2012

State of the JAMAICAN CLIMATE

Information for Resilience Building

Summary for Policymakers

SUMMARY FOR POLICYMAKERS

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A note about using this document

This document is a ***Summary for Policymakers*** of a much larger document entitled ***State of the Jamaican Climate 2012: Information for Resilience Building*****.** We strongly urge acquiring and reading the full report. A great way to read this summary is to start on page 46 with the ***10 Question Climate Change Quiz***. If you get them all correct then you have a great command of the issue. If not… we recommend page 1 as the next best place to start.

A note about Figure and Table Numbers:

To allow for easy cross referencing the Figure and Table numbers used in this ***Summary for Policymakers*** are the same as that in the full report. Where the original figure has been altered for the sake of this document a note has also been made.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
A1B	Scenario generated by the IPCC
A2	Scenario generated by the IPCC
AMO	Atlantic Multidecadal Oscillation
ASO	August to October
B1	Scenario generated by the IPCC
CO_2	Carbon Dioxide
DJF	December to February
ENSO	El Nino - Southern Oscillation
FMA	February to April
GCM	Global Climate Model
GDP	Gross Domestic Product
GHG	Green House Gas
GOJ	Government of Jamaica
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
JJA	June to August
km	kilometre
m	metre
m/s	metres per second
MAM	March to May

Abbreviation	Meaning
mb	millibar - a unit of atmospheric pressure
MJJ	May-July
mm	Millimetres
mm/day	Millimetres per day
mm/year	Millimetres per year
NAH	North Atlantic High
NAO	North Atlantic Oscillation
NDJ	November to January
PPCR	Pilot Program for Climate Resilience
PRECIS	**P**roviding **RE**gional **C**limates for **I**mpacts **S**tudies
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SCF	Strategic Climate Fund
SIA	Donald Sangster International Airport
SLR	Sea Level Rise
SON	September to November
SRES	Special Report on Emissions Scenarios
SST	Sea Surface Temperature

Sensitivity

1. sen·si·tiv·i·ty - The quality or condition of being sensitive.

Whereas weather refers to changes in the state of the atmosphere at a particular place and time — for example whether Kingston today is warm or cool, wet or dry, cloudy or windy — climate refers to the average state of the weather over long periods of time ranging from months or seasons to years and decades. Climate is important because it controls many things even without one's realizing it. This is especially true for Jamaica, where life in part revolves around whether it is wet or dry or whether it is hot or cool.

There is an intimate and undeniable link between day-to-day life and climate in Jamaica. Jamaica's yearly climatic cycles (or its ***climatology***) form the backdrop for a number of lifestyle and livelihood related activities, making Jamaica a climate sensitive country. For example, Jamaica's climate ***sensitivity*** can be found in planting and reaping cycles which are intimately bound up with Jamaica's rainfall and temperature climatologies i.e. its typically dry (December – April) and wet (May-October) seasons and its summer temperature maximum (July-August). Its climatology also influences other things such as disease cycles (e.g. the timing of dengue and asthma peaks), energy and water consumption patterns, sporting seasons and even seasonal employment statistics.

Jamaica's climate sensitivity is in part rooted in the country's dependence on climate sensitive economic activities such as agriculture and tourism and its reliance on seasonal rainfall for water. Jamaica's climate sensitivity is further enhanced by the island's relatively small size and its topography of hilly interiors and limited coastal plains which drives the use of the narrow coastal areas and/or steep hillsides for the location of key infrastructure and population settlements. There can be no denying that climate is deeply interwoven into and entrenched in all levels of Jamaican existence.

This, then, makes Jamaica vulnerable to climate variations. The country is highly susceptible whenever the climate changes irrespective of whether the change is on short (seasonal, year to year, or every few years) or longer (decadal) timescales. Because climate sensitivity pervades Jamaican existence, everyone and everything is affected by the ***variability*** of the climate. This is seen almost yearly in the impact of climate extreme events on the Jamaican economy (Table 1). But it is also true when the climate ***change*** is more gradual i.e. over decades or longer. There is strong scientific evidence to suggest that Jamaica's climate has changed in the recent past. There is equally strong scientific research to suggest that Jamaica's climate will continue to change, with the ***projections*** suggesting significant change through the end of the century. Jamaica's climate sensitivity and attendant vulnerability make long term climate change a developmental issue which must be given serious and urgent consideration.

There is, then, clear need to understand and quantify how climate variability will play out in Jamaica in the near term, as well as how long term climate change has and will continue to manifest itself in Jamaica. Understanding the state of the climate is critical to coming to grips with the likely associated ***impacts*** on society due its variability, and is also essential to the development of appropriate response strategies to build ***resilience***. Herein lies the significance of the document ***State of the Jamaican Climate 2012: Information for Resilience Building***.

Table 1: Estimated economic impact of recent climate extreme events on Jamaica

EVENT	Year	Category	Cost($J billions)	Impact (% GDP)
Hurricane Michelle	2001	4	2.52	0.8
May/June Flood Rains	2002		2.47	0.7
Hurricane Charley	2004	4	0.44	0.02
Hurricane Ivan	2004	3	36.9	8.0
Hurricanes Dennis & Emily	2005	4	5.98	1.2
Hurricane Wilma	2005	5	3.6	0.7
Hurricane Dean	2007	4	23.8	3.4
Tropical Storm Gustav	2008		15.5	2.0
Tropical Storm Nicole	2010		20.6	1.9

Source: Compiled by the PIOJ with data from various agencies.

About this Document

This document, ***Summary for Policymakers***, is a synopsis of a much larger document entitled ***State of the Jamaican Climate 2012: Information for Resilience Building***. The full report contains the most up to date compilation of the state of the climate of Jamaica (as of the year 2012), including how and why Jamaica's climate is known to vary, how it has changed historically and how it is likely to change through the end of the century. Importantly, it also draws on existing studies to compile a list of some possible climate impacts on important sectors or groupings in Jamaica. The list of chapters in the full document is given in Table 2. The full report was generated as a deliverable for 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 PPCR 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). It is felt that a well-reasoned evidence based strategic program for climate resilience for Jamaica is conditioned upon an assessment of the country's climate variability and change such as that detailed in the ***State of the Jamaican Climate 2012: Information for Resilience Building***.

Table 2: Chapters and explanatory summaries. ***State of the Jamaican Climate 2012: Information for Resilience Building***.

	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	A description of 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.

It is strongly urged that the full report from which this summary is drawn be consulted, particularly where there may be further clarification desired on points raised or data presented in this ***Summary for Policymakers***. As noted in the Introduction to the full report, the ***State of the Jamaican Climate 2012: Information for Resilience Building*** is intended to be an initial reference point for all interested persons who desire a description of Jamaica's climate, its variability and trends and future projections. It is intended 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.

This ***Summary for Policymakers*** summarises the major results of the larger report by presenting them under seven sections each captioned by a 'key' word. The seven 'key' words are: ***Sensitivity, Climatology, Variability, Change, Projections, Impacts*** and ***Resilience***. The discerning reader will note that the previous pages provided the context for and significance of the 'key' words which were also italicized and highlighted in blue. These are 'key' words or themes in any discussion on climate variability and change and hence 'key' words to be understood by policy and decision makers as they prepare medium and long term development plans for Jamaica. This ***Summary for Policymakers*** deliberately highlights the main scientific results of the full document in the context of these 'key' words as a way of aiding policymakers in easily accessing the appropriate and applicable climate information to support discussion on the seven 'key' themes. In this way it is hoped that both this summary and the full report will be seen as valuable aids when determining developmental pathways for Jamaica which, of necessity, must consider and incorporate climate.

Climatology

2. cli·ma·tol·o·gy - The study of climates and their phenomena.

Climatologies are most often expressed in terms of the annual cycle of key climatic variables such as temperature, rainfall and wind strength. Given that they give a picture of 'average' or mean conditions over the course of a year, the climatologist represent what the expected climate might be. The climatology of a country establishes the baseline against which deviations or changes are measured. It is also the backdrop against which much of life in Jamaica has evolved and around which it still revolves.

Temperature

Surface temperature in Jamaica is controlled largely by the variation in the earth's orbit around the sun which gives rise to variations in temperatures.

