[State of the Jamaican Climate 2012]

Information for Resilience Building

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
±	plus or minus
A1B	Scenario generated by the IPCC
A2	Scenario generated by the IPCC
AMO	Atlantic Multidecadal Oscillation
AR4	Fourth Assessment Report
ASO	August-September-October
B1	Scenario generated by the IPCC
CCCCC	Caribbean Community Climate Change Centre
CCRA	The CARIBSAVE Climate Change Risk Atlas
CIF	Climate Investment Fund
CO_2	Carbon Dioxide
CRU	Climatic Research Unit
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DFID	United Kingdom Department for International Development
DJF	December-January-February
ECHAM	ECMWF in HAMburg - Global Climate model
ECHAM4	ECMWF in HAMburg - Global Climate model, version 4
ECLAC	Economic Commission for Latin America and the Caribbean
ECMWF	European Centre for Medium-range Weather Forecasts
ENSO	El Nino - Southern Oscillation
ERA-40	ECMWF 40 Year Reanalysis
FMA	February-March-April
GCM	Global Climate Model
GDP	Gross Domestic Product
GHCN	Global Historical Climatology Network
GHG	Green House Gas
GOJ	Government of Jamaica
HadCM3	Hadley Centre Coupled Model, version 3
HadEX	Extremes dataset created by the Hadley Centre in the United Kingdom
hrs	hours
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate and Society
ITCZ	Inter-Tropical Convergence Zone
JJA	June to August
KAP	Knowledge, Attitude and Practice
km	kilometre

Abbreviation	Meaning
KWH	Kilo Watt Hour
m	meter
m/s	meters per second
MAM	March-April-May
mb	millibar - a unit of atmospheric pressure
MJ/m^2/day	Mega-Joules per meter-squared per day
MJJ	May-July
mm	Millimetres
mm/day	Millimetres per day
mm/year	Millimetres per year
NAH	North Atlantic High
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Agency
NATL	North Atlantic Ocean
NCEP	National Centres for Environmental Prediction
NDJ	November-December-January
NOAA	National Oceanic and Atmospheric Administration
^{o}C	Degrees Celsius
^{o}N	Degrees North of the equator
^{o}W	Degrees West of the Greenwich Meridian
PPCR	Pilot Program for Climate Resilience
ppm	Parts per million
PRECIS	Providing REgional Climates for Impacts Studies
R95pct	Percentage of rainfall greater than or equal to the 95th percentile
RCM	Regional Climate Model
RH	Relative Humidity
RX1day	Maximum 1 day rainfall
RX5day	Maximum 5 day rainfall
SCF	Strategic Climate Fund
SIA	Donald Sangster International Airport
SLR	Sea Level Rise
SNC	Second National Communication
SON	September to November
sq.	Square
SRES	Special Report on Emissions Scenarios
SST	Sea Surface Temperature
T	Temperature
TN10p	Cool Nights - Temperature in the night less than or equal to the 10th percentile
TN90p	Hot Nights - Temperature in the night greater than or equal to the 90th percentile

Abbreviation	Meaning
TX90p	Hot Days - Temperature in the day greater than or equal to the 90th percentile
UNDP CCCP	United Nations Development Programme Climate Change Challenge Programme
UNFCCC	United Nations Framework Convention on Climate Change
UWI	University of the West Indies

EXECUTIVE SUMMARY

The Pilot Program for Climate Resilience (PPCR)

Building adaptive capacity is the aim of The Pilot Program for Climate Resilience (PPCR), which is part of the Strategic Climate Fund (SCF), a multi-donor Trust Fund within the Climate Investment Funds (CIFs). The overall objective of the program is to provide incentives for scaled-up action and transformational change in integrating consideration of climate resilience in national development planning consistent with poverty reduction and sustainable development goals. In May 2009, Jamaica accepted the offer extended by the Sub-Committee of the Pilot Program for Climate Resilience (PPCR) to participate in the PPCR as one of the six countries in the Caribbean regional pilot program. The other five countries are Grenada, St. Vincent, St. Lucia, Dominica, and Haiti. The pilot programmes and projects to be implemented under the PPCR in Jamaica are to be led by the Planning Institute of Jamaica. The first component of the PPCR in Jamaica is a climatological data assessment and the development of projections specific to Jamaica, which forms the basis of the report *State of the Jamaican Climate: Information for Resilience Building*.

The Report

The report is intended to be an initial reference point for a description of Jamaica's climate, its variability and trends and future projections. It is to be used by key sectors and persons who wish to engage in climate change adaptation work with respect to Jamaica and who need to determine the climate state being adapted to. It is also intended to be an initial reference point for persons seeking out other sources of information which document how key sectors for Jamaica may be influenced by climate change.

Chapter 1, the ***Introduction***, outlines the structure and methodology of this first component of the PPCR project. Building on the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007a) and a report of the Caribbean Community Climate Change Centre (Taylor et al, 2007), this report draws on the recent research conducted by the Climate Studies Group Mona (CSGM), as well as other resources such as Jamaica's Second National Communication for reporting purposes to the UNFCCC and CARIBSAVE Climate Change Risk Atlas for Jamaica (CARIBSAVE, 2011). Historical data were collected where available and analysed to produce tables and diagrams representing the current climate of Jamaica, including its trends and variability. Available data from General Circulation Models (GCMs) and Regional Climate Models (RCMs) for Jamaica were collected and analysed to produce tables and diagrams representing the future climate of Jamaica. The last component of the methodology was a review and extraction from other reports on the impact of climate change on water quality and availability, energy supply and distribution, tourism, agriculture and food security, health, marine and terrestrial biodiversity and fisheries, sea level rise and storm surge impacts on coastal infrastructure and settlements, poverty, gender, and development.

Chapter 2 on ***Review of Relevant Literature and Data Availability*** introduces the study location and lists the sources of literature that lay the foundation for historical and projected trends in Caribbean climate. The list is comprehensive but not exhaustive. These include publications on rainfall, temperature and wind, as well as extreme events and sea level rise. Also included is a list of sources from which meteorological data can be obtained. For each dataset, a description is provided for evaluation of potential usefulness to the reader. Much of the data used in the analysis were obtained from the National Meteorological Service of Jamaica whose valuable collaborative contribution is recognized.

Chapter 3 on ***Climatology*** describes the average values of a number of climate variables for Jamaica- temperature, rainfall, radiation, wind and others - as data affords. In most cases island averages are given. In other cases averages for select stations are the best that can be given due to data availability, e.g., the best data come from the two international airports. The ensuing sections present the climatologies for the variables noted above. There is also some discussion of the climatic phenomena that give rise to the climatology, in particular the rainfall pattern. Finally large scale phenomena such as hurricanes are discussed at the end of the chapter.

Temperature and Rainfall

Surface temperature in Jamaica is largely controlled by the variation of solar insolation. The rainfall pattern is bimodal with early rainfall peaking in May and June and late season rainfall peaking in October. The main drivers of the rainfall pattern are the North Atlantic High (NAH) Pressure system, sea surface temperatures, easterly waves, and the trade winds.

For all seasons, the maximum rainfall is located in the parish of Portland, close to the border with St. Thomas. Because of the scarcity of stations in this border region (the Blue Mountains), especially in St. Thomas, the centre of the maximum rainfall should only be taken as approximate. It can be seen however that Portland is the wettest parish, being quite wet even in the dry seasons, November-December-January (NDJ) and February-March-April (FMA).

Other Variables

The data suggests that Jamaica receives an estimated average of 1825 kWH/m^2 per year of direct solar radiation. The south receives marginally more radiation than the north and the far eastern tip of Jamaica receives more than anywhere else. The annual variation suggests that for the given locations radiation peaks around June.

Winds are strongest in Portland and St. Thomas, Manchester and St. Elizabeth. The strongest influence is the prevailing wind from the East or North East.

Data paucity hampers the in depth analysis of other meteorological variables, particularly analysis of their spatial variation. Relative humidity does not vary significantly throughout the year. For morning hours the average humidity at the airport stations is higher and ranges from 72-80%. In the afternoon it is lower (59-65%). Sunshine hours vary little throughout the year, ranging between 7 and 9 hours per day. The average evaporation at Manley International Airport is 7.23 mm/day and 5.50 mm/day at Sangster International Airport.

There appears to have been a lull in hurricane activity near Jamaica between 1952 and 1973 and much increased activity since 2001.

Chapter 4 on ***Observed Climate Variability and Trends*** examines again the climate variables discussed previously for Jamaica, but in terms of their historical variability or long term trend. At the beginning of the chapter the primary drivers of climate variability in Jamaica are discussed. These include the El Niño phenomenon and sea surface temperatures, the North Atlantic Oscillation (NAO), Atlantic Multidecadal Oscillation (AMO) and Caribbean Low Level Jet (CLLJ).

Temperature Trends

There is a warming trend in Jamaican temperature data, evident from data collected at the airport stations. From 1992 to present the trend at the airport stations is approximately 0.1 degrees Celsius/decade. This is less than the all island value quoted in the CARIBSAVE Risk Atlas which indicates a statistically significant annual trend of 0.27 degrees Celsius/decade. CARIBSAVE values show that the annual and seasonal rate of temperature increase ranges from 0.20 – 0.31 °C per decade. They also suggest that observed increases have been most rapid in June-July-August (JJA) (at a rate of 0.31˚C per decade).

It is not only mean temperatures that have been increasing. Data for Jamaica shows that the frequency of very hot days and nights has increased by 6% (an additional 22 days per year) every decade. The frequency of hot nights has increased particularly rapidly in JJA – an increase in frequency of 9.8% or an additional 3 hot nights per month per decade. As for the Caribbean, the frequency of 'cold' nights has decreased at a rate of 4% fewer 'cold' nights i.e. 14 fewer cold nights in every year per decade.

Rainfall

The mean Jamaica rainfall record shows no statistically significant trend. This is not surprising given the large inter-annual variability in rainfall. However if a linear trend is fitted to data from individual stations across Jamaica, areas of increasing rainfall over the 1992-2010 period may be identified over the centre of the island and areas of decreasing rainfall over the eastern and western parishes.

Trends in rainfall extremes have largely been negative (decreasing) over the recent past. On an annual basis statistically significant decreases have been observed in the proportion of total rainfall that occurs in 'heavy' events at a rate of -8.3% per decade over the observed period 1973-2008. There have also been decreases in 1-day and 5-day maxima. These 'trends' should however be interpreted cautiously given the relatively short period over which they are calculated, and the large inter-annual variability in rainfall and its extremes.

Other Variables

Significant increases over the period have been noted in the annual and seasonal values of wind speed around Jamaica in all seasons over the period 1960-2006. The increasing trend in mean annual marine wind speed is 0.26 ms^{-1} per decade.

There is no significant trend in Relative Humidity (RH) over Jamaica. The small trends noted are generally positive and increasing except for the March – May and September – November seasons. The observed number of sunshine hours indicates statistically significant increases in sunshine hours in March-April-May (MAM) and June-July-August (JJA) for Jamaica over recent years (1983-2001). Sea surface temperatures from gridded dataset indicate statistically significant increasing trends in JJA and SON of +0.7˚C per decade in the waters surrounding Jamaica. The mean annual increase is +0.4˚C per decade.

Sea level measurements at Port Royal between 1955 and 1971 also indicate a 0.9 mm/year rising trend

Chapter 5 on ***About Projections*** briefly discusses how projections of future climate are generated. This information is necessary for interpreting the Tables and Figures of the following chapters. Emission scenarios of Greenhouse Gases (GHGs) are used to drive General Circulation Models (GCMs), which simulate the physics and chemistry of the atmosphere and the land-sea interactions that drive climate processes, to produce representations of future climate, generally through the end of the century. GCMs are run by large modeling centres across the globe which have the computational power to do so. The modality is usually to run GCMs over multiple scenarios since every scenario is plausible. This allows for a range of values for the future projected climate. For regions like the Caribbean results are also often taken from an ensemble of GCMs run over one or more scenarios. The biases of any one GCM are therefore minimized in the results presented.

Future emissions of GHGs will depend on multiple factors which may include changes in population, economic growth, energy use and technology. The Special Report on Emissions Scenarios (SRES) represent possible pathways for future GHG emissions premised on different storylines of change in the global development factors noted above (Nakicenovic et al. 2000). The storylines combine two sets of divergent tendencies: one set varying between strong economic values and strong environmental values, the other set between increasing globalization and increasing regionalization. The storylines are summarized as follows (Nakicenovic et al., 2000): A1 storyline and scenario family: a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. A2 storyline and scenario family: a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines. B1: storyline and scenario family: a convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. B2: storyline and scenario family: a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development.

Regional climate models (RCMs) are used to downscale GCM output to obtain higher resolution results. That is, the GCMs do not provide sufficient information at the scale of individual small island states, for example Jamaica, due to their coarse resolution. Though Jamaica would possibly be seen by a GCM it would be represented by at most two grid boxes. Therefore to achieve information at the 'small island scale', Regional Climate Models (RCMs) are used. RCMs are also comprehensive physical models of atmospheric, oceanic and land processes but with higher resolutions (e.g. 50 km or less) and which are run over limited areas using GCM output as boundary conditions.

Uncertainties

Climate models provide credible quantitative estimates of future climate change, particularly at larger scale but some deficiencies remain at smaller scales, stemming largely from the inability of modellers to simulate exactly processes such as cloud physics, radiation and rainfall processes. There will always be a range of uncertainty in climate projections. People doing impact assessments based on climate model projections need to understand and incorporate this uncertainty.

Chapter 6 on ***GCM Projections*** provides projections for the Caribbean and specifically Jamaica from the GCMs. The projections are compiled primarily from three sources:
a) The IPCC AR4 report.

b) The UNDP Climate Change Country Profiles

c) The CARIBSAVE Climate Change Risk Atlas for Jamaica.

Temperature

Jamaica's mean annual temperature is projected to increase across all models in a 15 GCM ensemble and across all scenarios by 1.1 to 3.2 ˚C degrees by the 2090s. The range of increase is 0.7 to 1.8˚C by the 2050s and 1.0-3.0˚C by the 2080s. Projected mean temperatures increase most rapidly over Jamaica in JJA. The frequency of 'hot' Jamaican days and nights should continue to increase, reaching 30-98% of days annually by the 2090s. It is to be noted that the rate of increase varies substantially between models for each scenario. 'Hot' days/nights are projected to increase most rapidly in JJA and SON, occurring on 60 to 100% of days/nights in JJA and SON by the 2080s. 'Cold' days/nights are projected to diminish in frequency, occurring on a maximum of 2% of days/nights by the 2080s. Cold days/nights decrease in frequency most rapidly in JJA.

Rainfall

GCM projections of future rainfall for Jamaica span both overall increases and decreases, but most models project decreases, especially by the end of the century. Projected rainfall changes range from -44% to +18% by the 2050s and -55% to +18% by the 2080s. The overall decrease in annual rainfall is strongly impacted by decreased JJA (early wet season) and SON (late wet season) rainfall. The drying will firmly establish itself somewhere in the middle of the current century. Until then, inter-annual variability will be a strong part of the rainfall pattern i.e. superimposed upon the drying trend. There is a tendency for decreases in rainfall extremes particularly in MAM. By the 2080s the range of changes is -19 to +9% for the proportion of rainfall during heavy events and -29 mm to +25 mm for 5-day maximum rainfall.

Other Variables

The GCM projections generally indicate an increase in mean wind speeds over Jamaica. Changes in annual average wind speeds range between -0.1 and +0.5 ms^{-1} by the 2080s across all models and emission scenarios. The greatest increases occur in MAM and JJA and range between -0.5 and +1.3 ms^{-1} and -0.2 to 1.2 ms^{-1} respectively by the 2080s.

Though relative humidity data is not available for all models in the 15-model ensemble, projections from those models for which the data are available tend towards small increases in relative humidity, particularly in DJF and MAM. Care must be taken in interpreting the relative humidity data since many of the GCMs do not explicitly represent Jamaica and therefore only see ocean. Relative humidity over land and ocean can differ significantly.

Most models project an increase in sunshine hours over Jamaica by the end of the century. This likely reflects reductions in average cloud cover fractions as the country tends towards drier conditions. Under the A2 scenario, the changes in annual average sunshine hours span -0.2 to +0.9 hours per day, with largest increases in JJA (-0.9 to +1.9 hours per day by the 2080s).

GCM projections indicate continuing increases in sea-surface temperatures for the waters surrounding Jamaica. Projected increases range between +0.9˚C and +2.7˚C by the 2080s. Increases tend to be fractionally higher in SON than in other seasons (1.0˚ to 2.9˚C by 2080).

Hurricanes, Storm Surges and Sea Level rise

Several recent studies have indicated that the frequency of storms may decrease in a warmer climate. In several of these studies, intensity of hurricanes still increases despite decreases in frequency (CARIBSAVE Climate Change Risk Atlas – Jamaica (2011)). This is supported by a simulation of current and future Category 3-5 storms based on downscaling of an ensemble mean of 18 global climate change models. The results show a doubling of the frequency of category 4 and 5 storms by the end of the 21st century, despite a decrease in the overall frequency of tropical cyclones (Bender et al., 2010).

"*Changes to the frequency or magnitude of storm surge experienced at coastal locations in Jamaica are likely to occur as a result of the combined effects of: (a) Increased mean sea level in the region …. (b) Changes in storm surge height, or frequency of occurrence, resulting from changes in the severity or frequency of storms. (c) Physical characteristics of the region (bathymetry and topography) …. There is a high degree of uncertainty in projecting potential changes in sea level and hurricane intensity that might be experienced in the region under (global) warming scenarios. This creates difficulties in estimating future changes in storm surge height or frequency."* – CARIBSAVE Climate Change Risk Atlas – Jamaica (2011)

"The IPCC's AR4 report summarised a range of SLR (Sea Level Rise) projections under each of its standard scenarios, for which the combined range spans 0.18-0.59 m by 2100 relative to 1980-1999 levels. These estimates have since been challenged for being too conservative and a number of studies … have provided evidence to suggest that their uncertainty range should include a much larger upper limit… Recent studies that observed acceleration in ice discharge … and observed rates of SLR in response to global warming … suggest that ice sheets respond highly-non linearly to atmospheric warming. We might therefore expect continued acceleration of the large ice sheets resulting in considerably more rapid rates of SLR." (CARIBSAVE Climate Change Risk Atlas – Jamaica (2011))

Chapter 7 on ***RCM Projections*** provide projections for Jamaica from the RCMs. The projections are compiled from two sources:

a) Climate Studies Group, Mona (CSGM) PRECIS analyses

b) The CARIBSAVE Climate Change Risk Atlas for Jamaica.

In both cases the data come from the PRECIS regional model run as a part of the PRECIS-Caribbean Initiative (Taylor et al., 2007). Because of the resolution of the PRECIS model (50 km), data for Jamaica exists for 12 grid boxes located over the island. Figure 7.1.1 (extracted an shown below) shows the grid boxes. This compares to one or at most two grid boxes from the GCMs. The projections are only presented for the end of the century (2080s) and are for the B2 (low) and A2 (high) SRES Emission scenarios. Where a single projection is provided it is an average of the change simulated over all the grid boxes. Otherwise projections are given for each grid box or compared for west to east changes across the island as follows:

a) West- boxes 2, 3, 8, 9

b) Centre- boxes 1, 4, 5, 10, 11

c) East- box 6

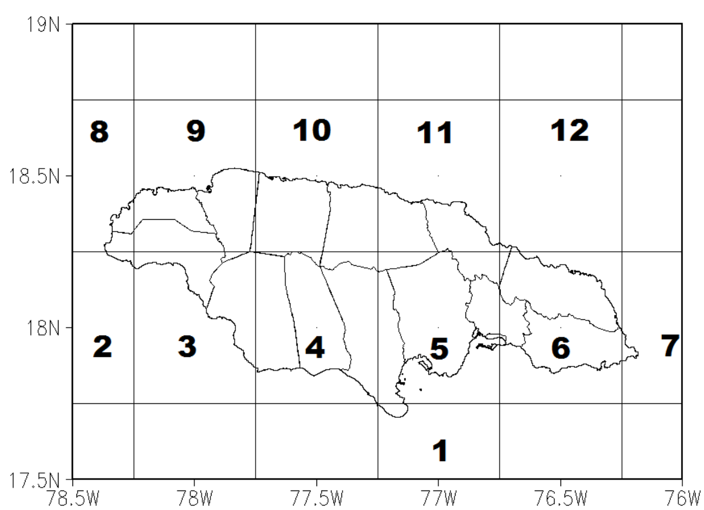

Figure 7.7.1 PRECIS RCM grid box representation at a resolution of 50 Km over Jamaica.

Temperature

The RCM generally indicates much more rapid increases in temperature over Jamaica than any of the models in the GCM ensemble (Chapter 6) when similar scenarios are compared. RCM projections indicate increases of 2.9˚C - 3.4˚C by the 2080s compared with GCM ensemble projections of 2.0-3.0˚C. The increased rate of warming is due to the improved spatial resolution which allows the land mass of Jamaica to be represented. Land surfaces warm more rapidly than the ocean. Grid boxes 3, 4, 5 and 6 experience slighter higher warming than all the others suggesting that southern Jamaica warms faster than northern Jamaica. Greatest warming will occur in JJA (up to 5 degrees warmer than present).

Rainfall

The PRECIS projections of rainfall for Jamaica are strongly influenced by which driving GCM provides boundary conditions. When driven by the ECHAM4 (Max Planck Institute of Meteorology, Germany) GCM, PRECIS projections suggest a moderate decrease in MAM and JJA rainfall, but very little change in total annual rainfall (-14%). When driven by HadCM3 (Hadley Centre, UK), the projections indicate dramatic decreases in annual rainfall (-41%), and more severe decreases in JJA and SON by the 2080s. These HadCM3-driven projections correspond with those that are at the most extreme end of the range of GCM projections. Though the entire island dries out, the most severe drying seems to occur in the west and least severe in Portland. From May onward, irrespective of scenario, it is drying which is projected for the entire island. The months of September through November seem to dry out the most. January through April seem to be least affected. In both scenarios for the HadCM3, rainfall is projected to increase slightly in April.

Temperature and Rainfall Extremes

Very little has been done to analyse changes in the extremes using the RCM. There is, however, work ongoing at the UWI, Mona (CSGM, 2010) which suggest the following:

- Under the A2 scenario the frequency of very hot (cold) nights per year will increase (decrease) across the entire island.
- Under the A2 scenario consecutive wet days appear to decrease (increase) in the western (eastern) grid boxes while very wet days (i.e. intense rain events) increases across the island.

Other Variables – Wind, Relative Humidity and Sunshine Hours

PRECIS projections for change in wind speed lie in the lower end of the range of changes indicated by the GCM ensemble, indicating small decreases in mean wind speed over Jamaica by the 2080s under the A2 scenario. The largest decreases in wind speeds in these models occur in SON at -0.3 to -0.5 ms^{-1}.

RCM simulations indicate decreases in Relative Humidity (RH) over Jamaica in all seasons, with changes in annual average RH of -1.1 to -1.7% by the 2080s under the A2 scenario. The largest decreases in RH occur in JJA.

The HadCM3 driven RCM projections indicate particularly large increases (+1.4 hours per day by 2080s under A2) in mean annual sunshine hours by the end of the century, and that these increases lie beyond the envelope of changes indicated by GCMs.

Putting it all together – GCMs and RCMs

Watson (2007) analysed the projected change in temperature and precipitation for three time slices: 2020s, 2050s and 2080s from 11 realizations of three GCMs and an RCM (Watson, 2010). Representative figures are shown in Chapter 7. The annual range of temperature increase will be smaller for the 2020s (a maximum of 0.9°C), with progressively larger changes through the end of the century i.e. a maximum of 2.0°C by the 2050s and 3.5°C by the 2080s. For rainfall, the overall picture is one of Jamaica initially being slightly wetter than current conditions but then transitioning to a drier state by the end of the century. The model consensus is that the 2020s will be wetter in the mean and across all seasons except MJJ. By the 2050s the country is biased to being drier in the mean though the dry seasons are slightly wetter. It is the magnitude of the drying in the traditional wet seasons that gives rise to the bias. The same sort of pattern also holds for the 2080s. However for the wet seasons there is a more robust picture as there are more models and scenarios projecting it will be drier, while for the dry seasons there is less certainty of its being wetter as it is six versus five projections which suggest wetter conditions.

Chapter 8 on ***Impacts of Climate Change*** explores the sensitivity of multiple sectors and resources to climate variability and extreme events. The contents are extracted from other studies which are listed in the chapter. It points users to possible impacts which climate change can have on the following sectors and areas:

- Water Quality and Availability
- Energy Supply and Distribution
- Agriculture and Food Security
- Human Health
- Marine and Terrestrial Biodiversity and Fisheries
- Storm Surge Impacts on Coastal Infrastructure and Settlements
- Natural Disaster Management
- Tourism
- Community Livelihoods, Gender, Poverty and Development

The results are displayed in the form of tables for each sector along with the list of references used, indicating how they can be obtained.

Chapter 9 on **Next Steps** presents the following recommendations:

1) **Make climate data gathering a priority issue for inclusion in all national climate change related proposals or projects.**
2) **Target investment in the installation and maintenance of automatic weather stations at strategic locations across the island. This includes training in the skill set to keep the stations operational.**
3) **Embark upon a deliberate climate data recovery exercise. The data recovered are to be centrally and securely stored in a national climatic database.**
4) **Human and technical capacity for real time monitoring of climatic variations should be strengthened.**
5) **Enhance research capacities (e.g. at Universities, National Meteorological Service) to undertake climate variability research specific to Jamaica.**
6) **Pursue downscaling of existing modelled data to national and sub-national scales.**
7) **New downscaled future scenarios should be generated premised on the 4 new Representative Concentration Pathways (RCPs) being focussed on by the IPCC.**
8) **Examine by sector, plans for mainstreaming known climate change impacts into developmental plans and/or initiating studies to determine the climate change impact on an understudied sector.**
9) **Disseminate the information in this report widely.**

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1. INTRODUCTION

1.1 RATIONALE AND BACKGROUND

Jamaicans are experiencing changes in variability in rainfall patterns and other climate parameters. While some of these changes are due to natural variability, some are attributable to climate change (Christensen et al., 2007). The Intergovernmental Panel on Climate Change (IPCC) considers inhabitants of small islands, like Jamaica, to be some of the most vulnerable to climate change (Mimura et al., 2007). This is so as climate change will impact their societies, economies and ecosystems in ways that will increase vulnerabilities; for example with regard to food security, water supply, natural disasters, and human health. In fact, the impact of climate variability has already been experienced in some of these areas. Over the last decade alone, damages from intense climatic conditions have cost the Caribbean region in excess of half a trillion US dollars (CARIBSAVE, 2011).

PPCR, Climate and Building Resilience

Some of the projected loss due to climate change can be avoided by adapting now to climate change, thereby making the island more resilient. Following agreements at the UNFCCC Meeting of the Parties in Copenhagen (2009) and Cancun (2010) adaptation funds have become available. The Pilot Program for Climate Resilience (PPCR) is part of the Strategic Climate Fund (SCF), a multi-donor Trust Fund within the Climate Investment Funds (CIFs). The overall objective of the program is to provide incentives for scaled-up action and transformational change in integrating consideration of climate resilience in national development planning consistent with poverty reduction and sustainable development goals (http://www.climatefundsupdate.org/listing/pilot-program-for-climate-resilience). The PPCR was approved in November 2008 to specifically pilot and demonstrate ways in which climate risk and resilience may be integrated into core development policies, planning and implementation. The intention is to provide incentives for the scaling up of climate resilient actions, building on other ongoing initiatives and the initiation of transformational change.

In May 2009, Jamaica accepted the offer extended by the Sub-Committee of the Pilot Program for Climate Resilience (PPCR) to participate in the PPCR as one of the six countries in the Caribbean regional pilot program. The other five countries are Grenada, St. Vincent, St. Lucia, Dominica, and Haiti. The pilot programmes and projects to be implemented under the PPCR in Jamaica are to be led by the Planning Institute of Jamaica, a statutory body within the Office of the Prime Minister, and should build on the Hazard Risk Reduction and Climate Change Adaptation component of Vision 2030 Jamaica - the National Development Plan; the Jamaica National Climate Change Policy and Action Plan which is being finalized by the Office of the Prime Minister; and the Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC).

The Jamaica PPCR activities consist of the following components:

a) A climatological data assessment and the development of projections specific to Jamaica.
b) The establishment of an integrated, automated platform for climate data.
c) A review of development policies, regulations & plans for their inclusion of climate change information.
d) A review of institutional capacity and development needs.
e) A Knowledge, Attitude & Practice (KAP) Survey and the development of a Communication Strategy
f) The development of Climate Resilience Public Awareness Initiatives
g) The Development of a Strategic Programme for Climate Resilience using the output of actions a) through f) above.

1.2 About this Document

This document has been developed in response to PPCR component a) noted above. The task was to provide *(i) a comprehensive assessment of local weather and climatological data to ascertain the current knowledge with respect to climate norms and trends, and recent changes which have, or will yield climate change impacts and (ii) to present the results of modelling exercises using such data to make more realistic projections on the likely future climate over the medium to long term for the island; particularly bearing in mind the goal of changing the country's development status*. A well-reasoned evidence based strategic program for climate resilience for Jamaica, it is felt, is conditioned upon such an assessment of the country's climate variability and change.

It is not that documents do not exist outlining climate norms and trends for Jamaica or even climate change projections. There are a number of institutions doing good work and the necessary work and research to compile such data, key among them being the Meteorological Service of Jamaica. The Meteorological Service produced Jamaica's ***Second National Communication*** for reporting purposes to the UNFCCC, which has some of this kind of assessment. A second useful document is the ***CARIBSAVE Climate Change Risk Atlas for Jamaica*** (CARIBSAVE, 2011) and there are a growing number of journal articles emerging out of the University of the West Indies, Mona examining the dynamics of Caribbean (and by extension Jamaican) climate variability and (more recently) climate change.

Notwithstanding, journal articles are not as accessible for the non-academic community and there is no single document that attempts both an assessment and summary of the knowledge of the state of Jamaica's current and future climate which can be consulted as a first call of reference. In particular, with reference to the future projections, there are new regional efforts underway to generate climate change projections for Caribbean nations using regional climate models that capture the scale of the small islands of the region. The data from these models coupled with data from Global Climate Models previously available, are yet to be compiled in a single document specifically for Jamaica, which would provide for a quick overview of what is known and also make available a summary of the data for easy reference. This document attempts to do just that.

This document, then, is intended to:

a) Provide a simple overview of the state of Jamaica's climate, including a description of driving forces, climatology and historical trends.
b) Provide tables and figures summarizing future projections of Jamaica's climate under global warming using available data from global and regional climate models.
c) Be an initial reference point for key sectors and persons who wish to engage in climate change adaptation work with respect to Jamaica and who need to determine the climate state being adapted to.
d) Be an initial reference point for persons seeking out other sources of information which document how key sectors for Jamaica may be influenced by climate change.
e) Provide a representative listing of data sources, including journal articles and raw data, for those interested in finding more details about Jamaica's climate and how it is varying or will change.

What this document is not purporting to do is be the only reference point for persons interested in climate change data for Jamaica. It is merely a summary of what is known, and more importantly points to where further information can be found. It is, however, a good first reference, which may prove adequate for most users.

1.3 Structure of the Document

This report is structured as follows:

	Title	Summary
Chapter 1	Introduction	Provides the rationale and describes the structure of the document.
Chapter 2	Data and Resources	A listing of the literature used in ascertaining the current knowledge and the local weather and climatology data used in the analysis.
Chapter 3	Historical Climatology	An analysis of climate norms for a variety of climate variables as compiled from a variety of data sources.
Chapter 4	Variability and Trends	Describing the processes driving variability and an analysis of trends in available climate data for Jamaica.
Chapter 5	Modelling Overview	All about climate projection methodology from models and their reliability
Chapter 6	Projections – GCMs	Projections based on global climate models (GCMs).
Chapter 7	Projections – RCMs	Projections based on regional climate models (RCMs).
Chapter 8	Possible Impacts	A listing of some of the impacts of climate change on select sectors and areas
Chapter 9	Workshop report	A review of the stakeholder workshop.
Chapter 10	Next Steps	Next steps.

We note that the IPCC 4th Assessment report (Christensen et al., 2007) points out the inadequacy of the General Circulation Models (GCMs) used in their study of climate change in the Caribbean. For the purposes of this project, therefore, both GCM and RCM projections are given. An important distinction is that, whereas for the GCM the projections are for the country as a whole (one data point), the RCM provides data for up to 12 grid boxes located over the island. This allows for more detailed country projections taking into account spatial variation.

To point users of this report to the possible impacts of future climate change, this report includes extracts from other reports on the impact of climate change on the following sectors and areas: water quality and availability, energy supply and distribution, tourism, agriculture and food security, health, marine and terrestrial biodiversity and fisheries, sea level rise and storm surge impacts on coastal infrastructure and settlements, poverty, gender, and development. These are listed in Chapter 8 on Possible Impacts.

Chapter 9 is based on feedback received from a stakeholder workshop held in advance of the final production of this document. Chapter 10 provides a summary and recommendation of Next Steps.

1.4 Methodology

In developing this document the following methodology was followed:

- Historical data were collected where available and analysed to produce tables and diagrams representing the current climate of Jamaica. These include tables and diagrams of temperature, rainfall, relative humidity, solar radiation, sunshine hours, wind strength, sea level rise and hurricanes.
- A review of authoritative works on climate variability was done in order to examine the state of knowledge about the drivers of Jamaican climate and its variability.
- Available GCM and RCM data for Jamaica were collected and analysed to produce tables and diagrams representing the future climate of Jamaica. This was done for variables such as temperature, rainfall, relative humidity, solar radiation, sunshine hours, wind strength, sea level rise and, hurricanes.
- A review of authoritative works on climate change was done in order to examine the state of the knowledge about climate change for Jamaican climate. These included studies by the IPCC; Caribbean Community Climate Change Centre; and Climate Studies Group, Mona, UWI.
- A review and extraction from other reports on the impact of climate change on water quality and availability, energy supply and distribution, tourism, agriculture and food security, health, marine and terrestrial biodiversity and fisheries, sea level rise and storm surge impacts on coastal infrastructure and settlements, poverty, gender, and development.

- A compilation of relevant citations and datasets related to climate change and variability for the Caribbean and Jamaica.

1.5 A Final Note

Whereas this document was compiled to fulfil the requirements of the PPCR project, it is hoped that it will serve as a useful reference for a variety of users seeking climate variability and climate change information for Jamaica. As such, care was taken in compiling the information and data, tables and diagrams, and in making sufficient references and including references at the end of each chapter to enhance the document usability for all such persons. We sincerely hope it will prove useful for all.

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2. REVIEW OF RELEVANT LITERATURE AND DATA AVAILABILITY

2.1 ABOUT THE CHAPTER

This chapter introduces the study location. Thereafter it serves as an introduction to sources of literature that lay the foundation for historical and projected trends in Caribbean climate. The list is comprehensive but not exhaustive. These include publications on rainfall, temperature and wind, as well as extreme events and sea level rise. Also included is a list of sources from which meteorological data can be obtained. For each dataset, a description is provided for evaluation of potential usefulness to the reader.

2.2 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^{o}15' N and longitude 77^{o}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). – *Information extracted from Jamaica's Initial National Communication to the United Nations Framework Convention on Climate Change*

Figure 2.2.1: Map of Jamaica. Inset shows Jamaica's location in the Caribbean Sea.

2.3 Literature Listing

2.3.1 Historical Changes

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2.4 Data Sources

Table 2.4.1: Examples of sources of projected and observed meteorological data.

DATA SET	SOURCE	DESCRIPTION
A. A. Chen solar radiation data for Jamaica	Chen et al. 1994	Solar radiation station data interpolated for the island (map available in hardcopy).
CRU	http://www.cru.uea.ac.uk/cru/data/	Multiple station, gridded and modelled datasets covering a range of climatic variables. Datasets are monitored by multiple groups within the Climatic Research Unit (CRU), and so are not all readily available.
IRI	http://iridl.ldeo.columbia.edu/	A collection of atmospheric datasets from multiple sources. Offers data free of cost and visualisation options.
Local station data	Meteorological Services	Meteorological service can provide site specific observed data over time from weather stations upon request.
NASA Satellite Data e.g. TRMM	http://www.nasa.gov/ TRMM: http://trmm.gsfc.nasa.gov/	Global satellite observations of atmospheric variables not restricted to rainfall and temperature. Data are also often accompanied by maps and other visualisation aids.
NOAA e.g. NCEP, GHCN	http://www.noaa.gov/ GHCN: http://www.ncdc.noaa.gov/ghcnm/	Datasets developed for multiple meteorological variables from model simulations and station data from which inhomogeneities have been removed. Data are continuously updated.
PRECIS Caribe	http://precis.insmet.cu/eng/Precis-Caribe.htm	Output from the PRECIS RCM run for the Caribbean domain carried out by the Cuban Meteorological Institute (INSMET). Modelling was done for 1961-90 and 2071-2100 time slices using SRES A2 Greenhouse Gas emission scenario.
UNDPCCCP	http://www.geog.ox.ac.uk/research/climate/projects/undp-cp/	Modelled country specific GCM data for baseline and future. Data are provided for temperature and precipitation from approximately 15 models that use SRES Greenhouse Gas emission scenarios. Datasets are accompanied by analyses.

3. CLIMATOLOGY

3.1 ABOUT THIS CHAPTER

Climatology refers to the average behaviour of the weather. Climatologies can be expressed for varying time periods e.g. months to seasons, annual and decadal cycles, but are most often expressed in terms of the annual cycle. Averages are therefore calculated for each month of the year, ideally from data spanning 30 years or more. However, as is the case for Jamaica, for some variables, the lack of quality data means that shorter data spans are sometimes used. The climatology is important because it establishes the baseline upon which projected future change is added to produce a future climate scenario. Climatology is also indicative of the 'mean' against which we judge variations.

