5. CLIMATE SCENARIOS AND PROJECTIONS

5.1. INTRODUCTION

The literature on future climates in the Caribbean region has grown in the past two decades. As a result, a consensus picture of what the Caribbean may look like through to the end of the century has gradually emerged based on a variety of studies using different models (GCMs and RCMs), methodologies (statistical versus dynamical downscaling), and scenarios (SRES and RCPs).

A scan of the literature suggests that:

» The Caribbean as a whole will gradually warm through to the end of the current century. This is true across all the modelling studies and irrespective of model, methodology or scenario employed. The mean annual temperature of the Caribbean region will be warmer by between 1.0°C and close to 3.5°C compared to today. The entire region will experience the warming, including both ocean and land, with the largest warming occurring over the larger land masses (Taylor et al. 2018; Karmalkar et al. 2013; Campbell et al. 2011). Concomitant will be an increased frequency of temperature extremes, including very hot days and nights, a decrease in very cold days and nights, and an increase in consecutive hot days (or warm spells) (Taylor et al. 2018, Stennett-Brown et al. 2017, Mclean et al. 2015; McSweeney et al. 2010).

» The Caribbean in general will gradually dry going towards the end of the century. When taken as a whole, the Caribbean drying may be moderate as there is a gradient in drying with less in the far north Caribbean and more in the south and southeast. The GCMs, however, suggest for the central and southern Caribbean basin, drying up to 20% for annual rainfall, while RCM based projections suggest up to 25-30% less rainfall by the end of the century (Taylor et al. 2018; Karmalkar et al. 2013; Campbell et al. 2011). Projected drying is most pronounced in the early and late wet seasons between May and October. Most studies show that interannual variability will still be the dominant feature of the Caribbean rainfall record, but the linear downward trend in rainfall will be such that the variability will occur around a lower mean. The models also project changes in rainfall extremes but suggest these may have regional variations, for example, increases in the proportion of total rainfall that falls in heavy events toward the end of the century in the north and eastern Caribbean, and an increase in the number of consecutive hot and dry days particularly in the south and southeast (Taylor et al. 2018; Mclean et al. 2015, Hall et al. 2013).

» Whereas there is little consensus that there may be an increase in Atlantic storms and hurricanes, the literature is in agreement that the intensity of the storms and hurricanes will likely increase under global warming (IPCC 2012).

» Sea-levels will continue to rise in the Caribbean and may be close to the projected global mean rise. By mid-century, the global increase is between 0.24 and 0.30 m, while by the end of century, the change is between 0.40–0.63 m relative to 1986–2005 (IPCC 2013). A few studies suggest that the upper bound may be conservative and could be up to 1.4 m including for the Caribbean (Rahmstorf 2007; Rignot and Kanargaratnam 2006; Horton et al. 2008; IPCC 2013; Perrette et al. 2013).

It is to be noted, then, that the projections suggest that as the century progresses, the Caribbean under the worst scenarios will be a significantly different place (much warmer and drier, with higher sea levels and prone to more intense storms) than at present, with the magnitude of projected changes greater than the magnitude of change seen over the last century (Chapters 3 and 4).

The literature scan also suggests a number of deficiencies in the science of projections for the Caribbean region. These include, inadequate science on (i) projections using the RCPs (ii) future hurricane characteristics in the

Caribbean (intensity, frequency, genesis, etc.) (iii) future droughts at the regional or sub-regional scale, (iv) projections of other climatic parameters (e.g. wind speed, solar radiation, sea levels), and (v) projections on intermediary timescales i.e. near and medium term as opposed to end of century.

This chapter provides Caribbean climate projections based on GCMs, RCMs and statistical downscaling as described in Chapter 2. For both temperature and rainfall, the pattern of presentation is the same. First, data from the GCMs are used to provide region-wide projections under the four RCP scenarios. The RCMs are then used as the basis for providing projections over the six defined rainfall zones. Recall that a suite of GCMs are used for the CMIP5 project while the PRECIS 25 km simulations are used for the RCM projections (see again Chapter 2). In all cases projections are offered for three time slices: a near term or 2020s (averaged over 2020-2029), a medium term or 2050s (2050-2059) and end of century (2091-2100). Statistical downscaling is then utilised to determine projected changes in temperature and rainfall extremes, premised on the country station data (see Chapter 2). Projections for sea level rise and hurricanes are also presented and are largely gleaned from literature.

The data in the chapter are presented in the form of tables, maps, and graphs. A summary of the GCM, RCM and statistically downscaled results are provided in narrative form at the beginning of the sections for temperature and rainfall projections.

5.2. TEMPERATURE

All models and scenarios indicate a continuation of the historical warming trend across the Caribbean as a whole and its sub-regions. The following are noted about the projected changes in temperature and temperature extremes:

- GCMs suggest a warming trend across the Caribbean irrespective of scenario. The rate of warming is similar for mean, maximum, and minimum temperature under all scenarios.
- Considered as a whole, projected further warming of the mean temperature from the GCMs is up to 0.56oC (range of mean: 0.48 oC-0.56 oC) during the 2020s relative to a 1986-2005 baseline. (It is important to bear in mind that up to the baseline period the Caribbean will likely have already seen up to 0.5oC of warming.) However, by the 2050s, mean temperature is projected to rise by up to 1.50oC (0.86 oC to 1.50 oC) and 3.05oC (0.83 oC to 3.05 oC) by the end of the century.
- Projected changes in maximum and minimum temperatures are of similar magnitude to that for the mean temperature.
- The RCMs suggest that all zones will warm going toward the end of the century. The projected changes are summarized by time slice in Table 5.1 per zone. The warming shown is slightly greater than projected by the GCMs which is to be expected given the greater resolution of the RCMs and the fact that they capture the smaller land masses which are represented as ocean in the GCMs. The warming magnitudes are, however, comparable especially bearing in mind that the RCM baseline is 1961-1990. The warming will occur throughout the year in all zones for all future time slices.

Table 5.1: Range of annual temperature change across the six Caribbean zones from an RCM ensemble running the A1B scenario. Baseline is 1961-1990. See again Figure 2.3 for grid boxes in each zone.

		ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6
TMEAN	2020s	0.99 – 1.40	0.72 – 1.22	0.89 – 1.24	0.93 – 1.30	0.78 – 1.35	0.90 – 1.56
	2050s	1.84 – 2.49	1.57 – 2.40	1.71 – 2.30	1.64 – 2.37	1.34 – 2.28	1.56 – 2.56
	EOC	2.35 – 3.96	2.53 – 3.72	2.43 – 3.70	2.15 – 3.74	1.78 – 3.38	1.80 – 3.90
TMAX	2020s	0.98 – 1.48	0.70 – 1.21	0.87 – 1.25	0.93 – 1.27	0.79 – 1.33	0.95 – 1.61
	2050s	1.93 – 2.49	1.59 – 2.39	1.75 – 2.36	1.69 – 2.38	1.32 – 2.25	1.52 – 2.57
	EOC	2.46 – 4.02	2.74 – 3.74	2.49 – 3.75	2.20 – 3.75	1.76 – 3.38	1.65 – 4.02
TMIN	2020s	0.95 – 1.33	0.75 – 1.24	0.92 – 1.26	0.92 – 1.33	0.78 – 1.34	0.85 – 1.52
	2050s	1.79 – 2.50	1.59 – 2.43	1.73 – 2.29	1.62 – 2.39	1.36 – 2.28	1.63 – 2.57
	EOC	2.34 – 3.91	2.75 – 3.77	2.41 – 3.72	2.14 – 3.80	1.80 – 3.40	1.97 – 3.89

» There are regional variations in warming evident in the RCM results. The far western Caribbean (Zone 1) and the southern Caribbean (Zone 6) show slightly higher warming than the rest of the region. This likely reflects that these zones include continental Caribbean countries.

» From RCMs, the greatest seasonal warming will likely occur during SON in all zones in the 2020s except for Zones 4 and 5, in which the dry season shows the greatest warming. Of the six zones, the far south Caribbean (Zone 6) shows the greatest annual warming during the 2020s of 1.21oC.

» A similar trend persists in the 2050s, during which Zones 1, 2, and 6 show greatest warming during SON, and Zones 3, 4, and 5 during NDJ. Greatest annual warming occurs in the far western Caribbean (Zone 1) in the 2050s, reaching 2.12 oC warmer than baseline.

» By the end of the century, warming is projected to be highest in Zone 1, both seasonally and annually, where annual temperature may exceed baseline by a mean of 3.22oC. Range of mean annual temperature change for each zone by end of century is 2.35 – 3.96 oC in Zone 1, 2.53 – 3.72 oC in Zone 2, 2.43 – 3.70 oC in Zone 3, 2.15 – 3.74 oC in Zone 4, 1.78 – 3.38 oC in Zone 5, and 1.80 – 3.90 oC in Zone 6.

» End of century warming is projected to occur at a slightly faster rate in maximum temperature than in minimum temperature in Zones 1, 3, and 6, while the reverse is projected for Zones 2, 4, and 5. However, this difference is most prominent in Zone 1.

» SDSM projections show a projected increase for both warm days and warm nights for the end of century period. The number of warm nights was projected to increase more than the number of warm days. The projected increase in warm days ranged between 51 and 251 days and for warm nights between 24 and 360 days for RCP 8.5.

» The trend was for a decrease in both cool days and nights. The range for cool days was between 1 and 41 days and between 1 and 32 days for cool nights for the end of century under RCP 8.5.

5.2.1. GCMS

GCM projections of the Caribbean as a whole are provided below for future mean, minimum, and maximum temperature relative to a 1986 – 2005 baseline (Tables 5.2-5.4 and Figure 5.1).

Table 5.2: Mean annual temperature change for the Caribbean with respect to 1986-2005. Change shown for four RCP scenarios. Source: AR5 CMIP5 subset, KNMI Climate Explorer.

	TMEAN								
	2020s			2050s			END OF CENTURY		
AVERAGED OVER	2020-2029			2050-2059			2091-2100		
	min	mean	max	min	mean	max	min	mean	max
RCP 2.6	0.30	0.53	0.96	0.39	0.86	1.57	-0.04	0.83	1.74
RCP 4.5	0.23	0.52	0.89	0.56	1.09	1.83	0.68	1.53	2.50
RCP 6.0	0.20	0.48	0.79	0.69	1.00	1.66	1.00	1.85	2.92
RCP 8.5	0.31	0.56	0.87	0.94	1.50	1.23	2.10	3.05	4.22
RANGE OF MEAN:	0.48 – 0.56			0.86 – 1.50			0.83 – 3.05		

Table 5.3: Mean annual minimum temperature change for the Caribbean with respect to 1986-2005. Change shown for four RCP scenarios. Source: AR5 CMIP5 subset, KNMI Climate Explorer.

	TMIN								
	2020s			2050s			END OF CENTURY		
AVERAGED OVER	2020-2029			2050-2059			2091-2100		
	min	mean	max	min	mean	max	min	mean	max
RCP 2.6	0.30	0.53	0.97	0.39	0.87	1.58	-0.07	0.83	1.75
RCP 4.5	0.23	0.52	0.89	0.55	1.10	1.82	0.65	1.53	2.50
RCP 6.0	0.19	0.48	0.80	0.68	0.99	1.67	0.96	1.84	2.92
RCP 8.5	0.33	0.57	0.87	0.92	1.51	2.24	2.07	3.07	4.23
RANGE OF MEAN:	0.48 – 0.57			0.87 – 1.51			0.83 – 3.07		

Table 5.4: Mean annual maximum temperature change for the Caribbean with respect to 1986-2005. Change shown for four RCP scenarios. Source: AR5 CMIP5 subset, KNMI Climate Explorer.