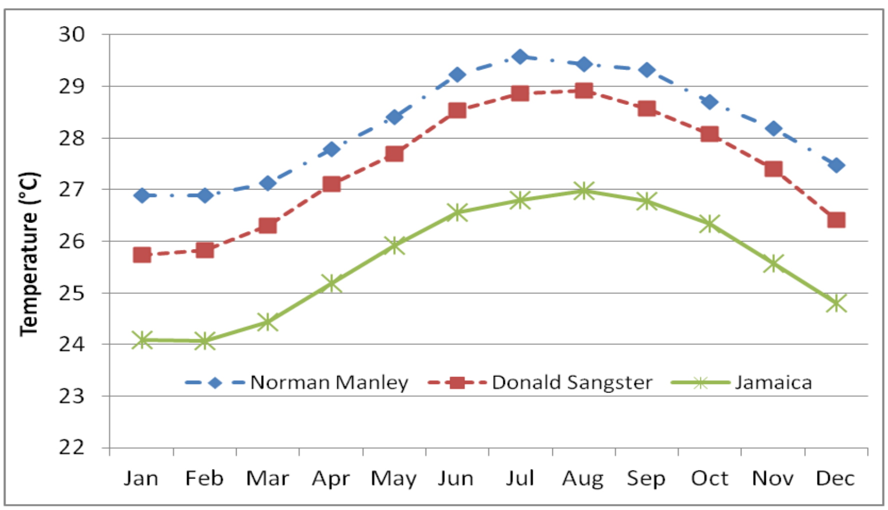


Figure 3.2.1: Temperature climatology of Jamaica, Norman Manley International Airport and Donald Sangster International Airport. The averaging period is 1992-2008. Data source: Meteorological Service of Jamaica.

The general pattern as seen in Figure 3.2.1[1] is one of cooler months in Northern Hemisphere in winter and warmer months in summer. Temperatures peak in July-August. The mean annual range between coolest and warmest months is small (about 3 degrees). 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, with proximity to the coast and/or elevation being two important factors in determining the temperature of a given location.

Rainfall

Jamaica's rainfall has a bimodal ('double peak') pattern with an early rainfall season occurring in May-June and a late rainfall season centered in October (See Figure 3.3.1.). The bimodality is perhaps the most well known feature of Jamaica's climate, and many activities in the country (e.g. planting cycles, water security measures, etc.) revolve around this pattern.

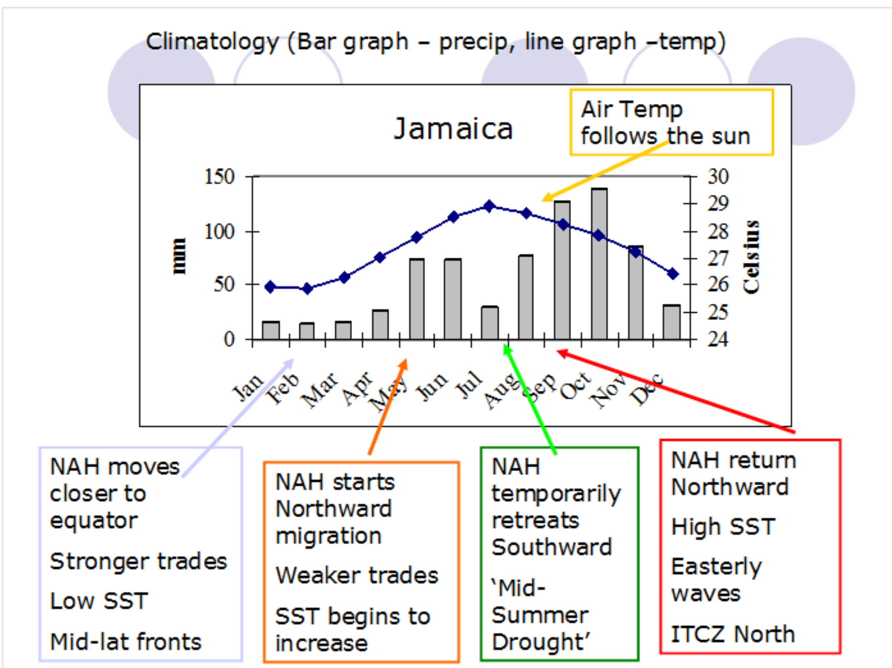


Figure 3.3.1: Rainfall (bar) and temperature (line) climatologies for Jamaica. Boxes track the changes in tropical Atlantic features which give rise to the rainfall climatology.

The early rainfall season is shorter (May-June) and usually receives less rainfall than the later season (August through November). About 70% of total annual rainfall falls between May and November, and about 40% of annual total rainfall between August and November (the late wet season). The late wet season also coincides with the peak in Atlantic hurricane activity.

There is a brief drier period in July

[1] See note at the top of Page ii. To allow for easy cross referencing the Figure and Table numbers used from this point forward in this ***Summary for Policymakers*** are the same as that in the full report ***State of the Jamaican Climate Report 2012: Information for Resilience Building.***

which separates the early and late wet seasons, and which is often referred to as the midsummer drought (MSD). The longer dry season runs from December through March, with March being the driest month of the year. Mean rain days vary from 60 to 200 days annually.

Jamaica's rainfall climatology is largely conditioned by changes in features of the tropical Atlantic such as the position of the North Atlantic High (NAH) pressure system, the tropical sea surface temperatures (SSTs), the passage of mid-latitude cold fronts early in the year, the strength of the trade winds and the passage of easterly tropical waves. These dynamic processes and the relative period of their greatest influence are also summed up in the boxes of Figure 3.3.1.Tropical easterly waves are significant climate features which travel from the west coast of Africa and through the Caribbean between June and November. Their significance arises not only because of the rain that accompanies their passage over the island, but also because the waves often develop into tropical depressions, storms and hurricanes under conducive conditions.

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.

	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
Trelawny	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

Source: Meteorological Service of Jamaica.

There is significant spatial variability in rainfall across the country – i.e. not everywhere receives the same amount of rain. It is generally known that north-eastern 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. Note that Portland generally receives significant rainfall, even in the traditional dry months.

This is depicted in Figure 3.3.3 which shows the patterns of average annual rainfall and of rainfall for the three-month seasons of November-December-January (NDJ), February-March-April (FMA), May-June-July (MJJ) and August-September-October (ASO). The averages are calculated using data from 1992-2010. For all periods, the maximum rainfall is located in the parish of Portland, as expected, close to the border with St. Thomas[2]. It is again noted that Portland is the wettest parish, being quite wet even in the dry periods of NDJ and F[2]MA.

[2] Because of the scarcity of stations in this border region the centre of maximum rainfall should only be taken as approximate.

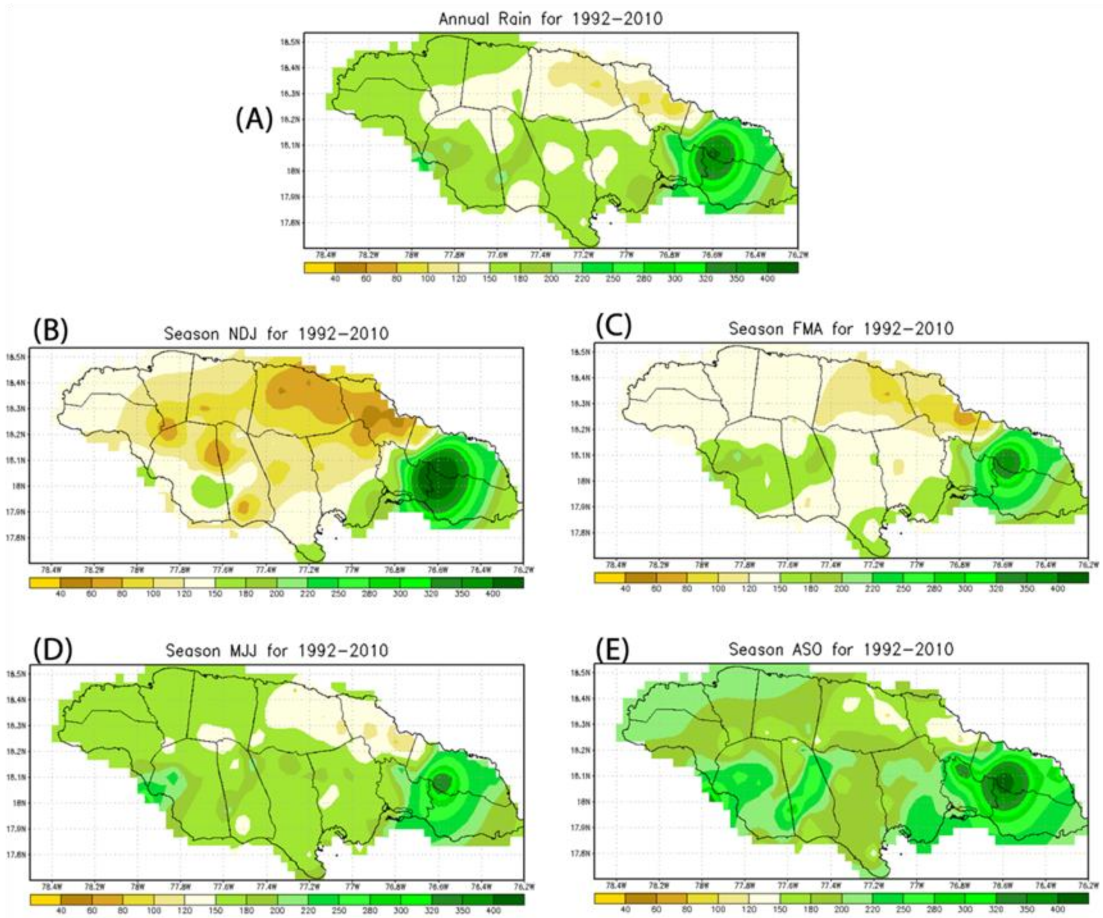


Figure 3.3.3: Map of rainfall means over Jamaica for (A) Annual, (B) November-December-January (NDJ) (C) February-March-April (FMA) (D) May-June-July (MJJ) and (E) August-September-October (ASO).

