Quantification and Magnitude of Losses and Damages Resulting from the Impacts of Climate Change:

MODELLING THE TRANSFORMATIONAL IMPACTS AND COSTS OF SEA LEVEL RISE IN THE CARIBBEAN

Prepared by The CARIBSAVE Partnership for UNDP Barbados and the OECS for CARICOM Member States

FULL DOCUMENT

CARICOM

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Quantification and Magnitude of Losses and Damages Resulting from the Impacts of Climate Change:

Modelling the Transformational Impacts and Costs of Sea Level Rise in the Caribbean

The United Nations Development Programme (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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FULL DOCUMENT

Please Note: A DVD was distributed at the Cancun COP16 November/December 2010 with the 'Key Points and Summary for Policy Makers' document of this report. The DVD contains copies of the following:

1. Quantification and Magnitude of Losses and Damages Resulting from the Impacts of Climate Change: Modelling the Transformational Impacts and Costs of Sea Level Rise in the Caribbean - KEY POINTS AND SUMMARY FOR POLICY MAKERS

2. Quantification and Magnitude of Losses and Damages Resulting from the Impacts of Climate Change: Modelling the Transformational Impacts and Costs of Sea Level Rise in the Caribbean - SUMMARY DOCUMENT

3. 'Partnerships for Resilience: Climate Change and Caribbean Tourism' A short film (18 minutes) commissioned by the British Foreign and Commonwealth Office and the UK Department for International Development; Highlights adaptation measures being taken by governments, private sector and communities across the Caribbean.

Copies of these documents, the Full Document and the short film can be obtained via free download at www.caribsave.org

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> “Climate change is the greatest challenge facing humanity at the start of the 21st Century. Failure to meet this challenge raises the spectre of unprecedented reversals in human development.”
>
> United Nations Development Programme (UNDP) – Human Development Report 2007/08

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1. Introduction

The inextricable links between climate change and sustainable development have been increasingly recognised over the past decade. In 2007, the Intergovernmental Panel on Climate Change (IPCC)[1] concluded with very high confidence that climate change would impede the ability of many nations to achieve sustainable development by mid-century and become a security risk that would steadily intensify, particularly under greater warming scenarios. Article 4.8 of the United Nations Framework Convention on Climate Change (UNFCCC) lists several groups of countries that merit particular consideration for assistance to adapt to climate change "especially: (a) small island countries, (b) countries with low-lying coastal areas, (c) countries with areas prone to natural disasters." Small Island Developing States (SIDS) have characteristics which make them particularly vulnerable to the effects of climate change, sea level rise (SLR) and extreme events, including: relative isolation, small land masses, concentrations of population and infrastructure in coastal areas, limited economic base and dependency on natural resources, combined with limited financial, technical and institutional capacity for adaptation.[2]

The nations of CARICOM[3] (the Caribbean Community) exemplify many of these characteristics, and even though they contribute less than 1% to global greenhouse gas (GHG) emissions[4], these countries are expected to be among the earliest and most impacted by climate change in the coming decades. Caribbean coastal communities in particular will be severely threatened by the direct and indirect impacts of climate change (e.g., sea-surface temperature, SLR, coastal erosion, extreme events and the loss of aesthetics), which are projected to accelerate in the coming decades and compound the existing threats to natural systems and society. Dulal et al. conclude that: "If the Caribbean countries fail to adapt, they are likely to take direct and substantial economic hits to their most important industry sectors such as tourism, which depends on the attractiveness of their natural coastal environments, and agriculture (including fisheries), which are highly climate sensitive sectors. ... and significant losses ... will not only increase unemployment but have debilitating social and cultural consequences to communities."[5] The significance of these threats has been emphasised by key decision-makers in government through regional statements such as the CARICOM Liliendaal Declaration on Climate Change in 2009.

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[1] Yohe, G.W., Lasco, R.D., Ahmad, Q.K., Arnell, N.W., Cohen, S.J., Hope, C., Janetos, A.C., and Perez, R.T. 2007. Perspectives on climate change and sustainability. 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, 811-841.

[2] Intergovernmental Panel on Climate Change (IPCC). (2007). 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.

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

[4] 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. Accessed from http://maps.grida.no/go/graphic/regional_ differences_in_co2_e missions_latin_america_and_the_caribbean

[5] Dulal, H.B., Shah, K.U., Ahmad, N. 2009. Social Equity Considerations in the Implementation of Caribbean Climate change Adaptation Policies. Sustainability, 1(3), 363-383.

There remains an urgent need to improve the information-base with regard to the risks posed by climate change impacts in the Caribbean and the capacity of adaptation options to cope with different levels of climate change, so as to enable greater evidence-based adaptation assistance from the international community. In 2009, The CARIBSAVE Partnership was commissioned by the United Nations Development Programme (UNDP) Sub Regional Office for Barbados and the Organization of Eastern Caribbean States (OECS) and the UK Department for International Development to undertake Phase I of an important project to provide the CARICOM nations with an overview of modelling of climate change impacts in the region.[6] The results and recommendations of Phase I of the project were presented to Heads of State and delegates at the Fifteenth Session of the Conference of the Parties (COP15) in Copenhagen, December 2009 and also to the CARICOM Task Force on Climate Change in January 2010.

Phase I clearly established that climate change will result in severe losses and damages to the Caribbean economy and to the livelihoods of the Caribbean people. It also emphasised, most strongly, the need for serious, comprehensive and urgent actions to be taken in the Caribbean and the importance of a further detailed assessment of the impacts and costs of climate change to the CARICOM States, in particular the impacts of SLR, to be conducted in Phase II.

This report, commissioned by the UNDP Barbados and the OECS, builds on the scientific foundations of Phase I and focuses on the recommendations, which were prioritised by the CARICOM Task Force on Climate Change and Development to be undertaken as soon as possible: (1) improving climate change modelling for taking informed decisions, and (2) improving predictions of impacts on key sectors and assessing adaptation measures. Specifically, this report provides a detailed and vigorous assessment of the losses and damages associated with SLR impacts on the population, ecosystems and key economic sectors in CARICOM. Advancements in understanding the consequences of SLR at the regional level were accomplished through:

- utilisation of newly available higher resolution geospatial data of coastal areas (satellite based Digital Elevation Models);
- improved inventories of coastal infrastructure and other assets at risk;
- the first quantification of the extent of SLR-induced erosion risk in unconsolidated coastal areas;
- a more comprehensive understanding of combined SLR and storm surge risk; and,
- the first quantification of the extent and cost of structural protection works required to protect coastal cities in CARICOM countries from SLR.

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[6] Report available from The CARIBSAVE Partnership website. Accessed from http://caribsave.org/index.php?id=5.

The economic implications of the impacts of climate change and required adaptation are being increasingly quantified to better inform international negotiations regarding adaptation assistance. This study provides the most detailed analysis to date of the damages and costs associated with SLR for the CARICOM nations, and builds on work completed in Phase I in 2009[7], previous economic studies[8,9,10] as well as recent developments identified in the Economics of Climate Change Working Group (ECA) study[11] estimating impacts due to climate change. The methodology incorporates top-down and bottom-up approaches (i.e., macro, meso- and micro-scales analyses) to model impacts on the economies of each CARICOM country individually. A unique strength of this economic study is that it is based on the most detailed geographic reality of coastal geomorphology and development that determine vulnerability to SLR.

Such in-depth information is essential for the Caribbean States to strategically reduce vulnerability, through investment, insurance, planning, and policy decisions, and inform negotiations regarding adaptation assistance under the Copenhagen Accord that was agreed at COP15 in Copenhagen.

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[7] Simpson, M.C., Scott, D., New, M., Sim, R., Smith, D., Harrison, M., Eakin, C.M., Warrick, R., Strong, A.E., Kouwenhoven, P., Harrison, S., Wilson, M., Nelson, G.C., Donner, S., Kay, R., Geldhill, D.K., Liu, G., Morgan, J.A., Kleypas, J.A., Mumby, P.J., Palazzo, A., Christensen, T.R.L., Baskett, M.L. Skirving, W.J., Elrick, C., Taylor, M., Magalhaes, M., Bell, J., Burnett, J.B., Rutty, M.K., and Overmas, M., Robertson, R. 2009. An Overview of Modeling Climate Change Impacts in the Caribbean Region with contribution from the Pacific Islands, United Nations Development Programme (UNDP), Barbados, West Indies.

[8] Bueno, R., Herzfeld, C., Stanton, E.A. and Ackerman, F. 2008. The Caribbean and Climate Change: The Costs of Inaction. Stockholm Environment Institute. Accessed from http://ase.tufts.edu/gdae/CaribbeanClimate.html.

[9] Haites, E. 2002. Assessment of the Economic Impact of Climate Change on CARICOM Countries. In: Vergara, W., ed. Environment and Socially Sustainable Development – Latin America and Caribbean. World Bank.

[10] Tol, R.S.J. 2002. Estimates of the Damage Costs of Climate change: Benchmark estimates. Environmental and Resource Economics, 21, 47-73.

[11] Economics of Climate Change Working Group (ECA). 2009. Shaping climate resilient development: a framework for decision making. Accessed from http://www.mckinsey.com/App_Media/Images/Page_Images/Offices/SocialSector/PDF/ECA_Shaping_Climate%20Resilent_Development.pdf.

2. Climate Change Projections for the Caribbean Region under +2°C and +2.5°C Global Warming Scenarios

2.1 INTERPRETATION OF PROJECTIONS FROM CLIMATE MODELS

The IPCC Fourth Assessment (AR4)[12] declared that 'warming of the climate system is unequivocal', with global mean temperatures warming by approximately 0.76°C between 1850–1899 and 2001–2005,[13] and the observed increase in global average temperatures since the mid-20th Century *'very likely'* the result of human activities that are increasing GHG concentrations in the atmosphere. The IPCC's observations of how the global climate system is changing have been reinforced by more recent reports on the state of the global climate system.[14,15]

The IPCC further emphasised that human-induced climate change has only just begun and that the pace of climate change is *'very likely'* to accelerate throughout the 21st Century with continued GHG emissions at or above current rates (with the best estimate that globally averaged surface temperatures will rise by between 1.8°C and 4.0°C by 2100).[16] Critically, recent observations have shown that our current rate of GHG emissions is exceeding the worst case scenarios provided by the IPCC for modelling future climate change. Remaining on this emission trajectory would exceed 2°C average global warming,[17,18,19,20] the level of warming considered by many scientists and over 100 nations[21], including the G8 nations[22], and signatories to the Copenhagen Accord, to represent "dangerous interference with the climate system" as outlined in the UNFCCC. Even if atmospheric concentrations of GHGs were somehow rapidly stabilised at current levels, the Earth would continue to warm as a result of past GHG emissions and feedbacks in the climate system.

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[12] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[13] Over the past 50 years, increases in mean air temperature across the Caribbean have tracked the observed global warming trend.

[14] Copenhagen Diagnosis. 2009. Allison, I., Bindoff, N.L., Bindschadler, R.A., Cox, P.M., de Noblet, N., England, M.E., Francis, J.E., Gruber, N., Haywood, A.M., Karoly, D.J., Kaser, G., Le Quéré, C., Lenton, T.M., Mann, M.E., McNeil, B.I., Pitman, A.J., Rahmstorf, S., Rignot, E., Schellnhuber, H.J., Schneider, S.H., Sherwood, S.C., Somerville, R.C.J., Steffen, K., Steig, E.J., Visbeck, M., Weaver, A.J. 2009. The Copenhagen Diagnosis, 2009: Updating the world on the Latest Climate Science, 1-60. The University of New South Wales Climate Change Research Centre (CCRC), Sydney, Australia.

[15] National Oceanic and Atmospheric Administration (NOAA). 2010. 2009 State of the Climate Report. Washington: Government of USA. Accessed from http://www.noaanews.noaa.gov/stories2010/20100728_stateoftheclimate.html

[16] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[17] Anderson, K., & Bows, A. 2008. Reframing the climate change challenge in light of post-2000 emission trends. Philosophical Transactions A, 366(1882), 3863.

[18] Allen, M.R., Frame, D.J., Huntingford, C., Jones, C.D., Lowe, J.A., Meinshausen, M., & Meinshausen, N. 2009. Warming caused by cumulative carbon emissions towards the trillionth tonne. Nature, 458(7242), 1163-1166.

[19] Meinshausen, M., Meinshausen, N., Hare, W., Raper, S.C.B., Frieler, K., Knutti, R., Frame, D.J., & Myles, R.A. 2009. Greenhouse-gas emission targets for limiting global warming to 2°C. Nature, 458(7242), 1158– 1162.

[20] Parry, M., Lowe, J., & Hanson, C. 2009. Overshoot, adapt and recover. Nature, 458(7242), 1102–1103.

[21] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.) 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[22] G8. 2009. Declaration of the leaders of the major economies forum on energy and climate. Accessed from http://www.g8italia2009.it/static/G8_Allegato/MEF_DeclarationI.pdf

Future changes in temperatures, precipitation, extreme events and other important features of climate will manifest themselves differently across the world. A question posed to the research team was how would the climate of the Caribbean change comparatively if the average global temperature could be held to 2.0°C or 2.5°C above pre-industrial values. Projections from 14 Global Climate Models (GCMs) used within the IPCC AR4[23,24] have been assessed to examine this question. The models have been run under three of the Special Report on Emission Scenarios (SRES Scenarios) (A1B, A2 and B1) used by the IPCC to provide plausible storylines for GHG emissions through the 21st Century (but without consideration of emission reductions resulting from the Kyoto Protocol). Because projections from each GCM are not available under all SRES emission scenarios, a total 41 individual projections have been used in this analysis.

Care should always be taken in interpreting any climate model projections. Averages across projections from all 14 models (referred to as the ensemble mean), as well as results from individual models, have been used as appropriate. No results from projections using climate models can be presented without caveats; in the remainder of this section some of the more significant caveats are discussed to provide background to the interpretation of the results.

2.1.1 USE OF 14 MODELS

No individual model provides a perfect simulation of the global climate system; no two models provide identical simulations. All models are limited in their abilities to simulate important aspects of the climate system, including that at tropical latitudes, in ways that are discussed at length in the IPCC.[25] Nevertheless, all models employed in IPCC assessments have been subjected to rigorous tests and all are considered to be performing at, or close to, the state of the art.

Numerous analyses of future climate published in the literature have been based on projections from a single model, a valid approach but one that requires recognition in full of its inherent limitations given use of a single non-perfect model. A much-improved approach uses an ensemble of equivalent projections from different models; this is a standard approach in the IPCC and is used widely in weather and climate predictions on shorter time scales. To an extent, the strengths of each model combine to provide a higher-quality result than is available from any individual model.

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[23] Intergovernmental Panel on Climate Change. 2007. Climate change 2007: Synthesis report. Cambridge, UK: Cambridge University Press.

[24] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.) 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[25] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.) 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

The average taken across projections from all models, or the ensemble mean, provides the single best-estimate deterministic projection that is available, and it is frequently used as such. That said, it is certain that most, if not all details, provided by the ensemble mean will be in error to a certain amount, and that consideration of the distribution of information carried in all models will provide a more-substantive basis for decision making. Thus the ensemble mean provides a first assessment for decision making, but it is advisable that further information be considered in order to complete the picture. In this Phase II Report, additional information will be provided in terms of the maximum and minimum values across the ensemble. This provides more direct information than the standard deviation used in the Phase I Report.

2.1.2 EMISSIONS SCENARIOS

Anthropogenic-forced climate change results from emissions of GHGs and from changes in land use. As the future over the coming century of both variables is unknown, but this information is required to provide climate projections, the IPCC has used a scenario approach – the SRES scenarios[26]. In terms of emissions, the IPCC has broken the scenarios into 4 families to produce 40 scenarios in total, with each family defined by a single representative marker scenario; the model runs are based on these marker scenarios only. Those families with a name including 'A' represent economically-focused policy futures that inevitably have greater energy requirements and higher emissions than the more environmentally-focussed development paths of the 'B' families. Those families with a name including '1' represent futures in which policies are developed more globally as opposed to those in '2' families in which more competitive regional approaches are adopted. None of the scenarios may be 'correct' but collectively they are thought to bracket realistic futures; none of the scenarios take into consideration international action, such as that under the Kyoto Protocol.

For this Phase II Report the scenarios used are A1B (economically-focused global policies – the B indicates a balance between fossil fuel intensive and technological, including renewables, approaches to energy generation), A2 (economically-focused regional policies) and B1 (environmentally-focused global policies). As previously stated, the latest evidence suggests that so far measured global emissions are similar to, if not higher than, the worst-case A1B and A2 scenarios.[27]

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[26] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[27] Global Carbon Project. 2010. Accessed from http://www.globalcarbonproject.org/carbonbudget/08/presentation.htm - projections for 2009 suggest that emissions will fall somewhat below those envisaged under A1B and A2, but the drop reflects only the global recession and emissions are anticipated to return to be similar to those in recent years as economies recover.

2.1.3 CLIMATE SENSITIVITY AND TIMING OF CHANGES

Climate sensitivity is simply a measure of the responsiveness of the atmosphere to changes in atmospheric GHG concentrations; it is determined by the difference in average global temperatures given carbon dioxide (CO_2) concentrations at pre-industrial levels and at double that concentration. This temperature difference can be estimated from both observations and models, with both approaches giving roughly similar results; note that those models giving relatively high values are the more responsive/sensitive to changes in CO_2 concentrations. The range of modelled values for climate sensitivity as given by IPCC[28] is 2.1°C to 4.4°C, indicating that the most responsive model produces global temperature changes more than double those of the least responsive for the same change in CO_2 concentrations. Models used in this Phase II Report are representative of this range. There is evidence that the range of uncertainty might be wider than suggested by the IPCC.

The range of climate sensitivities given by the various models introduces uncertainties in areas such as the extent of emissions permissible in reaching target atmospheric concentration equilibrium levels, but the main uncertainty introduced within the context of this Phase II Report is one of timing. The standard approach in IPCC assessments is to examine projections for specific time slices, producing ensemble means and ranges of 20 to 30 years centred around periods such as 2020, 2050 and 2080. Under this approach average global temperatures will have risen by larger amounts at a given time slice in those models with higher climate sensitivities, possibly with consequent other changes simulated in the climate system. Time slice ensembles thus average across a range of simulated climates at different stages of disturbance.

In this Phase II Report it is required to examine differences between climate given increased average global temperatures of 2.0°C and of 2.5°C, increases reached at different times in the future by each model/scenario combination. Time slicing is not feasible under this requirement and instead the time that these temperature thresholds are reached within each projection has been determined independently (after smoothing of the average global temperature time series to remove inter-annual variability). In order to ensure consistency across all models, global temperature differences have been calculated against the base of model simulated global average temperatures for the years 1970 to 1990; these values were subsequently adjusted upwards by 0.7°C as the best estimate of change between pre-industrial times and 1970 to 1990. Results were then calculated

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[28] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

using 21-year periods centred on the year in which average global temperatures increases exceeded either 2.0°C or 2.5°C according to each particular projection. Thus these results cannot be taken as if occurring around a particular year as per the normal IPCC projections.

A summary of the models used, of the emissions scenarios employed with each model, and of the year in which each model/scenario combination produced global temperature increases exceeding the two thresholds, plus that at 1.5°C, is provided. The typical approach of the IPCC is to consider climate projections from a number of GCMs at a given time slice, 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 the case herein, with the need to examine changes in climate around times of specific increases in the average global temperature, this approach is not appropriate as the various models respond at different rates to increases in atmospheric GHGs (termed 'climate sensitivity'); hence the projections reach the threshold temperatures (+2.0°C or +2.5°C globally) over a range of dates. The earliest and latest dates when the threshold temperatures are reached are summarised in Table 1[29]. According to these models the earliest and latest dates the [1.5°C] 2.0°C (2.5°C) threshold is exceeded under scenario A1B are [2023 and 2050] 2038 and 2070 (2053 and not until later than 2100), under scenario A2 are [2024 and 2043] 2043 and 2060 (2056 and 2077), and under scenario B1 are [2027 and 2073] 2049 and not until later than 2100 (2068 and not until later than 2100). Not all projections have reached the 2.0°C and, in particular, 2.5°C thresholds by 2100, the time at which the projections terminate (Table 1). Models have been removed from calculations whenever threshold temperatures have not been achieved. Concerns over the validity of the data for one model at the 2.5°C threshold, noted in the Table, resulted in this projection also being removed from the calculations. These calculations have taken into account that there has been a 0.7°C rise in the global average temperature since pre-industrial times. Average temperature values have been calculated using 21-year periods, centred on the year that projections from each specific model/scenario combination exceeded the two specified thresholds. The results therefore do not relate to any particular year.

Because of the differing climate sensitivities of the models, the range of years over which each threshold is reached is not negligible. For the 1.5°C threshold all 41 models/scenarios achieve that increase between 2023 and 2073, a spread of 50 years. Two model/scenarios do not reach the 2.0°C threshold by 2100; for the rest, the spread of years covers 2038 to 2077.

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[29] Years for the 1.5°C and 2.0°C thresholds have been recalculated using a slight different method from that in the earlier Report; on occasion this results in a change of a year or two from the dates listed previously, which is a valid indicator of the uncertainties involved. A listing of "After 2100" means that a sufficiently high values averaged across 21 years have not been found, although some earlier individual years might have temperatures exceeding the threshold.

Similarly for the 2.5°C threshold 9 of the models/scenarios do not reach sufficiently high temperature increases by 2100, with the remaining 32 model/scenario sets doing so between 2053 and 2087.

Table 1: Details of the models used, scenarios under which each model was run, and years that average global temperature increase thresholds of 1.5°C, 2.0°C and 2.5°C were passed

Model Details	Scenarios	Year 1.5°C Threshold exceeded	Year 2.0°C Threshold exceeded	Year 2.5°C Threshold exceeded
BCM2 from the Bjerknes Centre for Climate Research, Norway - http://www.bjerknes.uib.no/default.asp?lang=2	A1B	2038	2051	2063
	A2	2036	2056	2067
	B1	2047	2071	After 2100
CGCM3.1 from the Canadian Center for Climate Modelling and Analysis - http://www.cccma.bc.ec.gc.ca/eng_index.shtml	A1B	2026	2043	2062
	A2	2029	2043	2058
	B1	2036	2060	After 2100
CM3 from the French Centre National de Recherches Météorologique - http://www.cnrm.meteo.fr/gmme/	A1B	2029	2042	2059
	A2	2034	2048	2059
	B1	2036	2064	After 2100
Climate Model Mark 3.0 from the Australian Commonwealth Scientific and Industrial Research Organisation - http://www.csiro.au/science/EMM.html	A1B	2050	2070	After 2100
	A2	2042	2059	2074
	B1	2073	After 2100	After 2100
Climate Model Mark 3.5 from the Australian Commonwealth Scientific and Industrial Research Organisation as above	A1B	2026	2041	2057
	A2	2027	2043	2056
	B1	2028	2049	2076
CM2.0 from the US Geophysical Fluids Dynamical Laboratory - http://www.gfdl.noaa.gov/research/climate/	A1B	2028	2042	2056
	A2	2030	2044	2058
	B1	2027	2052	2078
CM2.1 from the US Geophysical Fluids Dynamical Laboratory as above	A1B	2030	2041	2058
	A2	2033	2049	2064
	B1	2034	2065	After 2100
Version ER of the NOAA Goddard Institute for Space Studies climate model - http://www.giss.nasa.gov/research/modeling/gcms.html	A1B	2034	2057	2081
	A2	2035	2055	2071
	B1	2044	After 2100	After 2100

Model Details	**Scenarios**	**Year 1.5°C Threshold exceeded**	**Year 2.0°C Threshold exceeded**	**Year 2.5°C Threshold exceeded**
CM4 of the Institut Pierre Simon Laplace - http://www.ipsl.jussieu.fr/	A1B	2023	2038	2053
	A2	2027	2043	2056
	B1	2028	2049	2068
ECHAM5 from the German Max Planck Institute for Meteorology - http://www.mpimet.mpg.de/en/home.html	A1B	2034	2047	2059
	A2	2040	2052	2063
	B1	2043	2060	2077 A data issue casts doubt on the validity of these dates
ECHO-G from the German Meteorological Institute of the Rheinische Friedrich-Wilhelms Universität Bonn, the Meteorological Institute of the Korean Meteorological Administration, and the Model and Data Group, Germany/Korea - http://www.meteo.uni-bonn.de/index.en.html and http://www.metri.re.kr/metri_home/english/Introduction/uAboutE.jsp and http://www.mad.zmaw.de/	A1B	2034	2047	2062
	A2	2035	2051	2063
	B1	2041	2061	After 2100
GCCM2.3.2a from the Japanese Meteorological Research Institute - http://www.mri-jma.go.jp/Dep/cl/cl.html	A1B	2037	2054	2073
	A2	2043	2059	2072
	B1	2049	2077	After 2100
PCM1 from the US National Center for Atmospheric Reseach and collaborating laboratories - http://www.cgd.ucar.edu/pcm/	A1B	2037	2056	2087
	A2	2040	2060	2077
MIROC3.2(MEDRES) of the Centre for Climate System Research of the University of Tokyo and the Frontier Research Centre for Global Change - http://www.ccsr.u-tokyo.ac.jp/ehtml/etest.shtml and http://www.jamstec.go.jp/frcgc/eng/	A1B	2025	2039	2056
	A2	2024	2045	2059
	B1	2031	2052	2077

2.1.4 GLOBAL AND REGIONAL PROJECTIONS

Without doubt global average temperatures are amongst those climate parameters simulated with greatest inter-model agreement, although even here projections for the year 2100 from all models and scenarios differ across a range of about 5°C[30]. Regional temperature projections carry rather greater uncertainty, although there is little doubt that land areas will uniformly become warmer, the only uncertainties being in the extent and timing of the warming.

According to the IPCC[31] there is now greater confidence in precipitation projections than there was at the time of the previous assessment, but even so, regional precipitation projections need to be treated with some caution. There is some consistency amongst the models for decreases in rainfall over Central America through the 21st Century, whereas even the sign of the future trend in rainfall over the Amazon Basin is considered uncertain.[32]

Ensemble means, as discussed previously, provide the best-available deterministic projection, but ideally full distributions across all models should be considered in decision making; the greater the spread across the ensemble (as indicated in this Phase II Report by maximum and minimum values) the less confidence that should be placed in any values suggested by the ensemble mean.

2.2 CARIBBEAN REGION SCENARIO RESULTS

2.2.1 TEMPERATURE

Annual and seasonal temperature changes according to the ensemble means are illustrated in Figure 1 for the A1B scenario. To create the ensemble mean, differences were calculated between 1970 to 1990 values and values around the threshold dates as simulated by each model independently, and then the results averaged. The map on the left of both Figure 1 and Figure 2 illustrate changes at the 2.0°C threshold, the middle map at the 2.5°C threshold, and the map at the right the difference from the 2.0°C to the 2.5°C threshold.

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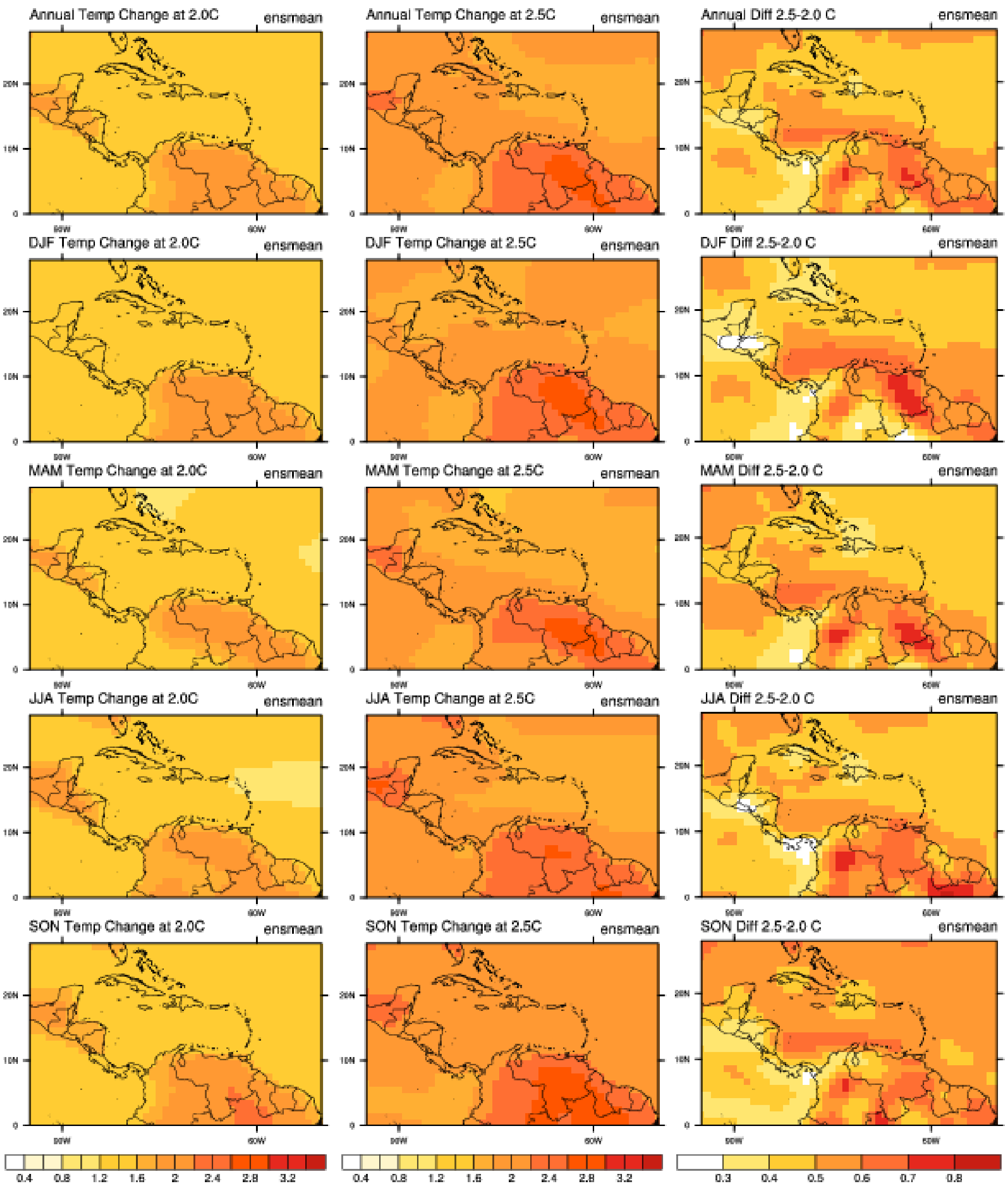
[30] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[31] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[32] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

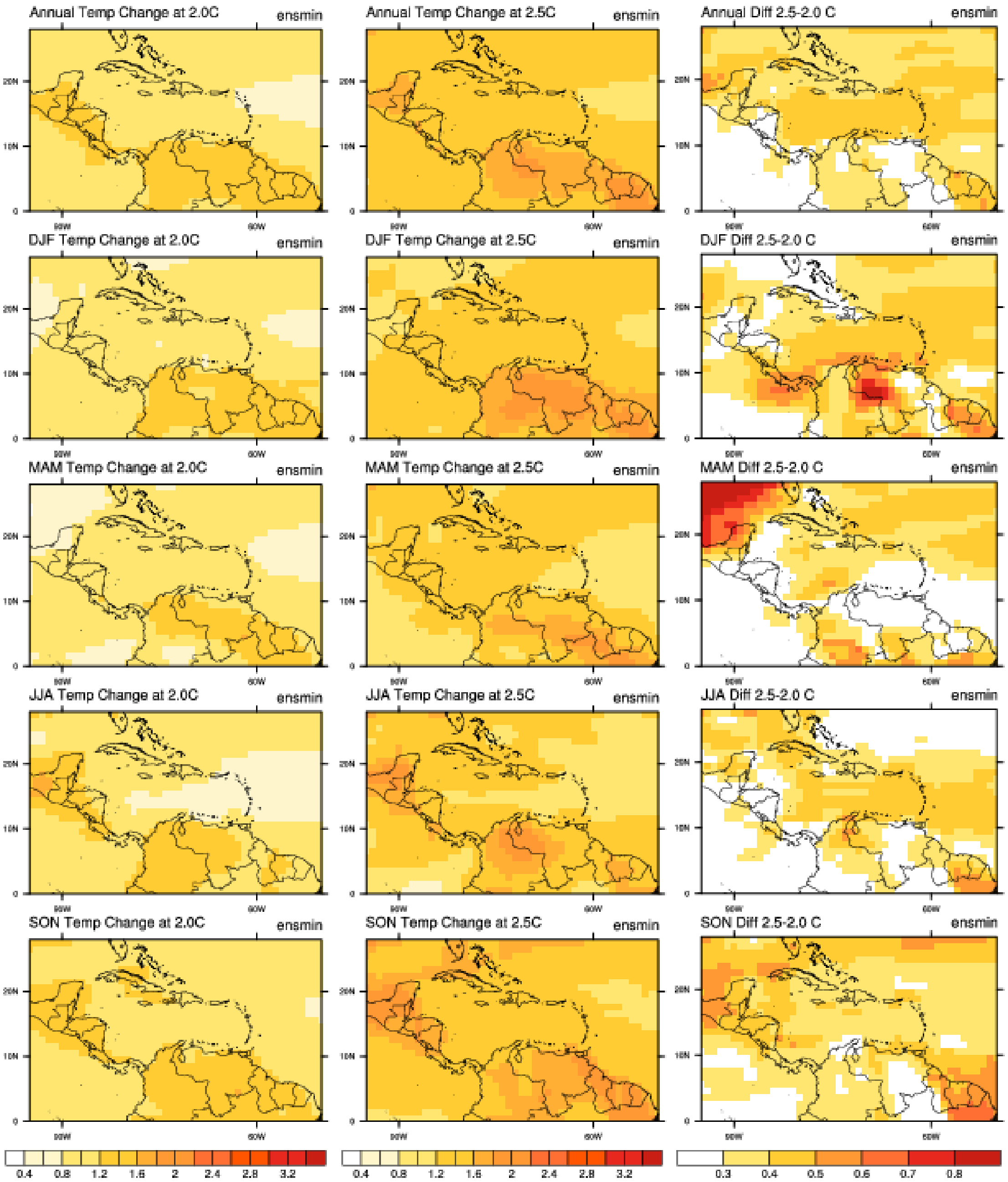
Figure 1: Annual and seasonal air temperature changes over land under scenario A1B according to the ensemble mean



The basic pattern of change is familiar from Phase I, with largest changes over continental interiors and for the higher threshold. In general the warming over the islands is less than that in the global average, as greatest warming is typically expected over continental interiors (in particular at higher latitudes) balanced by lesser increases across the oceans. The additional warming expected over the islands at the 2.5°C threshold according to the A1B ensemble mean is typically 0.4-0.5°C, whereas it might exceed 0.6°C over some continental areas.

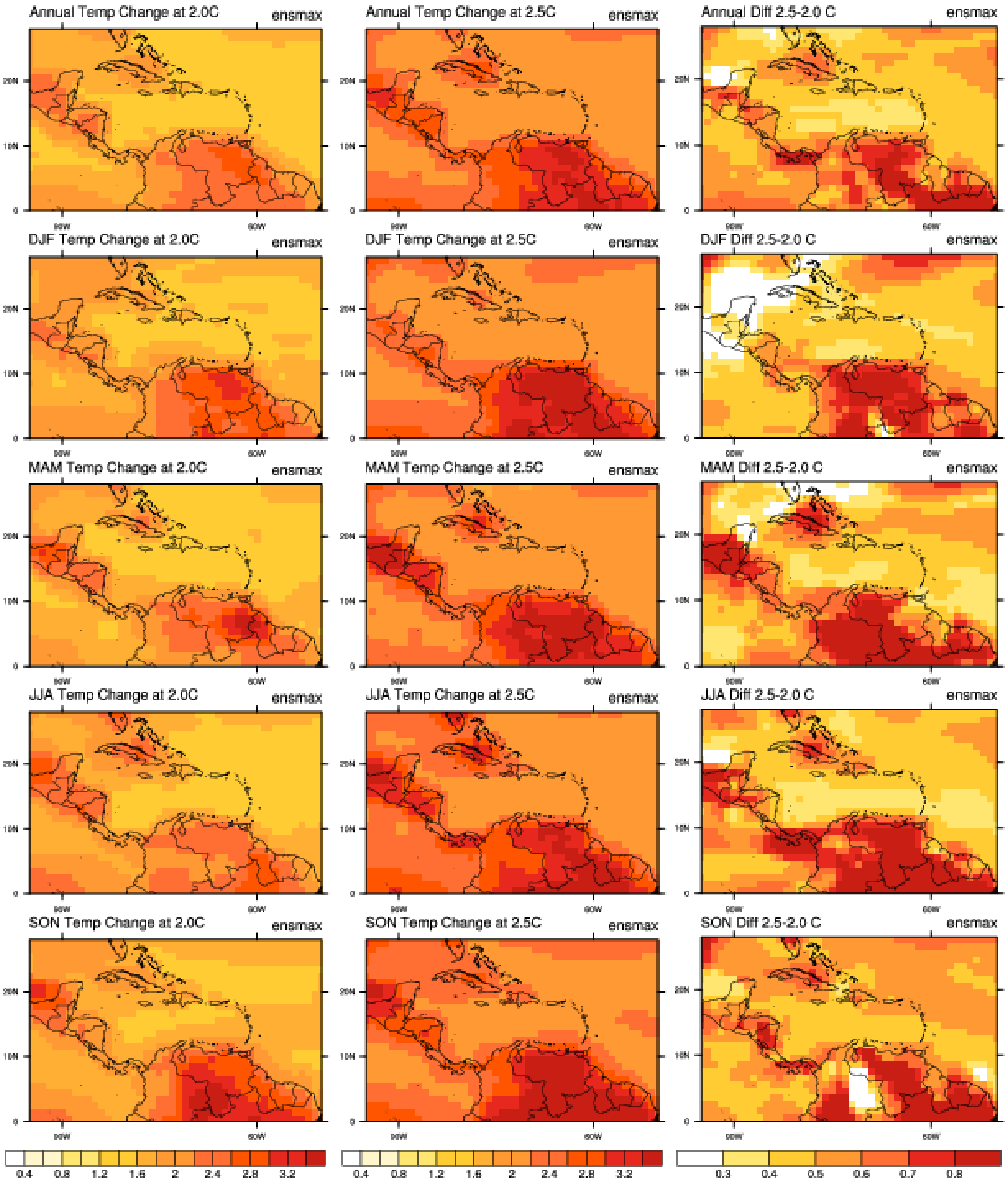
As noted earlier, the ensemble mean provides only the best deterministic estimate of change, some indication of the uncertainties in the projected changes being provided through the minimum (Figure 2) and maximum (Figure 3) values across the ensemble, each value being calculated independently for each grid point and thus the figures may reflect changes projected by more than one model.

Figure 2: Minimum annual and seasonal air temperature changes under scenario A1B according to the ensemble mean



As calculations are being made at specific temperature thresholds (rather than at specific time slices) it might be expected that the range of temperature values across the ensemble would be relatively small (although this does not apply to rainfall). Any differences between the model projections will reflect the different manners in which each model simulates regional climates. Minimum values within the ensemble (Figure 2) are perhaps 0.4°C cooler than those in the ensemble mean while maximum values (Figure 3) are typically about 0.4°C warmer. Values from all other projections are distributed within the limits indicated in the two figures. There is no way in which a 'best' figure can be identified, nor, in fact, certainty that temperature changes will lie within the limits indicated. Planning should take into consideration the full range of possibilities.

Figure 3: Maximum annual and seasonal air temperature changes under scenario A1B according to the ensemble mean



Certainly through much of the early part of the 21st Century GHG concentrations under the A1B and A2 scenarios are similar, a fact reflected in the temperature projections under A2. The A2 projections show no substantive differences from those under A1B, and are not illustrated here. Smaller increases would be expected under the B1 scenario, and in general this is the case at the 2.0°C threshold, but the differences are only perhaps 0.2°C. At the 2.5°C threshold the calculations have proved unrepresentative as so many of the models reach this threshold only after 2100 and thus unrepresentatively large values occur in the remaining models, but if a full analysis were possible then it is likely the temperature difference between the A1B and B1 scenarios would be similar to that at 2.0°C, or perhaps a little larger.

Changes in average temperatures tell only part of the story, with changes in maximum and minimum temperatures often more important in terms of impacts. While these might have been examined in similar manner to mean temperatures as above, there is perhaps more illumination in looking at daily maximum and minimum temperature distributions than there is examining averages. The difficulty is that, recalling that the models are less capable of simulating regional climates than they are the global climate, simulations of climate over areas the size of CARICOM nations are likely to be achieved with even less capability.

