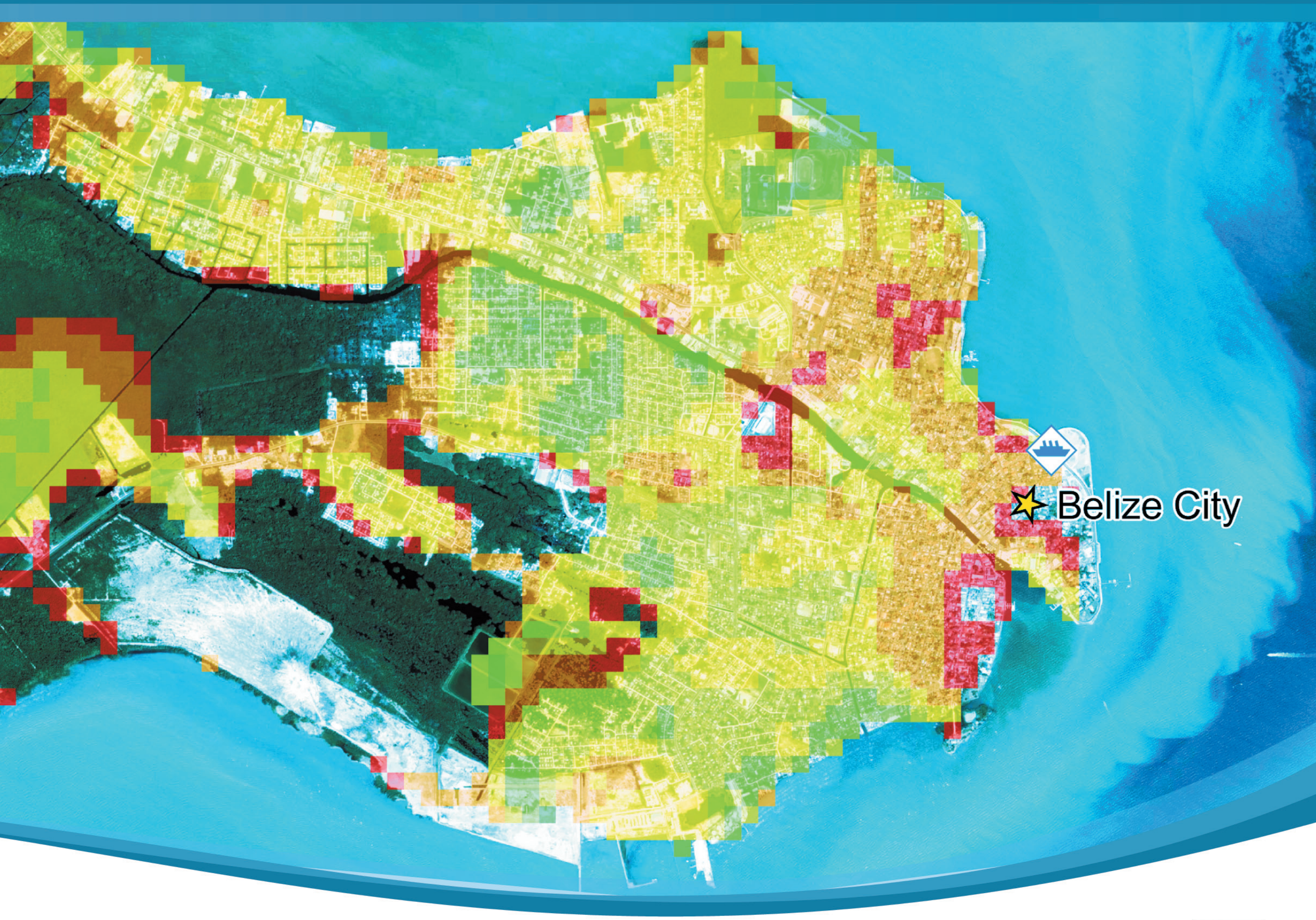
an overview of modelling CLIMATE CHANGE

Impacts in the Caribbean Region with contribution from the Pacific Islands

SUMMARY DOCUMENT



CARICOM

CARIBBEAN COMMUNITY CLIMATE CHANGE CENTRE

DFID Department for International Development

caribsave

UNDP

An Overview of Modelling Climate Change Impacts in the Caribbean Region with contribution from the Pacific Islands:

SUMMARY DOCUMENT

UNDP is the UN's global development network, advocating for change and connecting countries to knowledge, experience and resources to help people build a better life.

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Please note that at a DVD was distributed at Copenhagen COP15 December 2009 with the 'Key Points' of the report. The DVD contains copies of the following:

1. An Overview of Modelling Climate Change Impacts in the Caribbean Region with contribution from the Pacific Islands: KEY POINTS
2. An Overview of Modelling Climate Change Impacts in the Caribbean Region with contribution from the Pacific Islands: SUMMARY DOCUMENT
3. 'The Burning Agenda: The Climate Change Crisis in the Caribbean', Short Film (30 minutes) Commissioned by the British Foreign and Commonwealth Office
4. '1.5 To Stay Alive', Song written and performed by the Barbadian performance poet Adisa 'AJA' Andwele.

These items and copies of the report can be obtained via free download at www.caribsave.org

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Introduction

The nations of CARICOM[16] in the Caribbean together with Pacific island countries contribute less than 1% to global greenhouse gas (GHG) emissions (0.33%[17] and 0.03%[18] respectively), yet these countries are expected to be among the earliest and most impacted by climate change in the coming decades and are least able to adapt to climate change impacts. These nations' relative isolation, small land masses, their concentrations of population and infrastructure in coastal areas, limited economic base and dependency on natural resources, combined with limited financial, technical and institutional capacity all exacerbates their vulnerability to extreme events and climate change impacts. Stabilising global GHG emissions and obtaining greater support for adaptation strategies are fundamental priorities for the Caribbean Basin and Pacific island countries. CARICOM leaders recently unveiled their collective position that global warming should be held to no more than 1.5°C[19] and continue to develop a Climate Change Strategic Plan. The Pacific island countries have expressed their priorities for addressing climate change regionally through the Pacific Leaders' Call to Action on Climate Change[20] and the Pacific Islands Framework for Action on Climate Change 2006-2015.[21]

The people of the Caribbean and the Pacific have a long history of resilience to volatile climate conditions. However, the ability of Caribbean countries and Pacific island to adapt to the likely impacts of climate change is diminished by their exposure to these impacts, and their limited adaptive capacity. The high sensitivity of low-lying atolls to increases in sea level rise (SLR) in particular will threaten water, food security, coastal settlements, health and infrastructure.

This report was commissioned by the United Nations Development Programme (UNDP) Sub-Regional Office for Barbados and the OECS and by the UK Department for International Development (DFID), with support from Australia's International Climate Change Adaptation Initiative. The report was produced by The CARIBSAVE Partnership and authored by members of 15 key institutions around the world dealing with climate change (see page 7). This 'Summary Document' was drawn from the full report and provides an overview for all CARICOM member states of the risks from climate change and includes a section on the common threats of climate change for

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[16] Members of CARICOM: Antigua and Barbuda, The Bahamas, Barbados, Belize, Dominica, Grenada, Guyana, Haiti, Jamaica, Montserrat, St. Lucia, St. Kitts and Nevis and St. Vincent and the Grenadines, Suriname, Trinidad and Tobago

[17] The Caribbean Islands contribute about 6% of the total emissions from the Latin America and Caribbean Region grouping and the Latin America and Caribbean Region is estimated to generate 5.5% of global CO_2 emissions in 2001 (UNEP 2003. See http://maps.grida.no/go/graphic/regional_ differences_in_co2_e missions_latin_america_and_the_caribbean).

[18] According to the IPCC TAR. Cited in: Pacific Islands face up to global warming. http://www.acp-eucourier.info/Pacific-Islands-face-up-t.244.0.html and see Pacific Islands Applied Geoscience Commission (SOPAC), 2007. Funding for renewable energy and energy efficiency projects under the Kyoto Protocol's Clean Development Mechanism, SOPAC Miscellaneous Report 630.

[19] The "1.5°C to Stay Alive" campaign. See: http://www.caribbeanpressreleases.com/ articles/5831/1/CARICOM-Unveils-Climate-Change-Strategy-Ahead-of-Copenhagen/Page1.html

[20] http://www.pif2009.org.au/docs/call_to_action_final.pdf

[21] http://www.sprep.org/att/publication/000438_PI_Framework_for_Action_on_Climate_Change_2006_2015_FINAL.pdf

Pacific island countries. The report focuses on: climate change projections for the Caribbean region under +1.5° and +2°C global warming scenarios; the implications of ice sheet melt for global sea level rise (SLR); the projections and implications of SLR for the Caribbean region; evaluation of the differential impacts of +1.5° and +2°C on coral reefs, water resources and agriculture in the Caribbean, with additional analysis for the Pacific islands.

The impacts of a changing climate on the Caribbean and the islands of the Pacific are increasingly being manifested in economic and financial losses. According to the World Bank, in 2007 the Caribbean suffered US $10 billion in economic losses from weather related events representing over 13% of gross domestic product (GDP). While there is limited information on the economic impacts of climate change in the Pacific islands, predictions of SLR and other climate related impacts present significant risks to water, food security, coastal settlements, infrastructure and economic development, particularly for those small low lying atoll countries.

The lack of long-term datasets and high-resolution elevation data in the Caribbean region and Pacific islands provides a fundamental barrier to the improved quantification of the impacts of climate change and SLR. There is an urgent need for data collection and investment that would facilitate detailed risk mapping and more accurate evaluations of the impacts of climate change, as well as thorough cost-benefit analyses of different adaptation options and their abilities to cope with different levels of climate change and SLR. This would also help to secure assistance from the international community who are interested in supporting evidence-based adaptation strategies. Despite a significant and evolving effort to understand climate change impacts on small island states and developing nations, there remains the need for further assessment of practical outcomes and approaches that enhance adaptive capacity and resilience. This report provides the first thorough assessment of the consequences of projected SLR and storm surge leading to coastal inundation (+1m to +6m) for the people and economies of the 15 CARICOM nations, gives an overview of the impacts of climate change in the Caribbean region and Pacific islands, and provides recommendations for urgent future work required to enable adaptation to climate change.

Part 1 - Climate Change Projections for the Caribbean Region under +1.5° and +2°C Global Warming Scenarios

Human activities, including the burning of fossil fuels, deforestation, cement production, and other industrial and personal activities are releasing CO_2 into the atmosphere at a rate that is both rapid and expected to increase. Recent observations have shown that our current rate of CO_2 emissions is exceeding worst case scenarios used in modelling future climate change. Projections from 14 Global Climate Models (GCMs) used within IPCC assessments (IPCC, 2007) have been assessed to determine changes in the climates of the CARICOM countries when average global temperatures exceed threshold increases of 1.5°C and 2.0°C above pre-industrial values. The models have been run under three of the SRES Scenarios, A1B, A2 and B1, used by the IPCC to provide realistic storylines for greenhouse gas [GHG] emissions through the 21st Century (but without consideration of the Kyoto Protocol or subsequent GHG emission reduction treaties). Climate projections from each GCM are not available under all emission scenarios; however all of the 39 individual projections available have been used in this analysis.

The typical approach of the IPCC is to consider climate projections from a number of GCMs at a given time period, often presenting the results as a mean value (called the ensemble mean) and a corresponding range across the models (or members of the ensemble). In this analysis, where the objective is to examine changes in climate in the Caribbean Region around times of specific increases in the average global temperature (1.5° and 2°C above pre-industrial levels), this approach is not appropriate, as the various GCMs respond at different rates to increases in atmospheric greenhouse gases (these differences depend on the 'climate sensitivity' inherent in each model); hence the models reach each threshold global temperature over a range of dates. According to the GCMs used in this Report, the earliest and latest dates the 1.5°C (2.0°C) threshold will be exceeded under scenario A1B are 2023 and 2050 (2039 and 2070), under scenario A2 are 2024 and 2043 (2043 and 2061), and under scenario B1 are 2027 and 2073 (2050 and not until later than 2100; model simulations end in 2100) see Table 1.

Table 1: Earliest and latest years the two threshold temperatures are exceeded in the 39 projections

Scenario	1.5°C Threshold		2.0°C Threshold	
	Earliest	Latest	Earliest	Latest
A1B	2023	2050	2039	2070
A2	2024	2043	2043	2061
B1	2027	2073	2050	Later than 2100*

* Model simulation ends in 2100

These calculations have taken into account that there has been a 0.7°C rise to date in the global average temperature since pre-industrial times (IPCC 2007a). Consequently values have been calculated using 21-year periods centred on the year projections from each specific model/scenario combination exceed a given threshold;

the results therefore do not relate to any particular year.

Care should always be taken in interpreting any climate model projections; the ensemble means presented here are the optimal deterministic results that can be provided from the information available. However it is unlikely that values from these ensemble means will be flawless and standard deviations have been used to assess the ranges of values across all projections; confidence in the results for temperature changes is higher than in those for rainfall changes.

Figures 1 (air temperatures), 2 (sea surface temperatures) and 3 (rainfall) illustrate annual projected changes in the Caribbean Region at global temperature changes of 1.5°C and 2.0°C above pre-industrial levels. Equivalent results for individual seasons are provided in the main report. Average air temperatures will rise in the future in all seasons, more so in land than over the oceans and in island and coastal locations (Figure 1). Typical temperature increases in CARICOM countries are up to 1.5°C and 2.0°C when the same two global thresholds occur (i.e., the Caribbean region largely tracks projected global temperature changes), but less in coastal regions and over islands. In the continental interiors maximum temperature rises tend to follow the solar cycle on a seasonal basis. All projections indicate that temperatures will rise (according to standard deviations) within a spread in values of up to about 0.6°C.

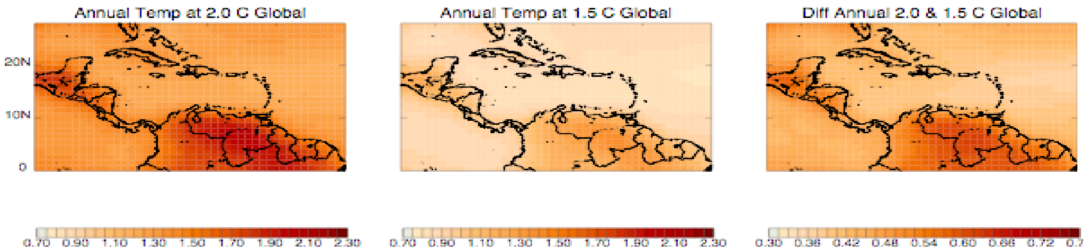

Figure 1: Changes in regional average annual temperatures compared to present day values at thresholds of 2.0°C and 1.5°C and differences between the two; all values in °C; note differences in the scales.

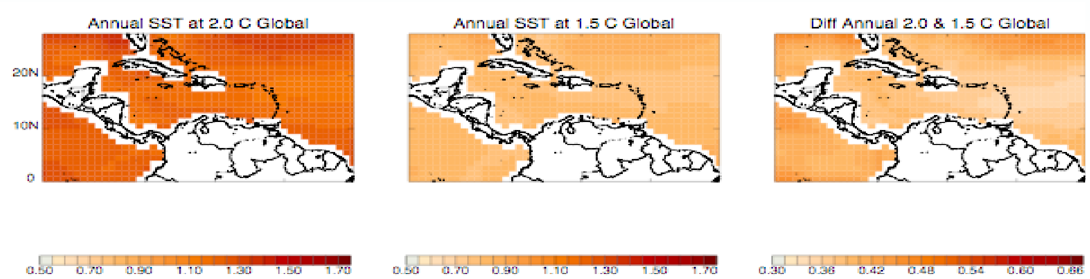

Figure 2: As Figure 1 but for changes in annual average sea surface temperatures; note differences in the scales and with the scales in Figure 1.

Changes in sea surface temperatures by and large are similar to those for air temperature over coastal regions and islands (compare Figures 1 and 2).

Total annual rainfall is projected to decrease through all CARICOM countries by between 10 to 20% according to the ensemble mean, with decreases amplifying with increased temperatures. The exception is in the north, particularly over The Bahamas, where the projections suggest hurricane-season rainfall will increase and rainfall will recover slightly by the 2.0°C as compared to the 1.5°C threshold, although there remains a net annual reduction of perhaps 5% given a 2.0°C threshold. However, examination of standard deviations (Figure 4) indicates that, while the majority of projections simulate rainfall decreases, a substantial set of projections simulate rainfall increases of up to perhaps 30% over the year. The most likely direction of change is thus downwards, but there remains an outstanding but significant probability that the trend could be upwards.

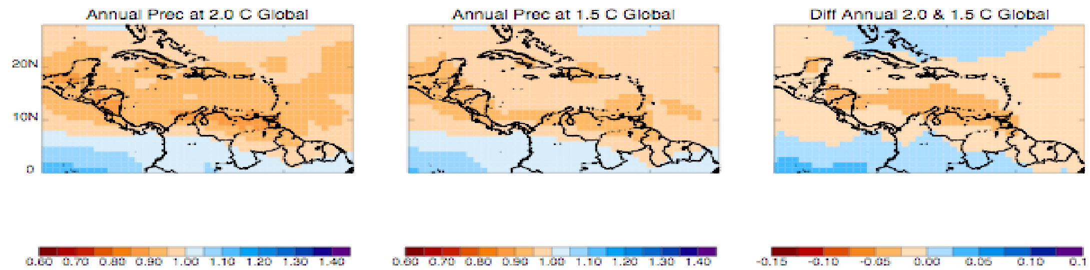

Figure 3: As Figure 1 but for fractional changes in total annual rainfall; reds indicate drying, blues increased rainfall; note differences in the scales.