Other Variables

Data suggest 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 radiation peaks in May-June.

In the mean, ***wind*** strengths vary inversely with rainfall, i.e. during the driest months e.g. January-April and again in 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. Winds are strongest in Portland and St. Thomas, Manchester and St. Elizabeth.

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.

3. **var·i·a·bil·i·ty** - The quality or state of being variable.

Climate variability refers to deviations from the climatology or average climate conditions (previously discussed). Deviations can be measured over short time periods such as a month, season or year-to-year or over longer periods such as decades or centuries. In general when one talks about climate variability the reference is to short term (year-to-year and up to decadal) change, as opposed to talking about climate change which is a reference to long term (multi-decadal) deviations from the known 'normal'.

El Niño

Variability is very much a part of the Jamaican climate record as no two years are ever alike when it comes to how much rain the country receives or how hot it is. Short term climate variability can be due to a number of factors, with perhaps the most well known being the global phenomenon known as El Niño.

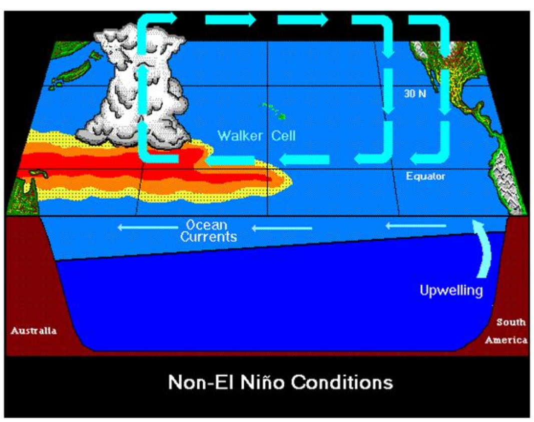
Variations in sea surface temperatures over the tropical Pacific and Atlantic Oceans are important drivers of Caribbean rainfall and temperature. Warmer than normal ocean temperatures over the eastern Pacific, off the coast of Peru, are associated with El Niño conditions. If the waters are cooler than normal it is called La Niña. El Niño events tend to occur every 3 to 5 years, though increases in the frequency, severity and duration of events have been noted since the 1970s (see the Box on following page). Because an El Niño represents a significant influence on Caribbean climate it is not unusual to find its timescale of variability (i.e. 3 to 5 year cycles) in Jamaican rainfall and temperature records. One can very often find the same periodicity in statistics of other socio-economic variables (e.g. dengue cases) that have a strong climate influence.

The impact of an El Niño event on Jamaica depends on the period of the year being considered. During an El Niño event, the Caribbean (and Jamaica by extension) tends to be ***drier*** and ***hotter*** than usual in the mean, and particularly during the ***late wet season*** from August through November. There is also, by extension, a tendency for reduced hurricane activity during El Niño events. Meteorological droughts occurring over the Caribbean in 1991, 1997-1998 and 2010 coincided with El Niño events. However, during the ***early rainfall season*** (May to July) in the year after an El Niño (the El Niño + 1 year), the Caribbean tends to be ***wetter*** than usual. The

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

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 below. 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 also shown below. 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 5 years.



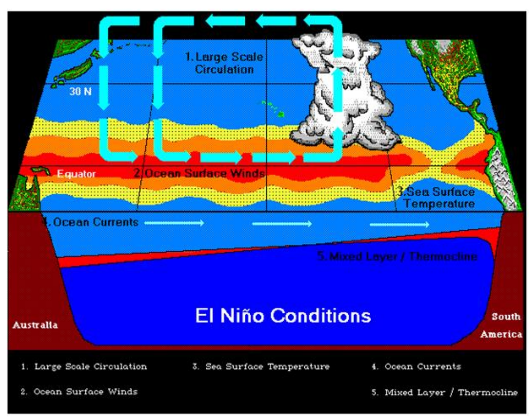


Figure 4.2.1: Schematic diagram of the most common mode of circulation in and above the tropical Pacific Ocean (left panel); during an El Niño event (right panel). Source: http://www.unc.edu/courses/2008ss2/geog/111/001/ClimateForecasts/ClimateForecasts.htm

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 Sea and/or equatorial Atlantic Ocean is at the time. 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*** but a ***cool*** tropical ***Atlantic*** scenario exists, there is ***less*** late season ***rainfall*** in the Caribbean and vice versa. This is illustrated in figure 4.2.2.

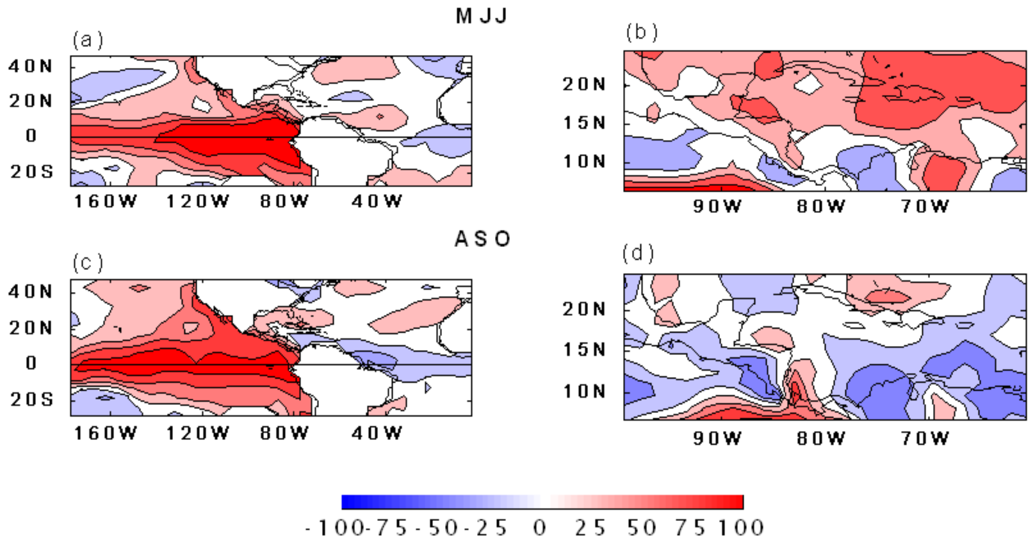


Figure 4.2.2: Dominant Sea surface temperature patterns and their corresponding rainfall patterns for (a)-(b) May-June-July (MJJ) and (c)-(d) August-September-October (ASO). Above normal ocean temperatures over the Pacific and together with Atlantic are associated with above normal rainfall over the 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).

Longer Timescale Variations

Climate variations on longer timescales (e.g. decades) are not as well studied, primarily because reliable Caribbean climate records are too short. Yet it is useful to know about variations on these timescales so that they can be distinguished in the records from trends induced by longer term climate change.

Known variations on decadal timescales condition the region to be drier or wetter. So, in much the same way that El Niño is known to impact Caribbean and Jamaican rainfall on a year to year basis, there are known links between the global phenomenon known as the North Atlantic Oscillation (NAO) which causes seasonal to decadal changes in Caribbean and Jamaican rainfall. In the ***positive phase*** of the ***NAO*** there are anomalously high pressures across the subtropical Atlantic which induces cooler ocean surface waters and as a result the Caribbean is background conditioned to be ***dry***. Research shows that the combination of a positive phase of the NAO and an El Niño can cause unusually intense drying out of the normal wet season. 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.

There is even longer term variability, i.e. on multidecadal timescales, 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 which 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 current warm phase of the AMO is expected to persist at least until 2015 and possibly as late as 2035, with a peak around 2020.