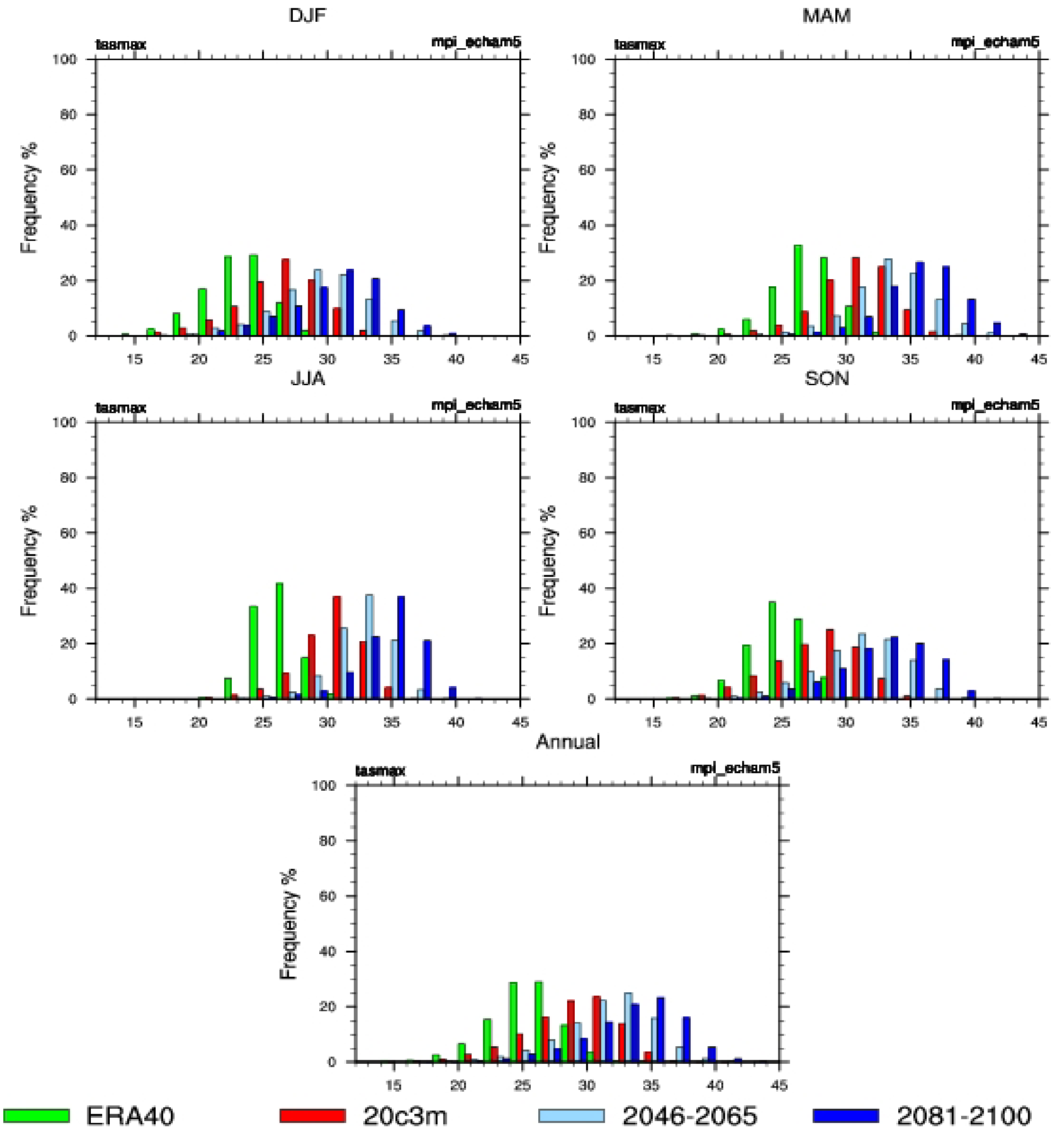
The way around the difficulty is to examine relative changes, rather than to interpret results in an absolute sense. Daily distributions of maximum and minimum temperatures, as illustrated in Figures 4 to 9 below, have been calculated for selected locations, with at least one per CARICOM country, for each of the models separately. There are 668 individual distributions available for each of maximum and minimum temperatures; only a sample will be discussed here. Unfortunately the design of the IPCC database is such that daily data are available only across two periods, 2046 to 2065 and 2081 to 2100. In general these periods will not accord precisely with the threshold dates as listed in Table 1, but it can be used to provide a rough indication of the temperature increases achieved in each of these two periods with daily data by each of the models; roughly speaking the 2046 to 2065 period corresponds to the 2.0°C threshold crossing date of many models and the 2081 to 2100 period with the 2.5°C threshold crossing date (although some models do this rather earlier and so would have exceeded a 2.5°C rise by these years).

In each of the distributions there are four separate sets of data. The first, shown in green, is derived from a calculated set of observed values for the period 1970 to 1990 known as ERA40. ERA40 data have been calculated by advanced weather prediction models, and so are not actual observations and may differ somewhat on a daily basis from in situ measurements (in particular for rainfall). However the ERA40 distributions should provide a more-than reasonable representation of past distributions at each point. The ERA40 distributions should be compared with those in red, labelled 20c3m. The 20c3m distributions are calculated from each model for the 1970 to 1990 period; comparison with the ERA40 distributions provides an indication of the fidelity with which each model is able to simulate real distributions at each point. The two blue distributions indicate model simulations during the 2046 to 2065 (light blue) and 2081 to 2100 (dark blue) periods; these should be compared with each other and with the 20c3m distribution, to examine distribution changes from the present to the two periods, but not with the ERA40 distribution. There are five plots per distribution set, covering each season plus the year.

Temperature results will be illustrated only for the Max Planck Institute ECHAM5 model using the A1B scenario. There is no particular reason for selecting this model or this scenario over any other; for temperature the results are broadly the same for all models and scenarios. To provide some geographical representativeness results will be provided for Belize, The Bahamas, Jamaica, Dominica and Guyana.

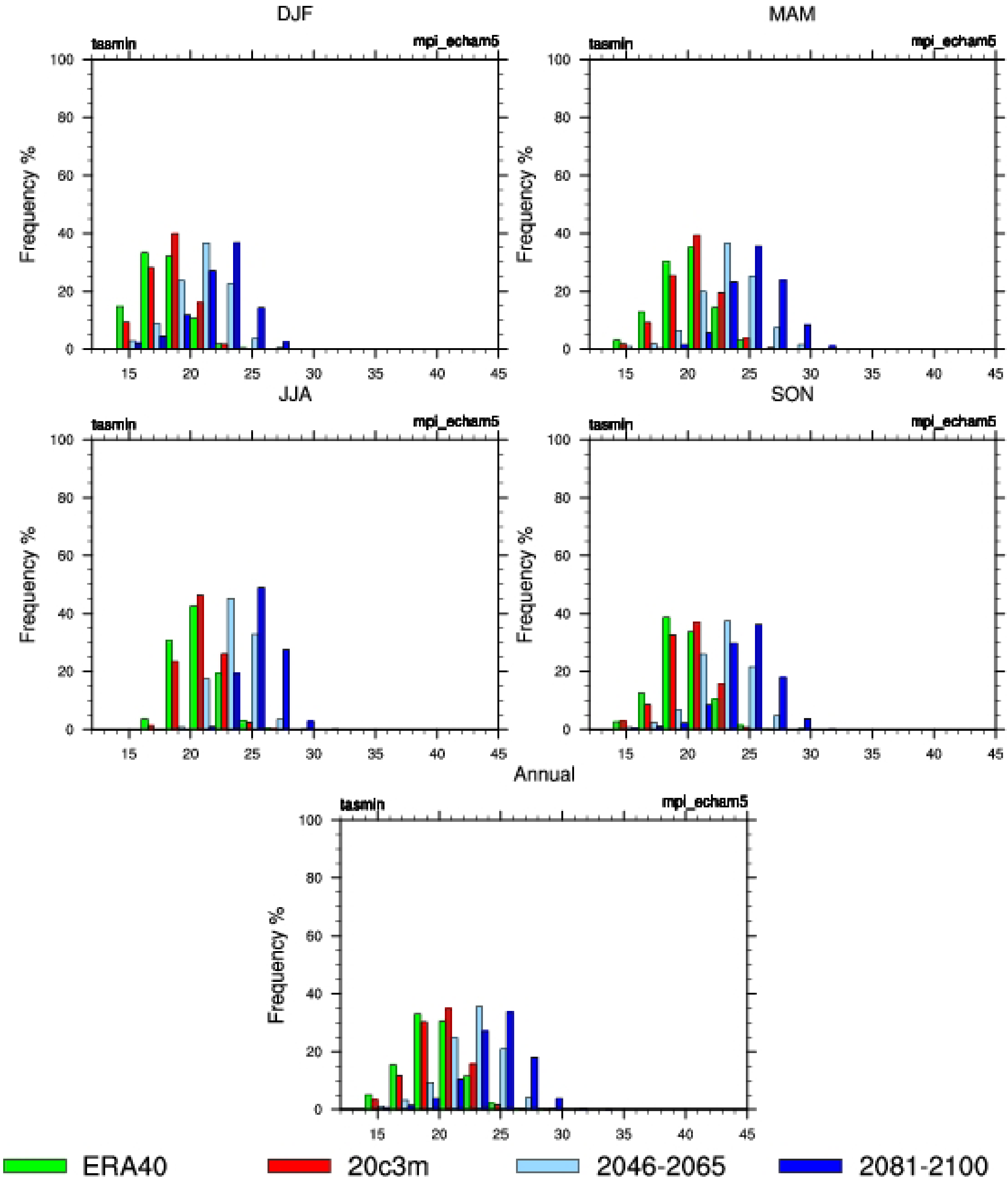
Distributions for maximum temperatures in Belize (Figure 4) indicate that the model simulates temperatures too warm in general compared to observations. There is a clear increase in the frequency of higher temperatures by 2046 to 2065, with a further increase to 2081 to 2100. Maximum frequencies of higher temperatures increase by about 2°C to 2046 to 2065, and by a further 2°C to the later period. There is increased frequency of the hottest days, especially by 2081 to 2100.

Figure 4: Distribution of maximum air temperature under scenario A1B in Belize according to the Max Planck Institute ECHAM5 model



Distributions of minimum temperatures for Belize are illustrated in Figure 5. The basic story is similar to that for maximum temperatures, with a general increase in minimum temperatures simulated and an increase in the frequencies of warm to hot nights.

Figure 5: Distribution of minimum air temperature under scenario A1B in Belize according to the Max Planck Institute ECHAM5 model



Essentially the same story is repeated for the remaining locations, although the exact details change a little. Distributions are provided in Figures 6 to 9 for maximum temperatures only, without further commentary.

Figure 6: Distribution of maximum air temperature under scenario A1B in The Bahamas according to the Max Planck Institute ECHAM5 model

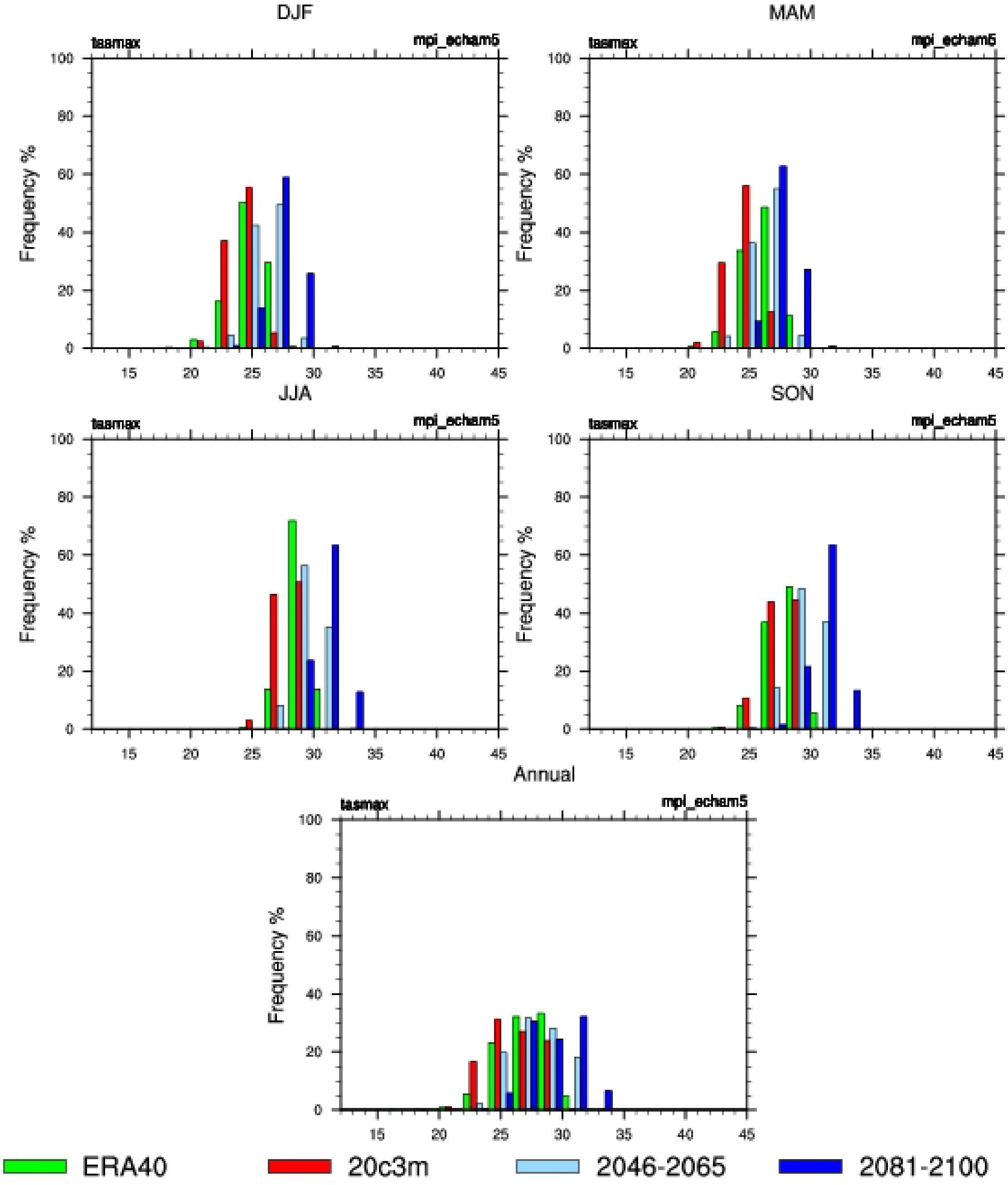


Figure 7: Distribution of maximum air temperature under scenario A1B in Jamaica according to the Max Planck Institute ECHAM5 model

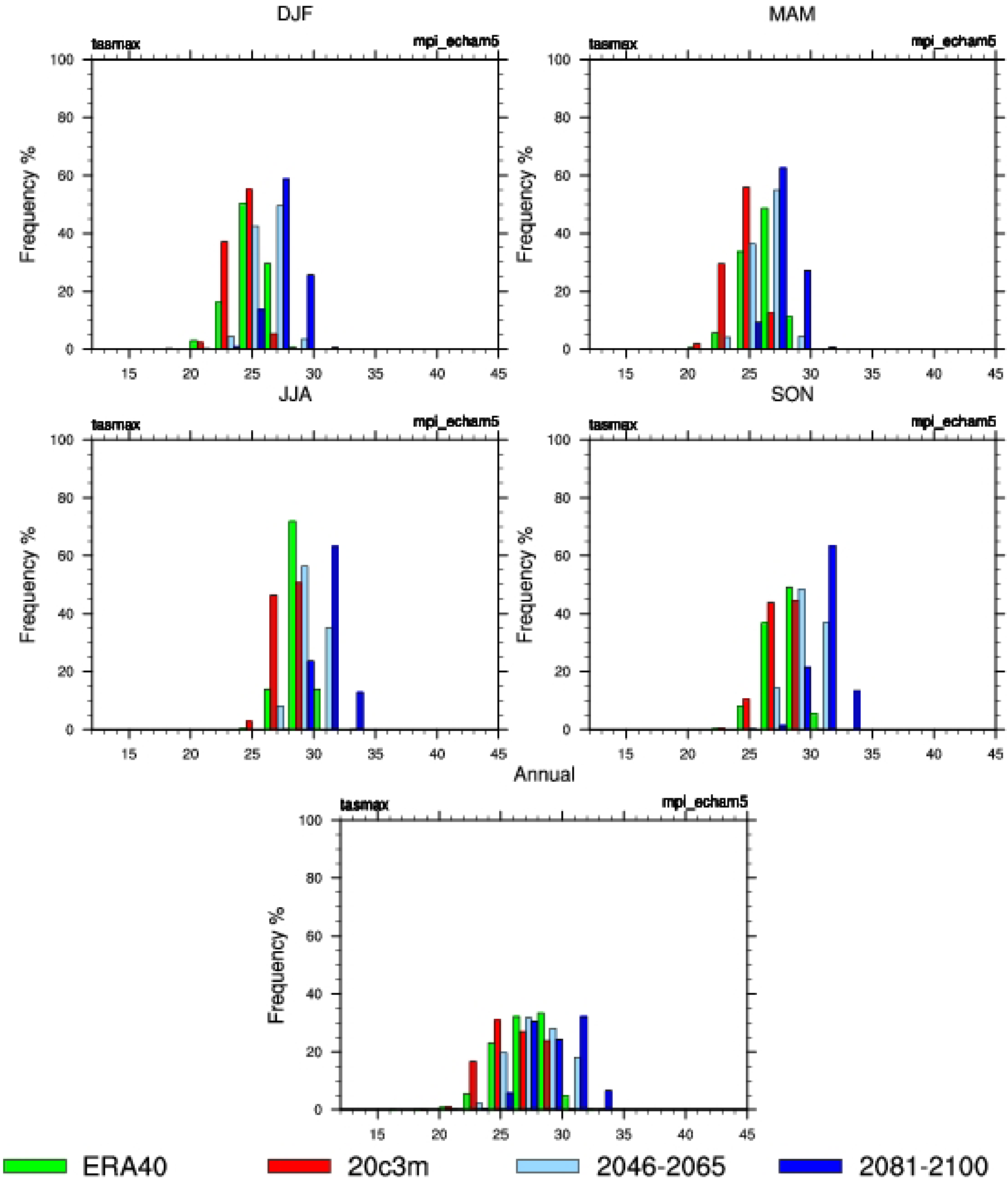


Figure 8: Distribution of maximum air temperature under scenario A1B in Dominica according to the Max Planck Institute ECHAM5 model

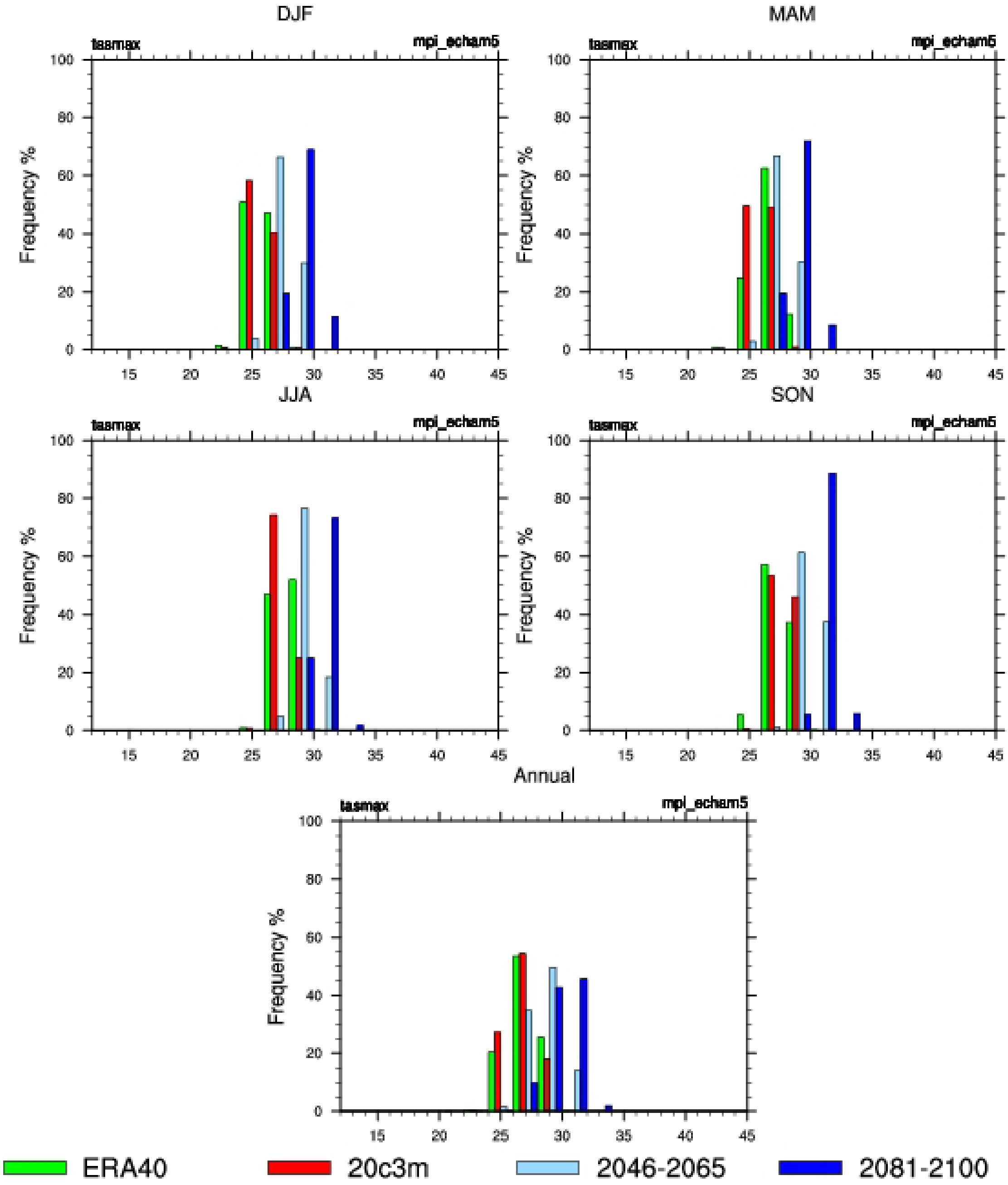
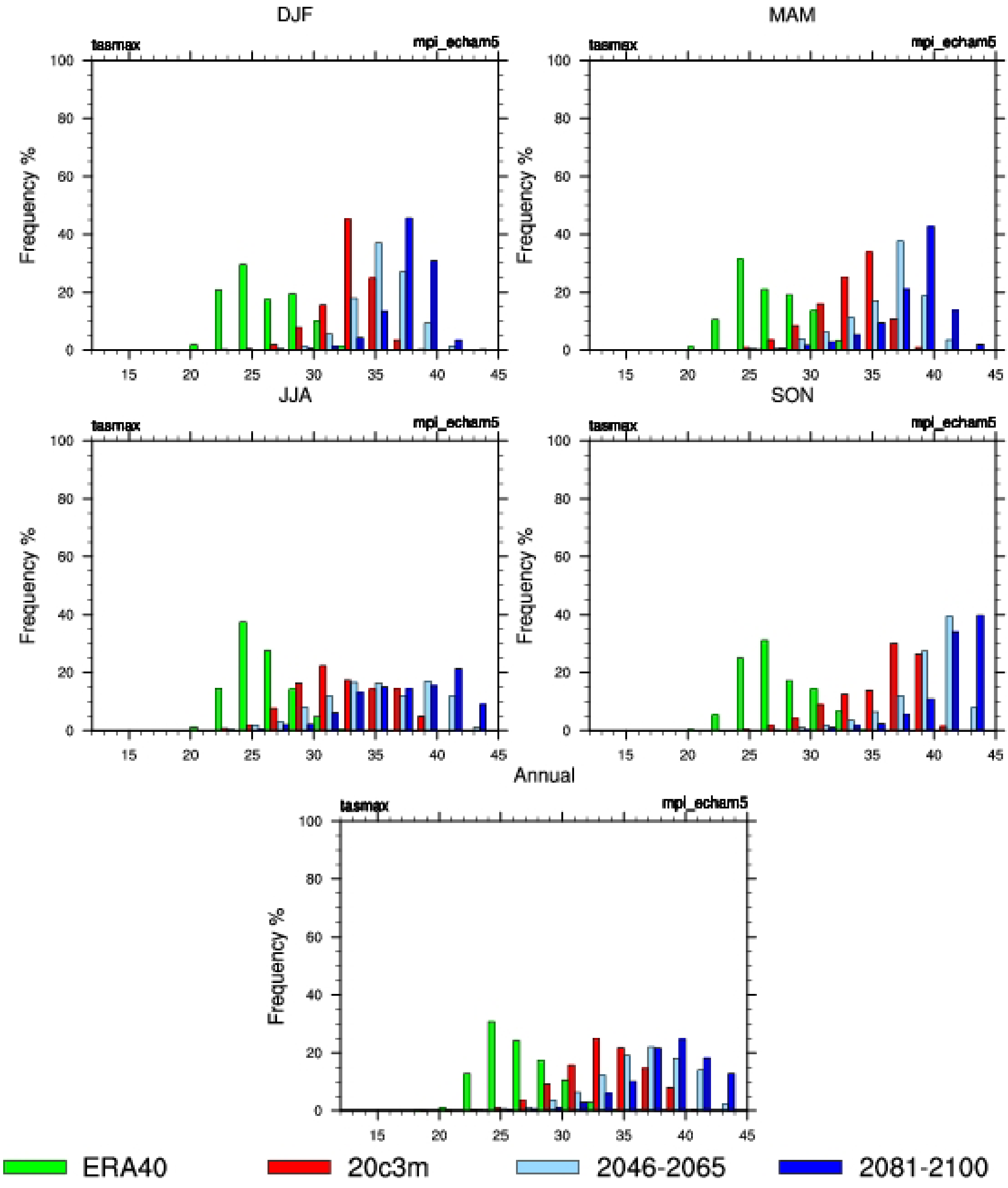


Figure 9: Distribution of maximum air temperature under scenario A1B in Guyana according to the Max Planck Institute ECHAM5 model



The basic pattern remains of the distributions shifting to higher temperatures in time, with increases in the frequencies of hot days (and, while not shown, warm to hot nights). Note that often the blue distributions reach warmer temperatures than any in the red distributions, suggesting that not only will days and nights become warmer but there will be frequent days and nights warmer than anything typically experienced at present.

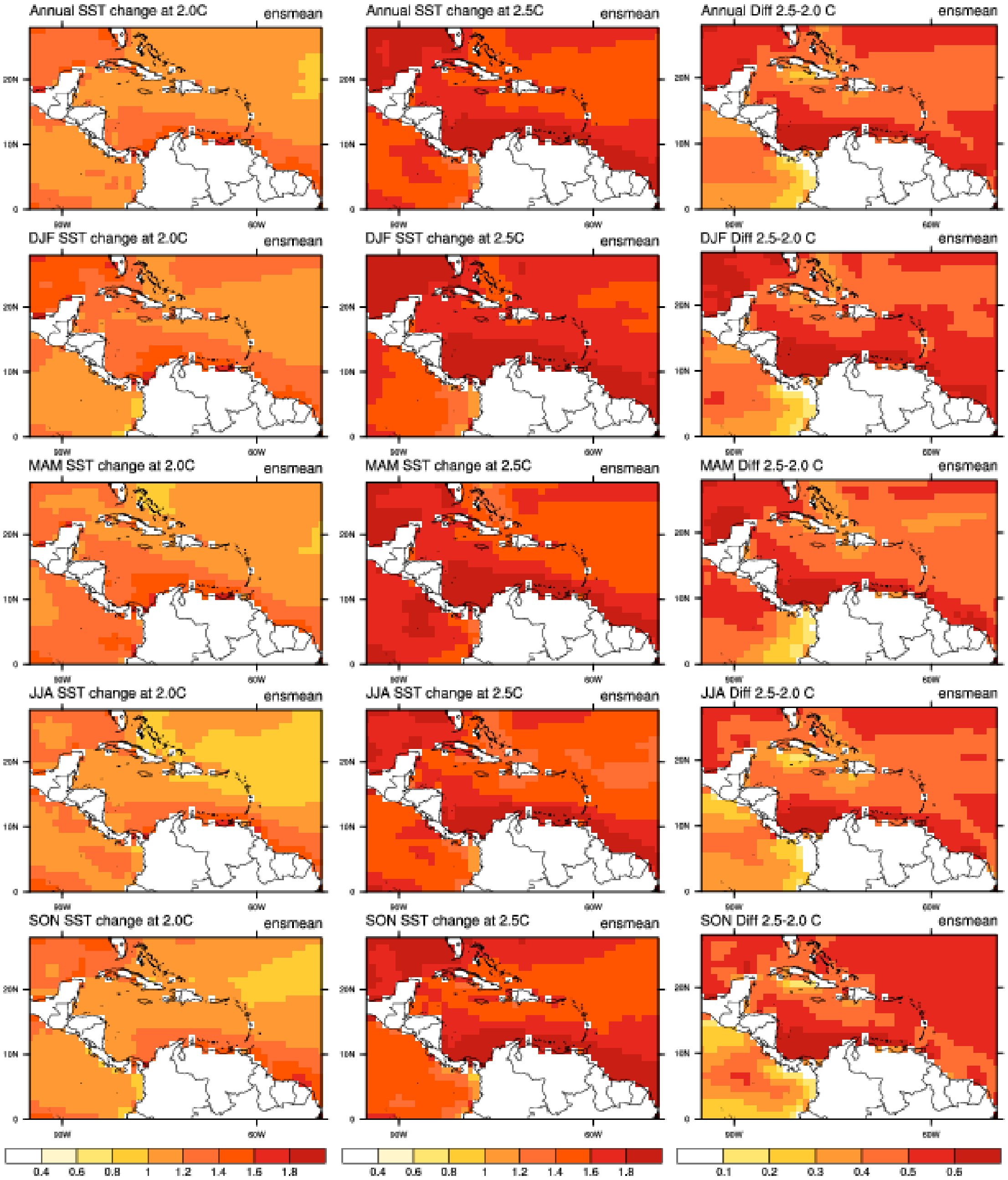
Results are also similar for scenario B1. Warming continues over the Caribbean as the average global temperature rises. The uncertainty around these mean figures is about ±0.4°C. The increased temperatures result from an across-the-board increase in daily temperatures, with more hot days and warm/hot nights and fewer cool days and nights, some being warmer than generally experienced at present. Average air temperatures are projected to increase in all seasons, more so in land than over oceans and in coastal locations.

2.2.2 SEA SURFACE TEMPERATURES

Results for sea surface temperatures (SST) in the Caribbean are equivalent to those for air temperatures, especially in the oceanic areas. Differences between the three scenarios are relatively small and adequate representation may be given by the ensemble mean under scenario A1B (Figure 10).

SSTs increase steadily, but slightly less so than the global average air temperature. The range of simulated increases is roughly 0.6°C. Maxima and minima for SSTs have not been calculated, but may be expected to resemble those for air temperatures, but with lesser ranges.

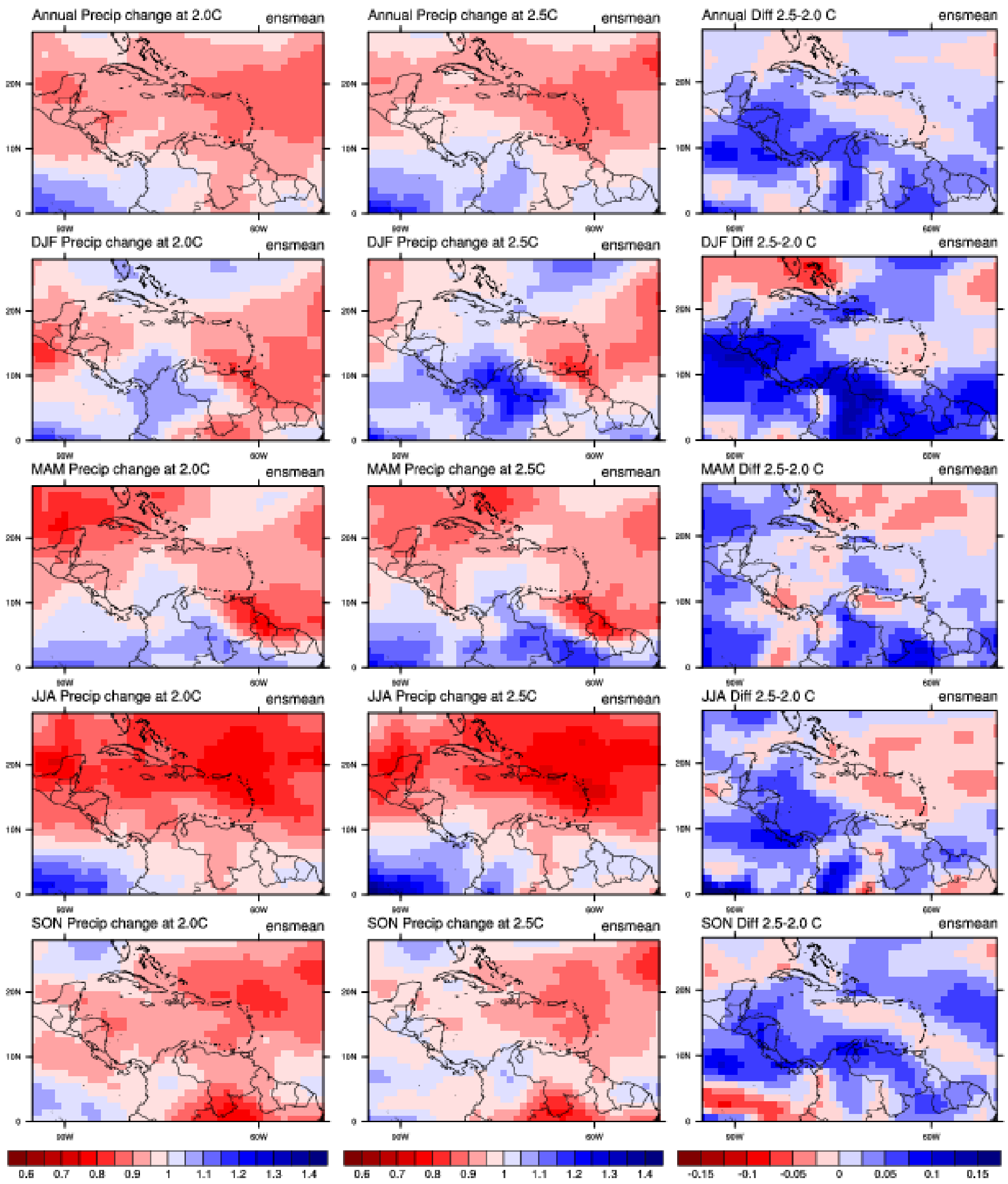
Figure 10: Annual and seasonal sea surface temperature changes under scenario A1B according to the ensemble mean



2.2.3 RAINFALL

On a regional scale there is rather less agreement and more uncertainty between model projections for rainfall than for temperature. Further, it must always be borne in mind that unlike temperatures, which given unrestricted emissions might trend continually upwards, rainfall trends are unlikely to be consistently in the same direction at any particular point throughout the 21st Century.

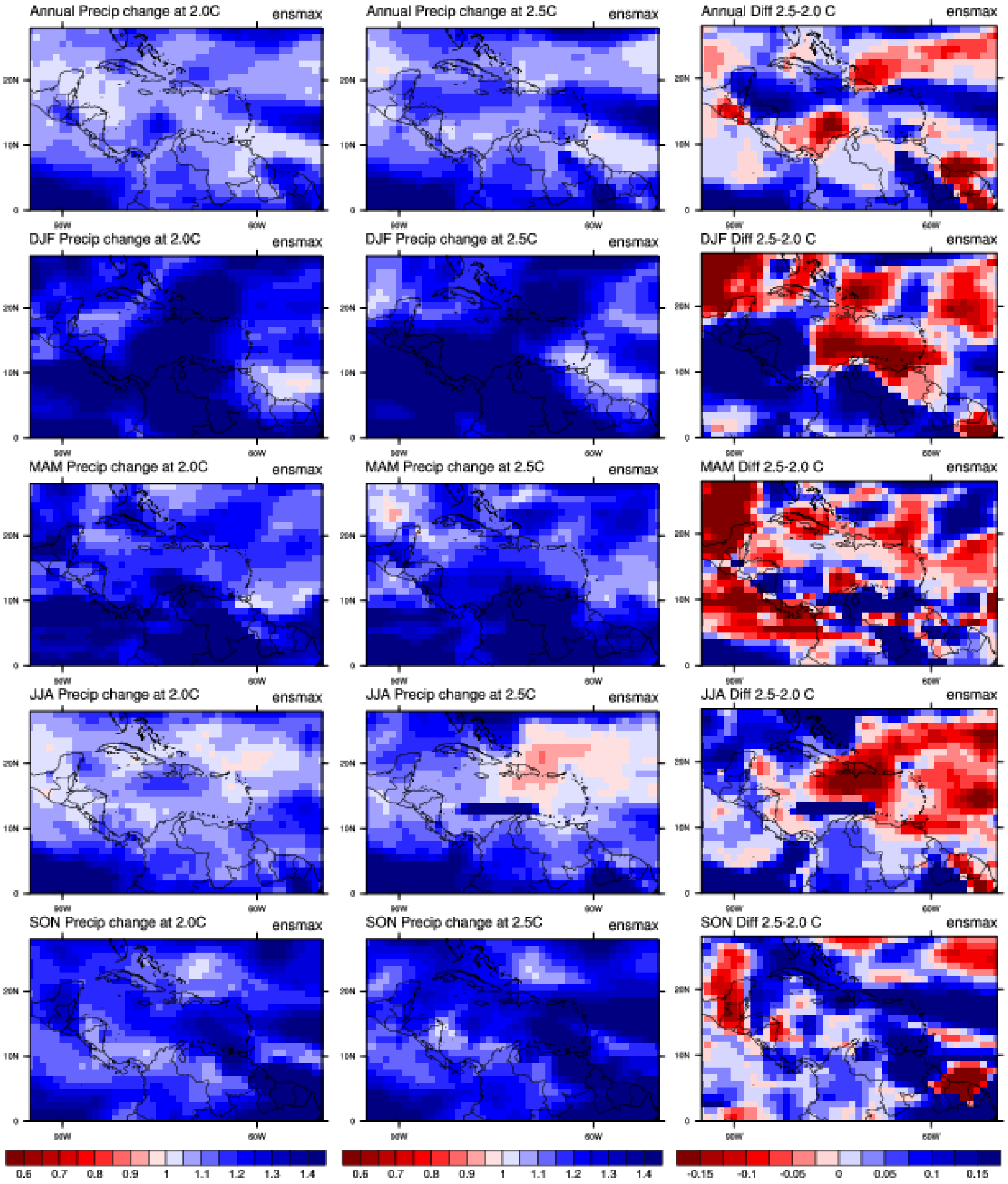
Figure 11: Annual and seasonal rainfall changes under scenario A1B according to the ensemble mean



The results presented here should only be treated as snapshots around each threshold temperature, but there is no reason shorter-term trends of opposing directions might not occur. The ensemble mean for the A1B scenario (Figure 11) resembles those given in the Phase I Report, with broadly reduced rainfall over the Caribbean and increases over parts of Latin America. For many areas, however, rainfall is higher according to this analysis at the 2.5°C threshold than at that at 2.0°C. If this is correct then the drying trend by similar amounts to air temperatures (maps not shown) and are projected initially appears to reverse over much of the area once the 2.0°C threshold is exceeded, although in general rainfall does not recover to current levels within this time frame.

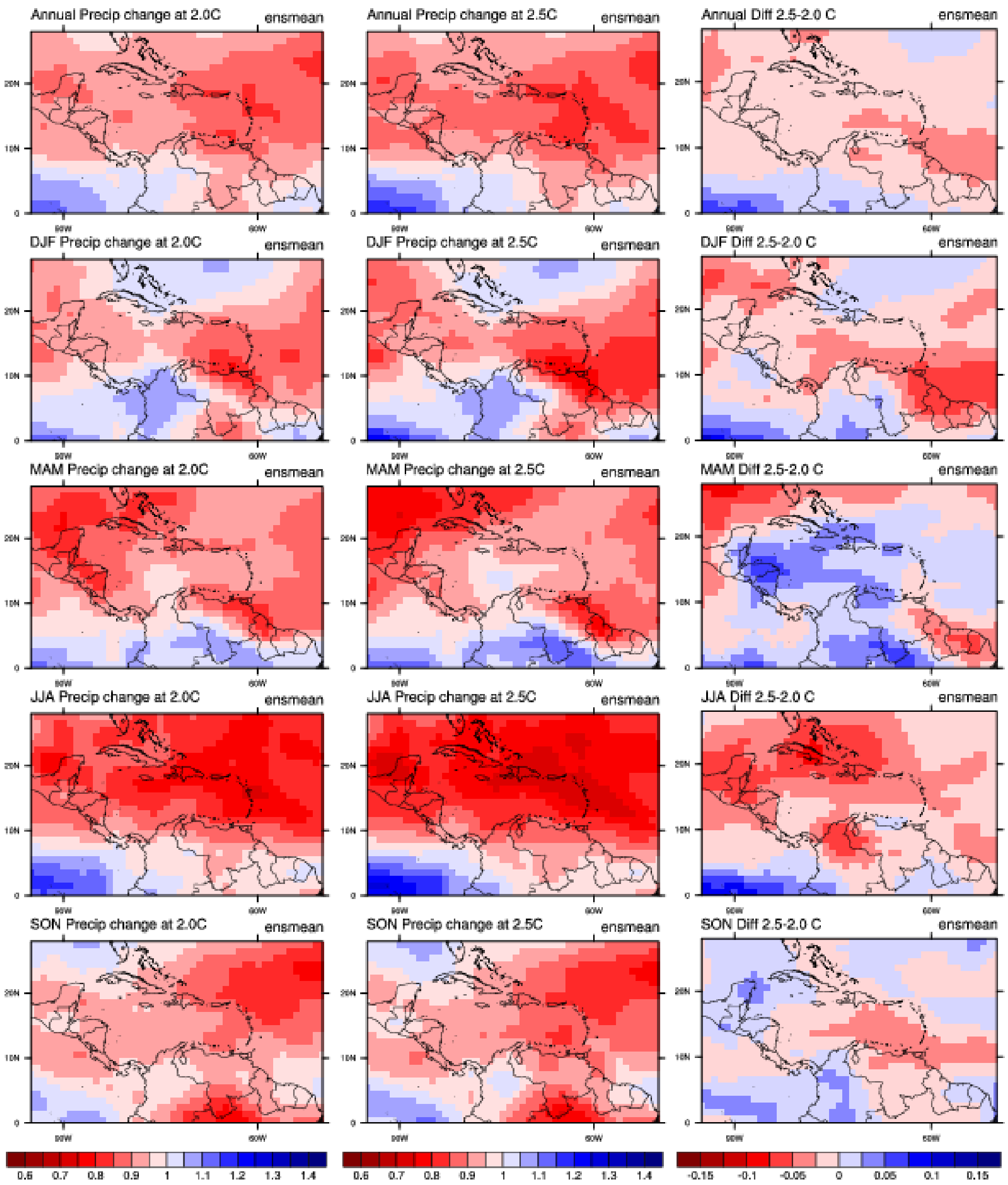
A more complex picture emerges when maximum (Figure 12) and minimum (Figure 13) values within the ensemble are considered.

