1 Current climate of Barbados

1.1 Definitions and data used

Barbados uses the guidance from the WMO on the definition of the current Climatological Standard Normal, the period 1991 – 2020.[1] That same period is used in the analyses in this annex.

For the analyses, use is made of observations at four weather stations in the densely population southern half of Barbados, coinciding with the project area. The locations of the stations are indicated on the map below.

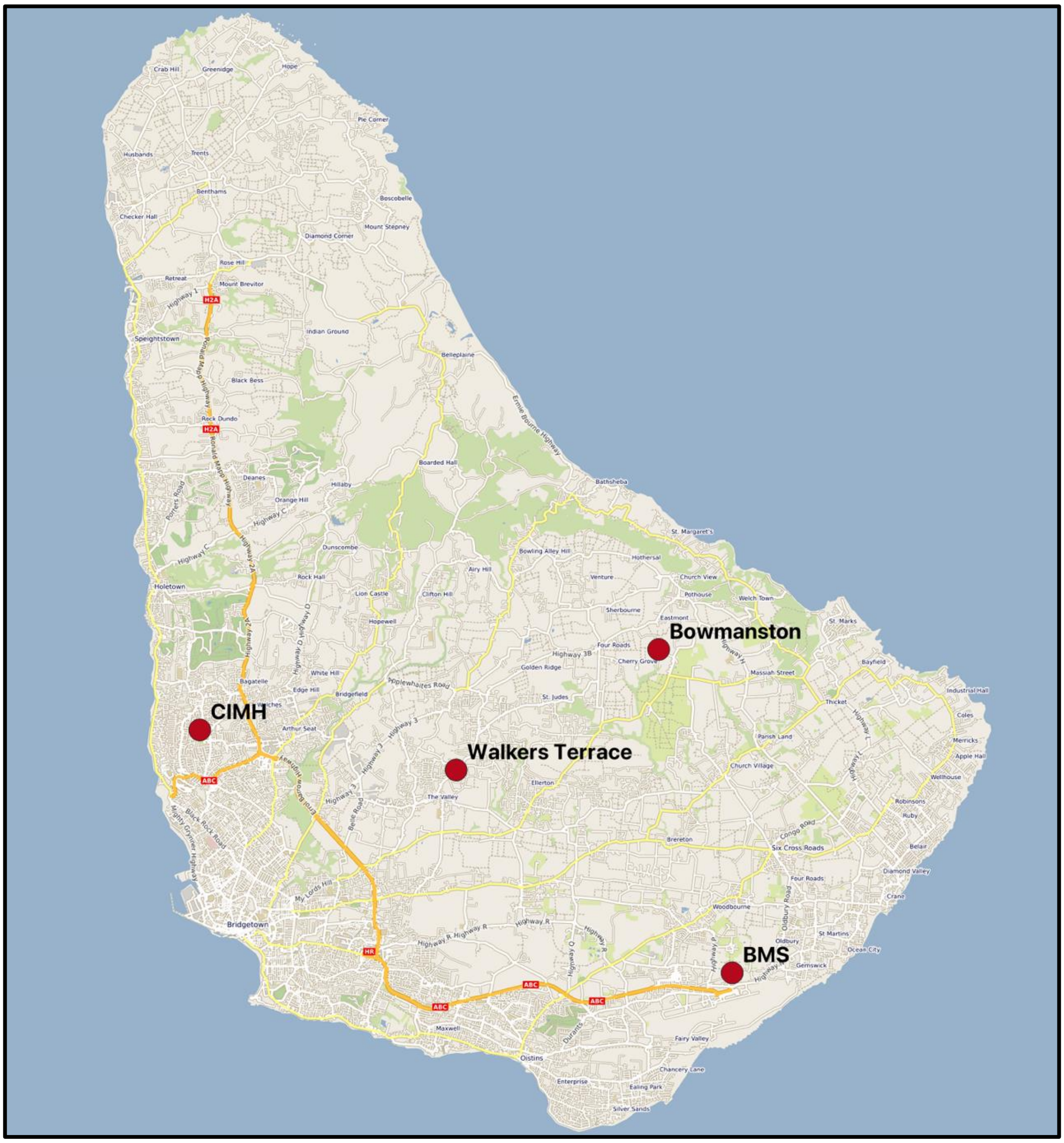

Figure 1: Map of Barbados with indication of the location of the weather stations used in the analyses in this document. Source of the base layer: OpenStreetMap contributors.

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[1] WMO, 2015. Report of the Seventeenth World Meteorological Congress. Resolution 16, recommendation 2. https://library.wmo.int/doc_num.php?explnum_id=3138#page=277.