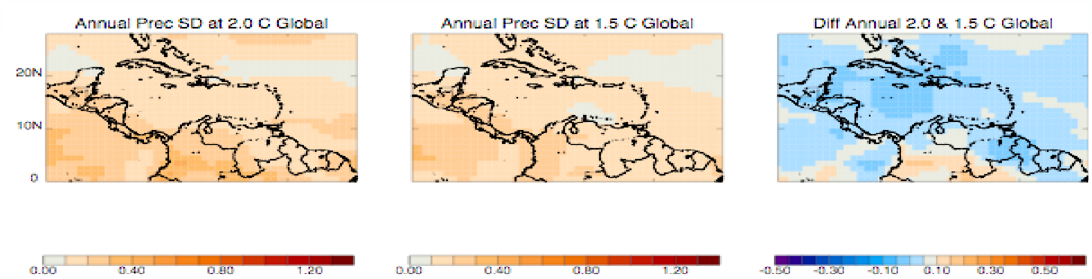

Figure 4: Standard deviations of the fractional change in precipitation on an annual basis, with layout as in Figures 1 to 3.

Table 2 summarizes the projected range of temperature and precipitation changes under each of the threshold global temperature changes. Note that at the 2.0°C threshold temperature, change represents additional change relative to the 1.5°C global warming threshold.

Table 2: Projected Range of Climatic Change in the Caribbean at Global Threshold Temperatures

Climate change effect	Change at 1.5°C global warming	Additional change at 2.0°C global warming
Temperature	~-0.9°C to ~1.7°C	~0.3°C to ~0.6°C
Precipitation	~+15% to ~-35%	~+12.5% to ~-15%
SST	~-0.9°C to ~1.3°C	~0.3°C to ~0.5°C

In order to provide improved spatial detail and to develop more specific information regarding the uncertainties associated with the results presented here, in particular those related to rainfall, it is recommended that a more detailed analysis of the projections employed here, together with research to downscale the information from the global models, be undertaken. This future research should also examine changes in the most intense climate events, such as those that produce heavy rainfall. Such research would support climate change impact assessments and development planning tasks at national and regional levels and provide important support to the UNFCCC Nairobi Work Programme.

Part 2 – Implications of Sea Level Rise for the Caribbean Region

IMPLICATIONS OF ICE SHEET MELT FOR GLOBAL SEA LEVEL RISE

Continued global warming for the rest of the century and into the 22nd century under some GHG emission scenarios poses a major threat to the stability of the world's ice sheets. The extent and speed of melt caused by air and ocean warming will largely determine the magnitude and timing of global sea level rise (SLR) in the future.

Ice sheet stability is closely linked with polar amplification. This is the result of positive feedbacks from the melting of ice and snow, which have high albedo (i.e., reflective of solar energy), with a less important response to feedbacks to water vapour fluxes. All modelling and observational data suggests that the immediate impact of polar amplification is an increase in surface temperatures by a factor of 2 to 3 above the global mean surface temperature rise. Clearly this has implications for the stability of the Greenland Ice Sheet (GIS) and the ice sheets of Antarctica, especially the West Antarctic Ice sheet (WAIS).

Understanding the past dynamic evolution of the ice sheets gives insight into likely future response to warming global average air and ocean temperatures. Thanks to recent advances in Quaternary science there is now detailed information on the nature and timing of deglacial events at the end of the Pleistocene circa two million years ago, and from palaeoglaciological investigations, it can be shown that the ice sheets with major terrestrial margins, such as large parts of the Laurentide and Fenno-Scandian ice sheet, were largely stable and melted slowly following the Last Glacial Maximum. Those ice margins that were significantly coupled to the ocean, such as those that drained through the Hudson Strait in central Canada, disintegrated rapidly and this resulted in rapid discharge of icebergs and significant sea level rise from displacement[22] [23].

Concurrent with this increased understanding of past ice sheet changes, has been the recent revolution in our understanding of ice sheet dynamics which suggests that considerable ice sheet change can occur over centennial timescales. Before this, the consensus was that ice sheets underwent dynamic change over periods of 1000s to 10000s of years, but this understanding was based on numerical ice sheet models with limited resolution (around 40km grid squares) that could not resolve important characteristics of ice sheets, such as individual ice streams.

West Antarctic Ice Sheet (WAIS): Much of the WAIS is at or below sea level, as are parts of the East Antarctic Ice Sheet (EAIS), and are therefore vulnerable to SLR and hence rapid collapse. Originally, the low temperatures of

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[22] Overpeck, J.T., Otto-Bliesner, B.L., Miller, G.H., Muhs, D.R., Alley, R.B. and Kiehl, J.T. 2006. Paleoclimatic evidence for future ice-sheet instability and rapid sea-level rise. Science 311, 1747-1750.

[23] Andrews, J.T., Maclean, B., Kerwin, M., Manley, W., Jennings, A.E. and Hall, F. 1995. Final stages in the collapse of the Laurentide ice sheet, Hudson Strait, Canada, NWT: 14 C AMS dates, seismic stratigraphy and magnetic susceptibility logs. Quaternary Science Reviews 14, 983-1004

Antarctica were assumed to preclude melting during global warming episodes; however, it has become clear that submarine melting is occurring where outlet glaciers come into contact with the ocean. Recent estimates show that annual ice losses from Antarctica approach 220 gigatonnes and this figure appears to be accelerating[24]. From the Antarctic Peninsula and ice shelves around the margins of the WIAS we now have evidence that significant warming is occurring.

Antarctic Ice shelves: In Antarctica, many of the large ice shelves that buttress the outlet glaciers have undergone recent recession or collapse. This includes the Wordie, Mueller, Jones and Larsen A and B ice shelves. Ice shelf collapse removes horizontal compressive forces and, as a result, the glaciers draining the Antarctic Peninsula have increased their velocities by factors of two to eight with downwasting rates in the order of 10s metres/year. Consequently, overall ice loss in the region is now greater than 27 cubic km/year[25]. As the buttressing affect of ice shelves decays, the flow of ice streams from ice sheets become more rapid. This fact points to a rapid decay in the future.

Greenland Ice Sheets (GIS): Unlike the WAIS, the GIS is not at or below sea level and, as a result, is unlikely to collapse quickly. However, parts of the ice sheet are clearly unstable; over the past decade a number of the large outlet glaciers draining the ice sheet have increased their velocities and ice discharge rates and this is helping to drain large areas of inland ice. Recent work analysed the surface mass balance of the GIS from 1958-2007 and used discharge variations to obtain an estimate of the mass balance of the ice sheet. This showed that the ice sheet had a negative mass balance of 110 ± 70 Gt/yr in the 1960s, 30 ± 50 Gt/yr or near balance in the 1970s–1980s, and 97 ± 47 Gt/yr in 1996 increasing rapidly to 267 ± 38 Gt/yr in 2007[26]. The increased discharge from outlet glaciers dominated the ice sheet mass budget.

It is estimated with increased ice loss from the GIS and WAIS the prospects for global sea level changes in the future are for a rapid rise on a decadal timescale up to ten times the rate observed a century ago, and up to 1.5m to 2m by the end of the century. Modelling indicates that in the event that the WAIS ice sheet is lost over a 100 year period, a total sea level rise of 3.3m globally will result[27]. To increase understanding of future sea level change, a suite of more advanced models and more detailed and complete observations of key physical processes are required. It is also vital to emphasize that SLR will continue after 2100, even if global temperatures are stabilized at 1.5°C, 2.0°C or higher, and the dynamical breakup of parts of the GIS and WAIS will continue over centuries, further contributing to SLR. Once set in motion, the break up of ice sheets and the contribution to SLR are irreversible on human timescales.

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[24] Velicogna, I. and Wahr, J. 2006 Measurements of Time-Variable Gravity Show Mass Loss in Antarctica science Science. Vol. 311. no. 5768, pp. 1754 - 1756

[25] Rignot, E. G. Casassa, P. Gogineni, W. Krabill, A. Rivera, and R. Thomas. 2004. Accelerated ice discharge from the Antarctic Peninsula following the collapse of Larsen B ice shelf. Geophysical Research Letters, 31(18), L18401, doi:10.1029/2004GL020697.

[26] Rignot, E., Box, J.E., Burgess, E. and Hanna, E. 2008. Mass balance of the Greenland ice sheet from 1958 to 2007. Geophysical Research Letters, Vol. 35, L20502, doi:10.1029/2008GL035417

[27] Bamber, J., Riva, R.E.M., Vermeersen, B.L.A. and LeBrocq, A.M. 2009. Reassessment of the Potential Sea-Level Rise from a Collapse of the West Antarctic Ice Sheet. Science 324, 901-903.

SEA LEVEL RISE PROJECTIONS FOR THE CARIBBEAN REGION

The coastlines of the Caribbean, which include many low lying and highly erodible shore areas, are particularly susceptible to sea level rise. Studies of both coral reefs and mangroves have established that the level of the sea surface has risen since the end of the last glacial maximum, around 25,000 years ago, by as much as 120 metres, and by around 45 metres over the last 11,500 years (e.g. Fairbanks, 1989)[28]. The rise in sea surface levels was marked by at least two and possibly three periods of acceleration before decreasing around 7,000 years ago and reaching present levels very recently. There is no evidence that sea surface levels in the Caribbean have been above present levels at any time since the last glaciation.

The IPCC Fourth Assessment Report in 2007 reported that the mean global sea surface rose by 1.8mm/year over the period 1961 – 1993, and by 3.1mm/year between 1993 and 2003 (IPCC 2007). There are few records of sea level change at the present time in the Caribbean (detailed information from tide gauges are lacking), but it is likely that a similar rate of rise to that estimated for 1961 – 1993 occurred in the area at the end of the last century, and if sea level in the region generally tracked global changes, there is no reason to suppose that the greater rate of rise for 1993 – 2003 did not take place. This is in agreement with observed trends in sea level rise from 1950 to 2000, when the rise in the Caribbean appeared to be near the global mean.[29] Land movement is only imperfectly known in the Caribbean, and it is therefore assumed that about 3.1mm/year applies to all areas. Given the most recent information on the Greenland and Antarctic ice sheets (see above) and on the effect of global warming on the oceans (i.e., thermal expansion of ocean waters), it seems increasingly likely based on scientific evidence published in the last two years that the rate of mean global sea level rise identified by the IPCC[30] will actually increase in the years ahead, and that the total SLR by the end of the century will be exceeded, perhaps reaching as much as 1.5m to 2m above present levels[31]. With a 1.5°C increase in mean global temperatures by 2100, this increase in SLR may slow versus recent observations. With a 2°C global temperature rise, the rapid increase in SLR will continue[32].

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[28] Fairbanks, R.G. 1989. A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. Nature 342, 637-642

[29] Church, J. A., White, N. J., Coleman, R., Lambeck, K., Mitrovica, J. X. (2004). Estimates of the regional distribution of sea-level rise over the 1950-2000 period. J. Climate 17, 2609-2625.

[30] IPCC mean global sea SLR being a maximum of 0.79 m by 2100 using the A1F1 scenario (95% confidence limit) with scale up ice sheet factors

[31] Mann, M.E., Woodruff, J.D., Donnelly, J.P. and Zhang, Z. 2009. Atlantic hurricanes and climate over the past 1,500 years. Nature 460, 880-883.

[32] Nyberg, J., Malmgren, B.A., Winter, A., Jury, M.R., K H. Kilbourne and Quinn, T.M. 2007. Low Atlantic hurricane activity in the 1970s and 1980s compared to the past 270 years. Nature 447, 698-701.

Furthermore, it is important to note that projected increases in global sea surface levels of 1.5m to 2m may well be even greater in the Caribbean region because of gravitational and geophysical factors. Recent modelling indicate that in the event that the GIS and WAIS melt quickly (over 100 years) the greatest rises in sea level will be experienced along the West and East coasts of North America and result in greater rises (up to 25% more than the global average) in the sea surface in the Caribbean.[33] Even partial melting of the ice sheets will result in greater rises in Caribbean sea surface levels than in most other areas of the Earth.

Set against the rises in sea surface levels, the extreme events to which the Caribbean is subject assume even greater prominence. Although there is no consensus on trends in either intensity or frequency of hurricanes and tropical storms, their range of inundation and capacity for coastal erosion will increase as the sea level rises. The same will be true for tsunamis, which occasionally occur the Caribbean and have in the past caused great loss of life.

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[33] Bamber, J.L., Riva, R.E.M.,Vermeersen, B.L.A., LeBroq, A.M. 2009. Reassessment of the potential sea-level rise from a collapse of the West Antarctic Ice Sheet. Science 324, 901-903.

IMPACTS OF SEA LEVEL RISE IN CARICOM MEMBER STATES

As indicated, there is overwhelming scientific evidence that sea level rise (SLR) associated with climate change projected to occur in the 21st century and beyond, represents a serious and chronic threat to the sustainable management of the coastal zone in CARICOM nations. Adaptations to future sea level rise will often involve revisions to development plans and major investment decisions, which must be based on the best available information about the relative vulnerability of specific coastal areas and the economic and non-market impacts on infrastructure as well as environmental and heritage resources. This report provides the first comprehensive assessment of the consequences of projected SLR for the people and economies of the 15 CARICOM nations.[34]

A Geographic Information System (GIS) was constructed using the best available geospatial data sets to examine the vulnerability of multiple key natural and economic indicators (total land area, population, urban areas, wetland area, agricultural land, major tourism resorts, and transportation infrastructure-airports/roads) to inundation from scenarios of 1 through 6 meters of SLR and storm surge in each CARICOM nation (at 1m intervals). While there remains considerable uncertainty related to the magnitude and timing of both climate change and SLR, the previous discussion indicated that the most recent studies on SLR project a range of 1-2m over the 21st century. The impacts of both a 1m and 2m SLR scenario are discussed in detail below. To examine vulnerabilities associated with the combination of SLR and storm surge, the potential impact of a 3m storm surge (recorded in several parts of the Caribbean during category 4-5 hurricanes) superimposed on a 2m SLR is also discussed. The impact of greater SLR and storm surge (3m to 6m) associated with long-term equilibrium response of sea levels to climate change under higher GHG emissions is also explored below

The analysis revealed that the impacts of SLR would not be uniform among the CARICOM nations, with some projected to experience severe impacts from even a 1 m SLR. The differential vulnerability can be largely explained by the geophysical characteristics of the islands and their different coastal topographic settings, which are briefly summarized below and in Table 3. The CARICOM countries can be broadly categorized into four groups in terms of their relative vulnerability to coastal flooding. The first group are the small islands and cays, largely comprised of coral reefs: The Bahamas, most of The Grenadines, Barbuda and a few small islands lying offshore other areas. These islands, lying mostly below 10m, are highly vulnerable to sea level rise and hurricane storm surge. They will likely experience periodic flooding, erosion and retreat of mangroves and seagrass beds together with saltwater intrusion into the small lenses of fresh groundwater upon which they frequently depend. Additional biophysical impacts will very likely be experienced from other climate change drivers such as ocean acidification, increased coastal water temperatures and changes to currents and wave climates.

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[34] To ensure comparability of SLR vulnerability results between the CARICOM nations and developing nations in other regions, some of the impact indicators selected for this study were common to a previous study by the World Bank (Dasgupta et al. 2007), which examined 84 developing nations, including six CARICOM nations. The results for the six CARICOM nations included in the World Bank study and this analysis were highly consistent for all common indicators (±2%).

Table 3: Summary of the vulnerability of islands with different topographical characteristics

Topographic Setting	Key Vulnerabilities	CARICOM Members
Coastal plain below 10m and low lying islands	1.Flooding from storms and tsunamis 2.Inundation from high tidal levels 3.Salt water penetration of ground water reservoir	Guyana, Suriname, Belize, Jamaica (locally), Haiti (locally), Barbuda, Bahamas
Coastal mangrove swamp	1.Erosion by storms 2.Erosion by waves during high tides	Guyana, Suriname, Belize, localised areas in other countries, e.g. Antigua, Barbados, Trinidad
Coastal dunes	1.Erosion by storms and tsunamis	Bahamas, Barbuda
Coral reefs	1.Erosion by storms and tsunamis 2.Bleaching	Bahamas, The Grenadines, local areas in Barbados, St. Lucia, The Grenadines, Belize
Volcanic island coasts	1.Beach erosion 2.Landslides (locally)	Dominica, Grenada, St. Kitts and Nevis, St. Lucia, St. Vincent, Montserrat

The second group are the mainly volcanic islands of St. Christopher and Nevis, St. Lucia, St. Vincent, Grenada, Dominica and Montserrat. These islands, with only narrow coastal areas, are vulnerable to beach erosion and local coastal landslides. In some, mangroves and seagrass beds are also threatened. Here, it can be seen that coastal roads are vulnerable, as well as homes and industry, especially the tourism industry. Saltwater intrusion is less of a problem in this group, but isolated areas of mangroves and seagrass beds are vulnerable, as are coral reefs. These islands, being tectonically active, may be experiencing land movement, which could mitigate against or exacerbate sea level rise.

The third group of countries are those where there are large coastal plains lying close to sea level, exemplified by Belize, Guyana and Suriname. These are highly vulnerable to sea level rise. In the case of Belize, hurricanes are also of great concern; less so in the case of Guyana and Suriname, although other storms may affect all three countries. Saltwater penetration of the groundwater reservoirs is of concern in Guyana and Suriname. Mangroves are more extensive in these areas than in other CARICOM countries, and deterioration in these will lead to accelerated coastal erosion.

The final group of CARICOM countries are Antigua, Barbados, Haiti, Jamaica and Trinidad and Tobago. The coastlines of these countries are varied and include both steep, sometimes volcanic coastlines and coastal plains, sometimes with mangroves and seagrass beds to seaward. Flooding of the coastal plains due to sea level rise is a considerable threat, as is coastal erosion and flooding from storms (including hurricanes in the case of Antigua, Barbados, Haiti and Jamaica, and tropical storms in all areas). These areas are tectonically active, and as with the volcanic islands this may cause rises or falls in land level, which would alter SLR projections slightly.

A summary of impacts from a 1m SLR is provided in Table 4. The total land area inundated by 1m SLR is just over 2,700 km^2. The market price of undeveloped land varies significantly by location and country, but based on an average market price for a hectare of undeveloped land just inland from the coast in four Caribbean nations[35], then the value of inundated land at 1m SLR would be just over US $70 billion. The value of developed lands would be much greater. The Bahamas was found to be the most vulnerable nation in terms of loss of total land area (10%).