Figure 12: Maximum annual and seasonal rainfall changes under scenario A1B according to the ensemble mean



With few exceptions the entire region becomes wetter according to the maximum values in the ensemble (Figure 12), although some drying occurs in a number of areas once the 2.0°C threshold is passed. For some areas increases are in excess of 40%. A reverse position occurs with minimum values (Figure 13), drying exceeding 40% in places although perhaps with some recovery after the 2.0°C threshold is crossed.

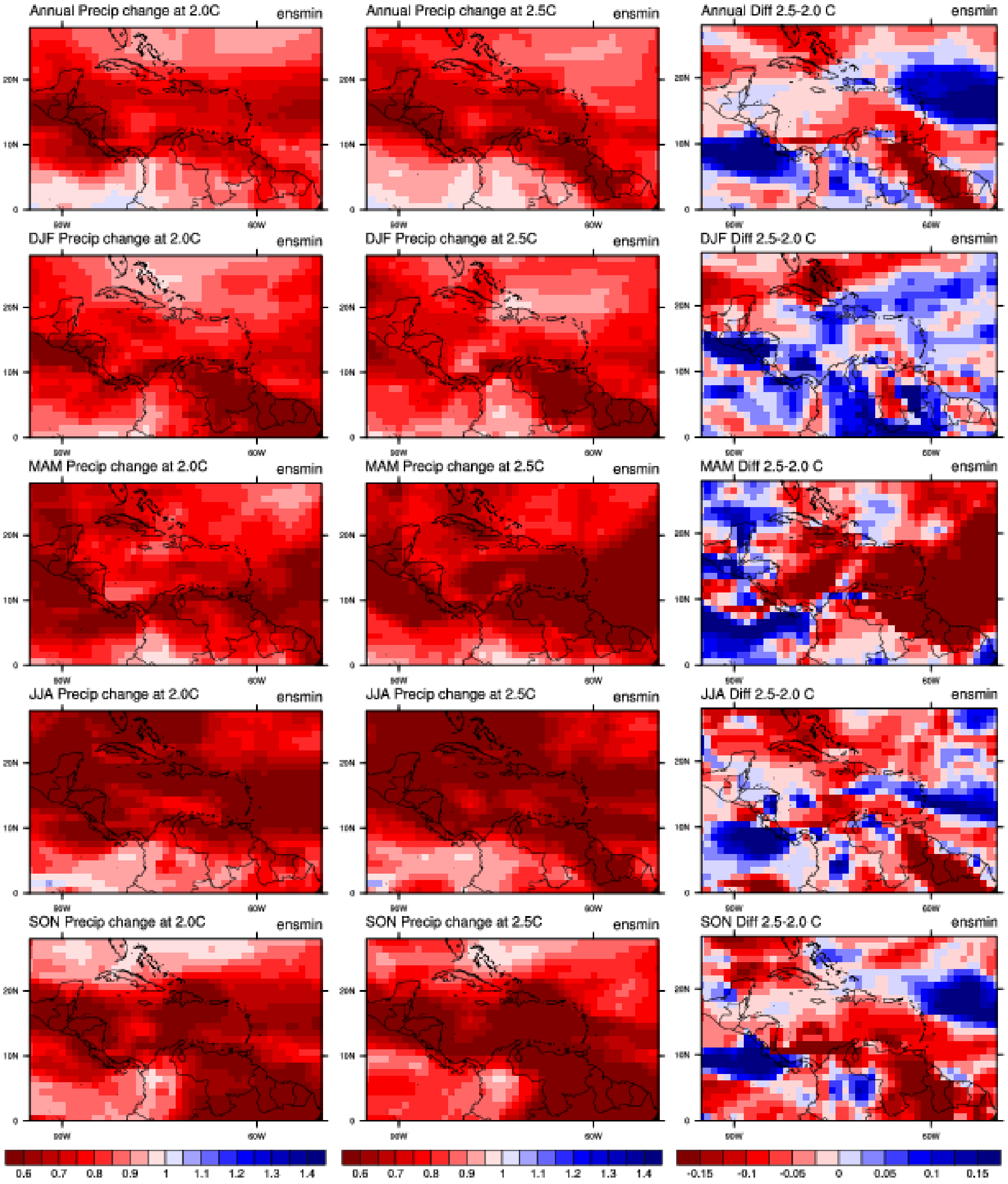
Figure 13: Minimum annual and seasonal rainfall changes under scenario A1B according to the ensemble mean



Estimates have also been made of changes in daily rainfall amounts, with one anticipated result that the GCMs do not simulate daily rainfall distributions with great precision. No overriding pattern emerged from a study of the results, with some models suggesting that an increase in the frequency/intensity of heavier rainfall events might occur, and others suggesting that rainfall intensities may decrease on a daily basis. No overall conclusions may be drawn regarding daily rainfall distributions, nor for daily wind speeds, which similarly to rainfall, increase in some models and decrease in others.

Under scenario A2 (Figure 14) the ensemble mean position is rather different to that under scenario A1B (Figure 11); although at first glance the two figures might look similar the downward trend in rainfall continues under A2 after the 2.0°C threshold has been passed whereas under A1B some recovery occurs. Maximum and minimum values under A2 resemble those under A1B (Figure 12 and Figure 13) and are not reproduced here.

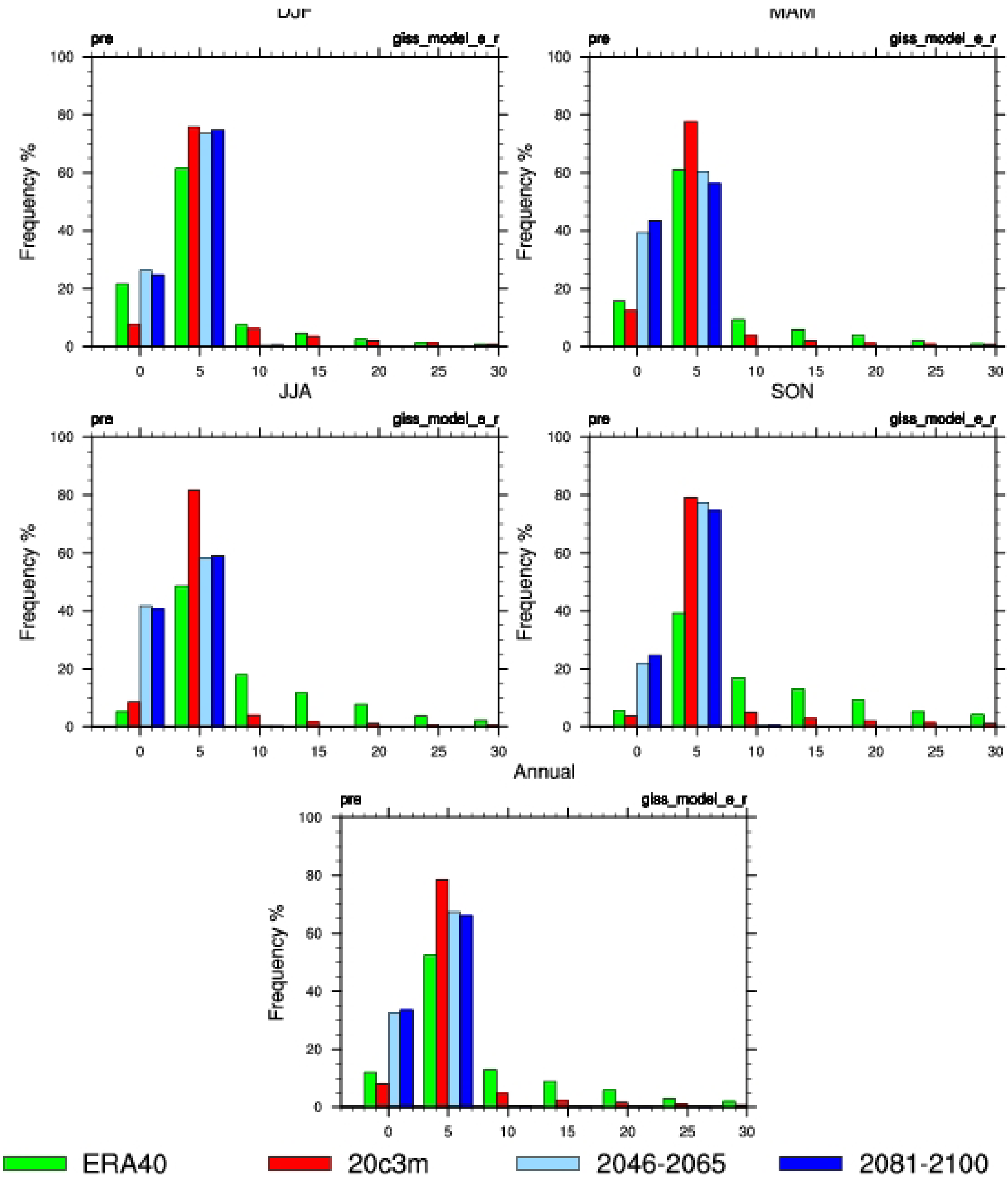
Figure 14: Annual and seasonal rainfall changes under scenario A2 according to the ensemble mean



Rainfall under scenario B1 at the 2.0°C threshold is similar to that under A1B, although in places, in particular over some continental areas, projected drying exceeds that under A1B. As for temperatures there are insufficient models to provide a valid ensemble mean estimate for the 2.5°C threshold under B1, although the range of values represented within the remaining models is similar to that under A1B and A2.

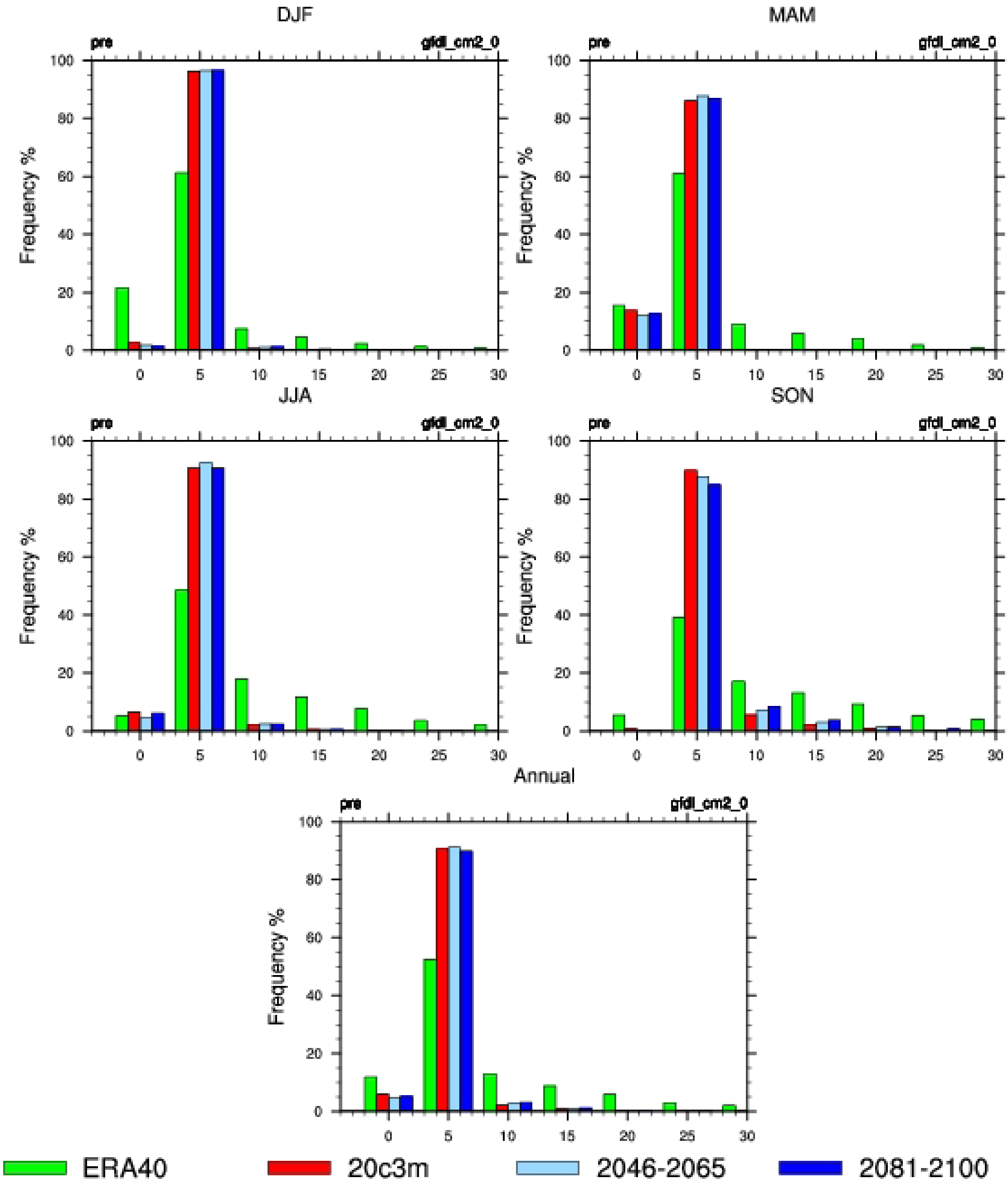
As with temperatures, distributions of daily rainfalls at selected points have been examined; these are presented in similar format to those for temperature and the notes regarding the layout of the distributions given in section 2.2.1 apply. However, a further caveat needs to be introduced regarding rainfall distributions. All weather and climate models face challenges in simulating the highest rainfall rates, although as a rule of thumb, better performance is achieved with higher resolution models. The model used for ERA40 is of lower resolution than those currently used for weather forecasting and is known to underestimate the frequencies of the heaviest events. All of the climate models used by the IPCC have substantially lower resolution than the ERA40 model, and it is characteristic of the distributions that the climate models underestimate the frequencies of heavier events compared to ERA40. Because of their lower resolutions climate models also suffer difficulties in simulating hurricanes together with their rainfall and wind systems. It is reasonable to expect that the distributions following will lose some realism because of these factors related to resolution. Because of the large number of distributions developed for various locations from the 41 individual projections (as set out in section 2.1) and two temperature thresholds, only a representative set of results can be presented.

Figure 15: Daily rainfall distributions (mm/day) for Jamaica from the GISS ER model



Jamaica: Perhaps the model providing results closest to that in the ensemble mean over Jamaica is the GISS ER model (see Table 1). This model fails to capture any of the high intensity events (Figure 15). However distributions at the two temperature thresholds (in shades of blue) are similar, and in both cases there is a reduction in the frequencies of heavier events and an increase of lighter events.

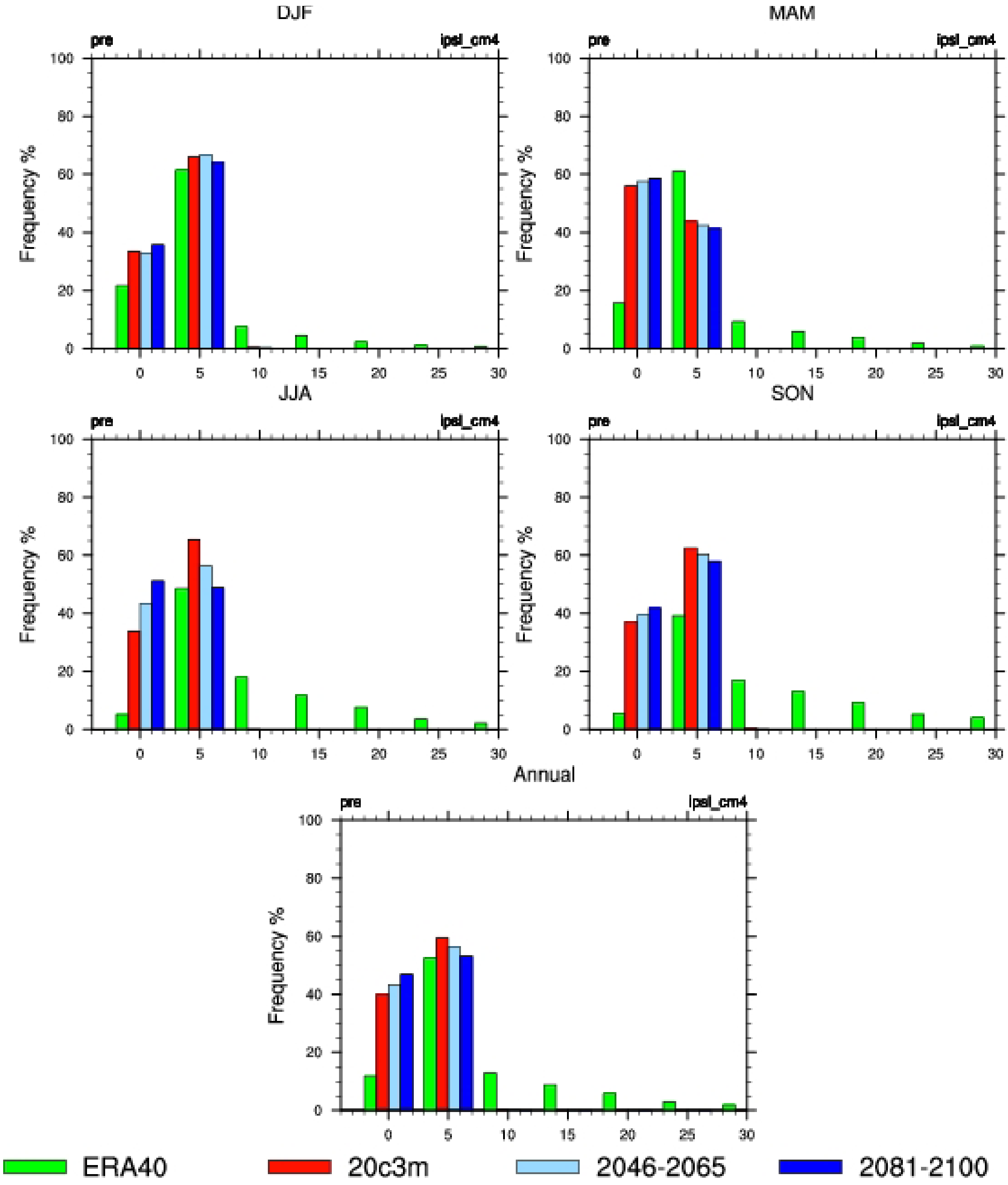
Figure 16: Daily rainfall distributions (mm/day) for Jamaica from the GFDL CM2.0 model



The GFDL CM2.0 is one of those projecting rainfall increases over Jamaica, but in general there is minimal change in the relative frequencies, suggesting than an increase in days of rain is a major contributor to the increases (Figure 16). Note, however, the suggestion from the model of an increase in the more intense events during the latter part of the hurricane season, which is in

September, October and November (SON). The IPSL CM4 model is one projecting strong rainfall decreases for Jamaica; as with the GISS ER model this suggests fewer high intensity days and more lower intensity rainfall days (Figure 17).

Figure 17: Daily rainfall distributions (mm/day) for Jamaica for the IPSL CM4 model



The basic pattern, as outlined above, continues through the remainder of the distributions. Where a model is projecting a decrease in rainfall this is normally seen as a reduced relative frequency of heavier rainfall events and an increased frequency of lighter events; it is possible there may be reductions in the absolute frequencies of heavier events also. Conversely where a model is projecting an increase this is typically seen as a relatively increased frequency of heavier events at the expense of the lighter events; again there may be increases in the absolute frequencies of heavier events.

While some of the models appear incapable of simulating the heaviest rainfall events, typically those associated with tropical cyclones and hurricanes, some, encouragingly, appear to have the ability to produce some of these intense events, although none to the frequencies according to ERA40. Equally encouraging is the fact that most of the models simulate all, or the larger portion, of these intense events during the main hurricane season (SON in the charts). However, there is disagreement amongst the models as to changes in frequencies of these events; in some cases the frequencies remain largely unchanged, in some cases they become less frequent (perhaps suggestive of reduced hurricane frequencies/intensities overall), and other cases they become more frequent (thus suggestive of increased hurricane frequencies/intensities).

2.2.4 WIND SPEEDS

Daily wind speed distributions may be investigated in similar manner to temperature and rainfall. In the case of rainfall, models tend not to be able to simulate the frequencies of heavier rainfall events well, but in the case of winds models can various under- and over-simulate wind speeds. The technical reasons behind this are complex, and include the abilities of each model to simulate cyclones in the various regions of the globe. Nevertheless, as with rainfall, some insight into changes associated with hurricanes might be gained from examination of wind speeds.

For example, for Jamaica, the GISS ER model tends to underestimate wind speeds (Figure 18) while the CSIRO Mk3.0 model overestimates them (Figure 19) – in both cases compare the distributions with the green “ground truth” plots from ERA40. The change in distributions is complex but in both models there is perhaps a suggestion that higher wind speeds might increase a little as climate change progresses, especially in the hurricane season of SON. However there are others, such as the MRI CGCM2.3.2a model that point to wind speed decreases in SON (Figure 20). While no detailed count has been made, a review of the distributions through the CARICOM region suggests that the models are roughly evenly distributed, with perhaps slightly more indicating decreases as indicate increases, with other models simulating little change.

Various data and sources have been investigated to elicit the response of hurricanes to global warming, including examination of rainfall trends, daily rainfall and wind speed distributions and changes in large-scale atmospheric patterns, but the conclusion remains similar to that given by the IPCC in 2007: *'Based on a range of models, it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical SSTs. There is less confidence in projections of a global decrease in numbers of tropical cyclones.'*[33]

While some new evidence suggests that hurricanes may decline in frequency and intensity, it is not possible to be confident in this and the distinct possibility of increased frequencies/intensities cannot be denied.[34,35,36 37,38,39]

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[33] IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of WorkingGroup I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. pp. 15.

[34] Holland, GJ and Webster, PJ. 2007. Heightened tropical cyclone activity in the North Atlantic: natural variability or climate trend? Philosophical transactions of the Royal Society A-Mathematical, Physical and Engineering Sciences, 365(1860), 2695-2716.

[35] Kossin, J.P., Knapp, K., Vimont, D.J., Murnane, RJ., and Harper, B.A. 2007. A globally consistent reanalysis of hurricane variability and trends, Geophysical Research Letters, 34 (4).

[36] Elsner J.B., Kossin, J.P. and Jagger, T.H. 2008. The increasing intensity of the strongest tropical cyclones Nature 455(7209), 92-95.

[37] Knutson, T., McBride, J., Chan, J., Emanuel, K., Holland, G., Landsea, C., Held, I., Kossin, J., Srivastava, A.K., Sugi, M. 2010. Tropical Cyclones and Climate Change. Nature Geoscience. 3, 157-163, doi:10.1038/ngeo779.

[38] Bengtsson, L., Hodges,K. and Keenlyside, N.2009. Will Extratropical Storms Intensify in a Warmer Climate? Journal of Climate, 22(9), 2276-301.

[39] Zhang, R., and Delworth, T.L. 2009. A new method for attributing climate variations over the Atlantic Hurricane Basin's main development region, Geophysical Research Letters, 36, L06701, doi:10.1029/2009GL037260.

Figure 18: Daily wind speed distributions for Jamaica from the GISS ER model

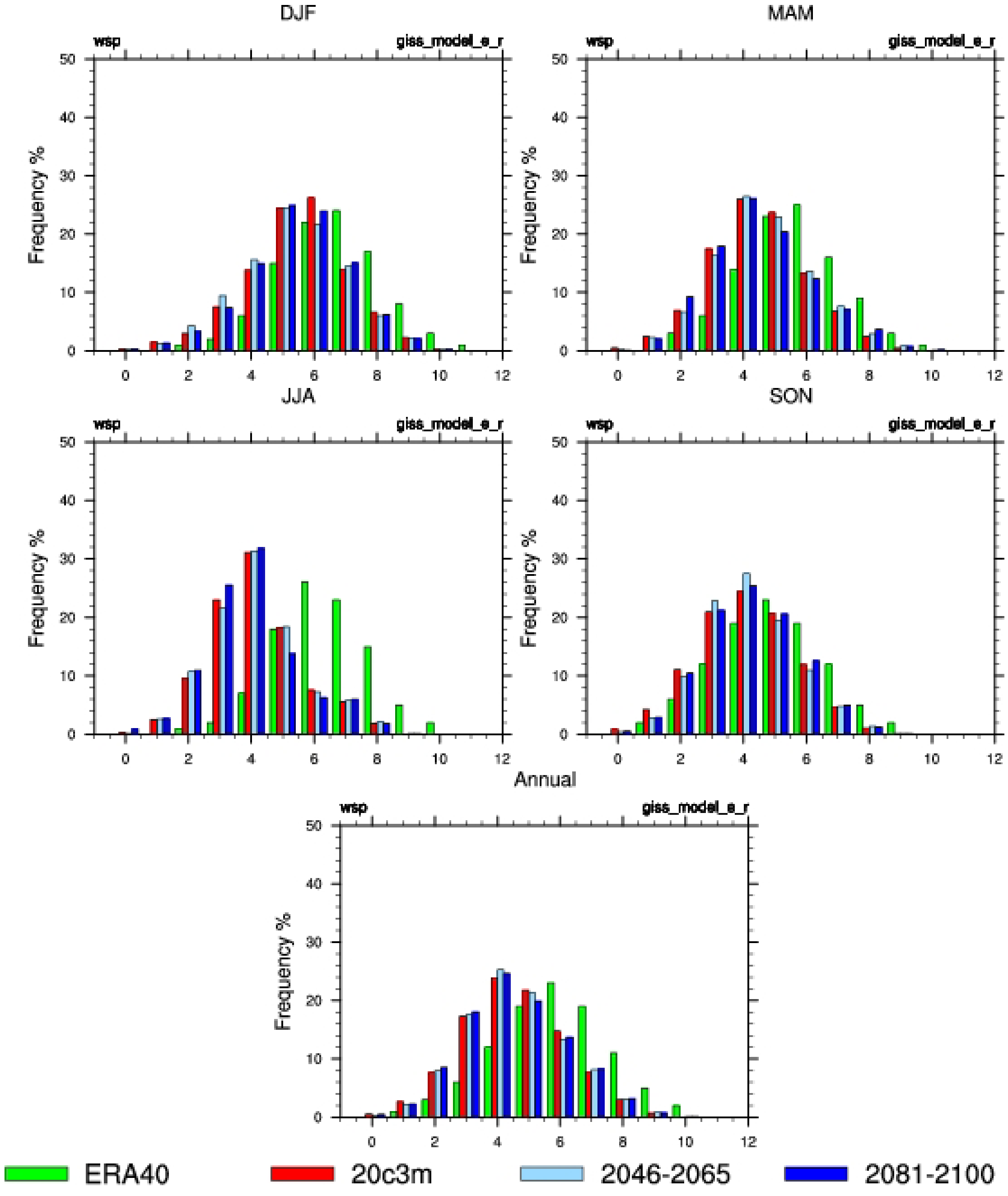


Figure 19: Daily wind speed distributions for Jamaica from the CSIRO Mk3.0 model

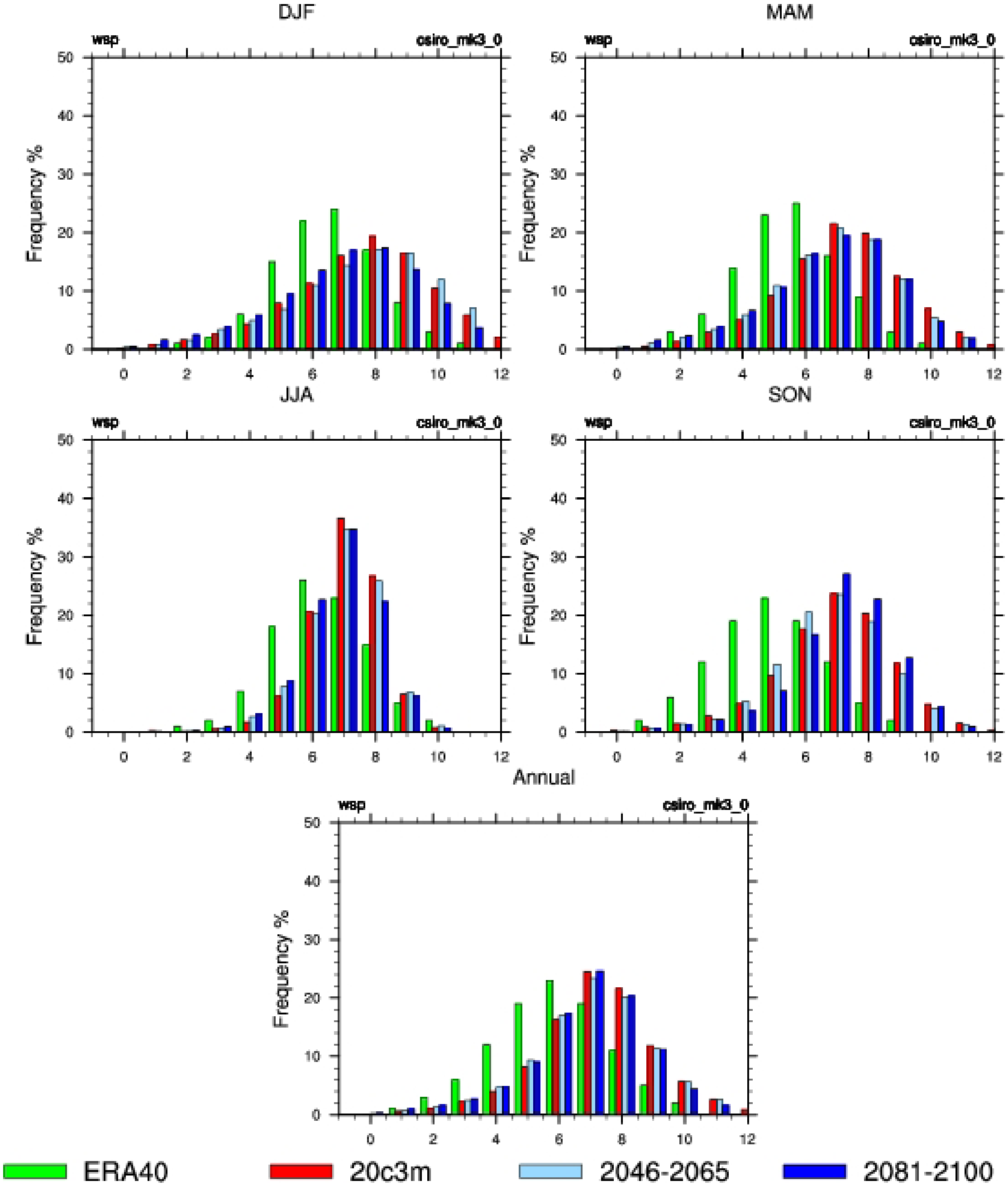
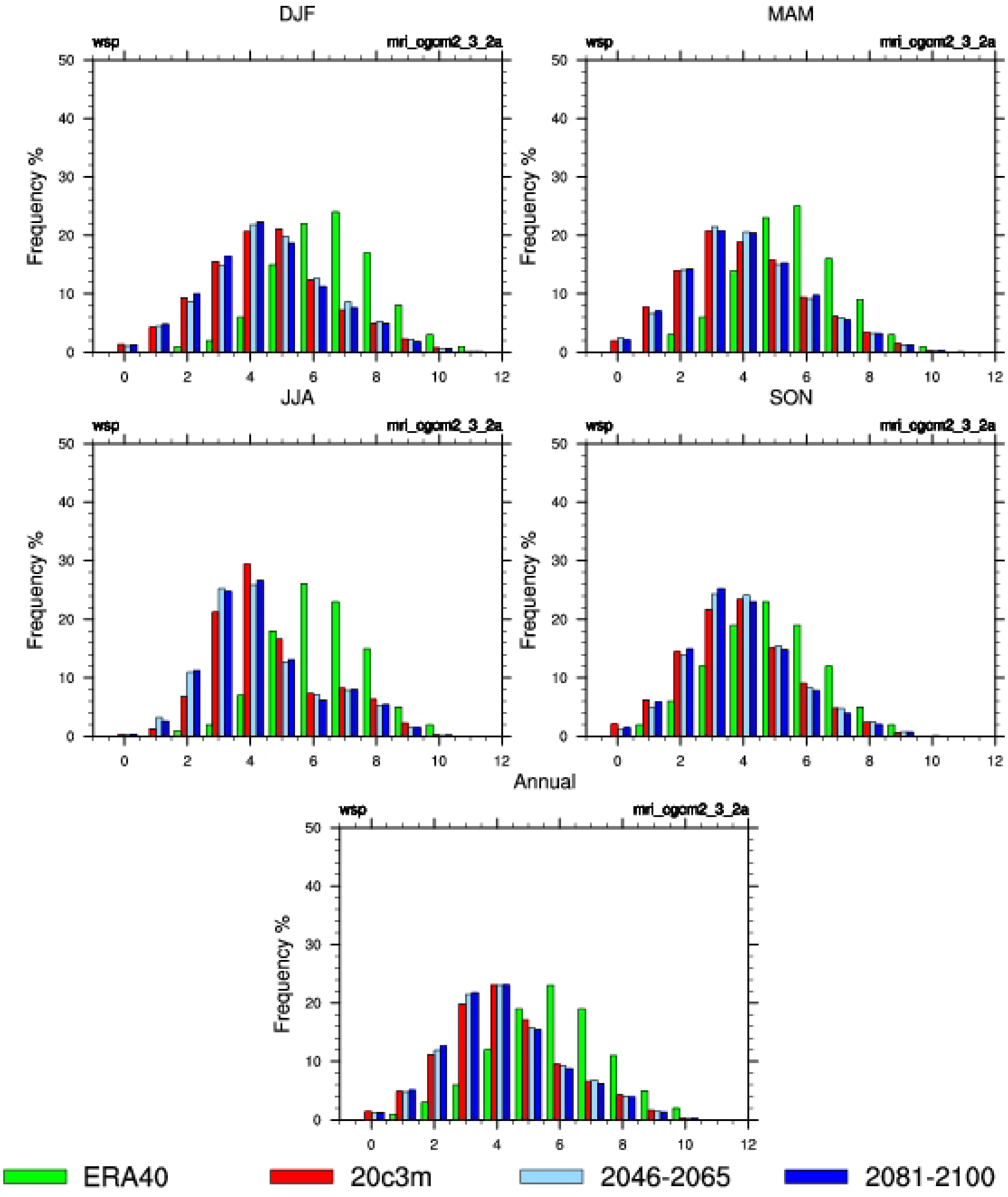


Figure 20: Daily wind speed distributions for Jamaica from the MRI CGCM2.3.2a model



2.3 INTERPRETATION OF THE CLIMATE MODELLING RESULTS

The uncertainties in the projections have been illustrated rather more vividly in the current results than was possible in the Phase I Report. For temperatures the uncertainties are readily assessed: both air and sea temperatures over the CARICOM region will continue to increase alongside global temperatures, but will be lower than the global average. For air temperatures distance from the coast is an important factor, larger rises being anticipated in continental interiors than in areas influenced by SSTs. The range of uncertainty is around 0.8°C centred roughly on the values given by the ensemble mean, which are typically about 1.3°C over the islands and 1.5°C over CARICOM continental countries away from the coast at the 2.0°C threshold and respectively about 1.7°C and 2.2°C at the 2.5°C threshold. Naturally at the upper end of the range of uncertainty temperature increases over parts of the CARICOM area would exceed the global average. SST rises are comparable to those for air temperature over the islands. Thus the picture is one of steadily increasing temperatures throughout, with the main dependency in terms of scenario being one of timing, changes occurring later under B1 than under A1B and A2. The higher temperatures result, in part, from higher daily both maximum and minimum temperatures.

For rainfall the picture is more complex, both in space and in time. It might be surprising that, after the generally progressive decreases in rainfall suggested in the Phase I Report, there is a broad wetting trend once the 2.0°C threshold has been passed according to the ensemble mean under scenario A1B. However under A2 the trend towards drier conditions largely continues en route to the 2.5°C threshold. It is unfortunate that the data are insufficient to give a clear indication of trends beyond the 2.0°C threshold under the B1 scenario, as GHG concentrations are rather lower under this than under the other two scenarios, and given the sensitivity of the results between the A1B and A2 scenarios it would have been helpful to examine further uncertainties as revealed under the B1 scenario.

Notwithstanding the trends as suggested by the ensemble means, the maximum and minimum values indicate a rather higher level of uncertainty in the rainfall than in the temperature projections. For all scenarios, with only a few local exceptions, some models suggest wetting trends exceeding 40% in places, while others provide equivalent indications of drying beyond 40%. Up until the 2.0°C threshold is reached the directions of rainfall trends from the ensemble mean are the same; it is only subsequently they become sensitive to scenario. Values given in the ensemble means provide indications of the trend directions simulated by the larger number of models, but there is a higher likelihood of errors being present in the ensemble mean estimates for rainfall than in those for temperatures. Results as published by the IPCC[40] are, reasonably, similar to those given here by the ensemble means, with the additional information that in December to February and June to August, particularly over the central Caribbean islands, over 90% of the models agree on the direction of the trend by 2090 to 2099, namely one of drying. IPCC results do not reveal the range of uncertainty, or the reversal of the trend under scenario A1B, nor the sensitivity of the trends to scenario.

One of the major features of the Caribbean climate is the hurricane, changes in the frequencies and intensities of which could have substantial impacts on the region. The warming of SSTs provides conditions conducive to increased frequencies and intensities of hurricanes. However, that can be offset by changes in the atmospheric circulation over the Atlantic Ocean in manners that have not been investigated here. One indicator that these changes might decrease the frequencies and intensities of hurricanes is given by the fact that many models tend to project trends towards increasing El Niño-like conditions in the future; while there is no absolute connection hurricanes tend to be less common and of lower intensity during El Niño years than at other times. In general the reduction in rainfall in the hurricane season is also suggestive of decreased frequencies and, possibly, intensities of hurricanes.

A reduction in hurricane frequencies and/or intensities is, by no means, a certainty, as some models suggest that rainfall may increase in the future, alongside an increase in heavy rainfall events and in wind speeds. Other models point to decreased rainfall, fewer heavy rainfall events and decreased winds. The IPCC[41] report confirms the inconsistency of the results amongst the climate models used here. However, there is a possibility that the increased rainfall possible under A1B may be associated with an increase in hurricanes once the 2.0°C threshold is passed.

In conclusion, the *timing* of when the atmosphere reaches any particular temperature threshold depends on the so-called climate sensitivity, with some models more sensitive to increases in GHG concentrations, and therefore reaching thresholds faster, than others. *Timing* depends also on the *scenario* used, with thresholds reached more quickly under the higher-

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[40] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[41] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

emissions A1B and A2 scenarios than under B1. Several of the models do not reach the 2.5°C threshold by the end of the 21st Century, particularly under B1. Worst case scenarios are that 1.5°C might be reached by 2023, 2.0°C by 2038, and 2.5°C by 2053; best case dates are 2073 for 1.5°C and not until after 2100 for the two warmer thresholds.

For *temperature*, the increases continue unabated between the various thresholds, with highest increases over the continent rather than the island areas. Perhaps 0.4°C to 0.5°C of additional warming over the islands, and 0.6°C over the continents, could occur by the time the 2.5°C threshold is reached from that at 2.0°C, probably with absolute temperature rises a little below the global average. There is a range of uncertainty of about 0.4°C either way on these values. Warmer temperatures will be accompanied by increased frequencies of hot days and warm to hot nights.