In this chapter we describe for Jamaica the average values of a number of climate variables - temperature, rainfall, radiation, wind and others - as data affords. In most cases, island averages are given. In other cases, averages for select stations are the best than can be given due to data availability, e.g. best data come from the two international airports. The ensuing sections present the climatologies for the variables noted above. There is also some discussion of the climatic phenomena that give rise to the climatology, in particular the rainfall pattern. Finally, we also discuss large scale phenomena (such as hurricanes) at the end of the chapter.

3.2 TEMPERATURE

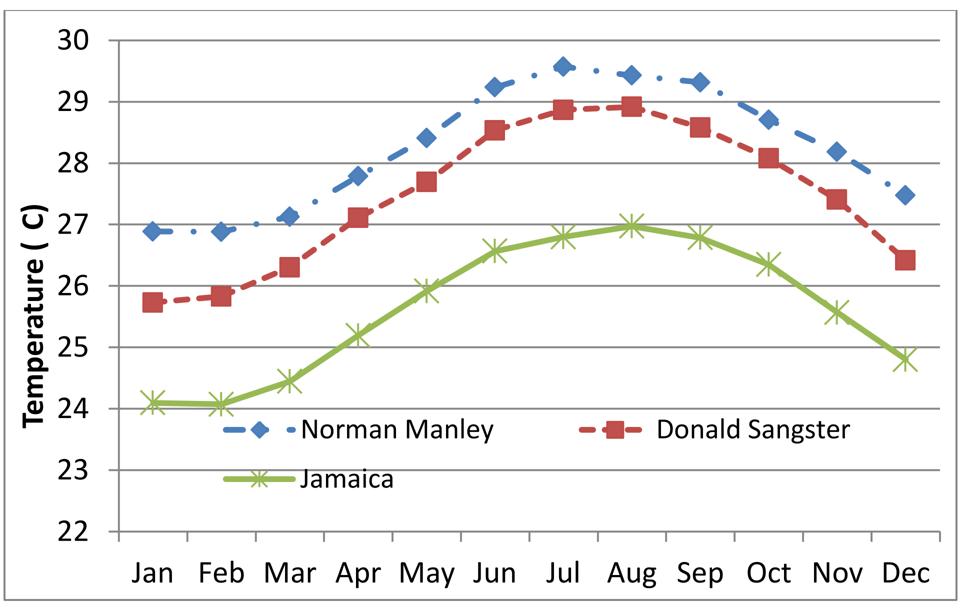

Figure 3.2.1: Temperature climatology (1992-2008) of Jamaica (green), Norman Manley International Airport (blue) and Donald Sangster International Airport (red). Data source: Meteorological Service of Jamaica.

Surface temperature in Jamaica is controlled largely by the variation in solar insolation, i.e. the earth orbits the sun (with its axis tilted at a nearly fixed angle of 23.5º to the plane of its orbit) and this gives rise to variations in temperatures. Table 3.2.1 gives the average monthly variation in temperature for selected stations in Jamaica from 1992 to 2008. Figure 3.2.1 plots the average variation for Jamaica when all the stations in Table 3.2.1 are considered and the variation for the two airport stations.

The general pattern is one of cooler months in northern hemisphere winter and warmer months in summer, with temperatures peaking in July-August. The mean annual range between coolest and warmest months is small (approximately 3 degrees) irrespective of station examined. At the airport stations, mean temperatures generally range between 25 and 29 degrees Celsius. There is some spatial variation in mean temperatures across the island as indicated by Table 3.2.1, with proximity to the coast and/or elevation being two important factors.

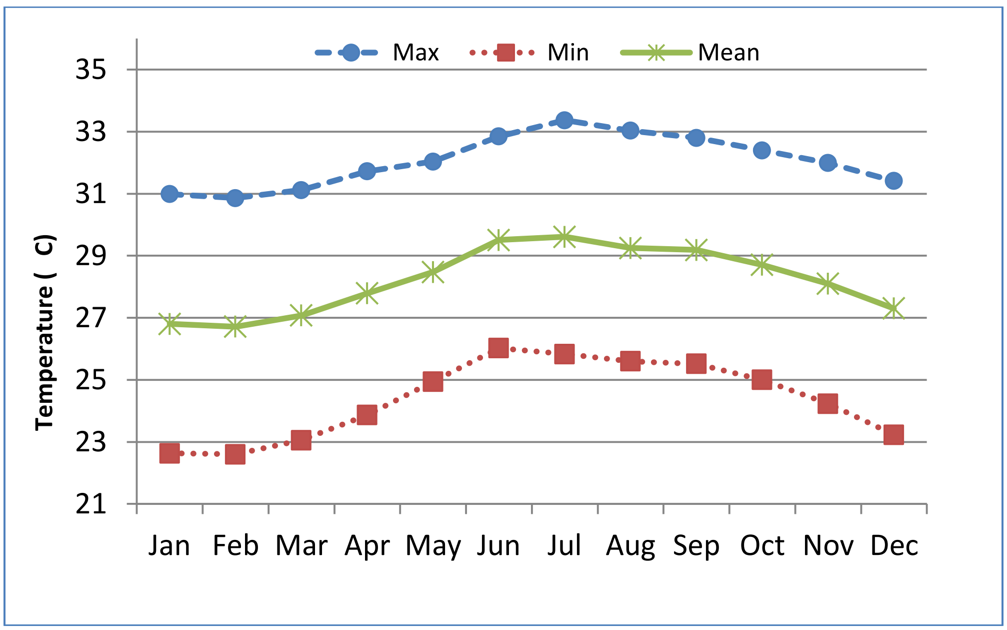

Figure 3.2.2: Mean, minimum and maximum temperature climatology (1992-2002) for Norman Manley International Airport. Data source: Meteorological Service of Jamaica.

Figure 3.2.2 gives the average minimum (night time), mean and maximum (daytime) temperatures for the Norman Manley airport as calculated from 10 years of data (1992-2002). For this station, mean maximum (minimum) temperatures can reach up to 34 (26) degrees Celsius in July (June). In the dataset some months in the early part of the year achieve a mean minimum value of as low as 17 degrees Celsius. The difference between mean maximum and minimum is fairly constant throughout the year.

Table 3.2.1: Monthly and annual temperature climatology for 11 stations in Jamaica from 1992 to 2008. Data source: Meteorological Service of Jamaica.

Station	Parish	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Annual*
Bodles	St. Catherine	25.4	25.0	25.3	26.2	26.9	27.5	27.8	27.8	28.0	27.1	26.4	25.7	26.6
Case	Portland	24.7	24.6	25.2	25.8	26.5	27.3	27.5	27.5	27.3	26.8	26.0	25.4	26.2
Discovery Bay	St. Ann	24.9	25.0	25.1	26.0	26.6	27.3	26.6	27.8	27.8	27.4	26.4	25.6	26.4
Sangster	Montego Bay	25.7	25.8	26.3	27.1	27.7	28.5	28.9	28.9	28.6	28.1	27.4	26.4	27.5
Duckenfield	St. Thomas	24.8	24.9	25.2	26.0	26.8	27.6	27.8	27.6	27.2	26.7	26.4	25.6	26.4
Frome	Westmoreland	25.0	24.8	25.2	26.1	26.8	27.4	27.6	27.9	27.7	27.4	26.6	25.7	26.5
Hampshire	Trelawny	23.2	22.9	23.1	23.5	24.5	24.9	25.5	25.9	25.5	25.2	24.4	23.7	24.3
Mason River	Clarendon	20.4	20.3	20.8	21.5	22.1	22.8	23.1	23.2	22.8	22.7	22.2	21.5	21.9
Manley	Kingston	26.9	26.9	27.1	27.8	28.4	29.2	29.6	29.4	29.3	28.7	28.2	27.5	28.3
Orange River	St. Mary	22.0	22.5	22.8	23.6	24.4	24.8	25.3	25.4	25.2	24.9	23.7	22.9	24.0
Worthy Park	St. Catherine	22.1	22.1	22.7	23.6	24.4	24.9	25.2	25.3	25.2	24.8	23.6	22.9	23.9

3.3 RAINFALL

Bimodal Pattern

Jamaica's rainfall has a bimodal pattern with an early rainfall season centred in May and a late rainfall season centred in October, as shown in Figure 3.3.1. The early rainfall season is shorter (May-July) and generally receives less rainfall than the later season which, spans August through November. Approximately 70% of total annual rainfall received by Jamaica falls between May and November, and approximately 40% falls between August and November (the late wet season). The late season also coincides with the peak in Atlantic hurricane activity (see final section). There is a brief drier period in July which separates the early and late wet seasons, which is often referred to as the midsummer drought (MSD). It is a feature of a number of the Caribbean islands particularly in the north western part of the basin, though its relative timing may differ for each island. Mean rain days vary from 60 to 200 days annually. The dry season runs from December through March, with March being the driest month of the year.

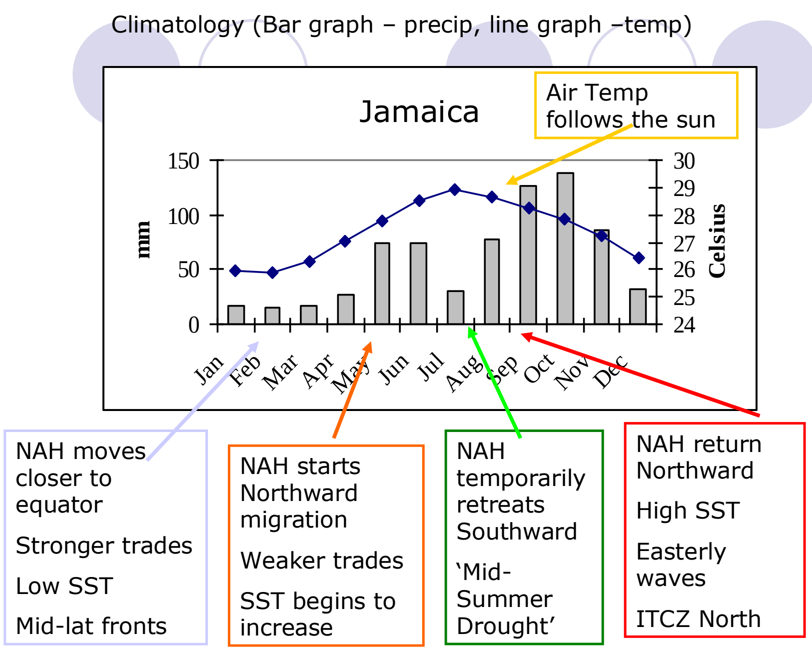

Figure 3.3.1: Rainfall (bar) and temperature (line) climatologies for Jamaica.

Why?

Jamaica's bimodal rainfall pattern is what has largely become the defining feature of Jamaica's climate, and many activities in the country (e.g. planting cycles, water security measures, etc.) revolve around this pattern. For this reason, we consider very briefly the dominant features that give rise to the pattern. It will be changes in some of these features under global warming that will determine/influence the future climate of Jamaica.

The rainfall pattern 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 (Figure 3.3.2). 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 generally is at its driest during the winter. Precipitation during this period is generally due to the passage of mid-latitude cold fronts.

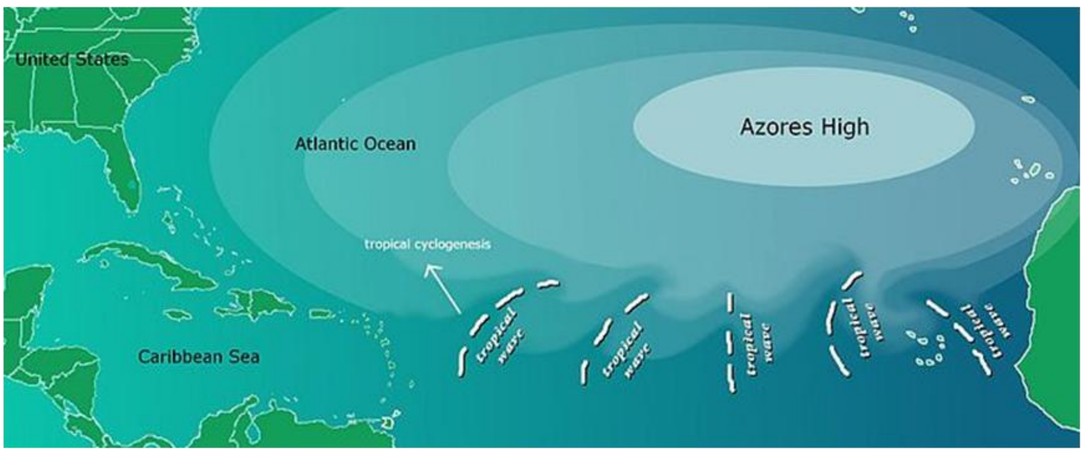

Figure 3.3.2: The semi-permanent North Atlantic High Pressure located south of the Azores, also known as the Azores High. (Source: http://en.wikipedia.org/wiki/Azores_High)

With the onset of boreal spring, the NAH moves northward, the trade wind intensity decreases, the Caribbean Sea becomes warmer and the southern flank of the NAH becomes convergent (Taylor and Alfaro, 2005). The primary source of rainfall from June to November is the passage of easterly tropical waves which traverse the Atlantic Ocean from the west coast of Africa to the Caribbean (Figure 3.3.2). The waves are themselves a source of convection and can develop into depressions, storms and hurricanes under conducive conditions. Around July, a temporary retreat of the NAH equatorward is associated with 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. When the NAH treks south again at the end of the year, it marks the onset of the dry season. We sum up the dynamical processes and the relative period of their greatest influence in the boxes of Figure 3.3.1.

Spatial Variations

There is significant spatial variability in rainfall across the country – meaning not everywhere receives the same amount of rain. It is generally known that northeastern Jamaica receives the highest annual rainfall, while parts of the southern coastal plains tend to be much drier. This is reflected in Table 3.3.1, which gives the average rainfall per parish calculated for the period 1951-1980. It is also to be noted that Portland generally receives significant rainfall, even in the traditional dry months.

Table 3.3.1: Mean monthly rainfall received per parish (mm). Mean calculated by averaging all stations in the parish. Mean is for 1951-1980. Source: Meteorological Service Jamaica.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Hanover	88	91	87	146	294	309	237	275	264	291	133	87
Westmoreland	64	70	91	164	302	262	261	275	245	290	122	70
Manchester	60	52	85	134	237	175	102	169	213	291	118	70
St. Elizabeth	69	60	84	182	243	163	145	204	211	273	133	71
Clarendon	54	39	58	93	191	149	97	119	180	257	104	67
St. Catherine	53	50	57	91	171	139	108	138	174	238	121	88
Trelawney	99	76	69	115	181	130	96	154	166	222	167	131
St. James	91	77	62	111	223	203	145	182	202	253	138	104
St. Ann	145	90	78	117	164	115	50	97	130	177	214	219
St. Mary	181	129	106	148	175	122	81	116	110	209	263	268
Portland	321	236	185	273	321	278	231	245	273	373	477	457
St. Thomas	121	91	65	120	251	219	150	213	281	368	232	177
K&SA	53	49	56	103	180	123	50	168	215	287	187	112
Jamaica	108	85	83	138	226	184	135	181	205	271	185	148

To try to illustrate the spatial variation, we use a statistical technique called Kriging to interpolate rainfall station data to fixed grid points and then contour the gridded data to show variations of average rainfall over Jamaica. This is possible for rainfall (as opposed to temperature) because of the significantly larger number of station data points. Figure 3.3.3 shows the patterns of average annual rainfall and of rainfall from November to January (NDJ), February to April (FMA), May to July (MJJ) and August to October (ASO) calculated using data from 1992-2010. For all seasons, the maximum rainfall is located in the parish of Portland, as expected, close to the border with St. Thomas. Because of the scarcity of stations in this border region (the Blue Mountains), especially in St. Thomas, the centre of maximum rainfall should only be taken as approximate. It can be seen, however, that Portland is the wettest parish, being quite wet even in the dry seasons, NDJ and FMA. There are other interesting features, including regions of drying that requires further investigation.

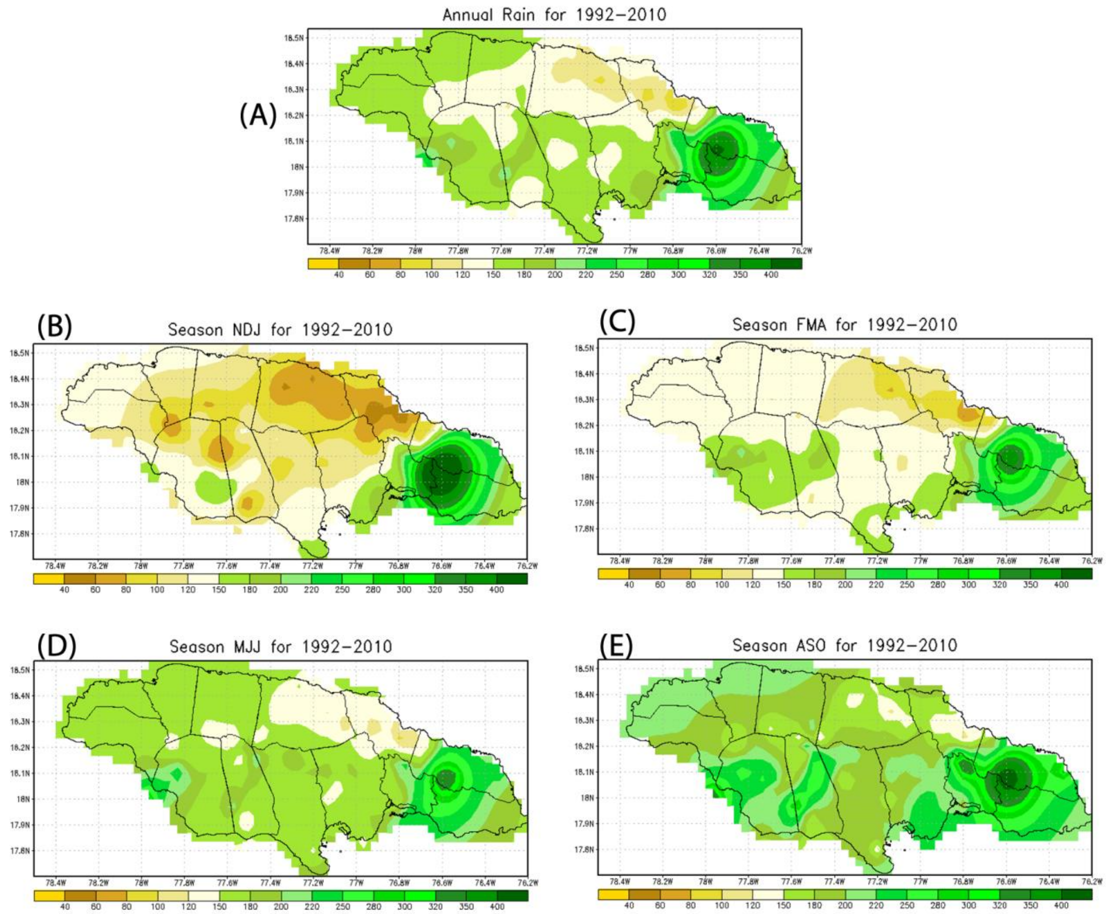

Figure 3.3.3: Map of rainfall means over Jamaica for (A) Annual, (B) November-December-January (C) February-March-April (D) May-June-July and (E) August-September-October.

It is also possible to deduce the dominant patterns in rainfall distribution over the island and to determine regions that co-vary. One of the methods that may be used is called Principal Component Analysis. Figure 3.3.4 shows the two dominant patterns in annual rainfall over the island. The pattern in (A) explains 72.3% of rainfall variability and shows that, in the annual, there is a dominant component in which rainfall varies fairly uniformly over the entire island. Graph (C) allows us to see that such a pattern is subject to significant inter-annual (year-to-year) variability (see the following chapter) and was (for example) very strong in 1975 (negative and dry) and 1981 (positive and wet). The pattern in (B) explains 20.7% of annual rainfall distribution over the island and represents distributions in which rainfall over the centre of the island has characteristics opposite to the eastern and western portions of the island. Graph (C) allows us to see that such a pattern has a strong decadal variation (see the following section) and was very strong, but oppositely signed in 1985 and 1995. There is need to investigate further the predominant global features that influence these two modes.

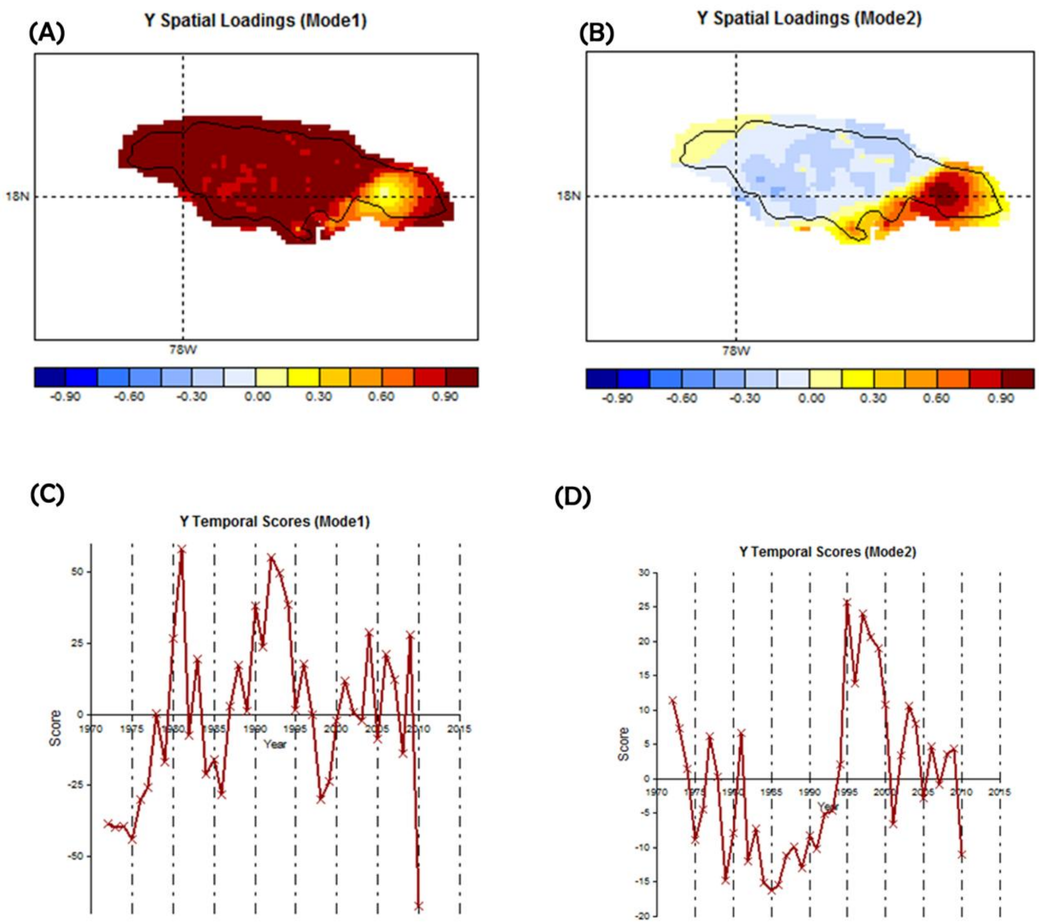

Figure 3.3.4: Two dominant patterns of rainfall distribution over Jamaica deduced from annual values using principal component analysis. The patterns shown in (A) and (B) explain 72.3% and 20.9% respectively of the overall annual rainfall pattern over Jamaica. Plots (C) and (D) shows how strongly patterns (A) and (B) respectively manifest each year since 1971. Source: Research done by Climate Studies Group, Mona 2012.

3.4 OTHER VARIABLES

3.4.1 SOLAR RADIATION

Total or global solar radiation incident in Jamaica is available from a Solar Radiation Map of Jamaica prepared by the Department of Physics, The University of the West Indies, Mona in

1994. The map is based on pyranometer data recorded by the Meteorological Service of Jamaica and the Department of Physics at 12 stations in Jamaica for one year. The interpolation technique is described by Chen et al. (1994). The mean daily global radiation values recorded at the 12 stations are given in Table 3.4.1. A version of the map (using a not too dissimilar interpolation technique) is shown in Figure 3.4.1 for annual mean global radiation. The data suggests that Jamaica receives an estimated average of 1825 kWH/m^2 per year of direct solar radiation. The south receives marginally more radiation than the north and the far eastern tip of Jamaica receives more than anywhere else. The annual variation suggests that, for the given locations (Table 3.4.1), radiation peaks in May-June.

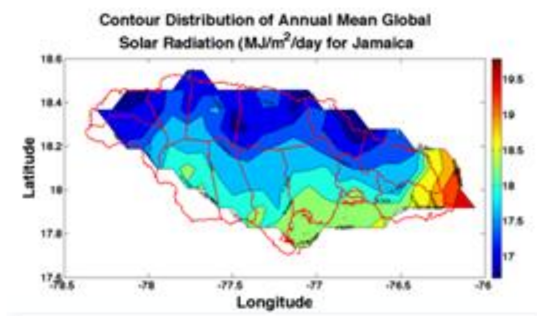

Figure 3.4.1: Distribution of annual mean global solar radiation in MJ/m2/day. Source: Alternative Energy Research Group, UWI (2012).

Table 3.4.1: 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.

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.											

3.5 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 wind from the East or North East. They are more commonly known as the Trade Winds and are associated with the NAH discussed in Section 3.3. In the mean, wind strengths vary inversely with rainfall, i.e. during the driest months (when the island is under the influence of the NAH e.g. January-April and July) wind speeds are largest, while during the wettest months wind speeds are smaller. This does not preclude very large wind speeds occurring when a tropical system is passing near or over Jamaica.

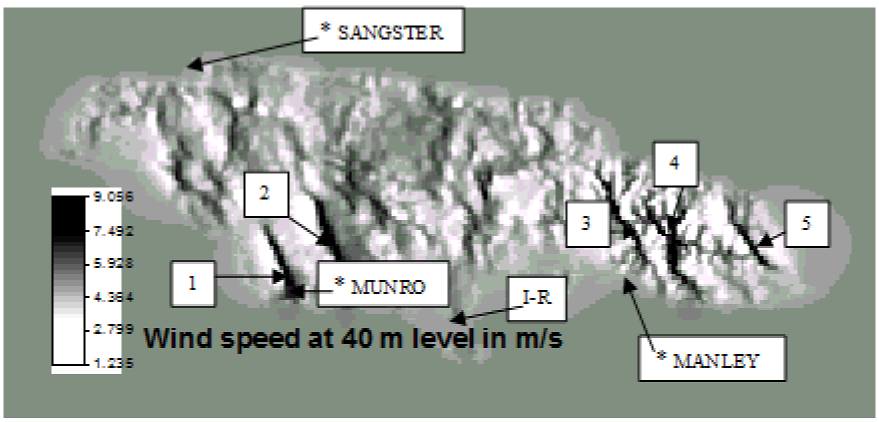

Figure 3.5.1: Modelled wind speed over Jamaica based on data collected at Manley and Sangster Airports and at Munro. Wind speeds at 40 m level are given in m/s on a gray scale (see insert). Best winds are located in St. Elizabeth (1), Manchester (2), South east of St. Mary, South west of Portland, North east of St. Andrew (3), Portland & St. Thomas (4) and East Portland (5). Areas suitable for irrigation by wind energy are located in Clarendon (I-R) (Amarakoon and Chen, 2001 & 2002).

Using wind measurements at Manley and Sangster International Airports and Munro College and WindMap software, a grey scaled contour map of wind speeds at 40 meters above the surface was developed for Jamaica (Amarakoon and Chen, 2001 and 2002). It is shown in Figure 3.5.1. Winds are strongest in Portland and St. Thomas, Manchester and St. Elizabeth. As part of a wind mapping campaign, the wind power at several locations was also determined (Chen et al., 1990) and these values are shown in Figure 3.5.2. Several wind mapping exercises have been conducted since then, but these are the only ones open to the public.

WIND ASSESSMENT SITES IN JAMAICA AND AVERAGE WIND POWER AT EACH SITE IN W/sq.m (first number in brackets). The second number in brackets gives the equivalent number of years of data.

Figure 3.5.2: Wind Power at 20 m above surface for anemometer stations given in units of Watts/sq. meter and the number of years of measurement (first and second numbers in brackets respectively). Data source: Chen et al. (1990).

3.6 Relative Humidity, Sunshine hours and Evaporation

Data paucity hampers the in depth analysis of other meteorological variables, particularly analysis of their spatial variation. Notwithstanding, values for Percentage Relative Humidity, Sunshine Hours, and Evaporation for the Norman Manley and Sangster International Airports are given in Table 3.6.1.

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, i.e. 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 (Meteorological Service 2000).

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

Table 3.6.1: Mean monthly and annual observed values for Relative Humidity, Sunshine Hours, Evaporation (mm/day) and Sea Level Rise for the Norman Manley and Sangster International Airports. All observations except Relative Humidity for SIA are for the time period 1992 – 2008.

	Norman Manley International Airport			
	Relative Humidity (%)		**Evaporation**	**Sunshine Hours (hrs)**
	7am	**1pm**		
January	76.94	60.31	5.92	8.37
February	76.50	60.69	6.75	8.75
March	75.50	61.13	7.59	8.65
April	72.87	61.47	7.96	9.10
May	73.40	64.67	7.76	8.03
June	72.08	63.08	8.53	7.94
July	71.93	61.73	8.47	8.13
August	73.73	64.93	7.85	7.90
September	75.33	65.93	6.98	7.36
October	77.31	66.88	6.99	7.49
November	77.07	63.75	6.03	7.87
December	77.63	61.19	5.89	7.94
Annual	75.02	62.98	7.23	8.13
Sangster International Airport				
January	80.45	62.94	4.29	7.75
February	79.64	59.88	5.00	8.48
March	78.36	60.52	5.89	8.52
April	77.36	59.51	6.46	9.10
May	79.09	66.99	6.31	8.11
June	75.82	59.92	6.51	8.27
July	76.00	58.82	6.78	8.71
August	77.27	59.81	6.19	8.00
September	78.45	59.93	5.09	7.27
October	81.27	63.52	4.83	7.40
November	82.00	63.28	4.58	7.59
December	82.00	62.79	4.10	7.48
Annual	78.98	61.50	5.50	8.06

3.7 HURRICANES

Easterly waves, mentioned in Section 3.3, frequently mature into storms and hurricanes under warm sea surface temperatures and low vertical wind shear generally within a 10ºN-20ºN latitudinal band referred to as the 'main development region'. The cumulative number of Atlantic systems per year, averaged over the period 1966-2009, is shown in Figure 3.7.1. The systems are differentiated according to named system (storms or hurricanes), all hurricanes and hurricanes of category 3 or greater. Figure 3.7.2 shows the tracks of all major hurricanes (category 3 or greater) that have traversed the Atlantic Ocean from 1851 to 2010.

Table 3.7.1 give the dates, wind speeds, category and names of hurricanes that came within 69 miles of Kingston or Montego Bay between the years 1852 and 2011. As can be seen, hurricane frequency is not uniformly distributed. There appears to have been a lull in hurricane activity near Jamaica between 1952 and 1973 and much increased activity since 2000.

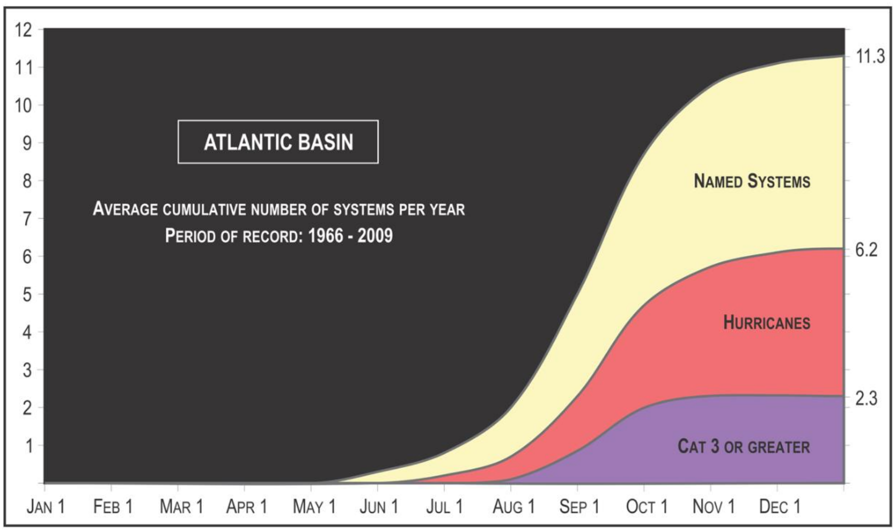

Figure 3.7.1: The average cumulative number of Atlantic systems per year, 1966-2009. Source: http://www.nhc.noaa.gov/climo/#bac

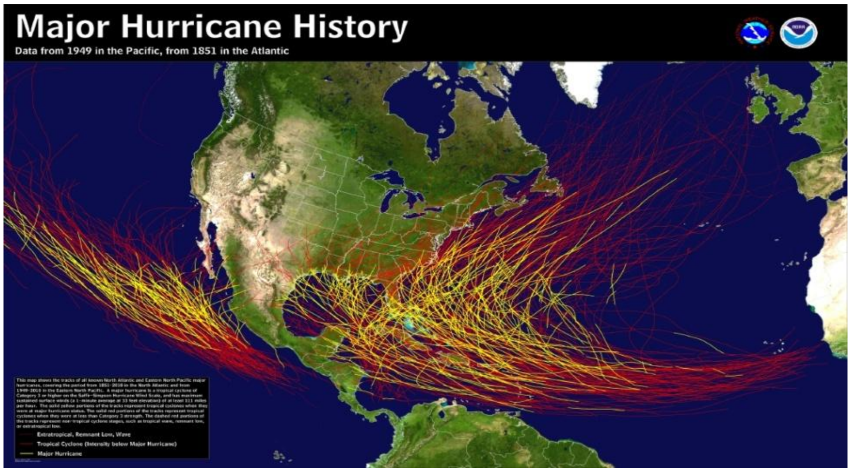

Figure 3.7.2: This map shows the tracks of all known North Atlantic and Eastern North Pacific major hurricanes (category 3 or above), covering the period from 1851–2010 in the North Atlantic and from 1949-2010 in the eastern North Pacific. The yellow portions of the tracks represent tropical cyclones when they were major hurricanes. The red portions of the tracks represent tropical cyclones when they were less than major hurricanes. Source: http://www.nhc.noaa.gov/climo/#bac

Table 3.7.1: Dates, wind speeds, category and names of hurricanes that came within 69 miles of Kingston or Montego Bay for 1852-2011.
Source: http://stormcarib.com/climatology/MKJS_all_isl.htm

Date			wind speed (miles per hour)	Category	name
6	Oct	1852	104	h2	NOTNAMED
9	Sep	1865	104	h2	NOTNAMED
2	Nov	1874	104	h2	NOTNAMED
7	Aug	1880	92	h1	NOTNAMED
19	Aug	1880	92-81	h1	NOTNAMED
20	Aug	1886	109	h2	NOTNAMED
25	Aug	1895	92-98	h1-h2	NOTNAMED
26	Sep	1896	81-86	h1	NOTNAMED
11	Aug	1903	121	h3	NOTNAMED
13	Jun	1904	81	h1	NOTNAMED
8	Sep	1910	81	h1	NOTNAMED
18-19	Nov	1912	92-115	h1-h3	NOTNAMED
13	Aug	1915	109-115	h2-h3	NOTNAMED
16	Aug	1916	86	h1	NOTNAMED
23	Sep	1917	104-109	h2	NOTNAMED
11	Aug	1928	81-75	h1	NOTNAMED
29	Oct	1933	86-98	h1-h2	NOTNAMED
20	Aug	1944	121	h3	NOTNAMED
18	Aug	1951	86-92	h1	CHARLIE
31	Aug	1974	75	h1	CARMEN
6	Aug	1980	132	h4	ALLEN
12	Sep	1988	127	h3	GILBERT
7	Oct	2001	86	h1	IRIS
12	Aug	2004	86	h1	CHARLEY
11	Sep	2004	155-144	h5-h4	IVAN
7	Jul	2005	115	h3	DENNIS
19-20	Aug	2007	144	h4	DEAN

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4. Observed Climate Variability and Trends

4.1 About this Chapter

Climate variability refers to deviations from the climatology or average weather behaviour discussed in Chapter 3 over a given time period such as a month, season or year. The deviations are determined relative to the long term mean for the corresponding period (month, season or year). These departures from the long term mean are often called anomalies and provide the basis for discussion of short term changes in climate (variability) and the long term changes (trends).

This chapter examines again the climate variables discussed previously for Jamaica, but in terms of their historical variability or long term trend. As for the last chapter, in many cases the discussion is limited by the data available. In some cases variations for Jamaica as a whole are discussed while in other cases it is for a given station. We rely heavily on data provided by the National Meteorological Service in determining some of the trends. We, however, also provide some country statistics taken from the CARIBSAVE Climate Risk Atlas for Jamaica. The observed data used there are compiled from a number of observed gridded datasets (e.g. McSweeney et al., 2010).

We begin the chapter by discussing the primary global drivers of climate variability for Jamaica, i.e. we discuss changes in the atmosphere and ocean that drive short term and longer changes in Jamaican climate. This provides the context for the ensuing discussion of the observed changes in climate variables such as temperature, rainfall, wind speed, relative humidity, sunshine hours and sea surface temperature. As also noted in the previous chapter, it is changes in these drivers which yield the future changes in Jamaican climate under global warming.