4. **change** – the act or instance of making or becoming different.

Has Jamaica's climate changed in the recent past?

Notwithstanding its patterns of variability, there is still the question of whether Jamaica's climate shows evidence of climate change. When one refers to 'climate change' one is most time speaking of long term change in the mean state which is anthropogenic or human induced (see Box on Climate Change). There is no doubt about climate change being evident in global historical climate record. The question above asks whether it is also noticeable in Jamaica's historical climate records.

To make any conclusive statements require the examination of climate records going as far back as is possible. Unfortunately, a big drawback to doing climate science in the Caribbean is the lack of reliable historical data. Notwithstanding, using what is available, there are some things that can be noted about long term changes in Jamaican climate, particularly changes in rainfall and temperature.

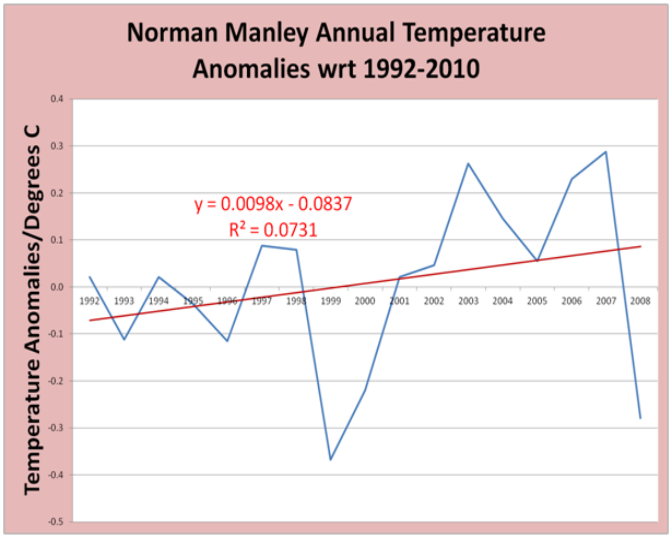
Temperatures

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. Average annual temperatures for Caribbean islands have similarly increased by just over 0.5 °C over the period 1900 – 1995 (IPCC, 2007).

Data collected at Jamaica's airport stations (Figure 4.3.2) for the much shorter period of 1992 to 2010 likewise show a warming trend for the country of about 0.1 degrees Celsius/decade. Some research sources suggest that the rate of warming may be slightly higher — about 0.27 degrees Celsius/decade — as indicated by the values in Table 4.3.1. Research also suggests seasonal rates of temperature increase which range from 0.20 – 0.31 °C per decade, with the period of most rapid increase being June-July-August (JJA) at a rate of 0.31˚C per decade.

It is not only the mean temperatures that have been increasing. Since the late 1950s the percentage of very warm days and very warm nights has increased significantly in Jamaica and the wider

Caribbean; and correspondingly the percentage of very cold days and very cold nights have decreased. The estimated magnitudes of these changes are given in Table 4.3.2.



Adapted from Figure 4.3.2: Annual temperature anomalies for Norman Manley International Airports with respect to 1992-2010. The linear trend is superimposed. Units are degrees Celsius. Data source: Meteorological Service of Jamaica of Jamaica.

Table 4.3.1: Observed means and trends in temperature for Jamaica.

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

Table 4.3.2: Observed trends in extreme temperature (frequency/decade) for Jamaica (1960 – 2006).

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

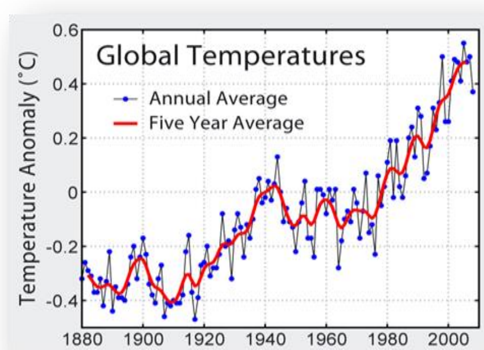
Source: CARIBSAVE Risk Atlas (2011).

What is Climate Change?

Climate change can be defined as distinct changes in measures of climate lasting for a long period of time. It is therefore not ‘weather’ which is a day-to-day phenomenon. Climate can vary on long timescales due to a variety of reasons as shown below, including due to natural variations and also due to *human induced activity*. It is the change due to the latter which is most often being referenced when climate change is discussed. The human induced change results from increased concentrations of greenhouse gases (e.g. carbon dioxide and water vapour) in the atmosphere as a result of human activities such as the *burning of fossil fuels and deforestation*. Greenhouse gases prevent the earth’s longwave radiation from reaching back into outer space and so keep the earth warm. This natural process, called the *greenhouse effect*, is being enhanced by the higher concentration of greenhouse gases in recent times, and so as the concentrations increase so does the earth’s surface temperatures. Research has shown that the *increase in mean global temperatures* of the last century, otherwise called *global warming*, has been primarily due to human activity.

Natural Variations	Volcanic Eruptions	Human Activity
• Changes in the earth’s orbit • Changes in solar intensity • Pre-industrialized era e.g. Ice Age	• Alter aerosols in the atmosphere (block sunlight) … not long term effect. • Alter carbon dioxide concentrations (CO_2)	• Changing land cover (reflective properties of earth). • Altering aerosol concentrations. • Post Industrial Revolution (~1750). Burning of fossil fuels and biomass has altered the composition of the atmosphere primarily through the **addition of greenhouse gases.**
		

The higher temperatures under global warming yield *other changes* in the climatic system including temporal and spatial changes in (i) the amount, intensity, frequency and type of *rainfall* received (ii) day time and night time temperatures (iii) *sea levels* and (iv) the occurrence of extreme events including *floods*, *droughts* and *hurricanes* . The earth has warmed by just about 0.8 degrees Celsius in the last decade. Projections are that during the 21st century the global surface temperature is likely to further rise by anywhere between 1 and 6 degrees Celsius.



Rainfall

Rainfall over Jamaica shows a great deal of variability between months, seasons and years. From Figure 4.4.1 which shows mean annual rainfall for Jamaica from 1880 to present it can be seen that there is significant year-to-year variability which were already noted is partly associated with El Niño activity (see previous section). Yet, even 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 also discussed previously. The year-to-year 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 Multidecadal Oscillation (AMO).

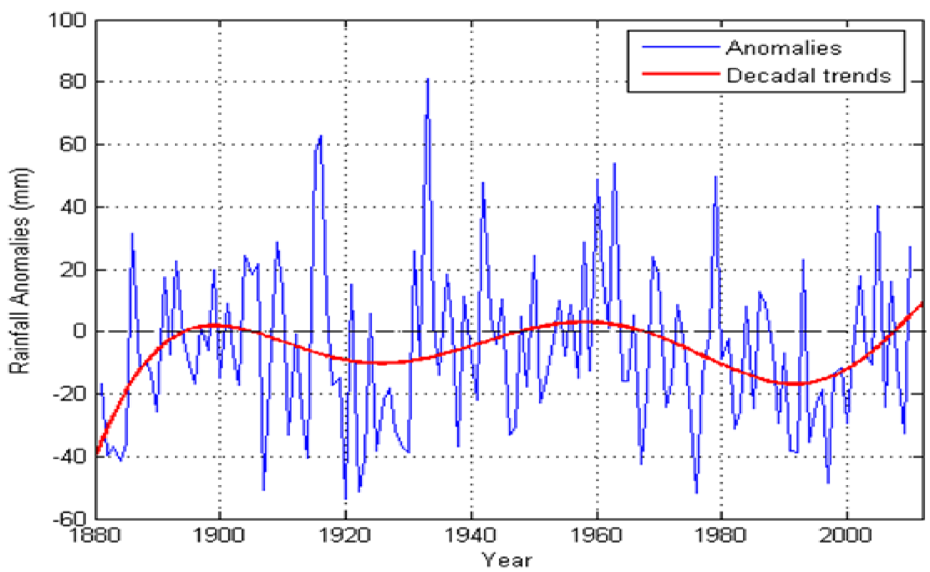


Figure 4.4.1: Graph of Jamaican rainfall (blue) with decadal trends (red) superimposed. Data source: Meteorological Service of Jamaica.

In the very long term, the mean Jamaican rainfall record shows no statistically significant trend, i.e. if a linear line was fitted to Figure 4.4.1 even if it were up or down it would not be statistically significant. But this is not surprising given the variability noted above. Notwithstanding, studies have noted small percentage decreases in annual rainfall and summer rainfall per decade between 1960 and 2006. The decrease in the June – August period is the strongest. A small increasing rainfall trend is also 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).