For *SSTs* the increases also continue undiminished, with rises perhaps of 0.4°C to 0.5°C between the 2.0°C and 2.5°C thresholds, although with uncertainties of perhaps 0.3°C on either side of these figures.

For *rainfall* the picture is more complex than for temperature, and perhaps more complex than revealed in the Phase I Report. Certainly the weight of evidence is tipped towards a reduction in rainfall over most of the CARICOM region, except possibly in the northernmost and southernmost parts. By and large that picture of broadly reduced rainfall remains consistent at the 2.5°C threshold. However, it is not certain that rainfall might be less at the 2.5°C threshold than it is at the 2.0°C threshold; under scenario A2 it is, but under scenario A1B some recovery in rainfall takes place – unfortunately too many models do not reach the 2.5°C threshold under scenario B1 for a reasonably clear picture to emerge in this case. There is wide disagreement between the models, however, with some projecting substantial increases in rainfall and others decreases much greater than indicated above. While it might be reasonable to suggest that a decrease in rainfall overall could be expected, contingency planning for increased rainfall should be considered, while it should be recognised that there is a level of certainty in the direction of trends once the 2.0°C threshold is past. Often the models suggest that lower rainfall is accompanied by a decrease in the frequency and/or intensity of heavier rainfall events, but even this picture is not entirely consistent across the models projecting rainfall reductions.

For *wind speed* there is an approximately equal split between those models suggesting the highest winds will increase in frequency and/or intensity, those that project decreases, and those suggesting no real trends.

For *hurricanes* the picture is as unclear perhaps as for rainfall. Much evidence points to a decreased frequency and perhaps intensity of hurricanes, and some to increased frequencies/intensities. Included on the former side are the projected rainfall decreases from the majority of models and the general tendency towards more El Niño-like conditions in the Pacific Ocean in the future, conditions that would be expected in general to be associated with reduced hurricane frequencies/intensities.

The wording used throughout this section is, to an extent, and intentionally, guarded. While the IPCC[42] has attempted to reach some conclusions regarding regional climate change, the reality is that the set of models used in the IPCC AR4 are not strictly up to the task of providing reasonably focussed assessments of future change in the forms that policy makers would prefer. There are many reasons for this, included amongst which are the relatively low resolutions of the models in which calculations are made on grids with sizes typically a few hundred kilometres in the horizontal. Such grid sizes cannot resolve much of the global topography or many of the vital atmospheric processes that determine climate. Equally, calculations in the vertical are somewhat too sparse to resolve key atmospheric features.

Two substantive changes will be incorporated in the IPCC AR5; first many of the global models, equivalent to those used in this Phase II Report, will have been run at rather higher resolutions in both the horizontal and the vertical. Secondly, through a project called CORDEX, even higher resolution information will be available for a number of continental regions, including the Caribbean. There will thus be much greater volumes of available climate change projections, including substantive amounts at resolutions of around 25km in the horizontal, than available currently. Caution must be expressed that this new burst of high-resolution information will not necessarily represent the panacea policy makers seek in terms of information with minimal uncertainties, but it is to be expected that new insights into climate change will be achievable through these coming data sets. That is, of course, provided the resource is available to undertake the detailed examination of the vast amounts of data that will become available that will be necessary.

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[42] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

There is probably a limit to the amount of information that can be mined from the existing data sets. It is quite possible to look at some aspects in more detail, to produce additional ranks of statistics, and perhaps to reveal a little more certainty in the projections than has been achieved currently. But it is a process of declining gains. That it will continue to warm as higher global temperature thresholds are passed is incontrovertible, although the exact degree of that warming might not be fully detailed. But what may happen to the rainfall is rather more clouded (if you will excuse the phrasing) in uncertainties. Even the direction of the trend, downwards in the majority of models, is genuinely open to some doubt. Equally what may happen to hurricanes cannot be stated with absolute certainties. The ranges of uncertainties may be reduced with the forthcoming higher-resolution data sets, but the proof of that remains for the future. In the meantime the best advice is to plan within the full range of uncertainties as outlined in this Phase II Report.

One recommendation given in the Phase I Report, not taken up as yet, was to introduce downscaling of the predictions to scales that would permit assessment of impacts on agriculture, on health, on water supplies, and so on. It is true that many downscaled scenarios undertaken to date are based on only a single global climate model and a single downscaling approach, and thus offering a restricted perspective, often without caveats. Impacts may be assessed based on such downscaling, and policies developed, but there remains the chance that reality will be rather different to these single scenarios. It would be possible at present to undertake downscaling with the set of models/scenarios employed here, and that would provide a much-improved overview of the range of potential impacts on which policies might be based. However, that work would be facilitated with the anticipated new data sets, and once those are available it is recommended that the focus be switched from analysis of climate change per se to analysis of the impacts of climate change and identification of response policy options.

3. Sea Level Rise Projections

3.1 HISTORIC SEA LEVEL RISE TRENDS

The impacts of climate change on global and regional sea levels are complex. An important recent review has placed present and future SLR into its historical and Pleistocene context.[43] For periods up to the last 900,000 years a SLR of 10m per 1,000 years (or 1m per century) was not unusual, even when the system is operating well into a warm interglacial, as now. For example, at the end of the last ice age, the Earth slowly warmed by 4–7°C globally, losing two-thirds of its land ice and raising global sea level approximately 120m in the process (at rates often exceeding 1m per century).[44] It is further argued that while SLRs up to 2m per century are unusual in the record, such rises "are well within the range of a warm system, beyond the 5-percentile of the overall range."[45] Other studies have similarly concluded that there does not appear to be evidence that the present ice-sheet configuration would rule out similar rates of SLR under future global warming.[46]

In the Caribbean region, studies of fossilized coral reefs from the last time the world was warmer than today (approximately 125,000 years ago) found evidence that a SLR of 2m took place in less than a century.[47] 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 120m, and by around 45m over the last 11,500 years[48]. 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.

Although present rates of global SLR are not yet approaching the figures noted above, over the past century the rate of SLR has roughly tripled in response to 0.8°C global warming.[49] The IPCC AR4 in 2007 reported that the mean global sea surface rose by

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[43] Berger, WH. 2008. Sea level in the late Quaternary: patterns of variation and implications. International Journal of Earth Sciences, 97, 1143–1150.

[44] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[45] Berger, WH. 2008. Sea level in the late Quaternary: patterns of variation and implications. International Journal of Earth Sciences, 97, 1143–1150 (pp. 1143).

[46] Schneider von Deimling, T., Ganopolski, A., Held, H. & Rahmstorf, S. 2007. How Cold was the Last Glacial Maximum? Geophysical Research Letters, 33(14), L14709.

[47] Blanchon, P., Eisenhauer, A., Fietzke, J., Liebetrau, V. 2009. Rapid sea level rise and reef back-stepping a the close of the end of the last interglacial highstand. Nature, April, 881-885.-

[48] 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

[49] Rahmstorf S. 2010. A new view on sea level rise. Nature Reports Climate Change, doi:10.1038/climate.2010.29.

1.8±0.5mm/year over the period 1961 – 1993, and by 3.1±0.7mm/year between 1993 and 2003.[50] Updated measurements using only the period when satellite measurements have been available indicate the rate of SLR has now reached 3.4±0.7mm/year, or about 80% faster than the average IPCC model projection of 1.9mm /year.[51]

Available information suggests that SLR trends in the Caribbean have been broadly similar to global trends over this same period.[52] 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 SLR from 1950 to 2000, when the rise in the Caribbean appeared to be near the global mean.[53] Land movement is only imperfectly known in the Caribbean, and it is therefore assumed that about 3.1mm/year applies to all areas.

3.2 FUTURE SEA LEVEL RISE PROJECTIONS

SLR due to climate change is a serious and unidirectional global threat to coastal ecosystems and development, since even if GHG emissions were stabilised in the near future, sea levels would continue to rise for many decades or centuries in response to a warmer atmosphere and oceans.[54] The IPCC AR4 projected a global SLR of 18 to 59cm from 1990 to 2100. These projections of future SLR assumed a near-zero net contribution of the Greenland and Antarctic ice sheets, on the basis that Antarctica was expected to gain mass from an increase in snowfall. However recent research suggests that both ice sheets have been losing mass at an accelerating rate over the past two decades. A number of experts have criticized the IPCC's SLR projections as being very conservative.[55,56,57,58] The differences between IPCC model-based estimates and more recent estimates can be attributed

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[50] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[51] Rahmstorf S. 2010. A new view on sea level rise. Nature Reports Climate Change, doi:10.1038/climate.2010.29.

[52] Nicholls, R. and Cazenave, A. 2010. Sea-Level Rise and Its Impact on Coastal Zones. Science, 328(18), 1517-1520.

[53] 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.

[54] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[55] Oppenheimer, M., O'Neill, B., Webster, M., Agrawala, S. 2007. The limits of consensus. Science, 317, 1505-1506.

[56] Pfeffer WT, Harper JT and O'Neel S. 2008. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise. Science, 321(5894), 1340-1343

[57] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[58] Hansen, J. 2007. Scientific reticence and sea level rise. Environmental Research Letters, 2.

largely to the response of continental ice to greenhouse warming.

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 SLR over the next two centuries. A major problem in assessing the future dynamic evolution of the major ice sheets is a lack of understanding of the physical processes driving ice sheet collapse, calving processes at marine margins and destabilising effects from ice shelf removal. These physical processes include: the stability of grounding lines; the ways in which ice shelves and ice tongues break up, and the implications of this on the discharge of inland ice streams, and the role of melt water in the sub glacial zone of ice sheets (each discussed below). Several new studies have improved our understanding of the complexities of these processes[59,60,61,62,63,64,65,66,67] and the vulnerability of the Greenland and West Antarctic ice sheets (GIS and WAIS respectively), giving greater confidence in more recent studies that suggest that future SLR may have been significantly underestimated by IPCC projections.

Recent research has shown that the tidewater glaciers that drain much of the GIS are highly sensitive to changes in glaciological and environmental conditions.[68,69,70] It is clear that short-term changes at glacier margins can result in substantial, long-term changes in ice-sheet dynamics and mass balance.[71] This is achieved by changes in the position of calving fronts (through increased calving and terminus melting), and by changes in the amount and timing of melt water drainage into the sub glacial zone. The balance of glacier stresses controlling ice flow is highly responsive to changes in the position and thickness of the

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[59] Holland, D.M., Thomas R.H., de Young, B., Ribergaard, M.H. and Lyberth, B. 2008. Acceleration of Jakobshavn Isbræ triggered by warm subsurface ocean waters. Nature Geoscience, 1(10), 659–664.

[60] Rignot, E., Koppes, M. and Velicogna, I. 2010. Rapid submarine melting of the calving faces of West Greenland glaciers. Nature Geoscience, doi: 10.1038/ngeo765.

[61] Straneo F., Hamilton, G., Sutherland, DA.., Stearns, L.A., Davidson, F., Hammill, M.O., Stenson, G.B., and Rosing-Asvid, A. 2010. Rapid circulation of warm subtropical waters in a major glacial fjord in East Greenland Nature Geoscience, 3, 182 – 186.

[62] Joughin, I., Howatt, IM., Fahnestock, M., Smith, B.,Krabill, W., Alley, RB., Stern, H., and Truffer, M. 2008. Continued evolution of Jakobshavn Isbræ following its rapid speedup. Journal of Geophysical Research, 113(F4),F04006, 10.1029/2008JF001023.

[63] Rahmstorf, S. 2010. A new view on sea level rise. Nature Reports Climate Change, doi:10.1038/climate.2010.29.

[64] Catania GA and Neumann TA. 2010. Persistent englacial drainage features in the Greenland Ice Sheet. Geophysical Research Letters, 37, L02501.

[65] Rignot, E., Koppes, M. and Velicogna, I. 2010. Rapid submarine melting of the calving faces of West Greenland glaciers. Nature Geoscience, published online 14 February 2010; doi: 10.1038/ngeo765.

[66] Motyka, R.J., Fahnestock, M., and Truffer, M. 2010. Volume change of Jakobshavn Isbræ, West Greenland:1985□1997□2007 Journal of Glaciology, 56(198), 635-645.

[67] Jenkins A, Dutrieux P, Jacobs SS, McPhail SD, Perrett JR, Webb AT and White D. 2010. Observations beneath Pine Island Glacier West Antarctica and implications for its retreat. Nature Geoscience, 3, 468 – 472, doi:10.1038/ngeo890.

[68] Holland, D.M., Thomas RH, de Young B, Ribergaard MH and Lyberth B. 2008. Acceleration of Jakobshavn Isbræ triggered by warm subsurface ocean waters. Nature Geoscience, 1(10), 659–664.

[69] Rignot, E., Koppes, M. and Velicogna, I. 2010. Rapid submarine melting of the calving faces of West Greenland glaciers. Nature Geoscience, published online 14 February 2010; doi: 10.1038/ngeo765.

[70] Straneo F., Hamilton, G., Sutherland, DA, Stearns, LA, Davidson,F., Hammill, MO., Stenson, GB, & Rosing-Asvid, A. 2010. Rapid circulation of warm subtropical waters in a major glacial fjord in East Greenland Nature Geoscience, 3, 182 – 186.

[71] Rignot, E. And Kanagaratnam, P. 2006. Changes in the Velocity Structure of the Greenland Ice Sheet. Science, 311(5763), 986-990.

calving front.[72,73] Relatively brief periods of increased calving and retreat, lasting days or less, can result in acceleration of ice flow that is sustained over much longer periods as the glacier evolves following the perturbation at the front.[74,75] Furthermore, this acceleration results in dynamic thinning, due to ice stretching, which can promote further retreat. Thus, increases in the calving rate can trigger long-term changes in glacier dynamics, providing a direct and rapid link between environmental forcing and ice-sheet mass balance. The actual processes linking variations in climate and ocean conditions to calving of the ice front, however, remain poorly understood.[76]

Research carried out on the GIS and WAIS is trying to explore some of these issues. New research on melt water production, routing and ponding, all of which have been identified as important elements affecting ice sheet stability,[77] show that surface melting on the GIS is common up to about 1400m elevation and, in extreme melt years, even higher. Surface melt water drains over the ice sheet and through it to its base via melt water streams and Moulin crevasses. In this study Moulin crevasses are seen as relatively persistent features of the ice sheet, helping to create effective pathways for melt water from the surface to the base of the GIS. The high sub glacial hydrological pressures that result are sufficient to cause local uplift, with consequent reduction in basal friction and enhanced sub glacial sliding velocities.

Recent research[78] on ice sheet loss assesses the uncertainties in satellite observations from Gravity Recovery and Climate Experiment satellite measurements (GRACE). These uncertainties include: different data processing methods, the shortness of the GRACE time series, and recent increases in ice loss affecting isostatic readjustment. Different results from previous estimates are seen to reflect differences in isostatic deglaciation models. However, the revised estimates of glacial isostatic adjustment following glacier recession are heavily dependent on a relatively small number of ground-based GPS sites close to the present ice margin. Enhanced constraints on GRACE data will be delivered via a considerably expanded network of GPS sites in Greenland and Antarctica which has developed since 2007 as part of the International Polar Year. Despite these caveats, these findings confirm the ongoing shrinkage of the polar ice sheets. However, the newly estimated ice-sheet mass

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[72] Rahmstorf, S. 2010. A new view on sea level rise. Nature Reports Climate Change, doi:10.1038/climate.2010.29.

[73] Joughin, I., Howatt, IM., Fahnestock, M., Smith, B.,Krabill, W., Alley, RB., Stern, H., and Truffer, M. 2008. Continued evolution of Jakobshavn Isbræ following its rapid speedup. Journal of Geophysical Research, 113(F4),F04006, 10.1029/2008JF001023.

[74] Joughin, I., Howatt, IM., Fahnestock, M., Smith, B.,Krabill, W., Alley, RB., Stern, H., and Truffer, M. 2008. Continued evolution of Jakobshavn Isbræ following its rapid speedup. Journal of Geophysical Research, 113(F4),F04006, 10.1029/2008JF001023.

[75] Rahmstorf, S. 2010. A new view on sea level rise. Nature Reports Climate Change, doi:10.1038/climate.2010.29.

[76] Rahmstorf S. 2010. A new view on sea level rise. Nature Reports Climate Change, doi:10.1038/climate.2010.29.

[77] Catania, G.A. and Newmann, T.A. 2010. Persistent englacial drainage features in the Greenland Ice Sheet. Geophysical Research Letters, 37 L02501.

[78] Bromwich, D.H. and Nicolas, J.P. 2010. Sea-level rise: Ice-sheet uncertainty. Nature Geoscience, 3, 596-597.

losses represent less than half of other recent GRACE-based estimates for the same time interval: −230 ± 33 Gt per year for Greenland and −132 ± 26 Gt per year for West Antarctica.

Much recent research in Greenland has concentrated on ice-sheet/ocean interactions. Measurements of undersea melting rates of four glaciers in central West Greenland found the melt rates of the glaciers studied was 100 times larger under the ocean at their terminus points than that observed at the glacial surfaces.[79] Another study identified the presence of warm subtropical water in Greenland fjords close to current glacier calving margins which is helping to drive submarine ice melting.[80] This work suggests that current recession of glacier termini represents a response to both atmospheric and oceanic forcing.

A new study found that the considerable ice losses experienced since 1997 from Jacobshavn Isbrae (one of the largest outlet glaciers draining 5.4% of the GIS) are likely due to ocean–glacier interactions and dynamic effects.[81] This was consistent with past work that concluded that increased ocean temperatures after 1997 resulted in increased submarine melting and consequent breakup of the floating tongue.[82] Changes in fjord water temperatures have been found to affect terminus dynamics by altering the rates of submarine melting of the floating tongue.[83] It is then argued that the thinning of the floating tongue by submarine melting and the subsequent loss of buttressing then led to an acceleration of ice flow and the break-up of the ice tongue.[84] This caused a dramatic increase in dynamic thinning.[85,86] Similar oceanic effects are thought to be responsible for terminus ice losses at minor outlet glaciers of the GIS.[87] For ice margins away from the outlet glaciers, ice losses may be a continuation of forcing trends that were already underway between 1985 and 1997. In addition, they may be due to redirection of inland ice flow towards the main outlet glaciers as a result of upstream drawdown.

Sub glacial topography also plays a major role in determining the behaviour of ice streams and outlet glaciers. In Antarctica,

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[79] Rignot, E., Koppes, M. and Velicogna, I. 2010. Rapid submarine melting of the calving faces of West Greenland glaciers. Nature Geoscience, doi: 10.1038/ngeo765.

[80] Straneo F., Hamilton, G., Sutherland, DA, Stearns, LA, Davidson,F., Hammill, MO., Stenson, GB, & Rosing-Asvid, A. 2010. Rapid circulation of warm subtropical waters in a major glacial fjord in East Greenland Nature Geoscience, 3, 182 – 186.

[81] Motyka RJ, Fahnestock M., and Truffer M. 2010. Volume change of Jakobshavn Isbræ, West Greenland:1985□1997□2007 Journal of Glaciology, 56(198), 635-645.

[82] Holland, D.M., Thomas RH, de Young B, Ribergaard MH and Lyberth B. 2008. Acceleration of Jakobshavn Isbræ triggered by warm subsurface ocean waters. Nature Geoscience, 1(10), 659–664.

[83] Straneo F., Hamilton, G., Sutherland, DA, Stearns, LA, Davidson,F., Hammill, MO., Stenson, GB, & Rosing-Asvid, A. 2010. Rapid circulation of warm subtropical waters in a major glacial fjord in East Greenland Nature Geoscience, 3, 182 – 186.

[84] Motyka RJ, Fahnestock M., and Truffer M. 2010. Volume change of Jakobshavn Isbræ, West Greenland:1985□1997□2007 Journal of Glaciology, 56(198), 635-645.

[85] Rignot, E. And Kanagaratnam, P. 2006. Changes in the Velocity Structure of the Greenland Ice Sheet. Science, 311(5763), 986-990.

[86] Joughin, I., Howatt, IM., Fahnestock, M., Smith, B.,Krabill, W., Alley, RB., Stern, H., and Truffer, M. 2008. Continued evolution of Jakobshavn Isbræ following its rapid speedup. Journal of Geophysical Research, 113(F4),F04006, 10.1029/2008JF001023.

[87] Motyka RJ, Fahnestock M., and Truffer M. 2010. Volume change of Jakobshavn Isbræ, West Greenland:1985□1997□2007 Journal of Glaciology, 56(198), 635-645.

recent work on Pine Island Glacier West (PIG) using underwater remote sensing has shown that PIG was recently grounded on a transverse submarine ridge.[88] With glacier recession, warm seawater has flowed through the gap above the ridge increasing ice melt and initiating rapid calving and breakup of the snout, and helping to drive glacier acceleration and downwasting. Understanding the role of sub glacial topography is therefore crucial to help assess the likely future evolution of such outlet glaciers, especially as it is estimated that acceleration of the outflow of such glaciers is contributing around 10% of the current observed rise in global sea level.[89]

The ice sheet and SLR section for the Phase I Report for COP 15 discussed the uncertainties in ice sheet models, arguing that understanding the physics of ice sheet calving, grounding line processes and the movement of water through the glacier system was crucial if we are to integrate ice sheet models with GCMs. Since the publication of this report there have been a number of important papers published on the behaviour of the WAIS and the GIS, and these will have an important bearing on the nature and rapidity of SLR and therefore on the negotiations for COP 16. Recent important papers on the GIS include Straneo et al.[90] and Rignot et al.[91] they looked at calving processes on tidewater outlet glaciers, the stability of ice sheet grounding lines and on the melting of sub glacial ice by warm ocean water. Work by Jenkins et al.[92] from Antarctica highlights the importance of sub glacial topography as a second-order control on glacier dynamics. Understanding all of these is important to successfully parameterize ice sheet models and improve their ability to couple with GCMs and RCMs.

Consequently, the new results from research on the two ice sheets, as well as new insights derived from earlier research, should be reviewed to support negotiations on climate change adaptation at COP 16. Important papers from this are highlighted below.

Other work since IPCC AR4 has attempted to clarify the link between global sea levels and global temperature, and analysis suggests that sea levels could rise approximately three times as much by 2100 as IPCC AR4 projections (which excluded rapid ice

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[88] Jenkins A, Dutrieux P, Jacobs SS, McPhail SD, Perrett JR, Webb AT and White D. 2010. Observations beneath Pine Island Glacier West Antarctica and implications for its retreat. Nature Geoscience, 3, 468 – 472, doi:10.1038/ngeo890

[89] Jenkins A, Dutrieux P, Jacobs SS, McPhail SD, Perrett JR, Webb AT and White D. 2010. Observations beneath Pine Island Glacier West Antarctica and implications for its retreat. Nature Geoscience, 3, 468 – 472, doi:10.1038/ngeo890.

[90] Straneo F., Hamilton, G., Sutherland, DA, Stearns, LA, Davidson,F., Hammill, MO., Stenson, GB, & Rosing-Asvid, A. 2010. Rapid circulation of warm subtropical waters in a major glacial fjord in East Greenland Nature Geoscience, 3, 182 – 186.

[91] Rignot, E., Koppes, M. and Velicogna, I. 2010. Rapid submarine melting of the calving faces of West Greenland glaciers. Nature Geoscience, doi: 10.1038/ngeo765.

[92] Jenkins A, Dutrieux P, Jacobs SS, McPhail SD, Perrett JR, Webb AT and White D. 2010. Observations beneath Pine Island Glacier West Antarctica and implications for its retreat. Nature Geoscience, 3, 468 – 472, doi:10.1038/ngeo890

flow dynamics).[93] Even for the lowest emission scenario (B1), SLR is then likely to be 1m; for the highest, it may even come closer to 2m during the 21st Century. This latter figure is seen as likely to be the upper limits on SLR by 2100, based upon kinematic constraints on the amount of ice that could be discharged from the ice sheets given our current understanding of glaciology.[94]

Based on scientific evidence published in the last two years, the rate of mean global SLR will increase in the years ahead and that the total SLR by the end of the century could perhaps reach as much as 1.5m to 2m above present levels.[95,96,97,98,99] Regardless of whether global temperatures rise 2°C or 2.5°C, the increase in SLR will continue. Importantly, recent studies of the relative magnitude of regional SLR also suggest that because of its proximity to the equator, SLR in the Caribbean would be more pronounced than in some other regions.[100,101]

Table 2 provides a summary of the most recent projections of global SLR over the 21st Century and compares these newer studies to the IPCC AR4 projections and continuation of current trends. Importantly the five studies that are more recent than the IPCC AR4 all project upper estimates of 1.4m SLR or more by 2100. That these upper estimates would occur is highly unlikely (as are the lower estimate range), but the precautionary principle requires that in the absence of scientific certainty policy-makers understand the more extreme possibilities that cannot be discounted. Examining the central estimates of these SLR projections is nonetheless more informative for the purposes of this assessment.

The central estimates of four of five of the most recent studies of SLR in the 21st Century exceed 1m. Therefore, the first scenario examined in the SLR vulnerability assessment in section 4.2 is +1m. However, as other recent government SLR vulnerability assessments in the US and Netherlands have explored SLR scenarios greater than 1m,[102,103] for comparability, a second +2m SLR scenario is also examined.

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[93] Vermeer M and Rahmstorf S. 2009. Global sea level linked to global temperature Proceedings, National Academy of Sciences, 106(51), 21527–21532.

[94] Pfeffer, W.T., Harper, J.T. and O'Neel S. 2008. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise. Science, 321(5894), 1340-1343

[95] Rahmstorf, S. 2007. A Semi-Empirical Approach to Projecting Future Sea-Level Rise. Science, 315(5810), 368-370.

[96] Vermeer, M. and Rahmstorf, S. 2009. Global sea level linked to global temperature Proceedings, National Academy of Sciences, 106(51), 21527–21532.

[97] Grinsted, A., Moore, J. C., and Jevrejeva, S. 2009. Reconstructing Sea Level from Paleo And Projected Temperatures 200 to 2100 AD. Climate Dynamics, 34, 461–472.

[98] Jevrejeva, S., Moore, J.C., and Grinsted. In Press. Recent Global Sea Level Acceleration Started over 200 years ago? Geophysical Research Letters, doi:10.1029/2010GL042947.

[99] Horton, R, Herweijer, C,Rosenzweig,C, Liu, J, Gornitz,V. and Ruane, A. 2008. Sea Level Projections for Current Generation CGCMs based on semi-empirical method. Geophysical Research Letters, 35, L02715.

[100] Bamber, J.L., Riva, R., 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.

[101] Hu, A., Meehl, G., Han, W and Yin, J. 2009. Transient response of the MOC and climate to potential melting of the Greenland Ice Sheet in the 21st century. Geophysical Research Letters 36, L10707.

[102] Herberger, M.,Cooley, H, Herrera, P., Gleick, P. and Moore, E. 2009. The impacts of Sea-Level Rise on the California Coast. California Climate Change Center for the State of California. Sacramento, California.

[103] Delta Commission. 2008. Working together with water: A living land builds for its future. Accessed from http://www.deltacommissie.com/doc/deltareport_summary.pdf

Table 2: Summary of global sea level rise projections for 21st Century[104,105,106,107,108]

	2050*	2100		
		Low Range	Central Estimate	High Range
Continuation of current trend (3.4mm/yr)	13.6 cm	-	30.6 cm	-
IPCC AR4 (2007)	8.9 cm to 23.8 cm	18 cm	-	59 cm
Rahmstorf (2007)	17cm to 32 cm	50 cm	90 cm	140 cm
Horton et al. (2008)	~ 30 cm		100 cm	
Vermeer and Rahmstorf (2009)	~40 cm	75 cm	124 cm	180 cm
Grinstead et al. (2009)	-	40 cm	125 cm	215 cm
Jevrejeva et al (2010)	-	60 cm	120 cm	175 cm

*Where not specified, interpreted from original sources.

It is also vital to re-emphasise that SLR will continue after 2100, even if global temperatures are stabilised at 2.0°C or 2.5°C, and the dynamical breakup of parts of the GIS and WAIS will continue over centuries, further contributing to SLR. Once set in motion, the breakup of ice sheets and the contribution to SLR are irreversible on human timescales. Considering this and analogues of sea level during periods with similar climatic conditions as today (when sea levels were an estimated 3-6m above current levels), then the question is not **if** the Caribbean will face SLR of 1m or 2m under either a 2.0°C or 2.5°C global warming scenario, but rather **when**.

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[104] Rahmstorf, S. 2007. A Semi-Empirical Approach to Projecting Future Sea-Level Rise. Science, 315(5810), 368-370.

[105] Vermeer M and Rahmstorf S. 2009. Global sea level linked to global temperature. Proceedings of the National Academy of Sciences, 106(51), 21527–21532.

[106] Grinsted, A., Moore, J. C., and Jevrejeva, S. 2009. Reconstructing Sea Level from Paleo And Projected Temperatures 2000 to 2100 AD. Climate Dynamics, 34, 461–472.

[107] Jevrejeva, S., Moore, J.C. and Grinsted. In Press. Recent Global Sea Level Acceleration Started over 200 years ago? Geophysical Research Letters, doi:10.1029/2010GL042947.

[108] Horton, R, Herweijer, C,Rosenzweig,C, Liu, J, Gornitz,V. and Ruane, A. 2008. Sea Level Projections for Current Generation CGCMs based on semi-empirical method. Geophysical Research Letters, 35, L02715.

4. Implications of Sea Level Rise and Storm Surge for CARICOM Member States

As indicated, there is overwhelming scientific evidence that 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 the impacts associated with future SLR, including coastal inundation and inland flooding, greater storm surge damage, and increased erosion, will involve considerable revisions to development plans and major investment decisions, which must be based on the best available information about the relative vulnerability of specific coastal infrastructure, ecosystems and heritage resources and the resulting economic impacts and non-market impacts.

This analysis provides the most comprehensive assessment of the consequences of projected SLR for the people and economies of the 15 CARICOM nations. It examines the SLR exposure risk of all of the major damage metrics recommended by the Organization for Economic Cooperation and Development (OECD): land area, people, ecosystems, economic value, important infrastructure, and cultural heritage.[109] 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 that examined 84 developing nations, including six CARICOM nations.[110]

A Geographic Information System (GIS) was constructed using the best available remote sensing, digital elevation model and 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, transportation infrastructure [airports, roads, sea port], sea turtle nesting sites, and major sea fuel/ energy plants) to inundation from SLR in each CARICOM nation (+1m and 2m scenarios). The remote sensing and GIS methods are outlined below.

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[109] Nicholls, R. and Cazenave, A. 2010. Sea-Level Rise and Its Impact on Coastal Zones. Science. 328(18), 1517-1520.

[110] Dasgupta, S., B. Laplante, C. Meisner, D. Wheeler, and J. Yan. 2007. The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis. World Bank Policy Research Working Paper No. 4136. Washington, DC: World Bank.
The results for the six CARICOM nations included in the World Bank study and this analysis were highly consistent for all common indicators.

4.1 REMOTE SENSING AND GIS METHODOLOGY FOR SEA LEVEL RISE IMPACT MAPPING

Although airborne LiDAR (Light Detection and Ranging) is one the most effective and reliable remote sensing technologies for collecting detailed elevation mapping and was one of the recommended approaches for future research in the Phase I Report, it is both cost prohibitive (an estimated US $98 million for all land areas of the CARICOM nations) and could not physically be obtained for all 15 CARICOM nations within the timeframe established for this analysis.

To improve on the spatial resolution of the Digital Elevation Model (DEM) utilised in Phase I, the project utilised the research-grade Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) data set that was recently publically released by North American Space Agency (NASA) and the Japanese Ministry of Economy, Trade and Industry. The GDEM covers approximately 99% of the earth's surface from 83° S to 83° N with elevation measurements taken at 30m intervals. This provided a three-fold improvement in the spatial resolution of Phase I (which was $90m^2$). As with some other satellite instruments, ASTER coverage is disrupted in areas with atmospheric interference (i.e., regular to constant cloud cover) and therefore does not perform as well in these areas. Data anomalies were observed in the ASTER GDEM in some coastal areas of Guyana and Suriname and as a result the results for these nations should be considered with some caution. The ASTER GDEM was integrated into a GIS with the land use and infrastructure geospatial data sets outlined in Table 3.

Table 3: Geospatial data sources utilised in the SLR vulnerability assessment

Variable	Dataset Name	Unit	Resolution	Source(s)
Coastline and country Boundary	WVS	km^2	1:250,000	NOAA/NASA
Elevation	ASTER GDEM	m^2	30m	NASA/METI
Population Data (2010 Projections)	glp10ag	Population Counts (millions)	5km	CIESIN
Urban Lands	Global Rural-Urban Mapping Project – GRUMP-1	km^2	1km	CIESIN
Agricultural Lands	GAE-2	km^2	1km	IFPRI (International Food Policy Research Institute)
Wetlands	GLWD-3	km^2	1km	Bernhard Lehner, World Wildlife Fund US[111]
Lakes, and Water Bodies	GHHS	km^2	1:250,000	Global Self-consistent, Hierarchical, High-resolution Shoreline Database (Version 2)[112]
Global Airports	DIAFF (Digital Aeronautical Flight Information File)	Count	n/a	NIMA (National Imagery and Mapping Agency)
Global Airport Runways	DIAFF	km^2	1:250,000	NIMA (National Imagery and Mapping Agency)
Roads	VMap Worldwide Vector Data (v5)	km (length)	1:250,000	LandInfo Worldwide Mapping
City areas	VMap Worldwide Vector Data (v5)	km^2	1:250,000	LandInfo Worldwide Mapping
Major Tourism Resorts	UW SLR Data	Count	n/a	University of Waterloo
Ports of the Wider Caribbean	NIMA World Port Index	Count	n/a	World Resources Institute (WRI)[113]
Sea Turtle Nesting Sites	OBIS-SEAMAP	km^2/Count	1:250,000	SWOT: The State of the World's Sea Turtles
Aerial Imagery (Used for maps production)	UW SLR Data	n/a	Varying Scales	Google Earth Pro©

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[111] Lehner, B. and Döll, P. 2004. Development and validation of a global database of lakes, reservoirs and wetlands. Journal of Hydrology, 296(1-4), 1-22.

[112] Wessel, P., and Smith, W.H.F. 1996. A Global Self-consistent, Hierarchical, High-resolution Shoreline Database. Journal of Geophysical Research, 101(B4), 8741-8743.

[113] Burke,L., Maidens,J., Spalding,M., Kramer,P., Green,E., Greenhalgh,S., Nobles,H., Kool, J. 2004. Reefs at Risk in the Caribbean. World Resources Institute. Washington, D.C.

4.1.1 ASTER DIGITAL ELEVATION MODEL CONSTRUCTION

The ASTER GDEM was downloaded from Japan's Earth Remote Sensing Data Analysis Centre using a rough outline of the Caribbean study area to select the needed tiles. After the data were downloaded they were unzipped and split into two folders, one with the GDEM data and the other with the quality assessment data for each tile. All of the GDEM tiles were then loaded into an ArcMap document. The next step was to mosaic the tiles into larger analysis areas. All of the CARICOM countries were split into 6 groups which are shown in Table 4.

Table 4: ASTER mosaic country groupings

- Bahamas_TC
    - Bahamas
- Belize
    - Belize
- Cayman_Jam
    - Jamaica
- Guy_Sur
    - Guyana
    - Suriname
- Haiti
    - Haiti

- East_Islands
    - Antigua & Barbuda
    - Barbados
    - Dominica
    - Grenada
    - Montserrat
    - St. Kitts & Nevis
    - St. Lucia
    - St. Vincent & The Grenadines
    - Trinidad & Tobago

The Mosaic to New Raster tool in ArcToolbox was used to mosaic the tiles for each of the analysis groups. All default values for this tool were kept except for pixel type which was set to 16bit signed integer to match the GDEM pixel type.

Once the mosaics were created the data were explored to look for anomalies and quality issues as well as to check that the mosaic process did not affect the data quality. Although it was determined that the mosaic process did not alter any of the values of the GDEM there were some quality issues with the data, especially in Guyana and Suriname (Figure 21). It seems the ASTER data has anomalies along the coasts of Guyana and Suriname due to cloud cover during collection. More exploration of these data will be a benefit in explaining any differences from the SRTM data used in Phase I.

Figure 21: Comparison of SRTM DEM and ASTER GDEM Data with Google maps image for reference

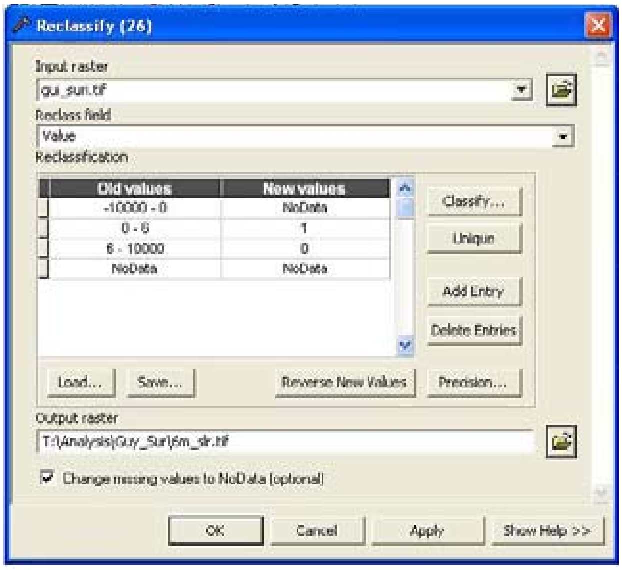
Google Image

SRTM DEM

ASTER GDEM

4.1.2 GIS ANALYSIS AND MAPPI

Figure 22: Example of criteria used to reclassify GDEM mosaics to binary sea level rise scenarios



Reclassify (26)

Input raster: gui_suri.tif

Reclass field: Value

Reclassification

Old values	New values
-10000 - 0	NoData
0 - 6	1
6 - 10000	0
NoData	NoData

Output raster: T:\Analysis\Guy_Sur\6m_slr.tif

☑ Change missing values to NoData (optional)

The SLR scenarios are binary raster layers that were created for the analysis and are used to determine if an area is affected by SLR. Creation of the SLR scenarios was completed by simply reclassifying the GDEM mosaics, using the spatial analyst reclassify tool within ArcGIS. SLR scenario rasters were created for 1-6m SLR for each of the six sub groups (36 SLR scenarios total) using a model in the ArcGIS model builder. The reclassification criteria are listed in Figure 22 but the general criteria for X amount of SLR were: 1) <0 = NoData, 2) >0 and <=X = 1, and 3) >X = 0. Anything below sea level is set to zero because those areas are not needed for the analysis, while all of the land areas not affected are set to zero because they are still used in analysis. On a final note the "batch build pyramids " tool was used in the model to build pyramids after each SLR scenario was created to save time when opening the files later on. This allowed the model to be run over-night and all of the SLR scenarios were ready for further analysis by morning.

To improve the accuracy of the analysis non–contiguous cells (cells that did not appear to be at risk of SLR were manually masked using polygons and changed to 0's in each of the scenarios. This assessment was completed using a combination of all applicable GIS data along with Google Earth for image verification. Once polygons had been created to mask out all non-contiguous areas a model was created in model builder to complete the masking process. This process was completed using the following steps.

1. Reclassify all data values to 0 (not affected by SLR) using the newly created vector mask as the analysis mask and the original SLR scenario raster as the extent. This step reclassifies all values within the masks to 0 but leaves all of the values outside of the masks as NoData.
2. Reclassify all NoData values in the masked layer to 1 using no analysis mask, with the extent set to the original SLR raster. This step prepares the raster to have all of the non-masked values added to the final output.
3. Run a conditional statement using the raster created in step 2 as the input raster so that all true values (1) were replaced with the original values, and all false values (0) were replaced with the new masked values.
4. Pyramids were also created in a batch process within the model builder model created for this procedure so that they would not need to be individually created during further processing tasks.
5. As an addition polygon shapefiles of the SLR scenarios were created using the raster to polygon tool with simplification turned off. These layers were created in case they were needed for further analysis during future steps.

The population layer was downloaded as a raster dataset for the entire world using a 5x5km grid. Unfortunately, the tools to calculate the effected population using the population grid as a raster are not available, so the raster was converted to a vector polygon layer before further analysis could be completed. The issue with simply converting the raster into a polygon is that adjacent cells with the same value are merged when the polygons are created. This creates false data because the final merged cells are given the same value as each of the single cells would have had, giving a gross underestimation of the actual population. To resolve this, the following methodology was used to create the polygon population layer:

1. A random raster was created with the same extents projection and cell size as the population data.
2. The random raster was then converted to a polygon shapefile which created a polygon for every cell within the raster.
3. An overlay was then used to give each polygon in the new random polygon layer a population attribute from the original population layer.

4. The population polygons were then spatially joined, using the closest option, with the good country name/shoreline data to give each population polygon a country attribute.
5. The country names were then verified and adjustments were made manually along the borders of (1) Guyana/Suriname, (2) Belize, and (3) Haiti. The manual adjustments that were made involved making sure that each polygon belonged to the country that contained the majority of that polygon. The east islands were also visually inspected to ensure accuracy and a few changes were made.

After the population polygons had been created the population affected by each SLR scenario for all of the sub-groups was determined using the following methodology.

