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Impacts of Climate Change on Extreme Events in the Coastal and Marine Environments of Caribbean Small Island Developing States (SIDS)

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EXECUTIVE SUMMARY

Globally, estimates of the potential destructiveness of hurricanes show a substantial upward trend since the mid-1970s, with a trend towards longer storm duration and greater storm intensity.
An increase in North Atlantic tropical cyclone activity has been observed since 1995. An increased frequency of very intense tropical cyclones within the North Atlantic region since the 1990s has also been noted.
It is estimated that from 1901-2010, global mean sea level increased by 0.19 ± 0.02 metres. For the Caribbean sea, levels have risen at a rate similar to the global rate.
The mean significant wave heights in the Caribbean have increased since 1948 at a rate of 0.024 cm/year.
While global frequency of tropical cyclones is likely to either decrease or remain essentially unchanged, it is more likely than not that the frequency of the most intense storms will increase substantially in some ocean basins. It is anticipated, though with low confidence, that North Atlantic tropical cyclone activity will follow the global trend.
Precipitation rates and wind speeds associated with Atlantic tropical cyclones may increase.
There is a possibility of increased storm surge levels for the Caribbean.
The Caribbean annual mean significant wave heights are projected to decrease.
It has been suggested that gravitational and geophysical factors may lead to the Caribbean experiencing a greater rise in sea levels than most global areas. In fact, sea level rise over the Northern Caribbean may exceed the global average by 25%.

Introduction

This review characterizes extreme events in coastal and marine environments and their observed and anticipated impacts for the Caribbean Small Island Developing States (SIDS). Gaps in the current state of knowledge are also highlighted. The report focuses on tropical cyclones (hurricanes), sea level rise, storm surge and significant wave heights.

The Caribbean faces a variety of impacts due to climate change. While the region is very familiar with natural hazards, coping with the impacts of more intense or frequent disasters is still a major challenge. Each year, climate extremes come at a substantial cost to human life, infrastructural damage, and disruptions to socioeconomic activities and everyday life. Table 1 shows few of the extreme events experienced by Caribbean countries since 2004 and some socioeconomic impacts.

Characteristics of extremes

Tropical cyclones: The Atlantic hurricane season extends from June 1 to November 30. During this period, conditions favourable to tropical cyclone development over the Atlantic basin typically emerge. These include: i) a decrease in vertical wind shear, ii) a weakening of easterly trade winds, iii) sea surface temperatures (SSTs) greater than 26°C (Goldenberg et al., 2001; Webster et al., 2005; Klotzbach, 2007). Tropical cyclone activity is also dependent on large-scale atmospheric and

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oceanic influences such as the El Niño Southern Oscillation (ENSO) and the Atlantic Multidecadal Oscillation (AMO). The ENSO is a recurring climate pattern across the tropical Pacific that is characterized by warmer than normal equatorial Pacific SSTs (warm phase called El Niño) and cooler than normal equatorial Pacific SSTS (cool phase called La Niña). The pattern varies irregularly between the two phases every two to seven years. El Niño events are associated with fewer North Atlantic tropical cyclones, particularly for the Caribbean (Chu, 2004) while La Niña events are characterized by increased cyclone formation. Another modulator of tropical cyclone activity is the AMO. The AMO is a natural decadal SST variation over the North Atlantic. In its warm phase, North Atlantic tropical cyclone activity increases (Goldenberg et al. (2001)). This is the prevailing phase since 1995.

Sea Levels: On decadal and longer time scales, global mean sea level change results from two major processes that are largely related to recent climate change and that alter the volume of water in the global ocean: i) thermal expansion, and ii) the exchange of water between oceans and other reservoirs (glaciers and ice caps, ice sheets, other land water reservoirs - including through anthropogenic change in land hydrology, and the atmosphere. All these processes cause geographically nonuniform sea level change as well as changes in the global mean; some oceanographic factors (e.g., changes in ocean circulation or atmospheric pressure) also affect sea level at the regional scale, while contributing negligibly to changes in the global mean. Vertical land movements such as resulting from glacial isostatic adjustment (GIA), tectonics, subsidence and sedimentation influence local sea level measurements but do not alter ocean water volume; nonetheless, they affect global mean sea level through their alteration of the shape and hence the volume of the ocean basins containing the water (Bindoff et al., 2007).