	TMAX								
	2020s			2050s			END OF CENTURY		
AVERAGED OVER	2020-2029			2050-2059			2091-2100		
	min	mean	max	min	mean	max	min	mean	max
RCP 2.6	0.30	0.53	0.95	0.40	0.87	1.56	0.01	0.84	1.73
RCP 4.5	0.24	0.52	0.89	0.57	1.10	1.84	0.73	1.54	2.51
RCP 6.0	0.22	0.48	0.79	0.70	1.00	1.66	1.05	1.85	2.91
RCP 8.5	0.33	0.57	0.86	0.96	1.51	2.21	2.12	3.08	4.21
RANGE OF MEAN:	0.48 – 0.57			0.87 – 1.51			0.84 – 3.08		

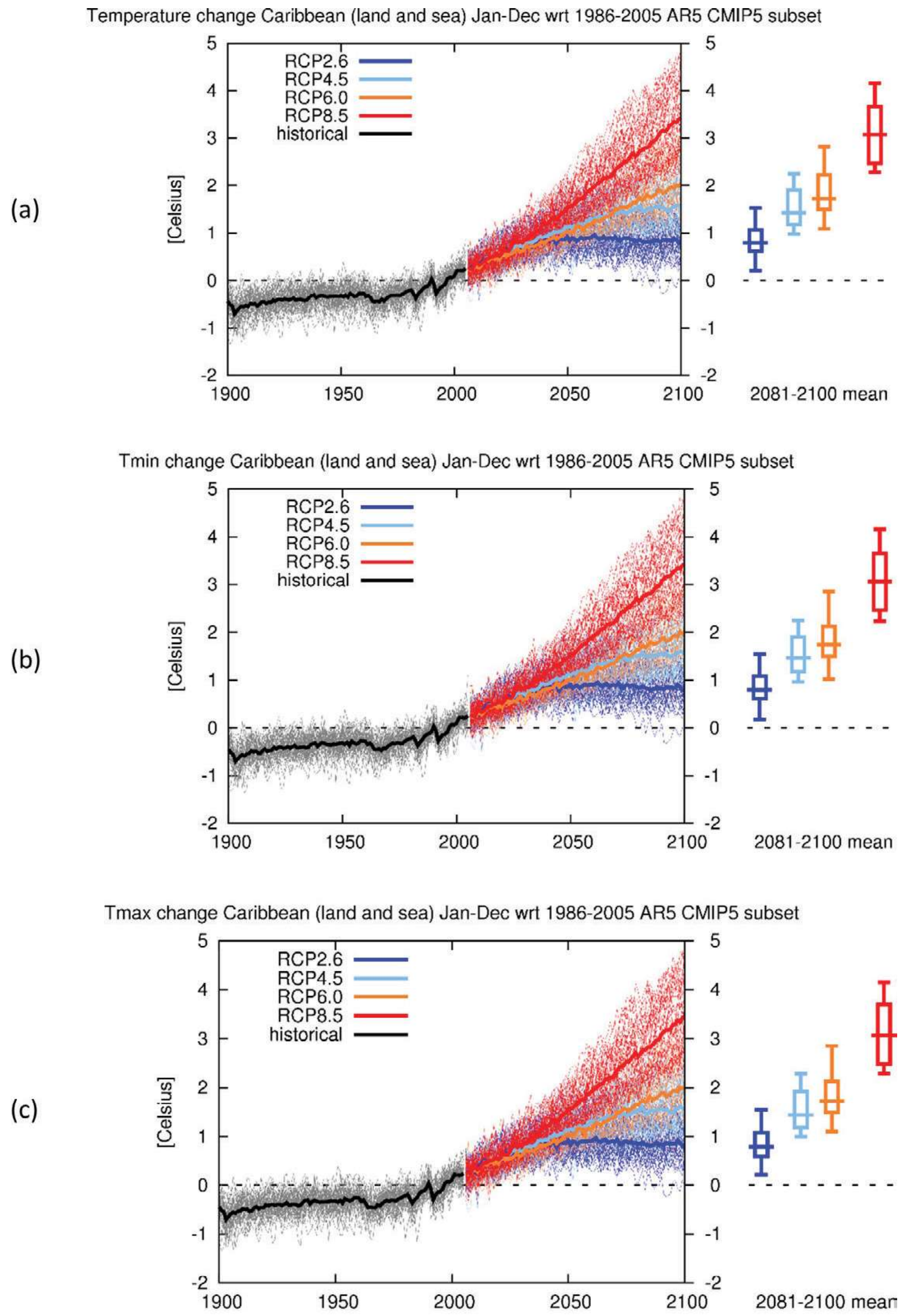

Figure 5.1: (a) Mean annual temperature change (°C) (b) Mean annual minimum temperature change (°C) (c) Mean annual maximum temperature change (°C) for the Caribbean with respect to 1986-2005 AR5 CMIP5 subset. On the left, for each scenario one line per model is shown plus the multi-model mean, on the right percentiles of the whole dataset: the box extends from 25% to 75%, the whiskers from 5% to 95% and the horizontal line denotes the median (50%).

5.2.2. RCMS

RCM projections are provided below for changes in mean, minimum, and maximum temperature in the six Caribbean climate zones (Tables 5.5 – 5.7 and Figure 5.2).

Table 5.5: Projected absolute changes in mean temperature by season and for annual average (°C) for the 2020s, 2050s and EOC (2081-2098) relative to the 1961-1990 baseline. Data presented for the mean value of a six-member ensemble. Range shown is over all the grid boxes in the zone (see Table 2). Source: PRECIS RCM perturbed physics ensemble run for A1B scenario.

ZONE 1									
	2020S			2050S			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.92	1.08	1.26	1.55	2.07	2.50	2.25	3.09	3.81
FMA	0.79	1.09	1.45	1.68	1.93	2.15	2.31	3.10	3.93
MJJ	0.83	1.19	1.58	1.76	2.17	2.55	2.24	3.28	4.24
SON	0.99	1.24	1.50	1.92	2.29	2.78	2.62	3.42	4.03
ANN	**0.99**	**1.15**	**1.40**	**1.84**	**2.12**	**2.49**	**2.35**	**3.22**	**3.96**

ZONE 2									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.56	0.98	1.34	1.43	2.02	2.50	2.24	2.99	3.57
FMA	0.60	0.94	1.30	1.18	1.75	2.13	2.40	2.98	3.46
MJJ	0.81	1.11	1.43	1.76	2.12	2.58	2.70	3.38	4.18
SON	0.90	1.17	1.38	1.93	2.18	2.56	2.77	3.33	3.85
ANN	**0.72**	**1.05**	**1.22**	**1.57**	**2.02**	**2.40**	**2.53**	**3.17**	**3.72**

ZONE 3									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.81	1.05	1.17	1.74	2.06	2.37	2.42	3.04	3.62
FMA	0.78	1.02	1.38	1.57	1.85	2.03	2.49	2.98	3.62
MJJ	0.84	1.06	1.29	1.71	1.99	2.38	2.35	3.07	3.89
SON	0.88	1.14	1.38	1.84	2.04	2.43	2.45	3.03	3.65
ANN	**0.89**	**1.07**	**1.24**	**1.71**	**1.98**	**2.30**	**2.43**	**3.03**	**3.70**

ZONE 4									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	1.00	1.16	1.44	1.70	2.09	2.55	2.22	3.06	3.81
FMA	0.89	1.08	1.35	1.74	1.97	2.26	2.30	3.00	3.84
MJJ	0.79	1.03	1.22	1.57	1.88	2.30	2.03	2.79	3.67
SON	0.98	1.13	1.42	1.53	1.91	2.38	2.04	2.85	3.64
ANN	**0.93**	**1.10**	**1.30**	**1.64**	**1.96**	**2.37**	**2.15**	**2.93**	**3.74**

ZONE 5									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.82	1.13	1.55	1.49	1.93	2.51	2.03	2.84	3.57
FMA	0.73	0.98	1.25	1.43	1.81	2.20	1.87	2.63	3.40
MJJ	0.67	0.97	1.22	1.22	1.71	2.18	1.52	2.38	3.23
SON	0.90	1.09	1.39	1.21	1.72	2.24	1.71	2.60	3.38
ANN	**0.78**	**1.05**	**1.35**	**1.34**	**1.79**	**2.28**	**1.78**	**2.61**	**3.38**

ZONE 6									
	2020s			2050s			EOC		
	Min	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
NDJ	0.86	1.24	1.74	1.73	2.11	2.79	2.02	3.16	4.00
FMA	0.74	1.08	1.43	1.46	1.93	2.41	1.63	2.75	3.64
MJJ	0.89	1.16	1.40	1.38	1.90	2.35	1.57	2.81	3.80
SON	1.09	1.36	1.66	1.67	2.20	2.68	2.00	3.24	4.21
ANN	**0.90**	**1.21**	**1.56**	**1.56**	**2.03**	**2.56**	**1.80**	**2.99**	**3.90**

Table 5.6: Projected absolute changes in maximum temperature by season and for annual average (°C) for the 2020s, 2050s and EOC (2081-2098) relative to the 1961-1990 baseline. Data presented for the mean value of a six-member ensemble. Range shown is over all the grid boxes in the zone (see Table 2). Source: PRECIS RCM perturbed physics ensemble run for A1B scenario

ZONE 1									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.90	1.09	1.27	1.62	2.12	2.37	2.28	3.28	3.74
FMA	0.83	1.12	1.49	1.78	1.97	2.18	2.28	3.21	4.00
MJJ	0.95	1.22	1.71	1.89	2.26	2.54	2.35	3.52	4.33
SON	0.94	1.30	1.58	2.11	2.45	2.95	2.92	3.71	4.19
ANN	**0.98**	**1.18**	**1.48**	**1.93**	**2.20**	**2.49**	**2.46**	**3.43**	**4.02**
ZONE 2									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.59	0.94	1.28	1.45	1.96	2.33	2.51	3.08	3.38
FMA	0.56	0.93	1.29	1.19	1.73	2.08	2.64	3.06	3.41
MJJ	0.74	1.12	1.45	1.79	2.14	2.62	2.79	3.62	4.27
SON	0.91	1.20	1.44	1.95	2.21	2.62	3.03	3.54	3.92
ANN	**0.70**	**1.05**	**1.21**	**1.59**	**2.01**	**2.39**	**2.74**	**3.33**	**3.74**
ZONE 3									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.80	1.02	1.16	1.75	2.04	2.29	2.40	3.14	3.61
FMA	0.78	1.00	1.35	1.59	1.87	2.13	2.48	3.09	3.63
MJJ	0.84	1.06	1.30	1.73	2.03	2.46	2.46	3.30	4.00
SON	0.87	1.15	1.41	1.92	2.12	2.55	2.62	3.26	3.75
ANN	**0.87**	**1.06**	**1.25**	**1.75**	**2.02**	**2.36**	**2.49**	**3.20**	**3.75**