1. The Geospatial Modelling Environment (GME) (formerly Hawth's analysis tools) was used to apply the values within each SLR scenario raster to the individual polygons of the population polygon layer. The isectpolyrst tool was used with the following command to complete this task: isectpolyrst(in="[Population]", raster="[1m_slr.tif]", prefix="SLR1", thematic=TRUE, proportion=TRUE); where "[Population]" is the population raster, "[1m_slr.tif]" is replaced by each of the SLR scenario rasters, "SLR1" is a prefix for the attribute name assigned to the polygons , and thematic, and proportion are both true to give the proportion of each value from the raster within the polygon.
2. The field calculator was used to calculate the number of people affected. This was done by simply multiplying the population within each cell by the proportion of that cell that is affected by SLR. There is an assumption during this process that the population within each 5x5km grid cell is uniformly distributed. This assumption is a limit to the data available and cannot be overcome.
3. Once the affected population is determined for each cell the values were summarised by country giving the total population affected by each SLR scenario for each country.

To determine the land area affected a similar methodology to the population data was taken where percentages of SLR in each polygon was calculated using GME.

To determine the effects on airports, a runways shapefile was acquired that contains polygons of all runways within the Caribbean. The following methodology was used to determine if a runway was affected by each of the SLR scenarios.

1. GME isectpolyrst tool was used for this to calculate the percentage of each runway affected by each of the 6 SLR scenarios.
2. If a runway was affected by any percentage it was considered as being affected and recorded in an excel spreadsheet.

Tourism facilities consisted of two geospatial layers, point and polygon. Point files were generated using municipal tourism website resources, travel websites and Google Earth. Only coastal tourism resorts were selected for use in the analysis layer. Coastal tourism resorts were defined in the study as:

1. They were within 100m of the sea and/or
2. The average elevation of the tourism lot was below 6m elevation.
3. Points were selected in the centroid (centre) of the tourism property.

Once a tourism resort data base was created for each CARICOM nation, a 100m buffer was applied to each point. The following methodology was used to determine if each of the SLR scenarios affected a resort.

1. GME isectpolyrst tool was used to calculate the percentage of each tourism resort polygon affected by each of the 6 SLR scenarios.
2. Resorts with at least 10% flooding were considered ‘flooded’; resorts below 10% flooding were disregarded.
3. Country totals for each of the tourism resorts affected by 1-6m SLR were incorporated into an excel table.
4. A separate master excel table was created showing a detail of each individual resort, and the amount of flooding experienced over the various SLR scenarios.

Geospatial sea turtle nesting data was obtained from The State of the World's Sea Turtles (SWOT) website.[114] A Google Earth kml file containing global Leatherback, Loggerhead, Hawksbill, Flatback, Olive Ridley and Kemp's nesting sites was converted for use in ArcGIS. The data was then clipped to incorporate all of the aforementioned 15 CARICOM study nations. A detailed analysis of the data, including data overlaying and visual inspection was used to determine only beach based sea turtle nesting sites.

The finalized sea turtle analysis data consisted of two geospatial layers (point and polygon). All point data obtained from SWOT were buffered by 50m to incorporate a larger area surrounding the recognized turtle spawning areas. The following methodology was used to determine if a sea turtle nesting site was impacted by SLR:

1. The Geospatial Modelling Environment (GME) (formerly Hawth's analysis tools) was used to apply the values within each SLR scenario raster to the individual polygons of the population polygon layer. GME isectpolyrst tool was used to calculate the percentage of each sea turtle nesting site polygon affected by each of the 6 SLR scenarios.
2. Nesting sites with at least 10% flooding were considered 'flooded', nesting sites below 10% flooding were disregarded.
3. Country totals for each of the sea turtle nesting areas affected by 1-6m SLR were incorporated into an excel table.
4. A separate master excel table was created showing a detail of each individual sea turtle nesting beach, and the amount of flooding experienced over the various SLR scenarios.

4.2 IMPACTS OF SEA LEVEL RISE AND STORM SURGE ACTIVITY

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 to 2m over the 21st Century. The differential impacts of a 1m and 2m SLR scenario for individual CARICOM nations are summarised in section 4.2.1. To examine the vulnerabilities associated with combined flooding risk of SLR and storm surge (section 4.2.2), the probable wave heights and related storm surge for a 1 in 100 year storm (averaged for each country) were obtained from the Atlas of Probable Storm Effects in the Caribbean Sea[115] and superimposed on +1m SLR. Adaptation to SLR through coastal protection is highly

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[114] State of the World's Sea Turtles. 2010. Working together to protect sea turtles and their habitat worldwide. Accessed from http://seaturtlestatus.org/

[115] Storm surge and wave heights were obtained from the: Organization of American States. 2002. Atlas of Probable Storm Effects in the Caribbean Sea. OAS. Accessed from http://www.oas.org/cdmp/document/reglstrm/index.htm.

probable in highly populated urban areas with high value properties and strategic infrastructure. Section 4.2.4 provides the first assessment of the length of protective structures required for 19 of CARICOM's most populous cities in CARICOM countries and the estimated costs of construction and annual maintenance associated with this critical adaptation strategy. To provide a first order assessment of damages associated with long-term erosion response to SLR (Section 4.2.3) the Bruun Rule[116,117] of landward erosion (50 to 100 times the vertical SLR) was applied to coastlines with unconsolidated beach materials and the absence of coastal protection structures (as determined through visual inspection of aerial imagery in Google Earth). The economic implications of projected erosion impacts are also discussed in detail in Section 5.2.

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 1m SLR. The differential vulnerability can be largely explained by the geophysical characteristics of the islands and their different coastal topographic settings, which are briefly summarised in Table 5. The CARICOM countries can be broadly categorised into four groups in terms of their relative vulnerability to coastal flooding.

Table 5: Summary of geophysical characteristics of CARICOM countries

Geophysical Setting	**Key Climate Change Vulnerabilities**	**CARICOM Members**
Coastal plains below 10m	1. Flooding from storms 2. Inundation from SLR 3. Salt water intrusion of ground water 4. Erosion with loss of mangroves	Guyana, Suriname, Belize,
Low lying islands	1. Inundation from SLR 2. Flooding from storms 3. Salt water intrusion of ground water 4. Erosion from SLR and storms	The Bahamas, Barbuda, The Grenadines
Volcanic island coasts	1. Beach erosion from SLR and storms 2. Landslides (locally) 3. Localized flooding from storms	Dominica, Grenada, St Kitts and Nevis, St Lucia, St Vincent, Montserrat
Varied geophysical characteristics	1. Localized erosion by SLR and storms 2. Localized inundation from SLR 3. Localized flooding from storms 3. Localized salt water intrusion of ground water	Antigua, The Bahamas, Haiti, Jamaica and Trinidad and Tobago

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[116] Bruun, P. 1962. Sea-Level Rise as a Cause of Shore Erosion, Journal Waterways and Harbours Division, 88(1-3), 117-130.

[117] Aboudha, P.A., Woodroffe, C.D. 2006, International Assessments of the Vulnerability of the Coastal Zone to Climate Change, Including an Australian Perspective. Report for the Australian Greenhouse Office in Response to RFQ116/2005, DEH, Keswick.

The first 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 SLR. In the case of Belize, hurricanes are also of great concern; less so in the case of Guyana and Suriname since they are south of the hurricane belt, although other storms may affect all three countries. Mangroves are more extensive in these areas than in other CARICOM countries, and deterioration in these will lead to accelerated coastal erosion.

The second group are the low lying 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 SLR 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.

The third group are the mainly volcanic islands of St. Kitts and Nevis, St. Lucia, St. Vincent, Dominica, Grenada and Montserrat. These islands, with only narrow coastal areas, are vulnerable to erosion of more limited beach areas and local coastal landslides. In some, mangroves and seagrass beds are also threatened. These islands, being tectonically active, may be experiencing land movement, which could mitigate against or exacerbate SLR.

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 SLR 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.

4.2.1 IMPACTS OF 1M AND 2M SEA LEVEL RISE SCENARIOS ON CARICOM COUNTRIES

While the total land area permanently inundated by 1m SLR is less than 1% for CARICOM as a whole, as subsequent indicators and the economic analysis reveals, that which is lost represents some of the most valuable land and has substantive implications for the economy in the region. For individual nations, land losses can be much more substantial. The Bahamas and Antigua and Barbuda were found to be the most vulnerable in terms of land area lost (at 5% and 2% respectively).

A 1m SLR would displace an estimated 110,000 people in the CARICOM nations.[118] Bahamas has the highest percentage of national population affected (5%) because of greater impacts on urban areas (3% inundated). Other nations with substantive populations affected by a 1m SLR include St. Kitts and Nevis (2%) and Antigua and Barbuda (3%).

Tourism and agriculture revealed key vulnerabilities for some nations. Considering its very close proximity to the coast, it is not surprising that tourism was by far the most vulnerable major economic sector. This is a key finding, as tourism is a major part of the economies of Caribbean nations and has been overlooked in most previous assessments of the impacts of SLR on national economies. The World Travel and Tourism Council (WTTC)[119] 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).[120] 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%, Dominica 22%. Of the 673 major resorts in the CARICOM countries inventoried for this analysis, 149 are at risk to 1m SLR. Beaches are critical assets for tourism in the Caribbean and a much greater proportion would be lost to inundation and accelerated erosion well before resort infrastructure was damaged.

Major resort properties were at significant risk to 1m SLR in various countries, notably, Belize (73%), St. Kitts and Nevis (64%), Haiti (46%), Bahamas (36%) and Trinidad & Tobago (33%). Such impacts would transform coastal tourism in the region, with

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[118] This figure is deemed conservative due to inherent constraints related to population and topographic data in the region; better socio-economic data and topographic data, based on scientific tools, are needed if these estimates are to be improved in a robust way. The population displacement figures in this study also account for protected shorelines in Guyana under which Georgetown and the Guyanese coastal strip is reasoned not to be as vulnerable to permanent inundation as might be expected given the on-going and planned improvements and technological enhancements to the coastal protection system (assuming continued adequate funding). Overtopping risk, however, will still be present under extreme events' scenarios. It should be noted that the Guyanese coastal strip, its' population, industries and infrastructure, is extremely vulnerable to flooding and overtopping from increases in precipitation and extreme events impacting on the Conservancy Dam.

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

[120] World Resources Institute. 2002. Table A4: Tourism Economy of the Wider Caribbean. Accessed from www.wri.org/publication/content/7863.

implications for property values, insurance costs, destination competitiveness, marketing and wider issues of local employment and economic well-being for thousands of employees. In some cases impacts to particularly high-profile tourism properties, such as the projected flooding of parts of Paradise Island in The Bahamas (Figure 23) would have a disproportionately large economic impact.

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 21 out of 64 airports within CARICOM. The vulnerability of airports was highest in Grenada, where the runway area will become completely inundated. More than 550km of roads were projected to be inundated by 1m SLR in CARICOM nations. The road networks were at greatest risk in The Bahamas (14%), Dominica (14%) and Guyana (12%). Seaports would also be affected, with the surrounding port lands of 35 out of 44 ports in CARICOM inundated by 1m SLR unless protected by coastal structures.

Agriculture was found to be less vulnerable than the tourism industry, however the estimated impact of 1m SLR is still important for food supply, security and livelihoods. Estimated total agricultural land loss was highest in The Bahamas (6%), Dominica (5%) and Haiti (3%). The loss of crop and plantation lands (the highest value agricultural lands) was highest in The Bahamas (3%), while other islands experienced losses around 1%.

SLR also represents a poorly understood threat to natural areas and biodiversity in the region. The largest percentage of protected areas inundated by a 1m SLR occurs in Antigua and Barbuda (5%). The area of wetlands inundated by 1m SLR was greatest in The Bahamas (5%) and Haiti (2%), though data gaps prevent such an analysis in most countries where greater wetland area may well be affected by 1m SLR. Nesting sites for sea turtles was also explored, with the largest loss of sites in Guyana (50%), Belize (44%), Haiti (44%), St. Kitts and Nevis (35%), and The Bahamas (35%). Due to the poor availability of required land use designation data, the implications of SLR on these types of key natural areas and 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 for the region as a whole and in the highly vulnerable nations was much more pronounced

(Table 7). Notable further vulnerabilities within CARICOM under a 2m SLR scenario included:

- more than a doubling of the number of people displaced,
- a doubling of total wetland area lost,
- an additional 84 major tourism resort properties at risk,
- an additional 10 airports partially inundated,
- a further 143 km of roads impacted, and
- a total of 9 power plants at risk (out of 47 inventoried)

The increase in impacts for some of the most vulnerable CARICOM members was marked. For example, Belize is projected to lose 1% of the land area, 40% of the port infrastructure and 33% of power plants, at the same time that 73% of the major tourism resorts and 50% of the airports runways are inundated. Guyana would be expected to have 1% of its population displaced, while losing 12% of its road network and 100% of its power plants. Also notable are the impacts to The Bahamas where 5% of the population would be displaced, large portions of major tourism resorts and the airport would be inundated (36% and 38%, respectively). The Bahamas would also experience significant impacts to their main ports (90%) and 38% of their power plants would be inundated.

Table 6: Impacts of a 1m sea level rise in CARICOM nations

	Land Area	Population	Urban Area	Wetland Area	Agricultural Land	Crop and Plantation	Major Tourism Resorts	Airports	Road Network	Protected Areas	Sea Turtle Nests	Power Plants	Ports
Antigua & Barbuda	2%	3%	2%	*	2%	1%	10%	0%	2%	5%	12%	0%	100%
Barbados	1%	1%	<1%	*	<1%	<1%	8%	0%	0%	*	3%	0%	100%
Belize	1%	1%	1%	2%	1%	1%	73%	50%	4%	0%	44%	33%	40%
Dominica	<1%	1%	<1%	*	5%	<1%	0%	0%	14%	0%	7%	0%	67%
Grenada	1%	1%	<1%	*	3%	1%	11%	100%	1%	*	8%	0%	100%
Guyana	<1%	1%	<1%	1%	<1%	*	0%	0%	12%	*	50%	100%	0%
Haiti	<1%	1%	1%	2%	3%	1%	46%	50%	1%	*	44%	0%	100%
Jamaica	<1%	0%	<1%	<1%	1%	<1%	8%	20%	2%	1%	25%	0%	100%
Montserrat	1%	1%	*	*	2%	1%	0%	0%	4%	*	4%	0%	100%
St. Kitts & Nevis	1%	2%	1%	*	5%	1%	64%	50%	0%	*	35%	0%	50%
St. Lucia	1%	1%	<1%	*	1%	1%	7%	50%	0%	0%	6%	0%	100%
St. Vincent & the Grenadines	1%	1%	1%	*	2%	1%	10%	50%	1%	*	11%	0%	67%
Suriname	<1%	1%	1%	<1%	<1%	<1%	5%	0%	7%	0%	0%	0%	100%
The Bahamas	5%	5%	3%	5%	6%	3%	36%	38%	14%	1%	35%	38%	90%
Trinidad & Tobago	1%	1%	1%	<1%	3%	*	33%	50%	1%	0.%	15%	0%	100%

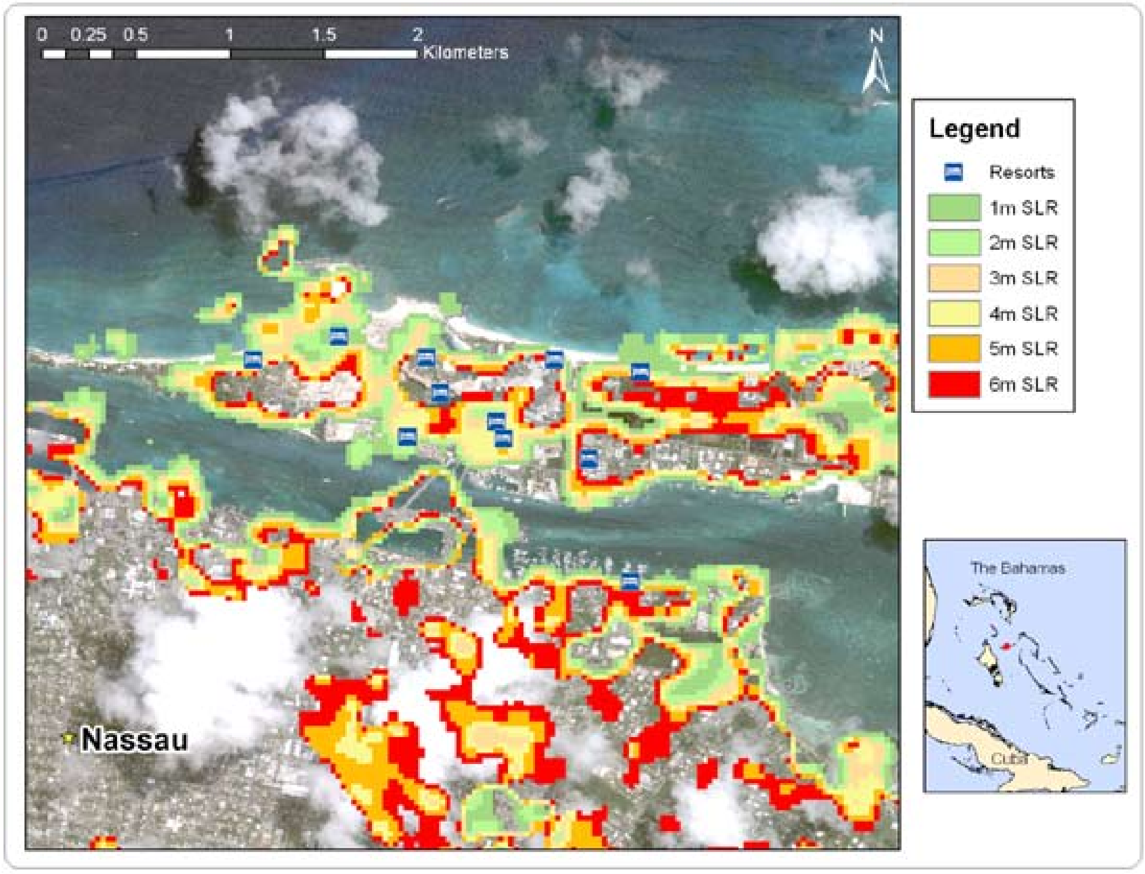
* Unable to calculate due to various data restrictions

Table 7: Impacts of a 2m sea level rise in CARICOM nations

	Land Area	Population	Urban Area	Wetland Area	Agricultural Land	Crop and Plantation	Major Tourism Resorts	Airports	Road Network	Protected Areas	Sea Turtle Nests	Power Plants	Ports
Antigua & Barbuda	5%	6%	5%	*	5%	4%	18%	100%	6%	8%	18%	50%	100%
Barbados	1%	1%	<1%	*	<1%	<1%	32%	0%	0%	*	8%	0%	100%
Belize	2%	3%	2%	8%	3%	5%	86%	50%	6%	1%	60%	33%	40%
Dominica	1%	1%	1%	*	5%	<1%	6%	50%	15%	0%	10%	0%	67%
Grenada	2%	2%	1%	*	5%	2%	18%	100%	1%	*	16%	0%	100%
Guyana	<1%	3%	1%	1%	1%	*	0%	0%	13%	0%	75%	100%	0%
Haiti	1%	1%	2%	4%	5%	1%	61%	50%	1%	*	53%	0%	100%
Jamaica	1%	1%	1%	<1%	2%	1%	18%	60%	2%	2%	32%	20%	100%
Montserrat	1%	1%	*	*	3%	1%	0%	0%	4%	*	8%	0%	100%
St. Kitts & Nevis	2%	3%	2%	*	8%	1%	77%	50%	0%	*	43%	0%	50%
St. Lucia	1%	1%	1%	*	1%	1%	10%	50%	0%	0%	10%	0%	100%
St. Vincent & the Grenadines	2%	2%	1%	*	3%	1%	24%	75%	1%	*	16%	0%	67%
Suriname	<1%	3%	2%	1%	1%	<1%	11%	0%	8%	0%	0%	100%	100%
The Bahamas	10%	10%	6%	10%	12%	8%	50%	53%	19%	2%	37%	50%	90%
Trinidad & Tobago	2%	2%	2%	<1%	6%	*	63%	50%	2%	0%	24%	0%	100%

* Unable to calculate due to various data restrictions

Figure 23: Vulnerability of tourism resorts in Nassau and Paradise Island, The Bahamas to sea level rise



4.2.2 IMPACTS OF 1M SEA LEVEL RISE COMBINED WITH 1 IN 100 YEAR STORM SURGE EVENT

Set against the rises in sea surface levels, the extreme events to which the Caribbean is subject to annually assume even greater prominence. Although there is no scientific consensus on the implications of future climate change for either the intensity or frequency of hurricanes and tropical storms in the Caribbean (see Section 2), the potential flooding from storm surges will increase as the SLRs. In this respect, the implications of SLR are not only long-term in nature, as even small changes in sea level can have substantial implications for the devastating impact of storm surges on coastal areas.

Consistent with other studies that have explored the implications of SLR and storm surge,[121] this analysis examined the exposure of people and infrastructure to combined 1m SLR and storm surge associated with a 1 in 100 year storm event. The probable wave heights and related storm surge for a 1 in 100 year storm (averaged for each country) were obtained from the Atlas of Probable Storm Effects in the Caribbean Sea[122] and superimposed on +1m SLR. The Atlas of Probable Storm Effects in the Caribbean Sea indicate that a 1 in 100 year storm surge event would range from 3m to 4m in most countries and when combined with 1m SLR, areas up to 4m to 5m above sea level would be exposed to flooding damages (see Table 8 for the estimated storm surge height averaged for each country[123]).

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[121] Herberger, M.,Cooley, H, Herrera, P., Gleick, P. and Moore, E. 2009. The impacts of Sea-Level Rise on the California Coast. California Climate Change Center for the State of California. Sacramento, California.

[122] Storm surge and wave heights were obtained from the Organization of American States .2002. Atlas of Probable Storm Effects in the Caribbean Sea. OAS: http://www.oas.org/cdmp/document/reglstrm/index.htm.

[123] These storm surge heights are averaged across each country, but the Atlas of Probable Storm Effects in the Caribbean Sea clearly reveals that some coastal areas in each country are projected to experience greater storm surge heights.

Table 8: Additional notes on a 1 in 100 year storm surge

Country	**1 in 100 yr storm surge (avg. in m.)**	**Notes**
Antigua and Barbuda	3	Antigua's northern coast will experience lower wave heights from storm surge than the rest of the island. Barbuda's west coast will experience lower wave heights from storm surge than the rest of the island.
Barbados	3.25	Model predicts east and south-eastern coasts will get higher storm surges.
Belize	4.5	The model shows a gradual transition in the northward direction with higher levels in the northern region near Corozal. Model predicts higher surge in southernmost part of country during the 1 in 25-50 year event prediction, with surges equalizing in a 100 year event.
Dominica	4	The model shows a gradual transition northward with higher levels in north. Model predicts higher surges on east coast and little change in surging on southwest coast
Grenada	3	The model shows a gradual transition northward with higher levels in north. East coast will see more surging, however heights are still not predicted to reach more than 0.5m
Haiti	3	The model shows that the southern coast experiences the highest wave crests over water (max 7m). Southern coast, especially Les Cayes, is more likely to see higher surges. A 100 year event could reach 3m.
Jamaica	4.5	Portland Bight, and other bays south coast as well, see higher storm surges and wave crests could reach 7m. A 100 year storm surge event could reach as high as 5m.
St. Kitts	4.5	South-east coast of St. Kitts will get higher surges
St. Lucia	3.75	The model shows a gradual increase as you move northward on the island.
St. Vincent and the Grenadines	3.5	The model shows a gradual increase as you move northward through the island chain.
The Bahamas	3.5	Model does not show all of the islands of The Bahamas, thus data for southern-most islands was extrapolated for the chain. Those 4 islands visible in the dataset, Crooked Island, Inaguas, Acklins Island and Mayaguana, thus storm surge estimates for those islands are considered accurate. General observations about that area: wave heights increase as you get further east into the Atlantic Ocean and also when moving northward.

The exposure of infrastructure and population to a 1 in 100 year storm surge under the 1m SLR scenario is summarised in Table 9. With a storm surge of this magnitude, many countries will see serious impacts to key infrastructure, such as airports and tourism resorts because of their close proximity to the coast. Belize, for instance, will see 100% of their airports impacted by a 1 in 100 year storm surge and 95% of their tourism resorts would also experience significant damage. In St. Kitts and Nevis the major tourism infrastructure is less vulnerable to a major storm surge event, with only 17% at risk, however, with nearly 6% of the land area and 6% of the population affected this would still represent a significant impact to the small island nation. The low-lying islands of The Bahamas are also extremely at risk to storm surge. The population and key sectors will see notable impacts from storm surge including 22% of the population being at risk and 63% of major tourism resorts potentially damaged. During disaster events transportation networks are very important for local people as well as emergency response personnel. Thus a country like Antigua and Barbuda, where 12% of the population will be at risk, will have further challenges in emergency response due to flooding of their airport facilities and nearly 12% of the road network. Belize would face similar challenges. The exposure of Belize City, Belize to a combined 1m SLR and projected 1 in 100 year storm surge of 4.5m can be seen in Figure 24 (see 5m and 6m expose levels). Furthermore, though some countries will experience serious impacts to infrastructure, the importance of natural resource damages cannot be ignored. In a major storm surge event, countries like Haiti and St. Kitts and Nevis will also experience notable inundation of agricultural land, 9% and 16% respectively. These losses will create challenges for food supply in the post-event recovery period.

Table 9: Impacts of 1 in 100 year storm surge for CARICOM nations under a 1m sea level rise scenario

	1m SLR + 1 in 100 yr storm surge (m)	Land Area	Population (2010 est.)	Urban Area	Wetland Area	Agricultural Land	Crop and Plantation Land	Major Tourism Resorts	Airports	Road Network
Antigua & Barbuda	4	11%	13%	11%	*	10%	9%	53%	100%	11%
Barbados	4.25	2%	2%	1%	*	1%	0.3%	45%	0%	0.1%
Belize	5.5	9%	13%	15%	36%	9%	17%	96%	100%	16%
Dominica	5	1%	2%	1%	*	8%	0.4%	18%	100%	17%
Grenada	4	4%	4%	2%	*	10%	3%	38%	100%	1%
Haiti	4	2%	4%	5%	19%	9%	3%	71%	50%	3%
Jamaica	5.5	2%	2%	2%	3%	6%	3%	38%	80%	3%
Montserrat	5.25	3%	3%	*	*	9%	2%	0%	0%	5%
St. Kitts & Nevis	5.5	6%	6%	4%	*	17%	%	86%	50%	3%
St. Lucia	4.75	2%	3%	2%	*	3%	3%	37%	100%	2%
St. Vincent & the Grenadines	4.5	3%	3%	1%	*	7%	2%	67%	100%	2%
The Bahamas	4.5**	21%	23%	15%	22%	24%	16%	63%	66%	27%
Guyana	No data									
Suriname	No data									
Trinidad & Tobago	No data									

* Data restrictions prevent an estimate on this indicator - Atlas of Probable Storm Effects in the Caribbean Sea[124]

** This is an estimate based only on the 4 southern most islands of The Bahamas that were visible in the dataset on wave height and storm surge

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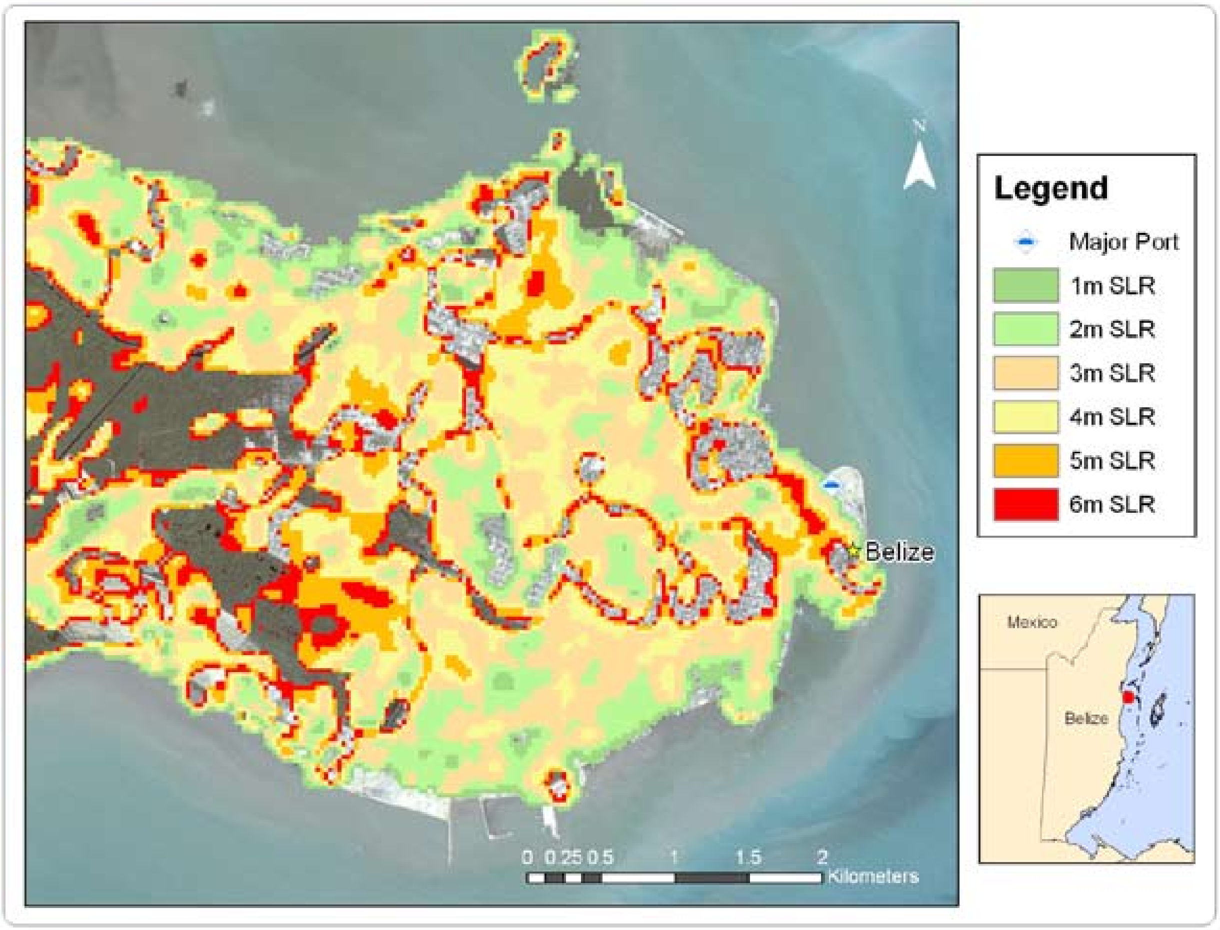
[124] Storm surge and wave heights were obtained from the: Organization of American States. 2002. Atlas of Probable Storm Effects in the Caribbean Sea. Accessed from http://www.oas.org/cdmp/document/reglstrm/index.htm

These SLR and storm surge scenarios only identify exposure risk to flooding impacts and do not take into account the additional coastal erosion during storm events. The extent to which infrastructure will be damaged and disruption costs resulting from such storm events is highly uncertain as is the timing (and thus state of the economy) and frequency of such events over an extended period, and therefore have not been incorporated into the economic valuation analysis in Section 5.

Figure 24: Vulnerability of Belize City to combined sea level rise and storm surge



4.2.3 IMPACTS OF EROSION ASSOCIATED WITH 1M AND 2M SEA LEVEL RISE SCENARIOS

Large areas of the Caribbean coast are highly susceptible to erosion, and beaches have experienced accelerated erosion in recent decades. Higher sea levels will accelerate coastal erosion in these areas due to increased wave attack. The amount of coastline retreat due to SLR can be estimated by several methods. In the absence of information necessary to apply more advanced three-dimensional shoreline recession modelling techniques, which was found to be almost universally the case throughout the Caribbean, two-dimensional conceptual models like the Bruun Rule[125,126] provide a means to complete a first order assessment of the importance of erosion related to SLR. Because of its simplicity, the Bruun Rule has been widely applied in the study of erosion impacts resulting from SLR. The Bruun Rule is based on the concept that an existing beach profile will remain largely constant and as sea level increases, sediment required to maintain this profile in deeper water is derived from erosion of the shore material. The readjustment of the beach profile to an equilibrium state produces inland retreat of approximate 50 to 100 times the vertical increase in sea level (i.e., for a 1m SLR, 50m to 100m of erosion is predicted). This analysis has applied the Bruun Rule very conservatively, by adopting the low end of the erosion range (i.e., 50 times vertical SLR) and only calculated erosion exposure for unconsolidated beach areas that were visually identified in Google Earth satellite imagery and digitised by the research team. Because areas with erosion resistant geology (limestone, volcanic rock) and the armored shorelines of urban areas and strategic infrastructure (ports, airports, power plants, etc) were excluded from the erosion analysis, the impacts of erosion focus on tourism and habitat functions.

A primary design goal of coastal tourism resorts is to maintain coastal aesthetics of undisrupted sea view and access to beach areas, as beach quality plays an important role in the selection of Caribbean destinations and individual resorts.[127] As a result, tourism resort infrastructure is often highly vulnerable to beach erosion. Of the 673 tourism resorts examined in this analysis, 307 (or 46%) are vulnerable to a 50m erosion scenario associated with 1m SLR (Table 10). With a further 50m erosion associated with a 2m SLR (or the high estimate of the Bruun Rule for a 1m SLR), an additional 79 resorts were found to be at risk (or 57% of the region's coastal resorts). The nations with proportionately the most vulnerable tourism infrastructure to a 50m erosion scenario are Belize (95% of resorts at risk), St Kitts and Nevis (68%) and St Vincent and the Grenadines (38%). However, the

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[125] Bruun, P. 1962. Sea-Level Rise as a Cause of Shore Erosion, Journal Waterways and Harbours Division, 88(1-3), 117-130.

[126] Aboudha, P.A., Woodroffe, C.D. 2006. International Assessments of the Vulnerability of the Coastal Zone to Climate Change, Including an Australian Perspective. Report for the Australian Greenhouse Office in Response to RFQ116/2005, DEH, Keswick.

[127] Wielgus, J., Cooper, E., Torres, R., Burke, L. 2010. Coastal Capital: Dominican Republic. Working Paper. Washington: World Resources Institute. Washington D.C.

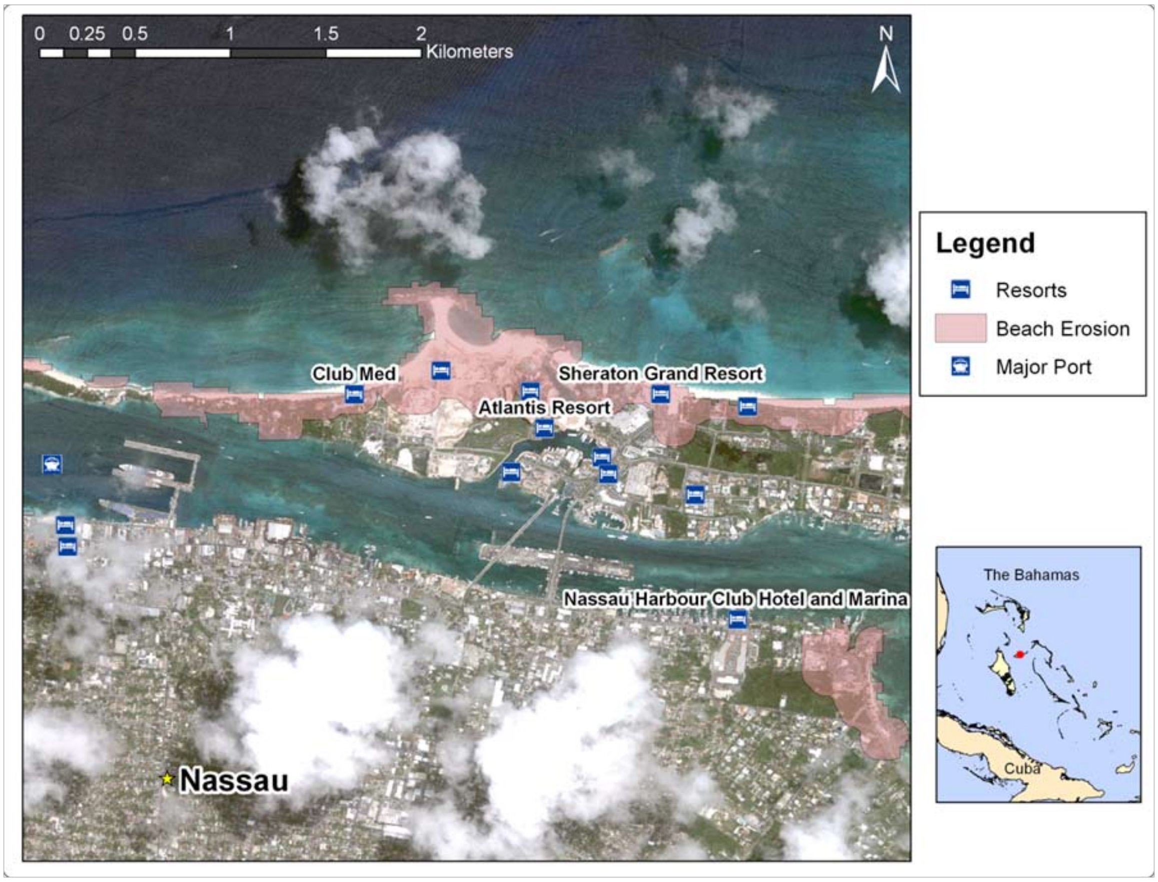
nations with the largest number of tourism resorts likely to be damaged by SLR induced erosion were The Bahamas, Belize and Barbados (77, 42 and 42 resorts, respectively, at 1m SLR - Table 10). It is important to note that the critical beach assets would be affected much earlier than the erosion damages to tourism infrastructure. Indeed if erosion is damaging tourism infrastructure, it means the beach has essentially disappeared. Figure 25 illustrates the erosion risk for high profile tourism infrastructure on Paradise Island, The Bahamas. Notably, the armoured shorelines of Nassau do not show any erosion.

Beach nesting sites for sea turtles are also at significant risk to beach erosion associated with SLR. For example, of the 331 beach nesting sites examined in the CARICOM nations, 146 were at risk with a 50m erosion scenario (44%) and 185 are at risk with a 100m erosion scenario (56%). If 50m were to erode, 100% of the beach nesting sites in Belize would be at risk, followed by 80% in The Bahamas and 79% in St. Kitts and Nevis.

Table 10: Impacts of beach erosion associated with 1m or 2m sea level rise in CARICOM nations

	Tourism Resorts (n=673)		Sea Turtle Nesting Beaches (n=331)	
	50m (1m SLR)	100m (2m SLR)	50m (1m SLR)	100m (2m SLR)
Antigua & Barbuda	34	44	24	31
Barbados	42	50	5	8
Belize	42	44	7	7
Dominica	5	6	6	7
Grenada	14	19	7	7
Guyana	0	0	0	-
Haiti	14	17	6	8
Jamaica	34	52	18	24
Montserrat	0	0	0	2
St. Kitts & Nevis	15	18	15	15
St. Lucia	5	9	9	16
St. Vincent & the Grenadines	8	16	16	22
Suriname	2	2	0	-
The Bahamas	77	93	4	4
Trinidad & Tobago	15	16	29	34

Figure 25: Vulnerability of tourism resorts in Nassau and Paradise Island, The Bahamas to sea level rise induced coastal erosion



4.2.4 SEA LEVEL RISE ADAPTATION CASE STUDY: STRUCTURAL PROTECTION OF CARICOM CITIES

A vital question posed by researchers and policy-makers is to what extent can the damages outlined in Sections 4.2.1 to 4.2.3 be off-set by adaptation, including coastal protection schemes? Many major coastal cities throughout the Caribbean utilise structures such as levees or sea walls as a means to protect densely populated urban areas and strategic infrastructure against erosion and flooding. The world's populated coastal areas have generally become increasingly managed and engineered over the 21st Century reflecting some increased capacity to adapt to future SLR.[128,129] Recent economic studies conclude that based

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[128] Nicholls, R. and Cazenave, A. 2010. Sea-Level Rise and Its Impact on Coastal Zones. Science. 328(18): 1517-1520.

[129] Nicholls, R. and Tol, R. 2006. Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century. Phil. Trans. R. Soc. A, 364, 1073-1095.

on cost-benefit analysis, coastal protection from SLR would be widespread in well-populated coastal areas with high value property and strategic infrastructure.[130,131] Coastal protection is not economic in moderately populated areas, for agricultural lands, or ecosystem areas that must maintain interactions with the sea to retain their function. Similarly, for many tourism developments outside of urban areas, property values are not sufficient to warrant the cost of coastal protection, particularly when the implementation of structural protection would result in loss of coastal tourism aesthetics and not prevent the 'drowning' of critical beach assets (both of which result in diminished tourism property values). Therefore, for this analysis of adaptation, only urban areas were considered candidates for structural coastal protection.