Storm Surge: Storm surge describes an abnormal rise of water generated by a storm above predicted astronomical tides. Surge risk varies depending on the strength and structure of a given hurricane as well as geography and tidal cycles along the coast it impacts. However, it is useful to note that any low-pressure system off shore with associated high winds can cause a coastal flooding event depending on duration and direction of winds.

What is Already Happening?

This section discusses climate change that has already been observed in the context of extreme events in coastal and marine environments. In the section, historical trends are examined with respect to tropical cyclones, sea level rise, storm surge, significant wave heights and Sargussum outbreaks.

Tropical Cyclones: Globally, estimates of the potential destructiveness of hurricanes show a substantial upward trend since the mid-1970s, with a trend towards longer storm duration and greater storm intensity. These are consistent with findings that a large increase in numbers and proportion of strong hurricanes have been evident globally since 1970 even as total numbers of cyclones and cyclone days decreased slightly in most basins. Specifically, the number of category 4 and 5

Table 1. Impacts of some extremes events occurring across the Caribbean region since 2004 in the context of yearly variability.

Climate Change Variable/ Extreme Events	Impacts
Tropical Storms and Cyclones/ Storm Surge	Hurricane Ivan in 2004 made landfall in Grenada causing significant damage to St. George, St. David, St. John, and St. Andrew. Estimated cost of damages was USD885 million. The south coast of Jamaica also experienced significant damage from Ivan. Fourteen percent of the total population was impacted and damages amounting to USD595 million were incurred (ECLAC, 2004). Hurricane Dean in 2007 uprooted 40% of mangroves in the Portland Bight Area, Jamaica. The high mortality is due in part to the young state of mangroves in the area in recovery from the impact of Hurricane Ivan in 2004 (PIOJ, 2007). Tropical Depression 16, though never making landfall in Belize, resulted in losses amounting to USD27.1 million (2% of the GDP) (ECLAC, 2009). Hurricane Sandy 2012 caused storm surge events in the north-eastern/eastern coasts of Jamaica. Flood events affect approximately 25% of the total population (PIOJ, 2013).
Sea Level Rise	Alligator Pond in St. Elizabeth, Jamaica experiences continued beach erosion (The Observer, 2010). Coastal erosion of Las Cuevas, Blanchisseuse, and South Cocos Bays in Trinidad and Tobago has been observed (Daily Express, 2014). Signs of a receding coastline at Manzanilla Beach has also been noted (CNS, 2015).
Sargassum	In 2014 Sargassum blanketed marine areas in Jamaica and across the Caribbean and as far north as Massachusetts, affecting fisheries, aquaculture, shorelines and tourism.

hurricanes increased by about 75% between 1970 and 2012 (IPCC, 2013). For 1995-2012, 13 of the hurricane seasons in the North Atlantic have been above normal and include the two most active seasons on record. Table 2 below shows the number of storms for above-normal North Atlantic hurricane seasons recorded between 1995 and 2016. The years 1998, 1999, 2003, and 2004 also rank among the top 10 most active seasons ever recorded. The accumulated cyclone energy (ACE) is an indication of the frequency, intensity and duration of a hurricane season (NOAA Archived Bulletins).

Table 2. The accumulated cyclone energy (ACE), number of tropical storms, hurricanes and major hurricanes for above-normal hurricane seasons in the North Atlantic since 1995 in order of most active.

Years	ACE	Tropical Storm	Hurricane	Major Hurricane	Total
2005	250	28	15	7	50
1995	228	19	11	5	35
2004	225	15	9	6	30
1998	182	14	10	3	27
1999	177	12	8	5	25
2003	175	16	7	3	26
1996	166	13	9	6	28
2010	165	19	12	5	36
2008	144	16	8	5	29
2016	138	15	7	4	26
2012	133	19	10	2	31
2011	126	19	7	4	30
2000	116	15	8	3	26

Additionally, studies have noted higher North Atlantic tropical cyclone activity (+60% $°C^{-1}$) since 1995 (Goldenberg et al., 2001) and increased frequency of very intense tropical cyclones (~+17% $°C^{-1}$) within the North Atlantic region since the 1990s (Emanuel, 2007; Holland & Webster, 2007, Bender et al., 2010). These trends have been observed in association with long term changes in tropical Atlantic oceanic and atmospheric conditions important to North Atlantic tropical cyclone development including increased mean surface temperatures (0.12 ± 0.04°C per decade for 1951-2010), increased tropospheric water vapor (7%˚C^{-1} since 1970s) and fluctuations in vertical wind shear (within 6 ms^{-1} since 1995) (Goldenberg et al., 2001; IPCC, 2013).