A 1m SLR would displace an estimated 115,000 people in the CARICOM nations. The estimated cost to rebuild housing, roads and basic services (water, electricity)[36] for this displaced population would be approximately US $1.8 billion. Suriname has the highest percentage of national population affected (8%) because of greater impacts on urban areas (4% inundated). Other nations with substantive populations affected by a 1m SLR include The Bahamas (5%), Guyana (3%), and Belize (3%). A list of major urban settlements that would be most affected by SLR and storm surge (1 through 6m) is provided in Figure 5. Figures 6 and 7 illustrate the progressive vulnerability of Belize City (Belize) and Montego Bay (Jamaica) to increased SLR (areas flooded by each increment of SLR are shown).

These same four nations were also the most economically vulnerable to 1m SLR, with estimated annual GDP (at 2008 levels) losses (or in need of relocation) of 6% in Suriname, 5% in The Bahamas, 3% in Guyana, and 3% in Belize. This translates into GDP losses of over US $840 million annually in these four nations alone and approximately US $1.2 billion for the CARICOM nations (or just over 1% GDP).

The geospatial indicator of GDP relates to location of economic activity. It does not account for the damage and replacement costs of infrastructure required to generate that economic activity or the costs of infrastructure associated with the relocation of displaced populations (discussed above). Further analysis of two pillars of the economy in most CARICOM nations, tourism and agriculture, revealed additional key vulnerabilities for some nations. Considering its very close proximity to the coast, it is not surprising that tourism was by far the more vulnerable major economic sector. This is a key finding, as tourism is a major part of the economies of Caribbean nations and this sector has been overlooked in most previous assessments of the impacts of SLR on national economies. The World Travel and Tourism Council (WTTC)[37] estimates that tourism represents 14.8% of GDP and 12.9% of employment (approximately 2 million jobs) in the Caribbean, and the importance of tourism for individual island economies can be much higher (GDP in 2002[38]: Antigua and Barbuda 72%, St. Lucia 51%, The Bahamas 46%, Barbados 37%, St. Vincent and the Grenadines 29%, Jamaica 27%, St. Kitts and Nevis 25%, Belize and Grenada 23%,

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[35] The average market value of US $250,000 was established for land in four CARICOM nations in 2000 by World Bank (2002).

[36] This calculation assumes replacement cost of US $30,000 for a four-person home and the replacement of service at an average cost of US $8,173 per person. Both estimates are based on average regional replacement costs in 2000, as quoted in World Bank (2002).

[37] WTTC (2008) WTTC Supports CARICOM Prioritization on Tourism. PRNewwire 13 March 2008. www.hispanicprwire.com/news.php?l=in&id=10940.

[38] World Resources Institute. www.wri.org/publication/content/7863.

Dominica 22%). The percentage of major resorts at risk to 1m SLR was highest in Guyana (50%), Belize (33%), Trinidad and Tobago (15%), Antigua and Barbuda (9%) and The Bahamas (9%). Figure 8 illustrates the vulnerability of a series of major resorts near Montego Bay, Jamaica. A total of 16 multi-million dollar resort developments were at risk. The replacement cost of these resorts is estimated at slightly over US $1 billion.[39] The permanent or temporary loss and relocation of these major resorts would affect the livelihoods of thousands of employees. Because of the coarse resolution of geospatial data available, this study was not able to account for the significant loss of beach area in all CARICOM nations. Beaches are critical assets for tourism and more research is needed to quantify the economic impact associated with their accelerated erosion and almost certain loss that would arise with even limited SLR. Figure 14 (Sandy Lane, Barbados) illustrates a higher resolution coastal surveying technique that is capable of assessing the vulnerability of beach areas that are key to tourism.

Also of importance to tourism, but also the wider economy in each nation, is the vulnerability of key transportation infrastructure. SLR of 1m inundated a total of 11 out of 105 airports, with a reconstruction cost of approximately US $715 million.[40] The vulnerability of airports was highest in Jamaica and The Bahamas. For example, Figure 7 illustrates the vulnerability of the Montego Bay airport, one of the newest in the CARICOM nations, to SLR of 1 to 2m. Port facilities were more vulnerable, with the land area surrounding 14 of 50 ports inundated by 1m SLR. The relocation and replacement cost of this key infrastructure is estimated at US $320 million.[41] Road networks were at greatest risk in Guyana (6%), Suriname (4%), and The Bahamas (2%). A total reconstruction cost to replace inundated roads in the CARICOM nations under 1m SLR exceeds US $178 million.[42]

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39 Replacement construction costs of a mid-specification resort is estimated at US $80,000 per room (as quoted in Fish et al. 2008) and the average size of the 16 lost resorts was 750 rooms (US $60 million per resort). Interviews with major civil engineering firms that operate in the Caribbean found that the rebuild cost on a mid-range resort complex (accommodations and typical associated infrastructure) is approximately US $103 million for a 275,000 sq foot resort (approximately 200 rooms). An estimate of US $100 million per resort was used, even though some of the resorts at risk were much larger than 200 rooms.
Fish, M.R., Côté, I.M., Horrocks, J.A., Mulligan, B., Watkinson, A.R., Jones, A.P. 2008. Construction setback regulations and sea-level rise: mitigating sea turtle nesting beach loss. Ocean and Coastal Management 51, 330-341.

40 Interviews with civil engineering firms operating in the Caribbean region revealed that airports the size of those recently built at St Kitts and Hato, Curacao are approximately US $65 million (US $45 million for terminal and fittings and US $20 million for asphalt international standard runway with lighting and control structures).

41 Interviews with civil engineering firms operating in the Caribbean region revealed that sea ports similar to the average size of those constructed within the last 10 -15 years are approximately US $20 million, although the range varies widely depending on size.

42 The estimate of average construction cost of a 2 lane paved road (US $866,000) was obtained from: http://siteresources.worldbank.org/INTROADSHIGHWAYS/Resources/338993-1122496826968/kmcosts.pdf and further confirmed by construction engineers in the Caribbean.

Table 4: Impacts of a 1m Sea Level Rise in CARICOM Nations

	Land Area	Population (2010 est.)	Urban Area	Wetland Area	Agricultural Land	Crop and Plantation Land	Major Tourism Resorts	Airports	Road Network	GDP (2008 est.)
Antigua & Barbuda	1%	2%	1%	*	1%	0%	9%	0%	1%	2%
Barbados	0%	0%	0%	*	0%	0%	6%	0%	0%	<0.1%
Belize	1%	3%	1%	17%	1%	0%	33%	0%	0%	3%
Dominica	0%	0%	0%	*	0%	0%	0%	0%	0%	0.1%
Grenada	0%	0%	0%	*	0%	0%	0%	0%	0%	<0.1%
Guyana	0%	3%	8%	1%	1%	0%	50%	0%	6%	3%
Haiti	0%	0%	0%	1%	0%	0%	0%	0%	0%	0.1%
Jamaica	1%	1%	0%	22%	2%	2%	4%	20%	1%	1%
Montserrat	0%	0%	0%	*	0%	0%	0%	0%	0%	0.1%
St. Kitts & Nevis	0%	0%	0%	*	0%	0%	0%	0%	0%	0.1%
St. Lucia	0%	0%	0%	*	0%	0%	0%	0%	0%	0.1%
St. Vincent & the Grenadines	0%	0%	0%	*	0%	0%	0%	0%	0%	0.1%
Suriname	0%	8%	4%	1%	4%	0%	0%	0%	4%	7%
The Bahamas	10%	4%	3%	15%	3%	2%	9%	13%	2%	5%
Trinidad & Tobago	0%	0%	0%	0%	0%	0%	15%	0%	0%	0.3%

* Due to the small scale of wetland areas and course scale of geospatial data, these nations had no areas classified as wetlands.

Table 5: Impacts of a 2m Sea Level Rise in CARICOM Nations

	Land Area	Population (2010 est.)	Urban Area	Wetland Area	Agricultural Land	Crop and Plantation Land	Major Tourism Resorts	Airports	Road Network	GDP (2008 est.)
Antigua & Barbuda	2%	3%	2%	*	1%	1%	27%	0%	1%	3%
Barbados	0%	0%	0%	*	0%	0%	6%	0%	0%	0%
Belize	3%	6%	4%	40%	3%	2%	33%	0%	1%	5%
Dominica	0%	0%	0%	*	0%	0%	0%	0%	0%	0%
Grenada	0%	0%	0%	*	0%	0%	0%	0%	0%	0%
Guyana	1%	8%	21%	3%	2%	0%	50%	0%	15%	8%
Haiti	0%	0%	1%	3%	0%	0%	0%	0%	0%	0%
Jamaica	2%	1%	1%	26%	3%	3%	4%	20%	1%	1%
Montserrat	0%	0%	0%	*	0%	0%	0%	0%	0%	0%
St. Kitts & Nevis	0%	0%	0%	*	0%	0%	14%	0%	0%	0%
St. Lucia	0%	0%	0%	*	0%	0%	0%	0%	0%	0%
St. Vincent & the Grenadines	0%	0%	0%	*	0%	0%	0%	0%	0%	0%
Suriname	1%	17%	9%	4%	9%	0%	0%	50%	9%	13%
The Bahamas	17%	8%	7%	23%	7%	6%	11%	25%	5%	8%
Trinidad & Tobago	1%	1%	1%	0%	2%	0%	15%	0%	0%	1%

* Due to the small scale of wetland areas and course scale of geospatial data, these nations had no areas classified as wetlands.

Figure 5: Most Vulnerable CARICOM Cities to SLR and Storm Surge (top 15 only)

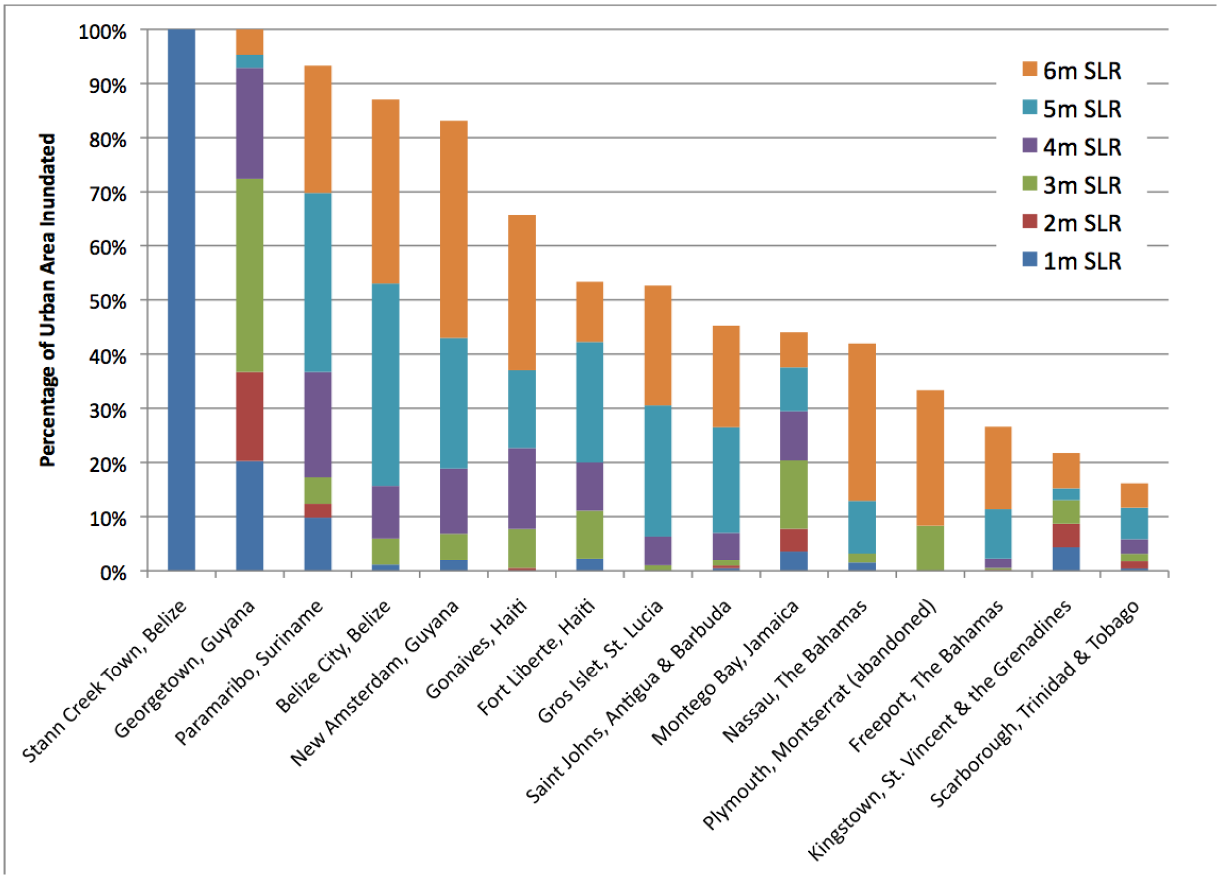


Figure 6: Vulnerability of Belize City, Belize to SLR and Storm Surge (1 to 6m)

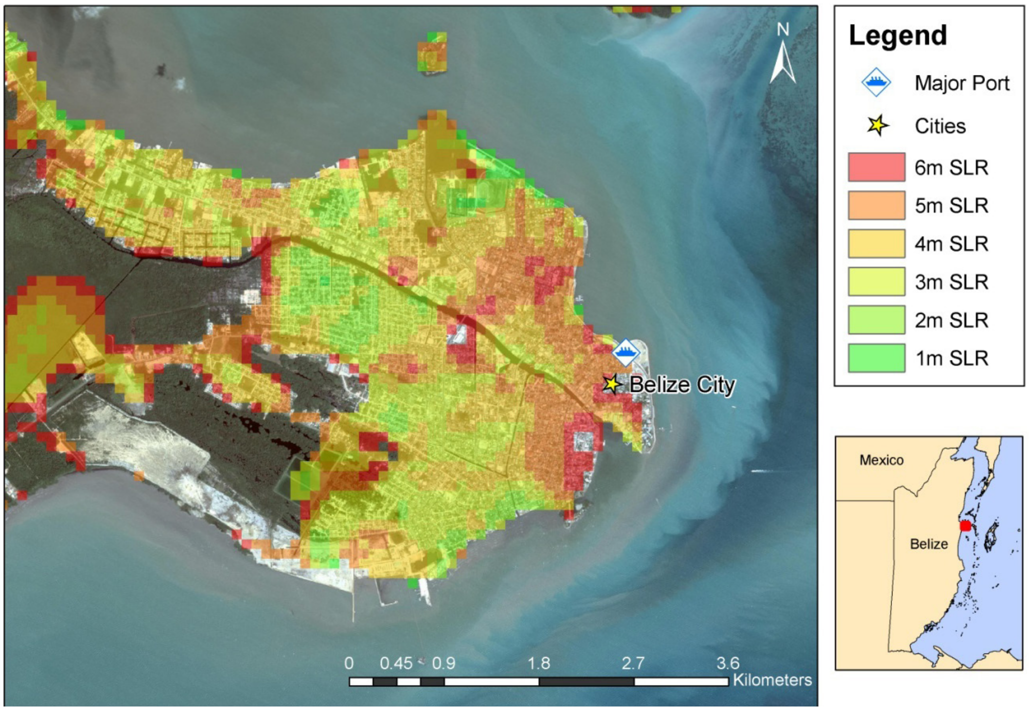


Figure 7: Vulnerability of Montego Bay, Jamaica to SLR and Storm Surge (1-6m)

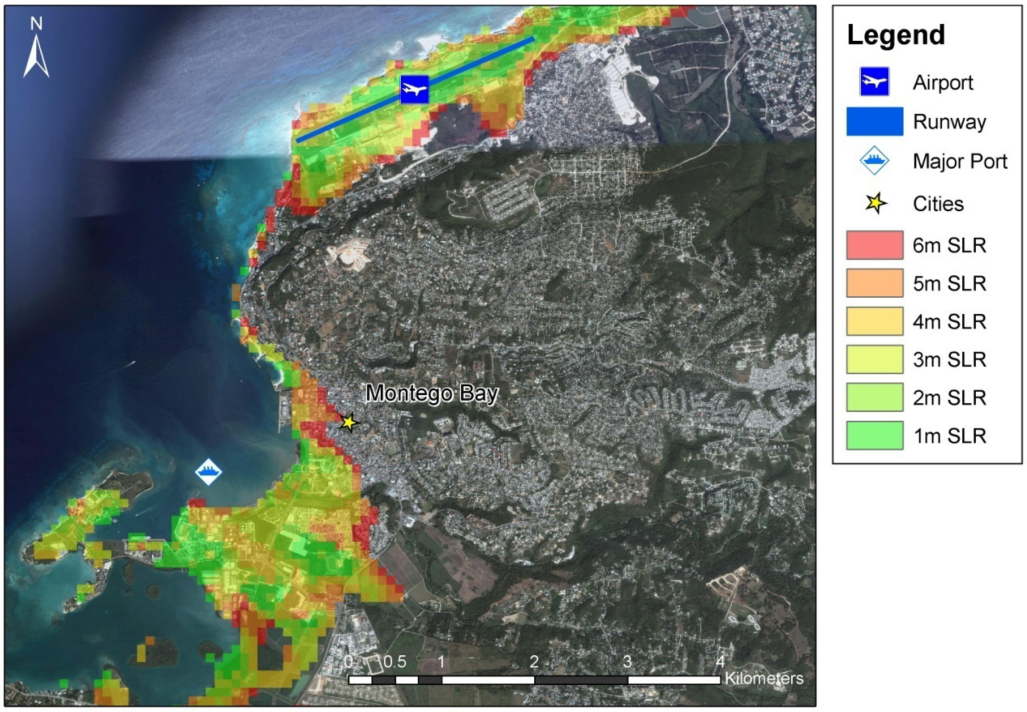
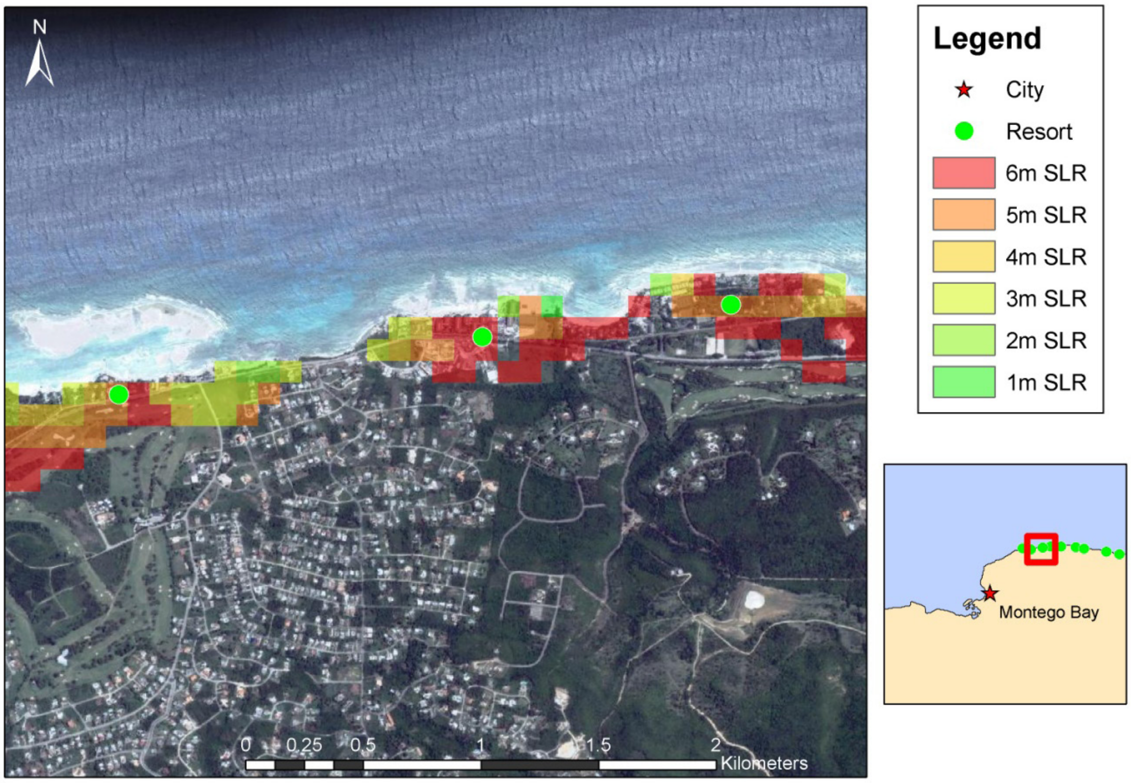