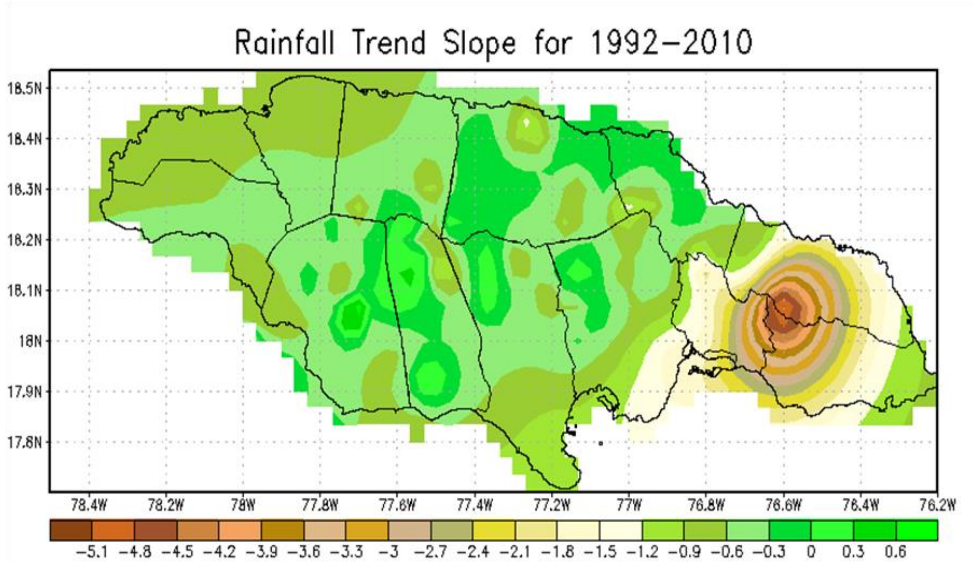


Figure 4.4.2: Map showing Rainfall trends slope. Positive slope suggest increasing rainfall, and negative slope suggest decreasing rainfall. Data source: Meteorological Service of Jamaica.

Trends in rainfall extremes have largely been negative (decreasing) over the recent past. Statistically significant decreases have been observed in the proportion of total rainfall that occurs in 'heavy' events as well as in peak 1-day and 5-day rainfall. These 'trends' should, however, be interpreted cautiously given the relatively short period over which they are calculated, and the large year-to-year variability in rainfall and its extremes.

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 (see previous section on Variability) and not necessarily to global warming. Additionally, El Niño and La Niña events influence the location and activity of tropical storms across the globe. There are generally less hurricane trackings through the Caribbean during an El Niño and more during a La Niña (see Figure 4.6.1).

Though attempts to link global warming and climate change to the increased number of hurricanes have proven to be inconclusive, it is still to be noted that the Atlantic Ocean has seen a statistically significant increase in the total number of hurricanes since 1995. Both frequency and duration of hurricanes also display increasing trends. However, while the number of intense hurricanes has been rising, the maximum intensity of hurricanes has remained fairly constant over the recent past.

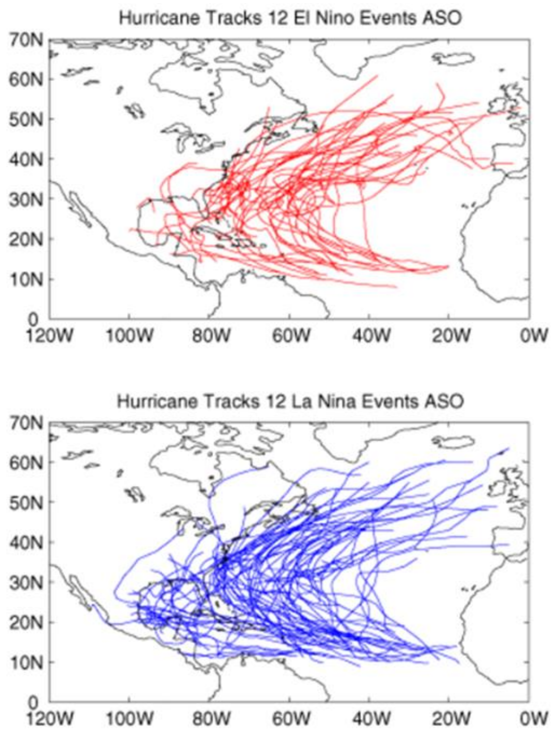


Figure 4.6.1: Tracks of Atlantic hurricanes August to October 1959-2001 for El Niño years (top) and La Niña years (bottom).
Source:
http://iri.columbia.edu/climate/ENSO/globalimpact/TC/Atlantic/track.html

Sea Level Rise

It is estimated that global sea levels have risen by 0.17 ± 0.05 m over the 20th century. Satellite measurements suggest the rate of rise may have accelerated in recent years to about 3 mm/year since the early 1990s. From estimates of observed sea level rise from 1950 to 2000, the rise in the Caribbean appears to be near the global mean. 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.

Table 4.4.1: 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

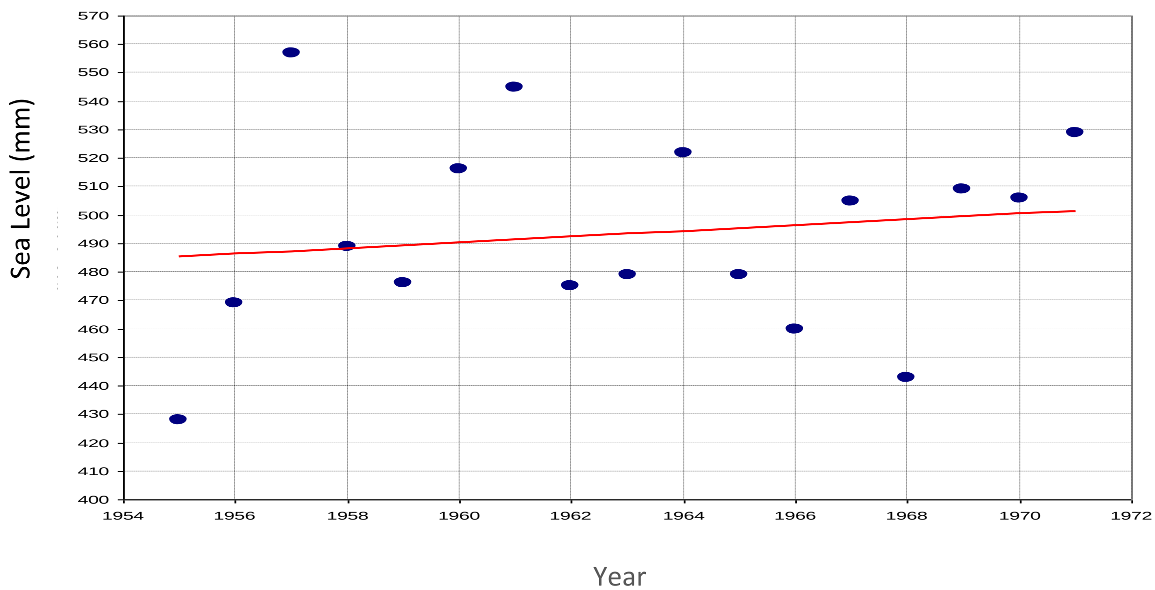


Figure 4.7.1: Mean annual sea levels at Port Royal measured between 1955 and 1971. Redrawn from Horsfield (1973). Linear trend inserted.

Projections

5. pro·jec·tion – An estimate or forecast of a future situation or trend based on a study of present ones.

How will Jamaica's climate change in the future?

Models and Scenarios

This too is a valid question which regional and local climate scientists are actively trying to answer. One of the ways to determine projections of future climate is to use climate models to project future climates. Climate models are computer models which simulate 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.

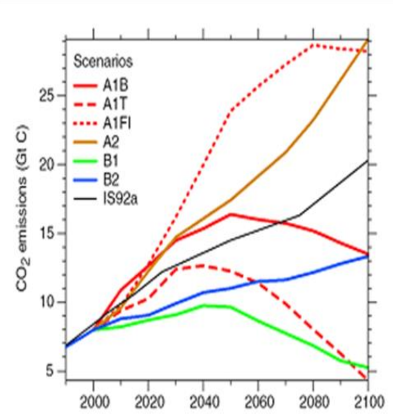
There are two types of climate models – global climate models (GCMs) and regional climate models (RCMs). GCMs simulate climate across the globe on coarse scales, generally of a few hundred kilometres, and represent for regions like the Caribbean, a first guess of their future climate. They therefore lay the foundation for decision-making concerning climate change. GCMs however do not provide sufficient information at the scale of individual small islands like Jamaica, due to their coarse resolution. Though Jamaica would possibly be seen in a GCM, it would be represented by at most two grid boxes. To achieve information at the 'small island scale', RCMs are therefore used. RCMs are run at higher resolutions (e.g. 50 km or less) but over smaller areas and use GCM output as their input or boundary conditions. The full document ***State of the Jamaican Climate 2012: Information for Resilience Building*** presents much more detail about GCMs and RCMs.