The table below describes the characteristics of the data set for each weather station.

Table 1: Characteristics of weather observation stations used in the analyses.

Station	Location	Tmax	Tmin	Pr	Description
Barbados Meteorological Service (BMS)	13.086°N – 59.487°W	✓	✓	✓	Monthly averages over the period 1991 – 2020
Caribbean Institute for Meteorology and Hydrology (CIMH)	13.150°N – 59.625°W	✓	✓	✓	Daily observations over the period 1991 – 2020. These data have been used for a Climpact analysis.[2] A discussion of analysis results and several relevant figures are included in section 1.3.
Walkers Terrace	13.139°N – 59.559°W			✓	Monthly averages over the period 1991 – 2020
Bowmanston	13.170°N – 59.506°W			✓	Monthly averages over the period 1991 – 2020

1.2 General description of the current climate

Barbados has a subtropical maritime climate. As such, temperature ranges throughout the year are relatively small, with daily maximum temperatures ranging from 27°C to 32°C and daily minimum temperatures ranging from 21°C to 24°C during the period of 1991 – 2020 (Figure 2).

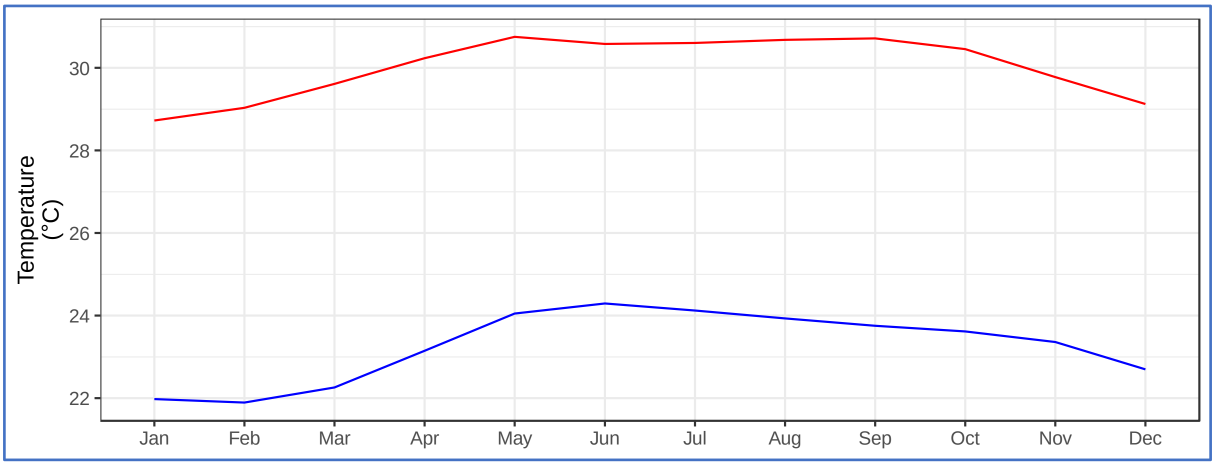

Figure 2: Average monthly minimum (blue) and maximum (red) temperatures during the period 1991 – 2020. Derived from daily observations from the weather station at CIMH.

Rainfall is concentrated in the August – November period, with monthly rainfall above 150mm, while other months are much drier. During the wet season, rainfall exceeds evapotranspiration, while during the dry season the situation is reversed (Figure 3). Barbados does not have any surface reservoirs to store excess rainfall during the wet season and the strong water deficit in the period January – May implies that irrigation is needed to support agricultural production.

[2] Climpact is an online tool developed by the University of New South Wales, Australia, and supported by the ARC Centre of Excellence on Climate Extremes, Australia, the WMO Commission for Meteorology, and the Green Climate Fund. https://climpact-sci.org