Table 11 illustrates the distance of either levee or sea wall systems that would be required to protect the 19 largest CARICOM cities from direct (sea ward) and indirect (via rivers or other low lying areas) inundation by SLR. In some cities, partial protection systems already exist, but are not yet adapted to future SLR. The construction and annual maintenance costs of levees and sea wall systems[132] are also outlined for each city in Table 11 and is illustrated in Figure 26 for Belize City. Cumulatively, the construction of the estimated 301km of new or improved coastal defences required to structurally protect these Caribbean cities from SLR projected for the 21st Century would cost between US $1.2 and US $4.4 billion.[133] Annual maintenance of these protection schemes is estimated at US $111 to US $128 million.[134]

Critically, the implementation of such an adaptation strategy for SLR takes time. Previous coastal defence projects have shown that implementing coastal protection infrastructure typically has a lead-time of 30 years or more.[135] Therefore to have such structural protection systems in place shortly after mid-century would require the planning and financing of these major infrastructure projects to commence within the next 10 to 15 years. The costs of such coastal protection schemes are beyond the financial capacity of local governments and may exceed the capabilities of some small island nations. The urgency for the international community to negotiate adaptation funding therefore cannot be understated.

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[130] Nicholls, R. and Cazenave, A. 2010. Sea-Level Rise and Its Impact on Coastal Zones. Science. 328(18): 1517-1520.

[131] Nicholls, R. and Tol, R. 2006. Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century. Phil. Trans. R. Soc. A, 364, 1073-1095.

[132] Using estimates from: Herberger, M.,Cooley, H, Herrera, P., Gleick, P. and Moore, E. 2009. The impacts of Sea-Level Rise on the California Coast. California Climate Change Center for the State of California. Sacramento, California.

[133] All figures are in US $, 2010 prices

[134] It must be recognised that at some point in the future the design event will be exceeded or some other unforeseen circumstances will lead to failure of protection systems and catastrophic damages will occur. No attempt has been made to estimate the economic impact of such events.

[135] Hallegatte, S. 2008. Strategies to adapt to an uncertain climate change. Global Environmental Change, 19, 240-247.

Table 11: Coastal protection cost estimates for CARICOM cities

City	Length of Protection Works Required (km)	New Levee Construction (millions US $)	New Sea Wall Construction (millions US $)
Belize City	40.13	$197.4	$684.3
Bridgetown	8.43	$41.5	$143.9
Cap Haiten	14.31	$70.4	$244.1
Carrefour	8.45	$41.6	$144.2
Dangriga	6.40	$31.5	$109.2
Fort Liberte	4.74	$23.3	$80.9
Freeport	48.55	$238.9	$828.0
Georgetown, Guyana	12.48	$61.4	$212.8
Gonaives	4.58	$22.6	$78.2
Kingston	58.27	$286.7	$993.8
Kingstown	3.73	$18.3	$63.6
Les Cayes	3.69	$18.1	$62.9
Montego Bay	18.75	$92.3	$319.8
Nassau	35.91	$176.7	$612.4
New Amsterdam	4.60	$22.6	$78.4
Petit Goave	3.55	$17.5	$60.5
Port au Prince	14.05	$69.1	$239.6
Port of Spain	11.43	$56.0	$194.9
Roseau	4.27	$21.0	$72.9
Saint Marc	6.08	$29.9	$103.6
San Fernando	7.62	$37.5	$130.0
Scarborough	2.24	$11.0	$38.2
St. Johns	4.93	$24.3	$84.1
Total	**301**	**$1,283.3**	**$4,448.8**

Figure 26: Extent of coastal protection works required for Belize City, Belize

5. Actuarial Analysis of the Costs of Losses and Damages Associated with Sea Level Rise

The countries of CARICOM are at varying levels of socio-economic development. Some are reliant on agriculture, others have an industrial base, while the remainder have a service oriented economy based on tourism and financial services.[136] Coupled with geophysical differences, this variation in economic focus results on the differential vulnerability of each country to climate change.

This study of the economic implications of climate change for CARICOM nations builds on work completed in Phase I in 2009,[137] previous economic studies[138,139,140] as well as recent developments in approaches by the ECA[141] in estimating impacts due to climate change. To the extent possible, comparable metrics of economic impact and valuation techniques have be used to facilitate comparisons with the literature, however as some recent studies do not provide transparent methods needed for peer review,[142] the extent of compatibility of approaches remains uncertain.

The scope of the study limited the analysis to the consideration of climate change impacts resulting from substantive SLR of 1m and 2m by 2100 on the terrestrial areas of the countries of CARICOM. The sole consideration of SLR excludes event hazards, such as storm surge, as well as other metrics of climate change (e.g., changes in mean and extreme temperature and precipitation). Consequently, impacts on ecosystem services, which are most vulnerable to impacts other than SLR will be conservative. Offshore impacts, including those on coral reefs, oil platforms and fisheries, are not considered. While this study provides the most detailed analysis to date of the damages and costs associated with SLR, it does not represent a comprehensive assessment of the economic implications of climate change for the CARICOM countries.

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[136] Greene, E., 2009. Perspectives on water security in caribbean small island developing states: keynote address. Accessed from http://www.caricom.org/jsp/speeches/water_security_greene.jsp.

[137] Simpson, M.C., Scott, D., New, M., Sim, R., Smith, D., Harrison, M., Eakin, C.M., Warrick, R., Strong, A.E., Kouwenhoven, P., Harrison, S., Wilson, M., Nelson, G.C., Donner, S., Kay, R., Geldhill, D.K., Liu, G., Morgan, J.A., Kleypas, J.A., Mumby, P.J., Palazzo, A., Christensen, T.R.L., Baskett, M.L. Skirving, W.J., Elrick, C., Taylor, M., Magalhaes, M., Bell, J., Burnett, J.B., Rutty, M.K., and Overmas, M., Robertson, R. 2009. An Overview of Modeling Climate Change Impacts in the Caribbean Region with contribution from the Pacific Islands, United Nations Development Programme (UNDP), Barbados, West Indies.

[138] Bueno, R., Herzfeld, C., Stanton, E.A. and Ackerman, F. 2008. The Caribbean and Climate Change: The Costs of Inaction. Stockholm Environment Institute. Accessed from http://ase.tufts.edu/gdae/CaribbeanClimate.html.

[139] Haites, E., 2002. Assessment of the Economic Impact of Climate Change on CARICOM Countries. In: Vergara, W., ed. Environment and Socially Sustainable Development – Latin America and Caribbean. World Bank.

[140] Tol, R.S.J. 2002. Estimates of the Damage Costs of Climate change: Benchmark estimates. Environmental and Resource Economics, 21, 47-73.

[141] Economics of Climate Change Working Group (ECA). 2009. Shaping climate resilient development: a framework for decision making. Accessed from http://www.mckinsey.com/App_Media/Images/Page_Images/Offices/SocialSector/PDF/ECA_Shaping_Climate%20Resilent_Development.pdf.

[142] Caribbean Catastrophe Risk Insurance Facility. 2010. Enhancing the Climate Risk and Adaptation Fact Base for the Caribbean. Caribbean Catastrophe Risk Insurance Facility. Cayman Islands: Grand Cayman

Climate change is a threat-multiplier as it has the potential to cause feedbacks throughout the economy; the interacting impacts and second-order and tertiary effects on the economy and society could potentially cause the greatest damage.[143] These impacts are outside the scope of the current study. The constituents of the economy are also likely to change over the multi-decade study period and these changes are not captured by the SRES socio-economic scenarios used to represent future demographic and economic changes in the region, and therefore could not be accounted for in this analysis.

5.1 METHODOLOGY FOR ECONOMIC ANALYSIS

The methodology for the economic analysis incorporates a combination of top-down and bottom-up approaches, encapsulated in a macro, meso- and micro-analysis outlined in Figure 27. Each country is modelled individually in this approach. The purpose of assessing individual components of the economy is to combine macro level data such as gross domestic product (GDP) with detailed modelling of the geospatial impacts of SLR. A particular strength of the study is that it has developed the most detailed geographic reality of coastal geomorphology and development for the region. No other study has this level of detail in geospatial data on land use and physical coastal characteristics that make properties, infrastructure, natural areas and people vulnerable to SLR.

SLR scenarios of 1m and 2m are considered for the 21st Century. These estimates of impacts are interpolated to determine impacts for 2050 and 2080. As illustrated in Figure 27, there are two types of cost estimates calculated: annual costs and capital costs. The annual costs capture the ongoing costs to the economy from the impact of SLR damages, while the capital costs identify the rebuild/relocation costs due to the direct damage as well as the lost land value. Capital costs estimated at 2050 and 2080 are not additive but cumulative damage costs at each of these periods. Due to limitations in data availability, proxies and extrapolations across countries are used where necessary.

It is not possible to predict future GDP and population growth with any degree of confidence over such a long-term time frame. We have used growth scenarios based on downscaled (country by country) estimates for the IPCC SRES A2 and B1

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[143] Due to time and data availability constraints, a full system analysis was not undertaken. A full system analysis is effectively a further development on the above methodology but identifies not only direct impacts due to climate change but also elucidates indirect impacts as they cascade through the economy. It includes feedbacks between macro, micro and meso analysis and the interactions between countries.

scenarios (see Table 12).[144] Where projections were considered unrealistic these were adjusted accordingly.[145]

The A2 and B1 scenarios were combined in Table 12 with the SLR scenarios and real growth estimates to provide a cost range.[146] Using A2 and B1 economic growth for extreme scenarios is imprecise, as small island state economies will be impacted by the climate impacts that are not reflected in the GDP numbers. However using this approach is illustrative, as it implicitly projects the damage against a baseline scenario where there is no climate change, and it gives an upper bound on the potential economic losses.

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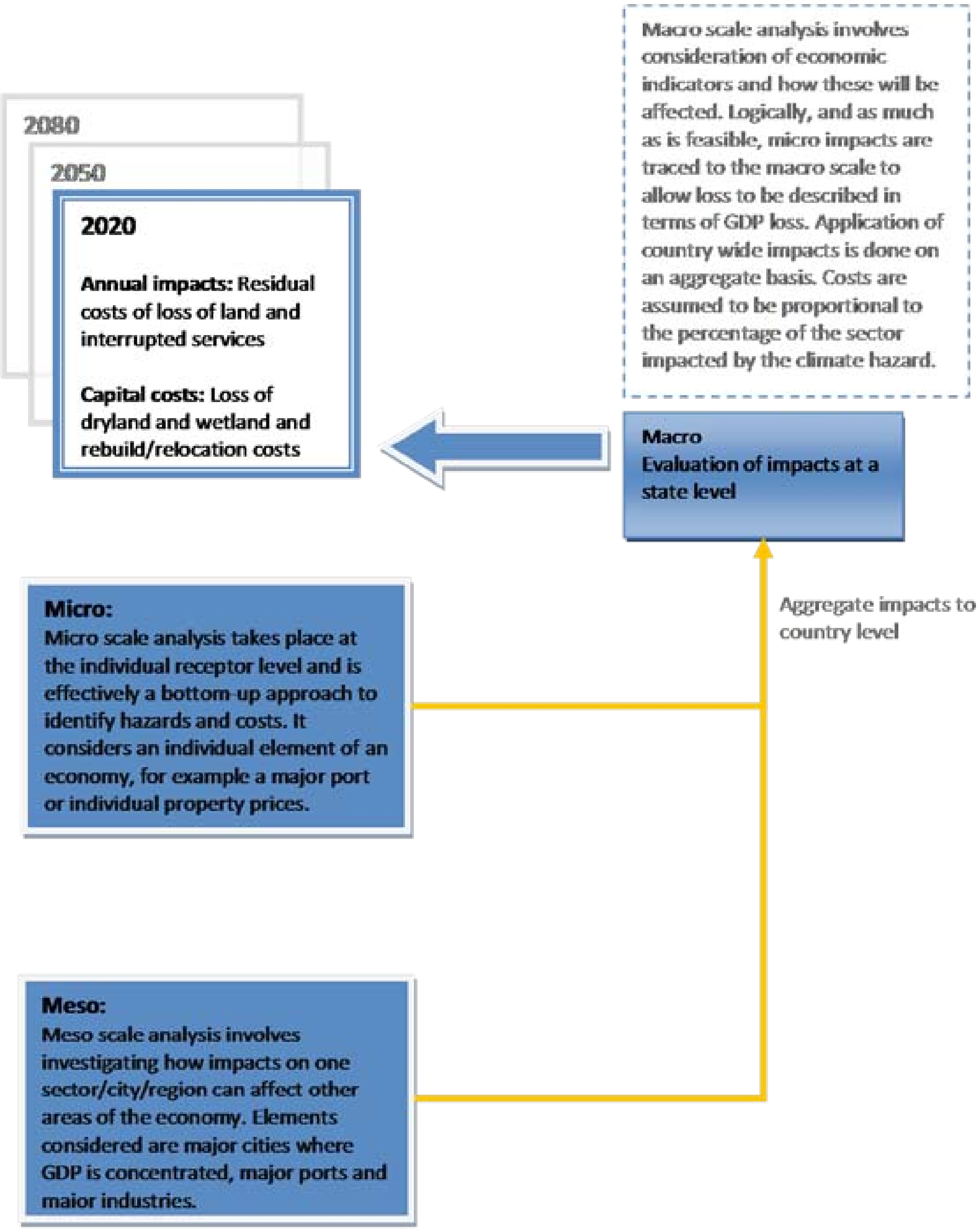
[144] PBL Netherlands Environmental Assessment Agency. 2006. Downscaling drivers of global environmental change. Accessed from http://www.pbl.nl/en/publications/2006/DownscalingDriversOfGlobalEnvironmentalChangeScenarios.html

[145] For example, the economic growth projections for Haiti were adjusted down from 6% to 4% for the B1 scenario and from 4.5% to 3% for the A2 scenario. The continuing vulnerability of Haiti to natural disasters such as the recent earthquake (believed to have cost the Haitian economy 15% of GDP) means that the economy is exposed to risk, which is reflected by the lower (but still substantial) growth assumption.

[146] This is not an upper and lower bound on costs, but provides a range for different 'what if' scenarios.

Figure 27: Methodological framework of economic analysis



2020

Annual impacts: Residual costs of loss of land and interrupted services

Capital costs: Loss of dryland and wetland and rebuild/relocation costs

Macro scale analysis involves consideration of economic indicators and how these will be affected. Logically, and as much as is feasible, micro impacts are traced to the macro scale to allow loss to be described in terms of GDP loss. Application of country wide impacts is done on an aggregate basis. Costs are assumed to be proportional to the percentage of the sector impacted by the climate hazard.

Macro
Evaluation of impacts at a state level

Micro:
Micro scale analysis takes place at the individual receptor level and is effectively a bottom-up approach to identify hazards and costs. It considers an individual element of an economy, for example a major port or individual property prices.

Meso:
Meso scale analysis involves investigating how impacts on one sector/city/region can affect other areas of the economy. Elements considered are major cities where GDP is concentrated, major ports and major industries.

Table 12: Economic indicators of impacts by sector in CARICOM nations[147]

				Economic sectors as % of GDP		
	Population ('000)	**Total land area (km²)**	**GDP (US $m)**	**Agriculture**	**Services**	**Industry**
Antigua & Barbuda	67	443	1,522	34%	74%	22%
Barbados	277	430	5,013	6%	78%	16%
Belize	276	22,996	2,550	21%	65%	14%
Dominica	70	751	745	18%	50%	33%
Grenada	107	344	1,103	24%	62%	14%
Guyana	761	214,969	5,149	25%	52%	24%
Haiti	9,507	27,750	11,976	28%	52%	20%
Jamaica	2,820	10,991	23,797	6%	65%	30%
Montserrat[148]	5	102	29	1%	76%	23%
St. Kitts & Nevis	36	261	726	4%	76%	26%
St. Lucia	163	616	1,746	7%	73%	20%
St. Vincent & the Grenadines	109	389	1,069	26%	57%	17%
Suriname	432	163,820	4,510	11%	65%	24%
The Bahamas	340	10,100	9,020	3%	90%	7%
Trinidad & Tobago	1,358	5,128	25,922	1%	40%	60%

Table 13: High and Mid range sea level rise scenarios used in the cost estimation

	SLR by 2100	Real wage/property growth	Population and GDP growth scenario[149]
High SLR scenario	2m	2%	B1
Mid range SLR scenario	1m	1%	A2

The A2 scenario describes a heterogeneous world where economic development is primarily regionally oriented and per capita growth and technological change is slower than other scenarios. Fertility patterns are slow to converge resulting in

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[147] All estimates are 2009 unless noted otherwise noted. Source: IMF 2010 except those indicated with *, where figures are taken from CIA Factbook. 2010. Accessed from https://www.cia.gov/library/publications/the-world-factbook/

[148] 2002 estimate

[149] Downscaled population and GDP growth scenarios were taken from the PBL Netherlands Environmental Assessment Agency. 2006. Downscaling drivers of global environmental change. Accessed from http://www.pbl.nl/en/publications/2006/DownscalingDriversOfGlobalEnvironmentalChangeScenarios.html.

continuously increasing global population, while the B1 scenario is marked by a global population that peaks mid-century and declines thereafter. In the B1 scenario, the emphasis is on global solutions with rapid changes in economic structures.[150] For the Caribbean region, the B1 scenario is characterized by high growth in GDP, particularly the lower income countries, before reducing after 2050 as GDP per capita converges while the A2 scenario has lower, more constant growth throughout the century. Population growth remains steady for the A2 scenario while the B1 scenarios sees growth rates reducing following a peak in populations towards the middle of the century (Table 14).

Table 14: Annual changes in GDP and population for the A2 and B1 scenarios[151]

	B1				A2			
	2050 - GDP	2080 - GDP	2050 - Pop	2080 - Pop	2050 - GDP	2080 - GDP	2050 - Pop	2080 - Pop
Antigua & Barbuda[152]	3%	2%	0.3%	-0.1%	3%	3%	1%	1%
Barbados	3%	2%	<0.1%	-0.3%	2%	2%	1%	1%
Belize	6%	4%	1%	1%	5%	4%	2%	2%
Dominica	4%	3%	0.1%	0.3%	3%	3%	1%	1%
Grenada	3%	3%	-0.4%	<0.1%	2%	2%	<-0.1%	0.2%
Guyana	3%	3%	-1%	-1%	3%	3%	<0.1%	0.2%
Haiti7	4%	4%	1%	1%	3%	3%	2%	1%
Jamaica	5%	4%	1%	0.3%	4%	4%	1%	1%
Montserrat	4%	3%	-0.1%	0.2%	3%	3%	1%	1%
St. Kitts & Nevis	2%	3%	-0.4%	<0.1%	2%	2%	-0.1%	0.2%
St. Lucia	4%	3%	0.1%	-0.1%	3%	3%	1%	1%
St. Vincent & the Grenadines	4%	3%	0.1%	-0.3%	4%	3%	1%	1%
Suriname	5%	4%	<0.1%	-0.2%	4%	3%	1%	1%
The Bahamas	3%	2%	1%	0.1%	3%	3%	1%	1%
Trinidad & Tobago[153]	3%	2%	0.3%	-0.1%	3%	3%	1%	1%

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[150] Nakicenovic, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S, Gregory, K., Grübler, A., Jung, T.Y., Kram, T., La Rovere, E.L., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Riahi, K., Roehrl, A., Rogner, H-H., Sankovski, A., Schlesinger, M., Shukla, P., Smith, S., Swart, R., van Rooijen, S., Victor, N., Dadi, Z. 2000. Summary for Policy makers Emissions scenarios. In IPCC: Emissions Scenarios. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[151] PBL Netherlands Environmental Assessment Agency. 2006. Downscaling drivers of global environmental change. Accessed from http://www.pbl.nl/en/publications/2006/DownscalingDriversOfGlobalEnvironmentalChangeScenarios.html.

[152] Not included in PBL data set. Assumed average of Barbados and The Bahamas as these have similar GDP per capita and sectoral make up.

[153] Capped at 4% for B1 and 3% for A2. Original projects considered unrealistic considering damage caused by 2009 earthquake.

The GDP growth assumptions are real (i.e., the economic growth in excess of inflation). However, many of the damage estimates that are being estimated are linked to wage or property prices. Typically, wages and property growth are linked in the long term, and together display real growth over and above inflation, but below the economies' growth rate. The approach we have taken reflects standard actuarial practice for valuing low term real trends, such as pension fund costs.

Along with the uncertainty surrounding growth projections, other factors such as the urban-rural population divide and sectoral contribution to GDP are assumed to remain in the same proportion, although in reality these are likely to change.

The methods utilised to estimate specific capital losses included:

Wetland loss: Depending on type, wetlands provide a number of goods and services that are of value to society; including flood control, storm buffering, groundwater recharge and carbon sequestration.[154] Wetland loss varies between islands due to island type with the small islands and cays of The Bahamas and the large coastal plains of Suriname, Guyana and Belize being highly vulnerable. Wetland loss constitutes land that is permanently lost. Wetland value is assumed to increase with income and population density, and fall with wetland size. The calculation of the asset value of this loss is carried using Anthoff et al.`s model:[155]

$$VW_{t,r} = \alpha \left(\frac{Y_{t,r}}{Y_o}\right)^{\beta} \left(\frac{d_{t,r}}{d_0}\right)^{\gamma} \left(\frac{W_{1990,r} - W_{t,r}^{c}}{W_{1990,r}}\right)^{\delta}$$

Where Y is the income per capita, $d_{t,r}$ is the population density, W^c is the cumulative wetland loss as time t in region r. $W_{1990,r}$ is the wetland area in 1990 taken to be current wetland area (as derived from GIS spatial analysis – Section 4), and d_0 and Y_0 are normalisation constants taken as the OECD average of 33p/km^2 (person per square kilometre) and US \$25,000p/yr (person per year), respectively. α, β, γ and δ are parameters taken as the Latin American average of US \$780,000,[156] 1.16, 0.47 and -0.11 respectively. Wetland value was estimated at between \$300,000/km^2 for Guyana and \$3,500,000/km^2 for The Bahamas. These estimates are supported by a Latin American average of \$900,000/km^2.[157]

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[154] Brander, L.M., Florax, R.J. and Vermaat, J.E. 2006. The empirics of wetland valuation: a comprehensive summary and meta-analysis of the literature. Environmental & Resource Economics, 33, 223-250.

[155] Anthoff, D., Nicholls, R.J. and Tol, R.S. 2010. The economic impact of substantial sea-level rise. Mitigation and Adaptation Strategies for Global Change, 15, pp.321-335.

[156] Fankhauser, S. 1994. Protection vs retreat—the economic costs of sea level rise. Environmental Planning A, 27, 299–319.

[157] Tol, R.S.J. 2002. Estimates of the Damage Costs of Climate change: Benchmark estimates. Environmental and Resource Economics, 21, 47-73.

Dryland loss: Dryland loss is estimated as proportional to the income density (US $/km^2) of the country and similarly calculated using Anthoff et al.`s model[158] with the following calculation provides a cost/km^2 of land lost:

$$VD_{t,r} = \varphi \left(\frac{Y_{t,r}/A_{t,r}}{YA_0} \right)^{\varepsilon}$$

Where $VD_{t,r}$ is the unit value of dryland (US $/km^2), $Y_{t,r}$ is the total income and $A_{t,r}$ is the area at time t in region r. YA_0 is a normalisation constant (US $0.635 million/km^2) and ε and φ are parameters with values 1 and 4 respectively. Estimates are comparable to those derived from a World Bank study in 2002[159] that valued land loss between US $0.4 and US $1 million per hectare.[160]

Residential property: A pronounced impact of SLR is the forced displacement of populations. Populations tend to cluster near water-courses, resulting in the effect of SLR being amplified. On many of the islands of the Caribbean, all the population live within 10km of the coast.[161] This is important for two reasons: first that they are disproportionately vulnerable to SLR, but also they are dependent on economic sectors that are more likely to be reliant on coastal activities. For reconstruction costs, the estimation uses a figure of $100,000[162] for a four-person home and the replacement of service at an average cost of US $8,173 per person.[163] As construction costs would vary within each country, this is partially weighted by GDP per capita as this would represent variations in building costs.

Tourist resorts: Rebuild cost was also estimated for tourist resorts, where the reconstruction cost of the lost resorts was based on typical rebuild cost of US $100,000,000.[164] This is the higher end of the rebuild estimate range, reflecting the increased land costs as development opportunities diminish, the need to purchase properties further away from the coastline that increasingly will have been previously developed, and the need to incorporate additional shoreline protection to the extent

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[158] Anthoff, D., Nicholls, R.J. and Tol, R.S. 2010. The economic impact of substantial sea-level rise. Mitigation and Adaptation Strategies for Global Change, 15, pp.321-335.

[159] Haites, E, Pantin, D., Attzs, M., Bruce, J. 2002. Assessment of the Economic Impact of Climate Change on Caricom Countries. Report to World Bank: Latin America and Caribbean.

[160] Toba, N., 2009. Potential Economic Impacts of Climate Change in the Caribbean Community. LCR Sustainable Development Working Paper No. 32. World Bank.

[161] Burke, Lauretta and Maidens, J. 2004. Reefs at risk in the Caribbean. World Resources Institute. Washington. Accessed from http://www.wri.org/publication/reefs-risk-caribbean (Accessed 28 Oct 2010)

[162] US $10,000 is considered a conservative estimate of construction cost for a house. This has been taken from a desktop study of online estate agents and construction engineers.

[163] Haites, E, Pantin, D,, Attzs, M., Bruce,J. 2002. Assessment of the Economic Impact of Climate Change on Caricom Countries. Report to World Bank: Latin America and Caribbean.

[164] 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.

possible to protect new properties to ongoing impacts of SLR.

This is the higher end of the rebuild estimate range, reflecting the increased land costs as development opportunities diminish, the need to purchase properties further away from the coastline that increasingly will have been previously developed, and the need to incorporate additional shoreline protection to the extent possible to protect new properties to ongoing impacts of SLR.

Infrastructure: Road infrastructure rebuild was determined on a km of road infrastructure inundated, where the cost of rebuild of a two-lane paved road was US $410,000 in 2007.[165] As for residential property construction costs for roads would vary within each country, this is partially weighted by GDP per capita as this represent variations in labour and other costs.

Sea Ports and Airports: Rebuild costs for airports were based on a figure of US $65 million (established based on interview with civil engineering firms for the Phase I Report).[166] For ports a typical rebuild cost of US $20 million was used for smaller ports. However, Kingston Container terminal is a major transhipment port for the region and therefore a rebuild cost of US $600 million[167] was used. A GDP per capita weighting similar to that applied to roads was applied to rebuild costs for airports and ports.

Power Plants: Estimates of construction costs of power plants are dependent on the plant capacity as well as how it is fired. These estimates tend be consistent globally, although annual increases in costs are high. A recent study in the U.S. suggested a rule of thumb of US $2100 per kW (kilowatt).[168] This figure supports the reported projected cost of a new 150MW (megawatt) plant in Jamaica in 2006 of US $300 million.[169] Existing plant capacities vary considerably in the Caribbean and are typically oil-fired. An average rebuild capacity of 150MW is adopted based on typical existing sites such as Clifton Pier in The Bahamas.[170]

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[165] Toba, N. 2009. Potential Economic Impacts of Climate Change in the Caribbean Community. LCR Sustainable Development Working Paper No. 32. World Bank.

[166] Simpson, M.C., Scott, D., New, M., Sim, R., Smith, D., Harrison, M., Eakin, C.M., Warrick, R., Strong, A.E., Kouwenhoven, P., Harrison, S., Wilson, M., Nelson, G.C., Donner, S., Kay, R., Geldhill, D.K., Liu, G., Morgan, J.A., Kleypas, J.A., Mumby, P.J., Palazzo, A., Christensen, T.R.L., Baskett, M.L. Skirving, W.J., Elrick, C., Taylor, M., Magalhaes, M., Bell, J., Burnett, J.B., Rutty, M.K., and Overmas, M., Robertson, R. 2009. An Overview of Modeling Climate Change Impacts in the Caribbean Region with contribution from the Pacific Islands, United Nations Development Programme (UNDP), Barbados, West Indies

[167] The cost of a 'makeover' at Venezuela's largest port, Puerto Cabello, was projected to be US $600m in 2010 Leander, T., Venezuela's main port in line for $600m makeover. See: http://www.lloydslist.com/ll/sector/ports-and-logistics/article344022.ece.

[168] Kaplan, S. 2008. Power plants: characteristics and costs. CRS Report for Congress, RL34746. Washington, DC: Congressional Research Service.

[169] Thame, C. 2006. Jamaica public service to build 150MW plant ......to be fuelled by coal. Jamaica Gleaner. Accessed from http://www.jamaica-gleaner.com/gleaner/20060920/business/business1.html.

[170] Mott, M. 2010. Clifton Pier Diesel Power Station, Bahamas. Power. Accessed from http://www.power.mottmac.com/projects2/thermalanddesalinationprojects/cliftonpier/ (Accessed 6 Nov 2010)

The methods utilised to estimate specific annual losses include:

Tourist expenditure loss: Annual tourism expenditure loss is estimated by assuming a loss of amenity factor where SLR causes beach loss and hence reduced the attractiveness of the country to tourism.[171] Assuming beach loss resulting from SLR would have a similar impact as beach erosion from storm events today,[172] the contribution of tourist expenditures to GDP is assumed to decline by 20% for the proportion of beach area lost. The proportion of beach loss is determined using resort loss as a proxy. As resorts are based in the most favourable beach locations, their inundation serves as a suitable beach loss proxy.

Agriculture loss: For island states, the ability to relocate lost agricultural land is limited due to land availability constraints. To represent this restriction, population density is used as a proxy for land flexibility. As population density increase, the proportion of agricultural activity that can be relocated is inversely proportional to its population density. It is considered that the reduction in contribution of agriculture to GDP is proportional to the proportion of agricultural land inundated and population density subject to a normalisation parameter (in this report, the normalisation parameter is the country with the largest population density in the base year, i.e., Barbados).

Industry loss: Industry in the region is predominantly export based and thus requires a functioning infrastructure. Therefore, impacts on the road network act as a proxy for impacts on industry where it is assumed that any loss in infrastructure would have a corresponding impact on industry. Although infrastructure would be rebuilt, the associated interruption is considered to cause annual losses of 5% of the proportion of road loss.

Impacts of Erosion: For the case of tourist resort impacts, further analysis was conducted to determine the combined impacts of SLR and its associated erosion (Section 4.2.3). To be consistent with estimates described above, a high SLR and mid-range SLR case was determined (both using an erosion estimate of 50 times vertical SLR – Section 4.2.3). The costs of rebuild were estimates using the same procedure as outlined in the previous section, but with the new estimates of resorts impacted.

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[171] Buzinde, C.N., Manuel-Navrette, D., Yoo, E.E., Morais, D. 2010. Tourists' Perceptions in a Climate of Change: Eroding Destinations. Annals of Tourism, 37(2), 333-354.

[172] Raybould, M., Mules, T. 1999. A cost-benefit study of protection of the northern beaches of Australia's Gold Coast. Tourism Economics, 5(2), 121-139.

5.2 ECONOMIC IMPACTS OF SLR FOR CARICOM

The study finds that the costs of SLR escalated significantly towards the end of the century, as greater SLR combines with increasing populations and GDP. Table 15 summarizes the pronounced annual and capital costs of SLR to CARICOM countries in 2050 and 2080 under mid-range and high SLR scenarios. In 2050 capital costs were estimated to be between US $26 to US $60.7 billion, while annual costs ranged from US $3.9 to US $6.1 billion. Estimates for capital GDP loss to CARICOM states in 2080 were projected to be between US $68.2 and US $187 billion. This was equivalent to between 8.3% and 19.2% of GDP respectively. Annual costs for 2080 were projected to be between US $13.5 and US $19.4 billion per annum (1.6% to 2% of GDP in 2080).

Table 15: Annual and capital costs of sea level rise in CARICOM countries

	2050		2080	
	Annual Costs (US $ billion)	Capital Costs (US $ billion)	Annual Costs (US $ billion)	Capital Costs (US $ billion)
Mid-Range SLR Scenario	3.9	26	13.5	68.2
High SLR Scenario	6.1	60.7	19.4	187

As Figure 28 and Figure 29 illustrate, both capital costs and annual costs of SLR more than doubled in many countries between 2050 and 2080. Countries with tourism dependent economies were particularly affected with annual costs. For example, The Bahamas tourism sector incurs annual losses of between US $869 and US $946 million in 2050 and between US $2.2 and US $2.6 billion in 2080. Typically, large annual impacts on the agriculture sector were avoided, except in the case of Haiti, which incurs losses of around 1% per annum of GDP in 2080 from agriculture alone. Impacts on industry were found to be negligible in almost all cases. However, this is believed to be a limitation of the analysis (not accounting for secondary and tertiary feedbacks in the economy) rather than indicating a resilient industrial base for the CARICOM countries. As discussed previously, undertaking a full system analysis would provide greater scope for determining impacts on this sector.

Much of the region's capital costs will occur in The Bahamas (airports, tourism and dryland losses), Jamaica (sea ports, tourism and dryland losses), and Haiti (dryland and property losses). Capital costs were dominated for the most part by dryland losses (US $9.4 to US $21billion in 2050, US $30.1 to US $60.6billion in 2080) and rebuild costs of tourist resorts (US $10 to US $23.3 billion in 2050 and US $23.5 to US $74 billion in 2080).[173] A summary of the total costs split by sector and country are shown for 2050 in Table 16 and Table 17 and total costs for 2080 are found in Table 18 and Table 19.

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[173] Particularly concerning is the amplifying effects erosion has on the mid range scenario, where rebuild costs were projected to increase by several hundred percent in several cases. Most notable in this case was Barbados where costs increased from US $945 million to US $6.6 billion in the mid range SLR scenario in 2080.

Figure 28: Summary of annual costs (US $ million) on CARICOM countries

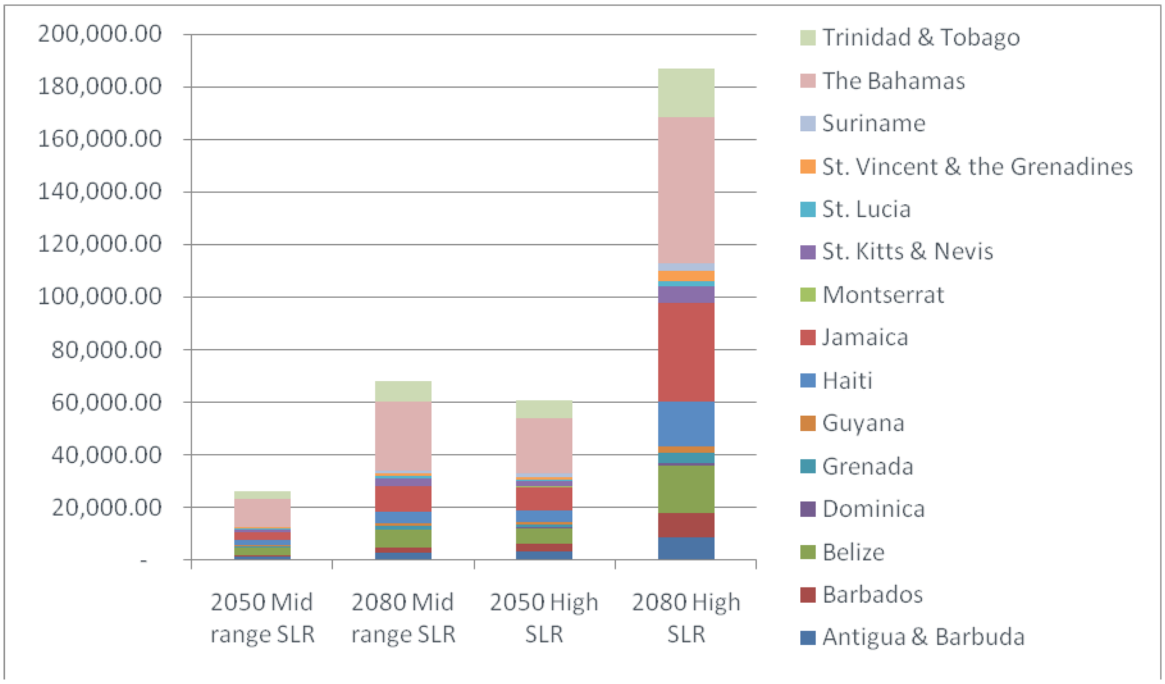


Figure 29: Summary of capital costs (US $ million) on CARICOM countries

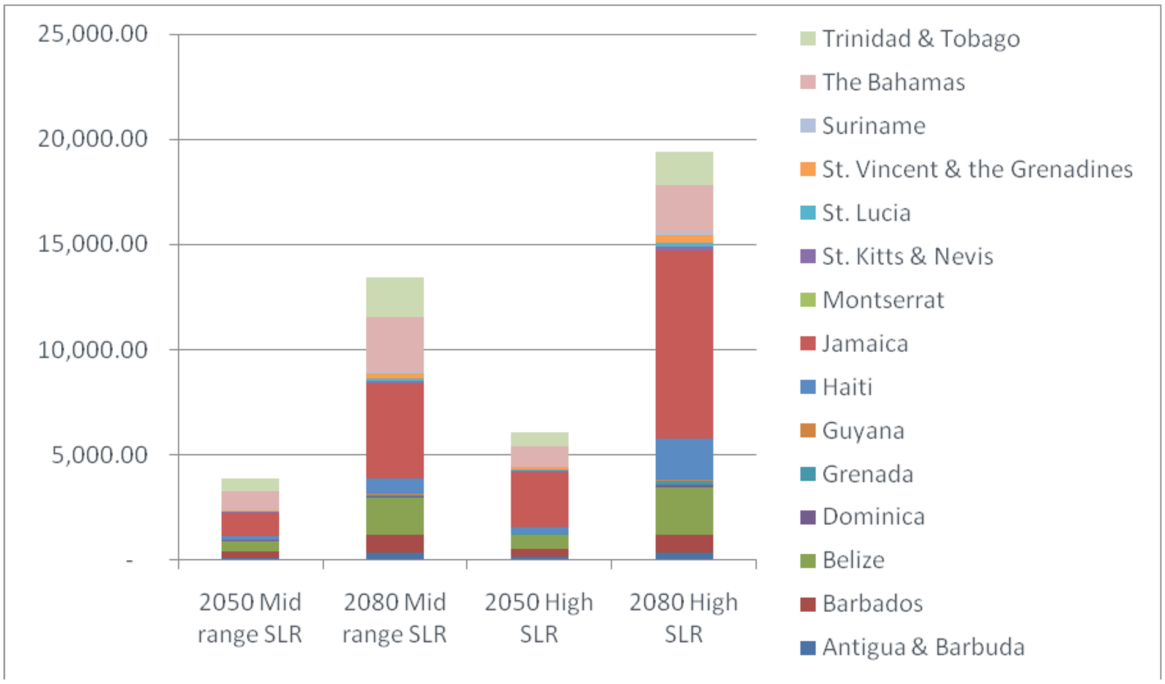


Table 16: Annual and capital costs mid range sea level rise scenario 2050

		Annual Costs (US $million)				Capital Costs (US $million)								
Countries	GDP (US $million)	Tourism	Agriculture	Industry	Total	Airports	Ports	Roads	Power plants	Property	Tourist resorts	Dryland loss	Wetland loss	Total
Antigua & Barbuda	4,538	102	0	0	103	-	19	1	-	43	668	307	-	1,038
Barbados	14,563	283	1	-	283	-	16	-	-	34	401	249	-	701
Belize	20,573	518	0	2	521	57	38	11	208	44	2,139	387	4	2,889
Dominica	2,446	16	1	3	20	-	24	4	-	7	-	26	-	62
Grenada	2,697	19	4	0	23	30	10	0	-	20	334	95	-	489
Guyana	21,214	-	0	14	14	-	-	27	208	87	-	84	21	427
Haiti	59,797	27	144	1	172	15	5	2	-	333	869	594	4	1,822
Jamaica	138,287	1,075	14	14	1,102	43	1,223	8	-	129	535	1,015	1	2,954
Montserrat	111	-	0	0	0	-	17	0	-	0	-	3	-	20
St. Kitts & Nevis	1,565	30	0	0	30	44	15	0	-	13	936	58	-	1,065
St. Lucia	7,438	41	0	0	42	42	57	0	-	16	134	118	-	367
St. Vincent & the Grenadines	4,655	46	5	0	51	81	54	0	-	20	134	156	-	445
Suriname	23,758	10	0	9	19	-	16	33	-	47	67	65	18	247
The Bahamas	33,764	869	2	8	878	926	234	110	625	469	3,208	4,348	650	10,570
Trinidad & Tobago	85,497	608	3	12	622	54	37	2	-	308	535	1,977	-	2,913
Total	420,904	3,642	176	62	3,880	1,292	1,766	199	,042	1,571	9,958	9,484	698	26,010

Table 17: Annual and capital costs high range sea level rise scenario 2050

		Annual Costs (US $million)				Capital Costs (US $million)								
Countries	GDP (US $million)	Tourism	Agriculture	Industry	Total	Airports	Ports	Roads	Power plants	Property	Tourist resorts	Dryland loss	Wetland loss	Total
Antigua & Barbuda	4,983	145	1	1	147	81	30	2	309	164	1,802	759	-	3,147
Barbados	15,916	368	1	-	369	-	26	-	-	87	2,402	462	-	2,978
Belize	24,769	654	2	4	660	72	53	22	309	182	3,804	1,425	18	5,885
Dominica	3,543	27	2	4	33	64	47	7	-	19	100	63	-	300
Grenada	3,729	35	8	0	43	56	20	0	-	47	801	212	-	1,137
Guyana	20,360	-	0	14	14	-	-	52	309	366	-	196	68	991
Haiti	59,797	32	283	3	318	21	8	5	-	1,208	1,702	1,366	10	4,319
Jamaica	211,674	2,516	52	24	2,592	215	3,167	16	309	376	1,902	3,027	3	9,016
Montserrat	125	-	0	0	0	-	30	0	-	1	-	5	-	37
St. Kitts & Nevis	1,898	44	0	0	44	77	28	0	-	32	1,702	120	-	1,959
St. Lucia	8,023	80	1	0	81	62	91	0	-	39	300	217	-	709
St. Vincent & the Grenadines	5,695	112	10	0	123	197	97	1	-	46	500	303	-	1,144
Suriname	28,736	12	0	13	25	-	29	66	309	242	200	234	75	1,155
The Bahamas	30,449	946	3	9	959	1,486	289	167	1,237	1,440	6,606	8,487	1,226	20,939
Trinidad & Tobago	84,865	644	5	22	671	71	52	6	-	995	1,501	4,379	-	7,004
Total	504,562	5,615	370	95	6,079	2,402	3,968	344	2,782	5,245	23,323	21,257	1,400	60,720

Table 18: Annual and capital costs mid range sea level rise scenario 2080

		Annual Costs (US $million)				Capital Costs (US $million)								
Countries	GDP (US $million)	Tourism	Agriculture	Industry	Total	Airports	Ports	Roads	Power plants	Property	Tourist resorts	Dryland loss	Wetland loss	Total
Antigua & Barbuda	8,657	340	3	2	344	-	46	2	-	102	1,576	1,024	-	2,749
Barbados	25,026	850	2	-	852	-	40	-	-	81	946	750	-	1,817
Belize	39,454	1,740	2	8	1,750	98	66	19	208	104	5,045	1,300	8	6,847
Dominica	4,939	55	7	9	71	-	66	10	-	17	-	93	-	186
Grenada	5,495	66	17	0	84	90	30	0	-	47	788	339	-	1,295
Guyana	37,673	-	0	43	43	-	-	76	208	205	-	261	65	816
Haiti	97,669	76	655	4	735	32	11	4	-	785	2,049	1,698	7	4,586
Jamaica	318,642	4,334	114	55	4,502	98	4,010	19	-	305	1,261	4,094	3	9,789
Montserrat	253	-	0	0	0	-	44	1	-	1	-	10	-	56
St. Kitts & Nevis	3,012	101	1	0	102	132	44	0	-	30	2,207	196	-	2,609
St. Lucia	14,896	144	3	0	147	98	132	0	-	37	315	414	-	996
St. Vincent & the Grenadines	10,064	174	34	1	208	201	135	1	-	47	315	592	-	1,290
Suriname	49,327	36	0	33	69	-	38	78	-	111	158	237	50	673
The Bahamas	58,444	2,632	10	23	2,664	1,779	449	211	625	1,107	7,567	13,171	1,422	26,331
Trinidad & Tobago	147,446	1,835	13	35	1,883	119	80	5	-	726	1,261	5,968	-	8,159
Total	820,996	12,383	861	211	13,455	2,646	5,191	427	1,042	3,705	23,489	30,147	1,555	68,200

Table 19: Annual and capital costs high range sea level rise scenario 2080

		Annual Costs (US $million)				Capital Costs (US $million)								
Countries	GDP (US $million)	Tourism	Agriculture	Industry	Total	Airports	Ports	Roads	Power plants	Property	Tourist resorts	Dryland loss	Wetland loss	Total
Antigua & Barbuda	6,687	340	2	3	345	227	84	7	309	519	5,711	1,783	-	8,640
Barbados	21,126	854	2	-	857	-	76	-	-	276	7,615	1,074	-	9,041
Belize	48,569	2,244	6	15	2,264	240	177	73	309	578	12,057	4,891	71	18,396
Dominica	7,691	103	10	14	128	199	146	22	-	59	317	241	-	984
Grenada	7,758	127	36	0	164	170	62	1	-	150	2,538	772	-	3,694
Guyana	30,408	-	0	36	36	-	-	209	309	1,161	-	513	275	2,467
Haiti	193,945	183	1,756	15	1,955	73	27	18	-	3,830	5,394	7,756	67	17,164
Jamaica	419,213	8,720	170	85	8,974	761	18,408	58	309	1,191	6,029	10,492	11	37,259
Montserrat	273	-	0	0	0	-	94	1	-	4	-	19	-	118
St. Kitts & Nevis	3,581	144	2	0	146	216	79	0	-	102	5,394	398	-	6,189
St. Lucia	13,218	231	2	0	233	200	294	0	-	123	952	626	-	2,194
St. Vincent & the Grenadines	9,518	328	24	1	354	677	332	2	-	146	1,586	886	-	3,629
Suriname	54,755	39	0	43	83	-	107	240	309	767	635	779	302	3,138
The Bahamas	41,312	2,247	7	21	2,275	3,993	777	448	1,237	4,566	20,942	20,151	3,330	55,443
Trinidad & Tobago	113,886	1,512	10	51	1,573	199	146	17	-	3,155	4,759	10,283	-	18,560
Total	971,940	17,073	2,030	285	19,388	6,956	20,810	1,095	2,782	16,626	73,931	60,662	4,055	186,916

5.3 SUMMARY OF ECONOMIC IMPACT BY COUNTRY TYPE

5.3.1 SMALL ISLANDS AND CAYS

The Bahamas, most of the Grenadines and Barbuda belong in this category of islands. The Grenadines and Barbuda are discussed in further sections.