ZONE 4									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.99	1.11	1.29	1.71	2.05	2.43	2.19	3.11	3.74
FMA	0.88	1.05	1.31	1.77	1.97	2.29	2.31	3.09	3.80
MJJ	0.80	1.02	1.22	1.65	1.91	2.34	2.14	2.98	3.73
SON	0.96	1.15	1.45	1.64	1.98	2.47	2.18	3.05	3.71
ANN	**0.93**	**1.08**	**1.27**	**1.69**	**1.98**	**2.38**	**2.20**	**3.06**	**3.75**

ZONE 5									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.83	1.12	1.44	1.47	1.90	2.40	1.99	2.91	3.54
FMA	0.74	0.99	1.26	1.40	1.80	2.20	1.83	2.71	3.38
MJJ	0.69	0.97	1.21	1.22	1.70	2.14	1.53	2.49	3.22
SON	0.91	1.10	1.41	1.19	1.72	2.25	1.67	2.71	3.38
ANN	**0.79**	**1.05**	**1.33**	**1.32**	**1.78**	**2.25**	**1.76**	**2.70**	**3.38**

ZONE 6									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.90	1.30	1.74	1.71	2.18	2.86	1.86	3.38	4.19
FMA	0.82	1.15	1.49	1.45	1.99	2.46	1.52	2.82	3.69
MJJ	0.91	1.18	1.40	1.25	1.81	2.15	1.42	2.88	3.74
SON	1.16	1.48	1.83	1.67	2.33	2.81	1.80	3.47	4.45
ANN	**0.95**	**1.28**	**1.61**	**1.52**	**2.08**	**2.57**	**1.65**	**3.14**	**4.02**

Table 5.7: Projected absolute changes in minimum temperature by season and for annual average (°C) for the 2020s, 2050s and EOC (2081-2098) relative to the 1961-1990 baseline. Data presented for mean value of a six-member ensemble. Range shown is over all the grid boxes in the zone (see Table 2). Source: PRECIS RCM perturbed physics ensemble run for A1B scenario.

ZONE 1									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.88	1.06	1.29	1.47	2.01	2.49	2.25	3.16	3.72
FMA	0.77	1.10	1.43	1.63	1.93	2.20	2.40	3.20	3.86
MJJ	0.76	1.16	1.45	1.74	2.13	2.58	2.21	3.33	4.18
SON	0.97	1.23	1.49	1.86	2.21	2.72	2.48	3.41	3.99
ANN	**0.95**	**1.14**	**1.33**	**1.79**	**2.07**	**2.50**	**2.34**	**3.28**	**3.91**
ZONE 2									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.59	0.99	1.39	1.42	2.04	2.47	2.65	3.23	3.59
FMA	0.57	0.99	1.33	1.20	1.82	2.19	2.78	3.24	3.55
MJJ	0.84	1.11	1.42	1.80	2.14	2.57	2.68	3.54	4.18
SON	0.95	1.18	1.42	1.94	2.20	2.61	2.87	3.46	3.85
ANN	**0.75**	**1.07**	**1.24**	**1.59**	**2.05**	**2.43**	**2.75**	**3.37**	**3.77**
ZONE 3									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.81	1.04	1.18	1.75	2.04	2.27	2.45	3.21	3.67
FMA	0.79	1.06	1.42	1.59	1.89	2.08	2.53	3.16	3.66
MJJ	0.86	1.09	1.31	1.74	1.99	2.37	2.31	3.19	3.89
SON	0.91	1.16	1.44	1.81	2.02	2.43	2.35	3.13	3.65
ANN	**0.92**	**1.08**	**1.26**	**1.73**	**1.98**	**2.29**	**2.41**	**3.17**	**3.72**

ZONE 4									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.98	1.17	1.40	1.71	2.09	2.50	2.29	3.22	3.92
FMA	0.91	1.12	1.40	1.74	2.01	2.34	2.32	3.17	3.92
MJJ	0.79	1.05	1.25	1.55	1.91	2.33	1.99	2.92	3.71
SON	1.01	1.15	1.47	1.48	1.89	2.39	1.98	2.96	3.64
ANN	**0.92**	**1.13**	**1.33**	**1.62**	**1.98**	**2.39**	**2.14**	**3.07**	**3.80**

ZONE 5									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.82	1.11	1.45	1.51	1.90	2.41	2.06	2.91	3.54
FMA	0.72	0.99	1.29	1.45	1.82	2.25	1.89	2.74	3.42
MJJ	0.66	0.97	1.24	1.23	1.72	2.20	1.50	2.48	3.24
SON	0.90	1.10	1.39	1.24	1.73	2.25	1.75	2.72	3.39
ANN	**0.78**	**1.04**	**1.34**	**1.36**	**1.79**	**2.28**	**1.80**	**2.71**	**3.40**

ZONE 6									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	0.82	1.18	1.59	1.79	2.05	2.59	2.20	3.17	3.84
FMA	0.65	1.05	1.41	1.49	1.90	2.41	1.75	2.84	3.63
MJJ	0.85	1.17	1.46	1.52	2.04	2.60	1.72	3.05	3.95
SON	1.06	1.32	1.62	1.71	2.16	2.70	2.23	3.36	4.14
ANN	**0.85**	**1.18**	**1.52**	**1.63**	**2.04**	**2.57**	**1.97**	**3.11**	**3.89**

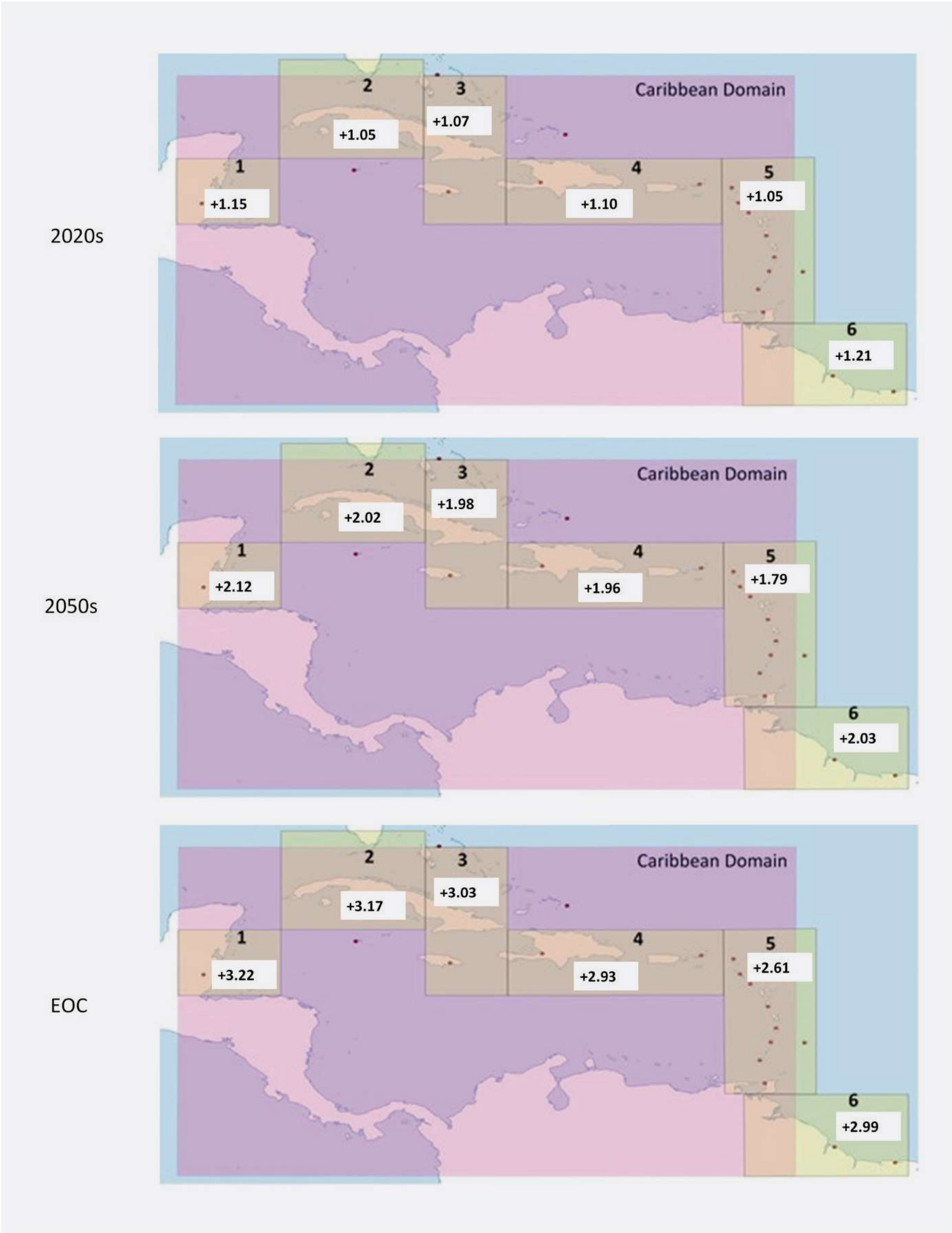

Figure 5.2: Summary map showing absolute maximum change per grid box of the ensemble mean of annual Mean Temperature (◦C) for the 2020's (top panel) and 2030s (bottom panel). Source: PRECIS RCM PPE.

5.2.3. STATISTICAL DOWNSCALING

The general trend was a projected increase for both warm days and warm nights for the period 2090 to 2100. Warm nights were projected to increase more than warm days. From Figure 5.3, the projected increase in warm days ranged between 51 and 251 days, and for warm nights between 24 and 360 days. St. Augustine, Trinidad had the greatest projected increase in the number of warm days and Belmopan, Belize had the least. Zorg en Hoop in Suriname had the greatest projected increase in the number of warm nights. However, the greatest percentage change in warm days and nights relative to the 2006 to 2016 period was Hewanorra, St. Lucia and Belmopan in Belize respectively. The model projected a decrease in warm days of 5 and 18 days for only two stations namely Nickerie, Suriname and Zanderij, Suriname respectively.

Figure 5.4 shows cool days and nights for the period 2090 to 2100 for RCP 8.5. The trend for the stations studied was a decrease in both cool days and nights. The range for cool days was between 1 and 41 days, and between 1 and 32 days for cool nights. The greatest decrease in the number of cool days and nights was for Barbados - Grantley Adams International Airport (GAIA) - and Cayman respectively. Two stations in Trinidad and Tobago projected an increase in the number of cool days (4 and 5 days), namely Crown Point and Piarco.

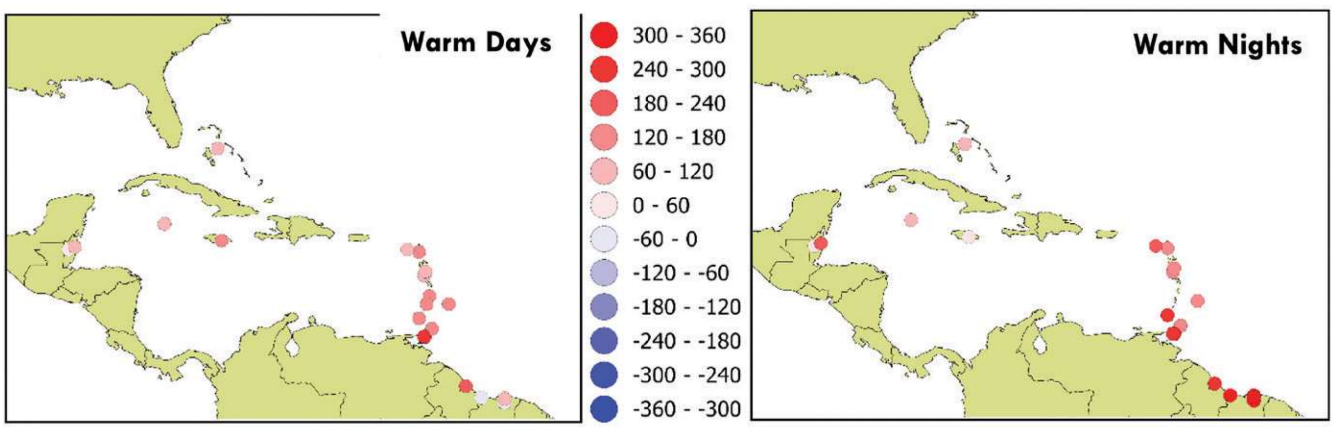

Figure 5.3: Projections of warm days and nights for the period 2090 to 2100 relative to 2006 to 2016 period for RCP 8.5. Units are in days.