4.2 Drivers

El Niño and Sea Surface Temperatures

Variations in sea surface temperatures over the tropical Pacific and Atlantic Oceans are important drivers of Caribbean rainfall and temperature. Warmer than normal ocean temperatures over the eastern Pacific, off the coast of Peru, are associated with El Niño conditions, whereas cooler than normal ocean temperatures are associated with La Niña. El Niño events tend to occur about every 3 to 7 years though increases in frequency, severity and duration have been noted since the 1970s. (See Box on following page). El Niño represents a significant influence on Caribbean rainfall and so it is not unusual to find this timescale of variability in Caribbean precipitation records.

The impact of an El Niño event varies depending on the period or year under consideration. During an El Niño event, the Caribbean (and Jamaica by extension) tends to be drier than usual in the mean, particularly during the late wet season from August through November (see previous Chapter). One explanation is that the changing circulation patterns lead to stronger west to east winds in the upper atmosphere over the Caribbean, which in turn prevent the formation of strong convective activity, thus reducing the potential for precipitation. There is also, by extension, a tendency for reduced hurricane activity during El Niño events (see Section 4.7). Meteorological droughts occurring over the Caribbean in 1991, 1997-1998 and 2010 coincided with El Niño events. Research has also shown that during an El Niño event the western equatorial Atlantic also tends to be warmer (Figure 4.2.1 and Figure 4.2.2).

What is El Niño?

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. In normal conditions, when neither El Niño or La Niña are present, very warm sea surface temperatures are found only in the western Pacific Ocean while cold water upwells in the east, as shown in Figure 4.2.1. This warm surface results in atmospheric convection or rising air in the west, while the air sinks in the east. The resulting atmospheric circulation, shown in blue, is called the Walker circulation. In El Niño conditions the pool of warm water expands into the central and eastern Pacific, cutting off the upwelling, as shown in Fig. 4.2.1. The atmospheric circulation (blue) has changed and the area of atmospheric convection has now shifted to the coast of South America. El Niño events and normal conditions are caused by a seesaw pattern of ocean circulation, with warm water moving from west to east, then looping back from east to west. When warm water loops back from eastern to western Pacific (normal conditions) cold water will move from western to eastern Pacific. Sometimes the eastern Pacific then becomes colder than usual leading to a La Niña. El Niño events have a return cycle of about 3 to 7 years.

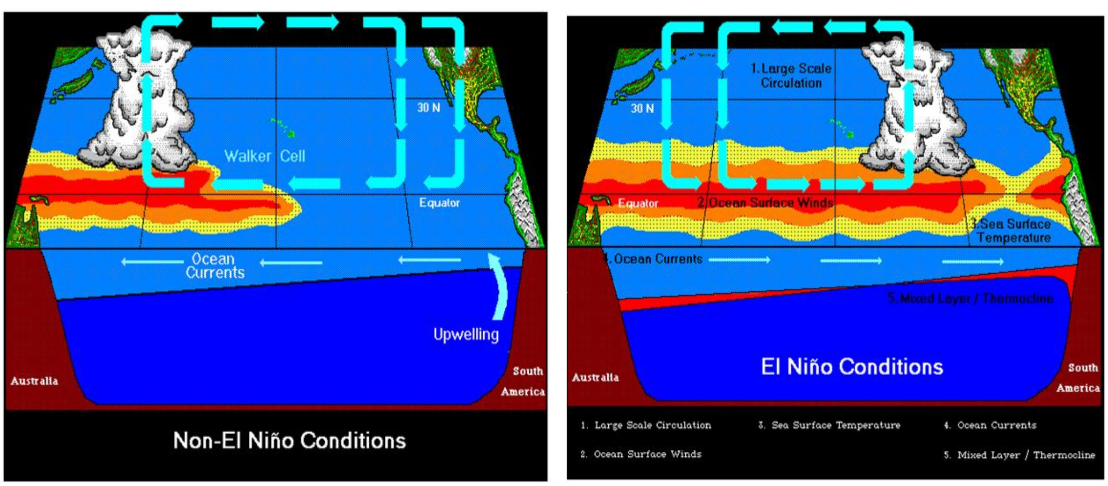

Figure 4.2.1: Schematic diagram of the most common mode of circulation in and above the tropical Pacific Ocean (left panel); during an El Niño event (right panel). Source: http://www.unc.edu/courses/2008ss2/geog/111/001/ClimateForecasts/ClimateForecasts.htm

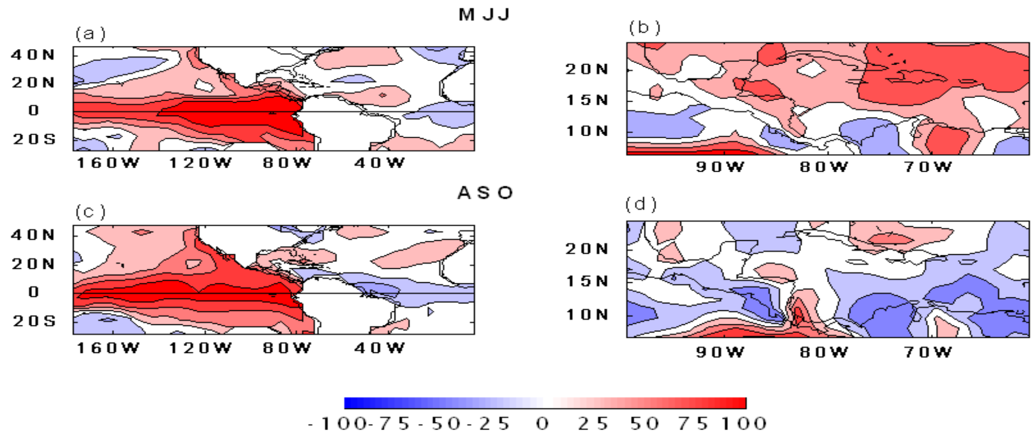

Figure 4.2.2: Dominant Sea surface temperature patterns and their corresponding rainfall patterns for (a)-(b) May-July and (c)-(d) August-October. Above normal ocean temperatures over the Pacific and together with Atlantic are associated with above normal rainfall over the Caribbean for May-July. Warm Pacific anomalies together with cold equatorial Atlantic anomalies are associated with below normal rainfall in the southern Caribbean. Source : Spence et al. (2004).

However, during the early rainfall season (May to July) in the year after an El Niño (El Niño+1 year), warmer than usual sea surface temperatures cover the central and eastern Caribbean and most of the Caribbean tends to be wetter than usual. This is again due to a discernible shift in the atmospheric circulation system. Because the air is in contact with the sea surface, the air temperature also increases. Thus, in an El Niño year, the Caribbean's late wet season tends to be drier and hotter, and in the early rainfall season in the year after an El Niño the Caribbean tends to be wetter and definitely hotter.

The El Niño also has an impact on the Caribbean dry period (DJF) as it tends to induce opposite signals over the north and south Caribbean, with strong drying in the southern Caribbean, but a transitioning to wetter conditions over regions north of Jamaica, particularly over north Cuba, Bahamas, Puerto Rico and Florida (Stephenson et. al 2008). In general, a La Niña event produces the opposite conditions in both the late wet season (wetter) and the dry season (drier south Caribbean).

It is also to be noted that the extent to which an El Niño event impacts the region can be modulated by how warm or cool the Caribbean and/or equatorial Atlantic is at the time of the ENSO event's occurrence (Taylor et al. 2002 and 2011). The tropical Atlantic usually warms due to the spreading of the north Atlantic warm pool (warm waters in excess of 26.5 degrees Celsius which develop in the Gulf of Mexico in early boreal spring and spread eastward through November). A number of recent studies show that when the gradient in temperature between the pacific and Caribbean Sea is heightened, i.e. a warm equatorial Pacific-cool tropical Atlantic scenario exists, this is associated with decreased late season rainfall in the Caribbean and vice versa (Enfield and Alfaro 1999, Taylor et al. 2002, Taylor et al. 2011) (see Figure 4.2.3).

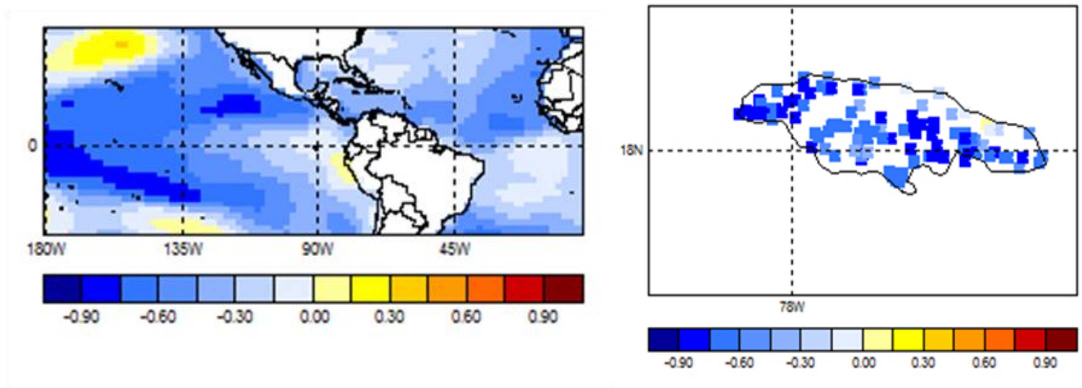

Figure 4.2.3: Dominant sea surface temperature pattern and its corresponding Jamaica rainfall patterns for (a)-(b) May-July. Figure shows that tropical Pacific and Atlantic sea surface temperature anomalies are associated with rainfall over Jamaica. Source: Research done by Climate studies Group Mona (2012).

NAO and AMO

Caribbean climate variations on longer timescales are not as well studied. Yet, because Caribbean climate records are short, it is useful to know about these variations so that they can be distinguished in the records from trends induced by climate change.

Known variations on decadal timescales condition the region to be drier or wetter by, for example, yielding spells of wet or dry years because of the background conditions they impose. For example, in much the same way that El Niño is known to impact Caribbean rainfall on a year to year basis, there are known links between the North Atlantic Oscillation (NAO) and seasonal to decadal variability of Caribbean rainfall especially over the eastern Caribbean (Giannini et al. 2001, Charlery et al. 2006, Jury et al. 2007, Jury 2009). In the positive phase of the NAO there are anomalously high pressures across the subtropical Atlantic which also induce cooler ocean surface waters and as a result the Caribbean is background conditioned to be dry. Giannini et al. (2001) point out that the combination of a positive phase of the NAO and an El Niño can cause the wet season drying to be unusually intense. Similarly, the negative phase of the NAO (weaker sea level pressures and warmer ocean surface temperatures) can heighten the wetter conditions brought on during the early rainfall season in the year following the onset of an El Niño event.

Even longer term variability, i.e. on multidecadal timescales, is to be found in the Caribbean climate and in particular its rainfall record. The Atlantic Multidecadal Oscillation (AMO) is one such variation, which is based on sea surface temperature variations in the North Atlantic and varies on a 50-to 90-year time scale. It has been in a warm phase since 1995. The historical records suggest that during warm phases of the AMO, the number of minor hurricanes (category 1 and 2) undergoes a modest increase and the number of tropical storms that can mature into severe hurricanes is much greater than during AMO cool phases - at least twice as many. The AMO's current warm phase is expected to persist at least until 2015 and possibly as late as 2035. Enfield et al. (2010) assume a peak around 2020.

Caribbean Low Level Jet (CLLJ)

The CLLJ is another circulation feature that can affect rainfall over the Caribbean and Jamaica. Throughout the year the trade winds intensify in a region in the south western Caribbean basin (70°W- 80°W) about an east-west axis located at approximately 15°N (Figure 4.2.4a). The intensification is restricted to the lower levels of the atmosphere below 600 mb (Figure 4.2.4b)and it has two wind speed maxima in February (the early jet) and July (the summer jet). It also has two minima in May and October. The easterly winds in the jet region increase to greater than 14 m/s at its core located near 925 mb level during the maxima. The jet also extends much deeper in the atmosphere during the summer, but by October, maximum wind speeds associated with the jet are less than 8 m/s. The CLLJ strongly influences rainfall characteristics of the surrounding islands and continental territories. Over the Caribbean, a strong summer jet enhances moisture flux divergence resulting in a tendency for the region to be dry in July/August.

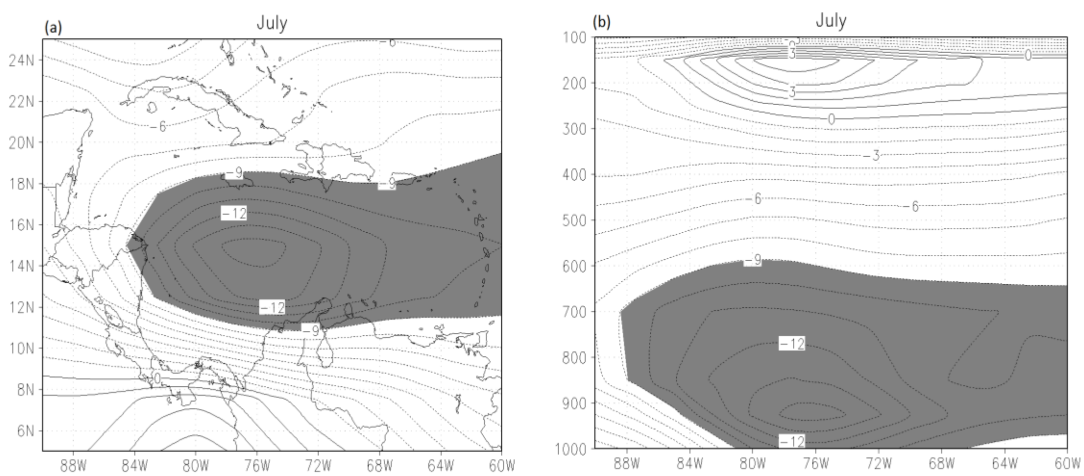

Figure 4.2.4: Zonal wind maps for July (a) 925 mb zonal winds (b) Zonal-vertical cross-section along 15°N. Calculated from NCEP/NCAR reanalysis data base period 1948-2007. Speeds greater than 9 ms^{-1} are shaded. Source: Taylor et al. (2012)

Table 4.2.1 below summarizes the associations between some of the primary global phenomenon that drive Caribbean climate.

Table 4.2.1: Some ocean – atmosphere linkages over the Pacific and Atlantic associated with Caribbean rainfall variability and trends

Ocean-Atmosphere Pattern	Comments	Caribbean	Some References
El Niño	• Warmer than normal eastern Pacific sea surface temperatures	• Caribbean drier and hotter than normal during year of onset • Diminished tropical Atlantic hurricane activity • December to March rainfall below normal in the south Caribbean and above normal in the north Caribbean; Jamaica is in the transition zone • May-July rainfall over Caribbean above normal in the year following onset	Gray 1994 Chen et al., 1997 Giannini et al., 2000 Chen and Taylor, 2002 Taylor et al, 2002 Martis et al., 2002 Spence et al., 2004 Ashby et al., 2005 Stephenson et al, 2007 Jury et al., 2007
La Niña	• Cooler than normal eastern Pacific sea surface temperatures	• On average opposite effect with respect to an El Niño	See El Niño References
Atlantic warm pool	• Warmer than normal Atlantic ocean temperatures	• Caribbean wetter than normal	Wang and Enfield, 2001 Taylor et al, 2002 Wang and Enfield, 2012
North Atlantic Oscillation (NAO)	• Opposing pressure variations between Iceland and Azores • Modulates the behaviour of El Niño	• Positive NAO phase implies a stronger than normal NAH and amplifies the drying during a warm ENSO • Negative NAO phase amplifies the precipitation in the early rainfall season in the year after an El Niño	Giannini et al., 2001 Charlery et al. 2006 Jury et al., 2007 Jury, 2009
Atlantic Multidecadal Oscillation (AMO)		• Positive AMO amplifies tropical Atlantic hurricane activity	Goldenburg et al., 2001
Caribbean low level jet	• Wind intensification south of Jamaica below 600 hPa • Primary peak in July • Secondary peak in February	• Stronger than normal low level jet associated with drier Caribbean	Munoz et al., 2008 Whyte et al., 2008 Wang, 2007

4.3 HISTORICAL TRENDS IN TEMPERATURE

Global mean surface temperatures have increased by 0.74 °C ± 0.18°C when a linear trend is used to estimate the change over 1906-2005. Using the same procedure, it can be shown that average annual temperatures for Caribbean islands have increased by more than 0.5 °C over 1900 – 1995 (IPCC, 2007). Figure 4.3.1 shows that, for every year between 1992 and 2009, the global mean anomaly over the period has been positive indicating a warmer than normal land and ocean surface. Surface temperatures averaged over Jamaica and superimposed for the same period (green line) show annual variations ranging from -3 to 3.5 degrees. The year to year variations in air temperatures over the Caribbean have been linked to El Niño and La Niña events. During El Niño years, air temperatures are higher than normal and during La Niña air temperatures are lower than normal (see previous section).

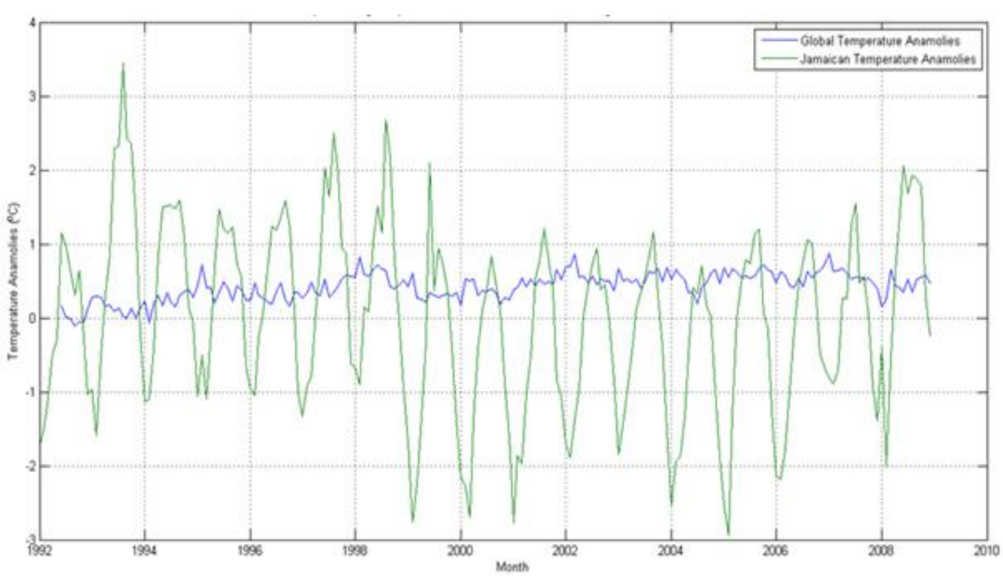

Figure 4.3.1: Global temperature anomalies (blue – source: IPCC) and Jamaican temperature anomalies (green – source: Meteorological Service of Jamaica) from 1992 to 2009. Units: degrees Celsius.

There is, nonetheless, a warming trend in Jamaican temperature data as is evident from data collected at the airport stations (Figures 4.3.2 and 4.3.3). From 1992 to present the trend at the airport stations is approximately 0.1 degrees Celsius/decade. This is less than the all island value quoted in the CARIBSAVE Risk Atlas which indicates a statistically significant annual trend of 0.27 degrees Celsius/decade. CARIBSAVE values are shown in Table 4.3.1, which gives the observed means and trends over Jamaica. The annual and seasonal rate of temperature increase ranges from 0.20 – 0.31 °C per decade. The table also suggests that observed increases have been most rapid in JJA (at a rate of 0.31˚C per decade).

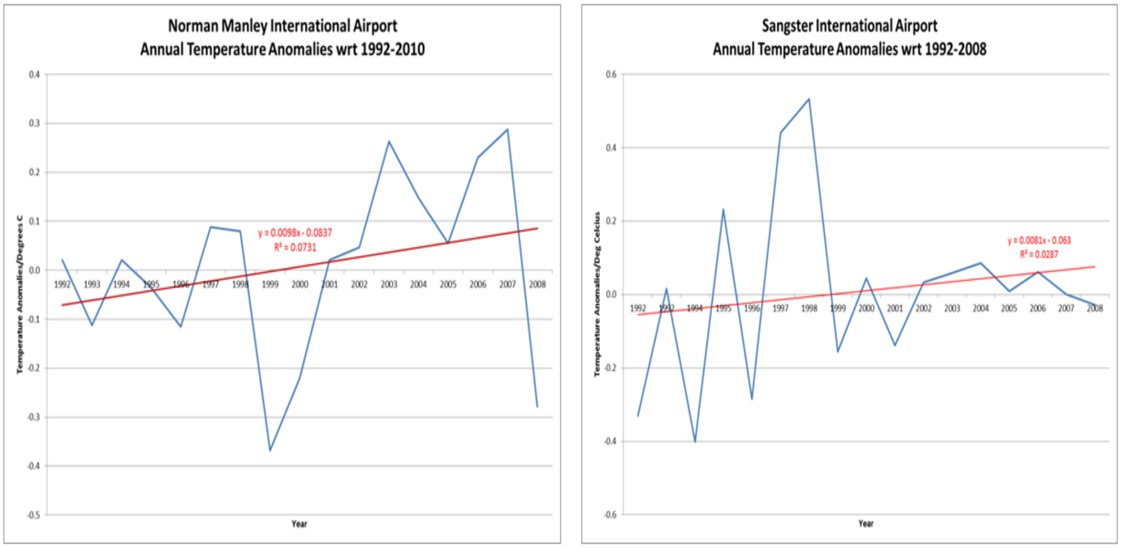

Figure 4.3.2: Annual temperature anomalies for Norman Manley (left panel) and Sangster (right panel) International Airports with respect to 1992-2010 for Norman Manley and 1992-2008 for Sangster International. Units are degrees Celsius. Data source: Meteorological Service of Jamaica.

Table 4.3.1: Observed means and trends in temperature for Jamaica. Source: CARIBSAVE Risk Atlas (2011).

Time	Mean (1970 -1999) °C	Trend (1960-2006) °C per Decade
Annual	23.7	0.27
DJF	23.7	0.20
MAM	24.3	0.27
JJA	23.7	0.31
SON	23.2	0.28

It is not only the mean temperatures that have been increasing. Since the late 1950s the percentage of very warm daytime and very warm night time temperatures over the Caribbean has increased significantly, while the percentage of days with very cold daytime and night time temperatures has decreased (Figures 4.3.3 and 4.3.4). Corresponding values for Jamaica (Table 4.3.2) show that the frequency of very hot days and nights has increased by an additional 6% (an additional 22 days per year) every decade. The frequency of hot nights has increased particularly rapidly in JJA by 9.8% (an additional 3 hot nights per month in JJA) per decade. As for the Caribbean, the frequency of ‘cold’ nights has decreased at a rate of 4% fewer ‘cold’ nights (14 fewer cold nights in every year) per decade. It is also to be noted that the difference between the highest and lowest temperatures for a given year (i.e. the diurnal range) is decreasing for the region and Jamaica, but is not significant at the 10% significance level (Peterson et al. 2002).

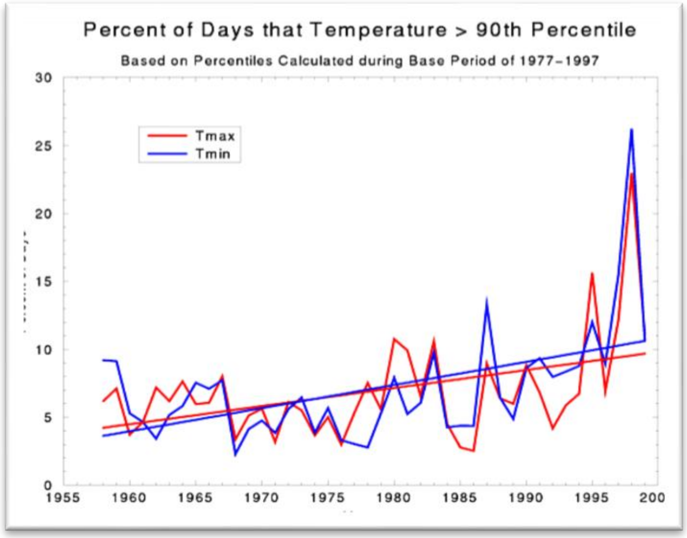

Figure 4.3.3: Percent of days maximum (red line) and minimum (blue line) temperatures are at or above the 90th percentile. Percentiles determined using data from 1977 through 1997. Source: Peterson et al. (2002). Source: Peterson et al. (2002)

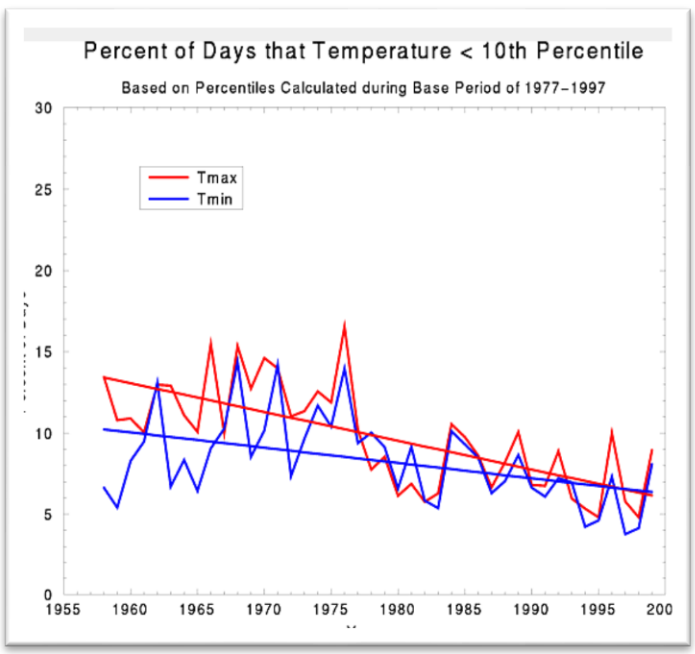

Figure 4.3.4: Percent of days maximum (red line) and minimum (blue line) temperatures are less than or equal to the 10th percentile. Percentiles determined using data from 1977 through 1997. Source: Peterson et al. (2002)

Table 4.3.2: Observed trends in extreme temperature for Jamaica for the period spanning 1960 – 2006. Source: CARIBSAVE Risk Atlas (2011).

	Variable	Annual	DJF	MAM	JJA	SON
Temperature	Hot Days (TX90p) *frequency / decade*	6.03	6.26	5.63	6.19	7.87
	Hot Nights (TN90p) *frequency / decade*	5.89	1.48	3.63	9.76	4.59
	Cold Nights (TN10p) *frequency / decade*	-4.03	-3.76	-2.81	-5.31	-7.58

4.4 Historical Trends in Rainfall

Rainfall over Jamaica shows a great deal of variability between months, seasons and years. Figure 4.4.1 shows mean annual rainfall for Jamaica from 1880 to present. It can be seen that there is significant inter-annual (year-to-year) variability which we already noted is partly associated with El Niño activity (see section 4.2). Amid the yearly fluctuations it is also possible to identify groups of years for which rainfall is largely above normal (1930s, 1950s) and years for which rainfall is below normal (1920s, 1970s). These groups of years represent the decadal variability discussed previously in Section 4.2. The inter-annual variability is therefore superimposed upon the decadal variability as depicted in the diagram. One should note that from the late 1990s the decadal trend for Jamaican rainfall is upwards. This is likely linked to the Atlantic multi-decadal oscillation (see again Section 4.2), which is in turn related to warmer than normal sea surface temperatures over the North Atlantic.

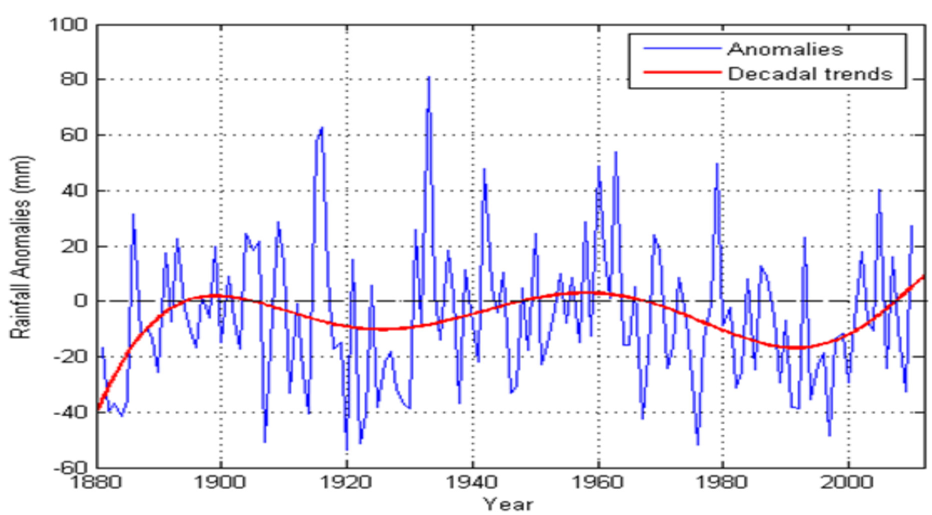

Figure 4.4.1: Graph of Jamaican rainfall (blue) with decadal trends (red) superimposed. Data source: Meteorological Service of Jamaica.

The mean Jamaican rainfall record shows no statistically significant trend, i.e. if a linear line were fitted to Figure 4.4.1 it would not be statistically significant. This is not surprising given the large inter-annual variability noted above. Values for the trendline are small for 1960-2006 as shown in Table 4.4.1. There are small percentage decreases in annual rainfall and summer rainfall per decade. The decrease in the June – August period is the strongest. A small increasing rainfall trend is evident for the drier seasons of the year (December – May). If a linear trend is fitted to data from individual stations across Jamaica, areas of increasing rainfall over the 1992-2010 period may be identified over the centre of the island and areas of decreasing rainfall over the eastern and western parishes (see Figure 4.4.2). The pattern of Figure 4.4.2 is strongly reminiscent of the second mode of rainfall variability shown in Figure 3.3.4.

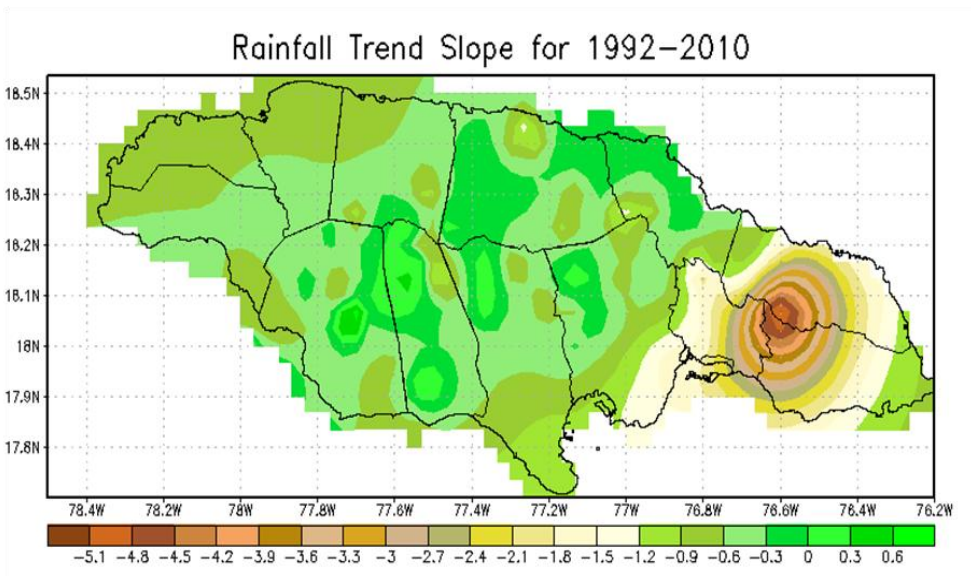

Figure 4.4.2: Map showing Rainfall trends slope. Positive slope suggest increasing rainfall, and negative slope suggest decreasing rainfall. Data source: Meteorological Service of Jamaica.

Trends in rainfall extremes have largely been negative (decreasing) over the recent past (Table 4.4.2). Statistically significant decreases have been observed in theproportion of total rainfall that occurs in 'heavy' events at a rate of -8.3% per decade over the observed period 1973-2008. The threshold value for 'heavy' events is determined according to the values exceeded on 5% of wet days in the reference period. There have also been decreases in peak 1-day and 5-day rainfall and decreases in 5-day maxima for DJF and MAM at a rate of -33 and -18 mm per decade, respectively. These 'trends' should, however, be interpreted cautiously given the relatively short period over which they are calculated, and the large inter-annual variability in rainfall and its extremes.

Table 4.4.1: Observed mean and trends in precipitation for Jamaica. Source: CARIBSAVE Risk Atlas (2011).

Time	Mean (1970 -1999) mm per month	Trend (1960-2006) % per decade
Annual	155.2	-1.6
DJF	107.2	0.2
MAM	142.4	1.3
JJA	141.0	-4.4
SON	227.6	-2.0

Table 4.4.2: Observed trends in extreme precipitation for Jamaica for the period spanning 1973 – 2008. Data source: CARIBSAVE Risk Atlas (2011).

	Variable	Annual	DJF	MAM	JJA	SON
Precipitation	% Rainfall in Heavy Rainfall Events (R95pct) *% / decade*	-8.32	No Data	No Data	No Data	No Data
	Maximum 1-day Rainfall (RX1day) *mm/decade*	-23.58	-28.70	-13.30	-0.03	-2.92
	Maximum 5-day Rainfall (RX5day) *mm/decade*	-48.56	-32.94	-18.26	-32.64	-24.88

4.5 OTHER VARIABLES – WIND, RELATIVE HUMIDITY, SUNSHINE HOURS AND SEA SURFACE TEMPERATURES.

Observed trends in other variables for Jamaica for the period spanning 1960-2006 are shown in Table 4.5.1

Significant increases over the period have been noted in the annual and seasonal values of wind speed around Jamaica in all seasons over the period 1960-2006 from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) mean monthly marine surface wind dataset. The increasing trend in mean annual marine wind speed is 0.26 m/s per decade.

There is no significant trend in Relative Humidity (RH) over Jamaica in observations from the HadCRUH dataset (1973-2003). The small trends noted are generally positive and increasing except for the March – May and September – November seasons.

The observed number of sunshine hours, based on the International Satellite Cloud Climatology Project (ISCCP) satellite observations of cloud coverage, indicates statistically significant increases in sunshine hours in MAM and JJA for Jamaica over recent years (1983-2001).

Sea surface temperatures from the HadSST2 gridded dataset indicate statistically significant increasing trends in JJA and SON of +0.7˚C per decade in the waters surrounding Jamaica. The mean annual increase is +0.4˚C per decade.

Table 4.5.1: Observed trends in other variables for Jamaica for the period spanning 1960-2006. Data source: CARIBSAVE Risk Atlas (2011).

Variable	Annual	DJF	MAM	JJA	SON
Wind Speed (ms-1)	0.26	0.27	0.25	0.27	0.25
Relative Humidity (%)	0.03	0.19	-0.06	0.09	-0.11
Sunshine Hours (hrs)	0.28	0.19	0.78	0.4	-0.26
Sea surface temperatures(°C/decade)	0.04	0.01	0.02	0.07	0.07

4.6 HURRICANES

Tropical cyclone activity in the Caribbean and wider North Atlantic Basin has shown a dramatic increase since 1995. This increase, however, has been attributed to the region being in the positive (warm) phase of the Atlantic multidecadal oscillation (AMO) and not necessarily to global warming (Goldenburg et al., 2001). Additionally, El Niño and La Niña events influence the location and activity of tropical storms across the globe (see Figure 4.6.1).

Attempts to link warmer sea surface temperatures (SSTs) with the increased number of hurricanes have proven to be inconclusive (Peilke et al., 2005). Webster et al. (2005) found that, while SSTs in tropical oceans have increased by approximately 0.5˚C between 1970 and 2004, only the North Atlantic Ocean shows a statistically significant increase in the total number of hurricanes since 1995. Both frequency and duration display increasing trends significant at the 99% confidence level. Webster et al. (2005) also noted an almost doubling of the category 4 and 5 hurricanes in the same time period for all ocean basins. While the number of intense hurricanes has been rising, the maximum intensity of hurricanes has remained fairly constant over the 35 year period.

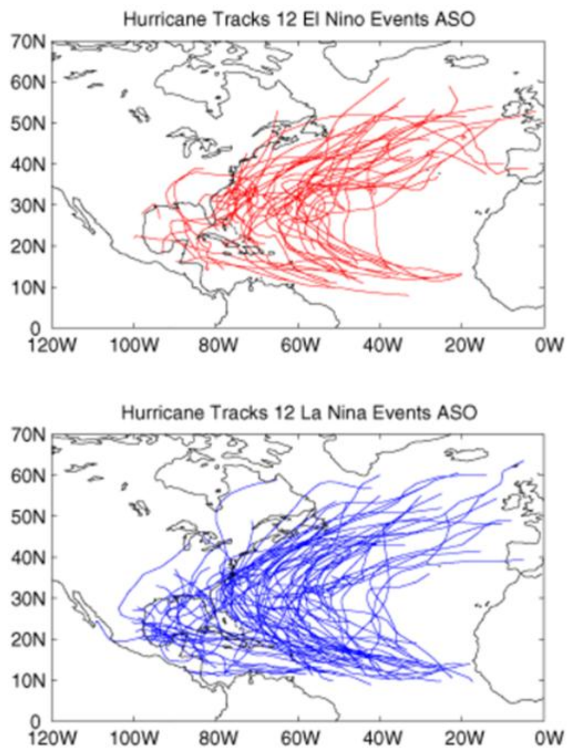

Figure 4.6.1: Tracks of Atlantic hurricanes August to October 1959-2001 for El Niño years (top) and La Niña years (bottom).
Source: http://iri.columbia.edu/climate/ENSO/globalimpact/TC/Atlantic/track.html

4.7 SEA LEVEL RISE

Global sea level rise over the 20th century is estimated to have been 0.17 ± 0.05 m. From estimates of observed sea level rise from 1950 to 2000 by Church et al. (2004), the rise in the Caribbean appeared to be near the global mean. Satellite altimeter measurements also show a rate of sea-level rise of about 3 mm/year since the early 1990s (Bindoff, 2007). Table 4.7.1 shows the rates of sea level rise for a number of locations in the Caribbean. All values suggest an upward trend. Sea level measurements at Port Royal between 1955 and 1971 (Figure 4.7.1) also indicate a 0.9 mm/year rising trend (Horsfield, 1973).