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) presented 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. The Box below (5a) adds more details. Since no scenario assumes any future policies that explicitly address climate change, they all represent a plausible and possible future i.e. the future may be equally a low or high emissions future.

When the emission scenarios are used to drive the climate models the output is a range of future climates. Generally GCM model runs are done through to the end of the century for multiple scenarios since every scenario is plausible. For regions like the Caribbean, results are then examined either for the entire ensemble of scenarios or downscaled using RCMs for a low (e.g. B2), medium (e.g. A1B) and high (e.g. A1 or A2) emission scenario to provide a range of possible futures. The full document ***State of the Climate 2012: Information for Resilience Building*** presents more details on scenarios.

Scenarios

Box 5a: 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).



The scenarios used in the modelling are the storylines of future global development developed by the IPCC and reported on in the Special Report on Emissions Scenarios (SRES) (Nakićenović et al., 2000). The SRES scenarios quantify how greenhouse gas emissions could change over the twenty-first century in the absence of policy interventions to reduce the emissions. In all there are forty different scenarios divided into four families (A1, A2, B1 and B2), each with an accompanying storyline which describes the relationships between future greenhouse gas emission levels and driving forces such as demographic, social and economic and technological developments. The families represent a range of equally plausible possible futures - from low emission to high emission futures.

The A-Family or High-Emissions Scenarios describe a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, with the rapid introduction of new and more efficient technologies. The A2 storyline describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. The B- Family describes relatively Low Emissions Scenarios. The B2 storyline describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability.

The PRECIS Project

The Providing Regional Climates for Impact Studies (PRECIS) Caribbean Initiative (Taylor et al. 2007) was a collaborative research effort among Cuba, Jamaica, Barbados and Belize to produce downscaled climate scenarios for the Caribbean using an RCM. The PRECIS RCM was run at 25 km and 50 km resolution over limited domains, covering the Caribbean for both present day (1961-1990) and future (2071-2100) periods for both a relatively high emissions scenario (A2) and a relatively low emissions scenario (B2). 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. (Recall that 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. This summary presents some results from the PRECIS RCM. Where a single value is provided for a projection from the RCM it is an average of the change simulated over all 12 grid boxes. In the full document ***State of the Jamaican Climate 2012: Information for Resilience Building*** projections are given for each of the 12 grid boxes. Projections in this ***Summary for Policymakers*** are limited to west, central and eastern Jamaica where west comprises data from boxes 2, 3, 8, 9; central uses data from boxes 1, 4, 5, 10, 11, and east uses data from boxes 6, 7 and 12..

Both GCM projections as well as results from the PRECIS RCM initiative are presented in the following sections. Of note, as before, data are presented for annual values as well as for three-month seasons defined as December-January-February (DJF), March-April-May (MAM), June-July-August (JJA) and September-October-November (SON).

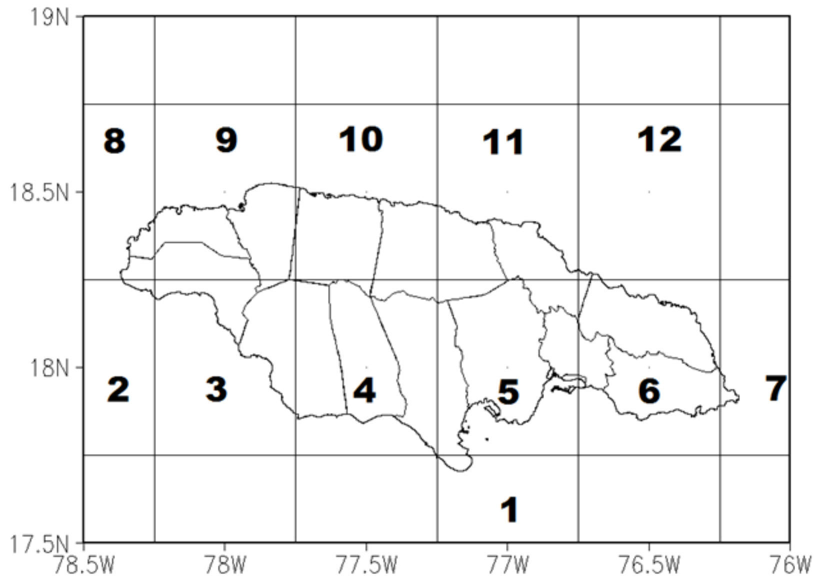


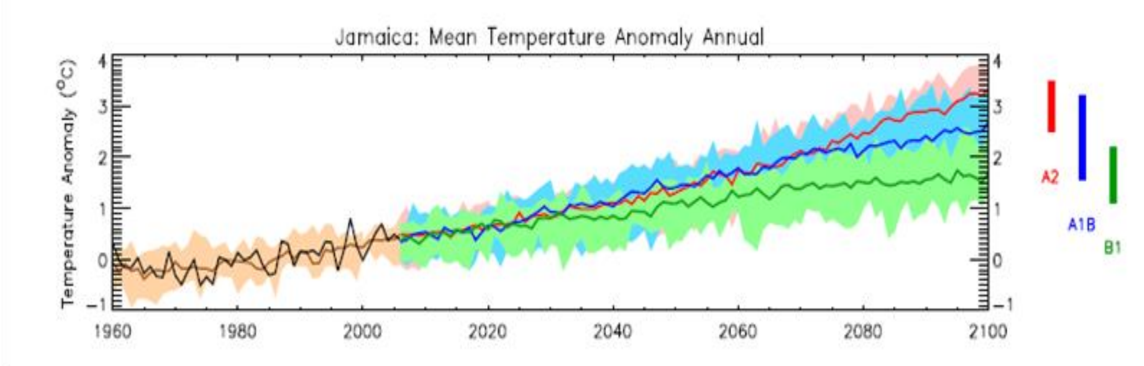
Figure 7.1.1: PRECIS RCM grid box representation at a resolution of 50 Km over Jamaica.

Temperatures

The GCMs suggest that Jamaica's mean annual temperature will increase by 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 in JJA. The frequency of 'hot' Jamaican days and nights will also increase, reaching 30-98% of all days annually by the 2090s. In this instance 'hot' is classified for each season according to recent climate standards. 'Hot' days/nights are projected to increase most rapidly in JJA and SON, occurring on 60 to 100% of days/nights by the 2080s. There will also be less 'cold' days/nights. These will occur on a maximum of 2% of days/nights by the 2080s, and do not occur in some GCM projections after the 2050s. Cold days/nights decrease in frequency most rapidly in JJA.

The PRECIS RCM generally indicates much more rapid increases in temperature over Jamaica than any of the models in the GCM ensemble. RCM projections indicate increases of 2.9˚C and 3.4˚C by the 2080s. Land surfaces warm more rapidly than nearby 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).

Some data for projected mean temperature change from both GCMs and the RCM are presented in the figures and tables below. Far more detail is given in the full report.

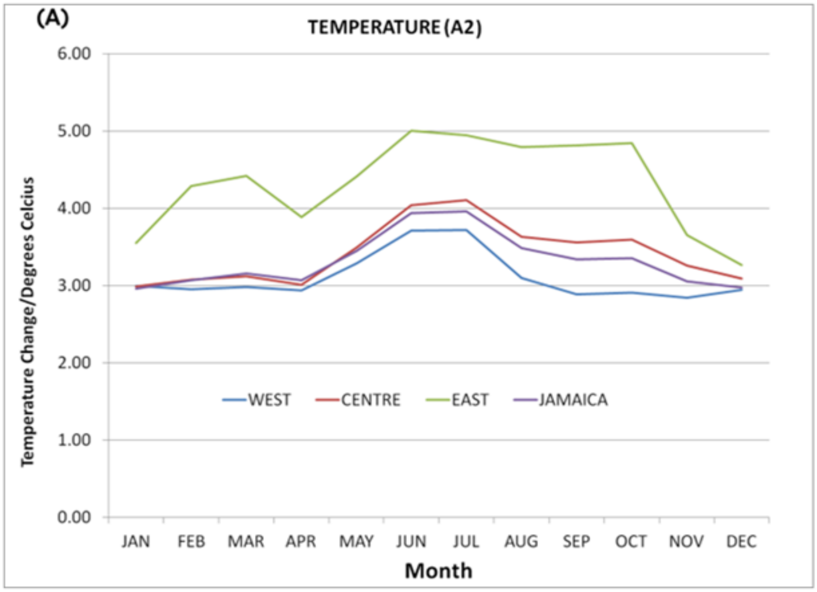


Adapted from Figure 6.3.2: Trends in annual mean temperature for the recent past and projected future. All values shown are anomalies, relative to the 1970-1999 mean climate. Black curves show the mean of observed data from 1960 to 2006, Brown curves show the median (solid line) and range (shading) of 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. Source: UNDP Climate Change Country Profiles (McSweeney et al, 2008). 15 model ensemble. http://country-profiles.geog.ox.ac.uk

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). 15 model ensemble.