Sea Level Rise: It is estimated that between 1901 and 2010, global mean sea level increased by 0.19 ± 0.02 metres (IPCC, 2013), although rates of sea level rise are not uniform across the globe and large regional differences exist. From estimates of observed sea level rise from 1950 to 2000, it is anticipated that Caribbean sea levels have risen at a rate similar to the global rate (Church et al., 2004). Table 3 below shows the trend of sea level rise across the Caribbean region.

Table 3. Mean rate of sea level rise averaged over the Caribbean basin.

Period	Rate (mm/year)	Information source
1950 and 2009	1.8 ± 0.1	Palanisamy et al. (2012)
1993 and 2010	1.7 ± 1.3	Torres & Tsimplis (2013)
1993 and 2010	2.5± 1.3	Torres & Tsimplis (2013), after correction for Global Isostatic Adjustment (GIA)*

*GIA describes the slow part of the response of the earth to the redistribution of mass following the last deglaciation.

Storm Surge: Most analyses on extreme water levels have focused on specific regions and find that extreme values have increased since the 1950s, using various statistical measures such as annual maximum surge, annual maximum surge-at-high-water, monthly mean high water level, changes in number of high storm surge events or changes in the 99th percentile events. Global analysis of tide gauge data that spans 1970s to the present, also suggests that the magnitude of extreme sea level events has increased in all regions studied.

Significant wave height (North Atlantic): The mean significant wave height (SWH) is defined as the average of the highest one-third of wave heights. Trends in the North Atlantic show an increase in mean significant wave height. The Caribbean shows less significant increases since 1948 (Reguero et al. 2013, IPCC 2013). SWH values can reach up to 2-2.5 metres with great spatial variability as more modest trends are observed along the eastern Caribbean. Table 4 below shows the trends of SWH in the Caribbean. The coastal response to this change in wave climate has not been documented.

Table 4. Trends in significant wave height (in centimetres per year) for the North Atlantic, Caribbean and Gulf of Mexico regions. Source: (Reguero et al., 2013).

Region	Significant Wave Height (cm/yr)
North Atlantic	0.134
Caribbean	0.024
Gulf of Mexico	0.018

Sargassum outbreak: Pelagic (floating) sargassum or seaweed, originating in the adjacent Sargasso Sea, floated into the Caribbean region. Sargassum provide feeding and spawning grounds for many marine species and is an essential habitat for some commercial value fish across the Caribbean region. However, events in which copious amounts of sargassum have washed up along the coasts of the Caribbean have intensified in more recent years. Extreme sargassum events have occurred in 2011, 2012, 2014, 2015, and 2016 (Maréchal et al., 2017). Sargassum shows substantial spatial and temporal variability as it is influenced by ocean conditions (such as sea surface temperatures, ocean acidification, and wind disturbances) and even thrives in warmer waters (Huffard et al., 2014).

Impact

Studies of beach attenuation and recession of Dominican beaches and bays show an overall vulnerability to beach erosion due to hurricane-associated storm surge between 1987 and 2000 (UNESCO, 2002a). Where there are cases of continued beach attenuation, other locations experience beach accretion, as with the cases of Grand Anse Central, Mount Rodney, Sauteurs, and Grenville in Grenada (UNSECO, 2002b).

Some other impacts of extremes have been in relation to mangroves within the Caribbean region. These have shown adjustments to rising sea levels prior to the year 1950 (McKee et al., 2007). Mangroves can actively adjust their environments and have the ability to migrate further inland over time (Krauss et al., 2014). However, there is evidence that mangroves are under threat and are in decline (Ellison & Farnsworth, 1996; The Jamaica Observer, 2011). The OECS *Biodiversity of the Caribbean* 2009 report stipulates that climate change is a major factor encouraging the reduction of mangroves along the coast. Rising sea levels result in an influx of fresh water in the ocean altering the ocean's salinity. This poses a threat to mangroves that are salt-tolerant plants. The report also indicates that changing climate and increased frequency of extreme events could undermine the stability of mangrove ecosystems, a feature that mangroves rely on for growth and survival. Ellison & Farnsworth (1996) show that the area occupied by mangrove swamps decreased from 14, 844 square kilometres in 1980 to 13, 501.3 square kilometres in 1990. The decline is consistent with trends in individual Caribbean countries and with more recent observed trends (see Table 5 below).