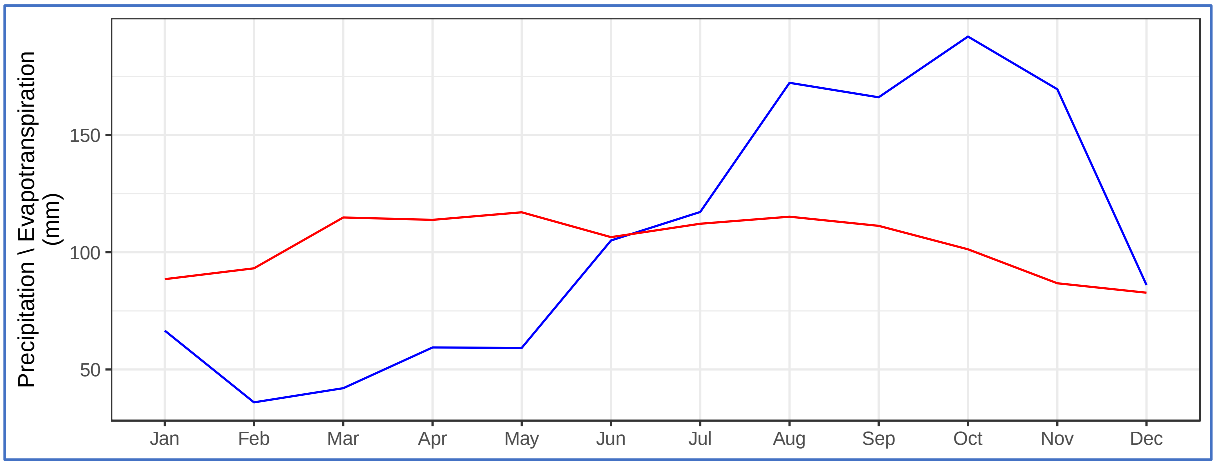

Figure 3: Average monthly precipitation (blue) and evapotranspiration (red) during the period 1991 – 2020. Derived from daily observations from the weather station at CIMH. Evapotranspiration was calculated using the Modified Hargreaves equation.

1.3 Climate trends

Barbados is noting significant changes in the local climate.

The average daily maximum temperature has remained relatively constant during the period 1991 – 2020, except for a marked increase during the hot season June – August (Table 2). The daily minimum temperature has been increasing more rapidly, by about 0.22°C per decade in February (the coolest month in the year for minimum temperature) over the period. As a result, the diurnal temperature range has been decreasing (Figure 4).

More importantly, however, is the increase in the extremes. In the first half of the current climatological normal, 1991 – 2006, there has been only a single day where the daily maximum temperature exceeded 33°C, 25 July 1998 with a maximum temperature of 33.5°C. During the second half of the climatological normal, 2007 – 2020, there have 26 such days with extreme heat, with the record of 38.0°C set on 29 July 2015 (Figure 5). This trend is also clear from the increase in heatwave events as shown in Figure 6.

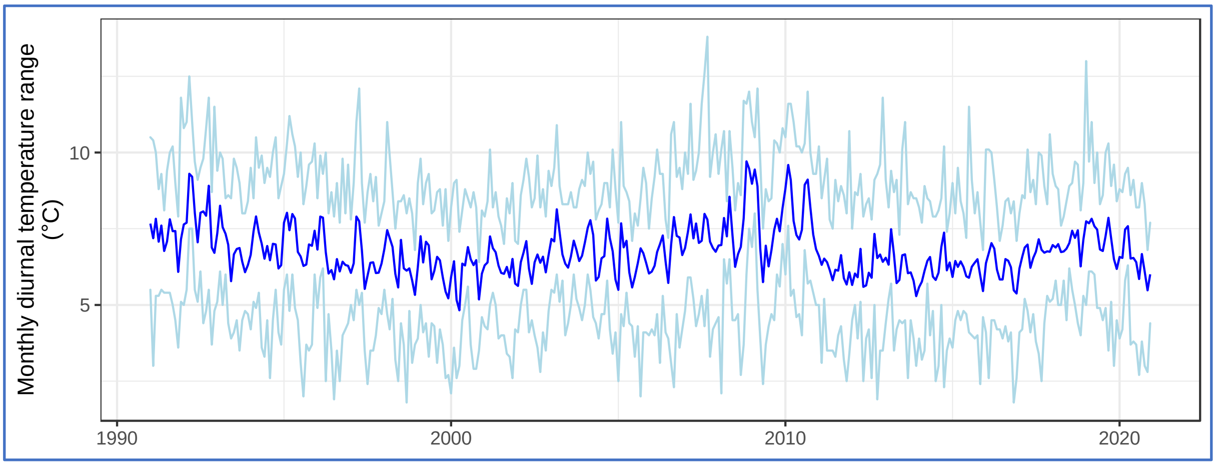

Figure 4: Monthly diurnal temperature range with lowest and highest daily values during the period 1991 – 2020. The monthly average corresponds to the Climpact 'DTR' indicator. Derived from daily observations at CIMH.

