffer during storm surges, but are also heavily damaged by them.
- There is a risk of secondary damage to natural resources by potential toxic spills from two gas stations in the area in the event of a disaster.
- Tourism is particularly vulnerable to hurricane winds and earthquakes. Tourist accommodation is mainly in guest houses, particularly along Crane Road. Examples of heritage guest houses located in this vulnerable zone are Invercauld and Waterloo Guest House. Riverine flooding is a threat to river based tours.
- Settlements are particularly vulnerable to storm winds, earthquakes and flooding.

RESPONSE AND RESILIENCE BUILDING INITIATIVES

» As is the case in Ocho Rios, ODPEM works with the St. Elizabeth Municipal Corporation through the Parish Disaster Committee, heads of local government and Regional Coordinator on all matters relating to disaster risk management, and coordination of disaster relief begins with ODPEM after an event. Disaster risk management is not a priority in the agenda of the Municipal Corporation, making disaster preparedness coordination difficult. A Parish Disaster Plan is in place, along with a Parish Disaster Coordinator and Parish Disaster Committee. NGOs such as the Salvation Army and Jamaica Red Cross often assist in disaster relief efforts that are coordinated by the Parish Disaster Coordinator.

» The Black River Development Area Committee was developed to provide public education on disaster and is composed of community volunteers. However, volunteers are few and meetings infrequent. Little support comes from government or businesses, leading to financial difficulty.

7.7. Montego Bay

Montego Bay gained much of its importance from being a critical port city used for export of banana and sugar from local plantations in the 18^{th} and 19^{th} centuries. The city is located on a coastal plain in the northwest of the island that allows for drainage of the Montego River from the steep hills bordering the inland portion of the city. It is known for white sand beaches and lagoons surrounded by coral reefs and mangroves, for example the Bogue Lagoon.

POPULATION AND DEMOGRAPHIC PATTERN

In 2011, Montego Bay had a population of 110,115. Settlements are distributed among the central urban area of 38 neighbourhoods and the more concentrated residential developments in the hills. Though settlements are low density (approximately 1,740 residents/km^2), the frequent occurrence of informal residential areas poses a health and safety risk, and reduces the ability of the government to carry out activities that can benefit tax paying residents. Examples include Creek Street, Upper King Street, settlements along the North and South Gullies, and Princess Street.

Rapid and unmanaged urban growth has also been an issue. Due to the influence of the strong tourism sector, many Jamaicans have moved to the city seeking employment, with some commuting from the neighbouring parishes, as shown in Figure 52, of Trelawny and Hanover. The result has been expansion at an uncontrolled rate and fragmented urbanization.

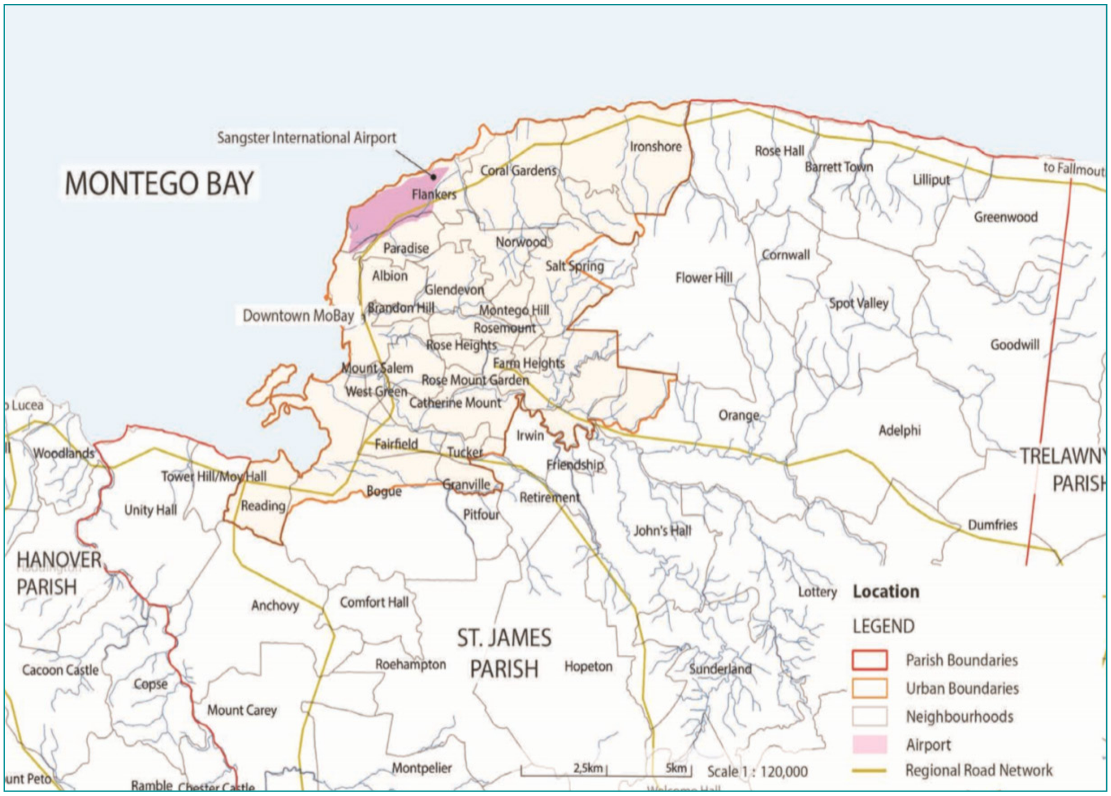


Figure 52: Urban boundaries of Montego Bay.
Source: IDB 2015.

LOCAL GOVERNANCE AND STRUCTURE

The city is led by the Municipal Corporation headed by a mayor. In addition to financing the operation of the city through its own income, the council also depends on transfers from the central government to supplement financial resources. This is because the expenditure of the corporation exceeds its revenue. However, the council is known for transparency and regular audits. The Parish Development Committee facilitates the input of citizens in local government, and is composed of representatives of civil society organizations.

BUSINESS/LIVELIHOODS/INDUSTRIES

The city is driven by tourism and hospitality, and is considered the tourism capital of Jamaica. Economic development formerly occurred along Gloucester Avenue, but now more than half of the city's economic activity, along with the Central Business District, is concentrated along a narrow strip of coastline east of the Donald Sangster International Airport. Sangster is one of the country's two international airports through which approximately 72% of Jamaica's visitors enter the country, and the city is also the site of a cruise ship terminal and the Montego Freeport. The success of the tourism industry has fed improvement of existing infrastructure, such as the upgrades made to roads, waste management systems and water treatment plants under the North Coast Improvement Project. The increase in development has been at the expense of forested and agricultural lands, which have declined in the past decade.

Unmanaged urbanization and rapid population expansion have led to an inadequate public service system and unequal distribution of resources. This includes services used by most residents such as public transportation, utilities, waste management and water resources. The unemployment as of 2013 was 15.2%, and 62% of the labour force was reported as lacking training, indicating that much of the population influx has consisted of unskilled workers. Health care is considered satisfactory by residents, but the crime rate is high.

ASSESSMENT OF WATER AVAILABILITY AND SUPPLY

Water is mainly distributed by the NWC, which also collects sewage. Some water supply services are offered by the Municipal Corporation and private companies. The primary water source is the Great River Water System, and minor sources are entombed springs and unmetered standpipes in communities paid for by the Municipal Corporation. Though most homes have running water, volume is inconsistent from a high rate of water loss due to broken standpipes and illegal connections. By NWC estimates, there was a shortfall of 4.4 mgd in the parish of St. James in 2010, which is estimated to increase with water demand if faults are not addressed.

WASTE MANAGEMENT

The current landfill is not considered sanitary and may only be sustainable for five more years. Waste is not separated, except by the activity of informal pickers retrieving recyclable materials. Waste collection is infrequent, and is substituted by burning and illegal dumping. Hotels employ private waste collectors and pay the NSWMA a small fee to use the city landfill, but the fee is disproportionate to the amount needed to properly handle the waste.

Wastewater treatment, drainage and proper connection to sewerage systems are lacking. Only 25% of households were connected to the wastewater treatment facility in 2004 and 77% were connected to public sewerage systems in 2013. These factors along with the sanitation challenges of informal settlements negatively impact natural water sources in the area.

HISTORICAL AND PROJECTED CLIMATE

Historical climate has been well documented for Montego Bay using the Meteorological Service's weather station at the Donald Sangster International Airport. Observations include the following:

- Mean annual temperature is typically around 27.5°C, and has increased by 0.41°C per decade over the period 1973-2008, occurring most rapidly in JJA. Monthly mean temperature is typically highest in July-August and lowest in January-February.
- Rainfall follows the bimodal pattern expected for Jamaica. Peaks occur in May and October, with a midsummer dry spell in July and the dry season beginning in December. There was a decrease in rainfall of approximately 18% over the period 1973-2008.
- Mean solar radiation is at a maximum in May-July, and a minimum in December.
- Wind speed is typically relatively high. Trends for the island have shown an increase since 1960.
- Relative humidity is higher in the morning hours than in the afternoon, as expected. Mean daily RH is approximately 70%. No significant trend has been noted for the island.
- Mean daily evaporation is 5.5 mm/day. Peak in evaporation occurs in July, while it is lowest in December.
- Mean daily number of sunshine hours is 8.06 hours, with a maximum in April and minimum in September. A statistically significant increase in sunshine hours in MAM and JJA has been noted for the island.

Trends in projected climate up to the end of the century are as follows:

- Mean annual temperature will likely increase by 2.5–3.2°C, occurring most rapidly in July.

Projections indicate an increase in the number of hot nights and days, and a decrease in cool days and nights.

- Mean annual rainfall is projected to decrease by 25 – 52%, with greatest drying occurring in the late wet season and dry season. Projections also indicate a decrease in consecutive wet days in western parishes, and an increase in intense rainfall events.
- Relative humidity is projected to decrease by up to 4% annually, with greatest seasonal change occurring in the summer months.
- Wind speed is projected to decrease across the island, and sunshine hours to increase.

CLIMATE RELATED HAZARDS

The geographical location of the city makes it highly vulnerable to climate hazards, such as erosion, storm surges and hurricanes. Despite this, the city itself has no early warning systems or preparedness plans in place, and must depend on general parish plans. Areas of vulnerability include:

- Montego Bay has been historically flooded by low-pressure systems and tropical cyclones. Flooding due to blockage has been prevalent along sections of the North Gully around William Street and St. James Street, and the South Gully along Dome Street and Princess Street. The Montego River is also known to flood extensively, inundating farmlands, roads and buildings in Barnett Estate, Barnett Street, Railway Lane, and Catherine Hall.
- Concentration of economically important infrastructure along the coast makes it vulnerable to general climate change, as well as local hazards such as storm activity and coastal erosion. These include a major airport, resorts, municipal buildings and markets.
- Heavy development of the coastline by tourist resorts has removed much of the natural beach and mangrove forest, reduced water quality and increased erosion. This degrades the natural protection of the coast against tropical cyclones and other coastal disasters. In turn, the degradation of natural resources reduces the potential for further use of the coastline by the tourism industry.
- Storm surge flooding is a particular threat to Catherine Hall, areas surrounding the airport and Bogue wastewater treatment plant, and Flankers. There is high potential for health impacts from contamination of floodwaters.
- Informal settlements are at high risk during disasters due to lack of sanitation, regulation of building codes and structural integrity. They are often positioned in the most vulnerable areas, on hillsides that are prone to slippage or along water sources that are likely to flood.
- A rise in development and demand for residential spaces is likely to occur in the near future, putting pressure on the outer limits of the city and encouraging development along hillsides. This will likely occur without consideration of water supply or vulnerability of the terrain, leading to risk of landslides and erosion, and further loss of agricultural and forested land.
- Strong winds are a risk to critical infrastructure, particularly power lines. Strongest winds occur in northern sections of the city and areas south of the South Gully.
- Development and critical infrastructure are also at high risk from landslides.