While Sargassum events have been observed to thrive in warmer waters, lower diversity is observed in more recent samples of Sargassum (Schmidt Ocean Institute, 2014). With less diverse marine life, Sargassum floats have become less habitable leading to declines in pelagic fish and marine species. This affects the availability of fish within the Caribbean region, and also affects attractiveness of coastal beaches, a prime asset in tourism for many Caribbean countries.

Environmental pollution, particularly marine oil spills, is a primary cause of the declines in mangrove coverage along some Caribbean coasts (Imbert et al., 2000). Hurricanes also contribute substantially to the slow regrowth of mangrove forests. The effect of hurricanes on the basal area of mangrove forest in the Dominican Republic were examined by Sherman et al. (2001). The results indicated that the area occupied by mangroves dropped drastically for intense storms, and the recovery time of mangroves further away from the coast took more than a year to achieve pre-hurricane seedling densities. However, the effects are not all negative. Hurricanes also result in rapid sediment input and the transfer of nutrients into mangrove areas that support the long-term maintenance of surface elevations necessary for mangrove growth (Ward et al., 2016).

Table 5. A comparison of area coverage in square kilometres of mangrove forests for some Caribbean islands over the years.

Country	Area coverage ca. 1980	Area coverage ca. 1990	Area coverage ca. 2000
Antigua and Barbuda	13	11.8	-
Bahamas	3086	1419	-
Barbados	<0.07	0.1	-
Belize	730	657.7	-
Dominica	2	0.1	-
Grenada	2	1.5	-
Guyana	-	804	160
Haiti	180	150	-
Jamaica	106	97.3	-
Puerto Rico	80	65	64.1
St. Kitts and Nevis	0.5	0.2	-
St. Lucia	3	1.8	2
St. Vincent and the Grenadines	1	0.6	-
Trinidad and Tobago	40	71.5	50
Suriname	-	981.2	900

Source: Ellison & Farnsworth (1996), FAO (2003), Lewsey & Kruse (2004).

What Could Happen?

This section discusses future changes that may be anticipated in relation to tropical cyclones, sea level rise, storm surge and significant wave heights for the North Atlantic and Caribbean and some possible impacts to the natural and built environments of the Caribbean.

Future Climate

Tropical Cyclones: The Fifth Assessment report of the Intergovernmental Panel on Climate Change (IPCC AR5) published in 2013 suggests that while global frequency of tropical cyclones is likely to either decrease or remain essentially unchanged, it is more likely than not that the frequency of the most intense storms will increase substantially in some ocean basins. It is anticipated, though with low confidence, that North Atlantic tropical cyclone activity will follow the global trend (Emanuel et al. 2008; Sugi et al. 2009; Knutson et al. 2010). Bender et al. (2010) suggested that while the overall frequency of Atlantic storms may decrease by 28%, the frequency of the most intense Atlantic storms (Category 4 and 5 on the Saffir-Simpson scale) may increases by 80% by the end-of-century under the SRES A1B (medium emissions) scenario. Increased precipitation rates and higher wind speeds are also likely for future Atlantic tropical cyclones (IPCC 2013; Knutson et al., 2010, 2013).

Sea Level Rise (SLR): Global mean sea levels are projected to continue rising. The Fifth Assessment Report produced in 2013 suggests that we will see changes in the combined range of 0.26

– 0.82 m by 2100 relative to 1986-2005 levels across all representative concentration pathways (RCPs). This is a more rapid rate of increase than once suggested by the IPCC Fourth Assessment Report produced in 2007. Some of the latest global and regional projections for four representative concentration pathways (RCPs) are given in Table 5. It has been suggested that gravitational and geophysical factors will lead to the region experiencing a greater rise in sea levels than most global areas. In fact, sea level rise over the Northern Caribbean may exceed the global average by 25% (IPCC 2013). Table 6 indicates that Caribbean countries are projected to exceed the global average under all RCP scenarios. Under the worst-case scenario (RCP8.5), it is suggested that most Caribbean SIDS may reach 0.5-m SLR by the mid-century (2046-2065) and 1-m sea level rise by the end-of-century (2081-2100). Countries located in the southernmost Caribbean show marginally higher rates of increase, as in the case of Trinidad.

Table 6. Projected increases in global mean sea level (in metres) and select Caribbean Small Island States Projections are taken using the CMIP5 suite of global climate models and are relative to 1986-2005.