	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

Source: UNDP Climate Change Country Profiles (McSweeney et al, 2008).



Adapted from Figure 7.2.1: Projected change in monthly temperature (°C), for the period 2071-2099 over the western, central and eastern sections of Jamaica, as well as for Jamaica as an averaged whole. The projected changes are shown for the A2 SRES emissions scenarios. Source: The PRECIS Project.

Table 7.2.1: Projected change in monthly temperature (°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

Source: The PRECIS Project

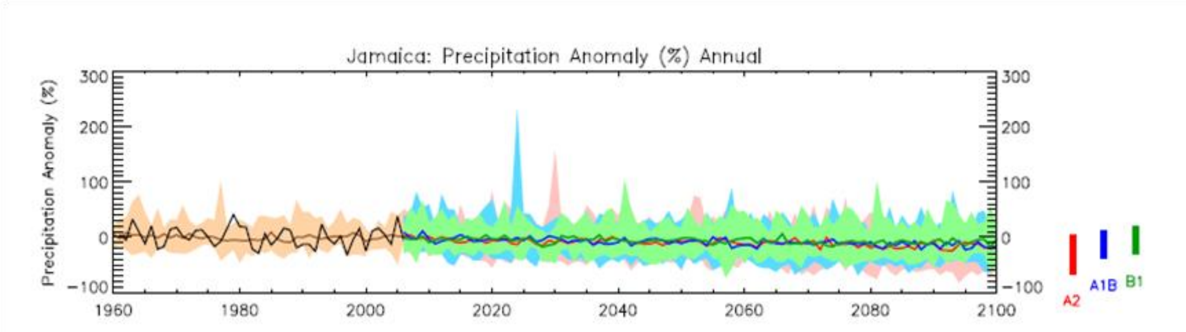
Rainfall

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, but until then, short term variability will be a strong part of the rainfall pattern, i.e. superimposed upon the drying trend. The same statements can be made from GCM projections for Jamaica, but with higher projected magnitudes of change, 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 July to August (early wet season) and September to November (late wet season) rainfall. The projections of rainfall extremes are mixed across the ensemble. By the 2080s the range of changes is -19 to +9% for the proportion of rainfall falling as heavy events and -29 mm to +25 mm for 5-day maximum rainfall.

The PRECIS RCM projections of rainfall for Jamaica are strongly influenced by which driving GCM provides boundary conditions. The most conservative simulations suggest moderate decrease in MAM and JJA rainfall, as well as in total annual rainfall (-14%). The more severe suggest more dramatic decreases in annual rainfall (-41%), and more severe decreases in JJA and SON by the 2080s. Notwithstanding, the largest end-of-century decreases occur from May onward, with rainfall in the months of September through November the worst affected. Rainfall in January through April seem to be least affected. Though the entire island dries, the most severe drying seems to occur in the west and least severe in Portland.

If one considers both the GCMs and the RCM, the picture that emerges is of a Jamaica which is in the short term (2020s) slightly wetter than present day conditions but which will transition to a much drier state by the end of the century. The consensus seems to be that the 2020s will be wetter in the mean across all seasons except the early wet season (May through July). By the 2050s the country will be biased to being drier in the mean due to decrease in rainfall during the traditional wet period (May through November), though the main dry season (December through March) may be slightly wetter. The same pattern will likely hold but intensify by the 2080s, when the models agree on a robust picture of drying (up to 60%) particularly during the two wet seasons.

Some data for projected mean rainfall changes from both GCMs and the RCM are presented in the figures and tables below. Far more detail is given in the full report.

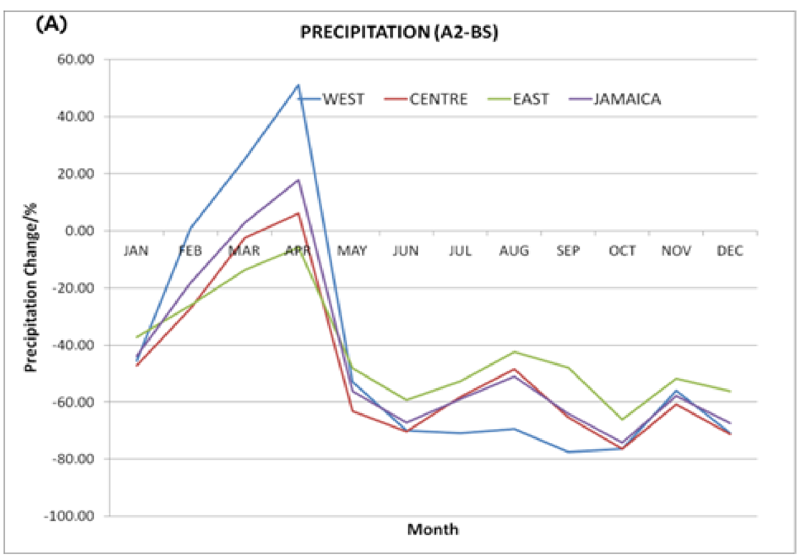


Adapted from Figure 6.4.2: Trends in monthly precipitation for the recent past and projected future. All values shown are percentage anomalies, relative to the 1970-1999 mean climate. See Figure 6.1.2 for additional legend details. Source: UNDP Climate Change Country Profiles (McSweeney et al, 2008). 15 model ensemble. http://country-profiles.geog.ox.ac.uk

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
			-35	**-3**	17	-45	**-10**	9	-65	**-14**	3
Annual	155.2	-1.6	-32	**-7**	9	-51	**-7**	15	-36	**-13**	11
			-20	**-2**	10	-34	**-5**	9	-30	**-6**	22
			-31	**1**	25	-37	**-3**	18	-52	**-4**	26
DJF	107.2	0.2	-28	**-7**	7	-45	**-5**	17	-33	**-4**	30
			-21	**0**	33	-28	**-7**	12	-24	**-2**	20
			-33	**-5**	38	-49	**-9**	4	-59	**-24**	0
MAM	142.4	1.3	-36	**-3**	22	-46	**-9**	26	-40	**-23**	5
			-20	**-2**	47	-43	**-6**	28	-35	**-10**	51
			-38	**-13**	22	-59	**-20**	-5	-72	**-32**	-3
JJA	141.0	-4.4	-36	**-14**	2	-55	**-19**	-9	-72	**-23**	-9
			-28	**-8**	15	-56	**-7**	7	-65	**-16**	12
			-35	**-3**	29	-46	**-5**	39	-66	**-4**	24
SON	227.6	-2	-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

Source: UNDP Climate Change Country Profiles (McSweeney et al, 2008).



Adapted from Figure 7.3.2: Projected percentage change in monthly rainfall (°%), for the period 2071-2099 over the western, central and eastern sections of Jamaica, as well as for Jamaica as an averaged whole. The projected changes are shown for the A2 SRES emissions scenarios. Source: The PRECIS Project.

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

Source: The PRECIS Project

Hurricanes

There seems to be some consensus amongst the research community that there will be increases in rainfall intensity as well as in associated peak wind intensities and mean rainfall associated with tropical storms under climate change (see Table 6.6.1 below). However, the models are strongly divergent with regards to the frequency of tropical storms in future climate. Whereas several recent studies show that the frequency of storms may decrease due to decreases in vertical wind shear in a warmer climate, many of the same studies suggest an increase in the intensity of the hurricanes when they do occur (see also Figure 6.6.1). Results from the PRECIS project suggest 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.