RESPONSE AND RESILIENCE BUILDING INITIATIVES

- CARIBSAVE produced a Climate Change Risk Analysis of the city in 2009 as part of the IDB/DFID funded and CDERA implemented Regional Disaster Risk Management for Sustainable Tourism in the Caribbean Project, specifically the component Mainstreaming Climate Change Impacts on Tourism into Comprehensive Disaster Management (CDM) using Evidence-based Planning. This report evaluated historical and future climate, as well as existing vulnerabilities in the city. Suggested actions included a focus on adaptation, climate data collection and statistical analysis, and identification of most vulnerable sectors and social groups.

» The most recent initiative in response to climate change vulnerability in Montego Bay is "One Bay for All: Sustainable Montego Bay", which was a comprehensive assessment of the city's vulnerability and needs for sustainability conducted in 2015. It is a collaboration between the government of Jamaica and the Inter-American Development Bank (IDB), through the IDB's Emerging and Sustainable Cities Initiative (ESCI). The document is an action plan that details the geographical, economic and social features of the city, projects future development, and proposes actions in response to climate risks. This is all with the goal of making Montego Bay as sustainable as possible in the near future, while supporting growth and development.

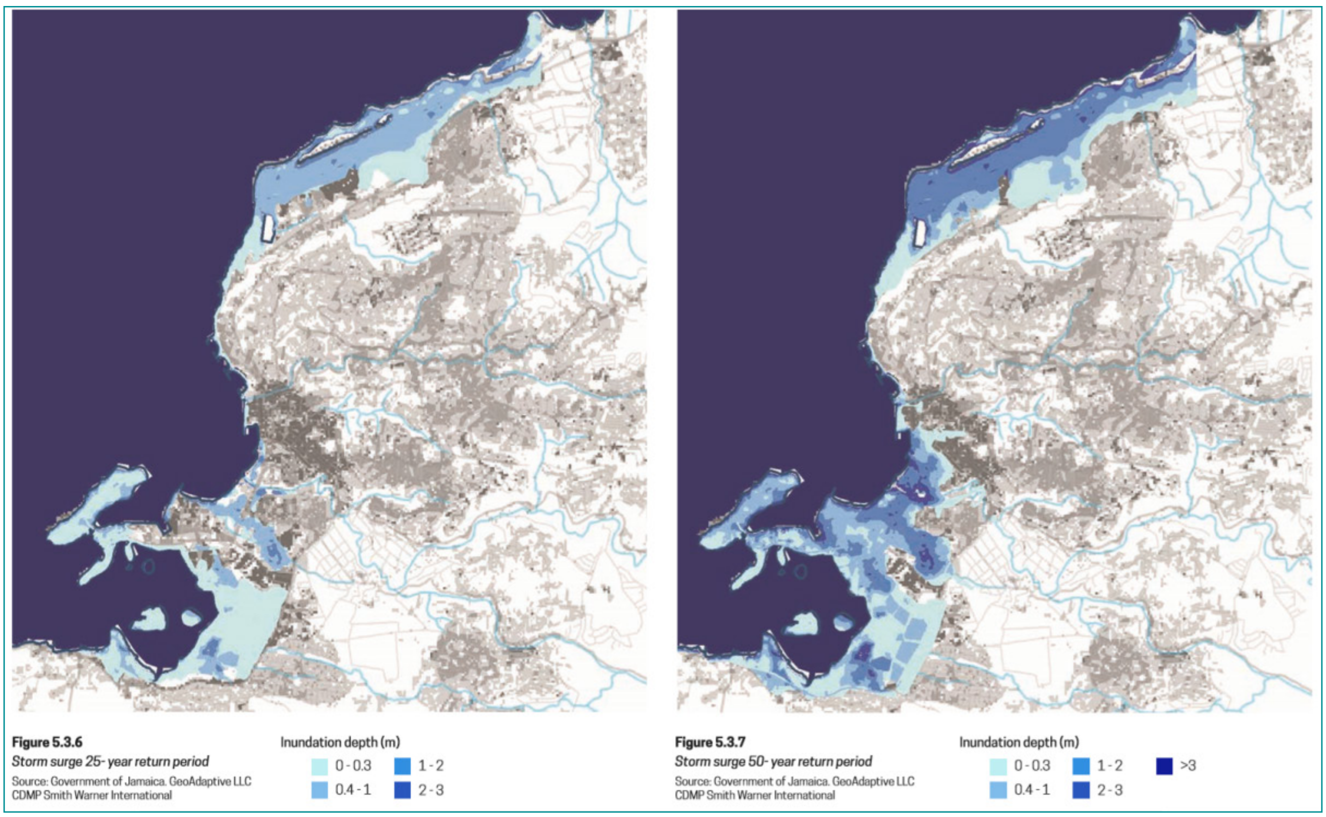


Figure 53: Likely inundation due to 25-year (left) and 50-year (right) storm surge return periods.
Source: IDB 2015.

7.8. Portmore

The municipality of Portmore is an urban centre situated on the south coast of St. Catherine covering 32,400 acres. It is on a low-lying plain with an average elevation of 4 metres (13 feet) adjacent to Kingston Harbor. Coastal areas are characterized by mangrove forests and alluvial deposts consisting of clayey silt and sand deposited by the bordering Rio Cobre river in the north. The city is bordered on the southeast by Port Henderson Hill and on the south by the Hellshire Hills, both of which are composed of limestone.

The Hellshire Hills are home to one of the best preserved dry forests in the western hemisphere, and are a habitat for a number of endangered endemic species, such as the Jamaican Iguana (*Cyclura collei*) and the Blue-tailed Galliwasp (*Celestus duquesneyi*). Due to its location, it is highly susceptible to earthquakes, hurricanes and flooding. Land uses are mainly woodland, residential, mangroves, and mixed cultivation.

DEMOGRAPHIC PATTERN AND TRENDS

Portmore was once an agriculturally dominated region growing primarily banana and sugarcane until the mid-1900s. Since the 1950s , Portmore has become a primarily residential municipality with over half of its citizens working in the Kingston Metropolitan area. Population growth has occurred at a rate of 5.5% per annum over the last decade, down from 61% in 1991-2001. Today, Portmore is the largest residential area in the Caribbean with over 200,000 residents across 49,407 households with an average household size of 3.7.

In 2003, The Portmore Municipal Council was established to deliver modern services to the citizens of the area, while focusing on sustainable development and environmental management. At present, Portmore continues to develop, as the region expands to erect its own ports, to construct the Portmore International Hospital, and to increase tourism with the allure of white sand beaches and local culture.

Demographics according to age and gender: According to the 2011 census, Portmore's population is characterized by 85,046 males and 97,107 females, of which approximately 131,868 are 18 years or older. Of the steady population growth since 2001, females represent the larger proportion. The municipality is divided into three (3) constituencies, namely (in order of population size): St. Catherine South (Hellshire, Braeton and Greater Portmore), South East St. Catherine (Waterford, Independence City, Westchester, Bridgeport and Edgewater) and the East Central constituency (Gregory Park, Portmore Pines and Southborough).

LOCAL GOVERNANCE AND STRUCTURE

An Act of Parliament created the Municipality of Portmore in the parish of St. Catherine on June 19, 2003. Subsequently, the Municipality has been governed by the Portmore Municipal Council. The Portmore Municipal Council comprises a Mayor and eleven (11) Councillors who are all elected by the residents. In addition to the Municipal Council, there is also the Portmore Citizens Advisory Council (PCAC), a legal body that is comprised of representatives of civil society. The PCAC possesses the right and power to audit the Municipal Council and appoint members to the Municipal Council Committees with full voting rights, thereby ensuring greater accountability and citizens' participation in governance.

TRANSPORTATION

Public transportation in the municipality of Portmore is provided by the Jamaica Urban Transit Corporation. Additionally, a number of residents own vehicles for commuting. There are primarily four (4) transportation routes used to access Portmore, which are also used as the municipality's main evacuation routes. The Causeway Road to Kingston (which is also a toll road) is one of fastest routes into the capital city, but may become impassable during hurricanes and storm surges. Other routes include roads leading into Kingston, Mandela Highway to Kingston or Spanish Town, Bernard Lodge to Spanish Town and Dunbeholding Road to Spanish Town.

BUSINESS/LIVELIHOODS/INDUSTRIES

The economic sector of Portmore is characterized by fishing villages, e-commerce and the commercial districts (see Figure 54). The Portmore Municipality obtains its general revenue from the issuing of licenses and fees to several commercial businesses within the city. These mainly include trade licenses, barbers and hairdresser licenses, fees from places of amusement, pound and building fees, as well as fees for billboards and signs. Recreational facilities such as the Caymans Park Track and the Hellshire, Forum and Fort Clarence beaches are also part of the municipality's business sector.

Several fishing villages can be found along the coastline of the beaches as well as many small shops and restaurants that specialize in the preparation of seafood for visitors to the beach. In 2004, the Portmore Causeway Fishing Beach had one hundred and three (103) boats in use. Since the town was initially constructed in response to the urban sprawl of Kingston, most citizens commute to work daily outside the municipality. Much of the area surrounding the Causeway to Kingston also houses warehouses and the freezone. The periphery of Portmore is largely wetlands or open space, with a few interspersed squatter settlements.

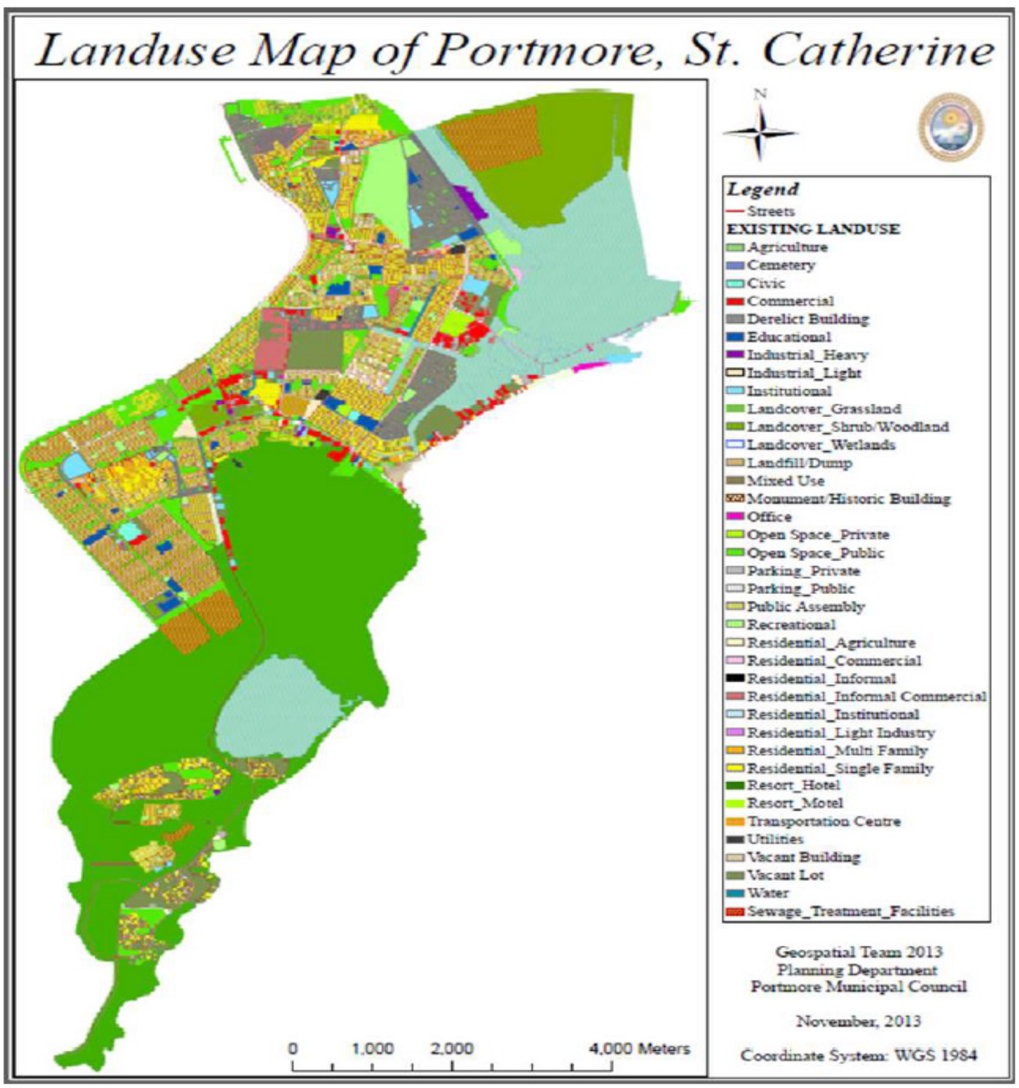


Figure 54: Existing land use in the municipality of Portmore as of 2013.