		2046 – 2065		2081– 2100	
Variable	**Scenario**	**Mean**	**Likely range**	**Mean**	**Likely range**
Global Mean Sea Level Rise (m)	RCP2.6	0.24	0.17 – 0.32	0.40	0.26 – 0.55
	RCP4.5	0.26	0.19 – 0.33	0.47	0.32 – 0.63
	RCP6.0	0.25	0.18 – 0.32	0.48	0.33 – 0.63
	RCP8.5	0.30	0.22 – 0.38	0.63	0.45 – 0.82
Bahamas	RCP2.6	0.33	0.27 – 0.40	0.57	0.51 – 0.64
	RCP4.5	0.35	0.28 – 0.42	0.65	0.56 – 0.74
	RCP6.0	0.33	0.25 – 0.41	0.66	0.56 – 0.76
	RCP8.5	0.40	0.30 – 0.50	0.86	0.71 – 1.02
Belize	RCP2.6	0.37	0.29 – 0.45	0.64	0.58 – 0.72
	RCP4.5	0.39	0.31 – 0.47	0.74	0.63 – 0.83
	RCP6.0	0.38	0.29 – 0.46	0.74	0.63 – 0.86
	RCP8.5	0.44	0.34 – 0.56	0.97	0.80 – 1.15
Guadeloupe	RCP2.6	0.35	0.27 – 0.41	0.60	0.53 – 0.66
	RCP4.5	0.36	0.28 – 0.44	0.68	0.59 – 0.77
	RCP6.0	0.35	0.27 – 0.43	0.69	0.59 – 0.80
	RCP8.5	0.41	0.32 – 0.52	0.90	0.74 – 1.07
Jamaica	RCP2.6	0.34	0.27 – 0.41	0.59	0.52 – 0.65
	RCP4.5	0.35	0.28 – 0.43	0.67	0.58 – 0.76
	RCP6.0	0.34	0.27 – 0.42	0.68	0.58 – 0.78
	RCP8.5	0.40	0.31 – 0.51	0.88	0.73 – 1.05
Trinidad	RCP2.6	0.38	0.30 – 0.45	0.65	0.58 – 0.73
	RCP4.5	0.39	0.31 – 0.48	0.74	0.64 – 0.84
	RCP6.0	0.38	0.30 – 0.46	0.75	0.64 – 0.87
	RCP8.5	0.45	0.35 – 0.57	0.98	0.81 – 1.170

Storm Surge: Despite the lack of studies on storm surge within the Caribbean and the wider North Atlantic region, it is anticipated that with projected sea level rise and increases in number of the most intense storms, storm surge levels will increase (Lin et al., 2012; Grinsted et al., 2013). Grinsted et al. (2013) showed that storm surge heights increase with an increase in wind speed and SST. The study further asserts that storm surge events that occur due to more intense storms (such as Katrina 2005) are likely to become more frequent, with shorter return periods as global temperatures continue to increase. However, the number of tropical cyclone events in the North Atlantic region (including the Caribbean) is expected to decline. It is anticipated therefore that the North Atlantic region will see fewer but more intense storm surge events, following in the fashion of projected regional storm events (Mori et al., 2010).

Significant wave heights: Future wave heights in the latitude range of 30°N–45°N in the North Pacific and the North Atlantic Ocean will decrease by 7% which corresponds to 0.15 m of averaged wave height. A figure from the IPCC AR5 suggests that for the Caribbean annual mean significant wave heights are projected to decrease by approximately 1-2% by the end of century.