Figure 8: Vulnerability of Major Tourism Resorts near Montego Bay, Jamaica to SLR and Storm Surge (1-6m)



In summary, conservative estimates of the economic costs of known 1m SLR impacts in CARICOM nations would be US $1.2 billion per year in GDP, permanently lost land value of US $70 billion, and US $4.6 billion in relocation/reconstruction costs. These figures are based on SLR scientific evidence and do not include other major economic impacts, such as losses in agricultural production, costs of changing energy needs, increased storm or hurricane damage and related insurance costs, necessary water supply construction, increased health care costs, or any non-market value impacts.

Agriculture was found to be less vulnerable than the tourism industry, however the estimated impact of 1m SLR is still important for food supply and livelihoods. Estimated total agricultural land loss was highest in Suriname (4%), The Bahamas (3%) and Jamaica (2%), however the loss of crop and plantation lands (the highest value agricultural lands) was highest in Jamaica (3%) and The Bahamas (2%).

SLR also represents a poorly understood threat to natural areas and biodiversity in the region. The area of wetlands inundated by a 1m SLR was highest in Jamaica (22%), Belize (17%), and The Bahamas (15%). The implications for fisheries and water supply in some communities remain important uncertainties. Because of the coarse resolution of geospatial data, the implications of SLR for wetland habitat in many of the smaller CARICOM nations could not be assessed in this study.

The geographic pattern of impacts among the CARICOM nations was found to remain broadly similar under a 2m SLR scenario, however the magnitude of impacts in the highly vulnerable nations was much more pronounced (Table 2). For example, The Bahamas would be expected to lose 17% of its total land area, have 8% of its population displaced, lose over 10% of its major tourism resorts and 25% of its airports, and suffer annual GDP loses of over 8%. While projected to lose less land area, over 16% of Suriname's population would be displaced at the same time that is loses 9% of its agricultural lands and suffers a GDP loss of over 13%. Guyana and Belize would also need to relocate tens of thousands of people (8% and 6% respectively), while also losing substantive GDP (8% and 5% respectively). For the CARICOM members, the value of lost land (valued as undeveloped land) is estimated at over US $143 billion. The annual GDP loss from inundation by 2m SLR was estimated at US $2.3 billion annually (or roughly 2% GDP). Finally, reconstruction/relocation costs estimates for ports, airports, road network, major tourism resorts, and the relocation of nearly 250,000 displaced persons was estimated at US $8.2 billion.

As indicated, SLR is projected to continue throughout the 22nd century and beyond as the world's ice sheets and oceans continue to respond to warmer average global temperatures. A new equilibrium sea level is not anticipated for centuries. Although the eventual extent of SLR remains highly uncertain, this study has analyzed the implications of a higher range of SLR that might be considered worst-case scenarios for CARICOM nations. In addition, the scenarios also provide a useful analysis of sensitivity to storm surges. The amount of land area (in km^2) lost to inundated by the sea is represented in Figure 9, increasing from approximately 10,00 km^2 under 3m SLR (2% of land area in the analysis) to over 23,00 km^2 (5% of land area in the analysis) under 6m. Much of this land is urban and heavily developed by the tourism industry, transportation and other critical infrastructure. These estimates only account for inundation and do not include land areas lost or degraded by accelerated erosion. Figure 10 reveals the increased displacement of current populations from inundated lands under progressively greater SLR and storm surge (1 to 6m). These estimates do not account for population growth throughout the 21st century and beyond and the proportional displacement would need to be applied to projected population growth to obtain a more accurate representation of total displaced persons in the future. The increased impact of SLR on the combined GDP of the CARICOM member states is represented in Figure 11. The impacts are significant for the region, but are far greater for the most vulnerable nations. For example, at 3m SLR GDP loss in Suriname is 25%, 17% in Guyana, and 12% in The Bahamas. These estimates do not account for economic growth and only represent losses from the estimated GDP in 2008. Figures 12 and 13 illustrate the vulnerability of major transportation infrastructure. The increasing extent of road networks inundated by 1 to 6m SLR and storm surge is displayed in Figure 12. Many major port facilities are threatened at relatively low levels of SLR due to their location and vulnerability of surrounding land areas. The ability of port facilities to operate at higher sea levels was not examined in this analysis. The proportion of airports affected is initially lower, as many are located inland, but over half of airports in CARICOM nations are vulnerable to 5m SLR (or damage from a combination of SLR and storm surge).

Figure 9: Land Area (sq. km) Inundated by SLR and Storm Surge (1-6m)

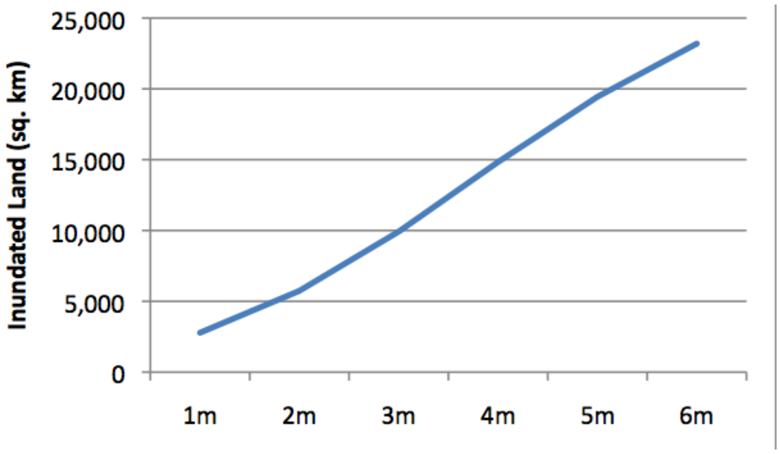


Figure 10: Population Displacement Under SLR and Storm Surge (1-6m)

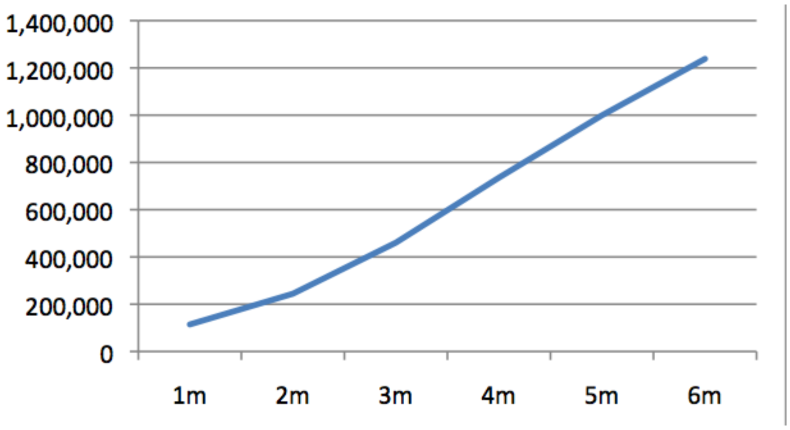


Figure 11: GDP Loss for CARICOM Nations Under SLR and Storm Surge (1-6m)

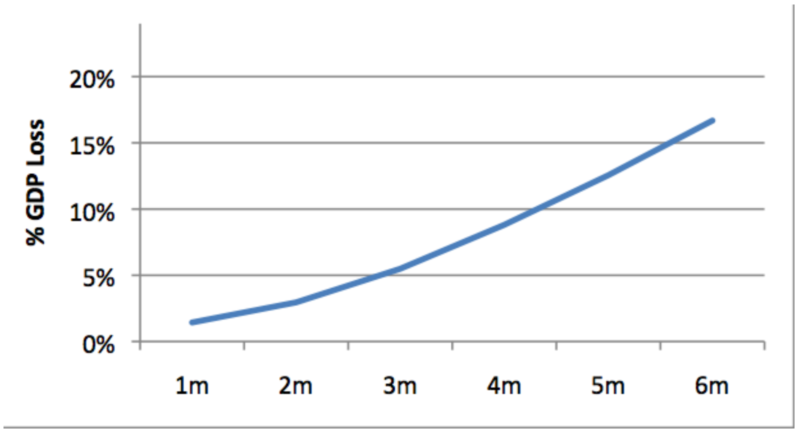


Figure 12: Road Network (km) Loss in CARICOM Nations Under SLR and Storm Surge (1-6m)

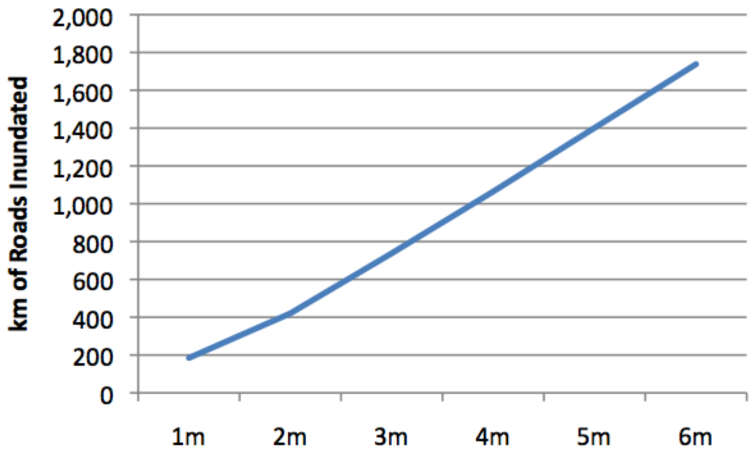
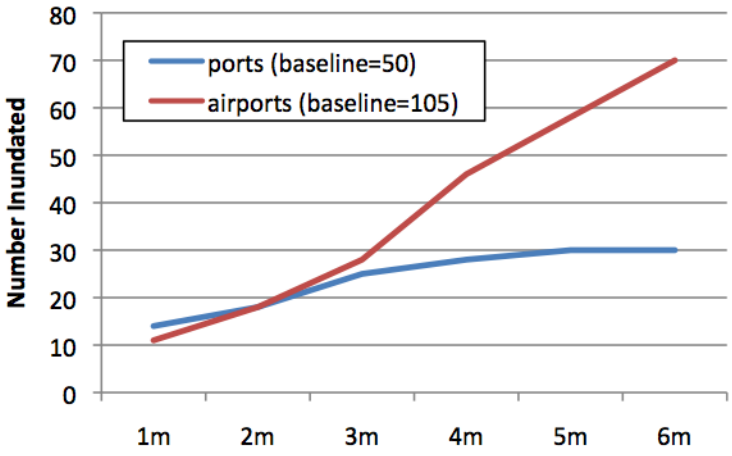


Figure 13: Port* and Airport Facilities Inundated in CARICOM Nations Under SLR and Storm Surge (1-6m)



* Port facilities are generally classified as being located in 'water' grid cells in the GIS and inundation therefore refers to surrounding land areas (within 250m).

As the aforementioned impacts clearly illustrate, mean SLR will have a major influence on the future development of the members of CARICOM. Importantly, major flooding damage and accelerated coastal erosion are associated with the storm surge and waves associated with major storms events. Even if the frequency and intensity of hurricanes remain unchanged under climate change, SLR will increase the frequency that coastal infrastructure is exposed to wave action and flooding. When the combination of a 1m to 2m SLR and storm surge of 3m from a major hurricane was examined, approximately 1 million people in the CARICOM nations were found to be at risk. In three nations, more than 25% of the population would be at risk to such a disaster (Suriname 58%, Guyana 30%, and The Bahamas 29%). Figure 5 identifies the many cities that would be heavily damaged by such an event. In addition, over 50% of the tourism resort infrastructure in the CARICOM nations was also found to be vulnerable to such an event.

This study has revealed highly differential vulnerability to SLR that will cause severe disruptions to the economies of some CARICOM nations, where SLR represents an obvious impediment to sustainable development. As significant as the above impacts are for the CARICOM nations, in particular The Bahamas, Suriname, Guyana and Belize, it is important to stress that these estimates ***must be considered highly conservative for three reasons***. First, this study assumes population and GDP remain fixed at recent levels (estimates for 2010 and 2008 respectively). With growing populations, growing economies and increasingly rapid coastal development, where much economic activity is concentrated, this analysis undoubtedly underestimates the magnitude of future impacts in the CARICOM nations. Second, the coarse resolution of geospatial data available for this region-wide analysis masks the vulnerability of coastal infrastructure, natural areas and people to inundation from SLR in some areas. This is because the averaged elevation for an entire GIS grid cell (90m^2 in this analysis) with varied heights (e.g., a beach with nearby hills) can be sufficient so that the area does not flood under a 1m SLR. Figures 14, 15, and 16 illustrate examples (Sandy Lane, Barbados; Gros Iset, St. Lucia; Harbour Island, The Bahamas) where SLR does not affect the major tourism resort complexes in the coarse scale GIS analysis that used satellite-based Digital Elevation Model data at all or only under scenarios of 6 to 7m of SLR and storm surge. However, high-resolution elevation data obtained from GPS based coastal surveying (completed by the CARIBSAVE Partnership), clearly identifies all three locations would suffer substantial beach area loss under only 0.5m SLR (see the yellow 0.5m SLR line) and resort infrastructure would be affected by SLR of 2m or less (see the green 1m and red 2m SLR lines). In some forested areas, the satellite radar does not penetrate the canopy of the forest and artificially records the land elevation several meters higher than it is. Third, the coarse scale of this analysis precludes consideration of the implications of SLR for accelerated coastal erosion and its subsequent impacts on infrastructure central to the economies of CARICOM nations. For example, the Bruun "Rule" estimates that beach erosion is approximately 100 times the extent of SLR (i.e., the equilibrium response of beach areas to a 1m SLR would be 100m inland retreat). The vulnerability of tourism infrastructure in particular is likely to be highly underestimated, because this infrastructure generally lacks coastal protection common in cities or other infrastructure (ports, airports, fuel bunkers), because of the need to maintain beach area and aesthetics of pristine ocean views. The analysis also does not account for potential adaptation to protect coastal infrastructure and populations. Such adaptation may reduce the impacts projected here, but will require substantial investment and these costs are not accounted for here. Future studies using high resolution Digital Elevation Models and that account for erosion and not just inundation are needed to understand the true threat

SLR poses to the people and economies of CARICOM, as well as to identify the options to adapt to SLR and estimate the costs of such adaptations. Addressing this crucial knowledge gap should be a priority for Official Development Agencies.