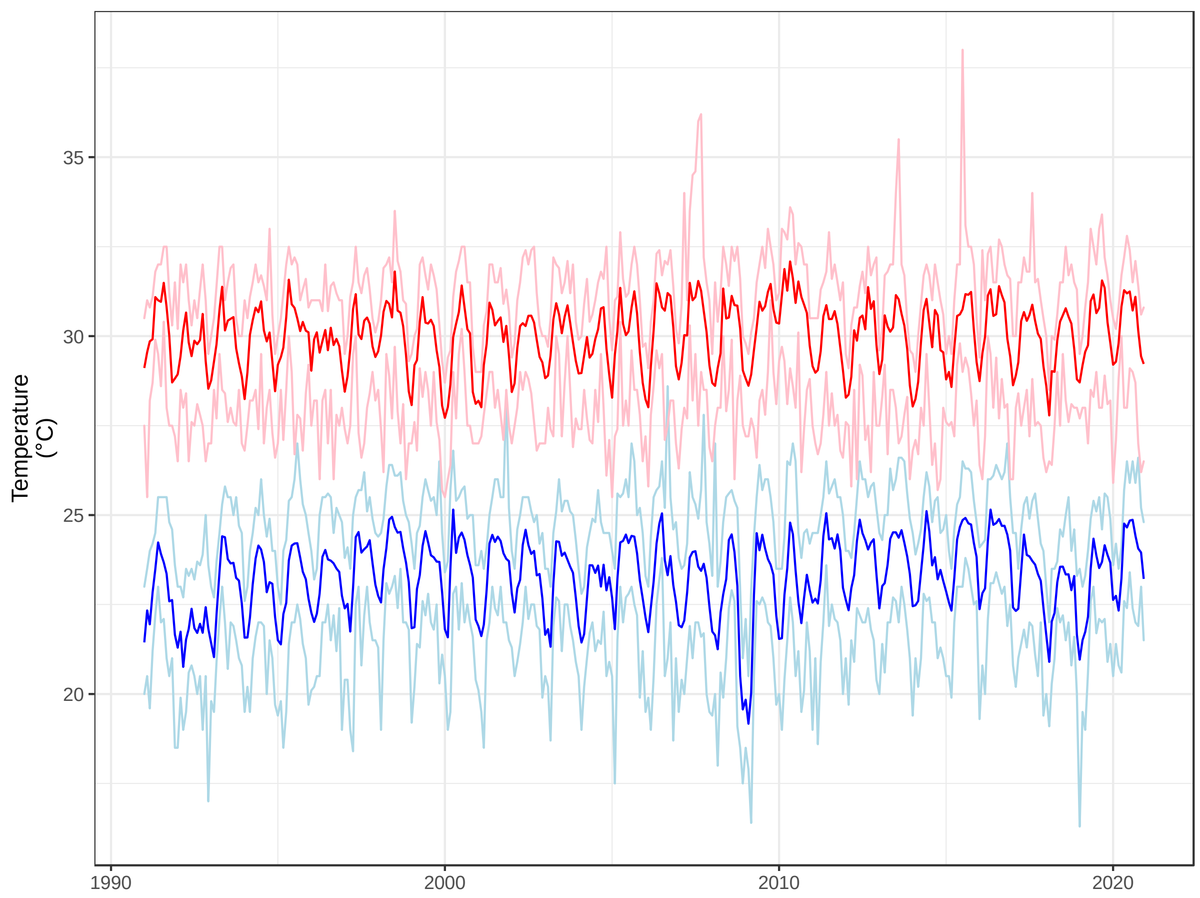

Figure 5: Average monthly minimum (blue) and maximum (red) temperatures with lowest and highest daily values for the month during the period 1991 – 2020. The lowest and highest daily maximum temperature per month (pink lines) correspond to the Climpact 'TXn' and 'TXx' indicators, respectively, the lowest and highest daily minimum temperature per month (light blue lines) to the 'TNn' and 'TNx' indicators, respectively. Daily observations from the weather station at CIMH.