Table 4.7.1: Observed sea level rise rates for the Caribbean basin.

Tidal Gauge Station	Observed Trend (mm/yr)	Observation Period
Bermuda	2.04 ± 0.47	1932 – 2006
San Juan, Puerto Rico	1.65 ± 0.52	1962 – 2006
Guantanamo Bay, Cuba	1.64 ± 0.80	1973 – 1971
Miami Beach, Florida	2.39 ± 0.43	1931 – 1981
Vaca Key, Florida	2.78 ± 0.60	1971 – 2006

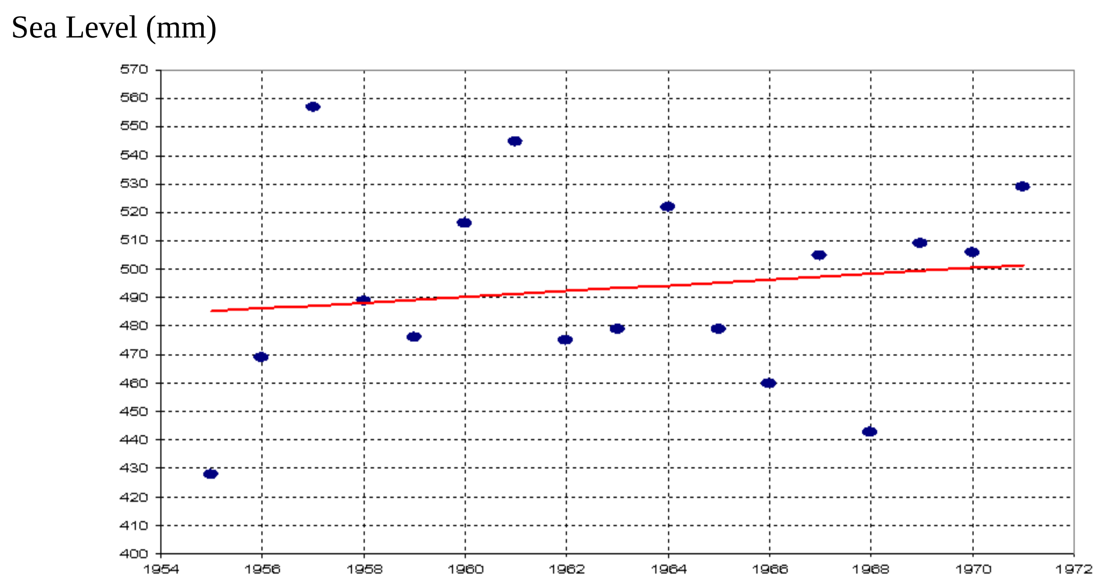

Figure 4.7.1: Mean annual sea levels at Port Royal measured between 1955 and 1971. Redrawn from Horsfield (1973). Linear trend inserted.

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5. ABOUT PROJECTIONS

5.1 ABOUT THIS CHAPTER

In this brief chapter we discuss how projections of future climate are generated. The information is necessary for interpreting the Tables and Figures of the following chapters.

5.2 CLIMATE MODELS AND SCENARIOS

Coming up with future projections of climate requires the use of climate models. Climate models are important tools used by scientists to understand the complexities of the Earth's climate. They enable the simulation of the large scale systems of the atmosphere by incorporating the latest scientific understanding of the physical processes of the atmosphere, oceans, and the earth's surface using comprehensive mathematical descriptions. There are two types of climate models – global climate models (GCMs) and regional climate models (RCMs – see the following section). GCMs simulate climate across the globe on coarse scales, generally of a few hundred kilometres, and represent for regions like the Caribbean, a first guess of their future climate. They therefore lay the foundation for decision making concerning climate change.

To estimate future changes in climate some assumptions have to be made about what the future world might look like, especially with respect to the concentration of greenhouse gas (GHG) emissions that will be in the atmosphere. Future concentrations of GHGs will depend on multiple factors which may include changes in population, economic growth, energy use and technology. The Special Report on Emissions Scenarios (SRES) represent possible pathways for future GHG emissions premised on different storylines of change in the global development factors noted above (Nakicenovic et al. 2000). There are forty different scenarios or storylines divided into four families (A1, A2, B1 and B2), with each family having an accompanying narrative describing the relationships between GHG emission levels and the driving factors, i.e. demographic, social and economic and technological developments. Figure 5.1.1 shows a typical representation of the families of scenarios.

None of the scenarios, however, assumes any future policies that explicitly address climate change, so they represent a range of plausible possible futures, i.e. low emission to high emission futures. Figure 5.1.2 shows the projected carbon emissions for a subset of scenarios. In the figure, A1fi is a high emissions scenario resulting from assumptions of a future with fossil fuel-intensive economic growth and a global population that peaks mid-century and then declines. In this scenario, CO_2 concentrations reach 940 parts per million (ppm) by 2100—more than triple pre-industrial levels. In comparison, B1 is a lower emissions scenario where atmospheric carbon dioxide reaches 550 ppm by 2100 in comparison to current levels of 380 ppm. The B1 scenario is premised on a world with high economic growth, a global population that peaks by mid-century then declines, and a shift to less fossil fuel-intensive industries and the introduction of clean and resource-efficient technologies.

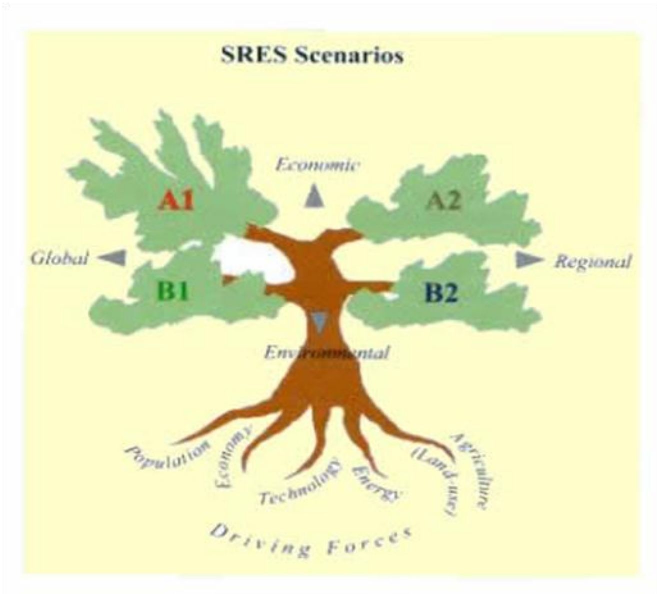

Figure 5.2.1: Schematic illustration of the four SRES storylines. The four storylines combine two sets of divergent tendencies: one set varying between strong economic values and strong environmental values, the other set between increasing globalization and increasing regionalization. The storylines are summarized as follows (Nakicenovic et al., 2000): **A1** storyline and scenario family: a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. **A2** storyline and scenario family: a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines. **B1:** storyline and scenario family: a convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. **B2:** storyline and scenario family: a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development.

Emission scenarios are used to drive GCMs to produce representations of future climate, generally through the end of the century. GCMs are run by large modeling centres across the globe which have the computational power to do so. The modality is usually to run GCMs over multiple scenarios since every scenario is plausible. This allows for a range of values for the future projected climate. For regions like the Caribbean results are also often taken from an ensemble of GCMs run over one or more scenarios. The biases of any one GCM are therefore minimized in the results presented.

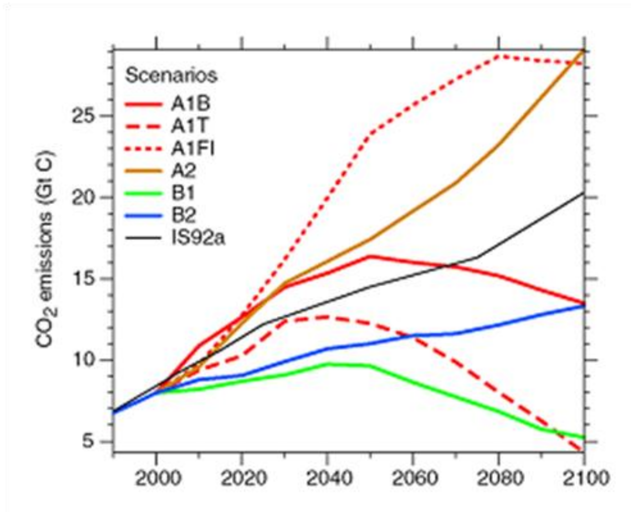

Figure 5.2.2: Projected future carbon emissions for the SRES emission scenarios. The higher-emission scenario (A1fi) corresponds to the highest red dotted line, while the lower-emission (B1) scenario is indicated by the solid green line. (Nakićenović et al. 2000).

5.3 Regional Climate Models

Regional climate models (RCMs) are used to downscale GCM output to obtain higher resolution results. That is, the GCMs do not provide sufficient information at the scale of individual small island states, for example Jamaica, due to their coarse resolution. Though Jamaica would possibly be seen by a GCM, it would be represented by at most two grid boxes. Therefore, to achieve information at the 'small island scale', Regional Climate Models (RCMs) are used. RCMs are also comprehensive physical models of atmospheric, oceanic and land processes, but with higher resolutions (e.g. 50 km or less) and which are run over limited areas using GCM output as boundary conditions. Figure 5.3.1 illustrates the difference between a GCM and RCM grid over Jamaica.

The PRECIS-Caribbean Initiative (Taylor et al. 2007) is a collaborative research effort involving Cuba, Jamaica, Barbados and Belize to produce downscaled climate scenarios for the Caribbean using an RCM. The PRECIS (Providing Regional Climates for Impact Studies) RCM was run at 25 km and 50 km resolution over limited domains covering all or part of the Caribbean, Central America, Florida and the northern territories of South America as well as portions of the Atlantic and Pacific oceans, for both present day (1961-1990) and future (2071-2100) periods. The PRECIS RCM was forced with output from the HadCM3 GCM (Jones et al. 2004) and the ECHAM GCM (Jones et al. 2003), for both a relatively high GHG emissions scenario (A2) and a relatively low GHG emissions scenario (B2) to provide a range of projections. Details of the PRECIS-Caribbean initiative and the validation of the PRECIS model for present day Caribbean climate are given in Taylor et al. (2007) and Campbell et al. (2010), respectively. Results from the PRECIS initiative are presented in Chapter 7.

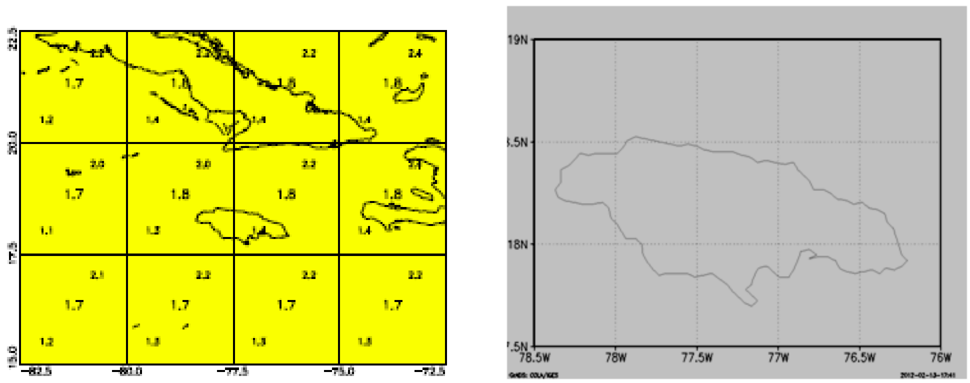

Figure 5.3.1: Jamaica represented in a GCM (left panel) and an RCM of 50 km resolution (right panel).

5.4 STATISTICAL DOWNSCALING

Statistical downscaling is a third technique to attain future projections of climate. The technique involves the application of relationships developed between observations for a location (e.g. rainfall measured at a station) and large-scale climate variables (e.g. surface pressure, temperature) to the output of the GCMs to determine future changes in the local variable. The technique assumes that the relationships obtained from current observations will remain unchanged in the future.

5.5 STRENGTHS AND WEAKNESSES OF MODELS

Climate models are based on the laws of physics, chemical processes in the atmosphere and land-sea interaction with the atmosphere, and can reproduce many observed features of the current climate and past climate changes. Confidence in model simulations is higher for some climate variables than for others. For example, confidence in temperature simulations is higher than for rainfall simulations, since the processes involved in the latter are more complex. Confidence is also generally higher for changes on continental or larger scales than for sub-continental and island scales. For island scales, a major problem is the computational burden of simulating small areas at high resolution.

Confidence in the reliability of global climate models is based on tests of their ability to represent the following:

- the present day average climate and year-to-year variability;
- observed climate trends in the recent past;
- extreme events, such as storms and heat waves;

- climates from thousands of years ago.

Models show significant and increasing skill in representing many important mean climate features, such as the large-scale distributions of atmospheric temperature, rainfall, radiation and wind, and of oceanic temperatures, currents and sea-ice cover. Patterns of climate variability that are generally well-simulated include the advance and retreat of the major monsoon systems, the seasonal shifts of temperatures, storm tracks and rain belts. A major test that models have succeeded in is the reproduction of the observed large-scale changes in surface temperature over the 20th century, when both natural causes and man-made contributions to global warming are included in the models.

However, there remain significant deficiencies in models, stemming largely from the inability of modellers to simulate exactly processes such as cloud physics, radiation and rainfall processes, having to rely on approximate equations. Errors or biases remain in a number of aspects of the simulation of tropical rainfall, ENSO and the Madden-Julian Oscillation and tropical ocean temperatures. Relatively small-scale events such as tropical cyclones and thunderstorms are less skilfully reproduced. While regional climate models tend to produce more realistic simulations, increased resolution alone does not reduce some important biases.

In summary, climate models provide credible quantitative estimates of future climate change, particularly at larger scale, but some deficiencies remain at smaller scales. There will always be a range of uncertainty in climate projections. People doing impact assessments based on climate model projections need to understand and incorporate this uncertainty (IPCC, 2007 and Australian Bureau of Meteorology and CSIRO, 2011).

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6. GCM Projections

6.1 About this Chapter

In this chapter we provide projections for the Caribbean and specifically Jamaica from the GCMs. The projections are compiled primarily from three sources:

a) The IPCC AR4 report.
b) The UNDP Climate Change Country Profiles
c) The CARIBSAVE Climate Change Risk Atlas for Jamaica.

We summarise the methodology used by each source in the following section. Importantly we note that whereas we have summarised what each source says about the future climate of Jamaica, there is even greater detail to be had by consulting the sources as well. The projections presented from the sources above are for mean temperature and rainfall, temperature and rainfall extremes, and other climate variables including wind speed, relative humidity, and sea surface temperatures. Projections for storm surge, sea level rise and hurricanes from GCMs are also presented, but are largely drawn from journal articles.

Some things to be noted about the projections presented in this chapter are:

- In most cases the projections are for the near (2020s or 2030s), mid-term (2050s or 2060s) and long term (2080s or 2090s).
- GCMs generally cover Jamaica using one or two grid boxes, and in many the country is not represented at all. The values presented represent the average for the grid boxes which would contain Jamaica, i.e. only one value is presented representing the average change projected for Jamaica as can be gleaned from the one or two grid boxes.
- The projections presented are for the minimum, mean or maximum for an ensemble of GCMs. One can refer to the documentation for the data source (see below) to see the GCMs that constitute the ensemble. No judgment is made about which GCMs are to be used in the ensemble.
- The projections for precipitation are presented for (one or all of) the B1 (low), A1B (medium) and A2 (high) Special Report on Emissions Scenarios (see Figure 5.2.1 and 5.2.2 of the previous chapter).
- The projections are presented as changes with respect to present-day climate. In some cases absolute change is given. In the case of rainfall, it is percentage change that is given. This makes knowledge of the mean state important, (i.e. as described in Chapter 3) as the changes are with respect to this mean state.
- Projections are presented for three month seasons defined as DJF (December – February), MAM (March – May), JJA (June – August), SON (September – November), and as an annual change.

The following section provides some more details about the three main data sources. The sections thereafter examine projections for Jamaica by climate variable and phenomenon. In each case a summary of what the data suggests about the change in the variable or phenomenon is first given followed by plots and tables from which the reader can extract more details as needed.

6.2 Data Sources

The three primary data sources are:

The IPCC AR4 Report: From this report, we extract data for the Caribbean in general. This is necessary to provide a useful comparison against which the Jamaica change can be judged, and because in some cases the data represents the best that can be provided for the Caribbean (e.g. for projections of sea level rise and hurricanes). For the precipitation and temperature data, the values are (i) averaged over the entire Caribbean region defined as from 10 ^{o}N – 25 ^{o}N and 60 ^{o}W to 85 ^{o}W (ii) are for the A1B scenario, and (iii) are for an ensemble of 16 GCMs. For more information see IPCC (2007).

The UNDP Climate Change Country Profiles: The output from 15 GCMs is examined to determine temperature and rainfall changes through the end of the century. Changes are with respect to the 1971-2000 mean climate. For the observed climate, gridded station datasets from CRU, University of Delaware and GPCC (0.5° resolution) are used as well as NCEP and ERA-40 reanalysis (temperature only). In calculating extreme indices, the HadEX dataset (UK met office) is used and indices are calculated from daily observed data and gridded datasets, as well as from the GCMs. The A2, A1B, and B1 scenarios are analysed. Changes are presented for the 2030s, 2060s and 2090s. For more details see McSweeney et al. (2008).

The CARIBSAVE Climate Change Risk Atlas for Jamaica: The procedure is identical to that used to generate the UNDP Climate Change Country Profiles. Changes are, however, presented for the 2020s 2050s and 2080s. For more information see CARIBSAVE (2011).

6.3 Temperatures

Summary

Considering all models and all scenarios, the Caribbean as a region is expected to warm by between 1.4 and 3.2 degrees by the end of the current century. Largest warming is expected in SON. In comparison, for Jamaica, projected mean annual temperature increase across all models in the 15 GCM ensemble and across all scenarios is 1.1 to 3.2 degrees by the 2090s. The range of increase is 0.7 to 1.8˚C by the 2050s and 1.0-3.0˚C by the 2080s. Projected mean temperatures increase most rapidly over Jamaica in JJA.

The frequency of ‘hot’ Jamaican days and nights should continue to increase, reaching 30-98% of days annually by the 2090s. Recall that ‘hot’ is classified for each season according to recent climate standards. It is to be noted that the rate of increase varies substantially between models for each scenario, such that under A2 the most conservative increases result in a frequency of 49% by the 2080s, with other models indicating frequencies as high as 98%. 'Hot' days/nights are projected to increase most rapidly in JJA and SON, occurring on 60 to 100% of days/nights in JJA and SON by the 2080s.

'Cold' days/nights are projected to diminish in frequency, occurring on a maximum of 2% of days/nights by the 2080s, and do not occur at all in projections from some models by the 2050s. Cold days/nights decrease in frequency most rapidly in JJA.

The data for temperatures and extremes in temperatures are presented in Figures 6.3.1 through 6.3.3 and Tables 6.3.1 through 6.3.4.

A. Source: AR4 (IPCC, 2007). 21 model ensemble. http://www.ipcc.ch

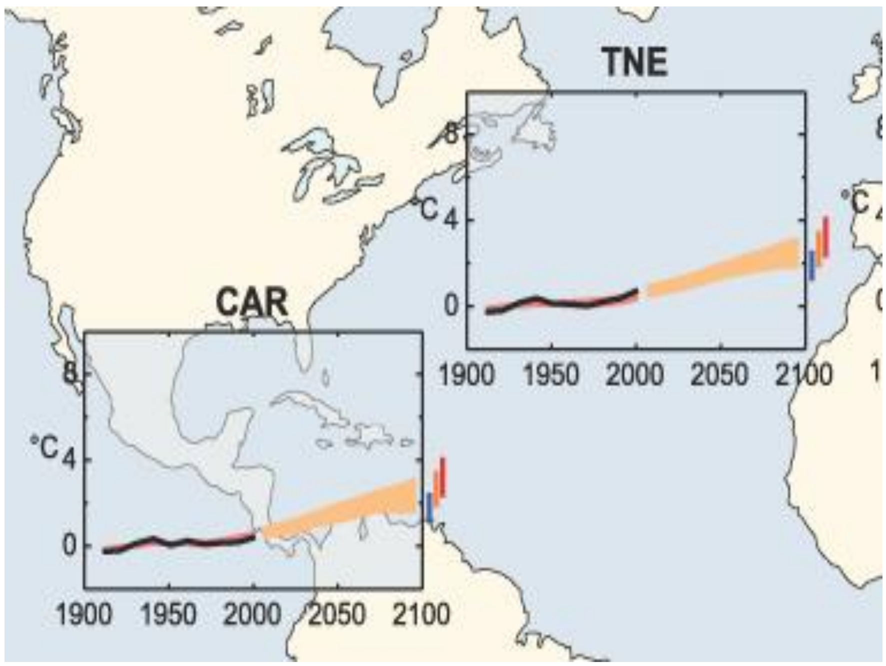

Figure 6.3.1: Temperature anomalies with respect to 1901 to 1950 for designated oceanic regions for 1906 to 2005 (black line) and as simulated (red envelope) by GCMs incorporating known forcings; and as projected for 2001 to 2100 by the models for the A1B scenario (orange envelope). The bars at the end of the orange envelope represent the range of projected changes for 2091 to 2100 for the B1 scenario (blue), the A1B scenario (orange) and the A2 scenario (red). The black line is dashed where observations are present for less than 50% of the area in the decade concerned. More details on the construction of these figures are given in Section 11.1.2 of IPCC (2007).

Table 6.3.1: Regional averages of temperature from a set of 21 global models for the A1B scenario. The table shows the minimum, maximum, median (50%), and 25 and 75% quartile values among the 21 models, for temperature (°C) change. Signal-to-noise ratios for these 20-year mean responses is computed. The frequency (%) of extremely warm seasons, averaged over the models, is also presented. Values are only shown when at least 14 out of the 21 models agree on an increase (bold) or a decrease in the extremes. (Source: IPCC 2007).

	Temperature Response (°C)							Extreme Seasons (%)	
	Season	**Min**	**25**	**50**	**75**	**Max**	**T yrs**	T yrs	Warm
CAR10N,85W to 25N,60W	DJF	1.4	1.8	2.1	2.4	3.2	10		100
	MAM	1.3	1.8	2.2	2.4	3.2	10	>100	100
	JJA	1.3	1.8	2.0	2.4	3.2	10	60	100
	SON	1.6	1.9	2.0	2.5	3.4	10		100
	Annual	1.4	1.8	2.0	2.4	3.2	10	60	100

B. Source: UNDP Climate Change Country Profiles (McSweeney et al, 2008). 15 model ensemble. http://country-profiles.geog.ox.ac.uk

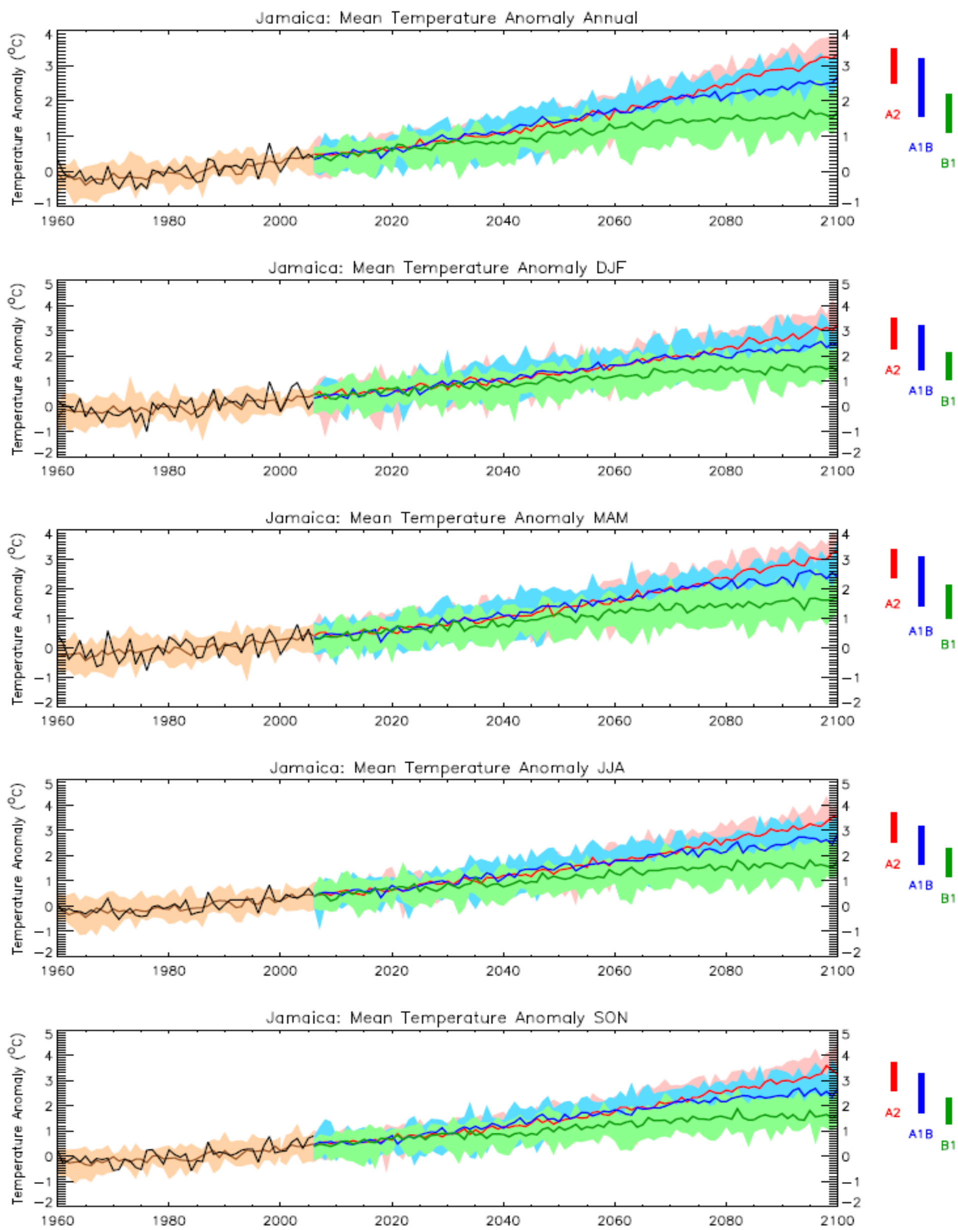

Figure 6.3.2: Trends in annual and seasonal mean temperature for the recent past and projected future. All values shown are anomalies, relative to the 1970-1999 mean climate. Black curves show the mean of observed data from 1960 to 2006, Brown curves show the median (solid line) and range (shading) of model simulations of recent climate across an ensemble of 15 models. Coloured lines from 2006 onwards show the median (solid line) and range (shading) of the ensemble projections of climate under three emissions scenarios. Coloured bars on the right-hand side of the projections summarise the range of mean 2090-2100 climates simulated by the 15 models for each emissions scenario.

Table 6.3.2: Observed trends and projected change in temperature, averaged over Jamaica, for the 2030s, 2060s and 2090s for annual change and seasonal changes. The projected changes for each season and for the annual mean are shown for the SRES emissions scenarios A2 (top row), A1B (middle row), and B1 (bottom row).

	Observed Mean 1970-1999	Observed Trend 1960-1999	Projected changes by the 2030s			Projected changes by the 2060s			Projected changes by the 2090s		
	(°C)	(°C/decade)	Change in °C			Change in °C			Change in °C		
			Min	**Median**	Max	Min	**Median**	Max	Min	**Median**	Max
Annual	26	0.14*	0.6 0.5 0.3	**1.0** **1.1** **0.8**	1.2 1.3 1.0	1.4 1.0 0.6	**1.9** **1.9** **1.4**	2.2 2.3 1.6	2.5 1.6 1.1	**3.0** **2.6** **1.5**	3.5 3.2 2.2
DJF	24.8	0.15*	0.6 0.4 0.3	**0.9** **1.0** **0.8**	1.2 1.3 1.1	1.3 1.0 0.6	**1.8** **1.8** **1.3**	2.0 2.2 1.6	2.3 1.4 1.1	**2.9** **2.4** **1.5**	3.5 3.2 2.1
MAM	25.6	0.11*	0.6 0.4 0.2	**0.9** **1.0** **0.8**	1.2 1.3 1.0	1.3 0.8 0.6	**1.8** **1.8** **1.2**	2.1 2.2 1.5	2.4 1.4 1.0	**3.0** **2.5** **1.6**	3.3 3.0 2.1
JJA	27.1	0.16*	0.6 0.5 0.3	**1.0** **1.1** **0.9**	1.3 1.5 1.2	1.4 1.0 0.6	**2.0** **1.9** **1.4**	2.4 2.4 1.7	2.5 1.7 1.2	**3.2** **2.6** **1.6**	3.7 3.1 2.3
SON	26.5	0.17*	0.7 0.6 0.5	**1.0** **1.1** **0.8**	1.2 1.3 1.1	1.3 1.1 0.7	**2.0** **1.9** **1.4**	2.3 2.4 1.7	2.5 1.8 1.3	**3.1** **2.6** **1.5**	3.7 3.3 2.3

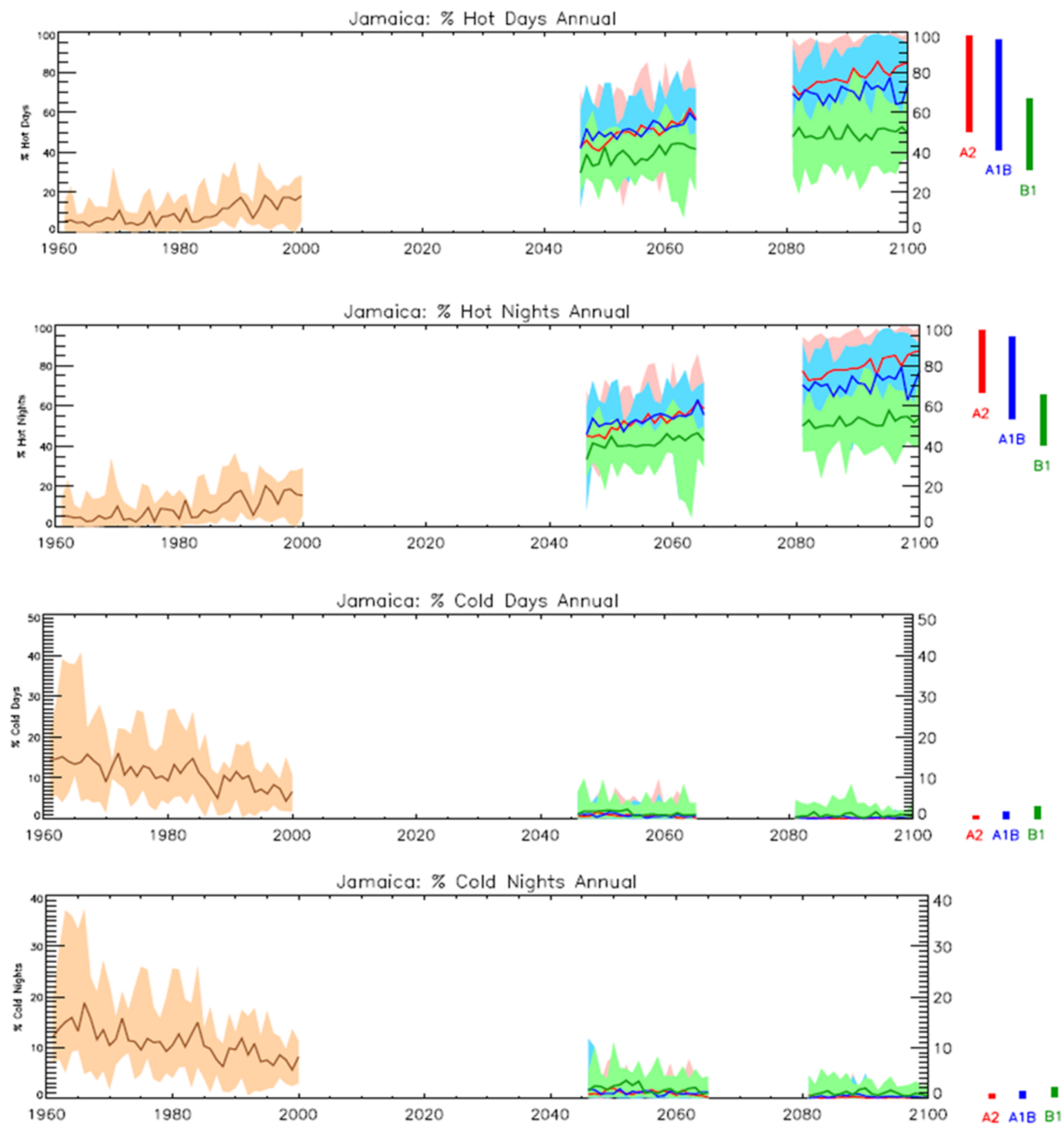

Figure 6.3.3: Trends in Hot-day, Hot-Night, Cold-Day, Cold-Night frequency for the recent past and projected future. See Figure 6.1.2 for details. 'Hot' day or 'hot' night is defined by the temperature exceeded on 10% of days or nights in current climate. Cold' days or 'cold' nights are defined as the temperature below which 10% of days or nights are recorded in current climate.

Table 6.3.3a: Projected change in Hot-days and Hot-Nights averaged over Jamaica, for the 2060s and 2090s for annual change and seasonal changes. The projected changes for each season and for the annual mean are shown for the SRES emissions scenarios A2 (top row), A1B (middle row), and B1 (bottom row). 'Hot' day or 'hot' night is defined by the temperature exceeded on 10% of days or nights in current climate.

	Projected changes by the 2060s			Projected changes by the 2090s		
	Future % Frequency			Future % Frequency		
	Min	**Median**	Max	Min	**Median**	Max
	Frequency of Hot Days (TX90p)					
Annual	32	**51**	73	49	**78**	98
	36	**53**	68	41	**71**	96
	27	**42**	53	30	**52**	66
DJF	52	**78**	92	84	**98**	100
	56	**82**	91	73	**96**	99
	34	**63**	79	58	**76**	93
MAM	39	**76**	97	70	**96**	99
	46	**81**	98	61	**94**	100
	32	**59**	96	37	**76**	99
JJA	67	**85**	95	89	**99**	100
	72	**86**	93	79	**97**	99
	43	**73**	80	59	**84**	96
SON	30	**86**	99	58	**98**	100
	33	**79**	99	42	**97**	99
	22	**66**	94	32	**85**	98
	Frequency of Hot Nights (TN90p)					
Annual	45	**51**	71	65	**79**	97
	41	**56**	67	54	**72**	94
	29	**46**	52	40	**54**	64
DJF	51	**73**	90	87	**96**	99
	49	**78**	88	79	**93**	98
	29	**60**	78	54	**73**	90
MAM	54	**71**	95	90	**95**	99
	45	**77**	96	78	**92**	99
	27	**58**	92	49	**76**	99
JJA	73	**87**	95	96	**99**	100
	68	**91**	93	91	**97**	99
	40	**76**	85	68	**88**	97
SON	74	**84**	98	93	**98**	100
	75	**88**	98	86	**97**	99
	51	**71**	92	70	**91**	96

Table 6.3.3b: Projected change in Cold-days and Cold-Nights averaged over Jamaica, for the 2060s and 2090s for annual change and seasonal changes. The projected changes for each season and for the annual mean are shown for the SRES emissions scenarios A2 (top row), A1B (middle row), and B1 (bottom row). Cold' days or 'cold' nights are defined as the temperature below which 10% of days or nights are recorded in current climate.

	Projected changes by the 2060s			Projected changes by the 2090s		
	Future % Frequency			Future % Frequency		
	Min	**Median**	Max	Min	**Median**	Max
	Frequency of Cold Days (TX10p)					
Annual	0	**0**	3	0	**0**	0
	0	**0**	2	0	**0**	1
	0	**1**	3	0	**1**	2
DJF	0	**0**	3	0	**0**	0
	0	**0**	1	0	**0**	1
	0	**1**	2	0	**1**	2
MAM	0	**0**	3	0	**0**	0
	0	**0**	3	0	**0**	1
	0	**0**	4	0	**0**	2
JJA	0	**0**	1	0	**0**	0
	0	**0**	0	0	**0**	2
	0	**0**	2	0	**0**	3
SON	0	**0**	1	0	**0**	0
	0	**0**	1	0	**0**	0
	0	**0**	4	0	**0**	2
	Frequency of Cold Nights (TN10p)					
Annual	0	**0**	2	0	**0**	0
	0	**1**	2	0	**0**	1
	0	**2**	3	0	**1**	2
DJF	0	**0**	3	0	**0**	0
	0	**0**	2	0	**0**	1
	0	**1**	4	0	**1**	2
MAM	0	**0**	2	0	**0**	0
	0	**0**	2	0	**0**	0
	0	**1**	3	0	**0**	2
JJA	0	**0**	0	0	**0**	0
	0	**0**	0	0	**0**	0
	0	**0**	3	0	**0**	0
SON	0	**0**	1	0	**0**	0
	0	**0**	2	0	**0**	0
	0	**0**	2	0	**0**	1

C. CARIBSAVE Climate Change Risk Atlas – Jamaica. (CARIBSAVE, 2011). 15 model ensemble.

Table 6.3.4: Projected change in temperature, averaged over Jamaica, for the 2020s, 2050s and 2080s for annual change and seasonal changes. The projected changes for each season and for the annual mean are shown for the SRES emissions scenarios A2 (top row), A1B (middle row), and B1 (bottom row).