The Bahamas has a predominantly service based economy, with the tourist sector contributing 50% of GDP. Beach tourism is particularly vulnerable to the impacts of SLR resulting in an annual loss of almost 3.5% of GDP in the high SLR scenario in 2080.

Figure 30: Annual costs of sea level rise to the Bahamas as % of GDP

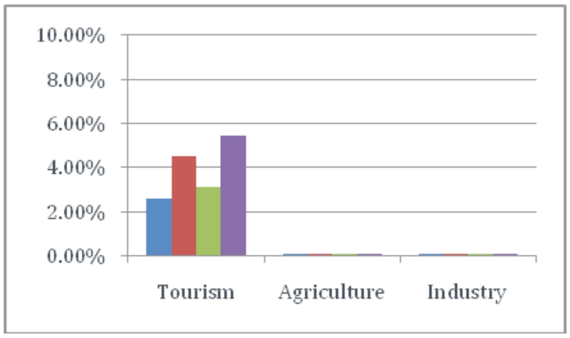
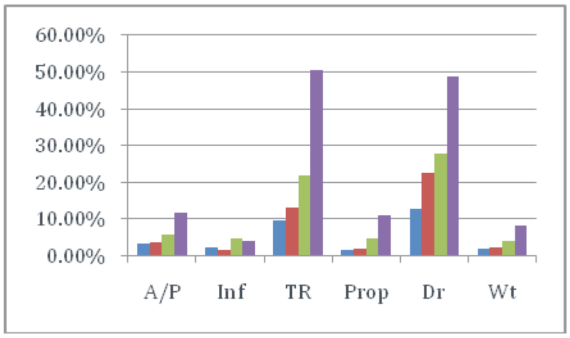


Figure 31: Capital costs of sea level rise to the Bahamas as % of GDP



Annual costs to tourism were estimated to be very high, with annual losses of US $868 to US $946 million in 2050 and US $2.2 to US $2.6 billion in 2080. However, it is the high cost of replacement of tourist resorts that will affect the tourist sector most with projected rebuild costs of between US $3.2 and US $6.6 billion in 2050 and between US $7.6 and US $20.9 billion in 2080. It also suffers significant airport and port loss in both scenarios as well as large dryland and wetland loss. This results in a total capital cost of between 45% and 134% of GDP in 2080. Taking into account erosion, rebuild costs increase further for tourist resorts to between US $12.1 and US $29.5 billion in 2080.

Wetland and dryland loss are particularly significant due to the large area of land lost coupled with population density constraints and a high GDP per capita.

5.3.2 VOLCANIC ISLANDS

The second group of islands are the mainly volcanic islands of St. Kitts and Nevis, St. Lucia, St. Vincent, Grenada, Dominica and Montserrat.

St. Kitts and Nevis is dependent on tourism. However, it is susceptible to shifting tourism demand. Other sectors of the economy of importance are export-oriented manufacturing and offshore banking. Annual losses are dominated by impacts on tourism of over 2% after 2050. Total capital costs are projected to be between 68% and 103% of GDP in 2050 and between 85% and 160% in GDP in 2080 due predominantly to the rebuild costs of tourist resorts. The additional impacts of erosion are projected to increase tourist resort rebuild costs by a further US $160 to US $320 million in 2080.

As one of the smaller islands of CARICOM, St. Lucia maintains a population of 165,000; it is dependent on tourism with it contributing over 50% of GDP.[174] Its small agricultural sector is based on agricultural exports (specifically bananas). Capital costs are dominated by rebuild costs of ports, airports and tourist resorts with total rebuild costs up to US $1.6 billion in 2080. The impacts of erosion are projected to more than double the tourist resort rebuild costs from US $315 to US $790 million in the mid range SLR scenario and from US $950 million to US $2.85 billion in the high SLR scenario in 2080.

The economy of St. Vincent and the Grenadines is dependent on agriculture, predominantly banana production and tourism. However, annual costs are significantly greater to tourism than agricultural with total annual costs between US $210 to US $350 million in 2080. Airports and ports are particularly vulnerable resulting in a combined loss of between 3% and 10% of GDP by 2080. According to projections, erosion acts a significant amplifier of impacts. Rebuild costs for tourist resorts increase from US $315 million to US $1.2 billion in the mid range SLR scenario and from US $1.6 to US $5.1 billion in the high SLR scenario in 2080.

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[174] Burke, L., Maidens, J., Spalding, M., Kramer, P., Green, E., Greenhalgh, S., Nobles, H., Kool, J. 2004. Reefs at Risk in the Caribbean. World Resources Institute. Washington, D.C.

The Grenada economy is based on a tourism and financial industry. The agricultural sector has been devastated by the effects of hurricanes; indeed it has 32% of its population below the poverty line. It's strongly import dependent requiring food and manufacturing goods. Impacts on ports and airports are of particular concern as full inundation occurs in both scenarios, resulting in rebuild costs of between US $120 and US $230 million in 2080. Tourist resorts are also severely impacted, resulting in rebuild costs of between 14% and 34% of GDP in 2080 for the mid range SLR and high SLR scenarios respectively. As for St. Vincent and the Grenadines, erosion increases this dramatically from US $2.5 to US $6 billion in 2080 for the high SLR scenario, more than doubling the already significant rebuild costs.

Agriculture accounts for about 20% of GDP and 40% of the labour force of Dominica. The agricultural sector is based on small farms that have formed into cooperatives and thus any loss of agricultural land would reflect a real loss in annual production as small farmers are less resilient to this loss. As a result of agricultural land inundation and population constraints, annual losses to GDP are projected for 2080 of between US $70 and US $130 million in 2080. Due to its underdeveloped infrastructure and lack of white beaches, Dominica's tourist industry does not have the same attraction as other islands in the region thus leaving its economy less exposed to tourism impacts. However, total capital costs to Dominica are still significant with high SLR and mid range estimates 12.8% and 3.8% of GDP respectively in 2080.

Montserrat is the smallest country of the CARICOM states with just over 5,000 residents. Its main economic activity resides in government services and construction that account for 50% of GDP, both of which are resilient to SLR impacts. Consequently, annual losses are negligible in tourism with total annual losses in all sectors between US $95 and US $110 million in 2080. The greatest impact on Montserrat is port impacts with complete inundation occurring at 1m SLR resulting in port and road rebuild costs of between US $45 and US $95 million in 2080.

Figure 32: Annual costs of sea level rise to St. Kitts and Nevis as % of GDP

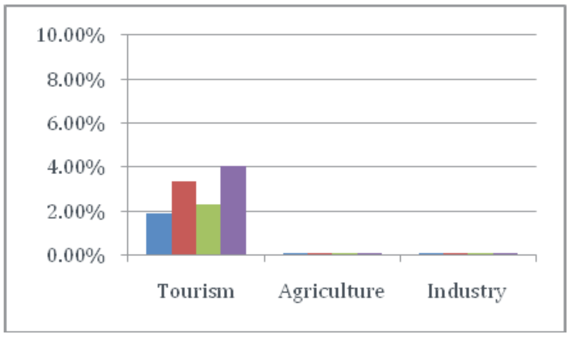


Figure 33: Annual costs of sea level rise to St. Lucia as % of GDP

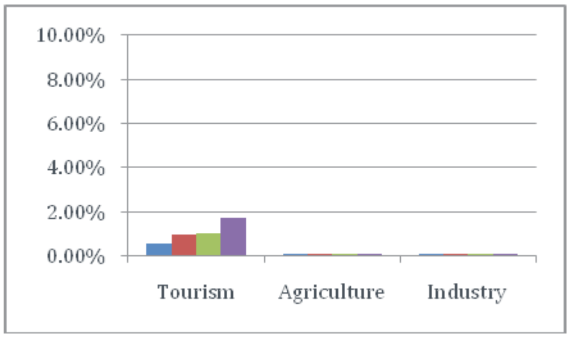


Figure 34: Annual costs of sea level rise to St. Vincent and the Grenadines as % of GDP

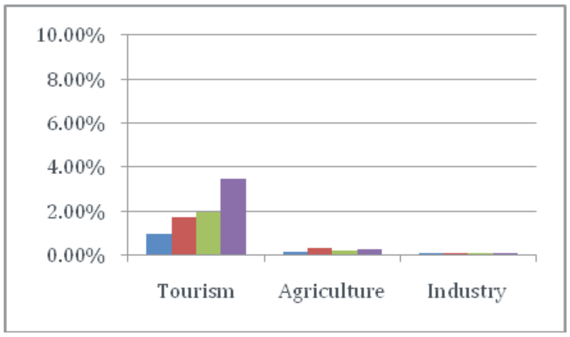


Figure 35: Annual costs of sea level rise to Grenada as % of GDP

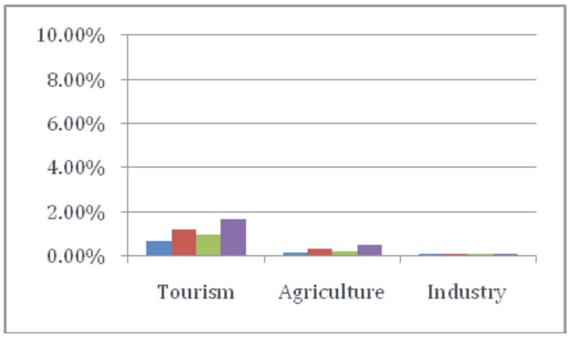


Figure 36: Capital costs of sea level rise to St. Kitts and Nevis as % of GDP

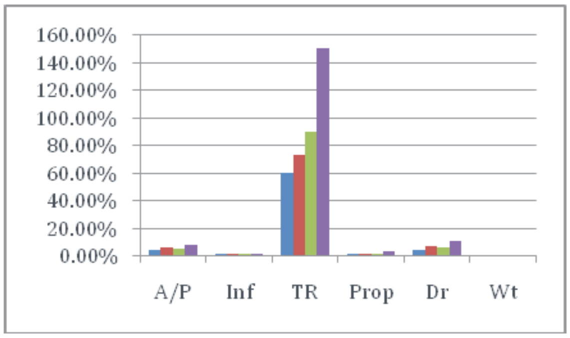


Figure 37: Capital costs of sea level rise to St. Lucia as % of GDP

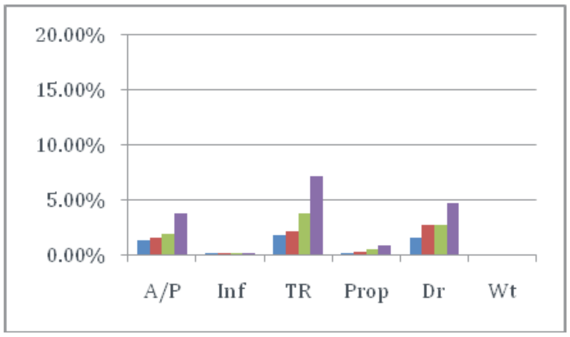


Figure 38: Capital costs of sea level rise to St. Vincent and the Grenadines as % of GDP

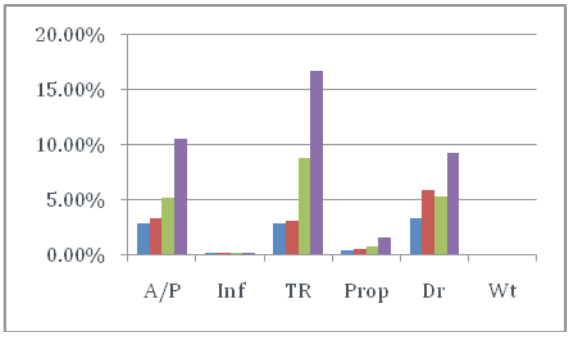
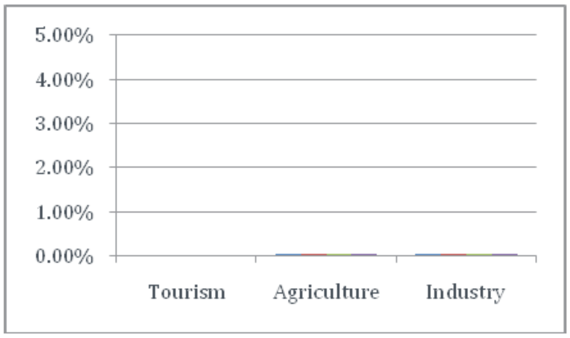


Figure 41: Annual costs of sea level rise to Montserrat as % of GDP



5.3.3 LARGE COASTAL PLAINS

The third group of countries consists of those with large coastal plains, located on the American continent: Belize, Guyana and Suriname.

Figure 39: Capital costs of sea level rise to Grenada as % of GDP

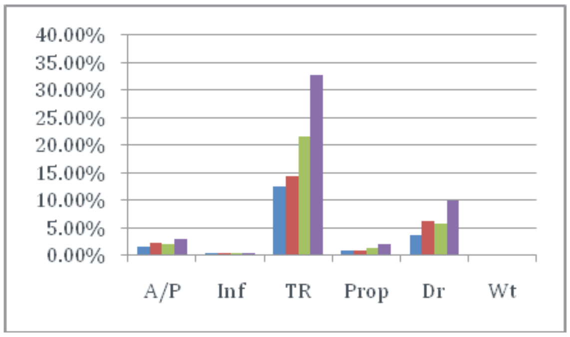
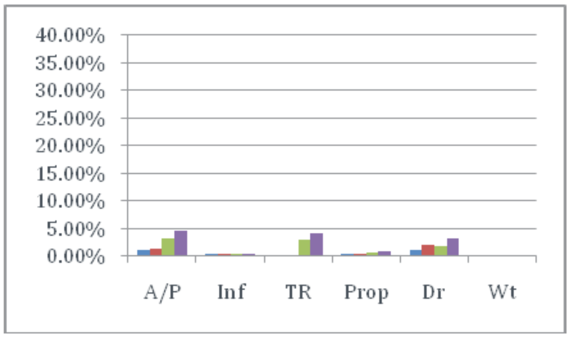


Figure 42: Capital costs of sea level rise to Dominica as % of GDP



Belize is strongly dependent on agriculture (21% of GDP) although it does have a burgeoning tourist sector. Its coastal region is extremely low lying and is thus already at risk to storm surges and hurricanes. A considerable area of wetland is under threat as well as dryland. Value of land loss in 2080 for both dryland and wetland is projected to be US $1.3 and US $5 billion for the mid range SLR and high SLR scenarios respectively. Its tourist industry is heavily dependent on its natural coastal endowments: the Belize Barrier Reef and numerous cays. Loss of natural amenities results in projected annual costs of greater than 2.5% of GDP for both scenarios from 2050. Tourist resort inundation is also significant totalling 13% and 25% of GDP for the mid range SLR and high SLR scenarios respectively in 2080. Indeed, this cost is amplified through the effects of erosion, resulting in additional tourist resort rebuild costs of up to US $1.6 billion in the mid range SLR scenario and US $2 billion in the high SLR scenario in 2080.

Figure 40: Annual costs of sea level rise to Dominica as % of GDP

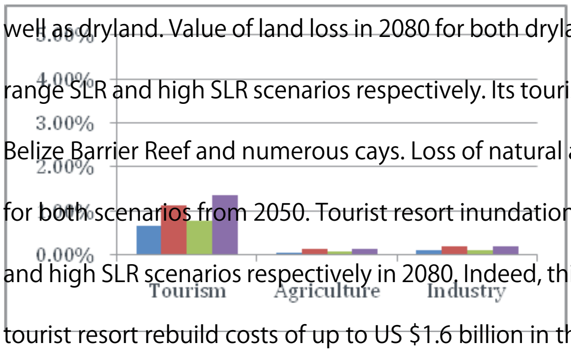
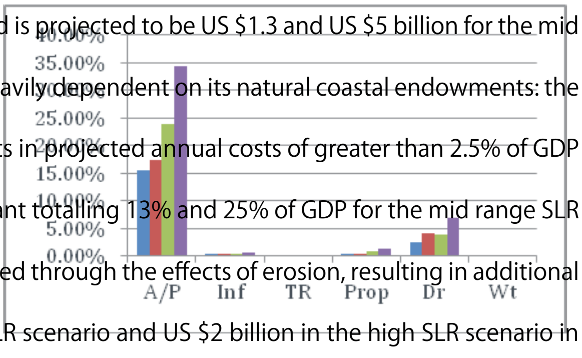


Figure 43: Capital costs of sea level rise to Montserrat as % of GDP



Guyana is dependent on its agriculture and extractive industries representing about 60% of GDP through its export of these commodities. SLR is found to have a negligible impact on these industries. Indeed the percentage of crop/plantation area affect by 2m SLR is negligible. Tourism is a nascent in the country, not attracting the tourists that the island states attract in the region. However, it was projected to suffer significant land loss and population displacement. Population relocation costs were calculated at US $205 million and US $1.2 billion for the midrange SLR and high SLR respectively in 2080.

The economy of Suriname is dominated by the mining industry accounting for about 85% of exports and 25% of government revenues. Although it does suffer annual costs, it is somewhat insulated to the impacts of SLR, as shown in Figure 46. However, due to its long coastal plains, it was projected to incur significant wetland and dryland loss as well as a population displacement of over 10,000 people in the 2m SLR scenario with relocation costs of US $110 and US $770 million for the mid range SLR and high SLR scenarios respectively in 2080.

Although these mainland countries lose significant land in both the high and low scenarios, they are somewhat insulated to the effects, due to their relatively low population density.

Figure 44: Annual costs of sea level rise in Belize due to SLR as % of GDP

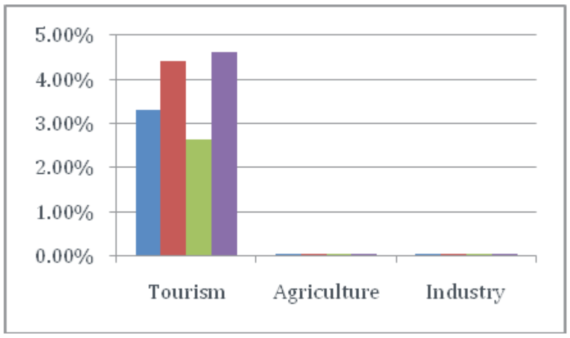


Figure 47: Capital costs of sea level rise in Belize due to SLR as % of GDP

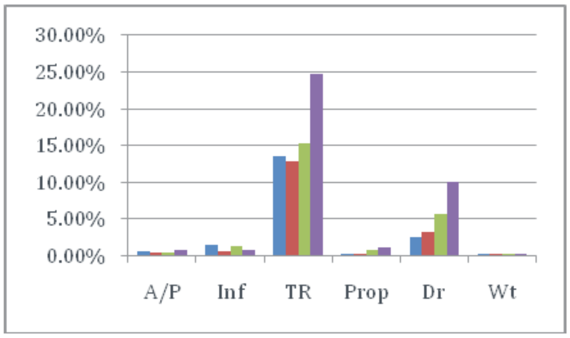


Figure 45: Annual costs to Guyana from sea level rise as % of GDP

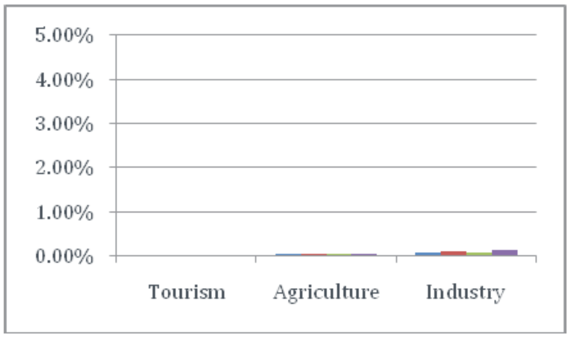


Figure 48: Capital costs to Guyana from sea level rise as % of GDP

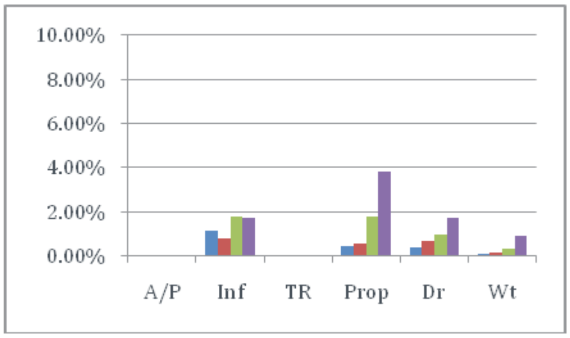


Figure 46: Annual costs of sea level rise to Suriname as % of GDP

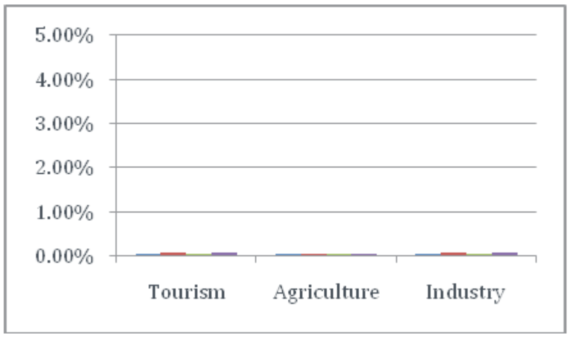
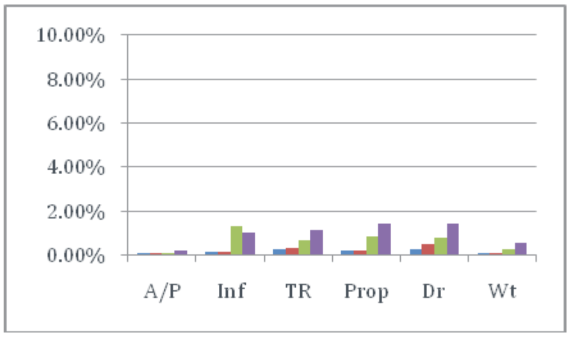


Figure 49: Capital costs of sea level rise to Suriname as % of GDP



5.3.4 VARIED COASTLINES

This final group of countries are Antigua and Barbuda, Barbados, Haiti, Jamaica and Trinidad and Tobago.

Antigua and Barbuda maintains a service based economy heavily reliant on tourism with it contributing 72% to GDP.[175] As a result, tourism dominates the projected annual losses of approx US $345 million in 2080. Capital costs are also dominated by the tourist sector, with rebuild costs of tourist resorts projected to be between 18% and 85% of GDP in 2080 for the mid range SLR and high SLR respectively. The associated erosion with SLR of 1m to 2m dramatically increases projected rebuild costs of tourist resorts. Combined impacts are projected to result in tourist resort rebuild cost of between 62% and 209% of GDP in 2080, almost a threefold increase in costs. Barbados also commands a service based industry, with a contribution of about 75% of GDP.[176]

Tourism plays a significant role in the economy but financial services and foreign investment are also significant contributors to GDP both of which would be insulated to SLR compared with tourism. It is difficult to quantify damage to wetlands due to SLR as a significant area of wetland has already been developed and it was not possible to identify wetland areas in the analysis. Inundation due to SLR is concentrated in the south and west of the island. No road, airport or power plant inundation occurs in either scenario, although some port inundation is projected to occur. However, it incurs an annual cost to the GDP through beach loss, with projected annual losses of between US $850 and US $860 million. Also, rebuild costs are projected to be significant, particularly for the high SLR scenario as costs reach 36% of GDP in 2080. The inclusion of erosion amplifies the effects of SLR, particularly in the mid range scenario increasing from US $945 million to US $6.6 billion in 2080.

Haiti is the poorest country in the Western hemisphere as well as commanding the largest population of the CARICOM countries with over 9 million people. Over two thirds of Haitians are dependent on the agriculture sector with it accounting for 28% of GDP through small scale subsistence farming. A country constantly rocked by natural disasters, tourism has struggled to get off the ground. Annual costs of SLR rise on agriculture in 2080 are projected to be between US $650 million and US $1.8 billion for mid range SLR and high SLR scenarios respectively. 120,000 of the population would be displaced due to SLR

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[175] Burke,L., Maidens,J., Spalding,M., Kramer,P., Green,E., Greenhalgh,S., Nobles,H., Kool, J. 2004. Reefs at Risk in the Caribbean. World Resources Institute. Washington, D.C.

[176] CIA Factbook. 2010. Accessed from https://www.cia.gov/library/publications/the-world-factbook/geos/bb.html

of 2m. For the mid-range SLR and high SLR scenarios relocation costs are projected to range between US $785 million to US $3.8 billion in 2080.

The second most populous country in the CARICOM with 2.8 million people, Jamaica is a country with an endowment of natural resources and a climate conducive to agriculture and tourism. It is a service based country with 27% of GDP contributed by tourism. Inundation resulted in total rebuild costs of between US $5.7 and US $26.8 billion in 2080. Rebuild costs for port infrastructure are significant due to impacts on the major trans-shipment terminal at Kingston.

Trinidad and Tobago has an economy strongly dependent on its natural resources with proven oil and gas reserves. However, it does maintain a small tourist sector constituting 12.8% of GDP[177] that suffers over 30% and 60% of resort loss for 1m SLR and 2m SLR respectively. As a result, the annual costs are dominated by the effects on this sector with total annual costs between US $620 and US $670 million in 2050 and between US $1.6 and US $1.9 billion in 2080. Capital costs in 2080 are dominated by dryland loss resulting in a loss of land value of between US $6 and US $10.2 billion in 2080 for the mid range SLR and high SLR scenarios respectively.

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[177] (ECLAC 2010) T&T

Figure 50: Annual GDP loss costs of sea level rise for Antigua and Barbuda as % of GDP

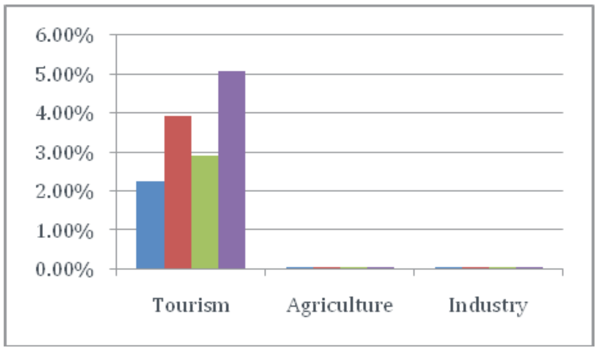


Figure 51: Annual costs due to sea level rise in Barbados as % of GDP

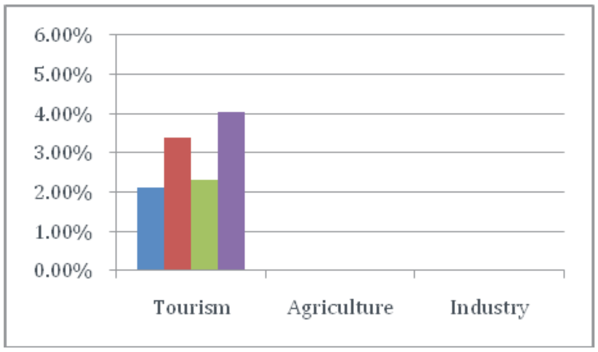


Figure 52: Annual costs to Haiti from sea level rise as % of GDP

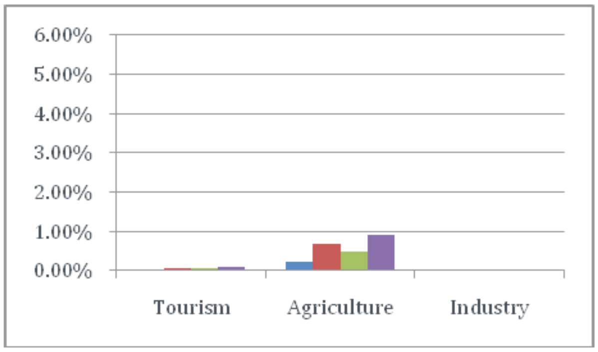


Figure 53: Annual costs of sea level rise to Jamaica as % of GDP

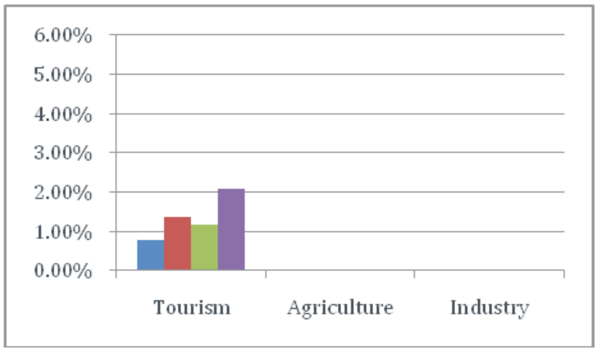


Figure 54: Capital costs of sea level rise at intervening periods for Antigua and Barbuda

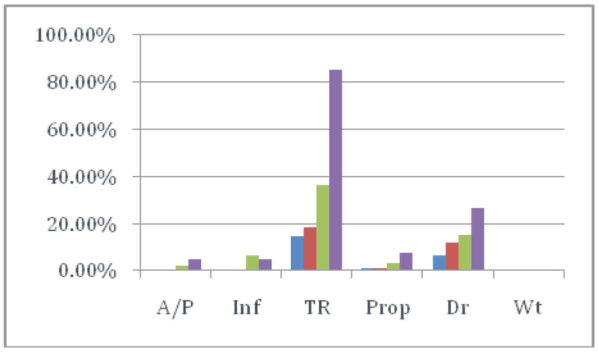


Figure 55: Capital costs due to sea level rise in Barbados as % of GDP

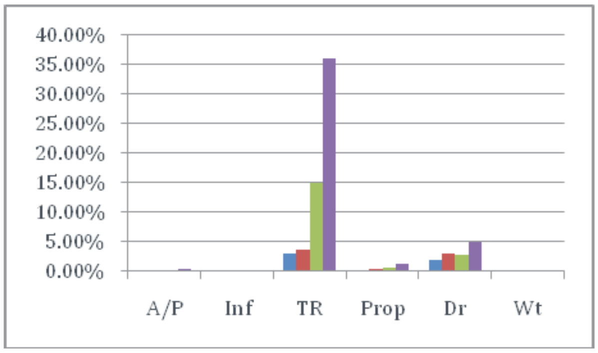


Figure 56: Capital costs of sea level rise to Haiti as % of GDP

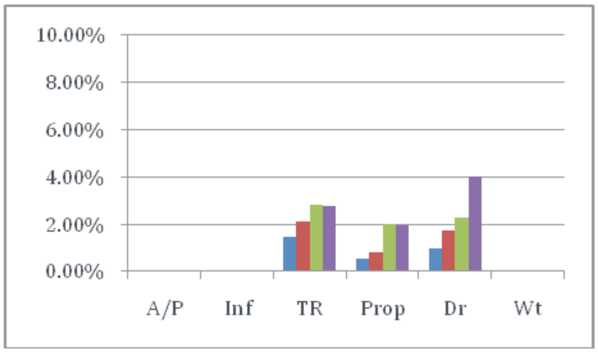


Figure 57: Capital costs of sea level rise to Jamaica as % GDP

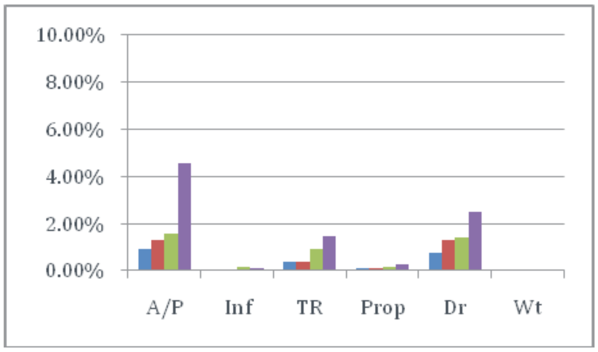


Figure 58: Annual costs of sea level rise to Trinidad and Tobago as % of GDP

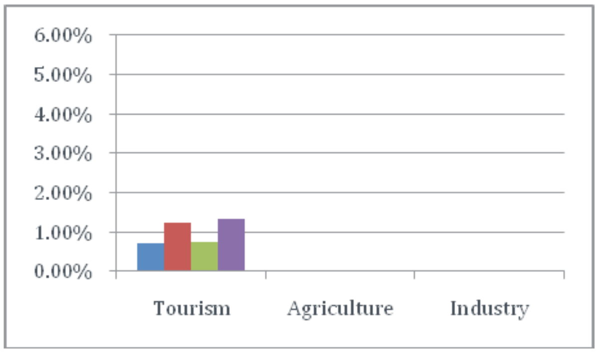
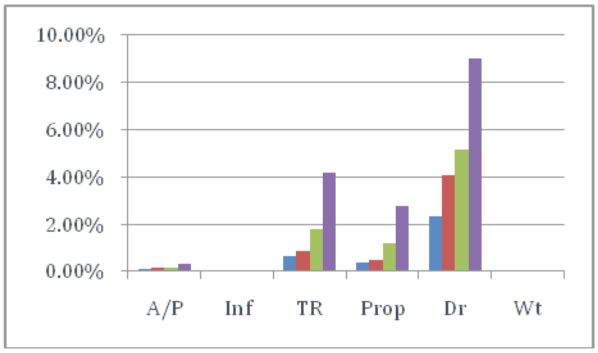


Figure 59: Capital costs of sea level rise to Trinidad and Tobago as % of GDP



6. Conclusion and Summary for Policy Makers

The IPCC AR4 declared that 'warming of the climate system is unequivocal' and that the pace of climate change is *'very likely'* to accelerate throughout the 21st Century if GHG emissions continue at or above current rates.[178] Indeed, analyses of GHG emission trajectories and mitigation commitments by the international community have led several recent studies to recommend that society should be preparing to adapt to +4°C global warming.[179,180,181,182] SLR and the resulting erosion impacts are some of the most serious long-term threats of global climate change, as even if GHG emissions were stabilised in the near future and global temperatures stabilised at +2°C or 2.5°C, sea levels would continue to rise for many decades or centuries in response to a warmer atmosphere and oceans. Consequently, on human time scales, SLR represents a unidirectional, negative threat to coastal ecosystems and economies.

Studies of previous sea level responses to climate change reveal that SLR of 1m per century has not been unusual and that rates up to 2m per century have been observed.[183] Although present rates of global SLR are not yet approaching 1m per century, they are observed to be accelerating in response to increased global warming.[184] The IPCC AR4 projections of a global SLR of 18 to 59cm from 1990 to 2100 are thought to be highly conservative,[185,186] because they assumed a near-zero net contribution of the Greenland and Antarctic ice sheets.[187,188] More recent studies that attempt to estimate the response of continental ice to global warming indicate that SLR by the end of the 21st Century could reach as much as 1.5m to 2m above present levels.[189,190,191,192,193] Notably, with its proximity to the equator, SLR will be relatively more pronounced in the Caribbean than some other coastal areas of the world.[194,195]

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[178] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[179] Anderson, K., & Bows, A. 2008. Reframing the climate change challenge in light of post-2000 emission trends. Philosophical Transactions A, 366(1882), 3863.

[180] Allen, M.R., Frame, D.J., Huntingford, C., Jones, C.D., Lowe, J.A., Meinshausen, M., & Meinshausen, N. 2009. Warming caused by cumulative carbon emissions towards the trillionth tonne. Nature, 458(7242), 1163-1166.

[181] Meinshausen, M., Meinshausen, N., Hare, W., Raper, S.C.B., Frieler, K., Knutti, R., Frame, D.J., & Myles, R.A. 2009. Greenhouse-gas emission targets for limiting global warming to 2°C. Nature, 458(7242), 1158– 1162.

[182] Parry, M., Lowe, J., and Hanson, C. 2009. Overshoot, adapt and recover. Nature, 458(7242), 1102–1103.

[183] Berger, WH. 2008. Sea level in the late Quaternary: patterns of variation and implications. International Journal of Earth Sciences, 97, 1143–1150.

[184] Rahmstorf, S. 2010. A new view on sea level rise. Nature Reports Climate Change, doi:10.1038/climate.2010.29.