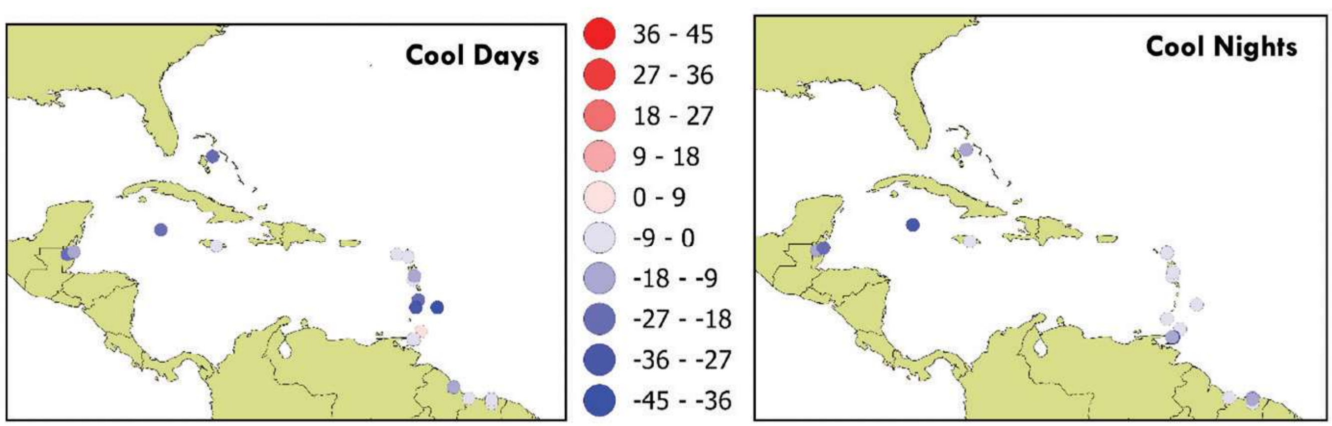

Figure 5.4: Projections of cool days and cool nights for the period 2090 to 2100 relative to 2006 to 2016 period for RCP 8.5. Units are in days.

5.3. RAINFALL

The following are noted about future changes in Caribbean rainfall from the GCM, RCM, and statistical downscaling projections.

- GCM projections suggest a drying trend in annual rainfall. Across all scenarios the drying is already established by the 2020s (up to 2% drier for the mean of all models). By the 2050s, the region is in the mean up to 6% drier, and by the end of century the region may be up to 17% drier (Figure 5.6).
- The Caribbean drying trend is likely driven by drying in the late wet season. It is slightly drier (up to ~ 1%) under all but a best-case scenario from as early as the 2020s. By the 2050s, it is up to 4% drier, while by the end of century, all scenarios result in drying, with up to 12% less rainfall projected for SON under RCP8.5.
- Drying in the Caribbean dry season (November through January) is projected to occur only under RCP8.5 in the 2050s and under RCP6 and RCP8.5 (up to 4%) by the end of the century. In general, the dry season may be slightly wetter or unaffected through to mid-century.
- The RCM projections suggest sub-regional variation in projections with some parts of the region being more significantly impacted by drier conditions than others (Table 5.8). A general pattern is for Belize in the far west Caribbean (Zone 1) and the Lesser Antilles and southern Caribbean (Zones 5 and 6) to be the most severely impacted once drying has onset, as well as the central Caribbean (Zone 4) to a lesser extent. Changes to mean annual rainfall in the far north and north Caribbean (Zones 2 and 3) suggest slightly wetter conditions through to mid-century which changes to drier conditions by the end of century. It is important to note however, that even for the far north Caribbean, the rainy seasons are projected to dry from as early as the 2020s.

Table 5.8: Range of percentage rainfall change across the six Caribbean zones from an RCM ensemble running the A1B scenario. Baseline is 1961-1990. See again Figure 2.3 for grid boxes in each zone.

		ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6
ANNUAL	2020s	-16.82 –11.03	-7.69 – 14.64	-9.16 – 16.16	-8.87 – 14.42	-20.15 – 4.09	-28.83 – -5.93
	2050s	-25.77 – 0.67	-4.4.3 – 9.90	-4.96 – 16.22	-28.16 – 21.66	-35.15 – 3.53	-37.82 – -13.92
	EOC	-38.32 – - 1.44	-6.82 – 9.39	-15.93 – -5.12	-41.09 – -11.40	-46.19 – -13.74	-54.32 – -0.69

- From as early as the 2020s, the wet seasons begin to show evidence of drying throughout the entire Caribbean. The RCMs project a mean decrease in rainfall during the May-July (MJJ) and September-November (SON) rainfall seasons in all six zones. Drying is also projected during the dry season (NDJ) in the far west and south Caribbean (Zones 1 and 6).
- The west (Zone 1), Lesser Antilles (Zone 5) and south (Zone 6) Caribbean seem most susceptible to drying. From as early as the 2020s, projections suggest drying in the far south Caribbean for all seasons of the year, while the west (Zone 1) and the Lesser Antilles (Zone 5) are projected to dry in three of four seasons. By the 2050s, RCMs project drying in all seasons for the Lesser Antilles and south Caribbean zones (Zones 5 and 6) and in three of four seasons in the west Caribbean (Zone 1). By the end of the century, RCMs project drying in all seasons for Zones 1, 4, 5, and 6.
- With respect to mean annual rainfall, the west Caribbean, Lesser Antilles and south Caribbean (Zones 1, 5, and 6) are projected to decrease in the mean by up to 3%, 6%, and 16% respectively from as early as the 2020s. In contrast the far north, north and central Caribbean (Zones 2, 3, and 4) show a slight increase of up to 3%, 2%, and 1%, respectively. By the 2050s, projections show a mean annual decrease in Zones 1, 4, 5, and 6 of 10%, 5%, 12%, and 22%, respectively. However, Zones 2 and 3 show an increase of up to 4% and 2%, respectively. By the end of the century, drying is projected across all zones, with the least drying occurring in Zone 2 and the greatest in Zone 6.

» SDSM projections show a likely increase in heavy rainfall as suggested by projected increases in the following extreme rainfall indices: number of days with rainfall above 10 mm, maximum 1-day rainfall, and maximum 5-day rainfall across most of the region.

5.3.1. GCMS

GCM projections are provided below for annual, late wet season, and dry season rainfall across the Caribbean relative to a 1985 – 2005 baseline (Tables 5.9-5.11 and Figure 5.5).

Table 5.9: Mean percentage change in rainfall for the Caribbean with respect to 1986-2005. Changes are shown for the four RCP scenarios. Source: AR5 CMIP5 subset, KNMI Climate Change Atlas.

	ANNUAL RAINFALL								
	2020s			2050s			END OF CENTURY		
Averaged over	2020-2029			2050-2059			2091-2100		
	min	mean	max	min	mean	max	min	mean	max
rcp26	-6.44	-0.22	10.06	-8.55	-0.09	14.75	-27.75	-0.46	10.73
rcp45	-12.09	-1.77	8.76	-20.50	-4.30	16.96	-32.45	-5.26	17.44
rcp60	-12.47	-0.86	11.75	-12.26	-2.42	10.62	-34.97	-6.91	10.74
rcp85	-11.33	-0.99	16.36	-20.06	-6.27	15.48	-51.13	-16.95	15.48
Range of mean:	**-1.77 – -0.22**			**-6.27 – -0.09**			**-16.95 – -0.46**		

Table 5.10: Mean percentage change in late season (September-November) rainfall for the Caribbean with respect to 1986-2005. Changes are shown for the four RCP scenarios. Source: AR5 CMIP5 subset, KNMI Climate Change Atlas.

	LATE RAINFALL SEASON								
	2020s			2050s			END OF CENTURY		
Averaged over	2020-2029			2050-2059			2091-2100		
	Min	mean	max	min	mean	max	min	mean	max
rcp26	-8.35	0.43	17.61	-9.82	0.53	13.34	-23.72	-0.26	15.28
rcp45	-15.89	-0.49	14.88	-23.31	-2.62	25.45	-30.41	-3.63	22.75
rcp60	-9.38	-0.64	10.99	-15.78	-2.28	11.61	-33.88	-4.91	16.09
rcp85	-9.48	0.37	16.28	-21.23	-4.30	18.56	-51.52	-12.27	36.64
Range of mean:	**-0.64 – 0.43**			**-4.30 – 0.53**			**-12.27 – -0.26**		

Table 5.11: Mean percentage change in dry season (November-January) rainfall for the Caribbean with respect to 1986-2005. Changes are shown for four RCP scenarios. Source: AR5 CMIP5 subset, KNMI Climate Change Atlas.

	DRY SEASON RAINFALL								
	2020s			2050s			END OF CENTURY		
Averaged over	2020-2029			2050-2059			2091-2100		
	min	mean	max	min	mean	max	min	mean	max
rcp26	-16.25	1.02	16.27	-11.68	1.86	14.22	-24.60	1.55	18.25
rcp45	-9.83	0.59	14.04	-13.21	0.68	18.52	-29.30	0.32	20.15
rcp60	-11.21	-1.23	11.12	-11.04	0.71	15.13	-30.28	-1.40	18.85
rcp85	-11.42	2.11	17.45	-16.25	-0.19	17.28	-43.76	-4.06	36.02
Range of mean:	**-1.23 – 2.11**			**-0.19 – 1.86**			**-4.06 – 1.55**		