Time Scale	Scenario	Projected Changes by the :								
		2020s			2050s			2080s		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
Annual	A2	0.4	0.7	0.9	1.0	1.6	1.7	2.0	2.7	3.0
	A1B	0.3	0.8	1.1	1.0	1.6	1.8	1.3	2.3	2.9
	B1	0.4	0.8	0.9	0.7	1.1	1.4	1.0	1.5	2.0
DJF	A2	0.4	0.7	0.9	0.8	1.5	1.8	1.8	2.5	3.0
	A1B	0.3	0.7	1.0	0.9	1.4	1.9	1.2	2.2	2.8
	B1	0.4	0.7	0.9	0.5	1.1	1.4	0.9	1.4	2.0
MAM	A2	0.4	0.7	0.9	0.9	1.5	1.7	1.8	2.7	2.9
	A1B	0.2	0.7	1.1	0.9	1.5	1.8	1.2	2.3	2.7
	B1	0.3	0.7	0.9	0.6	1.1	1.4	0.8	1.5	1.9
JJA	A2	0.4	0.8	1.0	0.9	1.7	1.8	2.1	2.9	3.1
	A1B	0.4	0.8	1.1	1.1	1.7	1.9	1.4	2.3	2.9
	B1	0.3	0.7	0.9	0.8	1.2	1.4	1.0	1.6	2.0
SON	A2	0.5	0.8	1.0	1.0	1.6	1.8	2.2	2.8	3.1
	A1B	0.3	0.8	1.1	1.1	1.7	2.0	1.5	2.4	3.1
	B1	0.4	0.8	1.0	0.7	1.2	1.4	1.1	1.5	2.0

6.4 RAINFALL

Summary

GCM projections of future rainfall for the Caribbean span both overall increases and decreases, but most models project decreases, especially by the end of the century (-39% to +11%). The drying will firmly establish itself somewhere in the middle of the current century as indicated by the T values in Table 6.4.1. This implies that, until then, inter-annual variability will be a strong part of the rainfall pattern, i.e. superimposed upon the drying trend. By the end of the century there is only a 3% chance of an extremely wet year compared to present day conditions but a 39% chance of an extremely dry year (see Table 6.4.1).

The same statements can be made of GCM projections for Jamaica, but with higher projected values, especially by the end of the century. Projected rainfall changes range from -44% to +18% by the 2050s and -55% to +18% by the 2080s. The overall decrease in annual rainfall is strongly impacted by decreased JJA (early wet season) and SON (late wet season) rainfall.

The projections of rainfall extremes are mixed across the ensemble, ranging across both decreases and increases in all measures of extreme rainfall. There is a tendency for decreases in rainfall extremes particularly in MAM. By the 2080s the range of changes is -19 to +9% for the proportion of rainfall during heavy events and -29 mm to +25 mm for 5-day maximum rainfall.

The data for temperatures and extremes in rainfall are presented in Figures 6.4.1 through 6.4.3 and Tables 6.4.1 through 6.4.4.

A. Source: AR4 (IPCC, 2007). 21 model ensemble. http://www.ipcc.ch

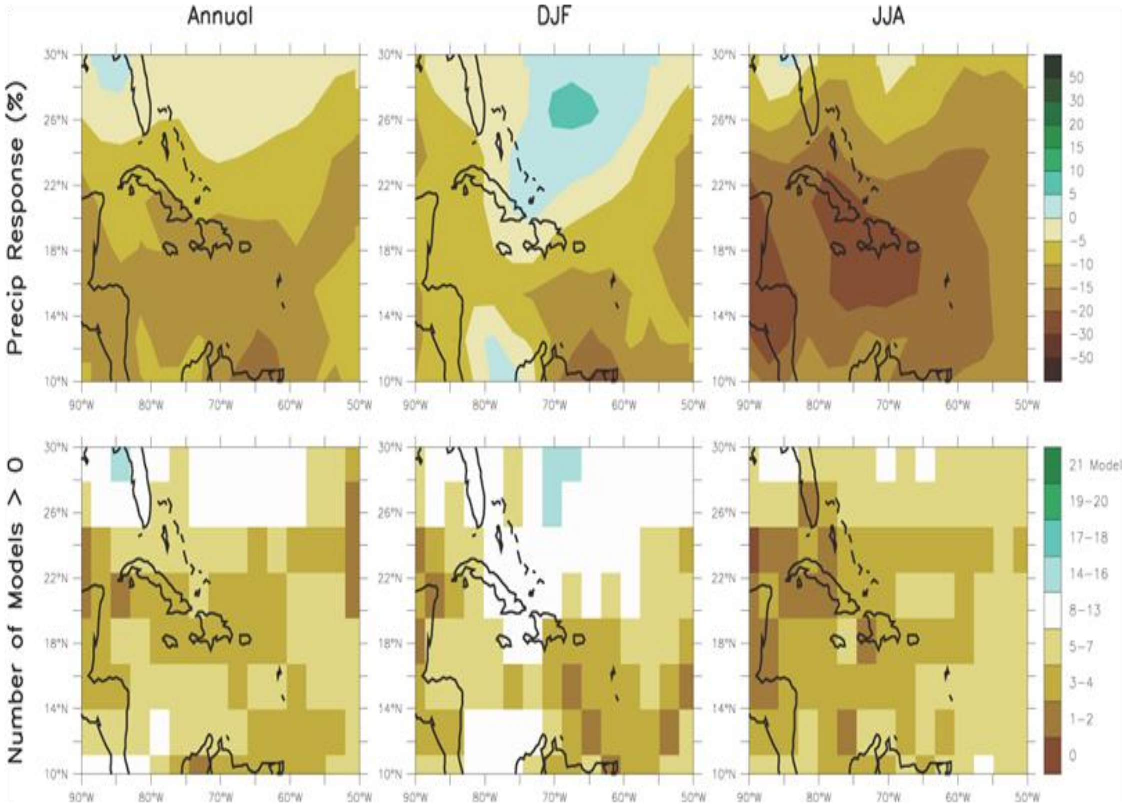

Figure 6.4.1: Precipitation changes over the Caribbean from the A1B simulations. Top row: Annual mean, DJF and JJA fractional precipitation change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Bottom row: number of models out of 21 that project increases in precipitation.

Table 6.4.1: Regional averages of precipitation projections from a set of 21 global models for the A1B scenario. The table shows the minimum, maximum, median (50%), and 25 and 75% quartile values among the 21 models, for precipitation (%) change. Regions in which the middle half (25–75%) of this distribution is all of the same sign in the precipitation response are coloured light brown for decreasing and light blue for increasing precipitation. Signal-to-noise ratios for these 20-year mean responses is computed. These estimates of the times for emergence of a clearly discernible signal are only shown for precipitation when the models are in general agreement on the sign of the response, as indicated by the colouring. The frequency (%) of wet and dry seasons, averaged over the models, is also presented. Values are only shown when at least 14 out of the 21 models agree on an increase (bold) or a decrease in the extremes. (Source: IPCC 2007).

		Precipitation Response (%)					Extreme Seasons (%)		
CAR10N,85W to 25N,60W	**Season**	**Min**	**25**	**50**	**75**	**Max**	**T yrs**	**Wet**	**Dry**
	DJF	-21	-11	-6	0	10		2	
	MAM	-28	-20	-13	-6	6	>100	3	18
	JJA	-57	-35	-20	-6	8	60	2	40
	SON	-38	-18	-6	1	19			22
	Annual	-39	-19	-12	-3	11	60	3	39

B. Source: UNDP Climate Change Country Profiles (McSweeney et al, 2008). 15 model ensemble. http://country-profiles.geog.ox.ac.uk

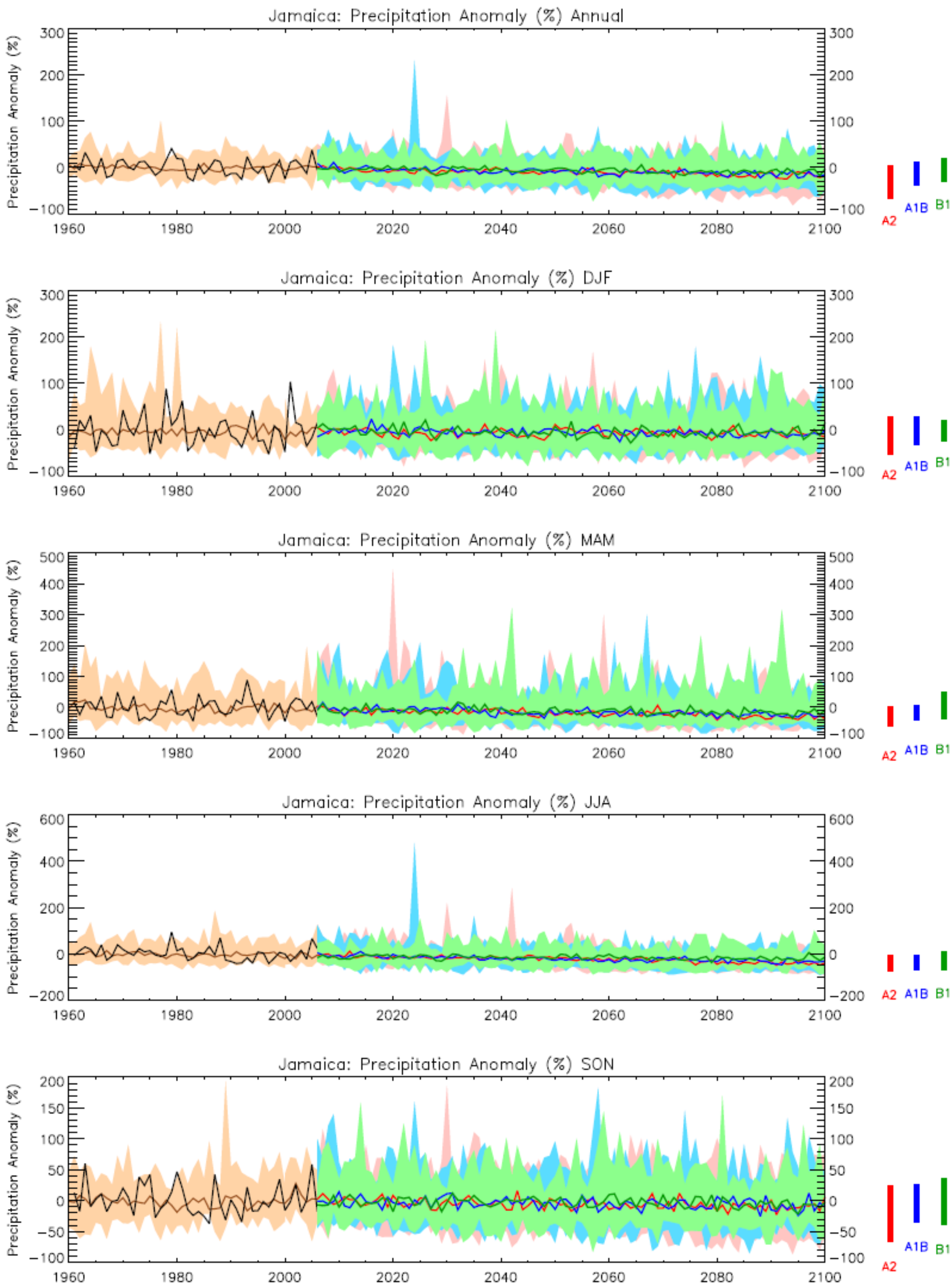

Figure 6.4.2: Trends in monthly precipitation for the recent past and projected future. All values shown are percentage anomalies, relative to the 1970-1999 mean climate. See Figure 6.3.2 for details.

Table 6.4.2: Observed trends and projected change in precipitation (%), averaged over Jamaica, for the 2030s, 2060s and 2090s for annual change and seasonal changes. The projected changes for each season and for the annual mean are shown for the SRES emissions scenarios A2 (top row), A1B (middle row), and B1 (bottom row).

	Observed Mean 1970-1999	Observed Trend 1960-1999	Projected changes by the 2030s			Projected changes by the 2060s			Projected changes by the 2090s		
	(mm/month)	(% change /decade)	% Change			% Change			% Change		
			Min	**Median**	Max	Min	**Median**	Max	Min	**Median**	Max
Annual	155.2	-1.6	-35	**-3**	17	-45	**-10**	9	-65	**-14**	3
			-32	**-7**	9	-51	**-7**	15	-36	**-13**	11
			-20	**-2**	10	-34	**-5**	9	-30	**-6**	22
DJF	107.2	0.2	-31	**1**	25	-37	**-3**	18	-52	**-4**	26
			-28	**-7**	7	-45	**-5**	17	-33	**-4**	30
			-21	**0**	33	-28	**-7**	12	-24	**-2**	20
MAM	142.4	1.3	-33	**-5**	38	-49	**-9**	4	-59	**-24**	0
			-36	**-3**	22	-46	**-9**	26	-40	**-23**	5
			-20	**-2**	47	-43	**-6**	28	-35	**-10**	51
JJA	141.0	-4.4	-38	**-13**	22	-59	**-20**	-5	-72	**-32**	-3
			-36	**-14**	2	-55	**-19**	-9	-72	**-23**	-9
			-28	**-8**	15	-56	**-7**	7	-65	**-16**	12
SON	227.6	-2	-35	**-3**	29	-46	**-5**	39	-66	**-4**	24
			-40	**-2**	34	-51	**0**	31	-34	**-2**	25
			-23	**0**	15	-31	**0**	19	-36	**-7**	38
			-35	**-3**	17	-45	**-10**	9	-65	**-14**	3

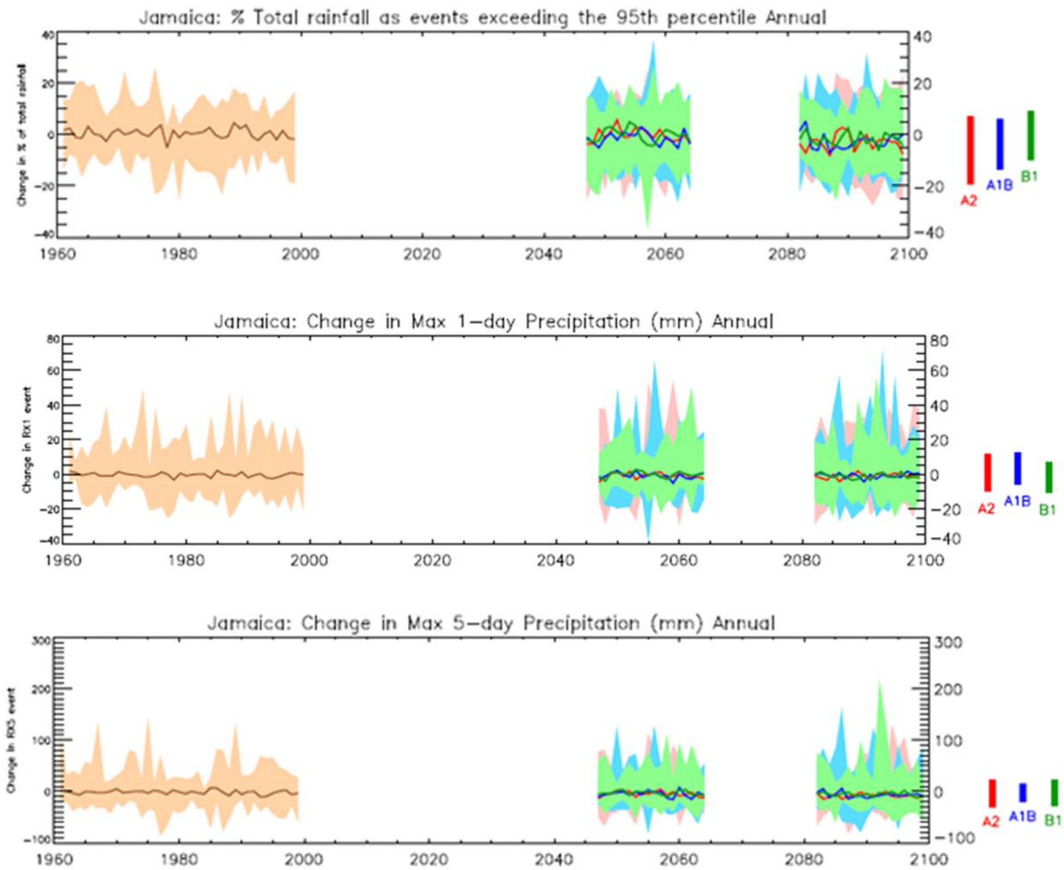

Figure 6.4.3: Trends in the proportion of precipitation falling in 'heavy' events, maximum 1-day rainfall, and maximum 5-day rainfall for the recent past and projected future. All values shown are anomalies, relative to the 1970-1999 mean climate. See Figure 6.3.2 for details. A 'Heavy' event is defined as a daily rainfall total which exceeds the threshold that is exceeded on 5% of rainy days in current climate.

Table 6.4.3a: Projected change in proportion of precipitation falling in ’heavy’ events (%) and maximum 1-day rainfall (mm) averaged over Jamaica, for the 2060s and 2090s for annual change and seasonal changes. The projected changes for each season and for the annual mean are shown for the SRES emissions scenarios A2 (top row), A1B (middle row), and B1 (bottom row). A ‘Heavy’ event is defined as a daily rainfall total which exceeds the threshold that is exceeded on 5% of rainy days in current climate.

	Projected changes by the 2060s			Projected changes by the 2090s		
	Min	**Median**	Max	Min	**Median**	Max
	% total rainfall falling in Heavy Events (R95pct) (change in %)					
Annual	-11	**0**	6	-19	**-1**	7
	-13	**0**	4	-13	**-1**	5
	-14	**0**	6	-8	**-2**	9
DJF	-14	**-1**	12	-16	**-3**	13
	-13	**0**	11	-14	**-5**	11
	-12	**-2**	7	-15	**2**	8
MAM	-16	**-4**	2	-25	**-10**	4
	-24	**-5**	3	-18	**-8**	2
	-13	**-6**	8	-15	**-1**	11
JJA	-19	**-1**	5	-25	**-8**	8
	-13	**-4**	4	-20	**-6**	8
	-18	**0**	6	-19	**-4**	12
SON	-11	**-1**	6	-17	**0**	8
	-12	**-1**	6	-13	**0**	8
	-10	**0**	8	-15	**0**	4
	Maximum 1-day rainfall (RX1day) (change in mm)					
Annual	-9	**0**	9	-10	**0**	11
	-4	**0**	6	-5	**0**	14
	-6	**1**	7	-9	**0**	6
DJF	-5	**0**	6	-4	**0**	4
	-4	**0**	8	-3	**-1**	6
	-2	**-1**	3	-4	**0**	2
MAM	-5	**0**	2	-8	**-2**	5
	-4	**-1**	3	-5	**-1**	5
	-6	**0**	2	-7	**0**	4
JJA	-7	**-1**	4	-7	**-2**	5
	-5	**-2**	7	-6	**-1**	6
	-7	**0**	5	-11	**-1**	2
SON	-7	**0**	8	-8	**0**	12
	-9	**0**	7	-7	**0**	8
	-4	**0**	5	-3	**0**	4

Table 6.4.3b: Projected change in maximum 5-day rainfall (mm) averaged over Jamaica, for the 2060s and 2090s for annual change and seasonal changes. The projected changes for each season and for the annual mean are shown for the SRES emissions scenarios A2 (top row), A1B (middle row), and B1 (bottom row).

	Projected changes by the 2060s			Projected changes by the 2090s		
	Min	**Median**	Max	Min	**Median**	Max
	Maximum 5-day Rainfall (RX5day) (change in mm)					
Annual	-18	**-1**	18	-29	**-3**	23
	-22	**-3**	11	-19	**-4**	19
	-15	**0**	21	-25	**-1**	25
DJF	-10	**0**	16	-12	**-1**	9
	-10	**0**	27	-10	**-3**	14
	-7	**-2**	4	-11	**0**	5
MAM	-11	**-4**	10	-16	**-7**	18
	-9	**-4**	11	-10	**-4**	9
	-15	**-2**	11	-13	**0**	13
JJA	-16	**-3**	9	-23	**-9**	7
	-16	**-8**	10	-21	**-7**	4
	-16	**-3**	19	-25	**-7**	5
SON	-20	**-1**	14	-32	**-2**	27
	-25	**0**	15	-26	**-1**	16
	-12	**0**	18	-17	**-1**	20

C. CARIBSAVE Climate Change Risk Atlas – Jamaica. (CARIBSAVE, 2011). 15 model ensemble.

Table 6.4.4: Projected change in temperature, averaged over Jamaica, for the 2020s, 2050s and 2080s for annual change and seasonal changes. The projected changes for each season and for the annual mean are shown for the SRES emissions scenarios A2 (top row), A1B (middle row), and B1 (bottom row).

Time Scale	Scenario	Projected Changes by the :								
		2020s			2050s			2080s		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
Annual	A2	-10	-2	0	-27	-4	7	-40	-8	1
	A1B	-20	0	11	-29	-3	4	-27	-8	11
	B1	-13	-3	11	-16	-3	7	-23	-6	8
DJF	A2	-9	-4	5	-13	0	20	-18	-1	17
	A1B	-7	-2	19	-16	0	8	-14	-3	21
	B1	-11	-1	11	-8	-2	6	-15	0	4
MAM	A2	-7	-2	12	-13	-5	8	-26	-7	0
	A1B	-13	0	14	-17	-1	4	-12	-6	5
	B1	-12	-2	7	-13	0	17	-13	-3	15
JJA	A2	-21	-6	3	-46	-15	23	-64	-32	-5
	A1B	-34	-7	36	-47	-13	5	-54	-24	0
	B1	-24	-10	3	-20	-5	7	-34	-14	6
SON	A2	-19	0	8	-38	-1	21	-53	-2	26
	A1B	-32	1	32	-43	0	18	-49	-2	49
	B1	-28	-5	43	-31	-4	19	-37	-9	25

6.5 OTHER VARIABLES – WIND, RELATIVE HUMIDITY, SUNSHINE HOURS, SEA SURFACE TEMPERATURES

Summary

The GCM projections generally indicate an increase in mean wind speeds over Jamaica. Changes in annual average wind speeds range between -0.1 and +0.5 ms^{-1} by the 2080s across all models and emission scenarios. The greatest increases occur in MAM and JJA, ranging between -0.5 and +1.3ms^{-1} and -0.2 to 1.2ms^{-1} respectively by the 2080s.

Though relative humidity (RH) data are not available for all models in the 15-model ensemble, projections from those models for which the data are available tend towards small increases in RH, particularly in DJF and MAM. Care must be taken in interpreting the relative humidity data since many of the GCMs do not explicitly represent Jamaica and therefore only see ocean. RH over land and ocean can differ significantly.

Most models project an increase in sunshine hours over Jamaica by the end of the century. This likely reflects reductions in average cloud cover fractions as the country tends towards drier conditions. Under the A2 scenario, the changes in annual average sunshine hours span -0.2 to +0.9 hours per day, with largest increases in JJA (-0.9 to +1.9 hours per day by the 2080s).

GCM projections indicate continuing increases in sea-surface temperatures for the waters surrounding Jamaica. Projected increases range between +0.9˚C and +2.7˚C by the 2080s. Increases tend to be fractionally higher in SON than in other seasons (1.0˚ to 2.9˚C by 2080).

Changes in wind strength, relative humidity, sunshine hours and sea surface temperatures are given in Table 6.5.1.

Source: CARIBSAVE Climate Change Risk Atlas – Jamaica. (CARIBSAVE, 2011). 15 model ensemble.

Table 6.5.1a: Projected change in wind speed (m/s), relative humidity (%), sunshine hours (hours), and sea surface temperatures (^{o}C) averaged over Jamaica, for the 2020s for annual change and seasonal changes. The projected changes for each season and for the annual mean are shown for the SRES emissions scenarios A2, A1B and B1.

Projected changes by the 2020s										
		Min			**Median**			**Max**		
		A2	**A1B**	**B1**	**A2**	**A1B**	**B1**	**A2**	**A1B**	**B1**
Wind	**Annual**	-0.2	-0.2	-0.2	**0.0**	**0.0**	**0.1**	0.1	0.1	0.1
	DJF	-0.5	-0.4	-0.4	**0.0**	**0.1**	**0.0**	0.4	0.3	0.2
	MAM	-0.2	-0.4	-0.2	**0.0**	**0.2**	**0.2**	0.4	0.4	0.5
	JJA	-0.4	-0.2	-0.3	**-0.1**	**-0.1**	**0.0**	0.2	0.0	0.1
	SON	-0.3	-0.5	-0.3	**-0.1**	**0.0**	**0.0**	0.1	0.2	0.1
Relative Humidity	**Annual**		-0.1	-0.6		**0.5**	**-0.2**		1.4	1.4
	DJF		-0.4	-0.7		**0.5**	**-0.1**		1.6	1.2
	MAM		-0.1	-0.3		**0.8**	**0.2**		2.0	1.7
	JJA		-0.1	-1.6		**0.1**	**-0.4**		1.0	1.5
	SON		0.1	-0.5		**1.0**	**-0.3**		1.6	1.1
Sunshine Hours	**Annual**	-0.2	-0.3	-0.4	**0.2**	**0.0**	**0.2**	0.5	0.4	0.3
	DJF	0.0	-0.2	-0.1	**0.2**	**0.0**	**0.0**	0.5	0.3	0.3
	MAM	-0.4	-0.6	-0.8	**0.1**	**0.1**	**0.2**	0.4	0.3	0.5
	JJA	-0.5	-0.7	-0.4	**0.2**	**0.2**	**0.3**	1.0	0.7	0.6
	SON	-0.1	-0.5	-0.5	**0.1**	**0.0**	**0.1**	0.6	0.4	0.6
Sea Surface Temperature	**Annual**	0.5	0.3	0.3	**0.7**	**0.7**	**0.6**	0.9	0.8	0.8
	DJF	0.3	0.3	0.3	**0.7**	**0.7**	**0.6**	0.9	0.8	0.8
	MAM	0.5	0.2	0.2	**0.7**	**0.6**	**0.6**	0.8	0.8	0.8
	JJA	0.5	0.3	0.2	**0.7**	**0.7**	**0.6**	0.8	0.9	0.8
	SON	0.5	0.4	0.3	**0.7**	**0.7**	**0.7**	0.9	0.9	0.8

Table 6.5.1b: Projected change in wind speed (m/s), relative humidity (%), sunshine hours (hours), and sea surface temperatures (^{o}C) averaged over Jamaica, for the 2050s for annual change and seasonal changes. The projected changes for each season and for the annual mean are shown for the SRES emissions scenarios A2, A1B and B1.

Projected changes by the 2050s										
		Min			Median			Max		
		A2	A1B	B1	A2	A1B	B1	A2	A1B	B1
Wind	Annual	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.1	0.2	0.2
	DJF	-0.7	-0.1	-0.2	-0.1	0.0	0.0	0.3	0.5	0.1
	MAM	-0.4	-0.3	-0.2	0.2	0.0	0.2	0.5	0.6	0.4
	JJA	-0.2	-0.1	-0.2	-0.1	0.0	0.1	0.3	0.3	0.5
	SON	-0.4	-0.4	-0.6	-0.1	-0.1	0.0	0.0	0.0	0.2
Relative Humidity	Annual		-0.7	-0.3		0.4	0.3		1.5	2.4
	DJF		-0.3	-0.6		0.7	0.1		1.5	2.3
	MAM		-0.1	0.4		0.7	0.6		2.1	4.0
	JJA		-1.7	-0.7		0.4	0.1		1.1	2.0
	SON		-0.8	-0.6		0.5	0.0		1.3	1.5
Sunshine Hours	Annual	-0.3	-0.2	-0.1	0.2	0.2	0.2	0.6	0.4	0.5
	DJF	-0.3	-0.4	-0.4	0.2	0.2	0.1	0.4	0.5	0.3
	MAM	-0.4	-0.8	-0.6	0.2	0.2	0.0	0.6	0.5	0.4
	JJA	-0.8	-0.3	-0.5	0.2	0.0	0.5	1.2	0.9	0.8
	SON	-0.6	-0.2	-0.4	0.2	0.0	0.1	0.7	0.7	0.9
Sea Surface Temperature	Annual	1.0	0.9	0.6	1.3	1.5	1.0	1.6	1.6	1.2
	DJF	0.8	0.9	0.4	1.3	1.4	1.0	1.7	1.7	1.3
	MAM	0.9	0.8	0.5	1.3	1.4	0.9	1.6	1.5	1.3
	JJA	1.2	1.0	0.7	1.3	1.5	1.1	1.7	1.7	1.2
	SON	1.0	1.0	0.7	1.4	1.5	1.1	1.7	1.8	1.3

Table 6.5.1c: Projected change in wind speed (m/s), relative humidity (%), sunshine hours (hours), and sea surface temperatures (^{o}C) averaged over Jamaica, for the 2080s for annual change and seasonal changes. The projected changes for each season and for the annual mean are shown for the SRES emissions scenarios A2, A1B and B1.

Projected changes by the 2080s										
		Min			**Median**			**Max**		
		A2	**A1B**	**B1**	**A2**	**A1B**	**B1**	**A2**	**A1B**	**B1**
Wind	**Annual**	-0.1	-0.2	-0.1	0.2	0.1	0.0	0.5	0.3	0.1
	DJF	-0.6	-0.7	-0.4	0.0	-0.1	0.0	0.3	0.3	0.2
	MAM	-0.1	-0.5	-0.4	0.2	0.2	0.1	1.3	0.7	0.4
	JJA	-0.2	-0.2	-0.1	0.1	0.2	0.0	1.2	1.0	0.5
	SON	-0.5	-0.5	-0.4	0.0	0.0	0.0	0.4	0.2	0.2
Relative Humidity	**Annual**		-1.2	-0.8		0.9	0.5		1.0	1.5
	DJF		-1.1	-0.7		1.0	-0.2		1.7	1.8
	MAM		0.4	-0.1		1.0	0.4		2.1	2.3
	JJA		-2.7	-1.6		0.3	0.4		1.1	0.8
	SON		-2.0	-1.3		0.5	0.3		0.8	1.9
Sunshine Hours	**Annual**	-0.2	-0.3	-0.2	0.4	0.3	0.3	0.9	0.8	0.6
	DJF	-0.5	-0.5	-0.1	0.3	0.2	0.0	0.6	0.7	0.6
	MAM	-1.1	-0.8	-0.5	0.3	-0.1	0.1	0.8	0.7	0.7
	JJA	-0.9	-0.7	-0.4	0.8	0.8	0.6	1.9	1.6	1.2
	SON	-0.4	-0.5	-0.6	0.4	0.3	0.1	1.0	1.1	0.6
Sea Surface Temperature	**Annual**	1.9	1.3	0.9	2.3	2.2	1.4	2.7	2.8	1.8
	DJF	1.8	1.3	0.9	2.2	2.1	1.3	2.8	2.6	1.9
	MAM	1.7	1.1	0.7	2.3	2.1	1.3	2.7	2.5	1.8
	JJA	2.0	1.3	0.9	2.4	2.2	1.4	2.7	2.5	1.7
	SON	2.0	1.5	1.0	2.5	2.3	1.4	2.9	2.9	1.8

6.6 HURRICANES

"The IPCC AR4 (Meehl et al., 2007) concludes that models are broadly consistent in indicating increases in precipitation intensity associated with tropical storms (e.g. Knutson and Tuleya, 2004; Knutson et al., 2008; Chauvin et al., 2006; Hasegawa and Emori, 2005; Tsutsui, 2002). The higher resolution models that simulate storms more credibly are also broadly consistent in indicating increases in associated peak wind intensities and mean rainfall (Knutson and Tuleya, 2004; Oouchi et al., 2006). With regards to the frequency of tropical storms in future climate, models are strongly divergent. Several recent studies (e.g. Vecchi and Sodon, 2007; Bengtssen et al., 2007; Emanuel et al., 2008, Knutson et al., 2008) have indicated that the frequency of storms may decrease due to decreases in vertical wind shear in a warmer climate. In several of these studies, intensity of hurricanes still increases despite decreases in frequency (Emanuel et al., 2008; Knutson et al., 2008). In a recent study of the PRECIS regional climate model simulations for Central America and the Caribbean, Bezanilla et al., (2009) found that the frequency of 'Tropical -Cyclone-Like –Vortices' increases on the Pacific coast of Central America, but decreases on the Atlantic coast and in the Caribbean." – ***CARIBSAVE Climate Change Risk Atlas – Jamaica(2011)***

Table 6.6.1: Changes in near-storm rainfall and wind intensity associated with Tropical Storms under global warming scenarios.

Reference	GHG Scenario	Type of Model	Domain	Change in near storm rainfall activity	Change in peak wind intensity
Knutson et al., (2008)	A1B	Regional Climate Model (RCM)	Atlantic	(+37, 23, 10)% when averaged within 50, 100 and 400 km of the storm centre	+2.9%
Knutson and Tuleya (2004)	1% per year CO_2 increase	9 GCMs + nested RCM with 4 different moist convection schemes	Global	+12 - 33 %	+5 – 7 %
Oouchi et al (2006)	A1B	High Resolution GCM	Global	N/A	+14%
			North Atlantic		+20%

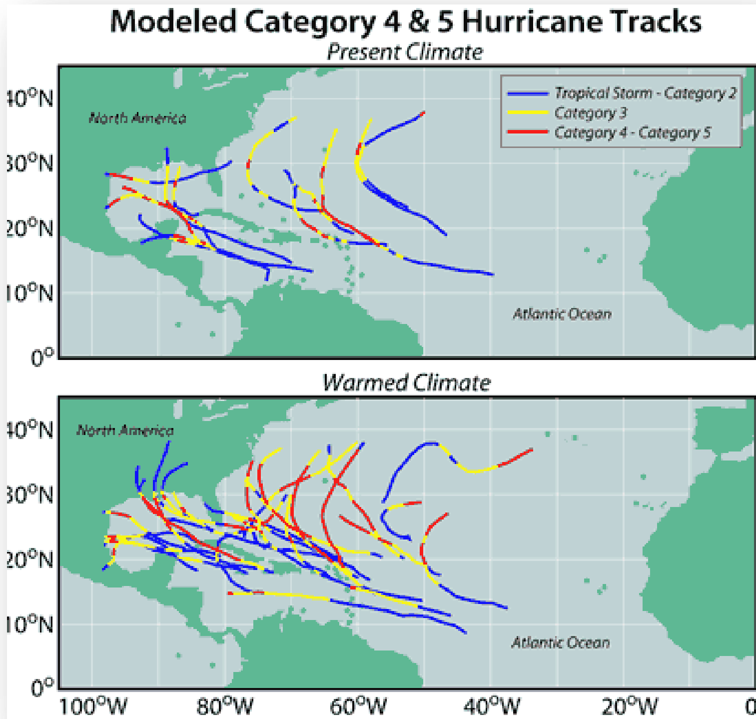

Figure 6.6.1: Simulated current and future Category 3-5 storms based on downscaling of an ensemble mean of 18 global climate change models. The figure shows nearly a doubling of the frequency of category 4 and 5 storms by the end of the 21st century, despite a decrease in the overall frequency of tropical cyclones. (Bender et al., 2010)

6.7 Storm Surge

"Changes to the frequency or magnitude of storm surge experienced at coastal locations in Jamaica are likely to occur as a result of the combined effects of: (a) Increased mean sea level in the region, which raises the base sea level over which a given storm surge height is superimposed. (b) Changes in storm surge height, or frequency of occurrence, resulting from changes in the severity or frequency of storms. (c) Physical characteristics of the region (bathymetry and topography) which determine the sensitivity of the region to storm surge by influencing the height of the storm surge generated by a given storm. [There is a high degree of uncertainty in projecting potential changes in sea level and hurricane intensity that might be experienced in the region under (global) warming scenarios. This creates difficulties in estimating future changes in storm surge height or frequency.]" ***– CARIBSAVE Climate Change Risk Atlas – Jamaica (2011)***

Table 6.7.1: Approximate future return periods for storm surge static water levels that would flood current elevations above sea level at Sangster International Airport. Data based on empirical examination of modelled return periods by Smith Warner International Ltd for most likely elevations at Sangster (SWIL 1999). Wave run-up not included. Source: Robinson and Khan (2008).

Approximate return periods (years) for flooding the current elevation.				
Sangster International	Current Elevations	Present day return period SWIL 1999	2050 Projection (based on IPCC, 2007 SLR Projections)	2050 Projection (based on Rahmstorf, 2007 SLR Projections)
	0.5	3.5 – 4.0	About 2	1.5
	1.0	7	About 5.5	5
	1.5	15	11.5	9
	2.0	100	56	33

6.8 Sea Level Rise

"Projections of future SLR associated with climate change have recently become a topic of heated debate in scientific research. The IPCC's AR4 report summarised a range of SLR projections under each of its standard scenarios, for which the combined range spans 0.18-0.59 m by 2100 relative to 1980-1999 levels (see Table below). These estimates have since been challenged for being too conservative and a number of studies (e.g. Rahmstorf, 2007; Rignot and Kanargaratnam, 2006; Horton et al., 2008) have provided evidence to suggest that their uncertainty range should include a much larger upper limit.

Total sea level rises associated with atmospheric warming appear largely through the combined effects of two main mechanisms: (a) thermal expansion (the physical response of the water mass of the oceans to atmospheric warming) and (b) ice-sheet, ice-cap and glacier melt. Whilst the rate of thermal expansion of the oceans in response to a given rate of temperature increase is projected relatively consistently between GCMs, the rate of ice melt is much more difficult to predict due to our incomplete understanding of ice-sheet dynamics. The IPCC total SLR projections comprise of 70-75% (Meehl et al., 2007a) contribution from thermal expansion, with only a conservative estimate of the contribution from ice sheet melt (Rahmstorf, 2007).