Some Possible Impacts

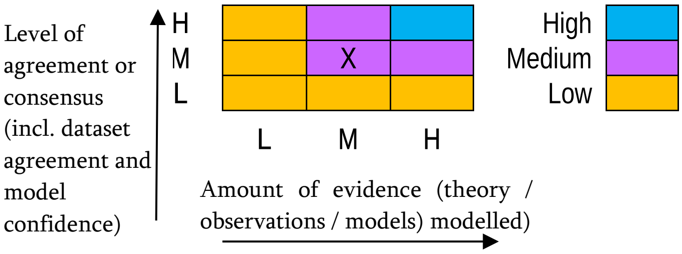
Coastal environments are expected to be threatened in the near to long-term future with the projected and continued rise in sea levels. Using the IPCC's most recent suite of global climate models (GCMs), the Caribbean SIDS are expected to see 0.5-0.6 metre (under RCP4.5) or 1-metre sea level rise (under RCP8.5) by the end of the century. The IPCC 2014 Report indicates that 1-metre sea level rise will have dire impacts on the fisheries (particularly aquaculture) with increases in flooding events and saltwater intrusion, and on tourism through beach erosion due to elevated rates of SLR, modified coastlines, and loss of biodiversity due to increases in the pH of marine habitats. According to the CARIBSAVE assessments, as the majority of Caribbean population live and work along the coastal regions, a substantial percentage of coastal infrastructure is likely to be severely impacted by rises in sea levels. For Jamaica, airports are the most vulnerable coastal infrastructures with a projected 20% of airport infrastructure and 22% of wetland areas being affected by a 1-metre rise in sea levels. For Guyana, sea level rise poses the greatest threat to major tourism resorts with 50% of infrastructure anticipated to be impacted by a 1-metre rise in sea levels. Belize shows a high sensitivity to sea level rise impacts, with total projected damages of 50% of wetland and major tourism resorts with just a 1-metre rise in sea levels.

The IPCC 2013 and 2014 reports indicate that the current declining trend in mangrove areas in the Caribbean region are very likely to continue towards the end-of-century. This is due to projected increases in temperature and rainfall extremes, sea level rise, and the frequency of intense tropical cyclones. It is anticipated that an increase in the frequency of extreme events may have the following negative impacts (Ward et al., 2016):

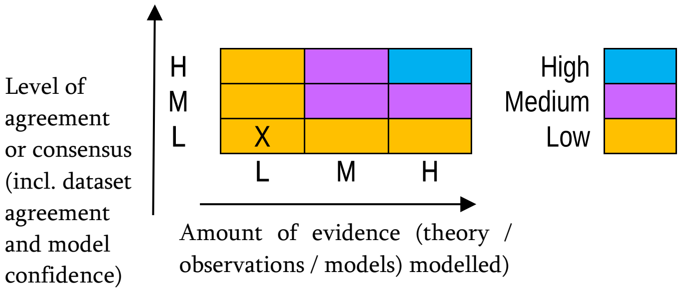
- Accelerated mangrove mortality: Changes in surface elevation (important for mangroves to thrive) due to accelerated sea level rise may have long-term effects on mangroves.
- Landward mangrove forest migration due to increases in storm surge and the most intense hurricanes.
- Fresh water wetland displacement due to saltwater intrusion from sea level rise.

Confidence Assessment

What is already happening



What could happen in the future



The main knowledge gaps that inhibit a more detailed analysis of the impact of climate extremes on coastal and marine environments are as noted below:

1. Significant wave heights need to be examined for the Caribbean but analyses may be restricted by the availability of data.
2. There is a need to examine sea level rise specifically for the Caribbean and to identify what the extreme scenarios may be. A closer look at storm surge over the Caribbean is also needed.
3. Future tropical cyclone activity within the Caribbean Basin should be the subject of future investigations. Current analyses are concentrated on the Atlantic and Pacific Oceans but there is value in conducting some regional evaluations.
4. Unreported impacts. Many assessments acknowledge that there are substantial gaps in impacts analyses due to incomplete surveys and damage assessments, especially in countries with limited resources and local capacity, for example Haiti (IPCC, 2007; Cohen & Singh, 2014).

Socio-economic Impacts

Cost of inaction

The cost of not adapting to climate change impacts is expected to have severe repercussions for Caribbean SIDS. Without action, the cost of damage is likely to increase substantially towards the end-of-century, crippling further development of island states (Bueno et al., 2008). For example, with the annual North Atlantic hurricane season, the Caribbean SIDS have the potential to incur damages and losses of up to 15% of the GDP. Table 7 outlines the impact (expressed as the percentage of the GDP) of historical tropical cyclones on the economic sector in Caribbean countries. With more intense storms, the severity of hurricane impacts is expected to increase.

If the region's vulnerability to climate change is not addressed, then the estimated loss due to future climate extremes such as hurricanes could increase. Table 5 indicates the inherent vulnerability to climate of Caribbean states. Countries such as Grenada and Haiti show high vulnerability and severe potential socio-economic impacts under climate change. The costs (as a % of GDP) noted in Table 8, further suggest that each Caribbean country could likely experience a perpetual economic recession, should projected impacts materialize. For the Caribbean in general, annual cost of inaction could total US $10.7 billion annually by 2025, $22 billion by 2050 and $46 billion by 2100. These costs represent 5%, 10% and 22% respectively of the current Caribbean economy (2004 GDP).