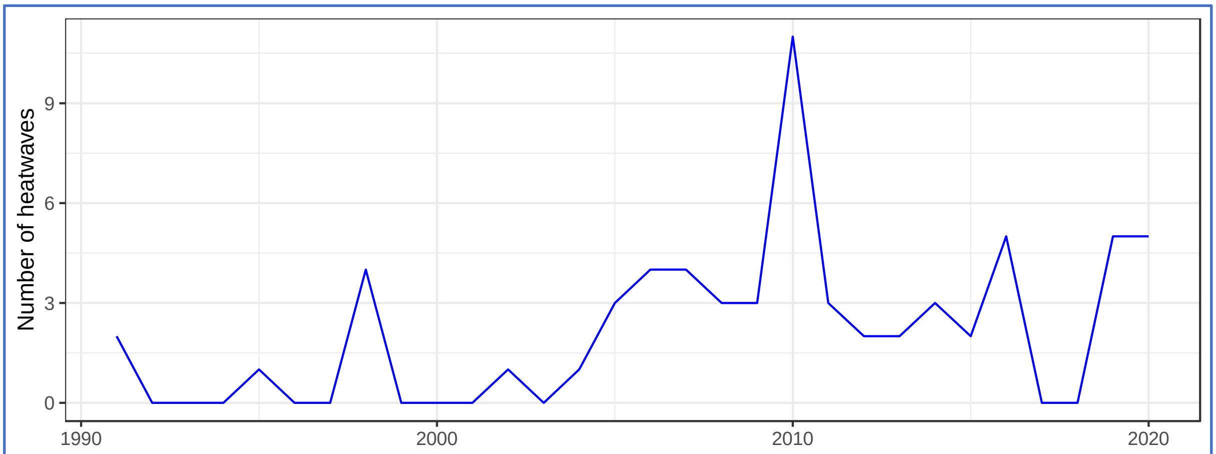

Figure 6: Number of heatwave events per year, at the CIMH station. A heatwave follows the definition of Climpact (indicator 'HWF-Tx90').

There has not been a pronounced change in the monthly precipitation over the current climatological normal, although there is a weak statistical signal of an increase in the incidence of days with heavy rainfall (>100mm per day) during the hurricane season, with 7 out of 10 occurrences happening during the second half of the climatological normal period, 2007 – 2020 (Figure 7). Simultaneously, the incidence of dry periods is increasing, with the two most severe dry periods (SPI < -2) during the climatological normal occurring in 2017 and 2019 – 2020 (Figure 8).