*Recent studies that observed acceleration in ice discharge (e.g. Rignot and Kanargaratnam, 2006) and observed rates of SLR in response to global warming (Rahmstorf, 2007), suggest that ice sheets respond highly-non linearly to atmospheric warming. We might therefore expect continued acceleration of the large ice sheets resulting in considerably more rapid rates of SLR. Rahmstorf (2007) is perhaps the most well cited example of such a study and suggests that future SLR might be in the order of twice the maximum level that the IPCC, indicating up to 1.4m by 2100." **– CARIBSAVE Climate Change Risk Atlas – Jamaica (2011).***

Table 6.8.1: Projected increases in sea level rise from the IPCC AR4

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 1.45m

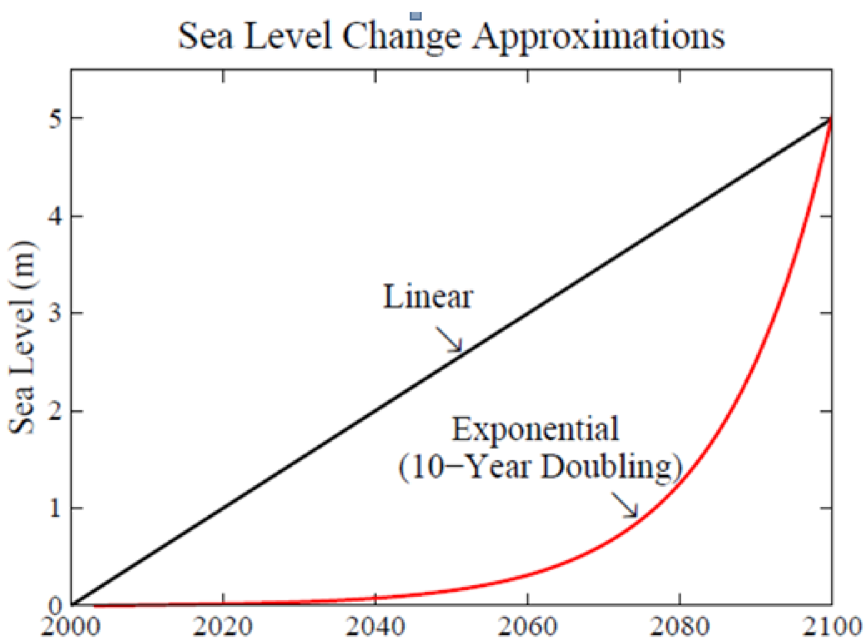

Figure 6.8.1: Five meter sea level rise in the 21st century (in red) under the assumption of exponential change with a 10 year doubling time for the mass of ice lost (after Hansen, 2007)

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7. RCM PROJECTIONS

7.1 ABOUT THE CHAPTER

In this chapter we provide projections for Jamaica from the RCMs. The projections are compiled from two sources:

a) Climate Studies Group, Mona (CSGM) PRECIS analyses
b) The CARIBSAVE Climate Change Risk Atlas for Jamaica.

In both cases, the data come from the PRECIS regional model run as a part of the PRECIS-Caribbean Initiative (Taylor et al., 2007). A brief summary of the initiative and the methodology used was given in Chapter 5. For now, PRECIS data represent the only RCM data available for the countries of the Caribbean.

Because of the resolution of the PRECIS model (50 km), data for Jamaica exists for 12 grid boxes located over the island. Figure 7.1.1 below shows the grid boxes. This compares to one or at most two grid boxes from the GCMs. All grid boxes are a combination of land and ocean in differing proportions. Where a single projection is provided it is an average of the change simulated over all the grid boxes. Otherwise projections are given for each grid box or compared for west to east changes across the island as follows:

a) West- boxes 2, 3, 8, 9
b) Centre- boxes 1, 4, 5, 10, 11
c) East- box 6

Projections are provided for mean temperature and rainfall, and other climate variables including wind speed, relative humidity, and sunshine hours. The following are also noted about the projections presented:

- The projections are only presented for the end of the century (2080s). New PRECIS simulations capturing the short and medium term have just been completed. However, the data are not yet available.
- The projections presented from the CSGM source are for the PRECIS model forced by the HadCM3 GCM (see again Chapter 5). Projections from the CAIBSAVE atlas are for the model forced by HadCM3 and ECHAM4.
- The projections are presented for the B2 (low) and A2 (high) scenarios, as described in the IPCC Special Report on Emissions Scenarios (see Figure 5.2.1 ad 5.2.2 of the previous chapter).
- The projections are presented as changes with respect to present-day climate. In some cases, absolute change is given. In the case of rainfall it is percentage change which is given. This makes knowledge of the mean state important (i.e. as described in Chapter 3) as the changes are with respect to this mean state.
- Projections are presented for three month seasons defined as DJF (December – February), MAM (March – May), JJA (June – August), SON (September – November), and as an annual change.

The following sections examine projections for Jamaica for the selected climate variables. In each case a summary of what the data suggests about the change in the variable or phenomenon is first given followed by plots and tables from which the reader can extract more details as needed.

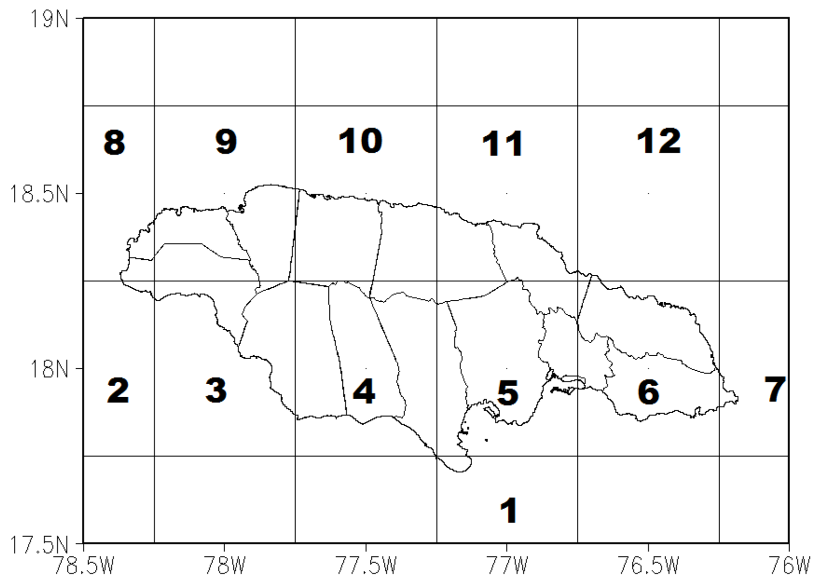


Figure 7.1.1: PRECIS RCM grid box representation at a resolution of 50 Km over Jamaica.

7.2 TEMPERATURES

Summary

The RCM generally indicates much more rapid increases in temperature over Jamaica than any of the models in the GCM ensemble (Chapter 6) when similar scenarios are compared. RCM projections indicate increases of 2.9˚C and 3.4˚C by the 2080s, when driven by ECHAM4 and HadCM3, respectively, compared with GCM ensemble projections of 1.0-3.0˚C. The increased rate of warming is due to the improved spatial resolution which allows the land mass of Jamaica to be represented. Land surfaces warm more rapidly than the ocean. Grid boxes 3, 4, 5 and 6 experience slighter higher warming than all the others suggesting that southern Jamaica warms faster than northern Jamaica. Greatest warming will occur in JJA (up to 5 degrees warmer than present).

A. Source: Climate Studies Group, Mona (2012)

Table 7.2.1: Projected change in monthly temperature (^{o}C), comparing baseline to the period 2071-2099. The projected changes are shown for the SRES emissions scenarios A2 and B2, over the western, central and eastern sections of Jamaica, as well as an overall average.

MTH	WEST		CENTRE		EAST		JAMAICA	
	A2	B2	A2	B2	A2	B2	A2	B2
JAN	3.0	2.3	3.0	2.2	3.6	2.2	3.0	2.2
FEB	3.0	2.1	3.1	2.1	4.3	2.4	3.1	2.1
MAR	3.0	2.2	3.1	2.4	4.4	3.4	3.2	2.4
APR	2.9	2.1	3.0	2.3	3.9	2.8	3.1	2.2
MAY	3.3	2.3	3.5	2.5	4.4	2.8	3.5	2.4
JUN	3.7	2.6	4.0	2.8	5.0	3.0	3.9	2.7
JUL	3.7	2.8	4.1	3.0	4.9	3.0	4.0	2.9
AUG	3.1	2.7	3.6	2.8	4.8	2.9	3.5	2.7
SEP	2.9	2.6	3.6	2.8	4.8	3.0	3.3	2.7
OCT	2.9	2.5	3.6	2.7	4.8	2.7	3.4	2.6
NOV	2.8	2.4	3.3	2.5	3.7	2.3	3.1	2.4
DEC	2.9	2.4	3.1	2.4	3.3	2.3	3.0	2.3

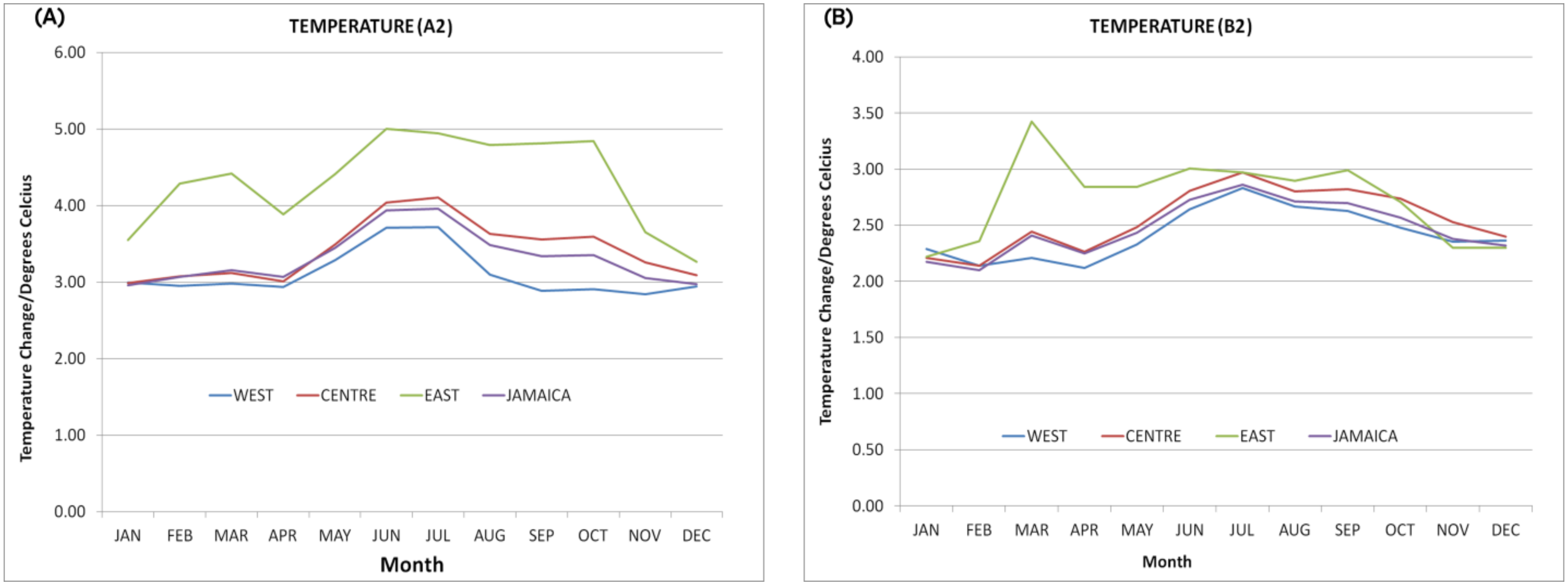


Figure 7.2.1: Projected change in monthly temperature (^{o}C), comparing baseline to the period 2071-2099. The projected changes are shown for the (A) A2 and (B) B2 SRES emissions scenarios over the western, central and eastern sections of Jamaica, as well as an overall average.

Table 7.2.2a: Projected change in temperature (^{o}C), comparing baseline to the period 2071-2099. The projected changes are shown for the A2 SRES emissions scenarios for each of the 12 grid boxes representing Jamaica.

A2	GRID_1	GRID_2	GRID_3	GRID_4	GRID_5	GRID_6	GRID_7	GRID_8	GRID_9	GRID_10	GRID_11	GRID_12
JAN	2.56	2.31	4.41	4.32	3.38	3.55	2.82	2.28	3.00	2.45	2.22	2.22
FEB	2.63	2.51	3.90	3.90	4.14	4.29	3.14	2.49	2.91	2.47	2.23	2.20
MAR	2.67	2.71	3.51	3.61	4.20	4.42	3.53	2.75	2.96	2.67	2.47	2.42
APR	2.62	2.76	3.16	3.35	3.50	3.89	3.45	2.87	2.97	2.84	2.72	2.67
MAY	2.49	2.67	4.18	4.48	4.37	4.41	3.46	2.86	3.43	3.14	2.98	2.95
JUN	2.58	2.72	5.29	5.56	5.17	5.00	3.81	2.90	3.95	3.51	3.37	3.38
JUL	2.55	2.44	5.97	6.10	5.14	4.94	3.74	2.50	3.98	3.42	3.32	3.40
AUG	2.34	1.85	5.42	5.25	4.92	4.79	3.47	1.78	3.33	2.82	2.85	3.00
SEP	2.20	1.47	5.58	5.65	4.99	4.81	3.35	1.38	3.11	2.49	2.44	2.61
OCT	2.13	1.49	5.52	6.24	4.80	4.85	3.33	1.49	3.12	2.51	2.31	2.43
NOV	2.27	1.81	4.70	5.45	3.59	3.65	2.85	1.85	3.00	2.58	2.39	2.47
DEC	2.45	2.10	4.55	4.86	3.21	3.27	2.76	2.11	3.03	2.56	2.37	2.41
ANN	2.46	2.24	4.68	4.90	4.28	4.32	3.31	2.27	3.23	2.79	2.64	2.68
NDJ	2.43	2.07	4.55	4.88	3.39	3.49	2.81	2.08	3.01	2.53	2.33	2.37
FMA	2.64	2.66	3.52	3.62	3.95	4.20	3.37	2.70	2.95	2.66	2.47	2.43
MJJ	2.54	2.61	5.15	5.38	4.89	4.79	3.67	2.75	3.79	3.36	3.22	3.24
ASO	2.22	1.60	5.51	5.71	4.90	4.82	3.38	1.55	3.18	2.61	2.53	2.68

Table 7.2.2b: Projected change in temperature (^oC), comparing baseline to the period 2071-2099. The projected changes are shown for the B2 SRES emissions scenarios for each of the 12 grid boxes representing Jamaica.

B2	GRID_1	GRID_2	GRID_3	GRID_4	GRID_5	GRID_6	GRID_7	GRID_8	GRID_9	GRID_10	GRID_11	GRID_12
JAN	2.01	1.78	3.20	3.20	2.27	2.22	2.04	1.87	2.30	1.89	1.68	1.66
FEB	1.98	1.79	2.79	2.82	2.50	2.36	2.01	1.85	2.12	1.80	1.61	1.58
MAR	2.01	1.86	2.83	3.05	3.51	3.43	2.69	1.94	2.21	1.93	1.73	1.70
APR	1.99	1.88	2.41	2.57	2.72	2.84	2.40	2.02	2.18	2.06	1.97	1.95
MAY	2.01	1.91	2.91	3.03	2.89	2.84	2.40	2.06	2.45	2.27	2.21	2.22
JUN	2.07	1.95	3.71	3.81	3.10	3.01	2.57	2.09	2.82	2.55	2.50	2.54
JUL	2.13	1.96	4.35	4.41	3.10	2.97	2.59	2.01	3.01	2.63	2.57	2.63
AUG	2.11	1.83	4.24	4.08	3.01	2.90	2.51	1.78	2.80	2.42	2.40	2.48
SEP	1.96	1.57	4.64	4.65	3.11	2.99	2.50	1.53	2.78	2.25	2.14	2.23
OCT	1.91	1.55	4.08	4.71	2.76	2.71	2.39	1.64	2.63	2.24	2.06	2.11
NOV	2.07	1.78	3.24	3.88	2.37	2.30	2.14	1.93	2.46	2.24	2.07	2.08
DEC	2.11	1.86	3.17	3.44	2.37	2.30	2.15	2.00	2.43	2.12	1.94	1.93
ANN	2.03	1.81	3.46	3.64	2.81	2.74	2.36	1.89	2.52	2.20	2.07	2.09
NDJ	2.06	1.80	3.20	3.50	2.34	2.27	2.11	1.93	2.40	2.08	1.90	1.89
FMA	1.99	1.84	2.68	2.81	2.91	2.88	2.37	1.93	2.17	1.93	1.77	1.75
MJJ	2.07	1.94	3.66	3.75	3.03	2.94	2.52	2.05	2.76	2.48	2.43	2.46
ASO	1.99	1.65	4.32	4.48	2.96	2.86	2.46	1.65	2.74	2.30	2.20	2.27

B. Source: CARIBSAVE Climate Change Risk Atlas – Jamaica. (CARIBSAVE, 2011).

Table 7.2.3: Projected change in temperature in °C, averaged over Jamaica, for the 2080s for annual change and seasonal changes. The projected changes for each season and for the annual mean are shown for an RCM driven by ECHAM4 (left column) and HadCM3 (right column) for the SRES emissions scenario A2.

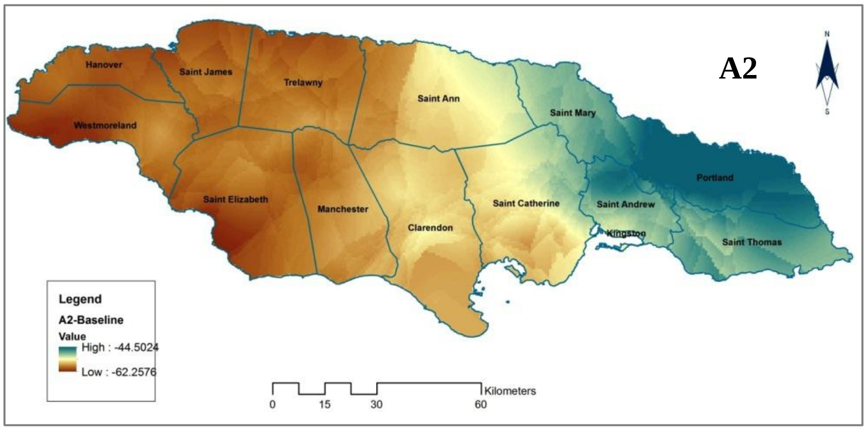
Projected changes by the2080s A2 *Change in ˚C*		
	Echam4	**HadCM3**
Annual	3.4	2.9
DJF	3.0	2.8
MAM	3.2	3.0
JJA	3.6	3.1
SON	3.6	2.8

7.3 RAINFALL

Summary

The PRECIS projections of rainfall for Jamaica are strongly influenced by which driving GCM provides boundary conditions. When driven by ECHAM4, PRECIS projections suggest a moderate decrease in MAM and JJA rainfall, but very little change in total annual rainfall (-14%). When driven by HadCM3, the projections indicate dramatic decreases in annual rainfall (-41%), and more severe decreases in JJA and SON by the 2080s. These HadCM3-driven projections correspond with those that are at the most extreme end of the range of GCM projections. Though the entire island dries out, the most severe drying seems to occur in the west and least severe in Portland. From May onward, irrespective of scenario, it is drying that is projected for the entire island. The months of September through November seem to dry out the most. January through April seem to be least affected. In both scenarios for the HadCM3, rainfall is projected to increase slightly in April.

A. Source: Climate Studies Group, Mona (2012)



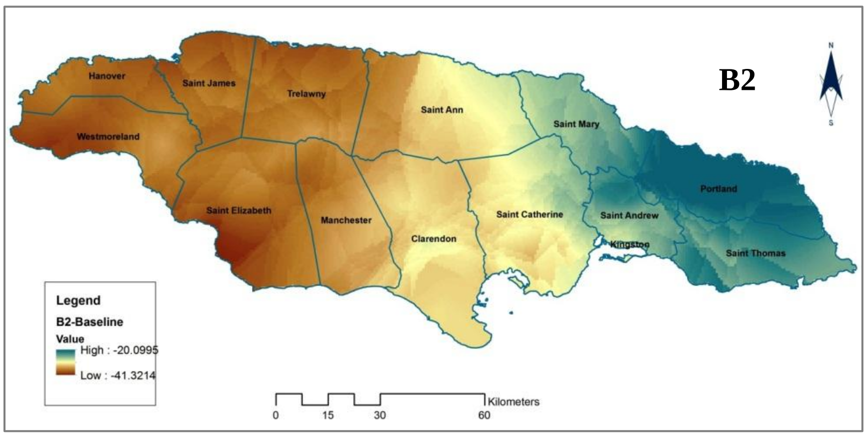


Figure 7.3.1: Change maps showing projected precipitation changes over Jamaica for the A2 (top) and B2 (bottom) simulations comparing baseline to 2071-2099 (produced using GIS mapping). Images produced using output from dynamic areal downscaling done for the island following the method outlined in Charlery (2010).

Table 7.3.1: Projected change in monthly rainfall (%), comparing baseline to the period 2071-2099. The projected changes are shown for the SRES emissions scenarios A2 and B2, over the western, central and eastern sections of Jamaica, as well as an overall average.

MTH	WEST		CENTRE		EAST		JAMAICA	
	A2	B2	A2	B2	A2	B2	A2	B2
JAN	-45.4	-25.0	-47.1	-17.8	-37.3	-8.3	-43.9	-18.6
FEB	1.0	4.6	-27.2	-13.2	-25.9	-9.5	-18.2	-6.5
MAR	25.0	-21.8	-2.4	-37.2	-13.7	-35.3	2.8	-32.3
APR	51.1	30.6	6.2	8.7	-5.9	-0.2	17.9	14.1
MAY	-52.8	-14.8	-63.1	-12.5	-48.0	-9.7	-56.2	-11.8
JUN	-70.0	-42.8	-70.3	-37.0	-59.2	-25.4	-67.1	-35.1
JUL	-70.8	-55.0	-58.3	-40.0	-52.7	-23.1	-59.0	-38.7
AUG	-69.4	-56.3	-48.5	-36.3	-42.4	-14.7	-51.0	-35.9
SEP	-77.5	-61.8	-65.3	-46.7	-47.9	-26.6	-64.0	-45.8
OCT	-76.4	-51.3	-76.4	-60.0	-66.0	-42.5	-74.1	-54.0
NOV	-56.1	-25.0	-60.8	-43.7	-51.8	-34.5	-57.8	-36.0
DEC	-70.8	-45.8	-71.3	-53.3	-56.2	-40.5	-67.3	-47.8

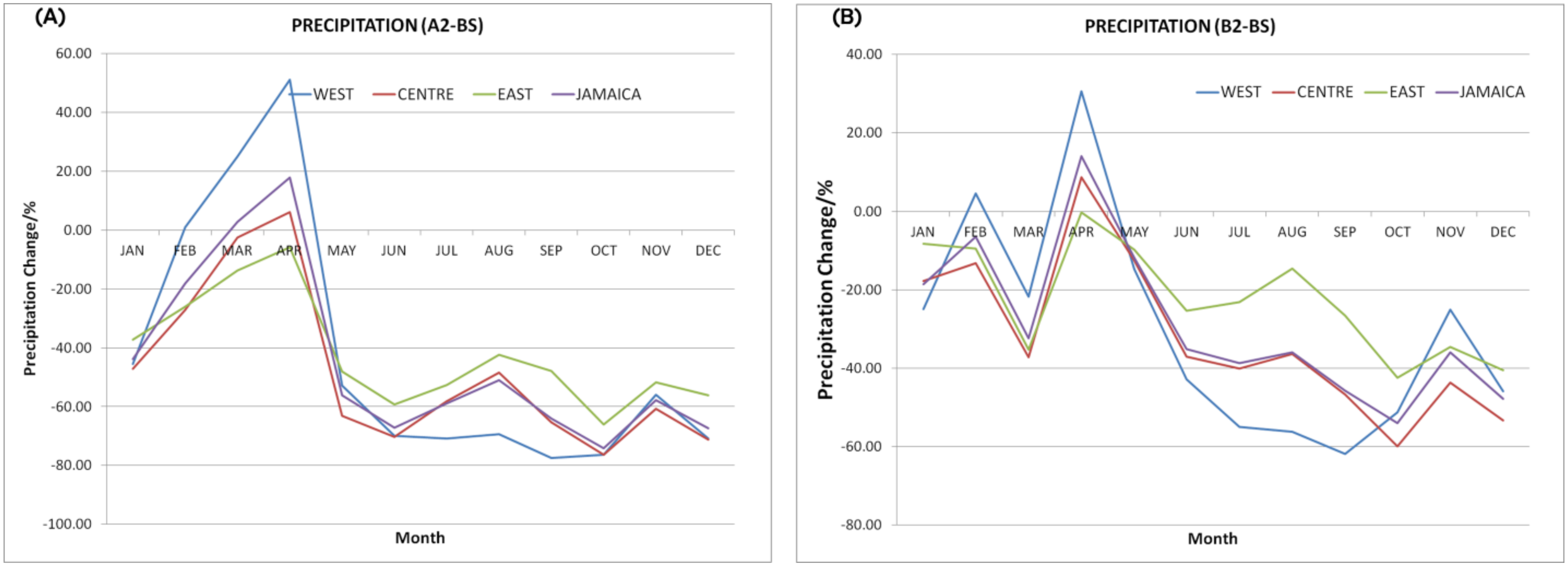


Figure 7.3.2: Projected change in monthly rainfall (%), comparing baseline to the period 2071-2099. The projected changes are shown for the (A) A2 and (B) B2 SRES emissions scenarios, over the western, central and eastern sections of Jamaica, as well as an overall average.

Table 7.3.2: Projected change in precipitation (%), comparing baseline to the period 2071-2099. The projected changes are shown for the A2 SRES emissions scenarios for each of the 12 grid boxes representing Jamaica.

A2	GRID_1	GRID_2	GRID_3	GRID_4	GRID_5	GRID_6	GRID_7	GRID_8	GRID_9	GRID_10	GRID_11	GRID_12
JAN	-30.9	-42.0	-50.9	-54.5	-38.3	-37.3	-23.5	-45.6	-43.3	-60.1	-51.8	-48.7
FEB	-13.6	20.5	-6.7	-19.1	-17.3	-25.9	-22.0	-15.3	5.4	-42.6	-43.2	-38.6
MAR	19.7	46.8	29.0	19.3	6.5	-13.7	-10.7	14.3	9.9	-21.5	-36.1	-30.3
APR	7.9	62.6	37.6	22.3	9.0	-5.9	-8.3	37.0	67.3	-3.0	-5.2	-6.7
MAY	-63.7	-61.4	-51.4	-58.0	-50.7	-48.0	-41.4	-59.3	-39.3	-71.4	-71.8	-58.0
JUN	-78.4	-77.8	-74.6	-78.3	-65.9	-59.2	-53.9	-76.0	-51.6	-71.6	-57.5	-60.9
JUL	-70.2	-73.5	-72.3	-74.8	-57.5	-52.7	-49.8	-84.0	-53.6	-65.5	-23.3	-30.7
AUG	-73.1	-67.2	-64.9	-65.9	-52.6	-42.4	-39.3	-84.1	-61.5	-60.8	10.0	-10.1
SEP	-75.6	-73.0	-72.8	-79.3	-62.1	-47.9	-42.5	-88.0	-76.2	-75.4	-34.0	-41.1
OCT	-74.5	-78.4	-66.8	-78.7	-68.5	-66.0	-58.9	-84.1	-76.4	-82.5	-77.7	-77.1
NOV	-52.2	-61.3	-42.0	-55.9	-41.3	-51.8	-44.5	-62.6	-58.4	-77.1	-77.7	-69.1
DEC	-73.1	-77.6	-66.5	-71.2	-54.6	-56.2	-45.5	-69.1	-70.0	-78.9	-78.6	-66.5
ANN	-63.2	-62.9	-57.9	-64.4	-51.5	-48.6	-42.1	-66.3	-51.9	-67.0	-63.9	-54.2
NDJ	-58.2	-65.5	-50.7	-60.6	-45.3	-51.3	-41.7	-63.0	-60.8	-75.7	-75.2	-64.8
FMA	5.8	45.5	25.2	11.1	1.4	-13.4	-12.6	12.2	28.6	-23.7	-30.5	-25.4
MJJ	-70.3	-69.0	-66.1	-70.1	-58.0	-53.3	-48.3	-70.6	-46.8	-70.3	-65.2	-53.9
ASO	-74.5	-75.3	-68.2	-76.0	-62.4	-53.2	-47.6	-85.2	-73.1	-77.2	-63.1	-58.9

Table 7.3.2: Projected change in precipitation (%), comparing baseline to the period 2071-2099. The projected changes are shown for the B2 SRES emissions scenarios for each of the 12 grid boxes representing Jamaica.

B2	GRID_1	GRID_2	GRID_3	GRID_4	GRID_5	GRID_6	GRID_7	GRID_8	GRID_9	GRID_10	GRID_11	GRID_12
JAN	9.3	-34.5	-28.3	-14.1	-5.4	-8.3	2.7	-25.7	-11.3	-41.0	-37.5	-29.0
FEB	-26.0	7.7	-3.4	-20.2	0.2	-9.5	-3.6	-0.6	14.8	-9.4	-10.7	-16.9
MAR	-17.3	-13.4	-23.8	-40.2	-33.6	-35.3	-32.7	-20.2	-29.8	-40.4	-54.4	-46.9
APR	-0.6	25.8	16.1	18.8	11.0	-0.2	1.4	30.5	49.9	7.2	7.3	1.9
MAY	-4.7	-16.3	-15.5	-12.8	-10.7	-9.7	-6.3	-21.0	-6.3	-23.0	-11.2	-4.2
JUN	-44.1	-51.5	-44.8	-48.5	-30.0	-25.4	-19.9	-50.2	-24.7	-46.4	-16.0	-19.6
JUL	-42.3	-60.0	-51.1	-53.1	-32.4	-23.1	-20.0	-73.9	-34.9	-53.8	-18.7	-1.7
AUG	-61.1	-65.3	-52.3	-57.5	-31.4	-14.7	-15.6	-73.1	-34.4	-46.0	14.3	6.1
SEP	-63.8	-65.5	-60.3	-68.8	-43.4	-26.6	-22.3	-75.5	-46.1	-58.4	1.1	-19.5
OCT	-53.5	-60.8	-41.7	-60.7	-43.9	-42.5	-36.6	-61.8	-40.7	-70.4	-71.4	-64.2
NOV	-28.9	-36.4	-17.6	-30.1	-19.6	-34.5	-24.4	-25.8	-20.2	-66.8	-73.2	-54.6
DEC	-55.3	-55.7	-43.9	-46.5	-30.7	-40.5	-26.8	-42.1	-41.6	-63.9	-70.3	-55.9
ANN	-38.1	-44.3	-37.7	-43.5	-27.6	-24.7	-19.0	-43.4	-25.3	-49.2	-47.8	-34.7
NDJ	-35.8	-43.0	-27.0	-34.0	-21.6	-33.0	-21.1	-31.3	-26.6	-62.6	-67.9	-51.1
FMA	-12.3	7.1	-0.5	-9.8	-5.1	-12.7	-9.9	3.5	10.1	-16.7	-25.0	-21.9
MJJ	-26.4	-36.1	-37.3	-37.4	-24.3	-19.3	-15.3	-43.2	-19.7	-33.0	-12.6	-7.8
ASO	-57.7	-62.7	-50.6	-62.4	-40.4	-29.0	-25.5	-67.4	-40.7	-63.5	-53.8	-44.0

B. Source: CARIBSAVE Climate Change Risk Atlas – Jamaica. (CARIBSAVE, 2011).

Table 7.3.3: Projected percentage change in rainfall, averaged over Jamaica, for the 2080s for annual change and seasonal changes. The projected changes for each season and for the annual mean are shown for an RCM driven by ECHAM4 (left column) and HadCM3 (right column) for the SRES emissions scenario A2.

Projected changes by the 2080s A2 Change in %		
	Echam4	**HadCM3**
Annual	-14	-41
DJF	9	-42
MAM	-23	-36
JJA	-35	-31
SON	-6	-53

7.4 TEMPERATURE AND RAINFALL EXTREMES

Summary

Very little has been done to analyse changes in the extremes using the RCM. There is, however, work ongoing at the UWI, Mona (CSGM, 2012) which suggest the following:

- Under the A2 scenario the frequency of very hot (cold) nights per year will increase (decrease) across the entire island (see Figure 7.4.1).
- Under the A2 scenario consecutive wet days appear to decrease (increase) in the western (eastern) grid boxes while very wet days (i.e. intense rain events) increases across the island (see Figure 7.4.2).

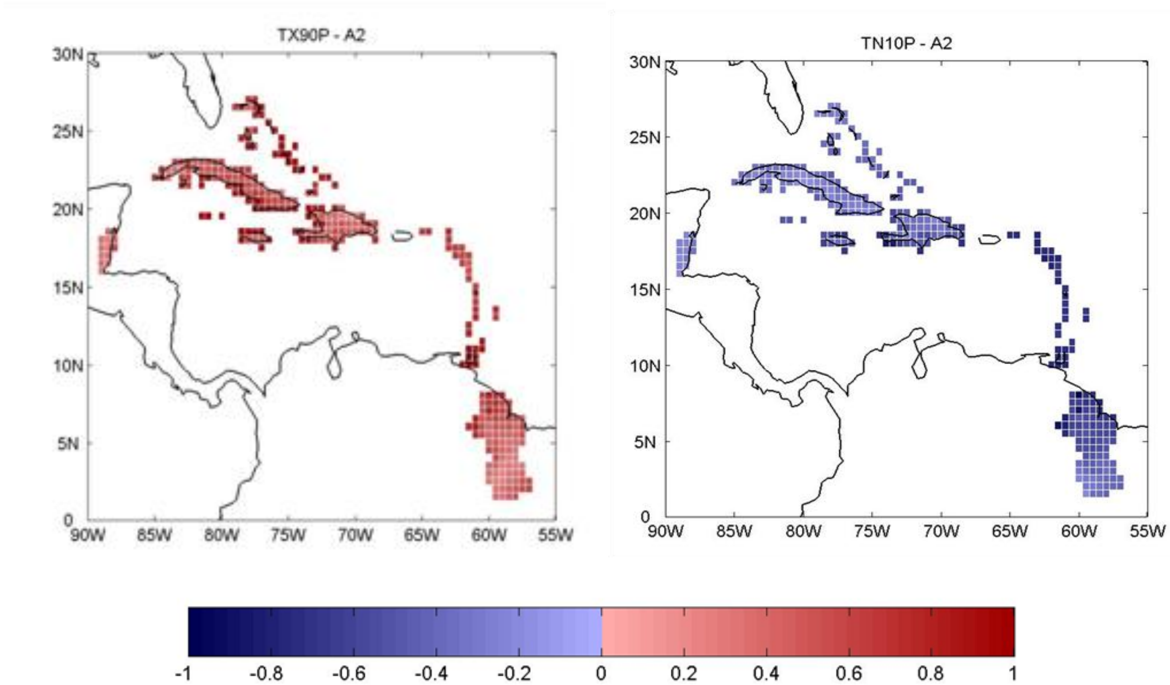


Figure 7.4.1: Projected change in frequency of very hot days (left panel) and very cold nights. Shading per grid box indicates comparative increase (red) or decrease (blue). Source: CSGM (2012).

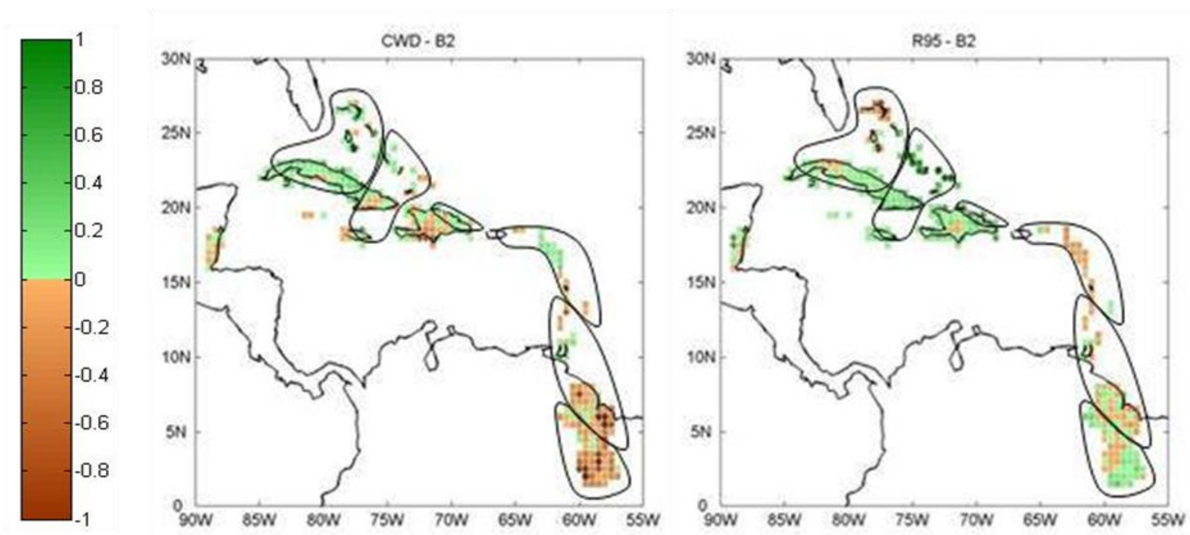


Figure 7.4.2: Projected change in frequency of consecutive wet days (left panel) and very wet days (right panel). Shading per grid box indicates comparative increase (green) or decrease (brown). Source: CSGM (2012).