Figure 14: A Comparison of SLR and Storm Surge Vulnerability Using both Satellite-based DEM (90m²) and High-Resolution GPS-based Elevation Data (Sandy Lane, Barbados)

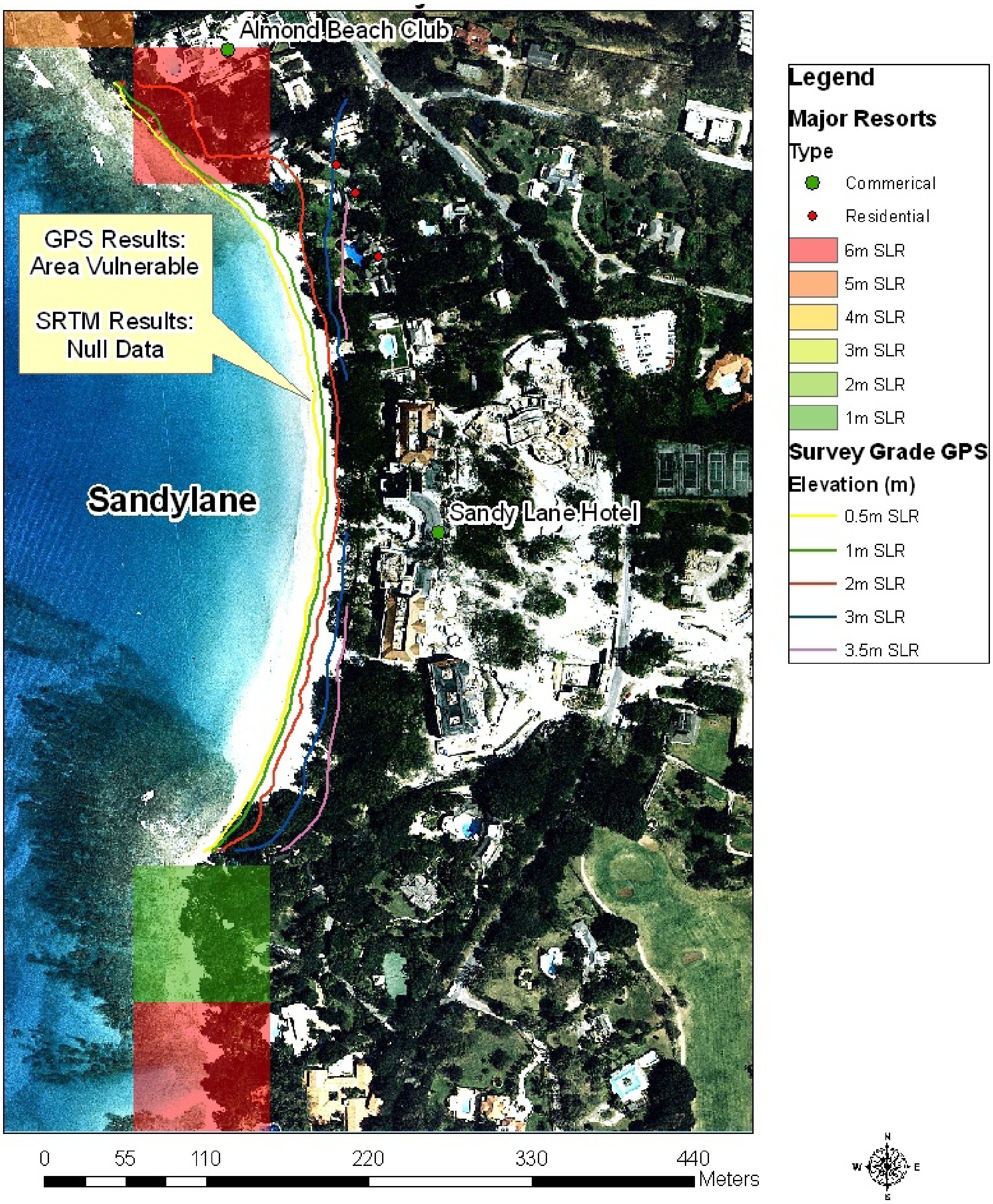


Figure 15: A Comparison of SLR and Storm Surge Vulnerability Using both Satellite-based DEM (90m²) and High-Resolution GPS-based Elevation Data (Gros Iset, St. Lucia)

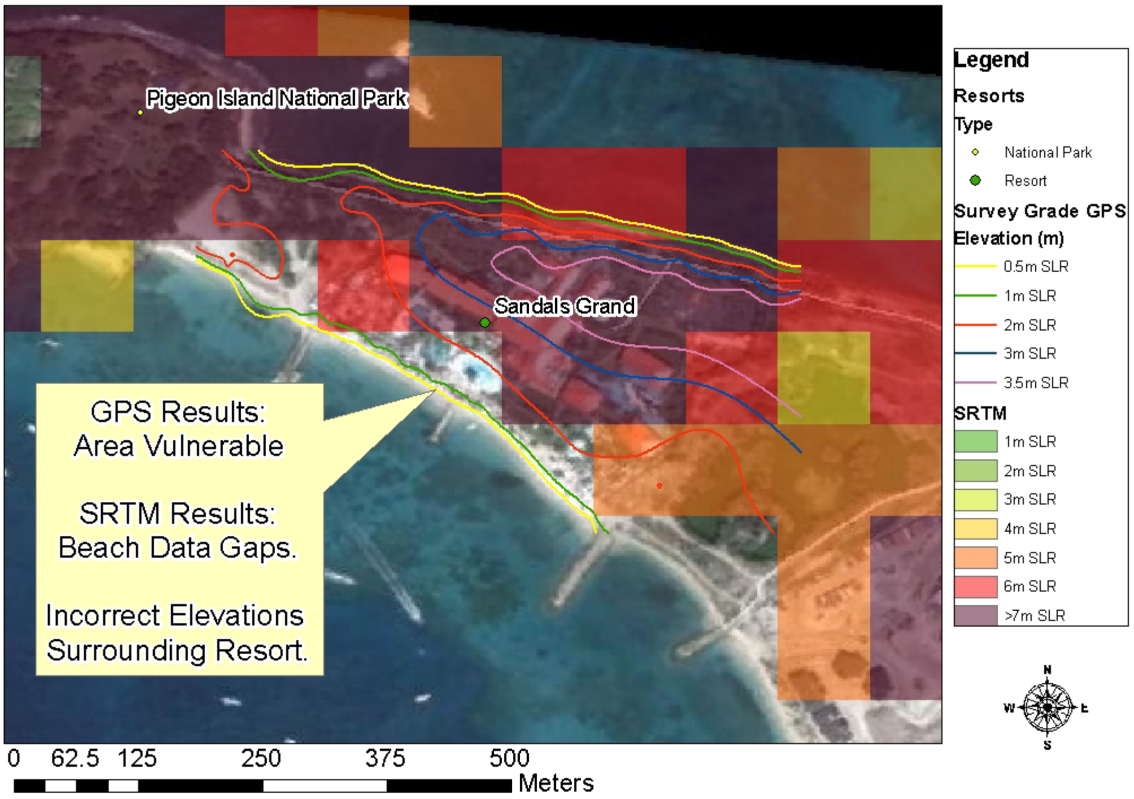
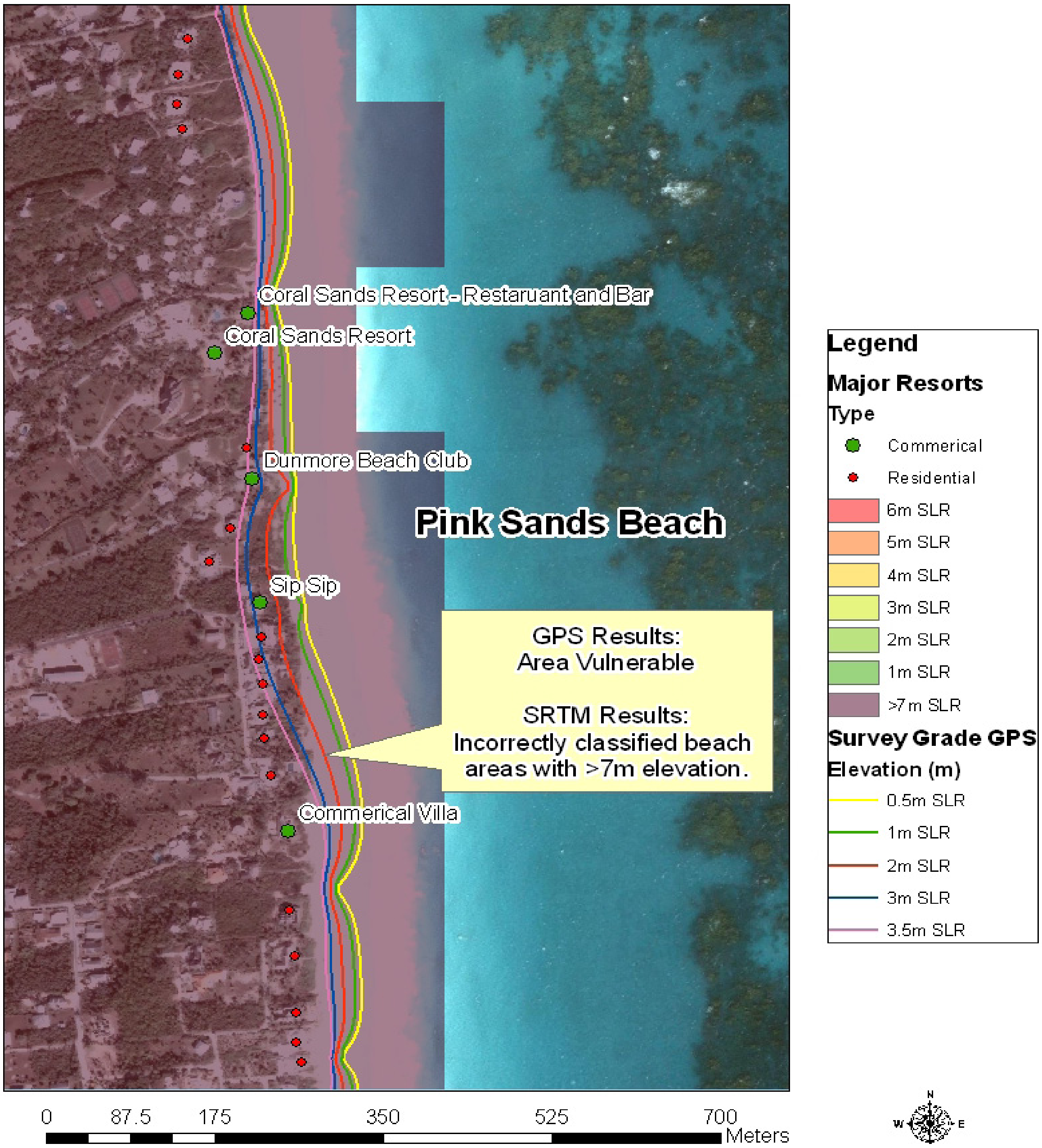


Figure 16: A Comparison of SLR and Storm Surge Vulnerability Using both Satellite-based DEM (90m²) and High-Resolution GPS-based Elevation Data (Harbour Island, The Bahamas)



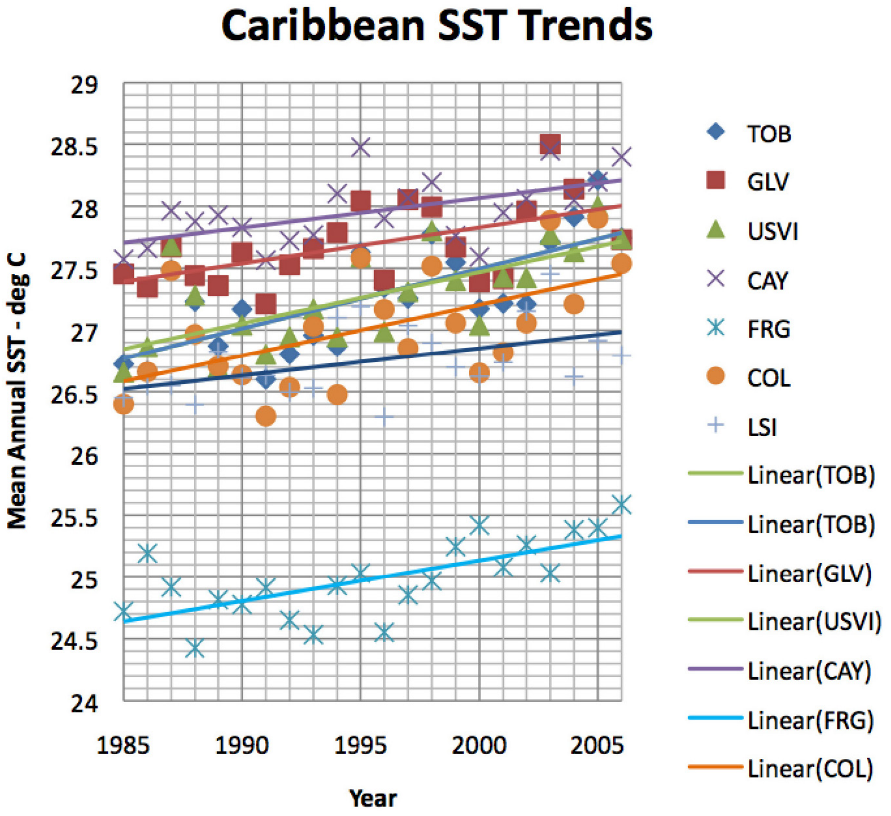
Part 3 – Differential Impacts of 1.5° and 2°C Global Warming in the Caribbean Region

IMPACTS ON CORAL REEFS

In the Caribbean, the three largest impacts of climate change on corals and coral reefs have been and will continue to be coral bleaching, infectious disease outbreaks, and ocean acidification. While many factors have contributed to the recent decline of coral reefs in the Caribbean, there is little doubt that rising temperatures, increased outbreaks of infectious disease related to higher ocean temperatures, and increasing ocean acidification are major contributors to this decline. These additional stress factors also greatly reduce the ability of corals to recover from non-climate disturbances, such as pollution, siltation and over-fishing. Other impacts such as sea level rise and changes in storms, precipitation, and circulation patterns may influence coral reefs but will have much greater impacts on human societies.

The greatest threat of climate change to Caribbean corals arises from the direct impacts of rising sea surface temperatures (SSTs) on coral health. Global ocean surface temperature has risen by 0.74°C, and if the current trend of accelerating global GHG emissions continues, a global ocean surface temperature increase of well over 2.0°C is a distinct possibility. Some tropical ocean areas, including parts of the Caribbean, are now experiencing over 0.4°C warming per decade. Figure 17 shows the rapid warming that has occurred in the last two decades, leading to increasing frequency and intensity of coral bleaching events especially in the Caribbean.

Figure 17: SST time-series of seven representative Caribbean Virtual Stations: 1985-2006.



Coral diseases have been a major factor in the decline of coral reefs in the Caribbean as there has been an increase in coral diseases since the 1970s and has threatened many Caribbean coral species.[43] Summertime thermal stress has been correlated with disease outbreaks even at temperatures below those that cause mass bleaching.

Atmospheric carbon dioxide (CO_2) already has increased by 35% from the pre-industrial level of 280 ppm to 385 ppm in 2008 and this rate is accelerating.[44] As atmospheric CO_2 and its partial pressure in oceanic waters (pCO_2) increases, the pH of ocean waters decreases, commonly described as ocean acidification. This reduces the concentration of the carbonate ions (measured as aragonite saturation state) that many corals use to build their calcium carbonate skeletons. This 'other CO_2 problem' can slow coral growth and retard processes that cement reefs together and can enhance bioerosion.

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[43] Harvell, C., K. Kim, J. Burkholder, R. Colwell, P. Epstein, D. Grimes, E. Hofmann, E. Lipp, A. Osterhaus, R. Overstreet, J. Porter, G. Smith, and G. Vasta. (1999). Emerging marine diseases - climatic links and anthropogenic factors. Science 285: 1505-1510.

[44] Metz, B., O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer [Eds.]. (2007). Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK, Cambridge University Press. 851 p.
CDIAC. (2009). Carbon Dioxide Information Analysis Center. Oak Ridge National Laboratory. Accessed from http://cdiac.ornl.gov/.

Sea level rise is less of a threat to coral reefs than either warming or acidification. Corals and coral reefs are likely to keep up with sea level rise if they remain healthy, but will be challenged in this effort by local pollution and acidification.

Hurricanes have damaged coral reefs for millennia but, in the absence of human disturbance, were previously able to recover.[45] It is uncertain how rising temperatures together with other climatic changes will influence tropical storm frequency (see section 1), but there is some indication that rising temperatures will increase tropical storm intensity.

Analysis of the most recent 22-year record of SSTs in the Caribbean points out that coral reefs are already experiencing rapid temperature increases beyond those to which they may be able to adapt. These rising average SSTs increase the likelihood that temperatures during warm summers will exceed coral's ability for short-term acclimation, and cause bleaching, disease, and death of corals. Such an event occurred from June to October 2005 when warm water persisted for many weeks across the tropical Atlantic and greater Caribbean. Elevated SSTs helped fuel the most active Atlantic hurricane season on record and caused the most severe and extensive mass coral bleaching observed in the Caribbean. Many areas exhibited over 90% bleaching and over 50% mortality. No sign of recovery has been seen on affected reefs.[46]

For the parameters of climate change that are affecting coral reefs, two can be reasonably quantified to differentiate impacts under 1.5° and 2.0°C globally averaged warming scenarios: coral bleaching due to thermal stress and ocean acidification. There is strong evidence that rising temperatures will result in more infectious diseases in corals, but we cannot predict these with sufficient accuracy to compare the extent of the disease outbreaks in the two global temperature regimes.

Several recent studies have used observations of mass coral bleaching, like the 2005 Caribbean event, and climate model simulations to evaluate the expected frequency and severity of coral bleaching under different future climate scenarios.[47] In these studies, the SSTs simulated by the climate model are tested against observations and used to calculate metrics of the heat stress likely to be experienced by corals. These studies conclude that within two to five decades Caribbean coral reefs will experience conditions that currently cause severe coral bleaching once every two years. One study evaluated the probability of the warming sufficient to cause a repeat of the 2005

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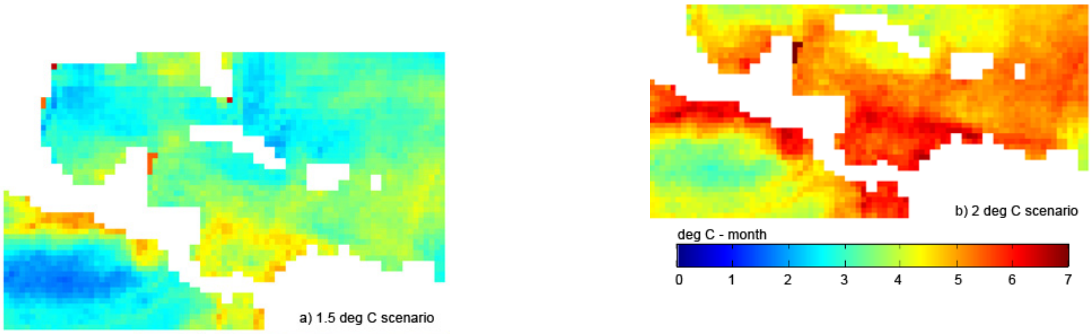
[45] Nystrom, M., C. Folke, and F. Moberg. (2000). Coral reef disturbance and resilience in a human-dominated environment. Trends in Ecology & Evolution 15: 413-417.

[46] Miller, J., E. Muller, C. Rogers, R. Waara, A. Atkinson, K. Whelan, M. Patterson, and B. Witcher. (2009). Coral disease following massive bleaching in 2005 causes 60% decline in coral cover on reefs in the US Virgin Islands. Coral Reefs 28(4): 925-937.