Implications for energy

One of the key sectors that will be severely impacted by extreme events is energy. Many power plants in the Caribbean are located along the coast. A case in point is Jamaica in which 7 of its 8 generation stations and all load centres are located on or near coastal plains (Figure 1). With continued sea level rise, there is the possibility of having to relocate power utilities further inland. This may result in higher population densities along the coast and competition for space. The anticipated increase in the intensity and precipitation associated with the strongest hurricanes as well as stronger storms will also affect energy supply.

Table 7. Impact of hurricane events on some Caribbean economies from 1990-2008

Country	Tropical Cyclone Event	Total national impact to economic sector (% GDP)
The Bahamas	Hurricane Frances and Jeanne (2004)	0.3%
Belize	Hurricane Keith (2000)	0.1%
Cayman Islands	Hurricane Ivan (2004)	4.8%
Cayman Islands	Hurricane Paloma (2008)	0.3%
Dominican Republic	Hurricane Frances and Jeanne (2008)	0.1%
Grenada	Hurricane Ivan (2004)	2.1%
Haiti	Hurricane Jeanne (2004)	7.7%
Haiti	Tropical Storm Fay, Gustav, Hanna, Ike (2008)	15.1%
Jamaica	Hurricane Michelle (2001)	1.3%
Jamaica	Hurricane Ivan (2004)	1.3%
Turks and Caicos Islands	Hurricane Hanna, Ike (2008)	0.3%

Adapted from ECLAC (2010).

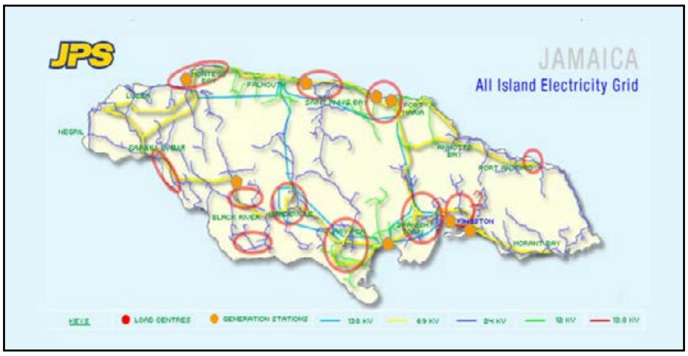


Figure 1. Locations of generation stations (orange pentagons) and load centres (areas circled in red). Medium to high voltage power lines of Jamaica's electricity grid are shown as follows: 12 kV power lines (light green), 13.8 kV (red), 24kV (blue), 69kV (yellow), and 138 kV (light blue). Source: Jamaica Public Service Limited.

Table 8. Cost of inaction on climate change in the Caribbean region by 2025, 2050, 2075 and 2100. The figures are estimates of the total annual impact of potential climate change on Caribbean countries for different time horizons.

Country	Cost of Inaction: % of 2004 GDP			
	2025	2050	2075	2100
Anguilla	10.4	20.7	31.1	41.4
Antigua & Barbuda	12.2	25.8	41.0	58.4
Aruba	5.0	10.1	15.1	20.1
Bahamas	6.6	13.9	22.2	31.7
Barbados	6.9	13.9	20.8	27.7
British Virgin Islands	4.5	9.0	13.5	18.1
Cayman Islands	8.8	20.1	34.7	53.4
Cuba	6.1	12.5	19.4	26.8
Dominica	16.3	34.3	54.4	77.3
Dominican Republic	9.7	19.6	29.8	40.3
Grenada	21.3	46.2	75.8	111.5
Guadeloupe	2.3	4.6	7.0	9.5
Haiti	30.5	61.2	92.1	123.2
Jamaica	13.9	27.9	42.3	56.9
Martinique	1.9	3.8	5.9	8.1
Montserrat	10.2	21.7	34.6	49.5
Netherland Antilles	7.7	16.1	25.5	36.0
Puerto Rico	1.4	2.8	4.4	6.0
Saint Kitts & Nevis	16.0	35.5	59.5	89.3
Saint Lucia	12.1	24.3	36.6	49.1
Saint Vincent & the Grenadines	11.8	23.6	35.4	47.2
Trinidad & Tobago	4.0	8.0	12.0	16.0
Turks & Caicos	19.0	37.9	56.9	75.9
U.S. Virgin Islands	6.7	14.2	22.6	32.4
TOTAL CARIBBEAN	5.0%	10.3%	15.9%	21.7%

Adapted from Bueno et al. (2008).