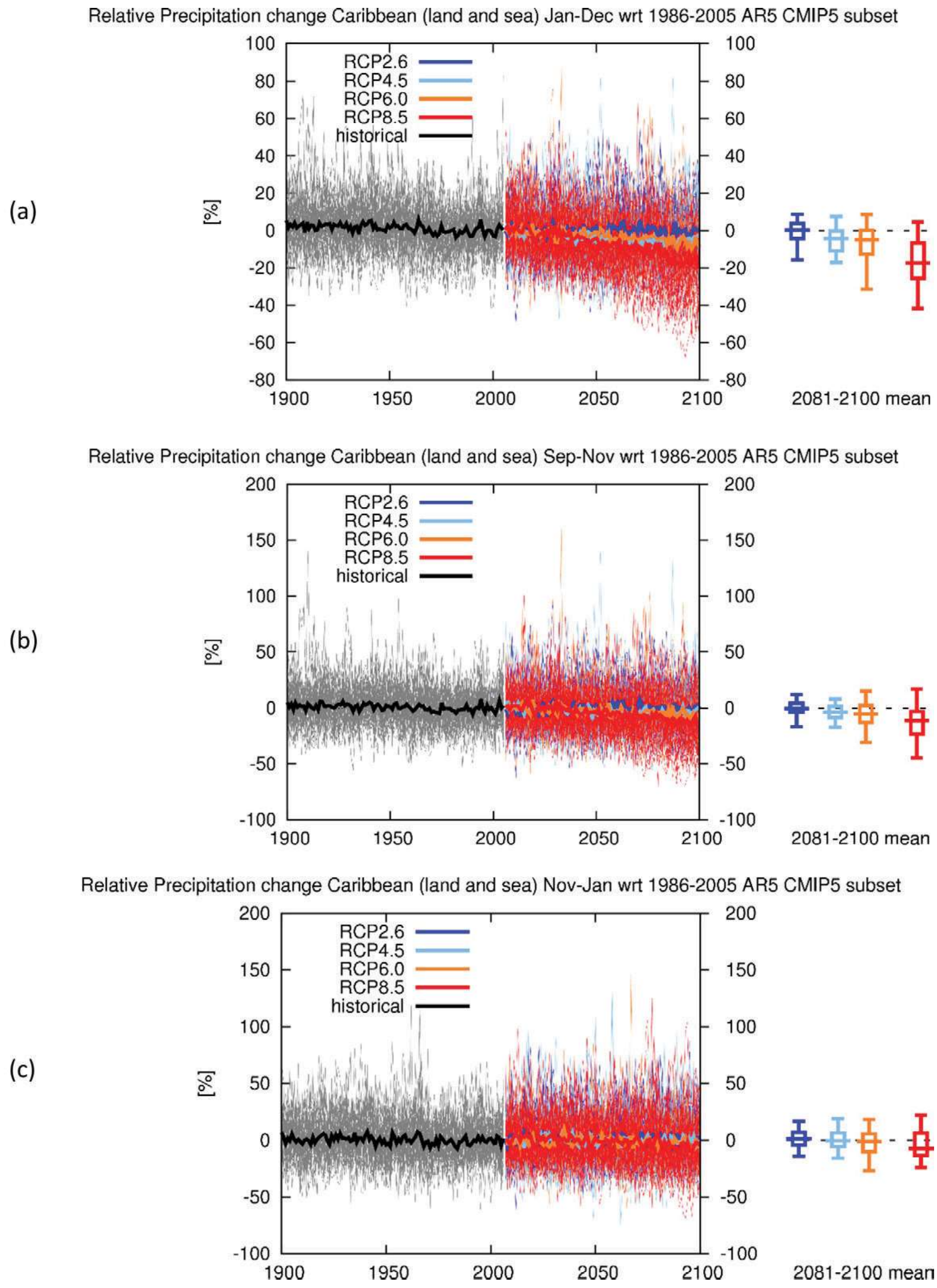

Figure 5.5: (a) Relative Annual Precipitation change (%) (b) Relative September-November Precipitation change (%) (c) Relative November-January Precipitation change (%) for the Caribbean with respect to 1986-2005 AR5 CMIP5 subset. On the left, for each scenario one line per model is shown plus the multi-model mean, on the right percentiles of the whole dataset: the box extends from 25% to 75%, the whiskers from 5% to 95% and the horizontal line denotes the median (50%).

5.3.2. RCMS

Rainfall Projections for the region from the PRECIS RCM have been provided in Table 5.12 below. A summary map showing percentage change per grid box of annual rainfall is given in Figure 5.6

Table 5.12: Percentage change in precipitation (%) for (a) the 2020s (2020-2029), (b) 2050s (2050-2059), and (c) end of century, EOC (2081-2098) relative to the 1962-1989 baseline. Values are representative of the 6 zones shown in Figure 2.3.

ZONE 1									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	-16.77	-5.03	8.56	-9.84	-2.49	5.55	-18.33	-5.55	32.31
FMA	-10.81	6.52	23.62	-4.56	3.63	11.64	-35.31	-10.07	26.75
MJJ	-29.01	-5.92	20.56	-48.76	-15.77	6.09	-65.52	-38.38	-17.54
SON	-21.47	-8.32	2.33	-39.93	-23.60	-11.24	-55.75	-38.66	-26.14
ANN	**-16.82**	**-3.19**	**11.03**	**-25.77**	**-9.56**	**0.67**	**-38.32**	**-23.16**	**-1.44**
ZONE 2									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	-11.61	1.31	19.61	-5.16	8.16	15.43	0.89	13.78	24.11
FMA	-4.88	15.03	42.19	-4.97	6.25	16.04	0.59	6.84	18.99
MJJ	-20.09	-5.66	18.65	-5.28	0.44	11.96	-23.72	-7.71	9.48
SON	-10.96	-0.26	8.21	-15.99	-0.44	6.62	-22.37	-14.78	-3.19
ANN	**-7.69**	**2.61**	**14.64**	**-4.43**	**3.60**	**9.90**	**-6.82**	**-0.47**	**9.39**
ZONE 3									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	-8.62	2.24	15.41	-1.44	7.90	19.49	1.76	11.22	30.52
FMA	-4.24	13.86	32.72	10.13	19.01	32.49	-8.53	9.10	18.09
MJJ	-13.00	-2.41	20.15	-20.41	-4.83	22.80	-47.38	-31.35	-19.83
SON	-14.79	-4.47	1.55	-18.22	-15.34	-9.90	-37.95	-32.25	-22.24
ANN	**-9.16**	**2.31**	**16.16**	**-4.96**	**1.69**	**16.22**	**-15.93**	**-10.82**	**-5.12**

ZONE 4									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	-0.49	7.99	16.57	-30.88	1.65	26.87	-27.36	-0.39	25.29
FMA	-9.50	6.75	33.04	-15.09	12.75	42.40	-25.28	-1.31	23.74
MJJ	-13.69	-4.76	7.51	-38.82	-7.75	43.46	-66.85	-48.03	-36.20
SON	-22.65	-5.22	10.11	-27.84	-25.32	-22.33	-44.88	-39.13	-29.55
ANN	**-8.87**	**1.19**	**14.42**	**-28.16**	**-4.67**	**21.66**	**-41.09**	**-22.22**	**-11.40**

ZONE 5									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	-9.40	1.54	18.43	-39.01	-10.26	3.48	-38.42	-15.73	19.60
FMA	-25.98	-6.18	11.38	-31.28	-8.73	10.91	-39.41	-21.56	1.55
MJJ	-30.45	-12.18	6.47	-43.15	-10.47	29.71	-66.27	-49.49	-32.14
SON	-14.76	-6.24	3.45	-27.16	-18.07	-12.48	-42.29	-30.83	-13.66
ANN	**-20.15**	**-5.76**	**4.09**	**-35.15**	**-11.88**	**3.53**	**-46.19**	**-29.40**	**-13.74**

ZONE 6									
	2020s			2050s			EOC		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
NDJ	-22.80	-13.66	-2.64	-41.36	-19.84	-4.93	-56.48	-28.01	35.40
FMA	-40.88	-18.00	-1.73	-48.23	-30.34	-13.74	-60.07	-46.96	-22.06
MJJ	-30.30	-11.98	4.20	-28.16	-8.84	14.55	-61.18	-33.53	-8.09
SON	-24.56	-19.10	-11.21	-37.28	-27.57	-7.11	-54.72	-27.49	22.40
ANN	**-28.83**	**-15.68**	**-5.93**	**-37.82**	**-21.65**	**-13.92**	**-54.32**	**-34.00**	**-0.69**

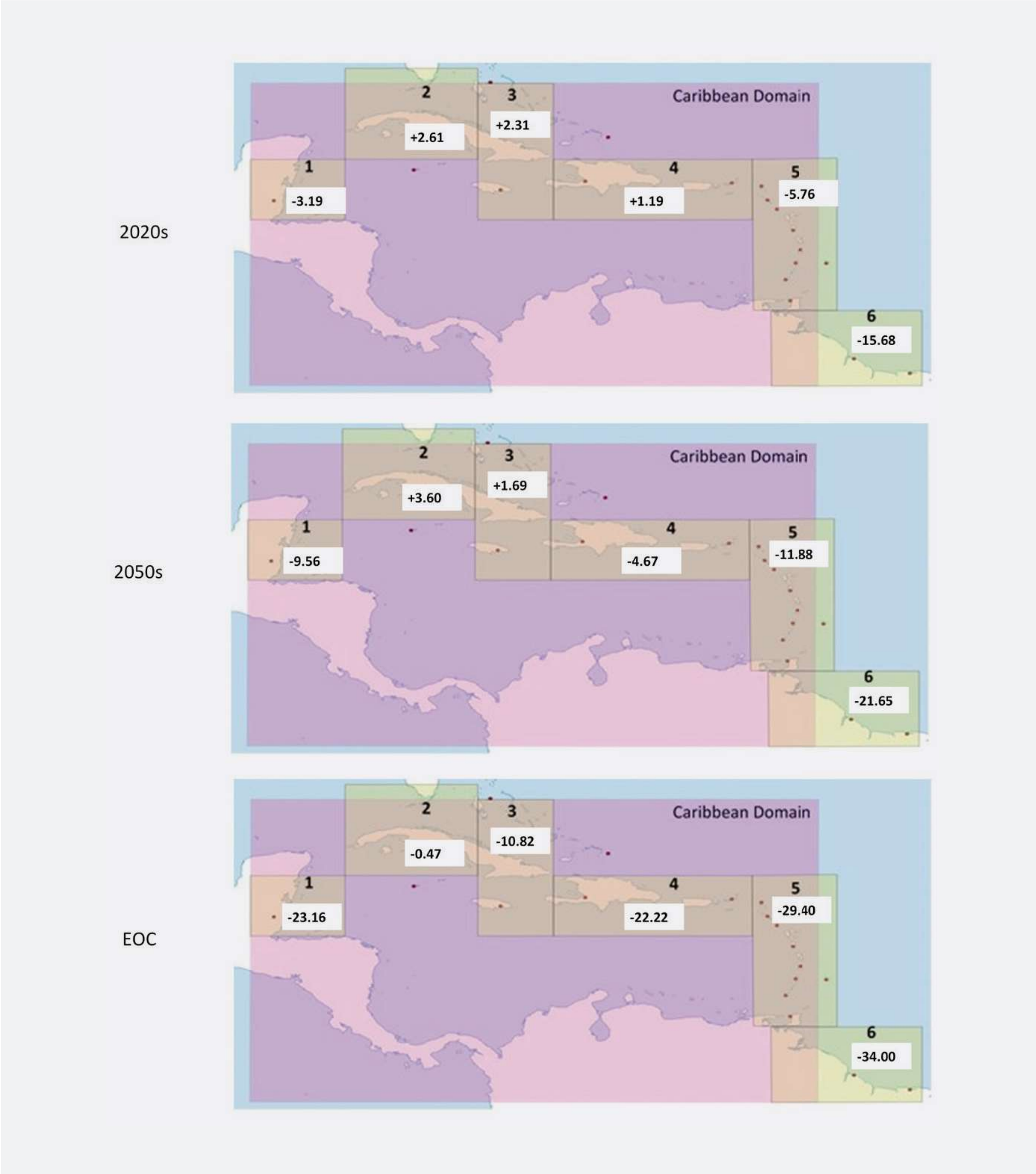

Figure 5.6: Summary map showing percentage change per zone of annual rainfall for the 2020s (top panel), 2030s (middle panel) and 2030s (bottom panel). Source: PRECIS RCM PPE.