7.5 Other Variables – Wind, Relative Humidity, Sunshine Hours

Summary

PRECIS projections for change in wind speeds lie in the lower end of the range of changes indicated by the GCM ensemble, indicating small decreases in mean wind speed over Jamaica by the 2080s under the A2 scenario. The largest decreases in wind speeds in these models occur in SON (the peak of the hurricane season) at -0.3 to -0.5 ms^{-1}. The RCM simulates larger decreases in wind speed in SON and DJF when driven by the GCM HadCM3 than by ECHAM4.

RCM simulations indicate decreases in RH over Jamaica in all seasons, with changes in annual average RH of -1.1 to -1.7% by the 2080s under the A2 scenario. The largest decreases in RH occur in JJA.

The HadCM3 driven RCM projections indicate particularly large increases (+1.4 hours per day by 2080s under A2) in mean annual sunshine hours by the end of the century, and that these increases lie beyond the envelope of changes indicated by GCMs.

A. Source: Climate Studies Group, Mona (2012)

Table 7.5.1: Projected change in monthly relative humidity (%), comparing baseline to the period 2071-2099. The projected changes are shown for the SRES emissions scenario A2, over the western, central and eastern sections of Jamaica, as well as an overall average.

MTH	WEST	CENTRE	EAST	JAMAICA
JAN	-2.49	-0.74	-0.87	-1.05
FEB	-0.96	-1.02	-2.19	-0.88
MAR	-0.74	-1.06	-2.79	-0.96
APR	-0.31	-0.83	-2.37	-0.77
MAY	-4.18	-3.70	-4.45	-3.64
JUN	-6.42	-5.18	-5.68	-5.12
JUL	-6.56	-5.13	-5.50	-5.07
AUG	-3.78	-3.92	-4.77	-3.43
SEP	-3.74	-3.74	-4.59	-3.22
OCT	-4.08	-3.68	-4.83	-3.34
NOV	-2.56	-1.13	-1.10	-1.19
DEC	-2.84	-0.39	0.25	-0.80

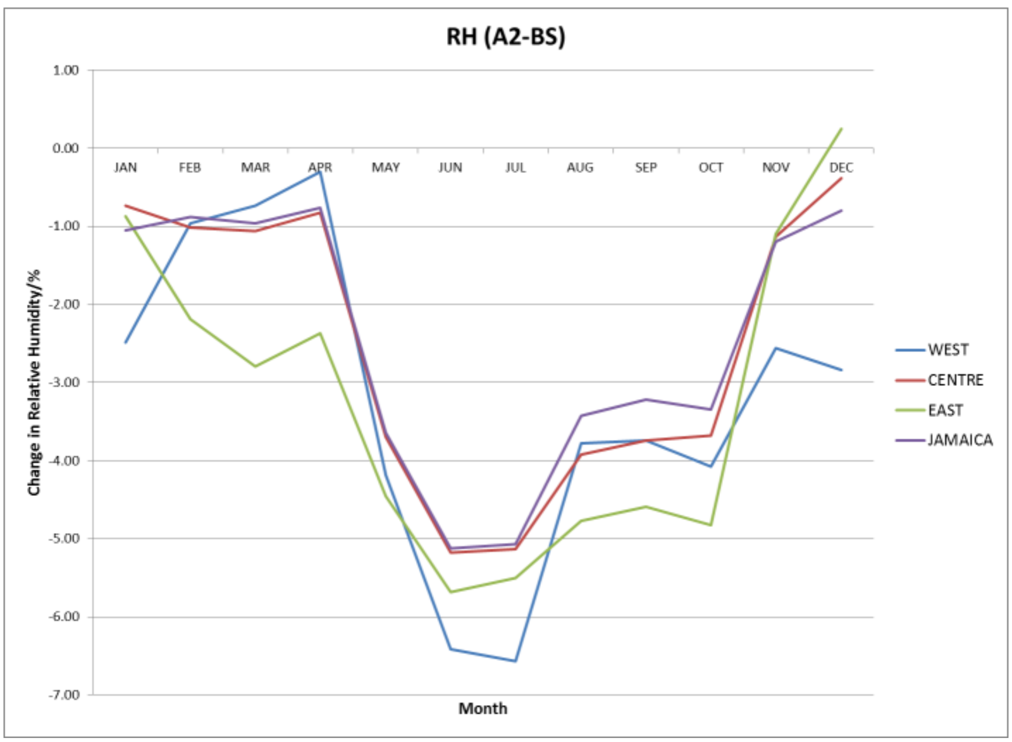


Figure 7.5.1: Projected change in monthly relative humidity (%), comparing baseline to the period 2071-2099. The projected changes are shown for the SRES emissions scenario A2, over the western, central and eastern sections of Jamaica, as well as an overall average.

Table 7.5.2: Projected change in relative humidity (%), comparing baseline to the period 2071-2099. The projected changes are shown for the SRES emissions scenario A2, for each of the 12 grid boxes representing Jamaica.

A2	GRID_1	GRID_2	GRID_3	GRID_4	GRID_5	GRID_6	GRID_7	GRID_8	GRID_9	GRID_10	GRID_11	GRID_12
JAN	-0.1	-1.9	-4.9	-3.6	-2.4	-0.9	0.6	-1.1	-2.1	0.9	1.4	1.2
FEB	0.2	-0.2	-2.4	-3.4	-4.1	-2.2	-0.1	-0.3	-0.9	1.0	1.3	0.7
MAR	0.3	-0.2	-1.3	-2.5	-4.1	-2.8	-0.5	-0.7	-0.9	0.4	0.6	0.0
APR	0.7	0.3	0.1	-0.9	-2.6	-2.4	-0.7	-0.6	-0.9	-0.7	-0.6	-0.7
MAY	-0.9	-2.6	-5.3	-5.6	-5.9	-4.5	-1.8	-3.6	-5.1	-3.4	-2.7	-2.2
JUN	-0.8	-4.3	-8.6	-8.5	-8.2	-5.7	-1.7	-5.1	-7.7	-4.8	-3.6	-2.5
JUL	-0.4	-4.0	-9.7	-8.9	-8.2	-5.5	-1.1	-4.4	-8.1	-4.7	-3.5	-2.3
AUG	-0.6	-1.5	-8.0	-7.7	-7.5	-4.8	-0.5	-0.6	-5.1	-2.2	-1.6	-1.1
SEP	-0.5	-1.1	-9.1	-8.9	-7.9	-4.6	-0.1	0.1	-4.9	-1.0	-0.4	-0.3
OCT	0.2	-1.2	-9.2	-9.3	-8.1	-4.8	-0.4	-0.6	-5.2	-1.0	-0.1	-0.2
NOV	1.5	-0.6	-6.2	-5.0	-3.0	-1.1	1.4	-0.1	-3.2	0.1	0.8	1.2
DEC	0.8	-1.8	-5.7	-3.4	-1.2	0.2	1.7	-1.1	-2.9	0.5	1.3	1.7
ANN	0.0	-1.6	-6.0	-5.7	-5.3	-3.3	-0.3	-1.5	-4.0	-1.3	-0.6	-0.4
NDJ	0.8	-1.4	-5.6	-4.0	-2.2	-0.6	1.2	-0.8	-2.7	0.5	1.2	1.4
FMA	0.4	-0.1	-1.2	-2.3	-3.6	-2.5	-0.5	-0.5	-0.9	0.2	0.4	0.0
MJJ	-0.7	-3.6	-7.9	-7.7	-7.5	-5.2	-1.5	-4.4	-7.0	-4.3	-3.2	-2.4
ASO	-0.3	-1.3	-8.8	-8.7	-7.9	-4.7	-0.3	-0.4	-5.1	-1.4	-0.7	-0.6

B. Source: CARIBSAVE Climate Change Risk Atlas – Jamaica. (CARIBSAVE, 2011).

Table 7.5.3: Projected change in wind speed (m/s), relative humidity (%), and sunshine hours (hours) averaged over Jamaica, for the 2080s for annual change and seasonal changes. The projected changes for each season and for the annual mean are shown for the SRES emissions scenario A2.

Projected changes by the 2080s			
		Echam4	HadCM3
WIND	Annual	-0.1	-0.2
	DJF	-0.1	-0.5
	MAM	0.0	0.0
	JJA	-0.1	0.2
	SON	-0.3	-0.5
RELATIVE HUMIDITY	Annual	-1.1	-1.7
	DJF	-1.1	-0.7
	MAM	-0.7	-1.3
	JJA	-1.6	-2.6
	SON	-0.9	-2.2
SUNSHINE HOURS	Annual	0.8	1.4
	DJF	1.0	1.0
	MAM	0.5	0.6
	JJA	0.8	1.9
	SON	0.7	2.0

7.6 PUTTING IT ALL TOGETHER – GCMS AND RCMS

Watson (2010) in a landmark study, presents an interesting picture for Jamaica from the consensus of three GCMs running three scenarios and the PRECIS RCM running two scenarios. Figure 7.6.1 summarises the projections for the GCMs (2020s and 2050s) and for the GCMs and RCM (2080s) for all scenarios examined (11 realizations in total). Table 7.6.1 is the summary of all 11 realizations. She notes:

"In the annual mean [for Jamaica] all the models project increases in temperature for all seasons and all scenarios, suggesting that Jamaica will be hotter. As seen from Table [3.7.1] the annual range of increase will be smaller for the 2020s (a maximum of 0.9°C), with progressively larger changes through the end of the century i.e., a maximum of 2.0°C by the 2050s and 3.5°C by the 2080s. The increases are well above variations noted for the 20th century simulation period and thus the argument that this increase must be due to increased greenhouse gas concentrations seems valid.

The models also offer some consensus on what the future rainfall will be like. The overall picture is one of Jamaica initially being slightly wetter than current conditions but then transitioning to a drier state by the end of the century. From Table [7.6.1] we note that the consensus is that the 2020s will be wetter in the mean and across all seasons except MJJ. By the 2050s the country is biased to being drier in the mean though the dry seasons are slightly wetter. It is the magnitude of the drying in the traditional wet seasons that gives rise to the bias. These magnitudes are reflected in Table [7.6.1]. The same sort of pattern also holds for the 2080s. However for the wet seasons it is a more robust picture as there are more models and scenarios projecting it will be drier, while for the dry seasons there is less certainty of its being wetter as it is six versus five projections which suggest wetter conditions.

Other things to note about the rainfall projections are that (i) By the 2080s rainfall decreases in the mean by up to 60%, (ii) The PRECIS model has the most dramatic changes in both temperature and precipitation (iii) By the 2050s all models project a reduction in rainfall during MJJ." – Watson (2010)

Table 7.6.1: Range of projections for Jamaica offered by all the models examined over 11 realizations from 3 GCMs and an RCM. Source: Watson (2010).

		2020s			2050s			2080s		
Annual	T (°C)	+0.65	-	+0.85	+1.16	-	+1.83	+1.55	-	+3.52
	Pcp (%)	-7.85	-	+19.51	-10.61	-	+10.70	-55.60	-	+16.49
NDJ	T (°C)	+0.58	-	+0.93	+0.96	-	+1.82	1.42	-	3.15
	Pcp (%)	-3.07	-	+18.43	-11.68	-	+22.58	-55.09	-	+16.97
FMA	T (°C)	+0.62	-	+0.88	+1.12	-	+1.76	+1.47	-	+3.18
	Pcp (%)	-15.20	-	+48.19	-13.22	-	+19.53	-22.87	-	+24.00
MJJ	T (°C)	+0.57	-	+1.03	+1.16	-	+1.85	+1.73	-	+4.00
	Pcp (%)	-32.24	-	+23.62	-29.9	-	-2.09	-60.43	-	-1.18
ASO	T (°C)	+0.73	-	+0.93	+1.16	-	+1.96	+1.58	-	+3.70
	Pcp (%)	-9.8	-	+37.92	-16.63	-	+32.92	-66.79	-	+33.42

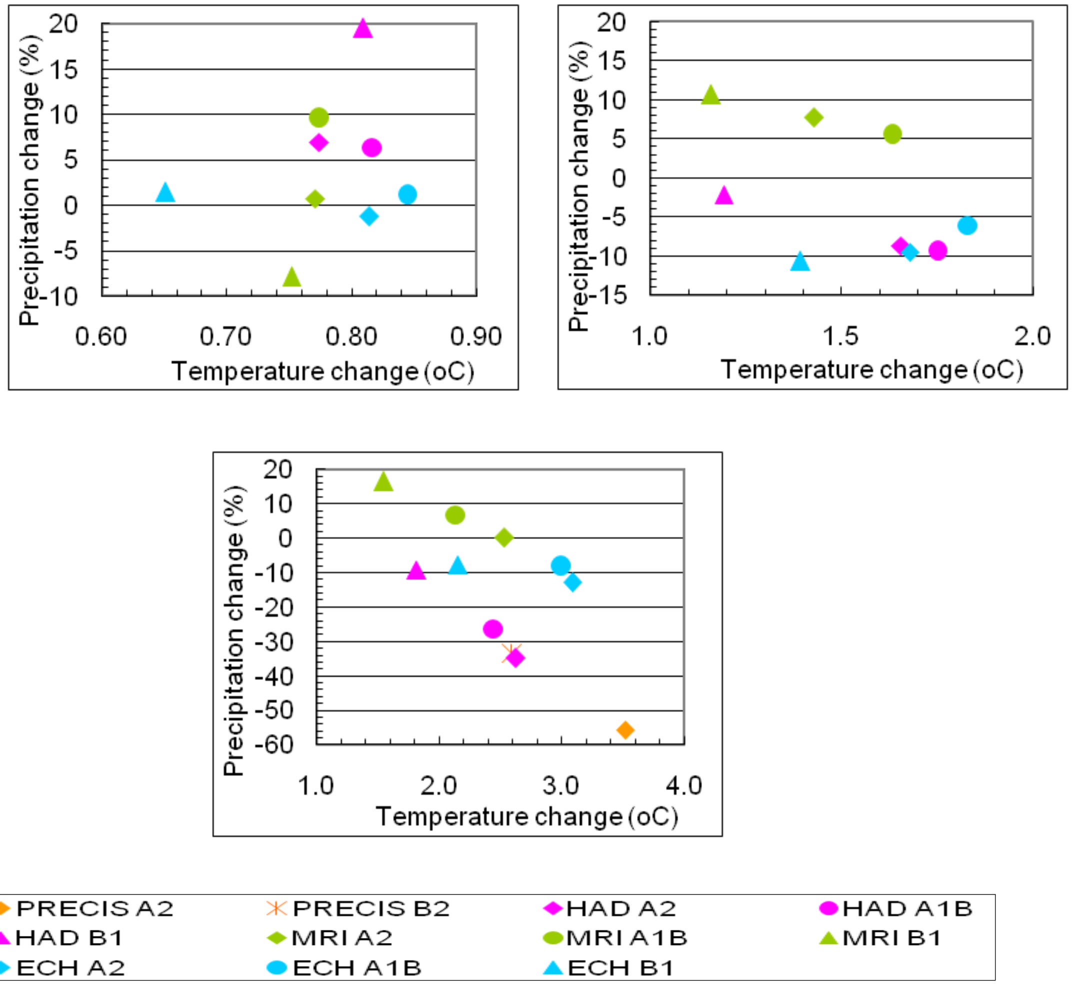


Figure 7.6.1: Projected change in temperature and precipitation for three time slices: 2020s (top left panel), 2050s (top right), and 2080s (bottom) from 11 realizations of three GCMs and an RCM. Mean temperature changes in ˚C are shown on the horizontal axis and percentage changes in mean precipitation are shown on the vertical axis. Source: Watson (2010).

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8. IMPACTS OF CLIMATE CHANGE

8.1 ABOUT THE CHAPTER

The impacts of shifts in climatic variables are far reaching and are particularly threatening to small islands. The Caribbean region is highly susceptible to these threats because of the heavy dependence of the islands on coastal development, tourism and agriculture, all of which are strongly linked to climate. These links can be direct or indirect, and so associated risks can far surpass expectations. In order to minimize and adapt to potential damages or benefits, risks must be assessed comprehensively. This chapter, therefore, explores the sensitivity of multiple sectors and resources to climate variability and extreme events.

In order to point users to possible impacts which climate change can have on sectors and areas, extracts from other studies are listed in tables under each subsection. The studies are numbered and given in numerical order in this chapter's reference section and the reference to the extract is given in brackets, e.g., (4, p.74) refers to page 74 of reference 4. Given at the end of some of the tables is additional information, which is not related to climate change impact, but which may be useful. It must be emphasized that many of these impacts are due not only to climate change but also to poor environmental practices, due largely to poor planning and illegal activities. Further some impacts need not be negative, and may provide benefits. Before giving the tables, general comments on each sector and area are given.

8.2 FRESHWATER RESOURCES

Water quality and availability in Jamaica is determined by the management of water resource distribution infrastructure, i.e. pipelines, dams, etc and climatic conditions. Due to the fact that this island nation, relies heavily (84%) on groundwater (GOJ Second National Communication, 2011, p.10), this sector is extremely vulnerable to climate variability and change. This table illustrates how sea level rise, rainfall patterns, extreme events and increasing temperatures affect this sector. The possible impacts of these variables include sea water intrusion, and excessive evaporation and damages to infrastructure. The table also makes reference to sanitation issues as a result of extreme rainfall patterns (droughts and floods) and its associated health implications. Refer to the corresponding tables below for further details and referencing.

8.3 ENERGY

Currently, Jamaica spends JD$2 billion dollars on fuel imports (Observer, 2011). Increasing temperatures will likely increase energy costs for cooling aids. Other variables, like rainfall patterns and extreme weather events, will also affect this sector by damaging infrastructure and distribution patterns. The table below describes briefly the impacts of these variables on energy supply from both traditional (non-renewable) and renewable sources. Refer to the corresponding tables below for further details and referencing.

8.4 TOURISM

Climatic features of a destination form part of its product offering and can either deter or attract visitors (ECLAC, 2009, p.87). Jamaica's tourism product of sun, sea and sand is currently being threatened by the impact of climate change. Since tourism is a major income earner in Jamaica, generating approximately USD $1.934 billion dollars for the country annually, climate change has negative implications for the local economy (GOJ, 2011). The possible impacts of these changes are listed in the corresponding tables. Refer to them for details and referencing

8.5 AGRICULTURE AND FOOD SECURITY

Agriculture is one of the mainstays of the local economy. Impacts of climate change which are denoted by the climate change variables in the corresponding tables bode disastrous effects for both agriculture and local food security. A summary of these impacts include, decreased precipitation and its effects on agro biodiversity, increasing temperature and its role in the breeding of pests and diseases and also the role of extreme events on agricultural infrastructure, livelihoods and assets. Refer to the tables below for further details and referencing.

8.6 HUMAN HEALTH

The direct impacts of climate on health are mainly due to changes in exposure to weather extremes (Bailey, Chen, Taylor, 2009, p.17). However these impacts must be considered in their broader socioeconomic contexts (Chen, et.al, 2009). The table illustrates the many ways in which climate change variables (increasing temperature, humidity, dust and extreme events) will continue and are projected to affect the local population. A summary of these impacts include an increase in respiratory diseases, heat related illnesses and public health consequences as a result of the passage of extreme events. Refer to the tables below for further information.

8.7 COASTAL , MARINE AND TERRESTRIAL ECOSYSTEM RESOURCES

This sector is vulnerable due to a confluence of factors. A decline in marine and terrestrial biodiversity has implications for tourism, local economy and nutrition in Jamaica. The Caribbean fishing industry is reportedly responsible for some US$1.2 billion dollars in annual export earnings (ECLAC, 2011, p.46). Therefore changes in fish abundance and distribution will impact the livelihoods of fishers, consumers and the value of commercial fisheries (ECLAC, 2011). The corresponding table illustrates the impacts of Climate Change variables like (temperature increase, decreased precipitation and extreme events) on sea turtles, coral reefs; coastal and terrestrial vegetation.

8.8 Sea Level Rise and Storm Surge Impacts on Coastal Infrastructure and Settlements

Continual coastal development in Jamaica, for commercial and residential purposes, increase local vulnerabilities to sea level rise and storm surges. The fact that 25% of Jamaica's population lives within coastal areas and 90% of our GDP is produced within these areas, makes this island nation extremely vulnerable. Refer to the tables for further information and referencing.

8.9 Poverty

In 2011, according to the IMF Regional Economic Outlook, the numbers of people living in Jamaica, on less than USD $2.50 (JA$215.00) a day is estimated at 43% of Jamaica's population. Climate change will obviously exacerbate these issues. This table makes no differentiation between relative and absolute poverty. It does however, highlight how much greater the impact of these climate change variables (i.e. Increasing Temperature, Drought conditions and extreme events) will be on the poor. This is mainly due to their socioeconomic status, living conditions, lack of access to potable water and proper health care infrastructure. Refer to the tables for further details and referencing.

8.10 Gender

Gender is defined as the socially learned differences between men and women (Dunn, 2008). Climate change however exacerbates the pre-existing inequalities in gender determined roles which places a special burden on females. The table below reflects the impacts of climate change variables (Increasing Temperature, Droughts and Extreme events) on gender. Specifically it highlights the vulnerabilities of women of lower socioeconomic status, their lack of access to skill sets and alternative livelihoods. It also brings to the fore, as corroborated by Dunn (2008), gender specific needs of women during disasters and their productive (earning supplementary income to the male) and reproductive (care provider for the family and responsibility for household needs, i.e. food water etc.) roles. These roles increase their vulnerabilities to the impacts of extreme events. Refer to the tables for further referencing and details.

8.11 DEVELOPMENT

Climate Change in many ways is a development issue. This table highlights the extent to which ill-planned development in many areas exacerbates economic and social vulnerabilities to the impacts of climate change. The climate change variables (i.e. increasing temperature, storm surges and sea level rise and extreme events) will possibly hinder productivity and growth, and cause displacement, loss of life and increased incidence of malnutrition. Refer to the tables for further referencing and details.

Figure 8.1.1: Some key sectors that are likely to be impacted on by Drought.

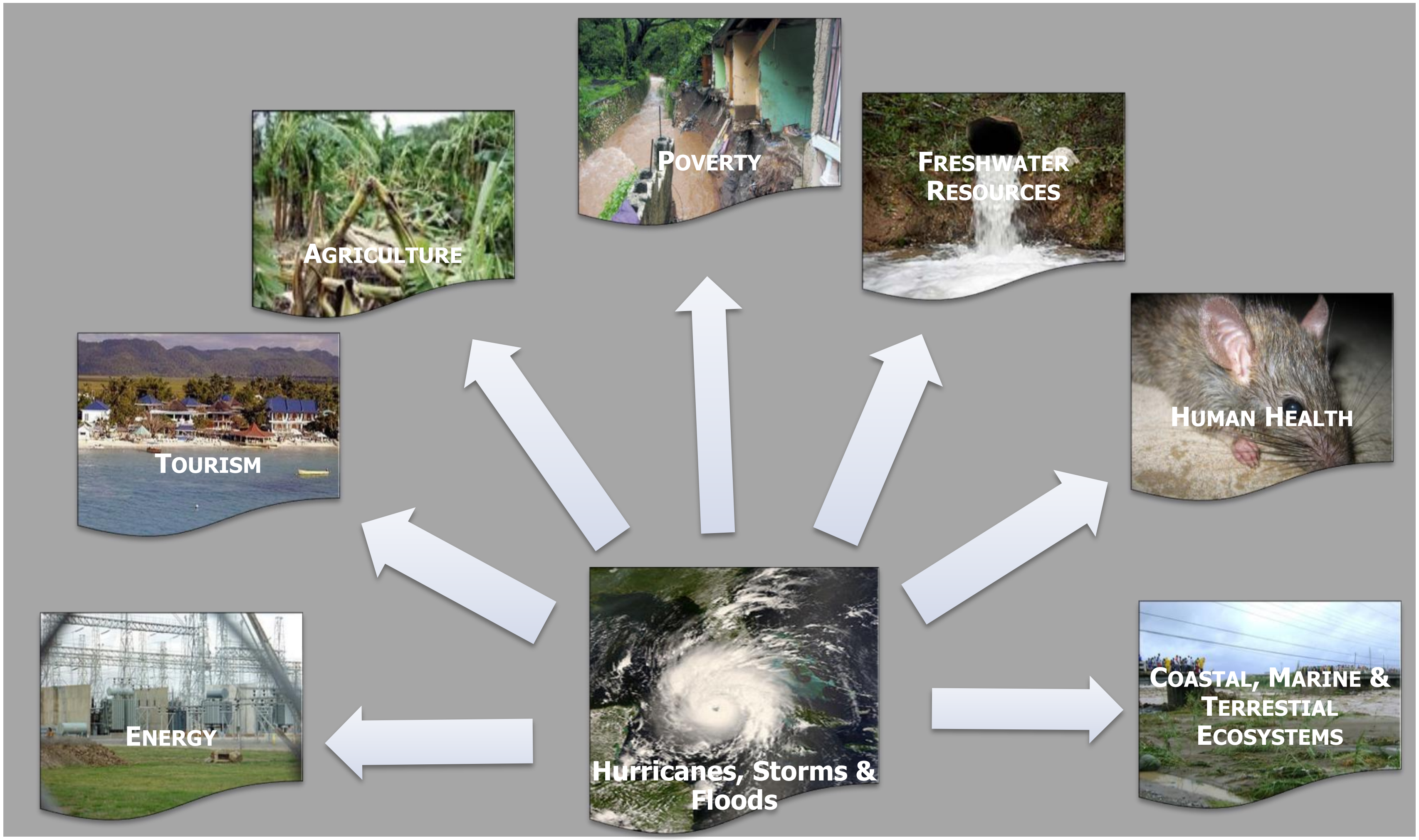

Figure 8.1.2: Key sectors that are likely to be impacted on by Hurricanes, Storms and Floods.

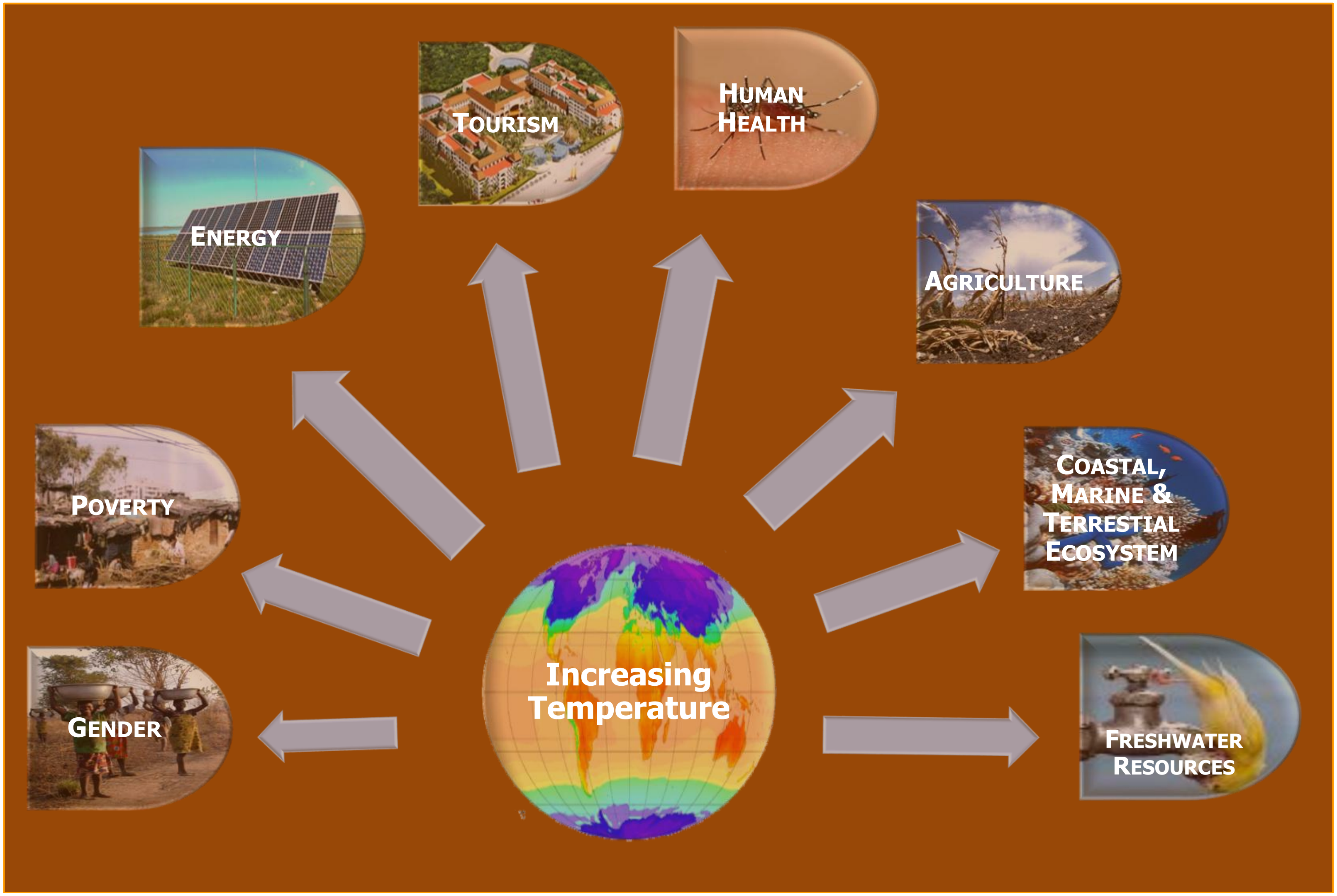

Figure 8.1.3: Some key sectors that are likely to face adverse impacts due to Increasing Temperatures.

Table 8.2.1: Impacts of Climate Change on Freshwater Resources.

CLIMATE CHANGE ON FRESHWATER RESOURCES	**Climate Change Variables and Extreme events**	**Impacts**
	Sea Level Rise	Groundwater quality continues to be and will be further affected by the proximity of some basins to the coast (4,p.74). Sea water intrusion has resulted in the loss of 100 million cubic meters of groundwater (10% of local supply) annually (4,p.74).
	Heavy Rainfall /Storms	Some water catchment areas are prone to flooding and exposed to the risk of debris and sediment flows (4,p.67). Heavy rains contaminate watersheds by transporting human and animal faecal products and other wastes into groundwater. (1,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 (6,p.15).
	Droughts	Drought affects sanitation due to lack of water for hygienic purposes, thereby affecting the transmission of disease (3,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 (3,p.29). Irrigated agriculture depends on 85% of local water supply (4,p.83). Water shortages: Loss of food production would create food shortage and a necessity for food importation. Hunger and malnutrition may increase(2,p.12).
	Increasing Temperature	Rising temperature and more evaporation (4,p.30). Evaporation leads to a greater pathogen density in the water and this could result in a lack of potable water (2,p.12).
	Additional Information: 84% of Jamaica's exploitable water comes from groundwater sources and its availability is subject to climatic conditions(3,p.29)	

Table 8.3.1: Impacts of Climate Change on Energy

	Climate Change Variables/Extreme events	Impacts
ENERGY	Increasing Temperature	Heat stress in buildings and in cars would increase pressure on electricity and fuel demand for cooling aids like fans and air conditioning units (12). Less favourable for the harnessing of solar energy. With photovoltaic solar voltage and power decrease with increased temperature (12). On the other hand increased sea surface temperatures will increase the efficiency of Ocean Thermal Energy conversions (OTEC) systems (16).
	Sea level Rise	A 1-2m sea level rise is expected within the Caribbean region by 2100(12).Sea level rise could greatly impact critical infrastructure which is located near the coastline,(2,p.391). Many power plants are located near the coastline to discharge waste heat.
	Hurricanes, Storms	Damage to on and off shore wind turbines .Damage to power lines, substations and other infrastructure, etc.(12).
	Inadequate rainfall	Inadequate rainfall and drought conditions place more electricity demand for desalination and pumping. Inadequate rainfall will negatively affect river flows and decrease hydropower (12) .
	Wind Speed	Wind power increases or decreases as the third power (cube) of the wind speed (17) .
	Additional information:	

Table 8.4.1: Impacts of Climate Change on Tourism Sector.

	Climate Change Variables/ Extreme Events	Impacts
TOURISM	Sea Level Rise	Beaches respond to sea level rise by retreating inland at approximately 100 times the rate of sea level rise (7, p.13).
	Increasing Temperature	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 (1,p.18). Heat storage of built structures, leads to 'heat island effect' (1, p.18). This leads to additional operating costs for cooling aids (5, p.87). Sea surface temperature increases of at least 1.0 degree Celsius will lead to coral reef bleaching (7, p.14)(NB: No base temperature was given for the 1 degree rise). These reefs contribute to Jamaica's tourism product through diving and fishing tours .They are also critical sources of beach sand (9,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 (3, p.29).
	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 (5, p.87). Tropical storms and hurricanes appear to be the dominant factor influencing beach erosion (7, p.14)
	Additional information: Aviation emissions are now included in global GHG pollution. This means that the aviation industry (like the EU) cap and trade emissions reductions programs now make long distance travelling environmentally unfriendly and expensive. As a result, tourists will have to spend more on tickets to visit island destinations (3, p. 52). Visitor numbers may decrease because of increased travel costs. Arrivals in Jamaica are reported to decline from 1.3% -3.7% (3,p.53).This reduces discretionary income of tourists which would affect tourism negatively (5, p.88).	

Table 8.5.1: Impacts of Climate Change on Agriculture and Food Security.

	Climate Change Variables /Extreme Events	Impacts
AGRICULTURE & FOOD SECURITY	Increased Temperature	Citrus and root crops are affected by changes in temperature and precipitation (7,p.18). Rising temperatures are expected to result in reduced yield and growth of weeds, pests, bacteria and diseases (5,p.26).
	Decreased precipitation	Drought conditions affect agro biodiversity. Droughts also lead to large scale losses of cattle and lower reproduction rates among livestock (5,p.26). Threatens local agriculture, which demands 75% of local water supply (3,p. 29). Soil degradation and loss of fertility due to droughts (3,p.34). With projected decreases in precipitation up to 40% and up to 2.8 degree Celsius rise in temperature expected by 2080s, many domestic crops will be under stress and food security will be threatened (2,p.262). Higher water and production costs for local food production (6,p.19). Malnutrition resulting from disturbances in food distribution and production could also occur (3,p.34).
	Sea level Rise	Sea level intrusion in coastal agricultural areas and salinisation of water supply (5,p.27) In Jamaica, some wells have been abandoned due to increased salinity and others produce water unsuitable for agricultural use (4,p.74).
	Storms, Hurricanes and Floods	Passage of extreme events incurs losses of agricultural assets, livestock, crops and agricultural infrastructure (2, p.264). Especially severe for standing export crops (like banana, sugar cane, coffee) (2,p.265). Increased flooding will lead to inundation of production fields.(5,p.27)Increased precipitation and flooding also leads to more favourable conditions for crop disease (3,p.34). Increased food costs, increased costs of insurance and higher rates for capital cost loans (10, p.6). Threatens livelihoods as agriculture employs 25% of Jamaica's population (3,p.34).
	Rainfall patterns	Unreliable/Unpredictable rainfall patterns would affect product distribution ,quantity and quality (3,p.34).
	Additional information: Agriculture is one of the Jamaica's key economic sectors, in 2000 it contributed approximately 7.3% of the island's gross domestic product (GDP), and represented approximately 12% of foreign earnings (3,p.34).	

Table 8.6.1: Impacts of Climate Change on Human Health.

	Climate Change Variables &Extreme Events	Impacts
HUMAN HEALTH	Increasing Temperature and Humidity, Changes in Circulation Patterns giving rise to transport of Sahara dust to the Caribbean	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 (1,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 (1, p.19).
	Increasing Temperature and Humidity	High temperatures and humidity stresses the body's ability to cool itself. This heat stress can lead to increased incidence of heat related illnesses like heat strokes, cramps.(1,p.18). Incidences of diarrhoeal diseases and cerebrovascular (strokes)are also susceptible to heat stress, with the latter being among the leading causes of deaths in Jamaica (2,p.12) The heat island effect exacerbates the impact of increased temperatures (1,p.18)
	Storms, Floods,Tropical Cyclones and Hurricanes	Public Health Consequences: Lack of potable water, loss of food production, population displacement, loss of livelihood security (1,p.19). Fatal injuries: Deaths by drowning (5,p.62). Possible increase in incidence of mental cases, malnutrition, increases in infectious diseases (water, rodent and vector borne) (1, p.19).
	Droughts	Storage of water in drums during droughts provides favourable conditions for the breeding of vectors and transmission of infectious diseases(2,p.12). Malnutrition could occur due to declines in food availability and production (3,p.34).
	Heavy Rainfall	Incidence 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 (1,p.79). Lack of potable water and poor sanitation also increases the likelihood of infection(2,p.12).
	Increased Temperature	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 (1, 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 haemorrhagic fever could also be increased (2,p.12).
		Warmer temperatures provide favourable conditions for RED TIDE (blooms of toxic algae) which can increase incidence of human shellfish poisoning (1, p.25).
	Additional information: Human population densities and the immunization of the exposed population determines the pattern of mosquito borne disease (Dengue fever) (1,p.79). Jamaica has had all four serotypes of the dengue virus (2,p.12).	

Table 8.7.1: Impacts of Climate Change on Coastal, Marine and Terrestrial (Ecosystems) Resources.

COASTAL, MARINE AND TERRESTRIAL (ECOSYSTEM) RESOURCES	Climate Change Variables and Extreme Events	Impacts
	Increasing Temperature	Rising temperatures are projected to affect reproduction of sea turtles since sex is determined by temperature (7, p.15). Sea surface temperature increases of at least 1.0 degree Celsius will lead to coral reef bleaching (7, p.14)(NB: No base temperature was given for the 1 degree rise). 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 (3,p.36). Sea grasses are also sensitive to thermal discharges and can only accept temperatures up to 2 - 3 degrees Celsius above summer temperatures (3,p.36).
	Increasing Temperature &Decreasing Precipitation	The frequency and extent of forest fires will be affected by changes in temperature and precipitation (7,p.18). Affects agro biodiversity: Citrus and root crops highly sensitive to changes in temperature and precipitation (7, p. 18).
	Sea level rise	Beach erosion as a result of 0.5 m sea level rise in the Caribbean is projected to cause a decrease in sea turtle nesting habitats by up to 35% (3, p.35). Storm surges and sea level rise could increase the salinity of estuaries and fresh water aquifers (3,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 (3, 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 waterways (5,p.46).
	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 (3,p.36).
	Additional Information:	

Table 8.8.1: Sea Level Rise and Storm Surge Impacts on Coastal Infrastructure and Settlements.