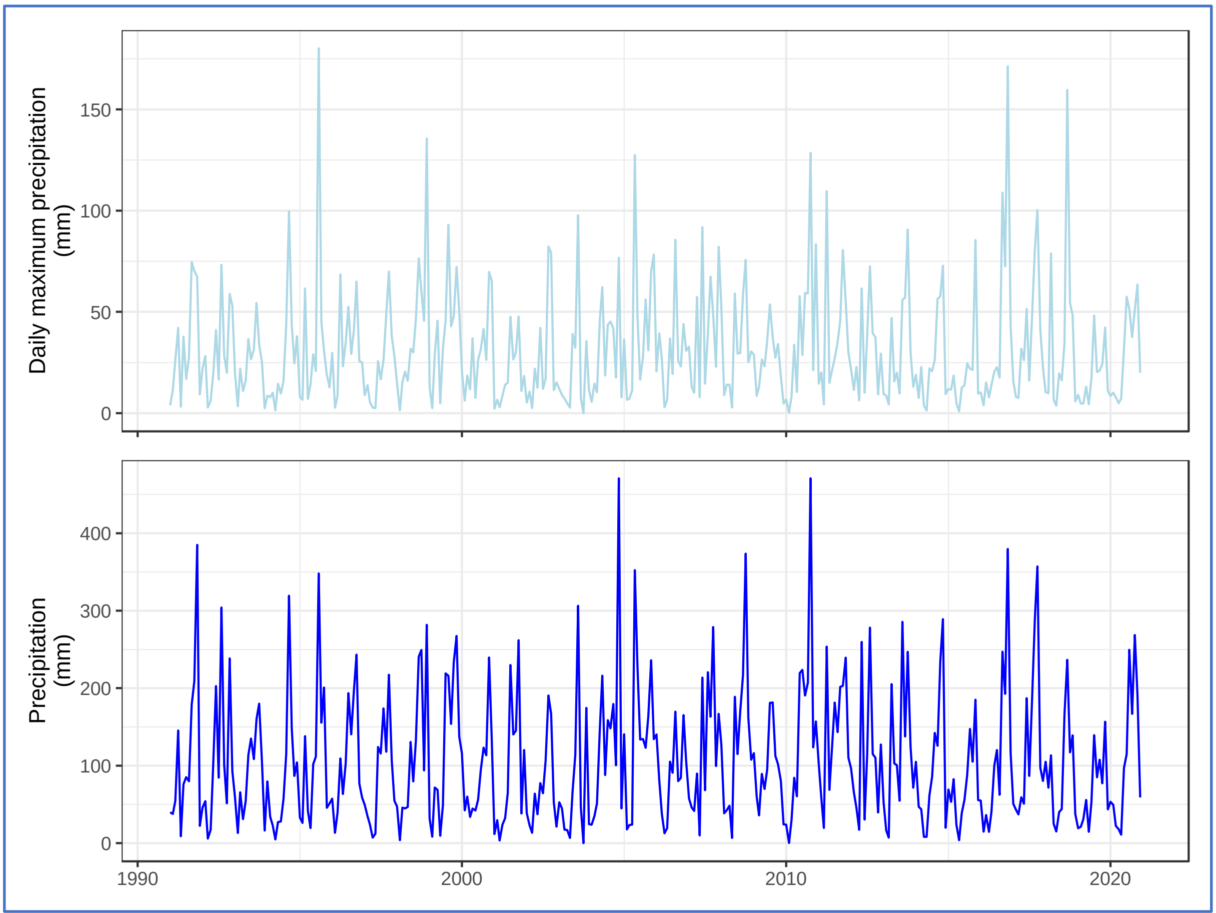

Figure 7: Daily maximum precipitation per month (top panel) and monthly precipitation (bottom panel) during the period 1991 – 2020. Derived from daily observations from the weather station at CIMH.

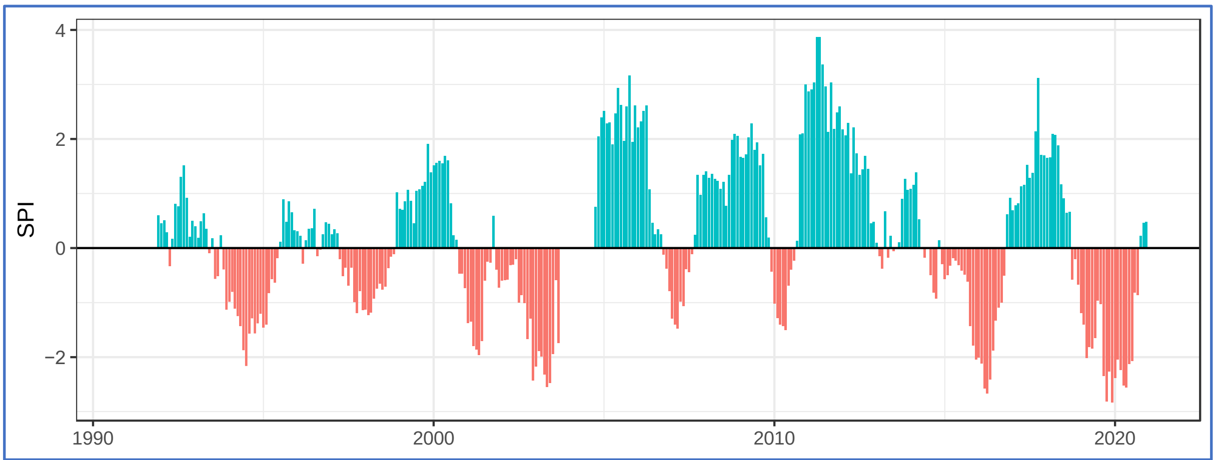

Figure 8: Standardised Precipitation Index values (12-month period) for the period 1991 – 2020. Derived from monthly averaged daily observations of precipitation from the weather station at CIMH.

Overall, it can be concluded that the average changes in temperature and precipitation are not very large, except for the increase in the daily minimum temperature, but that the extremes in both maximum daily temperature and precipitation are increasing rather more substantially. The Climpact analysis of the CIMH data reveals these trends in a statistically robust manner. The most significant indicators are presented in Table 2.

Table 2: Most significant trends in temperature and precipitation at the CIMH observation station, from Climpact analysis.

Parameter	Indicator	Season	Sen's slope	Significance
Monthly maximum temperature	TXx	DJF MAM JJA SON	0.017424 0. 0.043478 0.008333	Highest maximum daily temperatures are increasing at a rate of +0.29°C per decade, particularly during the hot season (+0.43°C per decade). Lowest maximum daily temperatures are virtually unchanged.
	TXn	DJF MAM JJA SON	0. -0.005263 0.00625 0.008696	
Monthly minimum temperature	TNx	DJF MAM JJA SON	0.02367 0.008696 0.013043 0.024	Minimum daily temperatures are increasing rapidly at an average rate of +0.19°C per decade.
	TNn	DJF MAM JJA SON	0.021825 0.014286 0.025 0.026316	
Diurnal temperature range	DTR	DJF MAM JJA SON	-0.027605 -0.017921 -0.001565 0.003683	Given that the minimum temperature is increasing faster than the maximum temperature, the diurnal range is decreasing by about -0.05°C per decade.
Precipitation	R10mm R20mm		-0.078461 0.	There is no significant change in the number of small to medium precipitation events. From analysis of the daily observations, the number of extreme precipitation events (>100mm per day) is increasing (but Climpact does not calculate this value).
	Rx1day Rx3day Rx5day		0.248077 0.020833 0.410444	The total precipitation over consecutive days increasing, especially so during the SON season (Sen's slope of 0.81, 0.68 and 0.92, respectively).