5.3.3. RAINFALL EXTREMES

Figure 5.7 shows spatial results for consecutive dry days (CDD) and days with rainfall amounts greater than 10 mm (R10) for the end of century period (2090 to 2100) for RCP 8.5. Generally, the Statistical Downscaling Model (SDSM) projected an increase in R10. Greatest projected percentage change in R10 was observed for Point Salines in Grenada (an increase of 305%). Smallest change was projected for Hewanorra in St. Lucia (6%). Some stations projected a small decline in CDD while others projected major increases. GAIA in Barbados had a projected increase in CDD of 398% whereas Lelydorp in Suriname had a projected decrease of 63%.

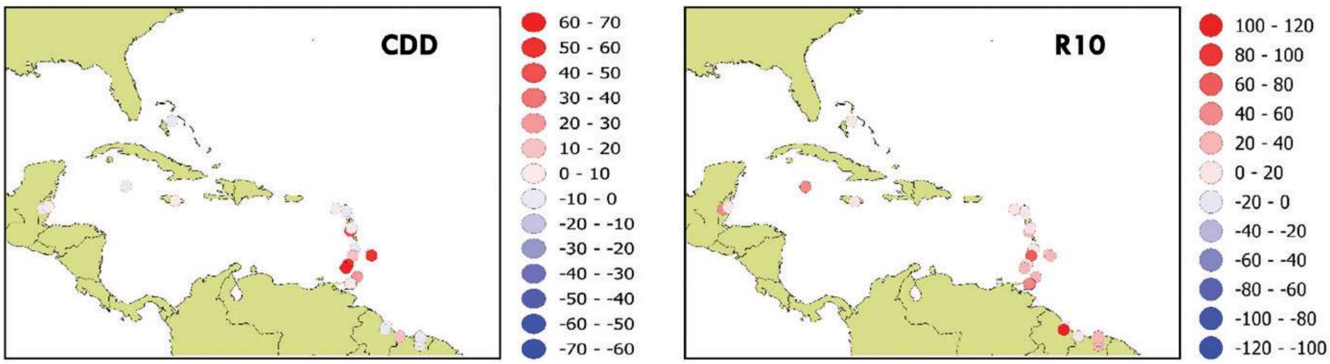

Figure 5.7: Projections of CDD and R10 for the period 2090 to 2100 relative to 2006 to 2016 period for RCP 8.5. Units are in days for CDD and mm for R10

Figure 5.8 shows projected changes in other heavy rainfall indices, namely maximum one-day rainfall (RX1) and maximum five-day rainfall (RX5) for 2090 to 2100 for RCP 8.5. The general trend is for an increase in both RX1 and RX5. Greatest percentage change is projected for St. Augustine, Trinidad of 185% and 195% for RX1 and RX5 respectively. Smallest percentage change was observed for Maurice Bishop International Airport (MBIA), Grenada (1%) for RX1 and St. Kitts (5%) for RX5. Georgetown, Guyana was the only station that had a projected decrease in both RX1 (8%) and RX5 (3%). CIMH, Barbados (3%) and Melville Hall, Dominica (2%) had a projected decrease for RX5.

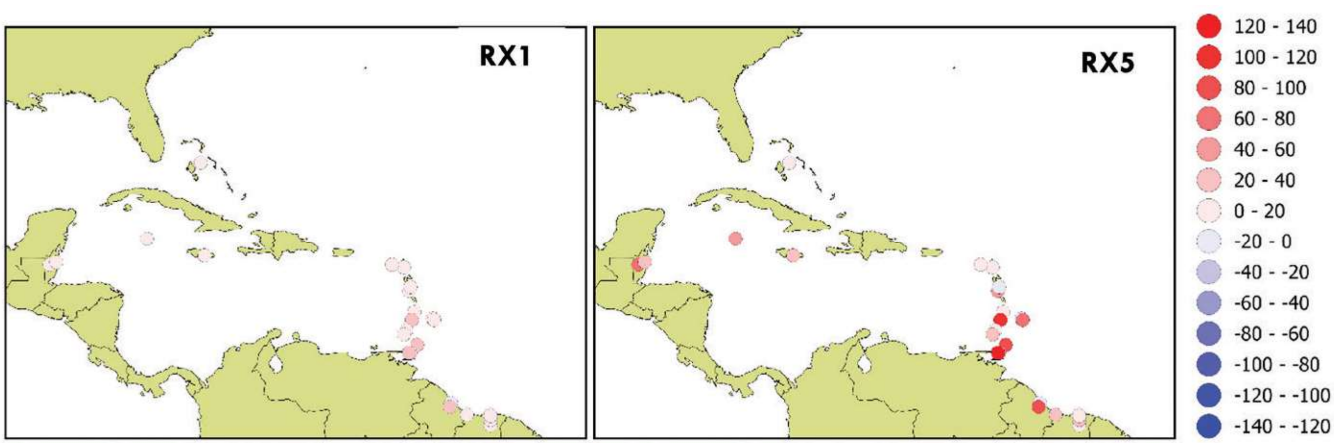

Figure 5.8: RX1 and RX5 for the period 2090 to 2100 relative to 2006 to 2016 period for RCP 8.5. Units are in mm.

5.4. HURRICANES

The IPCC Special Report on Extremes (IPCC 2012) offers five summary statements with respect to projections of future hurricane under global warming which are of relevance to the region. They are reiterated below as major conclusions, and supported with additional information (where available) specific for the Atlantic basin.

CONCLUSION 1: THERE IS LOW CONFIDENCE IN PROJECTIONS OF CHANGES IN TROPICAL CYCLONE GENESIS, LOCATION, TRACKS, DURATION, OR AREAS OF IMPACT.

Tropical cyclone genesis and track variability is modulated in most regions by known modes of atmosphere-ocean variability. The details of the relationships vary by region (for example, El Niño events tend to suppress Atlantic storm genesis and development). The accurate modelling, then, of tropical cyclone activity fundamentally depends on the model's ability to reproduce these modes of variability to produce reliable projections of the behaviour of these modes of variability (for example, ENSO) under global warming, as well as on a good understanding of their physical links with tropical cyclones. At present, there is still uncertainty in the model's ability to project these behaviours.

CONCLUSION 2: BASED ON THE LEVEL OF CONSISTENCY AMONG MODELS, AND PHYSICAL REASONING, IT IS LIKELY THAT TROPICAL CYCLONE RELATED RAINFALL RATES WILL INCREASE WITH GREENHOUSE WARMING.

Observed changes in rainfall associated with tropical cyclones have not been clearly established. However, as water vapor in the tropics increases, there is an expectation for increased heavy rainfall associated with tropical cyclones. Models in which tropical cyclone precipitation rates have been examined are highly consistent in projecting increased rainfall within the area near the tropical cyclone centre under 21st-century warming, with increases of 3 to 37% (Knutson et al. 2010). Typical projected increases are near 20% within 100 km of storm centres (see Figure 5.9). More recent work premised on RCP 4.5 suggest that rainfall rates increase robustly for the CMIP3 and CMIP5 scenarios (Knutson et al. 2013). For the late twenty-first century, the increase amounts to +20% to +30% in the model hurricane's inner core, with a smaller increase (~10%) at radii of 200 km or larger.

CONCLUSION 3: IT IS LIKELY THAT THE GLOBAL FREQUENCY OF TROPICAL CYCLONES WILL EITHER DECREASE OR REMAIN ESSENTIALLY UNCHANGED.

Hurricane research done at NOAA's GFDL laboratory using regional models projects that Atlantic hurricane and tropical storms are **substantially reduced in number,** for the average 21st-century climate change projected by current models, but will have **higher rainfall rates**, particularly near the storm centre. http://www.gfdl.noaa.gov/global-warming-and-hurricaneshttp://www.gfdl.noaa.gov/global-warming-and-hurricanes

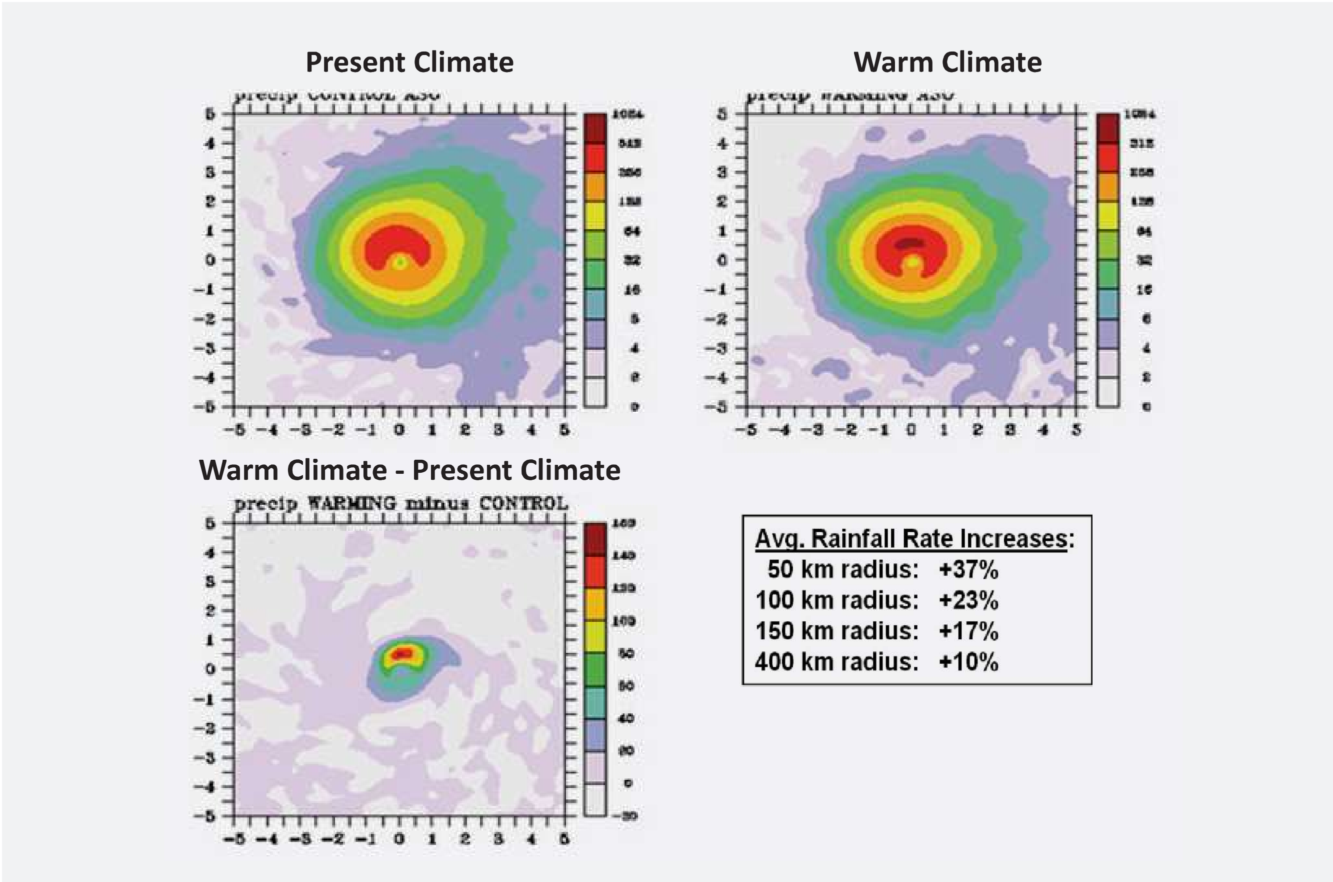

Figure 5.9: Rainfall rates (mm/day) associated with simulated tropical storms in a) a present climate b) warm climate c) warm minus present climate. Average warming is 1.72 °C. From Knutson et al. (2010).