An assessment of Water Availability and Supply

Jamaica is made up of ten (10) hydrological basins. The Portmore/Hellshire sub-district is located in the Rio Cobre basin. The municipality receives water supply from an extended pipeline from the Tulloch Springs and wells located near Bog Walk, St. Catherine.

- In 2012, a project was initiated within the Portmore community to provide more reliable water access. This project procured 10 kilometres of 750 mm diameter pipe which was anticipated to provide an additional 6 million gallons per day (mgd) to the municipality.
- The Rio Cobre Water Supply System supplies potable water to Portmore, Spanish Town and sections of Kingston and St. Andrew. A total of 13 production wells provide approximately 5.1 mgd of potable water to the Portmore and Greater Portmore Zone. In meeting its water requirement, the Portmore Zone has a surplus of 5.0 mgd of water; approximately 3.0 mgd of this amount is exported to the Kingston Metropolitan Area (KMA) region. However, if physical losses continue from the water supply system a deficit of 0.7 mgd is projected in meeting future water demand.
- Despite the surplus within the distribution system, several communities are not served adequately due to frequent breaks in power supply, leaks on the Rio Cobre transmission main as well as water quality issues within the Greater Portmore sector of the zone. The National Water Commission aims to combat non-revenue water ensuring that all unmetered customers are metered and distribution lines are upgraded. Stream flow data from the Water Resource Authority (WRA) suggest a deficit in some of the island's most important surface water resources, including the Rio Cobre (Jamaica's largest Watershed Management Unit). These surface water sources are not only designated as under stress areas due to reductions in rainfall or stream flow but they also represent three highly abstracted sources.
- Water extracted from the Rio Cobre is largely used for irrigation purposes and the municipal needs of St. Catherine and parts of the KMA. In the early 1970s, 13 million imperial gallons (mgd) of water was commissioned to be transferred from the Rio Cobre Scheme to Kingston and St. Andrew (KSA) to aids its water allocation. However, only approximately 4 mgd is tranferred currently. This is a cause for concern, as a deficit of 17.5 mgd was experienced in the Kingston and St. Andrew Water Supply System during the dry season of 2010, and projections of deficits of up to 18.9 mgd are anticipated by 2030 if technical losses continue. Moreover, significant increases in population growth in Spanish Town and Portmore, St. Catherine, are expected to continually decrease the amount of water available for exportation to the KSA from the Rio Cobre Scheme.
- Two of St. Catherine's 16 sewage systems are located within Portmore. The Independence City and the Bridgeport sewage treatment plants have a capacity of 3.5mgd and 2mgd respectively. There is also a 4mgd sewage treatment for the Greater Portmore housing development. Over 95% of the residents in Portmore have access to sewage facilities. Access to improved sanitary facilities limit the health risks associated with improper sanitation.

HISTORICAL AND PROJECTED CLIMATE

The Portmore area lies within the dry southern portion of the island, and follows the general Jamaican climate patterns. Despite the lack of weather data for Portmore itself, the climate of the area can be estimated using stations in nearby Kingston and mean conditions for the entire island.

- Temperatures are highest during the summer period of July-August. Mean monthly temperatures can reach 30°C during summer months and 26°C during winter months in the areas of Kingston and coastal St. Catherine.
- Maximum daytime temperatures can reach 34°C during the summer months and minimum night-time temperatures can go below 17°C during the winter months.

- Due to the density of housing and development, the city is subjected to the urban heat island effect. Concrete structures and pavement absorb far more radiation than green areas, which is then given off as heat. The result is an increase in already high temperatures.
- Rainfall follows a bimodal pattern, with an early wet season occurring April-June, a late wet season in August-November, and a midsummer drought around July. Mean monthly rainfall can exceed 280 mm during the wet seasons, and can be heavily influenced by the passage of tropical cyclones. Rainfall during the dry season (December-March) is via the intrusion of frontal systems from the north.
- Relative humidity is higher during morning hours than in the afternoon. It can range from 72-80% in the morning to 59-65% in the afternoon.
- There is little variation in solar radiation and sunshine hours throughout the year. There is a slight reduction in sunshine hours during the rainy periods, which is a result of increased cloudiness. Coastal areas receive a mean of eight hours of sunshine per day.
- Peak evaporation occurs during early summer, during the hotter months that follow the early rainy season.
- Temperatures have exhibited a statistically significant increase in the past two decades by approximately 0.1 degrees Celsius/decade in coastal areas close to Portmore. The warming has also manifested in an increase in the number of warm days and nights and a decrease in the number of cool days and nights. The fastest warming has occurred during the summer months of June-August.
- Rainfall has become more variable. The southeastern region of the island in which Portmore lies has experienced decreasing rainfall over the years.
- Other environmental variables, such as wind speed and sea surface temperature, have also increased in recent years. There has been no statistically significant increase in relative humidity.

Trends in future climate include:

- Model projections indicate that warming could occur at a faster rate in the south of the island than in the north. For the grid box in which Portmore is located, this could mean warming of 2.8 – 4.3˚C by the end of the century, with greatest warming occurring during June-September.
- Rainfall is likely to continue to be variable and is anticipated to change dramatically. Rainfall for the area is projected to decrease by 28 - 52% by the end of the century, with the wet seasons being most heavily impacted by these changes. In the coastal areas of Jamaica, there will be a decrease in the frequency of the maximum consecutive wet days annually, accompanied by longer dry periods.

CLIMATE AND RELATED HAZARDS

Perhaps the greatest risks to Portmore are the potential impacts from tropical storms, storm surges and sea level rise. Jamaica's location within the Atlantic hurricane belt makes it vulnerable to the passage of tropical storms, which often coincide with the late wet season. Most of these storms approach the island from the south thereby increasing Portmore's exposure to the intense winds and rainfall associated with these systems and susceptibility to landfall impacts. The coastal location of the city also renders it highly susceptible to incremental changes in sea levels and the potential for at least partial inundation that may result from future sea level rise.

- Despite the climatological dry conditions in Portmore and the surrounding areas, there is also a high risk of flooding in the event of intense rainfall events. Such events occurred during the passages of Hurricane Ivan (2004) and Tropical Storm Nicole (2010), during which parts of the south coast received more rainfall in one event than they did cumulatively for many months prior. The area is also highly susceptible to inundation, both in the short-term due to storm surges and riverine flooding, and in the long term due to sea level rise. Though the Rio Cobre Dyke protects the city from riverine floods, there are no natural obstacles to coastal threats from storms or surges.

» Given the proximity of Portmore to forested areas, there is an increased risk of fire hazards due to forest fires that may accompany hotter and drier conditions.

» In the period 1960 – 2010, the Portmore area was directly impacted by approximately six hurricanes within 100m, half of those being category 4. Studies of hurricane activity indicate that future storms will likely be more intense with stronger winds and heavier rainfall.

» Due to the low elevation (approximately 139 m above sea level) of much of Portmore, it is highly susceptible to at least partial inundation due to sea level rise. Satellite measurements indicate that sea levels have risen at a rate of approximately 3 mm/year in the Caribbean since the early 1990s. Measurements taken at Port Royal (less than 20km away from Portmore) between 1955 and 1971 confirm the rising trend though at a rate of 0.9 mm/year. Caribbean sea level rise could approach 1 - 2m by end of century, and may occur at faster rates than are currently being observed.

» One of the earliest storm surges recorded in 1722 was generated by a category 4/5 hurricane that resulted in storm surges of 5.49m in height and completely destroyed the area now known as Passage Fort (formerly Queens Town). Hurricane Ivan at category 4 generated 3.3m storm surges on the beaches of Hellshire and Port Henderson-Fort Augusta. In addition, surges reached 80m and 90m inland, impacting the hills of Hellshire and Port Henderson respectively. The surges destroyed several wooden structures erected along the Hellshire beach. Four years after Ivan, Hurricane Dean passing on the south coast of Kingston generated storm surges that reached a distance of 90m to 101m inland in the area of the Fort Augusta Prison. Storm surges again destroyed wooden shacks of fishing villages along the Forum and Hellshire beach. The likely increase in storm intensity and sea levels will also intensify the storm surges that impact the area. These surges will likely be higher and extend further inland, leading to erosion, flooding and other hazards. Therefore, Portmore and the surrounding areas will likely experience loss of land and natural resources.

» The municipality of Portmore is susceptible to several types of flooding- riverine flooding, urban flooding, coastal flooding and flash flooding. Prolonged rainfall associated with hurricanes or other low-pressure systems may cause the Rio Cobre in St. Catherine to overflow its banks. Before the construction of the dyke, the floodplain of the Rio Cobre would have been continuously flooded. The construction of the dyke prevented the continued flooding of the urbanized areas, but urbanization resulted in inadequate drainage systems that were poorly maintained, thus resulting in urban flooding. The major flood prone areas that have been identified by ODPEM are Passage Fort - Passage Fort Drive, Caymanas Gardens, Waterford - Wym Way, New Lands, Naggo Head, Breaton Phase 3 - Barracuda Avenue.

» Figure 49 shows areas within Portmore that have been prone to urban flooding and storm surges over the years. Historical record indicates that Gregory Park, Passagefort, Greater Portmore, Breaton and Waterford are the areas likely to be inundated after heavy and continuous rainfall or during the passage of a storm.

» Warmer and wetter conditions during the early part of the year have been linked to earlier and more intense outbreaks of dengue in Jamaica. Health risks are further compounded by flood and drought events, which can impact sanitation, water availability and the spread of water borne diseases.

RESPONSE AND RESILIENCE BUILDING INITIATIVES

» Several measures have been put in place to mitigate the impacts of extreme events and hazards including the development of the Portmore Evacuation Plan and the Waterford Community Disaster Risk Management Plan. The nation's Office of Disaster Preparedness and Emergency Management liaises with the Portmore Municipal Council through the Parish Disaster Committee and Coordinator on matters related to disaster risk management.

» There are initiatives within Portmore that are geared towards raising public awareness and several projects building resilience within the municipality. These initiatives are primarily carried out by:

- ODPEM: Providing capacity building through training and facilitating the Portmore Evacuation Plan
- Helpage International: Helping vulnerable populations and communities to manage risks associated with hurricanes and floods
- Panos Caribbean: Increasing the disaster response mechanism for persons with disabilities in Portmore, St Catherine via a pilot early warning system.