[47] Hoegh-Guldberg, O. (1999). Climate change, coral bleaching and the future of the world's coral reefs. Marine and Freshwater Research 50: 839-866.
Sheppard, C.R.C. (2003). Predicted recurrence of coral mass mortality in the Indian Ocean. Nature 425: 294-297.
Donner, S.D. (2009). Coping with commitment: Projected thermal stress on coral reefs under different future scenarios. PLoS ONE 4(6): e5712.
Donner, S.D., T.R. Knutson, and M. Oppenheimer. (2007). Model-based assessment of the role of human-induced climate change in the 2005 Caribbean coral bleaching event. Proceedings of the National Academy of Sciences 104(13): 5483-5488.
Donner, S.D., W.J. Skirving, C.M. Little, M. Oppenheimer, and O. Hoegh-Guldberg. (2005). Global assessment of coral bleaching and required rates of adaptation under climate change. Global Change Biology 11(12): 2251-2265.

Caribbean bleaching event.[48] It concluded that climate change increased the probability of the 2005 event from one in one thousand years to less than one in one hundred years. The study also found that within 20 to 30 years the probability will be one in two years. Figure 18 shows the difference between the 1.5° and 2°C warming scenarios.

Figure 18: Mean annual degree heating month (DHM, in deg C - month) for the Caribbean region under the (a) 1.5°C global warming scenario and (b) 2.0°C global warming scenario. DHM>1 indicates significant bleaching; DHM>2 indicates widespread bleaching and significant mortality.



Whether future coral bleaching thresholds will remain at current levels or corals adapt to warmer temperatures will depend on a variety of biological dynamics and management efforts that influence the potential for acclimatization and adaptation top higher temperatures of corals and the symbiotic algae (zooxanthellae) that live in their tissues. Most Caribbean coral reefs will need to adapt to 0.2 to 0.3°C per decade over the next 30 to 50 years to prevent bleaching more than once every five years. An estimate of the thermal flexibility of common coral species through a variety of possible mechanisms suggests that they may be able to adapt to at most a 1.5°C SST warming.[49] This indicates that it is important for Caribbean coral reefs to avoid SST warming more than 1.5°C. Assuming a 1.5°C adaptation threshold, and the "business-as-usual" emissions scenario, mass coral bleaching of the level observed in 2005 would become a once in five year event around the 2070s; in a lower emissions scenario, mass one-in-five coral bleaching would be pushed off to the latter half of the 22nd century.

At the same time as thermal stress affects Caribbean corals, increasing atmospheric CO_2 will be acidifying the

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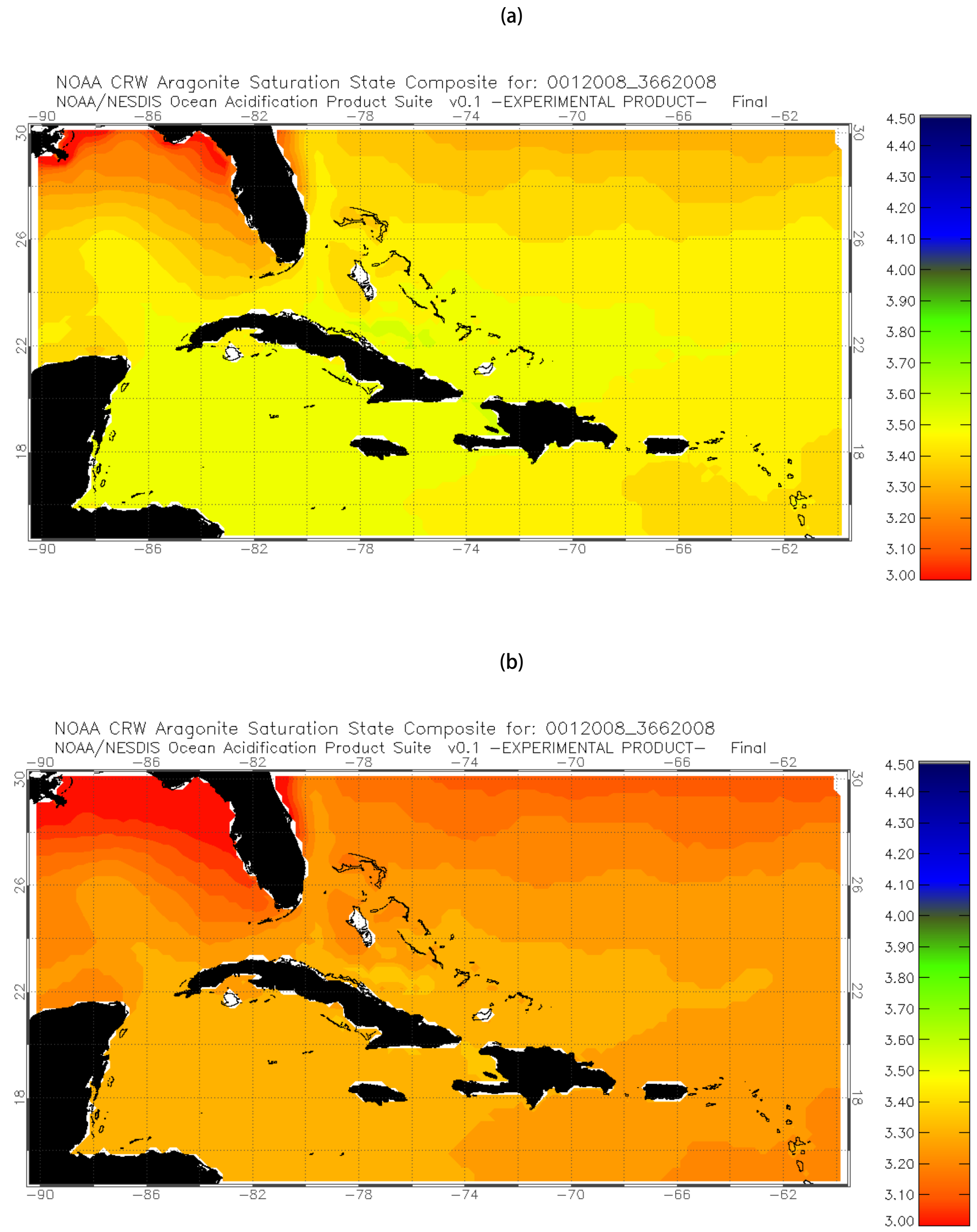
[48] Donner, S.D., T.R. Knutson, and M. Oppenheimer. (2007). Model-based assessment of the role of human-induced climate change in the 2005 Caribbean coral bleaching event. Proceedings of the National Academy of Sciences 104(13): 5483-5488.

[49] Berkelmans, R., and M.J.H. van Oppen. (2006). The role of zooxanthellae in the thermal tolerance of corals: a nugget of hope for coral reefs in an era of climate change. Proceedings of the Royal Society B: Biological Sciences 273(1599): 2305-2312.
Middlebrook, R., O. Hoegh-Guldberg, and W. Leggat. (2008). The effect of thermal history on the susceptibility of reef-building corals to thermal stress. Journal of Experimental Biology 211(7): 1050-1056.

surface waters and slowing the growth of corals and coral reefs. While global temperatures lag significantly behind changes in atmospheric CO_2, ocean acidification does not (equilibrium is reached within one year). Therefore, we must consider carbonate chemistry under two different sets of scenarios: the CO_2 at which we achieve equilibrium between temperatures and stabilized CO_2 for both 1.5° and 2.0°C globally-averaged warming scenarios (350 ppm and 450 ppm respectively), and also the peak CO_2-levels through which we are likely to transit upon reaching 1.5° and 2.0°C (490 ppm and 550 ppm, respectively) during the 21st century. If we can revert atmospheric CO_2 concentrations back to 350 ppm (which was surpassed in the 1980s), the average aragonite saturation state across the Caribbean would remain at levels generally considered to be adequate for coral reef growth (3.5-4.5). However, achieving this stabilization would still include a transition period within which saturation states would decline between 20 to 25% relative to pre-industrial values (pre-industrial saturation state was approximately 4.7) before returning to conditions better than today. In contrast, stabilizing at 2.0°C would require transiting through a period when CO_2 reaches around 550 ppm and saturation states decline by more than 30% relative to pre-industrial values, making it challenging for coral reefs to maintain net growth in light of natural erosion and dissolution. Figure 19 shows the carbonate saturation states in the 21st century when 1.5°C / 490 ppm and 2.0°C / 550 ppm conditions are reached. Once atmospheric levels drop back to 450 ppm the saturation state levels would recover to values greater than 3.6 – a level considered adequate to sustain reef growth. However, the longer CO_2 remain above 450 ppm at these high levels, the greater the damage to reefs. This clearly supports the need to dramatically reduce GHG emissions as soon as practicable prevent a temperature rise of more than 1.5°C.

Figure 19: Map showing annual mean aragonite saturation state values during the 21st century decade when globally averaged atmospheric temperatures reach (a) 1.5°C above the pre-industrial value (and estimated 490 ppm CO_2), and (b) 2.0°C above the pre-industrial value (and estimated 550 ppm CO_2). These correspond to the atmospheric CO_2 conditions in the 21st century decades in which the conditions in Figure 4 are reached. Note that saturation state > 4.5 is considered optimal for coral growth, 3.5-4.5 is adequate, and below 3.0 erosion is likely to exceed reef growth.



Taken together, the studies to date indicate that an increase in thermal stress and slowed coral growth on Caribbean coral reefs in the next 20 to 30 years is inevitable because of “committed” warming and the time required to eliminate emissions. During this time, management interventions that reduce non-climatic stressors (e.g. pollution, siltation, over-fishing) could play a big part in increasing the survival and recovery of corals after bleaching events and in improving their ability to adapt to warmer conditions. It is essential that we recognize that improved management and adaptation are only ways for corals to survive extinction while we work to stabilize atmospheric CO_2 and reduce it to a safe level.

In summary, two sets of actions are required for the continued survival of Caribbean coral reefs: (1) rapid reduction of CO_2 emissions and eventual reduction of atmospheric CO_2 level to 350 ppm, and (2) management actions to help corals survive long enough for our actions to stabilize the climate system. If the global temperature increase exceeds 1.5°C above pre-industrial levels, it is highly unlikely that adaptation through natural biological mechanisms and management will be sufficient to avoid severe degradation of Caribbean coral reefs from frequent bleaching events. More importantly, most known mechanisms that help corals adapt to warming also slow coral growth, making the problems caused by acidification even more severe. All of these impacts will be even more severe at 2.0°C.

IMPACTS ON WATER RESOURCES

The IPCC Fourth Assessment Report (AR4), projects global mean precipitation to increase by around 4 to 5%, but finds overall decreases over many sub-tropical areas (including tropical Central America and the Caribbean). The Caribbean region is projected to have a decline in the level of precipitation across all SRES scenarios (B1, A1B and A2) and at the 1.5° and 2.0°C global mean temperature thresholds (see section 1). For those CARICOM states that already face issues of water insecurity, climate change is likely to increase the severity of water resource problems. For states that currently have sufficient water resources, a decline in precipitation, particularly in dry seasons, may introduce new water resources issues. In addition, the Caribbean is projected to experience shorter wet seasons. The largest projected changes across the whole region are for the generally wet months of June to August. Between March and May, the largest decreases are projected for the north and west of the Caribbean region, with smaller mean precipitation changes and greater uncertainty in the south. Between September and November, this situation is reversed with the larger decreases projected for the southeast of the region, and smaller changes and greatest uncertainty elsewhere.

The greatest declines in precipitation are projected with the higher levels of average warming in scenario A2 (3.4°C by 2080-2099), compared to scenarios B1 (1.8°C) or A1B (2.8°C). Across all CARICOM states, projected changes to total annual precipitation ranges from +1.9% to -15.8% for the B1 scenario, -2.9% to -27% for the A1B, and -6.9% to -33.8% for the A2 scenario. The average projected changes in CARICOM states are -7.0%, -14.3% and -21.3% for the B1, A1B and A2 scenarios, respectively. When GCMs reach the threshold global mean temperature rises of 1.5°C the average projected change in precipitation across all CARICOM states is small at -0.4% (range: -27.2% to +34.1%);

for 2.0°C, the average projected change is -1.8% (range: -32.0% to +37.4%). For several nations (The Bahamas, Barbados, Belize, Dominica and Grenada), there is an average projected increase in precipitation levels at 1.5 and 2.0°C; these changes revert to a decline in precipitation by 2080-2099 under B1, A1B and A2 scenarios. In addition, when precipitation occurs it is likely to be more concentrated in shorter duration, intense rainfall events which are interspersed with longer periods of dry conditions.

A reduction in precipitation for CARICOM states will reduce both the available surface water reserves and the level of groundwater recharge. These declines in precipitation would lead to an increase in the risk of periods of drought for the Caribbean region, which are likely to occur more frequently and be more severe. Antigua and Barbuda, The Bahamas, Barbados, Dominica, St. Kitts and Nevis and St. Lucia have already experienced severe drought conditions. Countries that have a high dependency on surface water (particularly Dominica, Grenada, St. Kitts and Nevis, St. Lucia and St. Vincent and the Grenadines) but which do not have sufficient water storage would be less able to cope with interspersed rainfall conditions. In addition to a decline in overall precipitation levels reducing the overall amount of groundwater recharge, short bursts of intensive rainfall would lead to a greater proportion of rainfall being lost through surface runoff and a subsequent further reduction in the amount of recharge. Reduced groundwater recharge would lead to a reduction in the amount of available water within aquifers, reduce the ability of states to cope with periods of drought and increased the risk of saltwater intrusion to aquifers, particularly those close to the coast. In addition, declining precipitation will reduce the capability of states to generate electricity through hydropower.

A change to drier conditions may alter the vegetation characteristics in countries leaving a greater proportion of soil exposed to erosion. Increased soil erosion would lead to increased runoff in catchments, which in turn would lead to less infiltration and a reduction in groundwater recharge. There are several reported cases where hurricanes have caused the loss of topsoil, erosion of gullies and damage to vegetation (e.g. Antigua and Barbuda, Dominica), and a subsequent reduction in water resource availability. In addition, changes in evapotranspiration (evaporation and plant transpiration) due to higher temperatures could lead to substantial reductions in rainfall. Evapotranspiration can account for around 60% of precipitation in some Caribbean states.

Sea-level rise will increase the risk of saltwater intrusion into coastal aquifers, particularly those that are already at risk from over abstraction. Research[50] has shown that as little as a 0.1m rise in sea level can substantially reduce the availability of fresh water in coastal aquifers, yet projections of sea-level rise are up to 1.5 to 2m by 2100 (see section 2). Research suggests that melting of the ice sheets will occur with global mean temperature rises of only 1-2°C[51] [52]. Sea level rise will exacerbate the effect of drier conditions on salinisation of coastal aquifers – the reserves would be

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[50] Bobba A, Singh V, Berndtsson R and Bengtsson, L (2000), Numerical simulation of saltwater intrusion into Laccadive Island aquifers due to climate change. Journal of the Geological Society of India, 55, 589 612

[51] Hansen J (2005), A slippery slope. How much global warming constitutes “dangerous anthropogenic interference”? Climatic Change, 68, 269-279

[52] Oppenheimer M and Alley RB (2005), Ice sheet, global warming and Article 2 of the UNFCCC. Climatic Change, 68, 257-267

squeezed from both underneath via the rising saltwater layer, and above via reduced recharge rates from declining precipitation. In addition there is a potential secondary effect where coastal aquifers become saline due to sea-level rise, then neighbouring aquifers experience saltwater intrusion during dry periods with low groundwater recharge. Most CARICOM nations have already experienced saltwater intrusion into aquifers (particularly Antigua and Barbuda, The Bahamas, Barbados, Belize, Grenada, Guyana, Haiti, Jamaica, St. Kitts and Nevis, St. Vincent and the Grenadines, Suriname and Trinidad and Tobago). Should sea levels rise, all coastal aquifers would be threatened. Sea-level rise would also increase the effects of storm surges, which can lead to aquifers becoming contaminated through coastal flooding.

The water resources of the majority of CARICOM states are at high risk of declining, particularly under greater increases in global mean temperature. In order to keep declines in precipitation across CARICOM states to manageable levels, two main recommendations are made:

1. Reduce the global mean temperature rise to a minimum through international efforts to curb emissions of greenhouse gases, including CO_2. A 1.5°C temperature rise would impact water resources severely in the least number of CARICOM states and be relatively manageable for most other states. A global mean temperature rise of 2.0°C or more will impact severely the water resources in the majority of CARICOM states, and affect the greatest number of people. Based on projections of precipitation, water shortages and frequent drought conditions become increasingly likely for global mean temperature rises beyond 2.0°C, particularly in states which already experience water resource issues.

2. Improve water infrastructure and water management throughout CARICOM states, taking into account the impacts of projected climate change. In particular, it is recommended that states should (i) improve the management of watersheds and catchment areas (reforestation, suitable developments and agriculture) to optimise groundwater recharge; (ii) improve water resource monitoring, including groundwater and precipitation; (iii) improve water distribution to increase access to clean water and reduce loss; (iv) increase water storage capacity to mitigate the effects of drought conditions; (v) expand or initiate water metering and charging to encourage water conservation; and (vi) consider the implementation of desalination to assist with for periods of water shortages.

IMPACTS ON AGRICULTURE

Unfettered climate change will have substantial negative effects on agriculture productivity in many parts of the developing world. A recent Food Policy Report from IFPRI[53] found that by 2050 climate change will cause yield declines for the most important crops (rice, wheat, maize, and soybeans) in the developing countries assessed. Climate change will result in additional price increases for the most important agricultural crops. Higher feed prices will result in higher meat prices. As a result, climate change will reduce the growth in meat consumption slightly and cause a more substantial fall in cereals consumption. Calorie availability in 2050 will not only be lower than in the no climate-change scenario, it will actually decline relative to 2000 levels throughout much of the developing world. By 2050, the decline in calorie availability will increase child malnutrition by 20% relative to a world with no climate change. Climate change will eliminate much of the improvement in child malnourishment levels that would occur with no climate change. The IFPRI report however does not include any information specific to the CARICOM countries.