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%

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

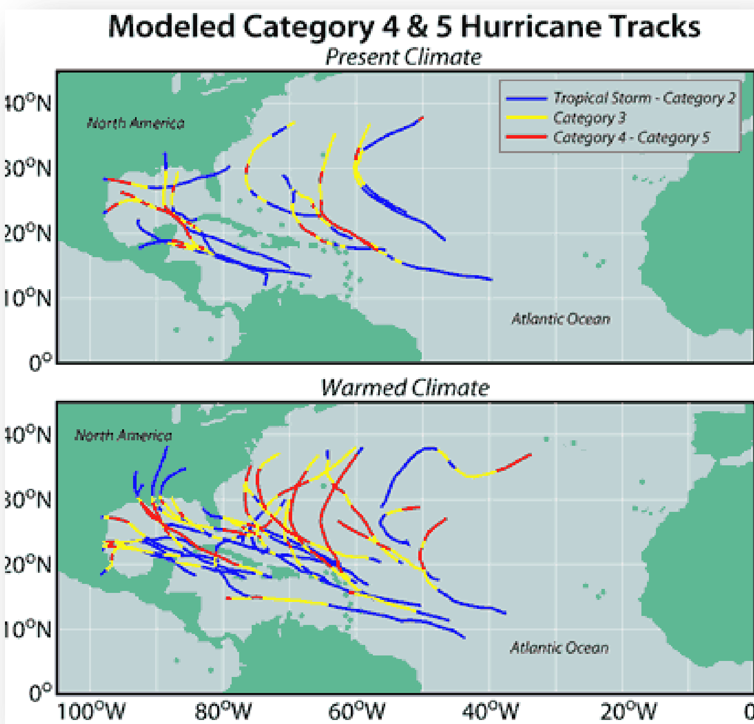


Figure 6.6.1: Simulated current and future Category 3-5 storms based on downscaling of an ensemble mean of 18 global climate change models. The figure shows nearly a doubling of the frequency of category 4 and 5 storms by the end of the 21st century, despite a decrease in the overall frequency of tropical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

Storm Surge

The CARIBSAVE Climate Change Risk Atlas for Jamaica notes that "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." (CARIBSAVE 2011, p. 25)

Sea Level Rise

The Intergovernmental Panel on Climate Change (IPCC) in their latest report provides a range of sea level rise (SLR) projections under each of the SRES scenarios. They suggest that global mean sea levels are projected to rise by between 0.18-0.59m by 2100 relative to 1980-1999 levels (see Table 6.8.1 below). Interestingly, these estimates have since been challenged for being too conservative, with a number of studies suggesting that the uncertainty range should include a much larger upper limit. 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 suggests i.e. up to 1.4m by 2100. Table 6.8.1 below also provides IPCC and Rahmstorf's estimates for the projected mean sea level rise for the Caribbean Sea.

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

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

Impacts

6. **im·pact** – The effect or impression of one thing on another.

There is little doubt that life in Jamaica has and will continue to be impacted by the changes in climate given the climate sensitivity alluded to in the first section of this document. There is a real need to determine the extent of impact and how it will play out across sectors and in communities. That is, in order to minimize and adapt to potential damages or benefits, risks must be assessed comprehensively.

In order to point interested persons to some of the possible impacts which climate change can have on Jamaica, the final section of the full report ***State of the Jamaican Climate 2012: information for Resilience Building*** provides a set of Tables, each of which summarizes some likely impact of the projected climatic change on a critical sector or area of Jamaican life. The tables are compiled from studies which explore impacts and the references for the studies are provided at the end of this section. It must be emphasized that the Tables are not mean as comprehensive listings of all possible impacts but rather they are meant to provide insight and to refer the user to more authoritative sources. It is also to be noted that many of the actual or likely impacts are due to a combination of climate change and poor environmental practices. The Tables are not also restricted to negative impacts since climate change may also provide some opportunities and benefits.

The list of tables provided in the full document ***State of the Jamaican Climate 2012: Information for Resilience Building*** is below. For each table there is also a short preamble in the full document on the sector or area impacted, which tries to justify its selection for consideration. The reader is strongly urged to consult the full report. Only the Tables highlighted in bold in the list below are reprinted in this summary. The intention is solely for the reader to get an idea of how useful the Tables are, i.e. the reprinting in this summary is not an indication in any way of the relative importance of the sector or area.

List of Impact Tables in the report *State of the Jamaican Climate 2012: Information for Resilience Building*

Table 8.2.1: Impacts of Climate Change on Freshwater Resources.

	Climate Change Variables and Extreme events	Impacts
CLIMATE CHANGE ON FRESHWATER RESOURCES	**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)[3] Sea water intrusion has resulted in the loss of 100 million cubic metres 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 will lead to 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)	

[3] The bracketed numbers refer the reader to the research document (including page number) which makes the point. The research documents used in the compilation of the Tables are numbered and listed in the full document and at the end of this section.

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 damages, 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 8.8.1: 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 damages 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 $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 US$462 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)

Table 8.9.1: Impacts of Climate Change on Community Livelihoods.

	Climate Change Variables/Extreme Events	Impacts
COMMUNITY LIVELIHOODS	**Increasing Temperature**	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 consisting of disabled or ill members are considered more vulnerable since this affects the number of people available for productive labour and puts a strain on household resources. (8,p.43)
	Droughts, Storms and Hurricanes	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.
	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 aggravates 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)	

Table 8.9.4: 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 (170,000 pop), 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 increases vulnerabilities to landslides and floods. (4, p.67) 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)
	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 include 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 (eg. 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, 60.7 billion US dollars. (12) During a hurricane or a storm, rainfall exceeds aquifer capacity, causing damages to infrastructure like bridges and roads. (3,p.30)

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7. re·sil·ience – An ability to recover from or adjust easily to misfortune or change.

Undoubtedly the ultimate aim is to make Jamaica resilient to the impacts of climate variations on both short and long timescales. Part of building that resilience is using the kind of information provided in the full document from which this summary derives in guiding decision making. As previously noted the report is intended to be an initial reference point for key sectors and persons who wish to engage in climate change work and discussion with respect to Jamaica and who need to determine the climate state being adapted to.

Preparation of the ***State of the Jamaican Climate 2012: Information for Resilience Building*** brought into sharp focus issues related to data and scientific research (specifically climate science). This has led to the following concluding observations and recommendations, addressing which forms part of building the resilience being sought after, since it ensures that action is premised on up-to-date and reliable data and research.

Observations and Recommendations:

1) **Address Data Need**: It is data which is being argued is the linchpin for planned action and response to climate change. Whereas the full 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 that for some climatic variables, the best that can yet 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) **Increased 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 producing information at even finer resolutions using statistical methods. At present, the range of variables for which observations are available 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) **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 short 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) **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: Strengthen the human and technical capacity for real time monitoring of climatic variations.

5) **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 the El Niño 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 the island.

Recommendation: Enhance research capacities (e.g. at Universities, National Meteorological Service) to undertake climate variability research specific to Jamaica.

6) **Continued 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). 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) **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 four (4)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) **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: Examine by sector, plans for mainstreaming known climate change impacts into developmental plans and/or initiate studies to determine the climate change impact on an understudied sector.

9) **Get the word out**: 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: Disseminate the information report widely and USE the information.

10 Question Climate Change Quiz

1. Global warming seen in the last century is primarily due to:
   a) natural cycles of variation b) volcanic eruptions c) burning fossil fuels
   d) all of the above e) none of the above.

2. Since the early 20^{th} century the mean annual temperature of the earth has increased by about:
   a) 0.5 °C b) 0.8 °C c) 1.5 °C d)2.0 °C e) no increase

3. Globally, which of the following is true:
   a) day time temperatures are increasing faster than night time temperatures
   b) night time temperatures are increasing faster than day time temperatures
   c) they are increasing at the same rate d) neither is increasing

4. Climate records suggest that Jamaica has also seen changes in climate
   a) no b) yes c) I don't know
   d) what… climate records exist for Jamaica?

5. To project future climate change we use:
   a) our imagination b) eeny, meeny, minie, moe c) computer models
   d) a crystal ball e) all of the above

6. Which of the following are projected end of century changes in Jamaican climate?
   a) a drier summer b) anywhere up to 1 metre sea level rise c) more intense hurricanes d) temperature increase of 1-3 degrees e) all of the above

7. By how much is annual rainfall projected to decrease in Jamaica by the end of the century under the worst case scenario using a regional climate model (RCM):
   a) 10% b) 20% c) 40% d) 50% e) 90%

8. Which of the following sectors will be impacted by climate change?
   a) agriculture b) tourism c) water d) health e) all of the above

9. What must be done by us in response to climate change:
   a) we must reduce greenhouse gas emissions b) we must learn to adapt
   c) we must do both a) and b) d) we must throw our hands up in the air and weep

10. When must we act in response to climate change:
    a)now b) now c) now d) now e) now

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Quiz Solutions:

1) c   2) b   3) b   4) b   5) c   6) e   7) c   8) e   9) c   10) any or all of a-e