» *Early Warning System:* In 2013 Panos Caribbean, alongside ODPEM and the Combined Disabilities Association, piloted an early warning system to facilitate the needs of persons with disabilities in designated shelters. The study took place in Waterford, Gregory Park and Bridgeport, communities with approximately 5000 disabled persons. The project targeted more than 200 persons with disability and disaster response workers. This led to the compilation of a list of persons with disabilities in disaster prone areas and these individuals were provided with climate and disaster related information to aid in their evacuation and response during a disaster. Early disaster responders were also trained on how to deal with the disabled community in light of a natural disaster. During the pilot program, the Naggo Head Primary School, one of Portmore's most heavily used shelters, was retrofitted to suit the needs of the physically challenged where ramps, portable potties and bathroom adjustments were made to facilitate the disabled in Portmore. The early warning system was also devised for three persons (blind, deaf and physically challenged) per community to receive disaster messages and to disseminate that information to other persons within the disabled community.

8. Climate Resources

8.1. Introduction

The chapter outlines some analytical and decision-making tools and services that may be employed to assess climate change risk. Though it is recognized that a plethora of tools, products and services exist, in this chapter the bias is toward those developed specifically for the Caribbean region.

TOOLS are used to monitor or measure different physical parameters (direct or derived) and provide the basis on which key decisions can be made. They include models, software, sensors and meters.

PRODUCTS are defined as outputs developed by different institutions, companies, and agencies to provide notice, warning messages, and advisories of climate status or likely impacts. They may also recommend remedial actions and take the form of bulletins, advisories and are provided in multiple formats (hard and soft copy).

SERVICES are user-driven systems that provide customized data and/or information to help with decision making in the face of climate hazards. The distinction from tools is that the user does not interface with, or manipulate the source of information, but accepts and utilizes the packaged information. These include websites and or weblinks.

The chapter ends with a compilation of some of the most recent publications on climate change relevant for Jamaica and the Caribbean. These publications address current outlooks on climate change, assess climate change impacts in specific sectors, and outline current policies outlining climate change mitigation efforts in sectors for Jamaica and the Caribbean region. It is noted that the State of the Jamaican Climate 2012 had a similar listing of publications. The listing in this chapter is an extension of that listing. It is therefore a listing of publications in the last four years.

8.1.1. CLIMATE ANALYSIS RESOURCES

Table 72: Climate tools that can provide users with local, regional, and international climate information and future climate outputs.

CLIMATE SERVICE ITEM	COMMENT	UTILIZATION/RELEVANCE TO JAMAICA
KNMI Climate Change Atlas	The KNMI Climate Change Atlas is a web-based interface that allows users to generate global or regional projections of temperature and rainfall using the most recent IPCC climate projections scenarios. The tool also allows for comparisons from a historical baseline period. https://climexp.knmi.nl/plot_atlas_form.py	The KNMI Climate Change Atlas provides global, regional, and country level observations and projections generated from both global climate models (GCMs) and regional climate models (RCMs).
Climate Interactive	The Climate Interactive suite of tools and simulations that help people understand the long-term effects of emissions levels, global temperature and sea level rise on climate. Climate Interactive includes such tools as C-ROADS and C-Learn. https://www.climateinteractive.org/	The Climate Interactive suite of tools and simulations are good learning aids at for students, professionals, and non-professionals alike.
IRI Climate Map Room	The Climate Map Room developed by the International Research Institute for Climate and Society provides interactive maps and time series of large-scale atmospheric variables. https://iridl.ldeo.columbia.edu/maproom/	This tool can provide a more detailed look at climate on global and regional scales, and how climate analyses may be applied to addressing climate impacts on health and food security for select regions.
Simple Model for the Advection Storms and hurricanes (SMASH)	SMASH is a simple model to allow planners and decision makers the opportunity of examining differing scenarios of tracks and intensity for hurricanes that traverse through the region, and determining the associated rain rates and wind speeds for a given location in a SIDS island. It is the University of the West Indies' contribution to a suite of climate tools developed under the Caribbean Weather Impacts Generator (CARIWIG) Project. http://173.230.158.211/SMASH/	SMASH allows users to assess the

CLIMATE SERVICE ITEM	COMMENT	UTILIZATION/RELEVANCE TO JAMAICA
Regional Climate Observations Database (ReCORD)	ReCORD is a climate tool that allows decision makers to analyze climate trends across Jamaica and the Caribbean region. http://173.230.158.211/ReCORD	The tool provides a full suite of carefully selected and packaged projected climate data for rainfall and temperature for sub-regions of Jamaica. This is complemented by the historical frequency of tropical storm passage close to that location, and climatologies of the same climate variables for stations located within the chosen sub-region.
Caribbean Weather Impacts Generator (CARIWIG)	The CARIWIG data portal is a web service that provides local and regional summaries of climate trends and weather projections based on observed climate data and climate model outputs. http://www.cariwig.org/ncl_portal/#info	The data portal also sports the following three simulators: i) weather generator that provides synthetic scenarios for variables, such as temperature and rainfall, for select meteorological stations across the Caribbean; ii) tropical storm model that generates weather scenarios using past tropical storms (see the SMASH tool outlined above); iii) threshold detector that allows for the post-processing of synthetic weather outputs.
SIMCLIM 2013	SIMCLIM2013 allows users to generate site-specific climate scenarios using superimposed shapefiles and future climate projections. The software was built for better informed climate change risk assessments for both governmental and non-governmental organizations and students. http://www.climsystems.com/simclim/	SIMCLIM allows users to better assess the impact of projections by pairing projections with geospatial information.

8.1.1. DECISION-MAKING WITHIN THE CLIMATE CONTEXT

Table 73: Climate tools that allow decision makers and policy makers to make informed decisions on climate-sensitive projects.

CLIMATE SERVICE ITEM	COMMENT	UTILIZATION/RELEVANCE TO JAMAICA
Caribbean Climate Online Risk and Adaptation Tool (CCORAL)	The CCORAL tool is a web-based support system that provides decision makers with tools that assess the degree of climate influence in proposed projects. The tool helps decision makers to consider projects within a climate context. http://ccoral.caribbeanclimate.bz/	Allows decision makers to view project proposals within the climate context; assesses the degree of climate sensitivity and impact.
Caribbean Climate Impacts Database	The Caribbean Climate Impacts Database (CCID) provides users with a platform for impacts reporting and also evidence-based information for improved climate risk management. The CCID helps to guide disaster risk planning and implementation. http://rcc.cimh.edu.bb/cid/	The CCID provides evidence-based information for improved climate risk management for various sectors.
Regional Clearinghouse Database	The Caribbean Community Climate Change Centre (CCCCC) is an online platform that provides a variety of climate information. Such information includes local and regional vulnerability and impacts assessments, climate-related project documents, and country profiles. http://clearinghouse.caribbeanclimate.bz/	The database provides a collection of sector-specific vulnerability and impact assessments at the local and regional level. The database also provides regional climate outputs from the PRECIS regional climate model.
C-ROADS World Climate	C-ROADS is a climate change policy simulator that helps people understand the long-term climate impacts of actions that reduce greenhouse gas emissions. https://www.climateinteractive.org/tools/c-roads/	The C-ROADS tool runs real-time policy analysis, easily translates climate mitigation scenarios into emissions, concentrations, temperature and per-capita emissions outcomes. It allows for comparisons between other regions.

8.2. Sector-Specific Climate Tools, Software and Resources

The Information provided below is relevant for the Agricultural Sector, along with sub-sectors Crop Production, Livestock and Fisheries, and Water sectors. This section is divided into two sub-sections. Sub-section 8.5.1 provides a list of useful climate products and services for the agriculture sector. Sub-section 8.5.2 describes tools and software that are either currently in use of sectors at the local, regional or international scale.

8.2.1. CLIMATE PRODUCTS AND SERVICES

Table 74: Outline of climate products and services specific to the Agricultural Sector.

AGRICULTURAL SECTOR		
CLIMATE SERVICE ITEM	**COMMENT**	**UTILIZATION/RELEVANCE TO JAMAICA**
A specialized website of climate products and services for the Jamaican Agriculture Sector	Site accessible via: http://www.jamaicaclimate.net/	Hosted by the Meteorological Service, Jamaica. Used widely in Jamaica and serves as good practice example for the wider Caribbean
Local Climate Products: Seasonal Forecast, Farmers Bulletin, Rainfall Summary, Drought and Evapotranspiration (ET0) Map	Site accessible via: http://www.jamaicaclimate.net/	Hosted by the Meteorological Service, Jamaica. Used widely in Jamaica and serves as good practice example for the wider Caribbean
The Caribbean Society for Agricultural Meteorology (CariSAM).	Information available via: http://carisam.cimh.edu.bb/ Serves as an interface between Meteorologists, Climatologists, and the Caribbean Agriculture Community.	Hosted by the Caribbean Institute for Meteorology and Hydrology and used throughout the Caribbean
Caribbean Climate Products: Agro-climatic bulletin, drought bulletin, coral reef bulletin, rainfall outlook (including extremes) and temperature outlook, weather forecast	Information available via: http://carisam.cimh.edu.bb/	Hosted by the Caribbean Institute for Meteorology and Hydrology and used throughout the Caribbean. Helps to predict and forecast inhospitable conditions for fisheries, livestock and crops and allows for preemptive remedial actions to be taken

AGRICULTURAL SECTOR		
CLIMATE SERVICE ITEM	COMMENT	UTILIZATION/RELEVANCE TO JAMAICA
World AgroMeteorological Information Service (WAMIS)-Global website for Agromet	http://www.wamis.org/	Hosted by the World Meteorogical Service, with links to multiple countries
Climate Impacts on Agriculture (Climpag)- A site that seeks bring together various aspects and interactions between weather, climate and agriculture in the general contat of food security	http://www.fao.org/nr/climpag/about_en.asp	Hosted by the FAO with links to multiple countries
FAOSTAT- A global database providing free access to agriculture data for over 245 countrie and terrirtories.	http://www.fao.org/faostat/en/#	Data available for most countries from 1961 to most recent records
The Caribbean Dewetra Platform- Dewetra is an IT system aimed at weather-related risk and forecasting and monitoring. It collects and systematizes all data, automatically or manually and produces value-added products. Forecast models, and in situ observations are integrated with vulnerability and exposure data to produce risk scenarios in real time.	Different modules aimed at forecasting specific hazards such as fires, landslides, stream flow and floods can be easily integrated into the platform. It can produce haard maps, details of land cove-land, land use and vegetation	Used at National level in Italy, Bolivia, Lebanon, Albania and the Caribbean (coordinated in the Caribbean by the CIMH). (http://www.cimafoundation.org/wp-content/uploads/doc/DEWETRA_english.pdf)
Caribbean Climate Impacts Database (CID)- a comprehensive open source geospatial inventory of impacts occurring from climate events	Provides historical records (both quantitative and qualitative) of severe events from prior to 1900. The site also Includes information of loss and damage to the Caribbean agriculture sector resulting from severe weather systems. Can be used to aid decision making especially with respect to hazard prone areas	Available via: http://rcc.cimh.edu.bb/cid/about.php and used throughout the Caribbean. Also consulted frequently by global users.

8.2.2. CLIMATE TOOLS, SOFTWARE, SENSORS AND MODELS

Table 75: Outline of climate tools, software, sensors and models specific to the Agricultural and Water sector.