In this section, available information for CARICOM countries is summarized and new country-specific results based on a variety of GCMs and SRES scenarios are provided where possible. Given the lack of data availability on much of agriculture for CARICOM countries the analysis must be considered preliminary. Due to data limitations, it does not distinguish between the relative effects of a 1.5° and a 2.0°C rise in the global annual mean surface air temperature change. Instead it compares the effects of a range of GCMs that result in roughly similar temperature increases of 1.5° and 2°C in the Caribbean .

Climate change generally has negative effects on yields in CARICOM countries. For three key crops in CARICOM countries – rice, maize, and cowpea – the biological effects of 2050 climate relative to 2000 climate are yield declines ranging from 3% to over 8%.

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[53] Nelson, G. C., M. W. Rosegrant, et al. (2009). Climate Change: Impact on Agriculture and Costs of Adaptation. IFPRI, September 2009.

Table 6: Estimates of 2050 agricultural value lost to climate change in CARICOM countries

Country	Agricultural value added (percent of GDP)	2005 value (million U.S. dollars)**	Value lost to climate change, lower bound (2.96% of 2005 value)	Value lost to climate change, upper bound (8.43% of 2005 value)
Antigua and Barbuda	4	34.8	1.03	2.93
Bahamas*	3	150.0	4.44	12.65
Barbados	4	122.4	3.62	10.32
Belize	15	166.5	4.93	14.04
Dominica	18	54.0	1.60	4.55
Grenada	5	25.5	0.75	2.15
Guyana	31	244.9	7.25	20.65
Haiti*	28	1078.0	31.91	90.88
Jamaica	6	669.0	19.80	56.40
Montserrat	-	-	-	-
Saint Kitts and Nevis	3	12.9	0.38	1.09
Saint Lucia	4	35.2	1.04	2.97
Saint Vincent and Grenadines	8	35.2	1.04	2.97
Suriname	6	106.8	3.16	9.00
Trinidad and Tobago	1	151.4	4.48	12.76
Total		2,886.60	85.44	243.34

** 2005 GDP times agricultural value added share.

If these results apply similarly to all major crops, an assumption for which there is yet little analytical support, the estimated effect on agriculture value ranges from $85 million per year to $243 million per year. The effects of the particular climate change scenarios we use do not differ much with underlying differences in temperature. This result is possibly due to the increases in precipitation that accompany higher temperatures, but at this stage in the analysis, this explanation is mainly speculation. To better understand the potential effects of climate change on CARICOM agriculture, the follow data and analyses are needed: improved downscaling of climate scenarios (to levels similar to that provided by the CARIBSAVE Partnership for the nations of Jamaica and The Bahamas[54]); improved characterization of the crop varieties grown, including location specific information on agronomic environments; and more detailed characterization of the agricultural sectors and their roles in CARICOM economies.

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[54] Eleuthera, The Bahamas Destination Profile Report, The CARIBSAVE Partnership, Department for International Development (DFID), UK www.caribsave.org
Montego Bay, Jamaica Destination Profile Report, The CARIBSAVE Partnership, Department for International Development (DFID), UK www.caribsave.org
Negril, Jamaica Destination Profile Report, The CARIBSAVE Partnership, Department for International Development (DFID), UK www.caribsave.org

As for many other countries in the developing world, climate change will bring declines in yields of important crops in the CARICOM countries. These serious biological outcomes must be addressed by investments in crop research, agro-biodiversity, agro-technology and development and dissemination that provide farmers with new varieties and management techniques that will help them adapt to the climatic changes. These investments need to begin now to deal with the expected changes in regional climate in the next 10 to 20 years. At this stage we cannot effectively analyze the differences between the 1.5°C and 2°C global temperature increase thresholds, especially at the level of CARICOM countries. However, the consequences of even the smaller increase highlight the need for urgent action.

Part 4 - Climate Change Impacts on Pacific Island Countries

The majority of people in the Pacific live in rural areas and are dependent on local natural resources and ecosystems for their food, water, shelter and livelihoods. Livelihoods are primarily subsistent and in many cases, communities are already highly vulnerable to droughts, floods and other natural disasters. Poor access to markets and government services, and limited transport infrastructure further reduces community resilience to shocks and stresses.

Like CARICOM countries, Pacific island countries have contributed little to the causes of climate change, but they are among the most vulnerable and least able to adapt to its impacts. The adverse effects of climate change are already a reality for small islands. Many of the observed and projected impacts of climate change parallel those of CARICOM countries. In the absence of a concerted global effort to reduce GHG emissions, significant impacts are anticipated on coastal communities and atolls, the security of water and food supplies and on the health of Pacific island people and natural ecosystems.

Higher sea surface temperatures and acidification threaten coral reefs and in-shore fisheries. Potential increases in peak wind speeds and the intensity of precipitation in tropical cyclones, coupled with sea-level rise, could worsen the impacts of storm surge and flooding, threatening coastal communities and placing important infrastructure at risk. Essential industries including fisheries, agriculture and tourism will be at risk.

This section examines projections of climate and sea-level changes for the Pacific region under global warming scenarios of 1.5°C and 2.0°C. These thresholds of global warming can occur at different future dates depending on emission rates of greenhouse gases and on the sensitivity of the climate system to increases in greenhouse gas concentrations. Consequently, this section produces “snapshots” of the climate and sea-level changes on the various future dates at which these levels of global warming were exceeded. Based on the median value of an ensemble of climate models[55], it was found that:

- An additional 0.5°C warming on 1.5°C would likely cause a relatively large increase in the frequency of ***extreme hot spells*** throughout the Pacific region.

- For the 1.5°C warming threshold, ***mean annual rainfall*** is generally projected to increase on the order of 5 to 15% over most of the equatorial Pacific where rainfall is already high. Such increases are likely to significantly increase the magnitude and/or frequency of extreme rainfall events and increase flood risks. Other areas of the Pacific show lesser increases or even slight decreases in rainfall.

Table 7: Summary of effects of climate change in the Pacific region

Climate change effect	Change for 1.5 °C global warming	Additional change for 2.0 °C global warming
Temperature	≤1.5°C	≤0.5°C
Precipitation	-10% to +20%	-3% to +7%
Sea level rise rate	+44-86% (over 1990)	+13-16% [57-102% (over 1990) total]

Coasts and infrastructure

The coastlines of small islands are long relative to the island area. They are also diverse and resource rich, providing a range of goods and services, many of which are threatened by a combination of human pressures and climate change and variability arising from sea level rise, increase in sea temperature, coastal erosion, salt intrusion into freshwater lenses and increased flooding from the sea. Even small amounts of SLR are problematic for many nations in the Pacific already struggling to cope with flooding and storm surge.

Examining the impact of SLR on the capital of Kiribati, South Tarawa Atoll, highlights the sensitivity of the atoll environment to very small (10-20cm) changes in mean sea-level rising through the water table in low-lying areas and direct inundation of low-lying land on the lagoon side of the island. The resolution of the contour heights is

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[55] The median value of ensembles of up to 21 General Circulation Models (GCMs) were used, depending on the climate parameter being examined, in order to portray the changes that may occur in the Pacific region. The ensembles and spatial analyses were conducted using the SimCLIM modeling software (CLIMsystems (2009) SIMCLIM, Climate Change Effect and Impacts Modelling Tool: http://www.climsystems.com/simclim/). To remove the effect of the differences in climate sensitivity between the models, the GCM regional patterns were "normalised" by dividing each by their global-mean warming, giving a pattern of change per degree of global warming. The ensembles of normalised patterns were then scaled by 1.5 and 2.0 in order to examine the magnitudes of regional climate changes for the two threshold values and to examine the differences between them.

not sufficient to show the small differences between the sea-level projections under the 1.5° and 2.0°C scenarios. However, the exercise shows how sensitive the inundation results are to climate model sensitivity. Figure 20 shows the impact of a 35cm SLR on South Tarawa Atoll, affecting properties, cultural services, roads and other infrastructure (electricity, telecommunications)[56].

Figure 20: Land affected by sea-level rise in Bikenibeu village, South Tarawa, at 35cm SLR

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[56] Elrick, C. & Kay, R. (in press) Adaptation Handbook: Undertaking Risk Treatment for Coastal Climate Change Risks in the Republic of Kiribati. Prepared for Kiribati Adaptation Project Phase II (KAP II), Government of Kiribati. Coastal Zone Management Pty Ltd, Perth.

Coastal inundation in Honiara, Solomon Islands

Honiara is typical of the majority of urban centres in the Pacific situated on the coast and in potentially vulnerable low-lying areas. The exposure of Honiara to coastal hazards such as cyclone-driven storm surge, extreme high tides and future climate change is significant, and reinforced by increasing human settlement and degraded land conditions in certain areas. The coastal areas of Honiara that are mostly affected during the wet season are from Mataniko to Ranadi.

Modelling to map inundation at 1 to 3 metres along the Honiara coastline identified low-lying areas that are susceptible to flooding from high tides and storm surge when coupled with rising sea levels. These areas should be prioritised for more detailed assessment. [57]

Storm surge events along the sea front of Honiara normally occur during the wet season/cyclone season from around November to April, peaking during the months of January and February. Observations from from Honiara indicate that Mamana Water (Lord Howe settlement) around the Mataniko Bridge and National Referral Hospital are continuously inundated especially during the wet season. With rising sea levels, coupled with high tides and increasing wind speeds, coastal inundation of between one and two metres is feasible. Considering the potential for storm surge and cyclone-driven impacts, inundation could occur at higher levels, as shown in the figures below.

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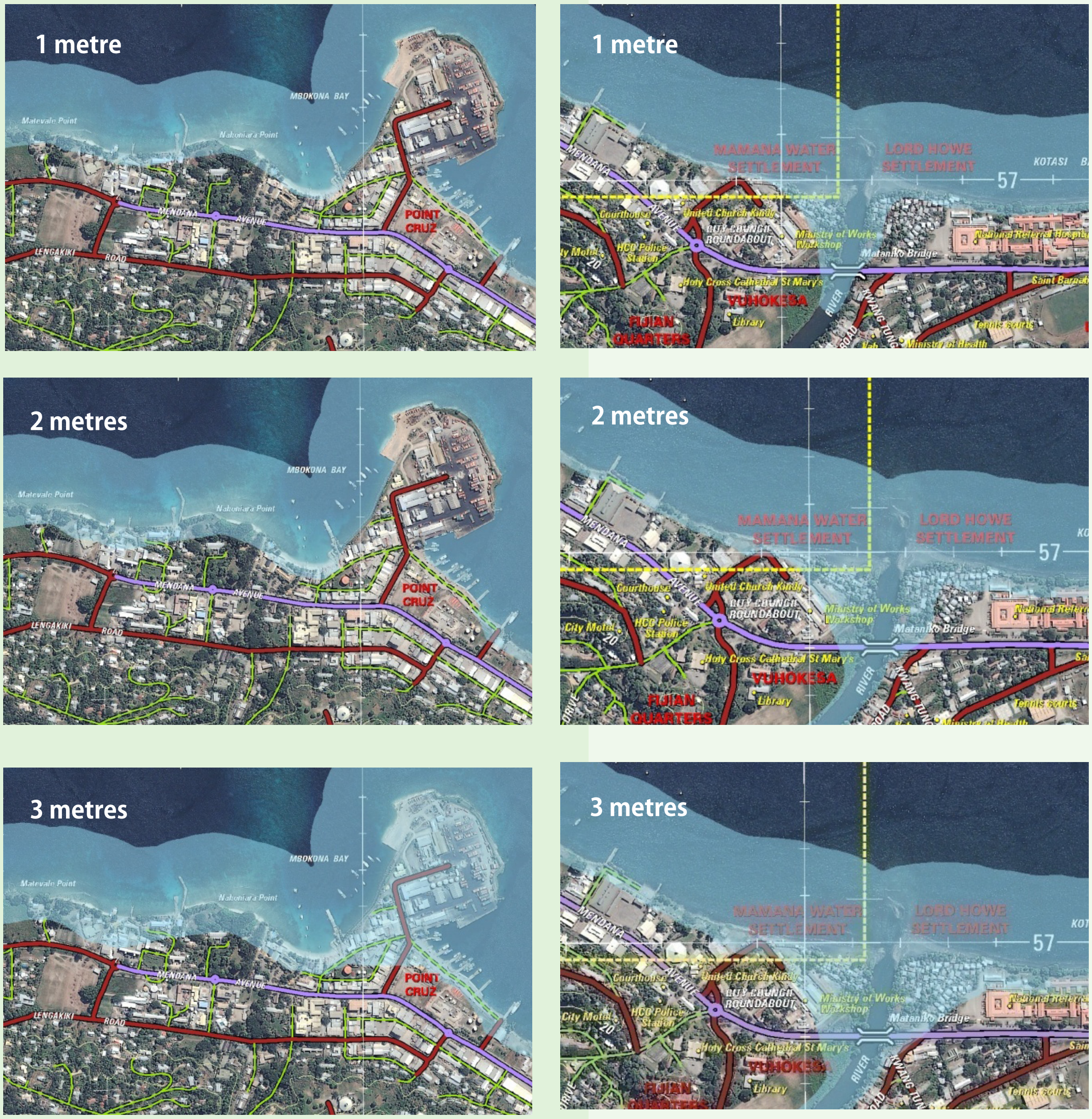
[57] Given the coarse resolution and other limitations to this modeling, inundation levels should be taken as indicative only. Tidal measurements have been obtained from the SEAFRAME gauge in Honiara, adjusted to the datum used by the inundation modeling.

Figure 21: Inundation modelling derived from high-resolution cartographic elevation data products (20m contour / spot heights) for Honiara, Solomon Islands: Point Cruz area (left) and Mataniko bridge area (right) at one, two and three metres inundation



As with the inundation modelling conducted in CARICOM member states in the Caribbean, such an approach can provide a strategic planning tool to assess risks to key assets, and guide further analyses, national planning efforts and investment decisions. Adaptation approaches based on integrated coastal zone management provide a framework to address existing threats and climate change related impacts such as the location of key infrastructure, adaptations options to maintain coastlines and the protection of key habitats such as coastal wetlands.

Water resources

Owing to factors of limited size, and geology and topography, water resources in small islands are extremely vulnerable to changes and variations in climate, especially rainfall. For example, a 10% reduction in average rainfall by 2050 is likely to correspond to a 20% reduction in the size of the freshwater lens on Tarawa atoll, Kiribati. Less rainfall coupled with land loss from sea level rise, is likely to reduce the thickness of the water lens on atolls by as much as 29%.[58]

By mid-century, climate change is expected to reduce water resources in many small islands in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low-rainfall periods.[59] This is particularly the case for countries in the non-equatorial region of the Pacific. Adaptation strategies such as demand management, integrated water resource management and increasing water storage and desalination plants (e.g. as in Tuvalu) are being explored in the Pacific region.

Agriculture

Projected impacts of climate change on agriculture include extended periods of drought on one hand, and on the other hand, a decline in soil fertility and erosion (due to increased precipitation) with loss of crops and reduced yields. A decline in agricultural production will have dramatic consequences for local economies and food security and reduce Pacific island countries' opportunities for trade and foreign exchange. Adaptation measures include initiatives to promote and support diversification of production systems, adopting integrated resource management approaches to food production, and building on traditional production systems to enhance resilience to climate change impacts.

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[58] Mimura, N., L. Nurse, R.F. McLean, J. Agard, L. Briguglio, P. Lefale, R. Payet and G. Sem, 2007: Small islands. Climate Change 2007:Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 687-716.

[59] IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22.

Fisheries

Fish is a cornerstone of food security in the Pacific – there are few alternative sources of animal protein. The majority (60 to 90%) of this fish is derived from subsistence fishing in coastal waters. However, the vital contribution of fish is under threat. Coastal fisheries will not be able to provide the fish needed by rapidly increasing human populations for food security in 16 of the 22 Pacific island countries[60] in the near future.

An assessment of the impacts of climate change on fisheries has determined that at 2°C warming, coral cover is expected to have decreased by 75% (compared with 30 to 40% under a 1.5°C scenario).[61] Loss of structurally complex coral reef habitat is projected to lead to declines in abundance of up to 65% for virtually all reef-associated fish. In these conditions, there is a moderate likelihood and confidence that declines in coastal fisheries production of 20 to 50% will also occur, depending upon reliance of local coastal fisheries on strongly reef-associated fishes. Adaptation strategies to improve access to fisheries resources in urban and rural communities include improving fisheries and coastal management to address overfishing and existing threats to coastal habitats, providing access to tuna for subsistence and artisanal fishers in rural areas by establishing low-cost, inshore fish aggregating devices, providing incentives for better use of by-catch from industrial fisheries and small pond aquaculture when feasible, such as in Melanesia.

Ecosystems

Terrestrial habitats expected to be most impacted by climate change are mangrove and coastal systems, montane systems, and dryland vegetation communities. Anthropogenic activities that are unrelated or only indirectly related to climate change – such as forest conversion for agriculture, over-logging and fire, will exacerbate the impacts of climate change and accelerate the rate of species extinction. Marine ecosystems, in particular coral reefs, are expected to be most affected by climate change. Coral bleaching, ocean acidification and marine invasive species, will add to existing threats such as overharvesting and coral mining.

Ecosystem–based adaptation can enhance the resilience to climate change, protect carbon stores and contribute to adaptation strategies. Better protection and management of key habitats (e.g. wetlands, coral reefs, forests) through protected area networks, and natural resources through ecosystem based approaches will increase resilience to climate change impacts and maintain ecosystem services and access to resources underpinning small islands economies.

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[60] SPC (2008a) Fish and Food security. Policy Brief 1/2008. Secretariat of the Pacific Community, Nouméa, New Caledonia.
Bell JD, Kronen M, Vunisea A, Nash WJ, Keeble G, Demmke A, Pontifex S and Andréfouët S (2009a) Planning the use of fish for food security in the Pacific. Marine Policy 33, 64-76.

[61] Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Steneck RS, Greenfield P, Gomez E, Harvell CD, Sale PF, Edwards AJ, Caldeira K, Knowlton N, Eakin CM, Iglesias-Prieto R, Muthiga N, Bradbury RH, Dubi A and Hatziolos ME (2007) Coral reefs under rapid climate change and ocean acidification. Science 318, 1737-1742.