[185] Oppenheimer, M., O'Neill, B., Webster, M., and Agrawala, S. 2007. The limits of consensus. Science, 317, 1505-1506.

[186] Pfeffer W.T., Harper, J.T. and O'Neel, S. 2008. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise. Science, 321(5894), 1340-1343.

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[191] Grinsted, A., Moore, J. C., and Jevrejeva, S. 2009. Reconstructing Sea Level from Paleo And Projected Temperatures 200 to 2100 AD. Climate Dynamics 34, 461–472.

[192] Jevrejeva, S., Moore, J. C. & Grinsted. In Press. Recent Global Sea Level Acceleration Started over 200 years ago? Geophysical Research Letters, doi:10.1029/2010GL042947.

[193] Horton, R., Herweijer, C., Rosenzweig, C., Liu, J., Gornitz,V. and Ruane, A. 2008. Sea Level Projections for Current Generation CGCMs based on semi-empirical method. Geophysical Research Letters 35, L02715.

[194] Bamber, J.L., Riva, R., 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.

[195] Hu, A., Meehl, G., Han, W and Yin, J. 2009. Transient response of the MOC and climate to potential melting of the Greenland Ice Sheet in the 21st century. Geophysical Research Letters, 36, L10707.

With the inextricable link between SLR and sustainable development of small islands and coastal areas increasingly recognised, there remains an urgent need to improve the information base on the risks posed by climate change impacts in the Caribbean and provide a robust foundation for adaptation decision making. The precautionary principle requires that in the absence of scientific certainty on extremes, policy-makers understand that the more extreme possibilities cannot be excluded. Therefore, consistent with other recent government SLR vulnerability assessments in the USA and the Netherlands, this study examined the impacts of both +1m and +2m SLR scenarios for comparability and evaluates the current population, infrastructure and property risk if actions are not taken to protect the coast.

This study evaluates the current population, infrastructure, and property risk from projected SLR, if actions are not taken to protect the coast. This study represents the most comprehensive assessment of the consequences of projected SLR, storm surge, and erosion for the 15 CARICOM Member States. The impacts of SLR will not be uniform among the CARICOM nations, with some projected to experience severe impacts from even a 1m SLR. Based on available information, The Bahamas, Suriname, Guyana, Trinidad and Tobago, and Belize are anticipated to suffer the greatest economic losses and damages in absolute economic terms, while the proportional economic impacts (losses compared to the size of the national economy) are generally higher in the smaller economies of St. Kitts and Nevis, Antigua and Barbuda, Barbados, St. Vincent and The Grenadines and Grenada.

In nations where low-lying land is extensive and 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 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.

Under a 1m SLR scenario, over 110,000 people in CARICOM will be displaced from their homes[196] and many more will be put at greater risk from SLR enhanced storm surge events. Limited agricultural lands will be lost throughout the region, however it is

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[196] This figure is deemed conservative due to inherent constraints related to population and topographic data in the region; better socio-economic data and topographic data, based on scientific tools, are needed if these estimates are to be improved in a robust way. The population displacement figures in this study also account for protected shorelines in Guyana under which Georgetown and the Guyanese coastal strip is reasoned not to be as vulnerable to permanent inundation as might be expected given the on-going and planned improvements and technological enhancements to the coastal protection system (assuming continued adequate funding). Overtopping risk, however, will still be present under extreme events' scenarios. It should be noted that the Guyanese coastal strip, its' population, industries and infrastructure, is extremely vulnerable to flooding and overtopping from increases in precipitation and extreme events impacting on the Conservancy Dam.

the vital tourism industry that was found to be one of the most vulnerable economic sectors. Nearly one-third of major tourism resorts and airports are at risk to 1m SLR. A large majority of land around seaports, which are so vital to island economies, were also vulnerable to flooding from 1m SLR.

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 for the region as a whole and in the highly vulnerable nations was far more pronounced.

Set against the rises in sea surface levels, the extreme storm events that the Caribbean is subjected to annually, assume greater prominence even if the present intensity and frequency remain unchanged. The study examined the vulnerabilities associated with combined flooding risk of SLR and the probable storm surge related to a 1 in 100 year storm event. The number of people at risk was found to increase substantially, particularly in Antigua and Barbuda, Belize and The Bahamas, where over 10% of the population (over 20% for The Bahamas) is put at risk by such events. With a storm surge of this magnitude, many countries would see serious impacts to key infrastructure, such as airports (100% of airports at risk to damage in Antigua and Barbuda, Belize, Dominica, Grenada, St. Lucia, and St. Vincent and Grenadines) and tourism resorts (over 50% of resorts at risk in Antigua and Barbuda, Belize, Haiti, St. Kitts and Nevis, St. Vincent and Grenadines, and The Bahamas) because of their proximity to the coast.

Large areas of the Caribbean coast are highly susceptible to erosion, and beaches have experienced accelerated erosion in recent decades. This study undertook the first detailed assessment of SLR induced erosion damages to highly erodible coastal properties. We estimate that with a 1m SLR and a conservative estimate of associated erosion, 49% of the major tourism resorts in CARICOM countries would be damaged or destroyed. Erosion associated with a 2m SLR (or a high estimate for a 1m SLR), would result in an additional 106 resorts (or 60% of the region's coastal resorts) being at risk. Importantly, the beach assets so critical to tourism would be affected much earlier than the erosion damages to tourism infrastructure, affecting property values and the competitiveness of many destinations. Beach nesting sites for sea turtles were also at significant risk to beach erosion associated with SLR, with 51% significantly affected by erosion from 1m SLR and 62% by erosion associated with 2m SLR.

A vital question for policy-makers is to what extent can such damages be off-set by adaptation, including coastal protection schemes? Many coastal cities throughout the Caribbean utilise structures such as levees or sea walls as a means to protect densely populated urban areas and strategic infrastructure against erosion and flooding. This study completed the first assessment of the distance of coastal protection works (levee and/or sea wall systems) that would be required to protect the 23 largest CARICOM cities from direct (sea ward) and indirect (via rivers or other low lying areas) inundation by SLR. It was found that 301km of new or improved coastal defences would be required to structurally protect these Caribbean cities from SLR projected for the 21st Century. The construction costs are estimated at between US $1.2 and US $4.4 billion. Annual maintenance of these protection schemes is estimated at US $111 to US $128 million. The costs of such coastal protection schemes are typically well beyond the financial capacity of local governments and in are highly likely to exceed the capabilities of the small island nations and coastal nations of CARICOM. With the implementation of similar coastal defence projects typically requiring 30 years or more,[197] the urgency for the international community to negotiate adaptation funding to support the planning and construction of such major projects cannot be understated.

This study provides the most comprehensive assessment of the economic impacts of SLR in the Caribbean and overcomes many of the limitations of previous studies that did not utilise a GIS approach, with its detailed geospatial data on land use and physical coastal characteristics that make properties, infrastructure, natural areas and people vulnerable to SLR. The more in-depth and robust approach of this study is also supported by previous studies of the economic implications of climate change for the Caribbean that have also shown damage costs to be dominated by the impacts of SLR.[198,199]

The countries of CARICOM are at varying levels of socio-economic development. Some are reliant on agriculture, others have an industrial base, while the remainder have moved to a more service oriented economy based on tourism and financial services.[200] Coupled with geophysical differences, this variation in economy focus results in differential vulnerabilities of each country to SLR.

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The study found that the costs of SLR escalated significantly towards the end of the century, as greater SLR combined with increasing populations and GDP. In 2050 capital costs are estimated to be between US $26 to US $60.7 billion (or between 6.2% and 12% of GDP), while annual costs range from US $3.9 to US $6.1 billion. Estimates for capital GDP loss to CARICOM states in 2080 were projected to be between US $68.2 and US $187 billion. This was equivalent to between 8.3% and 19.2% of GDP respectively. Annual costs for 2080 were projected to be between US $13.5 and US $19.4 billion (1.6% to 2% of GDP in 2080).

Capital costs were dominated for the most part by dryland losses (US $9.4 to US $21 billion in 2050, US $30.1 to US $60.6 billion in 2080) and rebuild costs of tourist resorts (US $10 to US $23.2 billion in 2050 and US $23.5 to US $74 billion in 2080). Much of the overall capital costs were concentrated on 5 countries; The Bahamas (airports, tourism and dryland), Jamaica (sea ports, tourism and dryland), Trinidad and Tobago (dryland and tourism), Belize (tourism and dryland) and Haiti (dryland and property). Importantly, while these countries were found to suffer the largest economic losses in absolute terms, in relative terms (losses compared to the size of the national economy), capital losses were greatest in following order both in 2050 and 2080: St. Kitts and Nevis, The Bahamas and Antigua and Barbuda.

Continued development of vulnerable coastal areas will put additional assets and people at risk and raise both damage estimates as well as protection costs. Protection of cities could offset the substantial damages in urban areas, but as noted, this adaptation strategy comes at substantial cost that is expected to be beyond the financial capacity of CARICOM governments.

Consequently, there can be no other conclusion than projected SLR would be nothing short of transformational to the economies of CARICOM nations. The costs of losses and damages resulting from unprotected coastlines and the costs of protecting high-value urban coastlines and strategic infrastructure will have a major impact on individual communities and national economies. Without significant support from the international community, the resource allocations needed for coastal protection alone represents a significant barrier to achieving the Millennium Development Goals by 2015 and more broadly, severely impedes the pursuit of sustainable development.

In light of the work conducted in Phases I and II of this climate change impacts quantification programme; taking account of the severity of the situation, and the recommendations that have been identified, a third phase is proposed as critical to the livelihoods and sustainable economic development of CARICOM Member States. It is anticipated that Phase III will examine and, using an actuarial approach, quantify the magnitude of the climate change impacts, losses and damages in key sectors of the CARICOM Member States. Some of the sectors anticipated to be included in Phase III are biodiversity, (e.g., coral reef and mangrove), agriculture, fisheries, health, tourism, energy, infrastructure and water.

What follows is a set of recommendations to (1) improve the information base available for SLR related decision-making through additional research and analysis and (2) actions and policies for decision-makers to consider as part of developing a strategic adaptation response to SLR within CARICOM and the broader Caribbean region.

7. Recommendations

The stated objective of the international community is to contain the global temperature rise to only 2.0°C above pre-industrial levels by 2100 through concerted global action. Collaborating with the international community to stabilise the global climate system must be the preeminent recommendation to policy-makers in CARICOM. Nevertheless, even if this important target should be achieved, sea levels will continue to rise. Recognising this, the following recommendations reinforce the need for serious, comprehensive and urgent action to be taken to address the challenges of adapting to SLR in the islands and coastal states of the Caribbean.

7.1 IMPROVING THE INFORMATION BASE FOR INFORMED DECISIONS

Recommendation: Develop an inventory of existing coastal protection defences and their design range and maintenance status. This analysis was hindered by inadequate data on existing coastal structures, their type, design specifications and expected lifetime. Future assessments of the costs and benefits of coastal protection require this information to provide accurate estimates of resources needed for SLR adaptation.

Recommendation: Local level studies should be undertaken to better understand the potential impacts of SLR for communities and facilitate the engagement of local governments and vulnerable stakeholders in the development of adaptation plans. The GIS developed in Phase I and II of this work represents a strategic overview of the vulnerability of coastal communities and infrastructure to future SLR. It enables national governments to begin the process of prioritising what strategic infrastructure and populations are most at risk and in need of protection or planned retreat. More detailed assessments of local impacts, including the impacts on sustainable livelihoods, are needed to inform potential response strategies.

Recommendation: Conduct a thorough cost-benefit analysis of coastal protection at a local level. Cost-benefit analysis of coastal protection will be informed by the estimated value of damage to specific infrastructure and properties. The specific locations of water treatment works, aquifers, oil refineries, power stations and other infrastructure are important for estimating impacts to a high level of fidelity. Similarly, property values are highly dependent on exact location - for example in some cities the most expensive property values may be on the coast, whereas in others they may be located in a hillside. Therefore a detailed analysis of property prices by location is required as part of local level studies.

Recommendation: Undertake focused analysis of vulnerable sub-populations. A general finding of climate change vulnerability assessments is that low-income households and communities face a disproportionate burden from climate change impacts. Through collaboration of national and local governments to provide geospatial demographic and household income data, the GIS created for this analysis could be used to more accurately assess the potential human costs of SLR. The GIS could also be used to examine the implications of the siting of coastal protection measures for vulnerable sub-populations.

Recommendation: Undertake detailed sectoral case studies of SLR vulnerability, for scale-up to national and regional economic assessments. Undertake sectoral and case study risk assessments for strategically important infrastructure and industries. Obtaining highly accurate costing of sectoral case studies would facilitate informed scale-up across CARICOM nations and through the economy. Such detailed costing work would be valuable for the water, power, transport, agriculture, tourism, and ecosystems (e.g., coral reefs and fisheries) sectors.

For example: tourism represents a sectoral priority given its considerably larger economic losses as a result of SLR compared to other sectors. In addition to refining estimates of rebuild costs (particularly in areas with high-density coastal development), there is an important need to investigate the response of international tourists and the private sector to the impacts of coastal erosion, coral degradation and market test adaptation strategies with this key stakeholder group.

Recommendation: Complete a focused analysis of the vulnerability of tourism dependent small island economies and develop adaptation strategies. A critical finding of this analysis was that while the absolute size of economic losses is generally much greater in the larger CARICOM economies, the proportional impacts (losses compared to the size of the national economy) are generally higher in the smaller economies of St. Kitts and Nevis, Antigua and Barbuda, Barbados, St. Vincent and the Grenadines and Grenada. Tourism infrastructure is particularly vulnerable in these nations and with tourism contributing a greater proportion to the national economies of these nations, the capacity of the economies in these countries to absorb and recover from proportionately higher economic losses is expected to be lower. Determining the secondary and tertiary economic impacts of damages to the tourism sector and possible adaptation strategies for the tourism sector should be a priority for future research within CARICOM.

Recommendation: Adopt a risk management approach consistent with actuarial science best practice. The framework proposed by ECA should be further developed, by taking into account best practice and research in risk management and actuarial science. This would give a full risk mapping of climate change impacts, which would be a powerful tool for policy makers.

Recommendation: Develop more realistic socio-economic scenarios to inform future cost-benefit analyses. More refined economic analysis requires more realistic projections of GDP, population and sectoral disaggregation for CARICOM nations. Although downscaled estimates of GDP and population projections were adopted from the IPCC, these were considered highly optimistic in some cases and required manual adjustment. The current economic projections currently do not take into account the impact of climate change on the region's socio-economic sectors, which is clearly unrealistic for small island states that are currently not employing adaptation measures on a large scale.

Recommendation: Improve the spatial detail and reduce uncertainties in climate change scenarios for the Caribbean Basin. Further examination of both GCM and Regional Climate Model (RCM) projections for the Caribbean is recommended to advance understanding of the regional manifestations of global climate change, particularly with respect to changes in precipitation and extreme climate events (e.g., heavy rainfall, tropical storms). Downscaling of the various projections to higher resolutions should be a key focus of climate scenario work in the region. New, higher resolution model outputs are expected to become available from leading international climate modelling centres within the next two years. These outputs will be derived from higher resolution versions of GCMs and from RCMs inter-comparison projects for example the CORDEX project through the World Climate Research Programme. Modelling centres in the Caribbean already conducting climate modelling work, such as: Climate Studies at the University of the West Indies; the Caribbean Community Climate Change Centre; and INSMET (the Cuban Meteorological Service) along with CARICOM Members States should seek to further collaboration with international modelling centres to develop the capacity to undertake additional downscaling work as the new data sets become available. **An important part of this Recommendation is also to build and strengthen the technical and human capacity of the regional**

climate modelling centres to conduct the identified tasks. Any such work would be consistent with the UNFCCC Nairobi Work Programme and would provide prospects for advancing information on the impacts of climate change on agriculture and food security, health and water security, not only in terms of single realisations of future scenarios, but in terms of building ranges of possible outcomes consistent with risk analysis approach for planning of adaptation options.

Recommendation: Invest in development of high-resolution topographical data sets. This study utilised the highest resolution DEM dataset publically available from satellites (30m^2). The United Nations Environment Programme has begun to invest in the development of a comprehensive LiDAR[201] data set for areas of the Caribbean. Securing these data should be a priority for CARICOM nations, as it is essential for high-resolution SLR risk mapping, determining bathymetry for improved assessments of erosion processes, and engineering studies of coastal protection structures. Regional collaboration to secure additional funds that would accelerate the process of flying and processing LiDAR data should be considered. Because the timing of the availability of a comprehensive LiDAR data set for CARICOM nations remains uncertain, countries and communities that would like to begin the process of adapting to SLR immediately could consider the purchase of improved DEM data (i.e., TamDEM) from TerraSAR-X, which should become publicly available in 2011 or 2012.

Recommendation: Assess the adaptive capacity of wetlands and mangroves to SLR. Wetlands and mangroves provide highly valued ecosystem service to the islands and coastal regions of the Caribbean and have been shown to be vulnerable to SLR. More detailed analysis of the impacts of SLR for the size, integrity and function of wetlands and mangrove is needed to accurately assess the implications for flood and erosion protection, water purification, and habitat. A necessary part of this evaluation is to determine where wetlands and mangroves have access to adjacent lands suitable for natural retreat in response to SLR. Identification and protection of these 'buffer' lands for adaptation is a key long-term conservation strategy for the region.

Recommendation: Better incorporate non-market values in future economic assessments of SLR and climate change impacts. An additional focus of future economic assessments of the costs of SLR must be to improve methods for incorporating ecosystem services, which are often ignored or undervalued in conventional economic analyses.

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[201] LiDAR (Light Detection and Ranging) is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target.

Recommendation: Utilise a multi-temporal systems approach in future economic analysis of climate change. Consistent with ECA recommendations, future assessments of the economic implications of SLR and related adaptation need to be integrated in holistic modelling that has the scope to account for other metrics of climate change. Climate change will cause a number of feedbacks in the economy. The secondary and tertiary impacts could cause larger and more lasting economic damage than the primary impacts. Attempting to value only SLR damages and adaptation vastly underestimates full impacts of climate change and omits the important interactions with other impacts (e.g., SST or ocean acidification related damage to corals that degrade their function as a natural barrier against storm surges) occurring throughout the economies of the CARICOM countries. As part of a systems analysis, it is necessary to complete a more detailed meso analysis at sectoral/city level to create inputs and outputs for the determination of cascading impacts.

Furthermore, this analysis has determined that analysis of economic impacts needs to be completed at a number of temporal scales. The report focused on a gradual shift hazard - SLR, in contrast, event hazards, such as hurricanes, act on a different temporal scale. Although these act over different scales, short run events can reduce resilience to a long-term change. The combinations of these impacts must be considered in any further analysis. Multiple time-scales are also important to enable consideration of refurbishment and even rebuilding cycles for economic efficiencies in adaptation. A pro-active economy could build in risk prevention and climate change adaptation measures within this cycle, whereas a reactive economy would suffer significantly more damage.

Recommendation: Transparency and Peer-Review. Transparency of methodologies must be a guiding principal for economic studies of climate change in CARICOM to allow for peer review and comparisons between estimates. The IPCC has reinforced the message that peer review will be the standard for consideration in the Fifth Assessment Report and the administering agencies of the UN Adaptation Fund will demand no less.

7.2 ADAPTATION ACTIONS AND POLICIES

Recommendation: Commence coastal projection adaptation planning early. The development of coastal project systems has been shown to take 30 years or more. The detailed local level planning for coastal protection needs to begin within the next 15 years if the environmental assessments, financing, land acquisition, and construction is to be completed by mid-century, so that the economic benefits of damage prevention are optimized.

Recommendation: Integrate SLR into the design of all coastal structures. Environmental assessments and construction permits for coastal structures should be required to take into account the most estimates of SLR from the scientific community.

Recommendation: Integrate SLR into government insurance policies. Insurance policies that account for the long-term risks of SLR will enable landowners to properly assess coastal protection and retreat options. Government subsidies to insure coastal properties that suffer repeated losses or are at high risk of SLR inundation and erosion will encourage maladaptative decisions by property owners and a continued expense to national economies.

Recommendation: Review and develop policies and legal framework to support coordinated retreat from high-risk coastal areas. Existing policy and legal frameworks should be reviewed to assess the responsibilities of the state and landowners for the decommissioning of coastal properties damaged by the impacts of SLR. Examine the utilisation of adaptive development permits that allow development based on current understanding of SLR, but stipulate the conditions for longer-term coastal retreat if sea level increases to a specified level. Reassess current coastal set-back regulations in light of the SLR projections.

Recommendation: Incorporate SLR into local and regional land use development plans as well as tourism master plans. Undertake national-level consultation with government ministries responsible for land use planning and tourism planning to utilise the broad scale results of this study and higher-resolution local scale studies to guide reviews and updates of official land use plans. Consider the development of official SLR risk maps to further guide future coastal development.

Recommendation: Communication, awareness and education activities for key target groups. Embark on a communication campaign to inform and raise awareness of SLR impacts and costs for policy makers, media, developers, architects, planners, private sector and communities.

Recommendation: Assess adaptation strategies to address the multitude of cross-sectoral impacts. An in-depth examination and costing of practical adaptation strategies is required to meet the challenges of SLR and erosion on the economies and livelihoods of CARICOM member states and their communities. A sectoral approach is recommended to take account of the integral and interrelated nature of the wide-ranging impacts.

8. Key Points for Policy Makers

8.1 CLIMATE CHANGE OBSERVED TRENDS AND PROJECTIONS FOR THE 21ST CENTURY

- Temperature trends in the Caribbean have roughly paralleled observed global warming over the past 50 years.[202]
- SST trends over the Caribbean generally exceed those being observed over the global tropical oceans over the past 20 years.[203]
  - 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.[204]
  - Recent SST increases are greatest throughout the Windward Islands of the Lesser Antilles such as Grenada, Dominica, St. Vincent and the Grenadines and St Lucia.[205]
- According to the ensemble mean of Global Climate Models, temperature increases in CARICOM countries will be similar to, but slightly less than, increases in average global temperatures over the 21st Century.
- The range of dates over which the global projections reach the 2.0°C and 2.5°C (shown in italics) above pre-industrial thresholds are:
  - under scenario A1B: 2038 to 2070 and *2053 to later than 2100 (model simulations end in 2100)*
  - under scenario A2: 2043 to 2060 and *2056 to 2077*
  - under scenario B: 2049 to later than 2100 and *2050 to later than 2100*
- Temperature will continue to rise for all CARICOM countries throughout the year; coastal regions and islands will experience the smallest rises, inland continental regions the largest.
- Average temperatures throughout the year in CARICOM countries would thus be in the order of 0.4°C to 0.5°C warmer at the 2.5°C threshold as compared to that at 2.0°C and perhaps a little more so at locations remote from the sea.
- Analysis of daily maximum and minimum temperature distributions suggests that these will warm steadily through the 21st Century, and will result in a significant increase in the number of hot days and of warm to hot nights, with some days/nights warmer than most experienced at the present.
- SST increases are similar to those for air temperatures over coastal areas and islands. Thus, as with air temperatures, average SSTs

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[202] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[203] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[204] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

[205] Solomon, S., and D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, H.L. Miller (Eds.). 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

would be roughly 0.4°C to 0.5°C warmer at the 2.5°C threshold.

- The more detailed analysis in this Phase II Report has revealed greater uncertainties in the rainfall projections than was the case in the Phase I Report in 2009.
- In most CARICOM countries total annual rainfall is expected to decrease at the 2.0°C threshold by perhaps 10% to 15%, 20% at the most, as compared to at present, according to the ensemble mean. This result is reasonably consistent across all three emission scenarios.
- From the 2.0°C threshold to that at 2.5°C the picture is more complex; under scenario A1B rainfall increases again according to the ensemble mean over much of the CARICOM area, although it does not return to current levels over most areas that would have experienced drying; however under scenario A2 drying continues; lack of data prevented an equivalent analysis for the B1 scenario.
- However, maximum and minimum rainfall values indicate that the spread of possibilities is substantial across the ensembles, and while drying trends are projected by the majority of models, there can be no absolute certainty that the trend will definitively be towards drying.
- Thus the direction of rainfall changes is somewhat uncertain, but with higher probabilities of a drying than an increasing trend over most CARICOM states, at least until the 2.0°C threshold is reached, but with uncertainty over the direction of the trend subsequently.
- There is little agreement amongst the models over whether the frequencies and intensities of rainfall on the heaviest rainfall days will increase or decrease in the region.
- Similarly, no clear trends in wind speeds have been identified in the GCM outputs for the region.
- Similar uncertainty remains with respect to the implications of climate change for hurricane frequencies and intensities.

8.2 SEA LEVEL RISE – OBSERVED TRENDS AND PROJECTIONS FOR 21ST CENTURY

- Studies of previous sea level responses to climate change reveal that SLR of 1m per century has not been unusual and that rates up to 2m per century have been observed. Although present rates of global SLR are not yet approaching 1m per century, they are observed to be accelerating in response to increased global warming.
- Recent studies accounting for observations of rapid ice sheet melt (Greenland and Antarctic) have led to greater and more accurate estimates of SLR than in the IPCC AR4 projections. There is an approaching consensus that SLR by the end of the 21st

Century will be between 1m and 2m above present levels.

- Moderate to high GHG emission scenarios pose a major threat to the stability of the world's ice sheets and introduce the possibility of rapid SLR on a decadal timescale up to ten times the rate observed a century ago.
- Global temperature and the magnitude of SLR are strongly linked. With a 2°C or 2.5°C global temperature rise, the current rate of SLR will continue or even accelerate.
- The Caribbean is projected to experience greater SLR than most areas of the world due to its location closer to the equator and related gravitational and geophysical factors.
- Even in the absence of increased intensity or frequency of tropical storms and hurricanes, SLR will intensify their impact on coastlines in the Caribbean.
- SLR will continue for centuries after 2100, even if global temperatures are stabilised at 2°C or 2.5°C and therefore represents a chronic and unidirectional, negative threat to coastal areas in the Caribbean and globally.

8.3 IMPACTS OF SEA LEVEL RISE AND STORM SURGE IN CARICOM MEMBER STATES

- The impacts of SLR will not be uniform among the CARICOM nations, with some projected to experience severe impacts from even a 1m SLR. Based on available information, The Bahamas, Suriname, Guyana, Trinidad and Tobago and Belize are anticipated to suffer the greatest economic losses and damages in absolute economic terms. A second critical observation is that while the absolute size of economic losses is generally much greater in larger CARICOM economies, the proportional impacts (losses compared to the size of the national economy) are generally higher in the smaller economies of St. Kitts and Nevis, Antigua and Barbuda, Barbados, St. Vincent and the Grenadines and Grenada. The capacity of the economies in these countries to absorb and recover from proportionately higher economic losses is expected to be lower.

Impacts from a 1m SLR in the CARICOM nations include:

- Nearly 1,300km^2 land area lost (e.g., 5% of The Bahamas, 2% Antigua and Barbuda).
- Over 110,000 people displaced (e.g., 5% of population in The Bahamas, 3% Antigua and Barbuda).
- At least 149 multi-million dollar tourism resorts damaged or lost, with beach assets lost or greatly degraded at many more tourism resorts.

- Damage or loss of 5 power plants.
- Over 1% agricultural land lost, with implications for food supply and rural livelihoods (e.g., 5% in Dominica, 6% in The Bahamas, 5% in St. Kitts and Nevis).
- Inundation of known sea turtle nesting beaches (e.g., 35% in The Bahamas and St. Kitts and Nevis, 44% in Belize and Haiti, 50% in Guyana).
- Transportation networks severely disrupted.
    - Loss or damage of 21 (28%) CARICOM airports.
    - Lands surrounding 35 ports inundated (out of 44).
    - Loss of 567km of roads (e.g., 14% of road network in The Bahamas, 12% Guyana, 14% in Dominica).

Impacts from a 2m SLR in the CARICOM nations include:

- Over 3,000km^2 of land area lost (e.g., 10% of The Bahamas, 5% in Antigua and Barbuda).
- Over 260,000 people displaced (e.g., 10% of population of The Bahamas, 6% Antigua and Barbuda).
- At least 233 multi-million dollar tourism resorts lost, with beach assets lost or greatly degraded at the majority of tourism resorts.
- Damage or loss of 9 power plants.
- Over 3% of agricultural land lost, with implications for food supply, security and rural livelihoods (12% in The Bahamas, 8% in St. Kitts and Nevis, 5% in Haiti).
- Inundation of over 40% of known sea turtle nesting beaches in The Bahamas, St. Kitts and Nevis, Belize, Haiti, and Guyana.
- Transportation networks severely disrupted.
    - Loss of 31 (42%) of CARICOM airports.
    - Lands surrounding 35 ports inundated (out of 44).
    - Loss of 710km of roads (e.g., 19% of road network in The Bahamas).

Impacts from a combination of SLR and 1 in 100 year Storm Surge in the CARICOM nations include:

- ◦ Over 1 million people at risk to flooding (e.g., 22% of population of The Bahamas, 13% of Belize, and 12% of Antigua and Barbuda).
    - ▪ Over 50% of major tourism resorts at risk to damage in Antigua and Barbuda, Belize, Haiti, St. Kitts and Nevis, St. Vincent and Grenadines, and The Bahamas.
    - ▪ Flooding risk at all of the airports in Antigua and Barbuda, Belize, Dominica, Grenada, Haiti, St. Lucia, and St. Vincent and Grenadines, and the majority of airports in all other countries with the exception of Barbados.
    - ▪ Flooding damage to road networks (e.g., 27% in The Bahamas, 16% in Belize, and Dominica)

Impacts from erosion (to coastal beach areas only) associated with 1m SLR in the CARICOM nations include:

- ◦ At least 307 multi-million dollar tourism resorts damaged or lost, with beach assets lost or greatly degraded at the majority of tourism resorts in the region
- ◦ Degradation or loss of 146 known sea turtle nesting beaches

- Adaptation to future SLR will require revisions to development plans and major investment decisions regarding which strategic assets and most vulnerable populations to protect.
- Coastal protection of 23 major cities in CARICOM would require the construction of 301km of new levees or sea walls, at an estimated construction cost of US $1.2 to US $4.4 billion respectively, and require annual maintenance costs of US $111 to US $128 million.
- With the implementation of coastal defence projects typically requiring 30 years or more, the planning of such large public works should begin within the next 10-15 years. This emphasises the urgency for the CARICOM nations to negotiate adaptation funding to support the planning and construction of such major projects.

8.4 ACTUARIAL ANALYSIS: COSTS OF LOSSES AND DAMAGES

- The study finds that the costs of both a mid-range (1m) and high (2m) SLR escalated significantly towards the end of the century, as greater SLR combines with increasing populations and GDP.
- Levels of vulnerability differ between islands because of varying levels of socio-economic development, and different constituents of the economy. Annual losses are dominated by losses to the tourism sector for most countries, except for Haiti where agricultural losses are projected to be significant. Antigua and Barbuda, Barbados, Belize, St. Kitts and Nevis and The Bahamas are expected to be impacted annually with losses of up to 5% of GDP.

Tourism

- Tourism will be impacted both through rebuild costs of tourist resorts as well as an annual reduction in contribution to national GDP from beach loss. Rebuild costs are found to dominate capital costs in most cases, particularly for Antigua and Barbuda, The Bahamas, Barbados, Belize, Grenada, St. Kitts and Nevis and St. Vincent and the Grenadines.
- The total rebuild costs of tourist resorts are projected to be between US $10 and US $23.3 billion in 2050 and US $23.5 and US $74 billion in 2080. Annual costs to tourism due to reduced amenity value from beach loss are projected to be between US $12.4 billion and US $17.1 billion in 2080.
- The Bahamas is particularly impacted by SLR, with damages contributing a significant part of total CARICOM losses. Annual costs to GDP were predominately tourism losses between US $869 and US $946 million in 2050 and US $2.2 and US $2.6 billion in 2080.
- Annual costs of SLR to Trinidad and Tobago are estimated to be between 1.3% and 1.4% of GDP in 2080 for the mid range SLR and high SLR scenarios respectively, dominated by costs to the tourist industry. Rebuild costs for tourist resorts in Trinidad and Tobago are between US $1.3 and US $4.8 billion for the mid range SLR and high SLR scenarios respectively.
- Impacts on Barbados are dominated by losses to tourism both through rebuild costs and annual losses through loss of amenities. Losses are projected to amount to between US $283 and US $368 million in 2050 and by 2080 losses would increase to between US $850 and US $860 million annually (cumulative rebuild costs of US $1.1 to US $8 billion). Total capital GDP loss is projected to be between 4.8% and 18.7% of GDP in 2050 and 7.3% and 42.8% in 2080 for the mid range SLR and high SLR scenarios respectively.

- Similar to Barbados, the tourism economy of Antigua and Barbuda will be severely impacted by SLR. This results in projected rebuild costs of resorts of up to 36% of GDP in 2050 and up to 85% of GDP in 2080.
- Suriname, Belize and Guyana are not as land constrained as the island states, resulting in lower annual losses. However, due to beach loss, the Belize tourism sector is projected to have annual costs of over 2.5% of GDP from 2050.
- Grenada will suffer large rebuild costs for tourist resorts of between 3.5% and 21% of GDP in 2050 and 14% and 33% of GDP in 2080. Total capital costs are between US $333 and US $801 million in 2050 and increase to between US $1.3 and US $3.7 billion in 2080.
- St. Kitts and Nevis has a similar capital cost profile to Grenada, but has tourist resort rebuild costs of between 60% and 89% of GDP in 2050, increasing to between 73% and 150% of GDP in 2080 for the mid range SLR and high SLR scenarios respectively.

Table 20: Tourism: Economic indicators and resort count and inundation under 1m and 2m sea level rise and erosion due to 1m sea level rise [206,207]

Country	Tourism % of GDP	No. of Resorts	Resorts Affected 1m SLR	Resorts Affected 2m SLR	Resorts Affected by 1m SLR and 50m erosion	Resorts Affected by 1m SLR and 100m erosion
Antigua & Barbuda	72%	99	10	18	34	44
Barbados	37%	75	6	24	42	50
Belize	23%	44	32	38	42	44
Dominica	22%	17	0	1	5	6
Grenada	23%	45	5	8	14	19
Guyana	23%	10	0	0	0	0
Haiti	1%	28	13	17	14	17
Jamaica	27%	105	8	19	34	52
Montserrat	1%	1	0	0	0	0
St. Kitts & Nevis	25%	22	14	17	15	18
St. Lucia	51%	30	2	3	5	9
St. Vincent & the Grenadines	29%	21	2	5	8	16
Suriname	23%	19	1	2	2	2
The Bahamas	46%	133	48	66	77	93
Trinidad & Tobago	2%	24	8	15	15	16

Population Displacement and Infrastructure Impacts

- All countries would be impacted by road loss with a large proportion also impacted by airport, seaport and power plant inundation. Due to the high capital cost of rebuilding, smaller island states are disproportionately affected as rebuild cost constituted a greater proportion of GDP.
- Population displacement and relocation costs particularly affected The Bahamas, Guyana, Haiti, Jamaica and Trinidad and Tobago. However, proportionate to population size, the greatest relocation costs occurred in the following order: The Bahamas, Antigua and Barbuda, St. Kitts and Nevis, Trinidad and Tobago and St. Vincent and the Grenadines. Cumulative rebuild costs for seaports, airports, power plants, infrastructure, tourist resorts and property relocation in The Bahamas amounted to between US $5.6 billion and US $11 billion in 2050 and US $11.7 and US $32 billion in 2080.

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206 Burke, L., Maidens, J., Spalding, M., Kramer, P., Green, E., Greenhalgh, S., Nobles,H., Kool, J. 2004. Reefs at Risk in the Caribbean. World Resources Institute. Washington, D.C.

207 Except Suriname and Guyana which were assumed to be the same as Belize; Montserrat value was based on the contribution of its hotels and restaurants to GDP (based on Caribbean Tourism Organization Statistics) and Haiti was assumed to be 1%

- Haiti is impacted heavily by land loss, tourist resort rebuild costs and population displacement. This results in projected capital costs of US $1.8 and US $4.3 billion in 2050; US $4.6 to US $17.2 billion in 2080.
- Smaller islands are vulnerable to the capital cost of rebuild, as their economies do not have the capacity to withstand these relatively high costs. For example, due to their relatively small GDP, the volcanic islands of St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Grenada and Dominica will be particularly impacted by inundation of seaports and airports resulting in rebuild/relocation costs of between 1% and 6% of GDP in 2050 and 2% and 11% of GDP in 2080.

Asset Value of Land Loss

- Due to the low lying nature of Suriname, Belize and Guyana, they each suffer significant land loss. Combined wetland loss is valued between US $43 and US $161 million in 2050 and US $123 and US $648 million in 2080 and dryland loss valued between US $0.54 and US $1.9 billion in 2050 US $1.8 and US $6.2 billion in 2080.
- In The Bahamas, loss of land value ranged between US $14.6 and US $23.4 billion in 2080. Proportionate to land area or population, loss of land was then greatest in Antigua and Barbuda, Belize, St. Vincent and the Grenadines and Barbados.

Agricultural Impacts

- Loss of agricultural land and land restrictions from population density increases resulted in a projected loss in 2050 of US $370 million and in 2080 a loss of approximately US $2 billion is projected.
- The agricultural sector of Haiti is projected to suffer greater than any other country in the region with annual costs of US $700 million to US $1.8 billion in 2080 for the mid range SLR and high SLR scenarios respectively.

Impacts of Erosion

- Further research was undertaken on the impacts of erosion on tourist resorts due to the projected SLR. If erosion is taken into account, rebuild costs for the mid range SLR scenario will increase from US $23.5 to US $48.4 billion and in the high SLR scenario from US $74 to US $122.5 billion in 2080. Erosion has a significant amplifying effect on the mid range scenario, where rebuild costs were projected to increase by several hundred percent in some cases. Most notable in this is Barbados where costs will increase from US $945 million to US $6.6 billion in the mid range SLR scenario in 2080.

Total Costs of Losses and Damages

- In 2050 capital costs were estimated to be between US $26 to US $60.7 billion (equivalent to between 6.2% and 12% of projected GDP in 2050 respectively), while annual costs ranged from US $3.9 to US $6.1 billion (0.9% to 1.2% of projected GDP) – see Summary Table below.
- Estimates for capital GDP loss to CARICOM states in 2080 were projected to be between US $68.2 and US $187 billion (8.3% and 19.2% of projected GDP in 2080) – see Table 19.
- Annual costs for 2080 were projected to be between US $13.5 and US $19.4 billion (1.6% to 2% of GDP in 2080). Antigua and Barbuda, Barbados, Belize, St. Kitts and Nevis and The Bahamas are expected to experience annual losses of up to 5% of GDP.
- It is important to reemphasise that these estimates of economic costs are in the absence of adaptation, either through structural protection or planned retreat and replacement of vulnerable infrastructure assets at the end of normal lifespan.

Table 21: Annual and capital costs of sea level rise in CARICOM countries

	2050		2080	
	Annual Costs (US $ billion)	Capital Costs (US $ billion)	Annual Costs (US $ billion)	Capital Costs (US $ billion)
Mid-Range SLR Scenario	3.9	26	13.5	68.2
High SLR Scenario	6.1	60.7	19.4	187

Quantification and Magnitude of Losses and Damages Resulting from the Impacts of Climate Change: Modelling the Transformational Impacts and Costs of Sea Level Rise in the Caribbean

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FULL DOCUMENT

Please Note: A DVD was distributed at the Cancun COP16 November/December 2010 with the 'Key Points and Summary for Policy Makers' document of this report. The DVD contains copies of the following:

1. Quantification and Magnitude of Losses and Damages Resulting from the Impacts of Climate Change: Modelling the Transformational Impacts and Costs of Sea Level Rise in the Caribbean - KEY POINTS AND SUMMARY FOR POLICY MAKERS

2. Quantification and Magnitude of Losses and Damages Resulting from the Impacts of Climate Change: Modelling the Transformational Impacts and Costs of Sea Level Rise in the Caribbean - SUMMARY DOCUMENT

3. 'Partnerships for Resilience: Climate Change and Caribbean Tourism' A short film (18 minutes) commissioned by the British Foreign and Commonwealth Office and the UK Department for International Development; Highlights adaptation measures being taken by governments, private sector and communities across the Caribbean.

Copies of these documents, the Full Document and the short film can be obtained via free download at www.caribsave.org

Quantification and Magnitude of Losses and Damages Resulting from the Impacts of Climate Change: Modelling the Transformational Impacts and Costs of Sea Level Rise in the Caribbean

SUMMARY DOCUMENT

This report was commissioned by the United Nations Development Programme (UNDP) Sub-Regional Office for Barbados and the OECS, for CARICOM Member States. The report was produced by The CARIBSAVE Partnership and authored by members of key institutions and organisations around the world dealing with climate change, development and economic impacts.

This 'Full Report' provides an in-depth assessment for all CARICOM Member States of the risks from climate change and sea level rise (SLR). The report focuses on: climate change projections for the Caribbean region under +2.0°C and +2.5°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; and, using an actuarial approach, the quantification and magnitude of the losses and damages resulting from sea level rise and related coastal erosion.

Prepared by The CARIBSAVE Partnership for UNDP Barbados and the OECS for CARICOM Member States

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