AGRICULTURAL SECTOR		
CLIMATE SERVICE ITEM	COMMENT/DESCRIPTION	UTILIZATION/RELEVANCE TO JAMAICA
Modelling System for Agricultural Impacts of Climate Change (MOSAICC)	An integrated package of models for assessing the impacts of climate change on agriculture including the variations in crop yields and their effect on national economies. The Four main components include: 1. Climate (downscaled data); 2. Hydrology (estimate of future water resources), Crops (Yield simulations under climate change); and Economy (economic impacts of future crop yields and water resources projections)	Developed by the Food and Agriculture Organization (FAO) of the United Nations. Links (climate) information and decision making to improve food security
FAO- AquaCrop Model	A Yield to water response model for herbaceous plants (therefore plants with a known annual cycle). It has capability to predict yield and biomass changes under multiple scenarios of climate change and can also simulate production with saline intrusion considerations	Model is freely available via: www.fao.org/nr/water/infores_databases_aquacrop.html. Model has been parameterized for several crops and is used globally. **(Has been applied successfully to Sweet Potato in Jamaica and relevant to several other crops)**
CROPWAT Model	Used to simulate crop growth and water flow in the rootzone in deficit irrigation studies. It is a powerful tool for extrapolating findings and conclusions from field studies. Very useful for drought impact assessment under climate variability and change	An FAO Model that has global utility
Ex-ACT: Climate Impact Assessment	A software that estimates the likely impacts of agricultural and forestry development projects on greenhouse gas emissions and sequestration in terms of carbon balances	Developed and hosted by the FAO
Decision Support System for Agrotechnology Transfer (DSSAT)- Very applicable to Jamaica	This is a software application programme that comprises crop simulation models for over 42 crops. It allows for various simulations to be made based on soil, weather, crop management (including fertilizer treatments, crop sequencing/rotation, and varietal selection)	Very widely used crop model globally. Highly documented model, **which has several crops grown in Jamaica** and the wider Caribbean. More information available at: http://dssat.net/

AGRICULTURAL SECTOR		
CLIMATE SERVICE ITEM	**COMMENT/DESCRIPTION**	**UTILIZATION/RELEVANCE TO JAMAICA**
Adapt-N Advanced Nitrogen Recommendation Software	The Adapt-N tool is a user friendly, web-based nitrogen (N) recommendation tool for corn crops. The tool provides precise N fertilizer recommendations that account for the effects of seasonal conditions using high-resolution climate data, a dynamic computer model, and field-specific information on crop and soil management.	The tool is used widely in the USA and can be accessed via- http://adapt-n.cals.cornell.edu/
Tensiometer	An instrument used to determine the matrix water potential (soil moisture tension) in pounds per square inch (PSI). High readings indicate low moisture content (drier soil) and hence the need for irrigation	Used in Jamaica and the wider Caribbean. A useful means of monitoring soil moisture, allowing for watering only according to the evaporative demand of the crop and therefore improves water conservation
(5TM) Soil Moisture & Temperature Sensor	One in a series of at **least 8 different types of Soil Moisture and temperature Sensors.** Allows for digital real-time monitoring of soil conditions. Other sensors also measure electrical conductivity. More information available at http://www.decagon.com	**For Jamaica:** Can be very useful for mitigating the impacts of heat stress on crops and for reducing impacts of drought. It also allows for monitoring f progress towards maturation through the different phases of crop development. Accumulation of heat units (termed growing degree days) is significantly controlled by temperature.
Spectral Reflectance Sensors (SRS). These are two band radiometers designed to measure Normalized Difference Vegetation Index 9NDVI) or Photochemical Reflectance Index (PRI)	The **Normalized Difference Vegetation Index** (**NDVI**) is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum, and is adopted to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not.	Very useful for rapid assessment of vegetation status and for constantly monitoring canopy development under different climate regimes.

AGRICULTURAL SECTOR		
CLIMATE SERVICE ITEM	COMMENT/DESCRIPTION	UTILIZATION/RELEVANCE TO JAMAICA
Ceptometer (ACCUPARLP-80)- used to measure canopy photosynthetically active radiation (PAR) for non-destructive leaf area index (LAI) measurements	LAI is one of the most commonly used measurement of canopy expansion, which is a key parameter for monitoring crop development. It allows you to measure canopy PAR interception and calculate LAI at any location within a plant or forest canopy. PAR data can be used with other climate data to estimate biomass production without destroying the crop. With the AccuPAR there is no need to wait, it uses radiation measurements and other parameters to accurately calculate leaf area index in real time, in the field	One in a series of three other tools used to measure canopy development (available via www.decagon.com). Can be useful for field work in Jamaica, especially as inputs for crop models
Lysimeter	A measuring device which can be used to measure the amount of actual evapotranspiration which is released by crops. It is a powerful tool since it allows better understanding of soil water balance, including deep drainage.	Very useful for soil water monitoring to maximize crop yields, reduce impacts of drought and improve water conservation. There are several brands on the market that can be used in **Jamaica**
Fisheries Sector		
Climate Service Item	**Comment/Description**	**Utilization/Relevance to Jamaica**
NOAA Coral Reef Watch Satellite Monitoring	Continuous monitoring of sea surface temperature provide reef monitoring environmental conditions to quickly identify areas at risk for coral bleaching. Bleached corals lead to mortality and eventual death of the whole colony, which in turn cause habitat and spawning ground destruction for most fish species	Used globally and provides input for Caribbean Coral reef watch. The watch provides different alert levels: No stress, Bleaching Watch, Bleaching Warning; Alert Level 1 (Bleaching likely); Alert level 2 (Mortality likely)

LIVESTOCK SUB-SECTOR		
CLIMATE SERVICE ITEM	**COMMENT/DESCRIPTION**	**UTILIZATION/RELEVANCE TO JAMAICA**
Digital Infrared Thermometer	Used to measure animal skin temperature which is an effective means to monitoring and predicting heat stress	Heat stress reduces reproductive rate in small ruminants, retards milk production and affects egg production in chickens
Water Sector		
Climate Service Item	**Comment/Description**	**Utilization/Relevance to Jamaica**
Water Evaluation and Planning (WEAP) System	Modelling tool for estimating water resources, demand and supply. The WEAP aims to incorporate these issues into a practical yet robust tool for integrated water resources planning. WEAP is developed by the Stockholm Environment Institute's U.S. Center. http://www.weap21.org/	WEAP is a unique approach for conducting integrated resources planning assessments and has several uses: 1) offers transparent structure facilitates engagement of diverse stakeholders in an open process 2) a database maintains water demand and supply information to drive mass balance model on a link-node architecture 3) calculates water demand, supply, runoff, infiltration, crop requirements, flows, and storage, and pollution generation, treatment, discharge and instream water quality under varying hydrologic and policy scenarios 4) evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems 5) dynamic links to other models and software, such as QUAL2K, MODLFOW, MODPATH, PEST, Excel and GAMS

LIVESTOCK SUB-SECTOR		
CLIMATE SERVICE ITEM	**COMMENT/DESCRIPTION**	**UTILIZATION/RELEVANCE TO JAMAICA**
The Hydrologic Modeling System (HEC-HMS) http://www.hec.usace.army.mil/software/hec-hms/	HEC-HMS is physically-based, semi-distributed hydrologic model that simulates the response of a watershed subject to a given hydro-meteorological input. The model has four basic components: the basin models, meteorological models, control simulations and input data. The outputs are represented as discharge hydrographs at junction points of the river system as well as volume of runoff with abstraction or losses from infiltration for each sub-basin.	The HEC HMS is designed to simulate the complete hydrologic processes of dendritic watershed systems. The software includes many hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing.
The Geospatial Hydrologic Modeling Extension (HEC-GeoHMS)	Developed as a geospatial hydrology toolkit for engineers and hydrologists with limited GIS experience. HEC-GeoHMS uses ArcGIS and the spatial analyst extension to develop a number of hydrologic modeling inputs. http://www.hec.usace.army.mil/software/hec%2Dgeohms/	HEC-GeoHMS is a GIS-based pre-processor that may be used to simulate watershed features and parameters such as slope, length, parameters for loss or abstraction, which are in turn used as input for HEC-HMS. Along with HEC-GeoHMS, the Arc Hydro Tool and ARC MAP 10.2 are used as pre-processor tools for extraction of catchments or sub-basins from the Digital Elevation Model (DEM) of the watershed.
Simple Model for the Advection of Storms and Hurricanes (SMASH)	SMASH allows users to simulate different scenarios of storm track and intensity by historical hurricanes moving across a Caribbean island along a path determined by the user. SMASH has three basic steps: data collection, execution and data distribution. http://173.230.158.211/SMASH/	SMASH allows planners and decision makers the opportunity of examining differing scenarios of storm tracks and intensities and the associated rain rates and wind speeds for a given location in a Caribbean island. SMASH also has been used with the HEC-HMS to generate rainfall run-off simulations with the HEC-HMS (please refer to Mandal et al. (2016)).

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10. Workshop Report and Stakeholder Feedback

AGENDA

TERRA NOVA HOTEL, KINGSTON

APRIL 20, 2017

WELCOME, INTRODUCTIONS AND OPENING REMARKS		
8:30 – 9:00 am	Registration	
9:00 – 9: 30 am	Welcome and Introductions Opening Remarks The PPCR Project Introduction to the Document · Overview of the Document · How to Use the Document?	Dale Rankine Claire Bernard Lehome Johnson Michael Taylor

SESSION 1: SEE DIS PATTERN		
9:30 am – 10:00am	About the SOJC 2015 I Activity 1: Are You Climate Smart?	Michael Taylor
10:00 am – 10:30 am	Coffee Break	

SESSION 2: WATCH DIS TREND		
10:30am – 11:30am	About the SOJC 2015 II · Historical Observations · Variability · Trends Activity 2: Are we in Jeopardy?	Michael Taylor Jayaka Campbell
11:30am – 12:00am	Coffee Break	

SESSION 3: PREE DIS CHANGE		
12:00pm – 1:30pm	About the SOJC III · Climate Projections · Impacts · Community Profile Activity 3: Tan Ya Ville	Michael Taylor
1:30pm – 2:00pm	Other Resources Participant Evaluation Closing Remarks	 Dale Rankine Dale Rankine
2:00pm – 3:00pm	Lunch	

10.1. Introductions and Overview of the Project

Welcome and Introductions

Dr. Dale Rankine of CSGM welcomed participants to the workshop and engaged them in an introduction exercise. The audience was asked to describe what they expected from the workshop and the report. Many participants related that they were interested in learning about the recent analysis to the climate data and scenarios across Jamaica, and how the updated analysis may be applied to their respective fields and climate mitigation and adaptation projects. Mrs. Sherine Huntley-Jones from the Ministry of Health noted that health is frequently impacted by natural disasters as many of their facilities are located on the coast. As such, she was interested in understanding what climate change had in store for the future and how the information may be applied in their mitigation and contingency plans to fortify hospitals.

Opening Remarks – Ms. Claire Bernard, Deputy Director General, PIOJ

Ms. Bernard pointed out that the *2015 State of the Jamaican Climate Report* builds on the previous *2012 State of the Jamaican Climate Report,* among other literature, by increasing the precision and quality of the data and analysis. The updated report puts the relevant institutions in a better position to plan more accurately and effectively. Ms. Bernard noted that most of the stakeholders at the workshop are planners, and that we are here to see how the climate data can be applied to increase the quality and impact of the work that is done at each institution. We are here to begin looking at how climate will impact sectors such as health and transport. We are also here to identify how these scenarios will shape our view of contingency planning. Ms. Bernard also pointed out that worsening climate conditions might trigger the need to look at both national and international response, for example in the case of refugee migration due to extremes. The participants were encouraged to understand the implications of the climate data provided and to take a closer look at how policy is constructed to consider such cases, not just for our own sectors but for all.