Implications for Coastal Infrastructure

Finally, for Latin America and the Caribbean, costs of adaptation to extreme weather events and fortification of coastal infrastructure are estimated to be a total of 0.21% (0.22%) of the GDP for the driest (wettest) scenario, and contributes quite significantly to the overall cost of adaptation (ECLAC, 2014). Figure 5 shows the projected annual costs of adaptation as generated using two models by sector. The National Centre for Atmospheric Research (NCAR) model provides cost projections in a drier climate, while the Commonwealth Scientific and Industrial Research Organization (CSIRO) model provides costs of adaptation under a wetter climate.

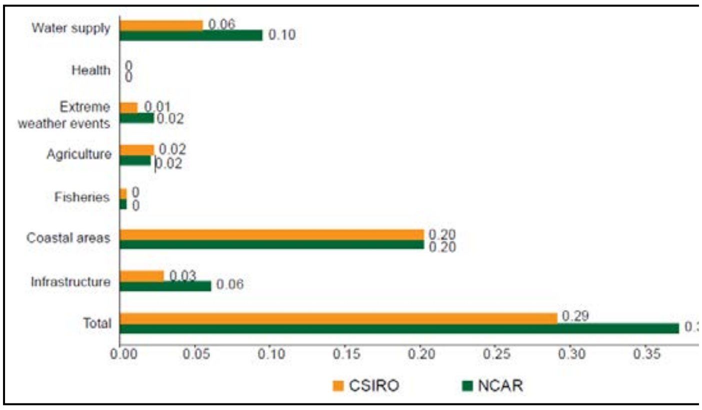


Figure 5. Annual costs of adaptation (as percentages of regional GDP) for Latin America and the Caribbean. The National Centre for Atmospheric Research (NCAR) model provides the wettest scenario; Commonwealth Scientific and Industrial Research Organization (CSIRO) model provides estimations under a wettest scenario. Source: (ECLAC, 2014).

Nicholls et al. (2010) further indicates that costs of adaptation for coastal zones are high particularly because of the continued increase in population along the coast and the exposure of many low-lying coastal regions to quite a few climate risks (sea level rise, storm surge, tropical storms). As such, Latin America and the Caribbean and East Asia and the Pacific account for two-thirds of total adaptation costs worldwide.

Another World Bank report also shows that the costs of fortifying coastal zones are very likely to increase with more intense climate risks. Table 9 below shows the incremental costs per year for adaptation of Latin American and Caribbean coasts. The annual costs for adaptation is projected to rise as climate hazards become more severe with storms and increases in population lending much to substantial increases in cost.

As the climate becomes warmer, it is anticipated that the Latin America and Caribbean region will see more stringent and costly impacts to coastal regions.

Table 9. Incremental annual costs of adaptation for coastal regions in Latin America and the Caribbean under a no-rise, low, medium, high sea level rise scenarios. Costs are given in billions per year at 2005 prices. Adapted from Nicholls et al. (2010).

		No-Rise	**Low**	**Medium**	**High**	**High with storms**	**High with no population growth**
Beach Nourishment	2010s	0.04	0.39	0.67	0.84	0.84	0.84
	2020s	0.05	0.48	0.37	1.17	1.17	1.16
	2030s	0.05	0.58	1.14	1.55	1.55	1.55
	2040s	0.05	0.70	1.44	2.09	2.09	2.08
Port Upgrades	2010s	0.00	0.02	0.04	0.05	0.05	0.05
	2020s	0.00	0.02	0.04	0.05	0.05	0.05
	2030s	0.00	0.02	0.04	0.05	0.05	0.05
	2040s	0.00	0.02	0.04	0.05	0.05	0.05
River Dikes	2010s	0.16	0.12	0.26	0.39	0.39	0.41
	2020s	0.15	0.12	0.27	0.42	0.42	0.42
	2030s	0.15	0.13	0.30	0.44	0.44	0.45
	2040s	0.14	0.13	0.31	0.47	0.47	0.48
Sea Dikes	2010s	2.28	3.33	7.59	11.34	11.74	11.05
	2020s	2.21	3.65	8.43	12.59	13.10	12.05
	2030s	2.28	3.99	9.24	13.76	14.30	13.55
	2040s	2.41	4.32	9.98	14.83	15.45	14.66

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