Health

Many small islands countries suffer from severe health burdens from climate sensitive diseases, vector born and food and water born diseases. Tropical cyclones, storm surges flooding and droughts have both short and long term effects on human health, including increased diseases transmission and decreased agricultural production.

Outbreaks of climate-sensitive diseases can be costly in terms of lives and economic impacts. An outbreak of dengue fever in Fiji coincided with the 1997-98 El Nino; out of a population of approximately 856,000 people, 24,000 were affected, with 13 deaths. The epidemic cost US $3-6 million.[62] Many Pacific island countries are already depending on external health services, and will be put under additional pressure from climate change.

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[62] World Bank (2000) Cities, Seas and Storms: managing change in Pacific islands Economies, Vol IV, Adapting to Climate change,. Wold Bank, Washington D.C. cited in Mimura, N. et al 2007

Conclusion

This report provides the first comprehensive assessment of the consequences of projected Sea Level Rise (SLR) and storm surge leading to coastal inundation (+1m to +6m) for the people and economies of the 15 CARICOM nations and provides evaluations of the differential impacts of +1.5° and +2°C on coral reefs, water resources and agriculture in the Caribbean and an analysis of climate change impacts on the Pacific islands.

The Caribbean will be affected more seriously by SLR than most areas of the world; SLR in the northern Caribbean may exceed the global average by up to 25%. In addition, the impacts of tropical storms and hurricanes on coastal areas, even at present intensity and frequency, will be compounded by SLR. The impacts of SLR will not be uniform among the CARICOM nations, with some projected to experience severe impacts from a 1 metre SLR. In nations where low lying-land is extensive and who are therefore more exposed to the impacts of SLR and storm surge, concerns are of damage to agriculture, industry and infrastructure as well as salt water penetration into the groundwater reservoirs. For nations with a more complex topography and characterized by steep sloped coasts fronted by only a narrow strip of low lying land, the main concerns are landslides, beach erosion and disruption to infrastructure that is concentrated in limited flat land areas. In both cases, damage to mangroves and seagrass beds is of concern, especially since these areas are of importance in coastal protection as well as fishery resources. In the case of most of the countries, the tourism industry is of particular concern, since it is preferentially located very close to the coastal, often in low-lying areas with highly erodible sandy beaches. These impacts and changes mean that much more needs to be done in terms of coastal protection and in the planning of coastal development. It terms of protection, the importance of natural inhibitors to erosion, such as beaches and mangroves, needs to be emphasised. In terms of planning, attention needs to be paid to the location of industry, communication and of course housing. In addition, care will need to be taken in the 'siting' of tourist developments, which generally occur close to the coastline. In all these matters, the topographic and geologic setting of locations at risk must be taken into account. The most vulnerable CARICOM nations to SLR were found to be: Suriname, Guyana, The Bahamas, and Belize.

The key impacts of a 1 metre rise in SLR can be summarised as follows: over 2,700 km^2 of Caribbean land area lost and 10% of The Bahamas land area; with the market value of undeveloped land lost across the CARICOM nations being over US $70 billion. Over 100,000 people will be displaced (8% of the population in Suriname, 5% of The Bahamas, 3% of Belize). The cost to rebuild basic housing, roads and services (water, electricity) for displaced population approximately US $1.8 billion. The annual GDP losses will be at least US $1.2 billion (over 6% in Suriname, 5% in The Bahamas, 3% in Guyana and Belize) not including hurricane and storm impacts on GDP. At least 16 multi-million dollar tourism resorts lost, with a replacement cost of over US $1.6 billion and the livelihoods of thousands of employees and communities affected. In addition to the impacts of increased temperature on agricultural yield over 1% agricultural land will be lost, with implications for food supply and rural livelihoods Transportation networks will be severely disrupted: 10% of CARICOM island airports will be lost at a cost of over US $715 million; lands surrounding 14 seaports will be inundated (out of a total of 50) at a cost of over US $320 million, the reconstruction cost of lost roads exceeds US $178 million (6% of road network in Guyana, 4% in Suriname, 2% in The Bahamas).

The total economic impact of 1 metre SLR in CARICOM nations includes a GDP loss of over US $1.2 billion per year, a permanent land lost value of US $70 billion and an initial reconstruction / relocation cost of $4.6 billion. These figures are based on SLR scientific evidence and do not include other major economic impacts, such as losses in agricultural production, losses in GDP from areas outside inundated regions, costs of changing energy needs, increased storm or hurricane damage and related insurance costs, necessary water supply construction, increased health care costs, or any non-market value impacts.

Sea level rise in the 21st century and beyond represents a serious and chronic impediment to sustainable development of some CARICOM nations and the impact estimates must be considered highly conservative for three reasons: a) population and GDP remain fixed at recent levels (estimates for 2010 and 2008 respectively); b) the coarse resolution of geospatial data available for this analysis masks the vulnerability of coastal infrastructure, natural areas and people to inundation from SLR in some areas; c) the implications of SLR for accelerated coastal erosion could not be assessed in this study.

Regarding water resources the study found that water insecurity will increase in CARICOM nations; Precipitation levels will decline under climate change 1.5° and 2°C increases and the severity of water resource problems for states which currently have insufficient water resources will have serious repercussions for the livelihoods of communities. For states that currently have sufficient water resources, a decline in precipitation will introduce new water resources issues. Reduced groundwater recharge will lead to a reduction in the amount of available water within aquifers, reduce the ability of states to cope with periods of drought and increased the risk of saltwater intrusion to aquifers, particularly in those close to the coast. Sea-level rise will increase the risk of saltwater intrusion into coastal aquifers, particularly those that are already at risk from over abstraction. As little as a 0.1m rise in sea level can substantially reduce the availability of fresh water in coastal aquifers. Most CARICOM nations have already experienced saltwater intrusion into aquifers. Sea-level rise threatens all coastal aquifers, and will also increase the effects of storm-surges that lead to aquifers becoming contaminated through coastal flooding. A 1.5°C temperature rise would impact water resources severely in a minority number of CARICOM states and be relatively manageable for most other states. A global mean temperature rise of 2.0°C or more will impact severely the water resources in the majority of CARICOM states. A reduction in precipitation for CARICOM states will reduce both the available surface water reserves and the level of groundwater recharge. These declines in precipitation would lead to an increase in the risk of periods of drought for the Caribbean region, which are likely to occur more frequently and be more severe.

On examination of the agriculture sector the report concludes that in developing countries and small island states, climate change will cause yield declines for the most important crops. Climate change will result in additional price increases for the most important agricultural crops – rice, wheat, maize, and soybeans and calorie availability in 2050 will not only be lower than in the no climate-change scenario—it will actually decline relative to 2000 levels.

By 2050, the decline in calorie availability will increase child malnutrition by 20 % relative to a world with no climate change. Climate change will eliminate much of the improvement in child malnourishment levels that would occur with no climate change. Average yields in CARICOM countries for three key crops (irrigated and rainfed rice, rainfed maize and rainfed cowpea) will be reduced – The declines range from about 3% to over 8%. Assuming these estimated yield effects apply to all crops, agricultural value in the CARICOM countries would fall by between US $85 million per year to US $243 million per year.

The ecosystem services provided to tourism and fisheries by Caribbean coral reefs are estimated to be worth between US $1.5 and $3.5 billion per year to the region. This economic valuation does not include the critical role played by coral reefs in the protection of coastal areas from storm surges and ocean swells - the environmental and economic importance of coral reefs to the Caribbean therefore should not be underestimated. The study examined the impacts of a 1.5° and 2°C increase in temperature and found that the Caribbean is warming quickly: Sea surface temperature (SST) trends across the Caribbean basin over the past 22 years indicate current warming is occurring at 0.2° to 0.5°C per decade. Current SST trends over the Caribbean exceed, and at some locations nearly double, those being observed over the global tropical oceans and recent SST increases are greatest throughout the Windward Islands of the Lesser Antilles such as Grenada, St. Lucia, St Vincent and the Grenadines. In addition committed warming is inevitable: An increase in thermal stress on Caribbean coral reefs in the next 20 to 30 years is inevitable due to "committed" warming from greenhouse gas emissions already in the atmosphere and even more from those that will be emitted before emissions are eliminated. Coral bleaching frequency will exceed the rate of recovery: Under either the 1.5°C or 2°C warming scenarios, the accumulation of thermal stress on Caribbean coral reefs far exceeds current mass coral bleaching thresholds across the Caribbean and the frequency of bleaching events will exceed the rate of recovery. Clearly, 2.0°C will be worse than 1.5°C.

An additional and equally dangerous threat to coral reefs is ocean acidification from increasing atmospheric CO_2 which reduces coral reef growth. Conditions we are likely to see in the 21st century decade when we reach 1.5°C above pre-industrial levels (~490 ppm atmospheric CO_2) may prove adequate for reef growth, whereas at 2.0°C and 550 ppm Caribbean reefs are likely to be eroding. Even at equilibrium, corals across most of the Caribbean are in conditions that are in the upper half of the range adequate for reef growth at 1.5°C and 350 ppm, but near the bottom of that range at 2.0°C and 450 ppm. It is doubtful that corals can adapt to as much as 2.0°C warming: It is highly unlikely that adaptation through biological mechanisms and management will be sufficient to avoid severe degradation of Caribbean coral reefs from frequent bleaching events. More importantly, most known physiological mechanisms that allow corals to adapt to warmer conditions also cause slower growth, making the problems caused by acidification even more severe. Climate change and ocean acidification at 1.5°C are likely to have significant impacts on coral reef ecosystems and the ecosystem services they provide. This will be even more severe at 2.0°C.

In the Pacific islands, the high sensitivity of low-lying atolls to increases in SLR will threaten water and food security, settlements, health and infrastructure. Overall, although impacts of climate change will affect Pacific island countries differently, likely impacts on key sectors such as water resources, agriculture, fisheries and infrastructure are similar to those forecast for Caribbean countries.

In particular, an additional 0.5°C warming on 1.5°C would likely cause a relatively large increase in the frequency of extreme hot spells throughout the Pacific. Projected changes in rainfall, combined with salt intrusion and rises in water tables, will result in **water scarcity** in many Pacific island countries, in particular atoll countries outside the equatorial Pacific region, adding to existing stress from high water demand and compounded by limited storage capacity. In addition, storm surge and coastal erosion threaten coastal settlements and the transport, water and sanitation infrastructure that support them. Potential increases in peak wind speeds and the intensity of precipitation in tropical cyclones, coupled with SLR, could worsen impacts of storm surge and flooding. The **consequences for coral reefs at 2°C warming are dire.** A decrease of 75% in coral cover (compared with 30 to 40% under a 1.5°C scenario) will result in **severe declines in the availability of reef-associated fish** and coastal fisheries production, with significant implications for food security for many Pacific nations.

Economic impacts of climate change and the costs of adaption have yet to be assessed comprehensively at the regional and country level to inform national development strategies and investment decisions. Although the Pacific region has a strong subsistence heritage, many countries import food staples and are vulnerable to rising food and energy prices. Predicted impacts of climate change are likely to increase reliance on imported food, unless adaptation strategies are developed to diversify primary production and broaden countries' economic base.[63]

As in the Caribbean, the lack of long-term datasets and high-resolution elevation data on all Pacific islands provides a fundamental barrier to improving and accurately quantifying the impacts that SLR will have on the Pacific region. There is a critical need for investment in high-resolution topographic data to facilitate detailed risk mapping of local areas. To enhance adaptive capacity in the Caribbean and the Pacific regions, further efforts are required to assess the practical outcomes of projects and ensure lessons are learned. Capacity building in vulnerability assessment and adaptive planning at the national and local levels are needed, building on Pacific institutions, knowledge and practices. Pacific islands have expressed their priorities for addressing climate change regionally through the *Pacific Leaders' Call to Action on Climate Change*, the *Pacific Plan for Strengthening Regional Coordination and Integration*, the *Niue Declaration on Climate Change* and the *Pacific Islands Framework for Action on Climate Change 2006-2015.*

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[63] This recommendation draws on research compiled in the Pacific Economic Survey 2009, AusAID, http://www.ausaid.gov.au/publications/pdf/Pacific_Economic_Survey09.pdf

Recommendations

The following selected recommendations based on the findings of this report should not be taken as exhaustive but are representative of a need for serious, comprehensive and urgent action to be taken to address the challenges of climate change in the islands and coastal states of the Caribbean Basin and the Pacific islands. Concerted global action will be needed to reduce the impacts of climate change on coastal areas of the Caribbean and the Pacific islands. Measures to contain the global temperature rise to 1.5°C by 2100 are an important objective and will reduce projected losses of land, infrastructure, resources and economies. The recommendations have been divided into two categories; 'Improving climate change predictions for informed decisions' and 'Predicting impacts on key sectors and implementing adaptation measures'.

IMPROVING CLIMATE CHANGE PREDICTIONS FOR INFORMED DECISIONS

Recommendation: In order to improve spatial detail and to examine uncertainties more closely, as well as to study changes in extreme climate events (e.g. heavy rainfall, tropical storms), further examination of the projections is recommended including downscaling; any such work would be consistent with the UNFCCC Nairobi Work Programme.

Recommendation: Detailed information on the vulnerability of coastal areas is needed. As the climate continues to change in the coming years, such information will be vital to inform coastal zone management and anticipate flood hazard. It seems likely that any continued global mean temperature increase will have serious consequences for the Caribbean and Pacific islands by 2100, but if the increase exceeds 1.5°C the consequences will be extremely serious in areas of high exposure. A strategy needs to be developed globally by which on the one hand, all nations would agree to curtail global emissions and address environmental degradation. On the other hand, the Caribbean and Pacific island communities themselves would agree to plan for the changes that will increasingly affect their coastlines as a result of increased warming and sea level rise that the world is already committed to from past emissions and climate feedbacks.

Recommendation: In both the Caribbean and the Pacific islands there is a critical need for: a) investment in high-resolution topographic data to facilitate detailed risk mapping of local areas; b) the extension of existing observational and sea-level monitoring programs, and efforts to improve understanding of wind and wave climate in the context of climate change; c) a detailed analysis of the capacity of adaptation options to cope with different levels of climate change and associated sea level rise; and d) more detailed costs assessments necessary to inform future negotiations regarding adaptation assistance from the international community.

PREDICTING IMPACTS ON KEY SECTORS AND IMPLEMENTING ADAPTATION MEASURES

Recommendation: Adaptation through biological mechanisms and management may allow some coral reefs to avoid severe degradation from frequent bleaching events and survive up to a 1.5°C warming. Such adaptation is uncertain and, if possible, would come with other costs such as reduced diversity and productivity. In summary, two sets of actions are required for the continued survival of coral reefs:

1. rapid reduction of CO_2 emissions and eventual reduction of atmospheric CO_2 level, and
2. management actions to help corals survive long enough for our actions to attempt to stabilize the climate system.

It is highly unlikely that adaptation through biological mechanisms and management will be sufficient to avoid severe degradation of coral reefs from frequent bleaching events if the temperature increase exceeds 1.5°C above pre-industrial levels. More importantly, most known physiological mechanisms that allow corals to adapt to warmer conditions also cause slower growth, making the problems caused by acidification even more severe. These impacts will be even more severe at 2.0°C.

Recommendation: To better address potential effects of climate change on agriculture, the following data and analyses are needed: a) improved downscaling of climate change scenarios; b) better characterization of the crop varieties, including location specific information on agronomic environments, crop diversification and sustainability of production systems, and; c) more detailed characterization of the agricultural sectors and their roles in economies and alternatives.

Recommendation: To address predicted impacts of climate changes on water resources, there is a need to improve water infrastructure and water management. In particular, states should a) improve water resource monitoring, including groundwater and precipitation; b) improve water distribution to increase access to clean water and reduce loss; c) increase water storage capacity to mitigate the effects of drought conditions; d) expand or initiate water metering and charging to encourage water conservation; and e) consider the implementation of desalination using renewable power sources to assist with periods of water shortages.

Recommendation: Adaptation to future SLR will require revisions to development plans and major investment decisions, based on impacts of climate change and SLR on coastal areas and vulnerability assessments. Caribbean and Pacific island countries need to develop a comprehensive understanding of their long term risk to SLR to negotiate appropriate adaptation assistance. Future studies using high resolution Digital Elevation Models that account for erosion and not just inundation are essential to understand the true threat SLR poses to the people and economies of Caribbean and Pacific island countries and addressing this crucial knowledge gap should be a priority for Development Agencies.

Please note that at a DVD was distributed at Copenhagen COP15 December 2009 with the 'Key Points' of the report. The DVD contains copies of the following:

1. An Overview of Modelling Climate Change Impacts in the Caribbean Region with contribution from the Pacific Islands: KEY POINTS

2. An Overview of Modelling Climate Change Impacts in the Caribbean Region with contribution from the Pacific Islands: SUMMARY DOCUMENT

3. 'The Burning Agenda: The Climate Change Crisis in the Caribbean', Short Film (30 minutes) Commissioned by the British Foreign and Commonwealth Office

4. '1.5 To Stay Alive', Song written and performed by the Barbadian performance poet Adisa 'AJA' Andwele.

These items and copies of the report can be obtained via free download at www.caribsave.org

An Overview of Modelling Climate Change Impacts in the Caribbean Region with contribution from the Pacific Islands:

SUMMARY DOCUMENT

This report was commissioned by the United Nations Development Programme (UNDP) Sub-Regional Office for Barbados and the OECS, and by the UK Department for International Development (DFID), with support from Australia's International Climate Change Adaptation Initiative. The report was produced by The CARIBSAVE Partnership and authored by members of 15 key institutions around the world dealing with climate change.

This 'Summary Document' is drawn from the full report and they provide an overview for all CARICOM member states of the risks from climate change and includes a section on the common threats of climate change for Pacific island countries. This document and the report focuses on: climate change projections for the Caribbean region under +1.5° and +2°C global warming scenarios; the implications of ice sheet melt for global sea level rise (SLR); the projections and implications of SLR for the Caribbean region; evaluation of the differential impacts of +1.5° and +2°C on coral reefs, water resources and agriculture in the Caribbean, with additional analysis for the Pacific islands.

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