CONCLUSION 4: AN INCREASE IN MEAN TROPICAL CYCLONE MAXIMUM WIND SPEED IS LIKELY, ALTHOUGH INCREASES MAY NOT OCCUR IN ALL TROPICAL REGIONS.

Assessments of projections by Knutson et al. (2010), Bender et al., (2010) and statistical-dynamical models (Emanuel, 2007) are consistent that that greenhouse warming causes tropical cyclone intensity to shift toward stronger storms by the end of the 21st century as measured by maximum wind speed increases by +2 to +11%.

CONCLUSION 5: WHILE IT IS LIKELY THAT OVERALL GLOBAL FREQUENCY WILL EITHER DECREASE OR REMAIN ESSENTIALLY UNCHANGED, IT IS MORE LIKELY THAN NOT THAT THE FREQUENCY OF THE MOST INTENSE STORMS WILL INCREASE SUBSTANTIALLY IN SOME OCEAN BASINS.

The downscaling experiments of Bender et al. (2010) project a 28% reduction in the overall frequency of Atlantic storms and an 80% increase in the frequency of Saffir-Simpson category 4 and 5 Atlantic hurricanes over the next 80 years using the A1B scenario. Downscaled projections using CMIP5 multi-model scenarios (RCP4.5) as input (Knutson et al. 2013) still show increases in category 4 and 5 storm frequency, but these are only marginally significant for the early 21st century (+45%) or the late 21st century (+40%) using CMIP5 scenarios.

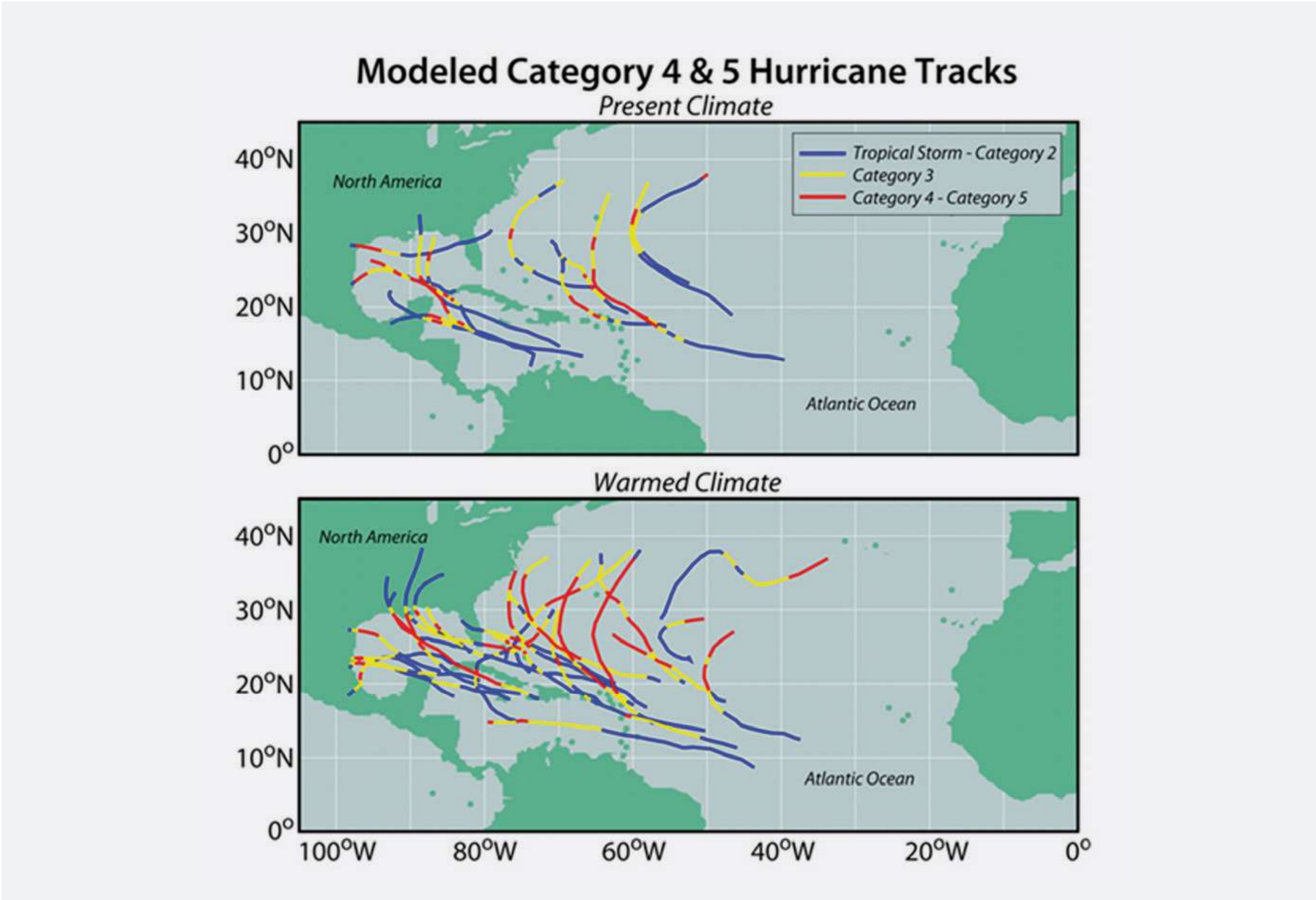

Figure 5.10: Late 21st century warming projections of category 4 and 5 hurricanes in the Atlantic. Average of 18 CMIP3 models. From Bender et al. (2010).

The uncertainty evident in the five conclusions suggests that at the very least the Caribbean should contemplate a future where tropical storm/hurricane genesis, frequency and tracks are similar to what has been experienced in the very recent past (last two decades), but intensities (rainfall rates and wind speeds) are increased.

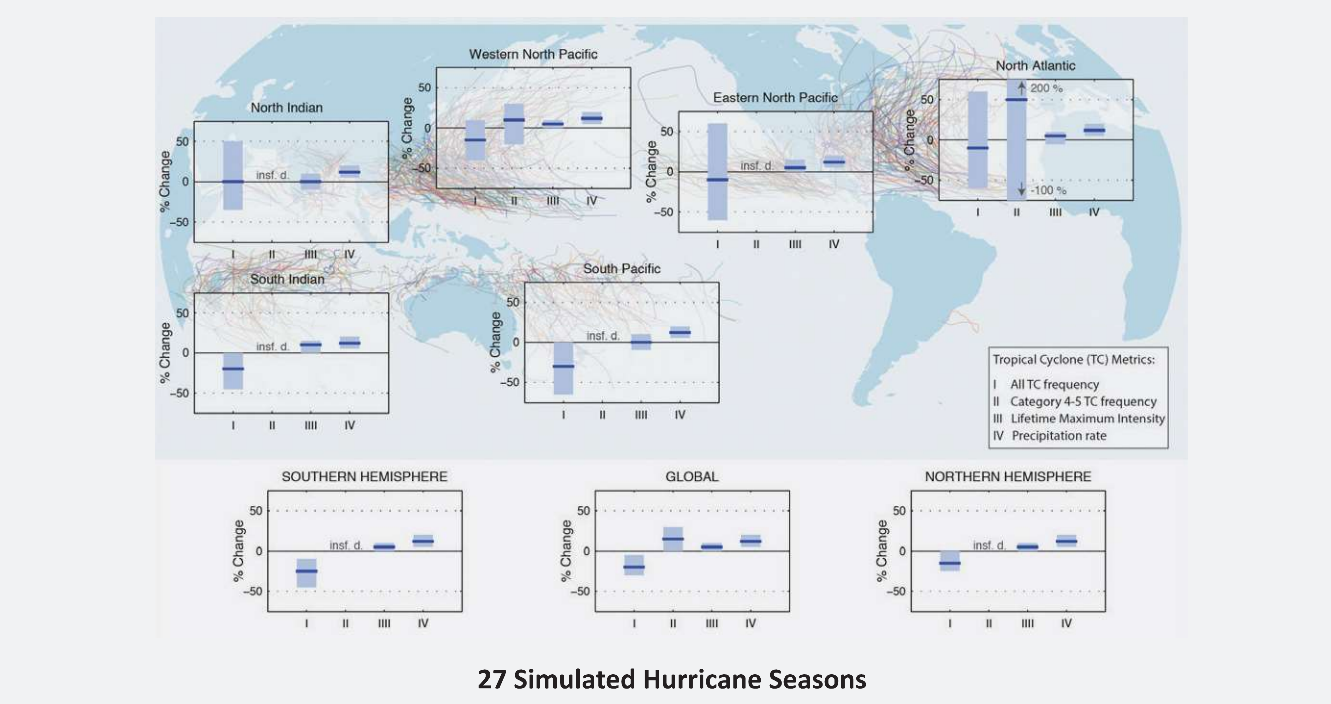

Figure 5.11: IPCC AR5 Summary Diagram
General consensus assessment of the numerical experiments described in IPCC (2013) Supplementary Material Tables 14.SM.1 to 14.SM.4. All values represent expected percent change in the average over period 2081–2100 relative to 2000–2019, under an A1B-like scenario, based on expert judgement after subjective normalization of the model projections. Four metrics were considered: the percent change in (I) the total annual frequency of tropical storms, (II) the annual frequency of Category 4 and 5 storms, (III) the mean Lifetime Maximum Intensity (LMI; the maximum intensity achieved during a storm's lifetime) and (IV) the precipitation rate within 200 km of storm centre at the time of LMI. For each metric plotted, the solid blue line is the best guess of the expected percent change, and the coloured bar provides the 67% (likely) confidence interval for this value (note that this interval ranges across –100% to +200% for the annual frequency of Category 4 and 5 storms in the North Atlantic). Where a metric is not plotted, there are insufficient data (denoted 'insf. d.') available to complete an assessment. A randomly drawn (and coloured) selection of historical storm tracks are underlain to identify regions of tropical cyclone activity.

5.5. SEA LEVELS

5.5.1. GLOBE AND CARIBBEAN

Projections of sea level rise for the globe and for the Caribbean region from the IPCC's Fourth assessment report are given in Table 5.13. There is not a significant difference between the global SLR projections and projections of Caribbean SLR.

Table 5.13: Projected changes in sea level by 2090s from a regional climate model.

SCENARIO	GLOBAL MEAN SEA LEVEL RISE BY 2100 RELATIVE TO 1980 – 1999	CARIBBEAN MEAN SEA LEVEL RISE BY 2100 RELATIVE TO 1980 – 1999 (± 0.05M RELATIVE TO GLOBAL MEAN)
IPCC B1	0.18 – 0.38	0.13 – 0.43
IPCC A1B	0.21 – 0.48	0.16 – 0.53
IPCC A2	0.23 – 0.51	0.18 – 0.56

The Fifth Assessment Report of the IPCC does not provide projections for the Caribbean separate from that for the global mean. Using the assumption that Caribbean SLR is similar to that for the globe, Figure 5.12 depicts the rate of change in global sea level for RCP 2.6 and RCP8.5. Table 5.14 also summarizes global sea level rise for a mid-century and an end of century period for the four RCPs. Sea level rise projections are similar through to mid-century irrespective of RCP. Toward the end of the century the projections diverge with the higher RCPs associated with higher sea levels.