SEA LEVEL RISE AND STORM SURGE IMPACTS ON COASTAL INFRASTRUCTURE AND SETTLEME NTS	**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 (4, p.67)Permanent inundation could occur in some areas (2,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 (2,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 (2,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 (5,p.43). Damages to road networks and bridges, during the passage of Hurricane Nicole resulted in losses totalling JD$14 billion dollars (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 (3,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(2,p.391). Continued coastal development is very likely to exacerbate risk of loss of life and property due to storms and sea level rise(9,p.2).

Impacts of Climate Change on Society

Table 8.9.1: Impacts of Climate Change on Community Livelihoods.

<table>
<tr><td rowspan="4">COMMUNITY LIVELIHOODS</td><th>Climate Change Variables/Extreme Events</th><th>Impacts</th></tr>
<tr><td>Increasing Temperature</td><td>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 (3,p.34).

Temperature increases could lead to the spread of dengue fever and other vector borne diseases (2,p.12). Households onsisting 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.(8,p.43).</td></tr>
<tr><td>Droughts, Storms and Hurricanes</td><td>Crop loss and flooding which are some of the effects of extreme weather conditions also affect farming communities, which are largely vulnerable to climatic variability (5,p.61).

Increased flooding will lead to inundation of production fields.(5,p.27).

Rainfall extremes (droughts; floods) are associated with the spread of waterborne diseases, due to a lack of potable water and sanitation issues (6, p.15) possibly leading to lack of productivity.</td></tr>
<tr><td colspan="2">Additional information: Pollution from sewage and agricultural runoff as well as unsustainable activity like (over harvesting of fish) also damage Jamaica's reef systems, negatively affecting marine life and contributing to declining fish stocks (3,p.36).

Flooding is also caused by poor land use practices in watershed areas (4, p.67).Some farmers reduce forest cover which aggravate the impact of extreme events like droughts (6, p.19). Hunger and malnutrition could affect local population due to a reduction in food production as a result of drought conditions (1,p. 18).

Increasing sea surface temperature will heighten storm surges which will create more damaging flood conditions to coastal zones and low lying areas. These changes are likely to affect goods and services produced within the coastal zone (5,p.45).</td></tr>
</table>

Table 8.9.2: Climate Change Impacts related to Gender.

	Climate Change Variables/Extreme Events	Impacts
GENDER	Droughts/Decreasing Precipitation	Crop loss and economic woes creates more economic pressure on female farmers (poorer than male counterparts and have less access to land) to find more resources-water and fertilizer for their crops (6,p.19). Women in some communities have less access to credit because they lack the collateral required (6,p.11). During droughts there are increased costs for water, which places a special burden especially on female headed households (6,p.14). In some communities without running water, water use by men and women are prioritized based on their gender determined roles. Men carry water for agricultural purposes. While women and children have the main responsibility of carrying water for hygiene ,sanitation, potable water , cooking and other duties.(6,p.13)Therefore during water shortages , there are increased economic demands on households, it creates more pressure on women and children in these local communities, to find dwindling water supply to carry out these duties ; more time used by women to purify water for drinking(6,p.40) Furthermore there is also an increase in workload for women; more time spent use at standpipes, they go to the river less and washing 'piles up" (6,p.40). The unavailability of potable water restricts economic opportunities for women in some communities, who are unable to pursue income earning activities like the production of fruit jams, other food related activities and hairdressing that are heavily dependent on potable water. Women involved in chicken farming, also face the same challenges which are worsened by their heightened exposure to natural hazards (6,p.11). Health and sanitation issues associated with water shortages affecting both women and men, increase during these periods (6,p.15).
	Storms, Hurricanes	Women may be more vulnerable in disaster situations, less mobile for evacuation and have the responsibility of taking care of the children in emergency situations(3,p.74). During heavy rains, when there are landslides and pit latrines are flooded, releasing waste directly into rivers it creates hygienic issues. These conditions increase the likelihood of illness among children and the elderly which brings burden on women as primary caregivers(6,p.40). Women belonging to low income groups more often than men have a limited capacity to adapt to extreme events. Also, they are

<table>
<tr><td rowspan="4">GENDER</td><th>Climate Change Variables/Extreme Events</th><th>Impacts</th></tr>
<tr><td></td><td>more exposed to health issues (including worse case risk of survival or death) (3,p. 49).</td></tr>
<tr><td>Storms ,Hurricanes</td><td>Diet of population compromised due to these extreme events has harsh implication for children and the elderly, pregnant and lactating mothers (6,p.40).

There are concerns about the safety of women in shelters. Women more vulnerable to sexual abuse (3,p.50).Women also have specific needs-i.e. may be pregnant or nursing in shelters (11).</td></tr>
<tr><td colspan="2">Additional information: Women are more vulnerable to climate change impacts as their livelihoods, which includes subsistence farming and service sectors are largely climate sensitive (3,p.50). Women more at risk of unemployment than male counterparts (3,p.50) .

Women's roles as key actors in climate change adaptation decision making at the household level could arguably be as a result of their status as heads of the household(40% in Jamaica) (3,p.48).</td></tr>
</table>

Table 8.9.3: Climate Change Impacts related to Poverty

All of these impacts below lead to increasing poverty due to a positive feedback process.

	Climate Change Variables/Extreme events	Impacts
POVERTY	Increasing Temperature	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 (3,p.35).
	Droughts	Households in low income communities with no running water are more at risk of dengue fever and other infectious diseases, than those with piped water supply since water storage becomes necessary (8,p.43). Health issues: During water shortages in some communities, diseases spread because of poor infrastructure, waste disposal issues and lack of access to clean water sources (6, p.15). Malnutrition resulting from disturbances in food distribution and production could also occur (3,p.34).
	Storms, Tropical cyclones, Hurricanes	Flooding and landslides lead to population displacement because of vulnerabilities of settlements in floodplains (4, p.67). 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 (6,p.15).
	Additional Information: Lack of access to physical/financial resources; infrastructure and competition restrict alternative opportunities for the most vulnerable (3,p.51). There exists a culture of dependence nurtured by the patronage in the political system which is more evident in our low- income communities, where some residents do not appreciate the importance of their role in disease prevention and feel that, for example, dengue prevention, is the responsibility of the state. This increases their vulnerability to disease infection (8,p.44). The most vulnerable groups are those generally with no financial resources, who are also working or dependent in 'high risk' sectors (agriculture, fisheries, tourism) and in particular when employed in low-paid staff positions (3,p.72).	

Table 8.9.1: Climate Change Impacts related to Development.

	Climate Change Variable/Extreme events	Impacts
DEVELOPMENTAL ISSUES	Storm Surges Sea Level Rise	Increased incidence of sea level rise and storm surges would lead to displacement of 25% of Jamaicans who inhabit coastal areas (2,p.391). Areas like Portmore, which is a drained low lying coastal area (170,000pop) would be at risk from flooding (4,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 (9,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 (2p.390).This could result in massive economic losses for the country (3, p.29).
	Increasing Temperature	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, 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 .Particularly there is the potential threat of increasing atmospheric temperature, on youth and their educational development. Reading speed, reading comprehension and multiplication performance of schoolchildren could be affected by temperatures of 27 to 30 degrees Celsius (15, p.1) (NB. Such temperatures are achieved in Jamaica regardless of climate change).
	Storms, Hurricanes, Droughts Tropical Cyclones, Floods	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(3,p.35). Improper land use/development in watershed/flood-prone areas increase vulnerabilities to landslides and floods (4, 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 (3,p.35).

DEVEL	Climate Change Variable/Extreme events	Impacts
	Storms, Hurricanes, Tropical Cyclones	Insurance sector: 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.(18,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 (18,p.1). The unpredictability of climate change is forcing insurers to develop adaptation strategies which includes putting a price on current and future risks(19). Banking sector: 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 (20,p.11). The effects of climate change on banking companies would be direct (e.g. Through extreme events that put facilities at risk or indirect (through imposed regulations or shifts in social preferences) (20,p.11).
	Additional Information: Population growth in coastal areas increase demand for land. This involves the removal of coastal vegetation and many natural barriers which increase risks to these events (i.e. storm surges and sea level rise) (9,p.9). Poor land use practices also exacerbate the impact of flooding (3,p.29). Impact by Mid Level Scenario of Sea Level Rise would cost the CARICOM countries (including Jamaica) in 2050, $USD60.7 billion US dollars (12). During a hurricane or a storm, rainfall exceeds aquifer capacity, causing damage to infrastructure like bridges and roads (3,p.30).	

Table 8.9.2: Impacts of Climate Change related to Natural Disaster Management.

NATURAL DISASTER MANAGEMENT	Extreme Events	Impacts
	Droughts, Storms, Hurricanes, Floods	All of these impacts have already been mentioned in previous tables.
	Additional Information: Displacement of population resulting from hurricanes and floods have been accompanied by outbreaks in shelters managed by the ODPEM (8,p.40).	

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9. NEXT STEPS

In the Introduction to this document we noted that its intended purpose was to:

a) Provide a simple overview of the state of Jamaica's climate, including a description of driving forces, climatology and historical trends.
b) Provide tables and figures summarizing future projections of Jamaica's climate under global warming using available data from global and regional climate models.
c) Be an initial reference point for key sectors and persons who wish to engage in climate change adaptation work with respect to Jamaica and who need to determine the climate state being adapted to.
d) Be an initial reference point for persons seeking out other sources of information which document how key sectors for Jamaica may be influenced by climate change.
e) Provide a representative listing of data sources, including journal articles and raw data, for those interested in finding more details about Jamaica's climate and how it is varying or will change.

We hope that it will indeed serve these purposes and will be well used by a wide variety of audiences.

The process, however, also afforded the opportunity for making some wide ranging observations and recommendations. We, therefore, note the following:

1) The need for more data: It is data which is being argued is the linchpin for planned action and response to climate change. Whereas we believe the document points to a sufficiency of data to make the case for such action, i.e. on the basis of trends and patterns evident which can be supported by similar documentation for other parts of the world, it is also clear that one cannot claim adequacy of the data, particularly as the premise for some scales of action. We further note below that for some variables the best that can yet still be reported are averages or single values for the entire country. This is true for both observed and modelled data. This does not allow for action at sub national scales including at the community level. **Recommendation: Make climate data gathering a priority issue for inclusion in all national climate change related proposals or projects.**

2) The need for more observations: Climate data at the sub national scale is needed for drawing conclusions about past variability and change, for validating modelled future change, and for downscaling to finer resolutions using statistical methodologies. At present, the range of variables decreases significantly when the airport stations are excluded from analysis. It is precipitation which has the best island wide coverage. A number of recent (at the time of writing) national projects should help address this issue e.g. the installation of Automatic Weather Stations (AWSs) at strategic locations across the island. The successful deployment and maintenance of such stations as well as the gradual supplementation of their number over time (to complement manual stations) should ensure that many more observations are available for vastly improving an update to this report in the not too distant future. **Recommendation: Target investment in the installation and maintenance of automatic weather stations at strategic**

locations across the island. This includes training in the skill set to keep the stations operational.

3) The need for data recovery: Efforts such as the installation and maintenance of AWSs will alleviate data needs in the medium to long term, when sufficient time has elapsed to enable inter-annual and longer term climatic trends to be deduced from the new data generated. In the meantime efforts should be concentrated on data recovery, where the data may exist in a variety of formats (e.g. paper, microfiche, etc.) and in a variety of locations (e.g. homes, libraries, etc.). Recovered data has to be digitized and then stored in a location which has the capacity to store both the volume of data recovered and new data generated. **Recommendation: Embark upon a deliberate climate data recovery exercise. The data recovered is to be centrally and securely stored in a national climatic database.**

4) The need for more real time monitoring of climatic trends: Whereas some climatic trends will take a lifetime to manifest themselves others can be quickly deduced with deliberate monitoring of climatic variables and indices. Drought and flood patterns, heat waves and rainfall intensity variations, whether related to seasonal or inter-annual variability can be quicker deduced with ongoing dedicated monitoring. Much of this monitoring can be done through the production of timely reports which can be automatically generated from data received e.g. via the AWSs. This would facilitate quick response times to variations that pose significant threat to life and livelihood. **Recommendation: Strengthening the human and technical capacity for real time monitoring of climatic variations.**

5) The need for sustained research on climate variability: There has been a considerable expansion of knowledge about the drivers of Caribbean climate variability in the past decade. Much has been garnered about the role of phenomena such as ENSO in determining modes of variability of, for example, regional rainfall regimes. There is need to further downscale this kind of research to examine modes of variability of Jamaican climate (spatial and temporal patterns and drivers). Whereas this kind of research is severely hampered by the lack of data alluded to above, ongoing data rescue and the creation of gridded datasets of variables at sub-national scales, are now facilitating the undertaking of this kind of research. There is potential for using the results to create Jamaica-specific prediction models e.g. for rainfall zones across Jamaica. **Recommendation: Enhance research capacities (e.g. at Universities, National Meteorological Service) to undertake climate variability research specific to Jamaica.**

6) The need to continue downscaling future projections of Jamaican climate: There is substantial data that already exists from regional and global models run under the Special Report on Emission Scenarios (SRES) scenarios. This data needs to be downscaled to national and sub-national scales even beyond that which appears in this report. Doing so will be facilitated by further investment in research capabilities and through the data rescue efforts noted above. Initially downscaling will have to be done according to prioritized need and/or as data becomes

available. However, there must be a coordinated effort to ensure that eventually (provided data is available) downscaled information for a multiplicity of key climate variables exist for Jamaica to drive 'evidenced based' adaptation planning. **Recommendation: Pursue downscaling of existing modelled data to national and sub-national scales.**

7) The need for new scenario based modelling exercises: The SRES scenarios are a decade old and globally the emphasis over the next few years will be on new projections premised on Representative Concentration Pathways (RCPs). It is RCPs that are becoming the basis for new runs of the latest climate models and the focal points for new research on socio-economic scenarios. The IPCC has decided to focus on four emissions trajectories (RCPs) and have labelled them based on how much heating they would produce at the end of the century — 8.5, 6, 4.5 and 2.6 watts per square metre ($W\ m^{-2}$). The range covered by the RCPs is wider than that of the SRES scenarios, partly reflecting a general shift in outlook to one where possible future emissions trajectories look more extreme than they did a decade ago. There is no need for Jamaica to play 'catch-up' with respect to global discussions in the near future on climate change, which will be premised on the RCPs. (To a large extent this was the case with the region and the SRES scenarios). **Recommendation: The pursuit and generation of new downscaled future scenarios premised on the 4 RCPs being focussed on by the IPCC.**

8) The need for sector based-studies and/or implementation of recommendations from previous studies examining climate change impacts: On the one hand, this report highlights the fact that information available on sector impacts is in many cases not specific to Jamaica. Whereas in some cases this may not be too significant a limitation (e.g. dengue increases under a warmer climate is a matter of concern wherever it will occur) in other cases more specific information for the country is needed (e.g. sea level rise information is critical to locating hotel and other coastal infrastructure). On the other hand, the compilation of this report revealed that a number of good studies have already been done with useful recommendations for consideration. It is then the move toward the implementation of the recommendations which is required in the near future. **Recommendation: Examining by sector, plans for mainstreaming known climate change impacts into developmental plans and/or initiating studies to determine the climate change impact on an understudied sector.**

9) The need to get the word out there: The value of this report is that, at least for the present time, it represents the state of the knowledge with respect to climate variability and change for Jamaica. Its true worth will be evident when the information becomes the basis for making decisions and formulating plans or not formulating plans. To do so, however, the data must get to those (at all levels) who have the responsibility for making such decisions and plans. **Recommendation: Disseminating the information in this report widely.**

10. WORKSHOP REPORT AND FEEDBACK

Agenda

State of the Jamaican Climate Workshop		
8:00- 8:30a.m.	Registration	
8:30- 9:00a.m.	Welcome and Opening Remarks Overview of the Project	Miss Claire Bernard Mr. Albert Daley
9:00-9:20 a.m.	Overview of the document	Dr. Michael Taylor
9:20-10:30a.m.	**Session 1:Climatology and Trends** - 20 minute presentation - 30 minute group exercise - 20 minute feedback/report	Dr. Tannecia Stephenson
10:30 -12:00 p.m.	**Session 2: Projections** - 20 minute presentation - 10 minute coffee break - 30 minute group exercise - 30 minute feedback/report	Dr. Michael Taylor
12:00- 1:10 p.m.	**Session 3: Impacts** - 20 minute presentation - 30 minute group exercise - 20 minute feedback/report	Professor A. Anthony Chen
1:10 – 1:30 p.m.	Thanks , Closing remarks and filling out of evaluation forms	Dr. Michael Taylor

1:30 – 2:30 p.m.	**LUNCH**

10.1 Introduction/Overview of the Project

The Pilot Project for Climate Resilience (PPCR) is a global project funded by the Climate Investment Fund to assist developing countries, like Jamaica, to develop along a climate resilient path that is consistent with poverty reduction and sustainable development goals.

The purpose of this workshop and in particular, the association with the Climate Studies Group, is to produce and provide climate data that can guide these development processes and assist in advancing this project's mandate.

This workshop was coordinated by the Climate Studies Group in association with the Planning Institute of Jamaica. It was held on May 2, 2012 at the Terra Nova All Suite Hotels and was attended by 30 stakeholders.

10.2 Sectors in Attendance

- Health
- Natural Disaster Management
- Development
- Gender
- Water
- Banking and Finance
- Physical Planning
- Agriculture
- Meteorology
- Environment
- Private Sector

10.3 Workshop Objectives

The purpose of the workshop was for stakeholders to be introduced to the document prepared by the Climate Studies Group entitled "State of the Jamaican Climate: Data for Resilience Building", which was subject to review and analysis of workability, i.e. from theory into praxis.

10.4 Overview of the Document

The workshop began with an introduction of the document given by Dr. Taylor, who described it as one that aimed to improve the understanding of the state of the Jamaican climate. The material contained in the document is divided into three main sections- Climatology, Future Trends and Possible Impacts of Climate Variability and Change in Jamaica. He emphasized that the document is very user friendly, by highlighting the fact that the 185 page document contains graphs, pictures, colourful images and simple language, which was a strategic imperative to make climate change information accessible to an audience outside of the scientific world.

It also represents a codified attempt to materialize one of the objectives of the PPCR, which is to "strengthen capacities at a national level to integrate climate resilience into development planning". In this way it can serve as a guide to assist policy makers within multiple sectors to make decisions that involve climatic considerations.

Furthermore, it was pointed out that much of the information presented is not new, but serves as a comprehensive collection of all that is currently known about Jamaican climate.

Finally, Dr. Taylor noted that the document was incomplete at the time of the workshop, and invited a more participatory process from the workshop attendees to conclude the final chapters with their feedback.

10.5 Session 1: Climatology- Climatic Variability and Trends

The presentation in Session 1 was about Climatology: Climatic Variability and Trends, summarizing Chapters 3 and 4 of the document. Both chapters discussed definitions, the seasonality of variables and scientific explanations for these phenomena across the island. Graphs and illustrations showing the areas with high climatic variability were included in the presentation. Participants were also directed to the brief section at the end of each chapter on how to use the materials provided.

After the presentation, the participants were given an activity based on the specifications of the profile of the communities to which they were assigned at registration. The focus of activity 1 was to investigate the climate variables that would have the greatest impact on the communities, and how planning would take this variability into account. Responses to the questions brought to light the variety of concerns that can arise based on the needs and existing capacity of an area.

For example, the first question in Session 1 asked participants to brainstorm climate variables that were important to their communities. Variables chosen ranged from rainfall patterns and wind speeds to sunshine hours and temperature for the coffee growing community; while extreme events like hurricanes were thought to have greatest influence on a community whose economic sources are tourism and artisanal fishing.

10.6 Session 2: Projections

Session 2 described projections as outlined in Chapters 5, 6 and 7. The presentation described how projections are made and the advantages of downscaling GCMs (Global Climate Models) to RCMs (Regional Climate Models). Some of the advantages included a higher resolution view of climatic conditions over smaller areas like the Caribbean region, and even to the scale of a country like Jamaica.

The activity based on session 2 asked participants to assess, from the specified chapters, what changes are projected for their previously chosen climate variables. Using this information, they were then asked whether these changes would have any bearing on existing community plans and if involvement of government representatives would be necessary. Examples of changes that must be made to community plans included growing more drought tolerant and flood resistant crops due to the impending changes in precipitation in one community, and in another they would address increased extreme events (i.e. heightened storm surges) by planting mangroves and reviewing coastal setbacks. Other suggestions were the use of water harvesting; organic farming techniques to conserve water and reduce the impacts of soil erosion during increased flooding events; and planting more trees to reduce the impact of increased winds and temperatures.

10.7 Session 3: Impacts

Session 3 was a presentation about Chapter 8. Chapter 8 explored the sensitivity of multiple sectors and natural resources to climate change variables and extreme events. It contains a how to use section and a guide for Vulnerability Risk Assessments (VRA).

The inherent goal of this chapter is to move away from the theory, and in so doing, encourage implementation of projects that are considering of the climate. In addition to this, the impacts that were presented were possible impacts, based on models and projections and are not to be interpreted as definite impending realities.

The activity for this session was aimed at planning for adaptation to potential impacts of climate change on the communities. Responses were in agreement that the tables do simplify the sectoral linkages to climate, for example the vulnerability of agriculture and food security to soil degradation and decreased precipitation. Mitigation was also emphasised, as well as a need to explore alternative tourism product offerings like nature based/ecotourism.

10.8 FINAL QUESTIONS & COMMENTARY

This section includes comments and recommendations expressed during the closing discussion.

- *How soon will the final document be available?*

Once feedback is received, the PIOJ should have the final document for public use by the end of the month of May.

- The document is useful, and it is one of the first collections of climate information that can be used by multiple sectors for future planning. *Will there be workshops for each sector so they can each do in depth analysis to further inform strategic planning?*

The idea of additional workshops will be taken as a suggestion. In phase 2 of the PPCR project, that will be a critical activity. Data will be required to help agencies to develop sectoral plans. Jamaica's second national communication also contains sector specific information, which was used in developing the PPCR/SPCR.

- The workshop was useful. *If NGOs working in the field identify the challenges communities have with respect to climate change & would like to work with communities to help build resilience, would the PIOJ assist?*

As a general rule, the PIOJ exists to help the country. Hence, if the idea is consistent with an existing PIOJ project, then assistance can be provided since that kind of need would have been anticipated by the concept of the project. Concepts have to be approved and criteria developed before assistance can be meted out. Potential exists and there are various ways in which the PIOJ helps to push forward the national interest. A sound proposal is required to acquire funding, with which this document will help.

- The document is comprehensive and effective. It provides scope for collaboration in mainstreaming gender in policies and activities.
- The document is readable & not "scary". It also does not contain as much 'overwhelming' material as was expected. References are convenient for further research.
- The document is timely. The Water Resources Authority's master plan is being updated & plans must be made taking climate change into consideration. For example, rainfall projections would help in projecting water availability. However, data availability and scale of some variables (such as evaporation) can be improved.
- The workshop was useful, but must extend to the meetings of individual sectors & to the vulnerable groups. There are currently more NGOs with good ideas in need of funding than there are funding opportunities, so we all need to work together to further the cause.

10.9 APPENDICES

10.9.1 APPENDIX 1: COMMUNITY PROFILES

Below are the profiles of the four communities into which the participants were grouped for session activities.

Community 1

Community 1 is a hillside community of about 1,800 persons on the outskirts of Kingston. The majority of the community members are farmers growing mainly cash crops – primarily bananas and Blue Mountain coffee. Most of the small farmers work seasonally on the large coffee farms e.g. harvesting the coffee berries. Additionally some have jobs in Kingston and others have small businesses (such as shops) in the community. This community is located in the mid-reaches of the Wag-Water watershed which feeds the Hermitage Dam, an important water supply for Kingston. The community farms on steep slopes, often using unsustainable agricultural practices such as slash and burn. These communities are already at risk from soil degradation which is reducing the productivity of their farms.

Community 2

Community 2 is based in St. Mary. It has 150 residents. Family structures vary, but young children and people over the age of 65 years constitute a significant percentage of the community. This means that these individuals are highly dependent for care and support. Within the community men and women are employed in different areas. The men are involved in small farming, welding and construction. While the women do mostly domestic work and work in hotels.

Lack of access to potable water within the community severely limits economic development for both men and women. This is especially severe for farmers who reside within the community who have to restrict their agricultural production because of the absence of water for irrigation. Fifty seven percent of residents within community 2 use water from the standpipe. Depending on one's location within this community, it can take 20-25 minutes to access water from one of the main sources, either river A, River B or standpipe C. Lack of access to water is time consuming and in average 2 to 5 hours is spent on carrying water (which is a task primarily carried out by the women). Seventy nine percent of residents in Community 2 use pit latrines. In times of heavy rainfall, these pit latrines are flooded releasing waste directly into rivers which these residents use for hygienic purposes.

Community 3

Community 3 is a bay coastal area located in Negril. This area has 7 resorts on the bay which take up most of the coastline. A large percentage of the population in the immediate and surrounding environs works within these hotels. It is situated near the Great Morass. A smaller section of the population does artisanal fishing for livelihoods.

Community 4

Community 4 is a poor community of rural squatters in ST. James. It consists of small crudely built houses, most lacking basic amenities and scattered over rugged terrain. Few heads were employed in agricultural pursuits, even for their own subsistence. A part of the explanation for this may be the fact that roughly 60 per cent of the households were headed by women. The women were of low educational attainment and lacked skills training. This placed them at a disadvantage in the labour market and those employed were in domestic service and petty trading, activities that attracted incomes at the minimum wage or below. Male heads shared similar characteristics and were employed as gardeners and labourers on construction sites. Unemployment in this community stood at 33 per cent. In addition a questionnaire administered to members of the community elicited the following information, which shows the topic of the question and the percentage of positive responses.

Income – Minimum Wage or less	68
No pipe at home	46
Water storage in drums	65
Chronic illness	53
Female household headship	60

10.9.2 Appendix 2: Session Activity Questions

Below are the questions used for each session activity.

Activity for Session 1

1. Brainstorm at least 3 climate variables which are important to your community.
2. With reference to Chapters 3 and 4 of the document identify how these variables vary annually and if any change (variability or trend) has been noted for them in the recent past.
3. How would this information guide short and long term planning in your community? Note no more than 10 ways.

Activity for Session 2

1. With reference to Chapters 6 and 7 of the document identify how the climate variables chosen in Session 1 change going into the future?
2. How does this information change the plans for your community?
3. Do you need to call the MP?

Activity for Session 3

1. Scan through the impact tables and choose 3 tables which would apply to your organization or community.
2. Do the tables help to improve or clarify or add to your (adaptation) action plan?
3. What impacts are missing from the 3 tables and other tables (if you have time)?

10.9.3 Appendix 3: Session Activity Results

Below are tables detailing group responses for each question during activities.

Table showing responses of communities 1 - 4 for Session 1 Activity: Question 1

	Activity 1: Question 1
Community 1	**Brainstorm at least 3 climate variables which are important to your community.**
	Temperature : Height affects coffee taste Wind affects coffee and bananas Rainfall affects the bananas and the key crops
Community2	The climate variables that were important for this community were listed as Rainfall, Evaporation and Relative Humidity. The reason for the importance of the Rainfall variable was listed as for residential and agricultural purposes. N.B: The rainfall variable was the only variable for which importance was explained.
Community 3	Solar radiation/ sunshine hours : Tourism products, Livelihood depends on availability, Potential for renewable energy Hurricanes/Tropical storms : Livelihood impacted/loss of fishing gears and equipment, Safety, Flooding (storm surge),Property damage, Loss of revenue/income; Potential loss of life Sea level rise: Increase shoreline vulnerability with severe economic consequences , Long term erosion, Increased impact of flooding
Community 4	Rainfall: source of water supply, heavy rainfall has the potential to accelerate soil erosion Temperature: Increased potential for drought, potential impact on farming Winds: Destructive impact on houses

Table showing responses of communities 1 - 4 for Session 1 Activity: Question 2

	Activity 1: Question 2		
	With reference to Chapters 3 and 4 of the document identify how these variables vary annually and if any change (variability or trend) has been noted for them in the recent past.		
	Variable	**Seasonality e.g. Time of max, Time of min**	**Trend**
Community 1	Temperature Wind Rainfall	Cold day and night time temps. have decreased In ref to figure 3.5 our community is in a very windy region Varies in extremes. Annually there could be a very wet or a very dry season	Mean temperatures have been increasing which affects coffee that requires cooler temps for growth Annual increase in wind speeds have been observed El Nino is below normal from Dec to Mar, but Jamaica is in transition zone so can swing either way-dry or wet. Has implications for local fruits.
Community2	Rainfall Relative Humidity Evaporation		Mostly dry annually and seasonally except for ASO
Community 3	Hurricanes Solar radiation/ sunshine hours Sea level rise	June to November March, April May, June and July	Increased cats 4& 5 in the last 50 years .28 increase per decade Based on increase trend in Port Royal, similar trend is anticipated in Negril
Community 4	Rainfall Temperature Wind speed	Max. 253 mm October, Min. 62 mm March Avg. 27.5 degrees Celsius 4.-5 m/s	Decreasing Range 0.6 – 0.9 mm/yr Increasing 0.27 degrees Celsius per decade Increasing island wide .26 m/s

Table Showing Responses of Communities 1-4 for Session 1 Activity: Question 3

	Activity 1: Question 3 **How would this information guide short and long term planning in your community?**
Community 1	1.We have to look at alternative crops in some cases 2. Review planting seasons so with bananas – you might have to plant wind breaks 3. Not sure how to tackle the coffee 4. Practice soil conservation practices such as check dams and mulching 5. Public education regarding slash and burn
Community 2	1.Water conservation measures e.g. community catchment 2.Change of farming practices e.g. mulching 3. Improve sanitation facilities e.g. pit latrines sealed in concrete
Community 3	1. Monitoring to reform planning at the community level 2. Build more solar forms to produce renewable energy for hotels 3. Rainwater harvesting 4. Education on burning of the morass 5. Working with fishing communities to: a. Develop alternative livelihoods b. Address safety issues and loss of assets associated with climate events
Community 4	1. Will need to engage in other economic activities 2. Improving farming technology 3. More education and public awareness 4. Look at community cultural change e.g. diversifying livelihood base 5. Look at land stabilization 6. Efficient storage and use of water 7. Relocation of residents

Table showing responses of Communities 1-4 for Session 2 Activity: Questions 1 and 2

<table>
<tr><td></td><td colspan="3">Activity 2: Questions 1 and 2</td></tr>
<tr><td></td><td colspan="3">1. With reference to Chapters 6 and 7 of the document identify how the climate variables chosen in Session 1 change going into the future?

2. How does this information change the plans for your community?</td></tr>
<tr><td rowspan="4">Community 1</td><td>Variable</td><td>Future Trends</td><td>Changes to community plans</td></tr>
<tr><td>Rainfall</td><td>Scen 1- 48% decrease in precipitation

Scen 2-25% decrease in precipitation</td><td>Severe implications for banana production and coffee yields
Community needs to find something else to plant – more drought resistant crops
• Changing crops to ones that do better under dry conditions – we don't have any of these crops in Jamaica now?
• Hydroponics – ways to use water better – is it cost effective and the technology – grow things in plastic
• How will adaptation affect men and women? – Access to land and technology, funding</td></tr>
<tr><td>Temperature</td><td>Annual mean increase in temp – 2.7 degrees Celsius</td><td>Sustainability of coffee farming and community livelihood options would have be reviewed – need more research on options</td></tr>
<tr><td>Wind</td><td>No significant change</td><td>Previously mentioned</td></tr>
<tr><td>Community 2</td><td>Rainfall</td><td>Much drier
A2 --78% to 10% AUG
B2 -71% to +7% APR</td><td>Mandatory water conservation measures
Explore ground water sources
More piped water
Develop sewer system
Divest to organic farming</td></tr>
</table>

Community 3	Hurricanes	Increase in wind 2.9 – 20% Storm surge will increase 100yr event will occur more frequent	• Mangrove planting • Review of coastal setbacks • Enforce regulations • Mitigations - breakwaters
Community 4	Rainfall	RCM: annual decrease 51.9%; ASO has greatest decrease of 73.1%	• Increased water control including: water harvesting and storage, tree planting • Increase use of technologies
	Temperature	GCM: 1.1-3.2°C increase RCM: Annual avg. 3.23°C; greatest change MJJ (3.79°C); smallest in FMA (2.95°C)	• Plant more trees to reduce temperature (i.e.. create micro-climate) • Retrofit to make use of variables (e.g. wind)
	Winds	Small decreases in wind by 0.3-0.5 m/s	• Increase wind-breakers (e.g. trees) • Redesign housing

Table showing responses of Communities 1-4 for Session 2 Activity: Question 3

	Activity 2: Question 3
	Do you need to call the MP?
Community 1	Yes – needs to address: • Mainstream gender in the community solutions so that the vulnerabilities of both sexes are addressed • Access to loans and lines of credit for men and women, technology • Need more research on more climate resilient crops • Work with partner organisations such Bureau of Women's Affairs, IGDS, SDC, • Policy changes are required – equitable access to credit and technology for men and women, more policies sensitive to climate change adaptation such as mainstreaming CC into agriculture at the macro level, filtering this to the community • Accessing funds to help with adaptation strategies at community, sectoral and national levels – always keep gender concerns in this
Community 2	Yes • MP can bring attention to the issue and attract funding
Community 3	Yes • To advocate for resources and implementation of mitigation measures • To influence planning decisions • Call Chamber of Commerce to assist in advocacy
Community 4	YES!!!!!

Table showing responses of Communities 1-4 for Session 3 Activity: Questions 1 and 2

	Activity 3: Question 1 & 2
	1. Scan through the impact tables and choose 3 tables which would apply to your organization or community. **2. Do the tables help to improve or clarify or add to your (adaptation) action plan?**
Community 1	**Agriculture and Food Security**: Soil degradation, decreased precipitation – higher production cost, malnutrition, , storms and hurricanes – loss of agriculture assets – solidify our information that coffee will be affected **Community Livelihoods**: Tables do a good job of clarifying information coming out of previous information, invest more in improved water harvesting, Improved planning – build more hurricane resilient structures, more reforestation efforts – and enabling policies
Community 2	**Community Livelihoods**: • Crop loss and flooding which are some of the effects of extreme weather conditions also affect farming communities, which are largely vulnerable to climatic variability (5, p.61) • Increased flooding will lead to inundation of production fields.(5, p.27) • Rainfall extremes (droughts; floods) are associated with the spread of waterborne diseases, due to a lack of potable water and sanitation issues (6, p.15) possibly leading to lack of productivity. **Water Quality and Availability**: Heavy Rainfall /Storms ,Droughts **Agriculture & Food Security**: Decreased precipitation ,Storms, Hurricanes and Floods; Rainfall patterns
Community 3	**Tourism**- coral bleaching: Expand tourism products to include nature/ecotourism ,Emphasize the need for mitigation **Fisheries**-loss of sea grass: Habitat rejuvenation – replanting, Public education , Livelihood diversification
Community 4	**Poverty**: Capacity building, training, new income generating activities **Human Health**: Water related sanitation issues **Agriculture**: Improved agricultural practices and technologies, irrigation, land use and infrastructure

Table showing responses of Communities 1-4 for Session 3 Activity: Question 3

	Activity 3: Question 3
	Write the title of one possible project that you could present to the SPCR for your community and specify one objective.
Community 1	❖ Title: Boost sustainable farming practices to enhance community adaptation of agricultural crops in Community 1 (include Increasing capacity to store and harvest water) ❖ Objective: To maintain the coffee and farming yield in the community through more effective storage and harvesting of water, and building resilience regarding more sustainable farming practices such as soil conservation and crop diversity
Community 2	❖ Title: Increasing the resilience of a rural farming community in St. Mary by assessing and implementing water adaption strategies for sustainable livelihoods. ❖ Objective: To develop and implement adaptation strategies including establishment of a safe and reliable water system, introduction of sustainable farming practices, improvement of sanitation practices & facilities and improvement in community awareness of climate change adaptation strategies.
Community 3	❖ Title: Community Resilience through livelihood diversification ❖ Objective: • Job creation and job security • Improved ecosystems management
Community 4	❖ Title: Capacity Building of Rural Communities in St. James ❖ Objective: Retraining community members to adapt to climate change effects on traditional economic activities while taking account of gender imbalances

10.9.4 APPENDIX 4: LIST OF PARTICIPANTS

NAME	ORGANISATION
Leith Dunn	Institute for Gender and Development Studies
Herbert Thomas	Water Resources Authority
Zelris Lawrence	Development Bank of Jamaica
Elizabeth Emmanuel	Planning Institute of Jamaica
Clifford Mahlung	Meteorological Services of Jamaica
Carlton Wedderburn	Ministry of Agriculture and Fisheries
Zuleika Budhan	Ministry of Agriculture and Fisheries
Stacy-Marie Bennett	JOAM(Jamaica Organic Agriculture Movement)& Organic Certification Committee
Andrea Kerr	Kingston Restoration Company
Leiska Powell	Office of Disaster Preparedness and Emergency Management (ODPEM)
Robert Wright	INMED Caribbean
Eistein Mclean	RADA
Omar Chedda	Private Sector of Jamaica
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Le-Anne Roper	Planning Institute of Jamaica
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Basil Fernandez	Water Resources Authority