2 Climate change forecasts

To assess climate change in Barbados in the period out to 2050, approximately coinciding with the expected lifetime of the planned investments in wastewater treatment, the current climate is compared to forecasts of precipitation.

For the forecasts, use is made of a suite of CMIP6 models. The following models have been used in this analysis:

- ACCESS-CM2
- ACCESS-ESM1-5
- AWI-CM-1-1-MR
- BCC-CSM2-MR
- CMCC-CM2-SR5
- FGOALS-g3
- GFDL-ESM4
- INM-CM4-8
- INM-CM5-0
- IPSL-CM6A-LR
- MIROC6
- MPI-ESM1-2-HR
- MPI-ESM1-2-LR
- MRI-ESM2-0
- NESM3

These models are used with the SSP2-4.5 scenario of socio-economic development and a 2041 – 2060 epoch.[3] An ensemble was created of these models to get more robust trends from the analyses. In this section, all graphs and tables use the ensemble average of the constituent models; in the graphs the 95% confidence interval of values predicted by individual members of the ensemble is also indicated.

Data for the analysis was retrieved from the KNMI Climate Explorer[4]. Surface variables from the 15 individual models were taken and analysed using R software.

2.1 Temperature forecasts

Average annual temperature in the 2041 – 2060 epoch is forecast to rise substantially throughout the year compared to the current climatological normal (Figure 9 and Table 3).

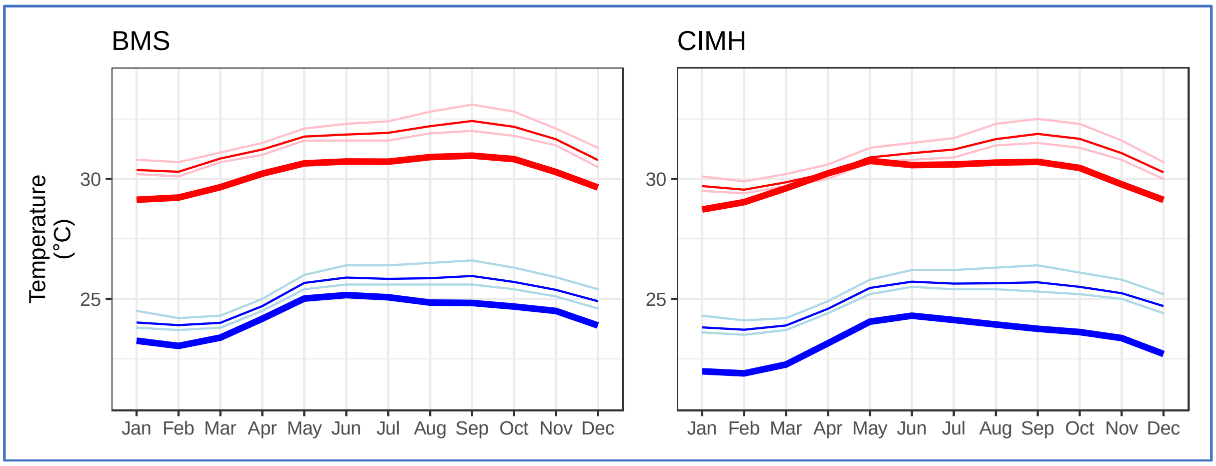

Figure 9: Predicted monthly average maximum (red) and minimum (blue) temperatures at two weather stations in the epoch 2041 – 2060, using an ensemble of CMIP6 models with the SSP2-4.5 scenario. The bold lines indicate the monthly averages during the climate normal period 1991 – 2020. The shaded regions indicate the 95% confidence interval of the values.

[3] Monthly predicted values for each model are averaged over the period 2041 – 2060 to arrive at a single estimate for the epoch.

[4] https://climexp.knmi.nl, in association with the WMO.