A number of studies, (e.g. Rahmstorf [2007]; Rignot and Kanargaratnam [2006]; Horton et al. [2008]) including some assessed in the IPCC's Fifth Assessment Report, suggest that the upper bound for the global estimates given in Table 5.13 are conservative and could be much higher, with a rate of 8 to 16 mm/year by the end of century (2081–2100). Diagrams from Perrette et al. (2013) suggest the same for estimates for the Caribbean Sea i.e. a higher upper bound of up to 1.5 m of seal level rise by the end of the century.

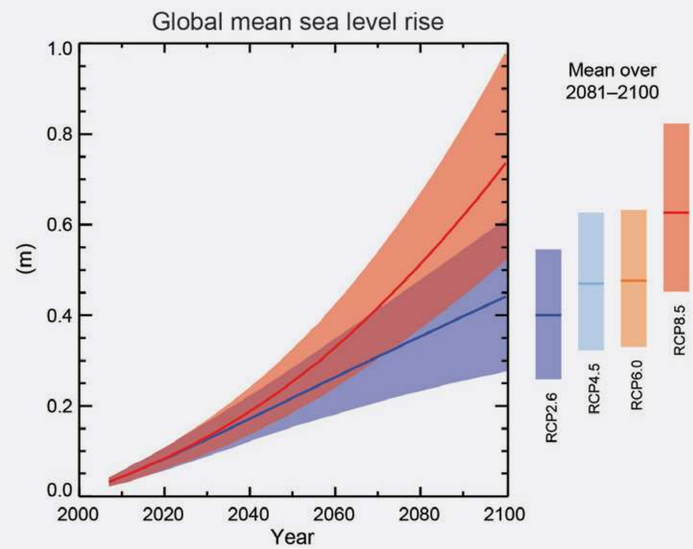

Figure 5.12: Projections of global mean sea level rise over the 21st century relative to 1986–2005 from the combination of the CMIP5 ensemble with process-based models, for RCP2.6 and RCP8.5.The assessed likely range is shown as a shaded band. The assessed likely ranges for the mean over the period 2081–2100 for all RCP scenarios are given as coloured vertical bars, with the corresponding median value given as a horizontal line. From IPCC (2013)

Table 5.14: Projected increases in global mean sea level (m) - Projections are taken from IPCC (2013) and are relative to 1986-2005 baseline levels.

TIME PERIOD		2046 – 2065		2081– 2100	
VARIABLE	SCENARIO	MEAN	LIKELY RANGE	MEAN	LIKELY RANGE
GLOBAL MEAN SEA LEVEL RISE (m)	RCP2.6	0.24	0.17 – 0.32	0.40	0.26 – 0.55
	RCP4.5	0.26	0.19 – 0.33	0.47	0.32 – 0.63
	RCP6.0	0.25	0.18 – 0.32	0.48	0.33 – 0.63
	RCP8.5	0.30	0.22 – 0.38	0.63	0.45 – 0.82

5.5.2. ZONES

Estimates for projected sea level rise across the six zones into which the Caribbean has been divided are provided in Table 5.15. Projections are shown for two RCPs. Regional variation is small with the north Caribbean tending to have slightly higher projected values than the southern Caribbean. By the end of the century, sea level rise is projected to reach or exceed 1 m across the Caribbean.

Table 5.15: Sea level rise projections for six Caribbean zones from the AR5 ensemble of 21 CMIP5 models. Projections are for the ensemble mean and the likely range represented by the 5% and 95% uncertainty bounds (See Chapter13 Sea Level Rise Supplementary Material[8]). Maximum projections for the listed decades are provided for two RCPs. Projections are relative to 1986-2005. Data source: Integrated Climate Data Center.

ZONE 1	4.5			8.5		
	5%	MEAN	95%	5%	MEAN	95%
2020	0.08	0.13	0.18	0.10	0.14	0.19
2050	0.18	0.28	0.40	0.21	0.33	0.46
2090	0.31	0.52	0.74	0.46	0.71	1.01
ZONE 2	4.5			8.5		
	5%	MEAN	95%	5%	MEAN	95%
2020	0.07	0.12	0.17	0.07	0.13	0.19
2050	0.18	0.29	0.41	0.21	0.32	0.44
2090	0.33	0.55	0.78	0.43	0.72	1.04
ZONE 3	4.5			8.5		
	5%	MEAN	95%	5%	MEAN	95%
2020	0.07	0.13	0.18	0.07	0.13	0.19
2050	0.18	0.30	0.41	0.21	0.33	0.45
2090	0.34	0.55	0.78	0.44	0.71	1.02

8 AR5 Sea Level Change Supplementary Material, Chapter 13:
Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change Supplementary Material. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)].

ZONE 4	4.5			8.5		
	5%	MEAN	95%	5%	MEAN	95%
2020	0.05	0.11	0.17	0.05	0.11	0.17
2050	0.16	0.26	0.37	0.18	0.29	0.41
2090	0.30	0.51	0.73	0.38	0.66	0.98
ZONE 5	4.5			8.5		
	5%	MEAN	95%	5%	MEAN	95%
2020	0.06	0.11	0.17	0.07	0.11	0.16
2050	0.16	0.27	0.38	0.20	0.30	0.41
2090	0.31	0.52	0.74	0.42	0.69	0.99
ZONE 6	4.5			8.5		
	5%	MEAN	95%	5%	MEAN	95%
2020	0.07	0.11	0.15	0.07	0.11	0.15
2050	0.18	0.26	0.35	0.21	0.30	0.39
2090	0.31	0.49	0.70	0.44	0.68	0.95

5.5.3. SEA LEVEL EXTREMES

ADAPTED FROM IPCC (2013)

Higher mean sea levels can significantly decrease the return period for exceeding given threshold levels. Hunter (2012) determined the factor by which the frequency of sea levels exceeding a given height would be increased for a mean sea level rise of 0.5 m for a network of 198 tide gauges covering much of the globe (Figure 5.13). The AR5 repeats the calculations using regional sea level projections and their uncertainty under the RCP4.5 scenario. The multiplication factor depends exponentially on the inverse of the Gumbel scale parameter (a factor which describes the statistics of sea level extremes caused by the combination of tides and storm surges) (Coles and Tawn 1990). The scale parameter is generally large where tides and/or storm surges are large, leading to a small multiplication factor, and vice versa. Figure 5.13 shows that 0.5 m mean sea level rise would likely result in the frequency of sea level extremes increasing by an order of magnitude or more in some regions. The multiplication factors are found to be slightly higher, in general, when accounting for regional mean sea level projections. In regions having higher regional projections of mean sea level the multiplication factor is higher, whereas in regions having lower regional projections of mean sea level the multiplication factor is lower.

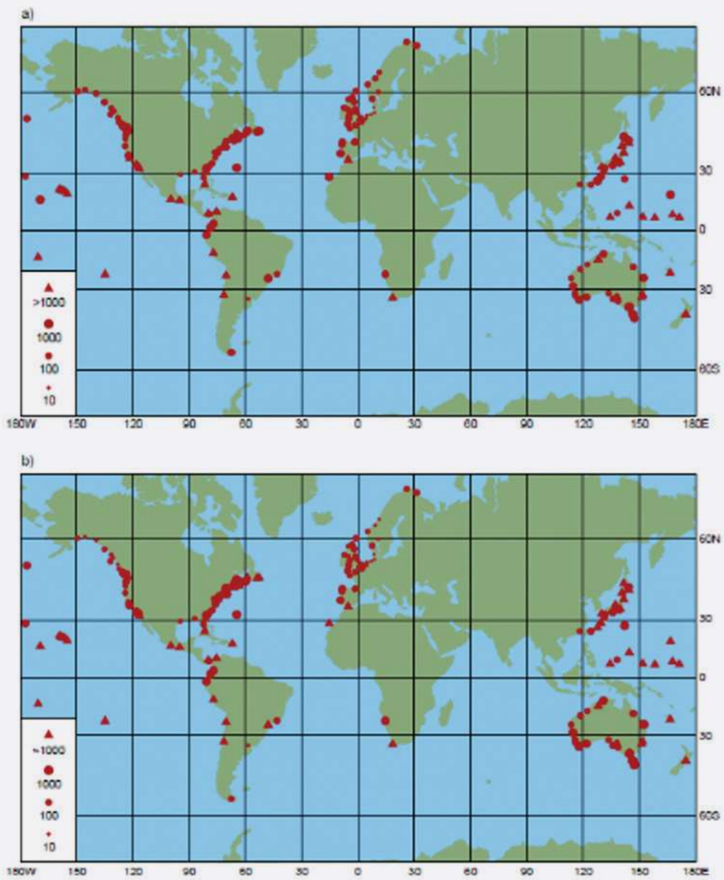

Figure 5.13: The estimated multiplication factor (shown at tide gauge locations by red circles and triangles), by which the frequency of flooding events of a given height increase for (a) a mean sea level rise of 0.5 m (b) using regional projections of mean sea level. The Gumbel scale parameters are generally large in regions of large tides and/or surges resulting in a small multiplication factor and vice versa. IPCC (2013)

5.6. SEA SURFACE TEMPERATURES

Not a lot of studies have examined projections of SSTs for the Caribbean. Antuna et al. (2015) determine future Caribbean SSTs for the period 2000-2099 for both a business-as-usual and a low CO2 emission scenario using a coupled ocean-atmosphere model. Their results are summarized in Table 5.16. The results show a continuation of the recent warming trend in SST (see again Chapter 4).

Table 5.16: Projected north tropical Atlantic SST trends (°C per century) for two future scenarios. Bracketed numbers indicate standard errors. Adapted from Antuna et al. (2015).

SST INCREASE (°C PER CENTURY)		
	BUSINESS-AS-USUAL SCENARIO	LOW CO2 SCENARIO
ANTILLES	1.80 (0.41)	0.77 (0.38)
WIDER CARIBBEAN	1.76 (0.39)	0.86 (0.43)
TROPICAL ATLANTIC	1.72 (0.42)	0.70 (0.42)

Nurse and Charlery (2014) also produced SST projections for two future SRES scenarios using data from a regional climate model. They examined three future time slices and deduced that SSTs will increase across the region throughout the twenty-first century irrespective of scenario examined. They note, however, that the mean decadal rate of warming increases from 0.13°C for the 30 year period 2000-2029 to 0.31°C for 2030-2059, and eventually reaches 0.41°C for 2070-2099 i.e., the warming intensifies.

Nurse and Charlery (2014) also suggest the following about the future warming of Caribbean SSTs:

- By mid-century, the expanding and contracting of the Atlantic Warm Pool (AWP) is replaced by a "blanket" of uniformly warm temperatures across the Caribbean Sea throughout the entire year. The projected SSTs therefore exceed 28°C across the entire Caribbean Sea year-round.
- The mean annual SST range of approximately 3.3°C currently observed in the Caribbean Sea is projected to contract to 2.9°C in the 2030s and to 2.3°C in the 2090s. By the end of the century, years of coolest projected SSTs fall within the range of the warmest years in the present.

This projected increase in Caribbean SST trends will likely support the generation of more intense future hurricanes and have increasingly negative impacts on coral health and general marine ecology (Taylor and Stephenson 2017).