Overview of the Pilot Programme for Climate Resilience (PPCR) Project – Mr. Lehome Johnson, Project Manager, PIOJ

The *State of the Jamaican Climate* Reports are prepared as deliverables under the national track of the PPCR project being implemented through the PIOJ. Mr. Johnson explained that the PPCR project is essentially a funding window providing climate investment funds for climate change adaptation and resilience building initiatives. The PPCR operates with a two-phase approach; it assists countries in integrating climate resilience in development planning. The first phase of the project resulted in the development of a *Strategic Plan for Climate Resilience* (SPCR) in 2011. The SPCR has been developed to help Jamaica with climate adaptation. It is also aligned to Vision2030 and addresses and builds on gaps that have been identified during the first phase, also making the implementation process easier. Several investment projects were formed from the 2011 SPCR:

- Investment Project 1: Improving Climate Data and Information Management Project (ICDIMP)
- Investment Projects 2 & 3: Adaptation Programme and Financing Mechanism (APFM), Mechanism for the PPCR Jamaica, implemented by the CCD
- Investment Project 4: Building Resilience in the Fisheries Sector (approval and implementation expected later this year)

Mr. Johnson also mentioned Jamaica's involvement in the regional track of the PPCR project. Currently, the regional track of the programme is being implemented in 6 countries: Jamaica, Haiti, St. Vincent and the Grenadines, St.Lucia, and Dominica.

The ICDIMP targets almost every sector to improve the quality of use and availability of data. The critical output of the project is the installation of weather radar stations at strategic positions across Jamaica. The SOJC Report is one of the most important aspects of the project as it serves as input into other activities under the project. The 2015 report will be used to guide and inform vulnerability assessment and sector plans among other things.

10.2. Stakeholders/Participants in Attendance

Representatives from the following institutions/sectors were in attendance:

Acclimatise (UK-based climate change adaptation firm)

Climate Change Division (CCD)

Environmental Foundation of Jamaica (EFJ)

Environmental Solutions Limited (ESL)

Forestry Department

Global Environment Facility (GEF) Small Grants Programme

Inter-American Development Bank (IDB)

Jamaica Civil Aviation Authority

Jamaica Organic Agriculture Movement

Meteorological Service of Jamaica

Ministry of Culture, Gender, Entertainment and Sport (MCGES)

Ministry of Economic Growth and Job Creation (MEGJC)

Ministry of Justice

Ministry of Local Government and Community Development

Ministry of Transport and Mining

Mona GeoInformatics Institute

National Environmental Planning Agency (NEPA)

National Works Agency (NWA)

Petroleum Corporation of Jamaica (PCJ)

Planning Institute of Jamaica (PIOJ)

PPCR Regional Track

USAID

University of the West Indies (UWI)

Water Resources Authority (WRA)

10.3. Overview of the Document

Professor Michael Taylor outlined key aspects of the 2015 SOJC document:

It is a climate information document. Coming out of Outcome 14 of the Investment Project 1 under the PPCR Project, the target was to improve the quality and use of climate-related data and information. The document is aligned with the need for climate information and its aim is to provide current climate information that may be used to inform resilience building efforts at the country and sub-country level, and allow for improved sector-based assessments for climate resilience planning and decision-making.

It is a review document. The document is a review of authoritative works and recent studies on climate change variability for Jamaica and the Caribbean region. The 2015 SOJC report pulls on previous documents such as the 2012 SOJC Report, the Near-term Climate Scenarios for Jamaica 2014 report, Jamaica's Second and Third National Communications to UNFCCC, Jamaica: Future Climate Scenarios, the IPCC series of reports, peer-reviewed literature, and many climate vulnerability assessments and data from the CCCCC. The aim was to reference as much information on climate change variability from multiple sources. In this respect, the 2015 SOJC Report is very much like the IPCC reports.

The 2015 SOJC Report does not contain 'new research'. There was no scientific research done specifically for this report. However, it does include latest information from peer-reviewed research that is relevant to Jamaica. It also provides updated maps based on new data and information.

It is a first stop for climate information for Jamaica. Another aim of the document is to serve as the first stop for obtaining and referencing climate information for Jamaica. It is however not the last and only stop for climate information. The 2015 SOJC Report also refers to more detailed sources of climate information, assessments and tools.

The 2015 SOJC Report is a complementary document and is not a replacement. It is meant to be a companion document, to be used and consulted together with other reports and assessments. The report is not meant to replace previous sources of climate information such as the 2012 SOJC Report and the Third National Communication.

Prof. Taylor also provided a quick comparison between the previous 2012 SOJC versus the 2015 document. Compared to the previous SOJC, the 2015 document is more concise in structure, contains a chapter dedicated to community climate vulnerability profiles, provides climate scenarios at high resolution country and sub-country scales using both the PRECIS (26 grid boxes) and RegCM (45 grid boxes) regional models, data updated to include the most recent years (2013-2015), and includes impacts assessment for previously excluded sectors.

10.4. Workshop Objectives

The aim of the workshop was to introduce stakeholders to the *2015 State of the Jamaican Climate* Report prepared by the Climate Studies Group, Mona, and garner feedback of the document.

10.5. Session 1: See Dis Pattern

The first interactive exercise in the form of a quiz based on Chapter 3 of the 2015 SOJC Report was handed out to the participants to test the extent of their prior knowledge of climate variability and change.

Prof. Taylor introduced seven interesting things given in Chapter 3:

» Chapter 3 provides a temperature analysis of Jamaica using data acquired through the Meteorological Service of Jamaica. Page 21 of the report illustrates trends in minimum, mean, and maximum temperature for nine stations across the island. Temperatures show a similar trend across Jamaica. The trends show that mean temperatures peak in August. Jamaica's mean temperatures vary within 3°C from the beginning to the end of the year. This becomes very important as it helps to characterize what normal variability is for the island and when the increases in temperature become abnormal due to climate change.

» The North coast of Jamaica is cooler than the South coast. Norman Manley was found to be the hottest station, while Discovery Bay was found to be the coolest of the nine stations.

» Jamaica's rainfall pattern is a bimodal pattern. The first peak is in May and the second peak is in October. Up until the last 30-year period, the October peak is higher than the May peak. However, from 1980 to 2009, the October peak is slightly lower than the May peak. One explanation for this may be the more frequent onslaught of El Nino events in recent years may be bolstering early-season rainfall (March-April-May) but inhibit late-season (August-September-October) rainfall.

» Jamaica is large enough to have micro-climates. There are four rainfall zones: Zone 1 (interior regions/ mountain range), Zone 2 (eastern Jamaica), Zone 3 (western Jamaica), and Zone 4 (coastal regions). The climatological patterns of the rainfall zones are not the same. Therefore, observed data and scenarios at the sub-country scale becomes very important as not everywhere experiences the same kind of rainfall. Unlike the other rainfall zones, Portland's rain peaks in November-December-January. While Zone 4 (coastal regions) do follow the characteristic bimodal pattern, it receives the least amount of rainfall than the other zones. Zone 3 also has the bimodal pattern but less variability from season to season, and so it is generally wet year-round. Due to these differences in rainfall patterns, sub-country analysis becomes very necessary for national planning.

- For the Atlantic, hurricanes normally peak in August. For Jamaica, hurricane numbers also peak in August, but tropical storms peak in September.
- The strongest winds are felt in St. Elizabeth, Portland, St. Thomas and Manchester.
- Jamaica also shows variability in other climate variables. Jamaica experiences a peak in solar radiation in June-July when we are the hottest. Variations in relative humidity is seen during the day and peaks during afternoon showers.

Workshop breaks for coffee.

Some comments given by the participants to the question: Do you think that Chapter 3 as the baseline setting for the report is an important feature?

I am noticing that there are more grid boxes covering Jamaica, so that there are more opportunities for local-level planning. However, I am not seeing that data being mainstreamed in decision-making, in building construction and land-zoning, and even in the way we build our roads and treat sewage disposal, and farming. I am not seeing the person pushing the gap between the data [presented] here and persons at the planning and ground level. But, the baseline does set the context of what needs to be done.

Prof. Taylor acknowledged that access to climate-relevant data is a barrier to closing the gap, and alludes to the report being able to break down that barrier. Another participant offered the following comment:

It is of interest to me that we are able to have more sub-national scale data which allows for more practical actions especially at the project level. If we can move to even deeper levels of spatial analysis and reporting of that baseline, it would further help because we do projects which are at a deeper level than the parish level. The move from a dependence on regional data to our own at this sub-national level is a good movement to me and a good development in the quality of the data being generated.

Prof. Taylor took the time to commend the Met Service of Jamaica for their initiatives in increasing spatial coverage, collecting the data, and providing the Climate Studies Group with observed data for analysis.

10.6. Session 2: Watch Dis Trend

Chapter 4 of the 2015 SOJC Report examined climate variability, trends and extreme indices. While Chapter 3 examined what the mean climate state of Jamaica is, Chapter 4 explains more about the variability surrounding the mean climate state. It is very useful to know what the variation is from the mean, what it is like and what is causing it.

Prof. Taylor outlined six key points addressed in Chapter 4:

Irrespective of the temperature variable, the linear trend (indicative of the climate change signal) dominates the variability and is increasing. Night-time temperatures increase faster than day-time temperatures. The daily temperature range, the difference between day-time and night-time temperatures, is decreasing. The linear trend shows an approximate 1° increase in temperatures across Jamaica since pre-industrial times, consistent with global temperature trends.

Rainfall variability shows no discerning linear trend, but there are increases in high and low extremes. Therefore, **the rainfall variable is dominated and driven by inter-annual variability**. However, at larger timescales and a longer time period, mean rainfall indicates a consistent drying becomes apparent towards the mid-century. Inter-annual variations in Jamaican and Caribbean climate is due in large part to the El Niño phenomenon, and may determines when Jamaica has a wet or dry year.

Decadal variations are also important as climate conditions (wet or dry) may continue over several years. Decadal variations are driven by the Atlantic Multidecadal Oscillation (AMO). We are currently in a wet phase coinciding with a warm-phase AMO. Therefore, we are in a group of years that characteristically wet, and may soon enter a time of dry phase due to the AMO shifting to its cold phase. The influence of the AMO along with the influence of ENSO may exacerbate dry and wet conditions across the island. Therefore, inter-annual and decadal variability becomes far more important for rainfall than for temperature.

Rainfall zones 1, 3, and 4 co-vary over decadal variations, except zone 2. Therefore, when zone 1 is dry, zones 3 and 4 will also be dry. Zone 2 shows the least variability on the decadal timescale and tends to be dry while the other zones are wet (and vice versa).

The intensity and occurrence of temperature and rainfall extremes are increasing over the last 45 years, and will continue to increase. Sometimes, the mean value of a climate variable is not the most significant variable and values that fall within the outer limits of the variability can show significant trends that may be considered. Chapter 4 outlines temperature and rainfall extremes indices such as the number of very wet days, and the maximum one-day precipitation. Such extremes are very important to such sectors as Agriculture. In general, these extremes indices show a positive trend.

Historically, hurricanes are most likely to make landfall along the southeastern and eastern region of Jamaica. Chapter 4 provides a map of probability density of hurricane landfall across Jamaica for each category of storms. Of all the categories, category 3 and 4 storms tend to make landfall impact Jamaica. Due to Jamaica's location along the hurricane belt, hurricanes tend to have more time to develop on the open ocean before making landfall as a mature hurricane.

The coastal regions are more prone to dry spells than the rest of the island. Drought events can exist on different time scales. The interior and the coastal regions tend to have more occurrences of seasonal droughts. The coastal regions, in particular, tend to be far more prone to year-long occurrences of drought while the western region is least impacted.

Participants were separated into three teams for Interactive Exercise 2: Climate Jeopardy.

Participant questions and comments were as follows:

The western region of Jamaica consists of St. Elizabeth and Hanover. We usually here about these places not having rain. I know that you are using mean data. But, the trend seems different from the lived experience. Could you please explain?

When we talk about 'wet', we talk about wet in comparison to the other rainfall zones. If you look on the next page which has the mean climatology, the west has consistent rainfall. It is lower than the east but over the coast of a year, the west gets more rainfall than the coast. Therefore, the northern regions of St. Elizabeth may have more rain compared to its southern regions. This is why we suggest looking at climate trends using rainfall zones rather than parishes, as rainfall zones cut across parishes.

***

I like the focus on the El Niño and that we are to pay attention when El Niño is on the horizon. And I am thinking that we should do a bit of planning from the government's perspective. Considering what is to happen in 2020 and from the government's perspective, what are plans are in place so that Jamaica isn't negatively impacted in 2020 as we are now?

Chapter 4 is trying to make the point that rainfall variability is key right now. Since we know of the sources of variability such as El Niño, we must pay attention to what's happening because it affords us some time to plan. And we cannot give a specific year in which an El Niño event may occur. But, we must also pay keen attention to the AMO because when it swings into its dry phase, that will bring about dry conditions across Jamaica. These conditions can be exacerbated with El Niño events. In terms of medium term planning for things like water, the AMO becomes a critical thing to think about.

***

If we follow what you just said, then when you were talking about droughts and the intensity and frequency of drought events, is there any relationship there?

Yes, but we haven't touched projections yet. Chapter 4 only deals with historic trends and variability. This is just a look on what has happened and using it as a basis for decision-making.

***

Most participants are associated with the government. The question was asked, 'what is the government doing?' What I really want to say is that us being here today is a part of what the government is doing. It means that everybody here has access to the information. We all have influence in our various organizations. So, the important thing is to begin to sensitize ourselves; we are in the era of climate literacy. Members of the Climate Change Focal Point Network are also here, and we are ensuring that this information gets put into the work that we're doing. The government can also make this data available to its partners, to the NGO sector, the private sector, our development partners and academia. So, the government is beginning to work.

***

One of the things that struck me most is that we are in the wet phase of the AMO and still experiencing all of these droughts. That, for me, is telling especially since being in Kingston and with frequent water lock-offs. And I would certainly hope that the government is internalizing this kind of information, so that we can make better plans for the next couple of years.

***

This session was particularly usefully to me as it relates to vector-borne diseases and other viruses. We tend to see an increase in the transmission of viruses at the end of the year following the rainy season in October and going into January. But, considering what is happening in May, we may have to change our transmission period. We tend to implement our activities based on the rainfall patterns. So, we may have to go back and look on when we need to intensify our activities. It is quite useful to see that trend. Temperatures are also going up which is significant for the transmission of vector-borne diseases.

So, watching the patterns becomes important. I think that one of the things we need to identify in areas of research is what is happening in May and in October. One of the things that we have to be careful about is that it isn't that May rains were increasing but that rains in October were decreasing. So, we do want to pay attention to those little things. This is now where research becomes important, because once we begin to identify these things, we now use that data to drive the research and to make these decisions.

***

I am thinking that we need to get the government more involved at all levels. We need to overlay our maps and graphs unto constituency maps because we plan from constituencies outward. We don't plan on using these ecological zones, we plan per constituency. We can overlay the maps so that they can see the vulnerabilities to the constituencies. Therefore, we must seriously revamp our system of local government, which cannot handle these metrics as we have them now. I do not see these metrics being incorporated as it is now. I am questioning now the validity of national planning given that there are so many localized variables to deal with. For example, a national spatial plan will not make sense given the localized variations that exist. So, the local government is where the change must begin to start from.

***

From the national security point-of-view, I think we need to have a very conscious discussion about the issue of food security. Oftentimes, when think of security, we think of the police force or the army and so forth, but the security net is so wide that we have to take into consideration food security, water security. The gentleman (see above) raised an interesting point about overlaying our maps and seeing where the vulnerabilities take place. When the 'Bread-Basket' parish is experiencing drought, we have to think about food prices for those in Kingston. What does it mean for female-headed households? Those types of social discussions need to take place with this type of climate presentation.

***

One thing that I would clarify is not to say that the government needs to look at the constituency scale because most of us here are from the government and the central government structure. I think it would be more accurate to say that the political directorate, political parties, councilors, members of parliament and those persons need to see that overlay as they are better positioned to inform the government on what is needed at the constituency level.

***

I think we have a very good thing going with the Climate Change Focal Point Network. Last week, we discussed the whole matter of a reporting framework on what the different sectors are doing. Because it is important that as focal points, when we come to these workshops, we are able to go back to our respective agencies and work to mainstream the information and move the dialogue along.

***

The importance of this information is fully recognized. One way of getting this information into our plans is through the Focal Point Network. But more importantly, this workshop we have here is funded by the PIOJ and they have been instrumental in getting this information together. Therefore, CSGM's input is recognized at that level.

10.7. Session 3: Pree Dis Change

Chapter 5 of the 2015 SOJC Report outlines future climate scenarios for Jamaica. The chapter provides data for Jamaica from a variety of sources: global climate models (GCMs), regional climate models (RCMs), statistical downscaling and station data. It is anticipated that all of this data will help to develop a good climate change profile for Jamaica.

The following key points can be observed in Chapter 5:

GCM Projections. The GCM data provides an outline of future climate trends for Jamaica overall. Projections are provided for minimum, mean and maximum near-surface temperature and precipitation under the four IPCC climate scenarios: RCP2.6, RCP4,5, RCP6.0, and RCP8.5.

RCM Projections. Sub-country scale data was generated using RCMs for the 2020's (2020-2029), 2030's (2030-2039), 2050's (2050-2059), and 2080's (2081-2100). Chapter 5 outline in tabular form the trends in seasonal projections occurring in each rainfall zone. Projections for key geographical areas (represented by grid boxes) are also presented.

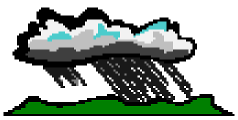
Statistical Downscaling. Statistical downscaling (SDSM) is a method that allows for the generation of projections for a single location. In chapter 5, Norman Manley International Airport is used as the location for the SDSM projections. Projections are generated for mean and extreme daily maximum temperatures, and warm day frequency per decade for 2016-2035 and 2036-2075. Projections are based on 30 years of historical daily data.

Prof. Taylor also noted that Chapter 6 provides a comprehensive outline of sector-specific climate change impacts. The chapter is based on as many sector assessments and studies, and provides a wealth of references for further reading.

Prof. Taylor also introduced Chapter 7, 8, and 9. Chapter 7 outlines climate vulnerability profiles for key public hubs, agricultural and tourism-relevant towns and communities that may be used as an example for climate vulnerability assessments. Chapter 8 outlines further climate resources. Chapter 9 provides an up-to-date list of references and literature that picks up from the previous SOJC report.

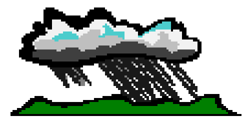
10.8. Appendix: Interactive Exercises

10.8.1. INTERACTIVE EXERCISE 1: ARE YOU CLIMATE SMART? CLIMATE QUIZ



Are YOU Climate SMART?

THE CLIMATE CHALLENGE



How much do you know about Jamaica's mean climate? Take this 14 question challenge.

1. Over the course of a year Jamaica's mean monthly temperature varies by (*Hint see page 17*)
   a. 10 °C b. 5 °C c. 1 °C d. 3 °C

2. Mean monthly night time (minimum) temperatures in Jamaica can be as low as (*Hint see table 7*)
   a. 10 °C b. 15 °C c. 25 °C d. 19 °C

3. Is there a difference between the south and north coast in mean temperature? (*Hint page 17 & fig 5*)
   a. No. Jamaica just hot everywhere. b. North coast tends to be cooler
   c. North coast tends to be warmer d. Wait… let me ask a tourist…

4. Jamaica's mean rainfall pattern is best described as (*Hint Figure 6 and Page 23*)
   a. Unimodal / Having a single peak b. Bimodal / Having two peaks c. Erratic d. Too little

5. What is Jamaica's wettest month of the year? (*Hint Table 10*)
   a. January b. September c. May d. November e. October

6. When does Portland record its highest rainfall totals? (*Hint Table 8*)
   a. April-May-June b. July-August-September c. November-December-January
   d. February-March

7. The section of Jamaica that shows least month to month variation in rainfall is (*Hint Page 26/Figure 9*)
   a. The west b. The mountainous interior c. The east d. The coast

8. Jamaica gets most rainfall on the ______ and ______ coast. (*Hint Figure 7 and Page 25*)
   a. North and South b. South and West c. East and West d. North and East

9. The Atlantic hurricane season peaks in (*Hint Figure 10*)
   a. June b. July c. August d. September e. October

10. The parishes of Jamaica that register the strongest winds are? (*Hint Page 30 and Figure 12*)
    a. St. Thomas, Portland, St Mary b. Trelawny, St. Ann, St. James
    c. Portland, St. Thomas, Manchester d. Westmoreland, Manchester, St. Elizabeth

11. When does Jamaica typically receive its peak solar radiation? (*Hint Page 33*)
    a. June-July b. January – February c. August – September d. Evenly across all months

12. Variations in Jamaica's daily relative humidity value can be said to be attributed to? (*Hint see page 35*)
    a. Lack of data b. Afternoon showers c. Too much construction d. All of the Above

13. Wave heights recorded for Negril are greater than those recorded for Kingston. (*Hint see Page 33*)
    a. True b. False

14. This test a. was easy b. was hard c. should have been open book
    d. proved I was climate smart! e. none of the above

10.8.2. INTERACTIVE EXERCISE 3: TAN YA VILLE

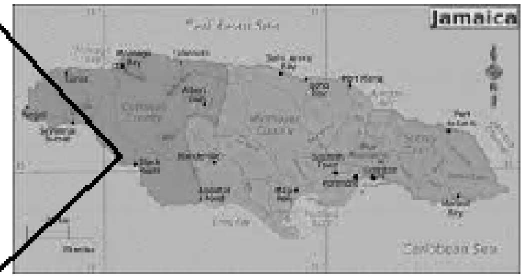
Welcome

Tan Ya Ville

Population: 15,000

About us

Our motto is "Family, Fun, Fiesta". We are small south coast community near Black River. We are farmers and fishermen and some tourist workers. Best of all we know how to have a good time!



1

Make a Choice

Congratulations! Good Times have finally come to **Tan Ya Ville**. As mayor you have been gifted with 4 million US dollars to spend on your community in any way you wish. Here are some options. Tick what you would spend it on. Use the blue million dollar dots to show it on the Decision Board.

	√		√
Water Tank ($2M)		Sea Wall ($4M)	
Christmas work fund for next 5 years ($2M)		Surveillance and mosquito control ($1M)	
Sports Complex ($3M)		Fix drains and fill potholes ($1M)	
Waste Recycling Programme ($2M)		Agriculture greenhouses ($2M)	
Subsidized bus fares for 3 years ($2M)		Community Center for computer training ($2M)	
Relocate coastal roads in and out of Community ($2M)		Small Business loan fund ($3M)	
Solar powered streetlights ($1M)		Police Post & squad cars ($2M)	
'Y Pree Wednesdays' Community Dance for next 5 years. ($1M)			

2

What's the Risk?

Assess the climate risks to Tan Ya Ville's investment by consulting the State of the Jamaican Climate 2015 Report. You can refer to the following chapters:

- Chapter 5: Climate Scenarios and Projections (page 55)
- Chapter 6: Sector Impacts (page 90)
- Chapter 7: Climate Vulnerability Profiles (page 120)

By 2035, **Tan Ya Ville** will be:

Hotter (page 55)		Cooler (page 55)	
Wetter (page 71)		Drier (page 71)	
Subject to higher sea levels (page 81)		Subject to lower sea levels (page 81)	
Prone to intense hurricanes (pages 47, 86)		Immune from hurricanes (pages 47, 86)	

From Science to Decision Making

3

So what?

It is very likely that these conditions will impact your community. Use Chapters 6 and 7 of the SOJC 2015 to see how if at all the following features of **Tan Ya Ville** will be impacted. Page references to the SOJC 2015 Report are given in brackets.

	Better	Worse		Better	Worse
Agriculture & Farming (page 105, page 115)			**Adequate Water (page 117)**		
Coastal Roads (page 98, page 119)			**Whey it Deh Beach (pages 112, 119)**		
Jobs in the Tourism Industry (page 112)			**Energy Costs (page 118)**		
Spread of Chik V, Zik V, Dengue (page 113)			**Crime (page 104)**		
Mayor's Christmas Fund (page 119)			**Housing Infrastructure (pages 98, 119)**		
Y Pree Wednesdays (page 119)			**Insurance Rates (page 99)**		

Hmmm…?

Would knowing what you now know matter? You now have a chance to make your decision again. Tick again the choices below and use the four million dollar dots to show it on the 2nd Decision Board. If no change go straight to the Decision Board.

4

	√		√
Water Tank ($2M)		**Sea Wall ($4M)**	
Christmas work fund for next 5 years ($2M)		**Surveillance and mosquito control ($1M)**	
Sports Complex ($3M)		**Fix drains and fill potholes ($1M)**	
Waste Recycling Programme ($2M)		**Agriculture greenhouses ($2M)**	
Subsidized bus fares for 3 years ($2M)		**Community Center for computer training ($2M)**	
Relocate coastal roads in and out of Community ($2M)		**Small Business loan fund ($3M)**	
Solar powered streetlights ($1M)		**Police Post & squad cars ($2M)**	
'Y Pree Wednesdays' Community Dance for next 5 years. ($1M)			

From Science to Decision Making

10.8.3. PARTICIPANT RESPONSES TO INTERACTIVE EXERCISE 3

Participants were separated into groups to govern a fictional town called TanYaVille. The aim of the exercise is to see what the effect of climate change information on investment behaviours for the town. Each group indicates which investment projects they have chosen by placing the monetary equivalent ($1M per sticker) beside their chosen project.

Group responses to the exercise are as follows:

GROUP 1 *Our initial decision was to provide sustainable development to the town through the Small Business Loan Fund so that people can use this to climate-proof their own plans, Fixing drains and filling potholes. So, after having a look at the climate issues facing the town, we kept the Small Business Loan Fund. We figure that people have a good idea of what they need to survive. We did change from fixing drains and filling potholes to Surveillance and mosquito control. The drains are important and fixing the drains does help with mosquito control. Therefore, some of the money from mosquito control may be used to tackle drains.*

GROUP 2 *We decided on Community Centre for Computer Training. For us, the community centre is a multi-purpose facility. So, it can be used as a shelter in event of persons being evacuated from their homes. The training would also help to empower the community members, particularly at-risk youth, and would help them to move into jobs. We also invested in Relocation of coastal roads to sustain access for farmers and fishermen. The relocation of the roads could provide employment to the community members during that period. One member of the group had suggested investing in Small Business Loan Funds as an alternative to government support, allowing for more flexible and community-tailored decision-making.*

GROUP 3 *We first identified access as a base for the community; if there is no access, there is no community. Access to the community will secure its economic base. So, we have invested in the Relocation of Coastal Roads to mitigate against the impacts of sea level rise. This will protect the tourism product, the families, and the small businesses. We also invested in Water Tanks to support greenhouse agriculture and tourism. So, we secured the two basic requirements for the community: water and access. We didn't change after consulting the report.*

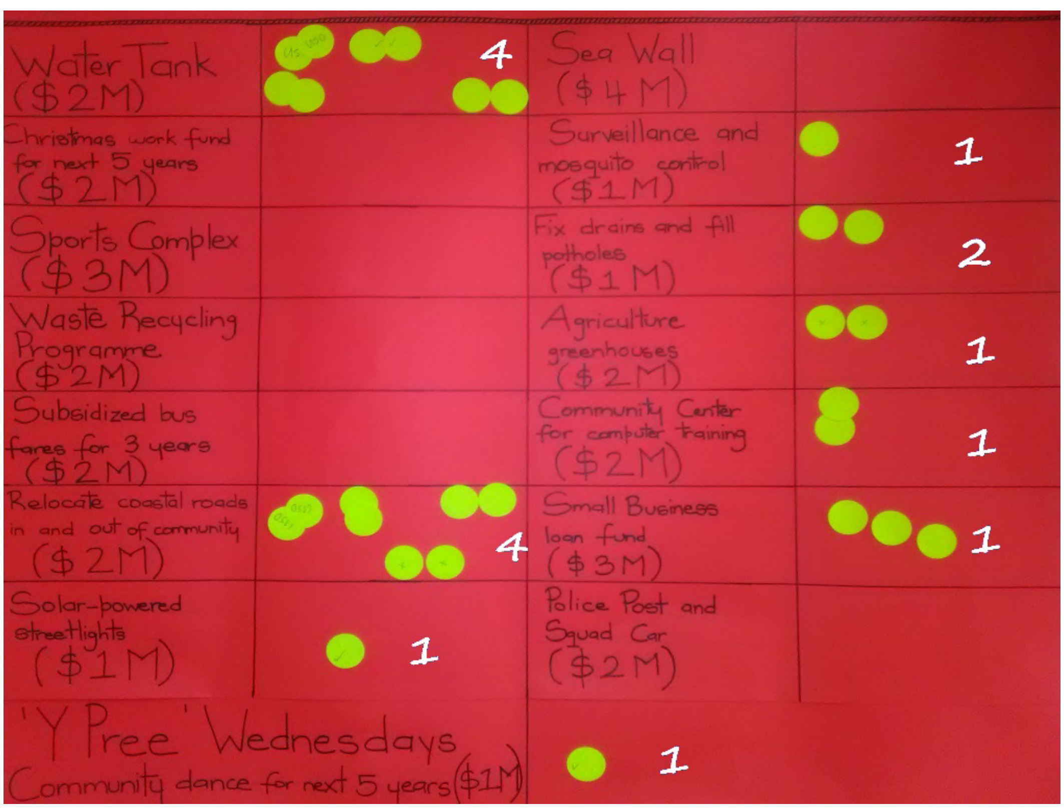
GROUP 4 *First, we looked at the demographic of our community and recognized that we had to provide for the farmers, the fishermen, and the tourism workers. That being the case, we felt that access to the community was critical. So, we invested in the Relocation of Coastal Roads to ensure that there would always be access. And we figure that there might be spin-off benefits for both the ongoing economic growth and ensuring that our citizens are happy and healthy. The second thing we chose at the time was Water Tanks, and that was by consensus. At the time, we were considered that the community was based in one of the drier zones in the island, and that it would make sense to increase our access to and storage of clean and potable water. After putting in the climate considerations, we decided to keep the Relocation of coastal roads because that remains a critical factor for us. We determined, however, that we would shift to solar-powered lights from water tanks. Part of the reason for this shift is that, after consulting the 2015 SOJC Report, we determined that our community sits in Zone 3 which is wetter. So, since we sit in one of the wetter zones, we switched to surveillance and mosquito control to ensure that the citizens remain healthy.*

GROUP 5 *Initially, we discussed our role as the council and made sure not to take on anything that was the responsibility of the central government. So, we did not invest in the Relocation of Coastal Roads. So, we decided based on the role of the council, our community motto (Family, Fun, Fiesta), the type of person living in our community, and the need to reduce our electricity bill and to generate money for the council to do its business, we invested in the Water Tank and Solar-powered Streetlights to contribute to the safety of our community. And to contribute to our community enterprise and invest in income security and* *alternative livelihood, we invested in 'Y Pree' Wednesdays. When we looked at the report, we kept the Water Tank. We sacrificed the Solar-powered streetlights and re-invested in Surveillance and mosquito control. We also decided to use 'Y Pree' Wednesdays as an important vehicle for behavior change.*

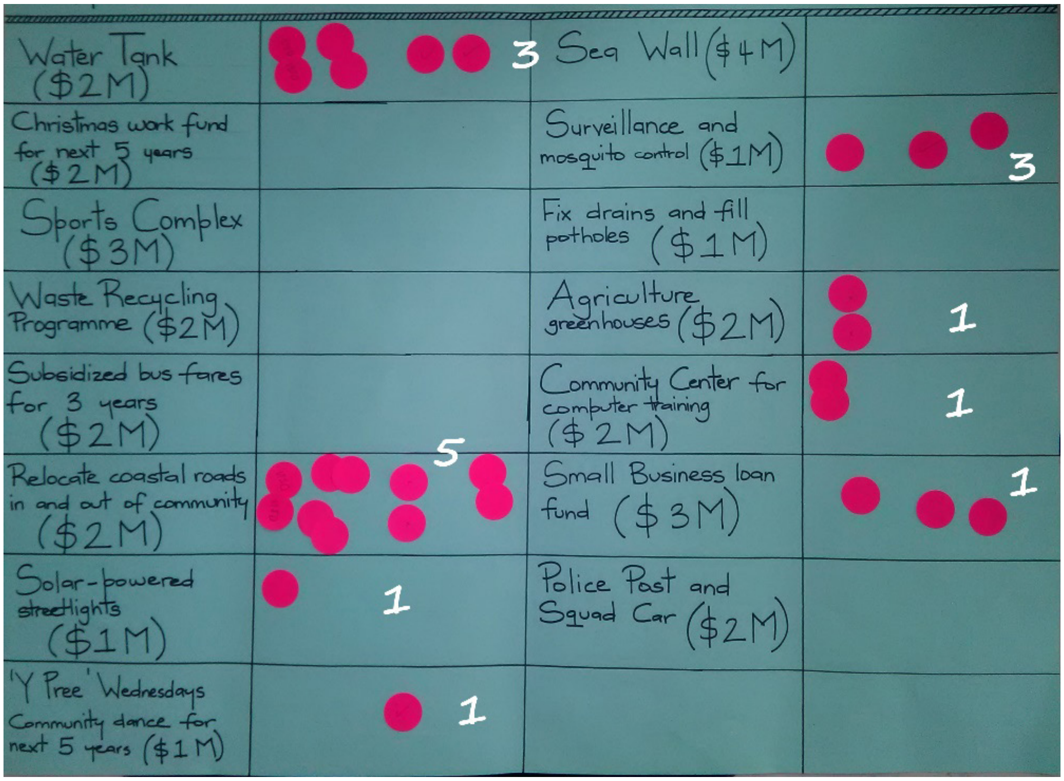
GROUP 6 *We have always been a climate-conscious council. So, we kept in mind our vulnerability to past extremes events. So, we decided to invest in the Relocation of Coastal Roads so that when we invest in our greenhouses, we can have better access to markets. With the variability of rainfall and changes in temperature, we want to have some kind of control. Also, this community relies heavily on farmers, fishermen, and the tourism industry, by investing in greenhouses, we support the community and the local food supply. We made no changes after consulting the report.*

GROUP 7 *At the beginning, we chose to invest in the Water Tank because we realized that we lived in an area with little rainfall. According to the 2015 SOJC report, the climate is projected to become hotter and drier. So, we had to ensure that the residents have water. We also decided to invest in Surveillance and mosquito control and the Fixing of drains and filling potholes. However, after considering climate projections, we decided to re-invest in the Water Tank. We considered investing in Solar-powered streetlights as this would prove important for security. But, we finally settled with the Relocation of Coastal Roads.*

Prof. Taylor pointed out that very often resources are limited and prioritizing is necessary. Having this climate information can either justify your initial decisions or it could result in a new choice, as can be witnessed in the results of Exercise 3 (see figure below). It is also noted that some projects were never touched at all. Some participants thought that a sea wall required much more than any other project and left too little to include any other project. There was also some doubt as to whether or not a sea wall would be effective in curbing vulnerability. Prof. Taylor also pointed out that, in the case of finite resources, decision-making can be difficult and climate isn't the only consideration. However, climate must be one of the considerations.



a)



b)

Figure 55. Charts indicating the investments made each of the seven groups of participants. The number of groups that invest in a particular project are given in white.

The State of the Jamaican Climate 2015

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