Table 3: Predicted increase in minimum and maximum temperatures (Δ°C) from an ensemble of CMIP6 models with the SSP2-4.5 scenario, relative to the climate normal period 1991 – 2020.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Tmax	1.11	0.80	0.72	0.51	0.63	0.81	0.91	1.13	1.30	1.28	1.33	1.15	0.97
Tmin	1.30	1.34	1.12	0.98	1.03	1.07	1.14	1.37	1.53	1.45	1.38	1.51	1.27

The faster increase in the minimum temperature compared to the maximum temperature was already observed in the trends over the current climatological normal, as well as the more pronounced increase in the maximum temperature during the wet season (SON) compared to the rest of the year (Figure 4, Table 2). This trend of decreasing diurnal temperature range has been confirmed in the scientific literature.[5]

2.2 Precipitation forecasts

Precipitation is forecast to decrease by 237 mm annually, 18% compared to the average precipitation at the four observation stations during the climatological normal, with the most severe drop in the May – July season. While the 95% confidence interval suggests that there may be a seasonal increase in the precipitation, particularly in the January – April season, the overall trend is downwards (Figure 10, Table 4). This is coincident with the findings presented in the Technical Summary report of Working Group I for the Sixth Assessment Report of the IPCC (AR6).[6]

The rather severe decrease in the May – July season is especially concerning given that this is the end of the dry season, when water demand in agriculture is particularly high, and the onset of the wet season. Effectively, this means that the dry season (evapotranspiration > precipitation) is extended by two months. When observing the trend of the SPI from the current climatological normal to 2060, drought conditions (relative to current conditions) are set to increase throughout the year, particularly from the year 2044 onwards (Figure 11).

While the CMIP6 models do not reveal this, it may be expected that the incidence of extreme weather events with very high precipitation will increase.[7]

Table 4: Predicted change in precipitation (Δmm) for the epoch 2041 – 2060 from an ensemble of CMIP6 models with the SSP2-4.5 scenario, relative to the climate normal period 1991 – 2020.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pr	-8.9	-6.6	-5.7	-9.2	-22.7	-60.6	-47.4	-31.8	-15.8	-11.0	-25.9	-27.5	-237

[5] Wang, K., and G.D. Clow, 2020. "The Diurnal Temperature Range in CMIP6 Models: Climatology, Variability, and Evolution", J.Climate, DOI: 10.1175/JCLI-D-19-0897.1

[6] See, for instance, section *TS.4.3.2.7 Small Islands*, in the Technical Summary: a "*likely* decrease in rainfall during boreal summer in the Caribbean".

[7] The CMIP6 models have a temporal resolution of 1 month, meaning that separate extreme weather events, such as hurricanes that are prevalent in the Caribbean basin during the wet season, are not captured in the projections but rather averaged out over the month. In the IPCC AR6 WG I Technical Summary, section TS.4.3.2.7: "Small Islands will face fewer but more intense TCs [tropical cyclones]".

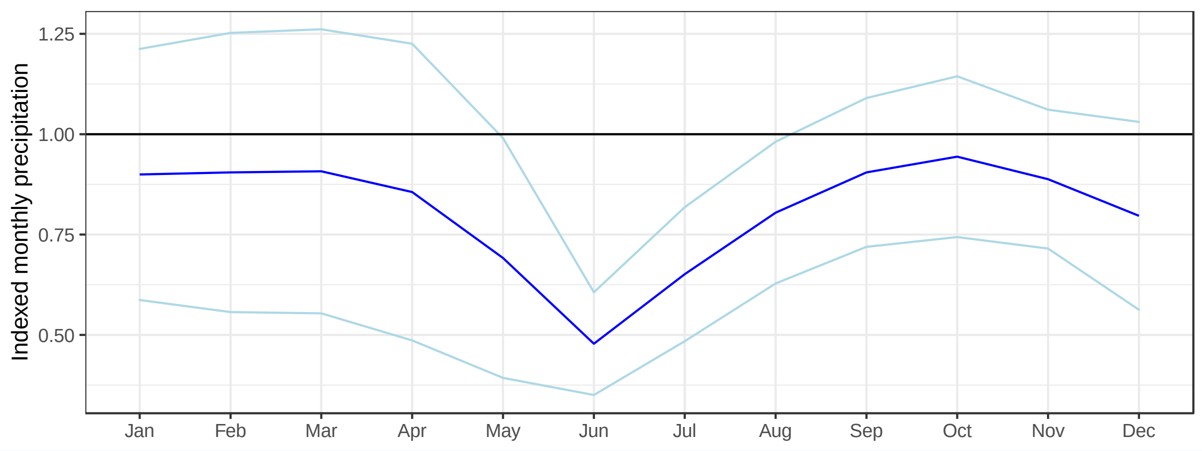

Figure 10: Predicted monthly average precipitation index for the epoch 2041 – 2060 relative to the climate normal period 1991 – 2020, using an ensemble of CMIP6 models with the SSP2-4.5 scenario. The solid blue line indicates the ensemble mean, with the 95% confidence interval of the range of values in the shaded region.

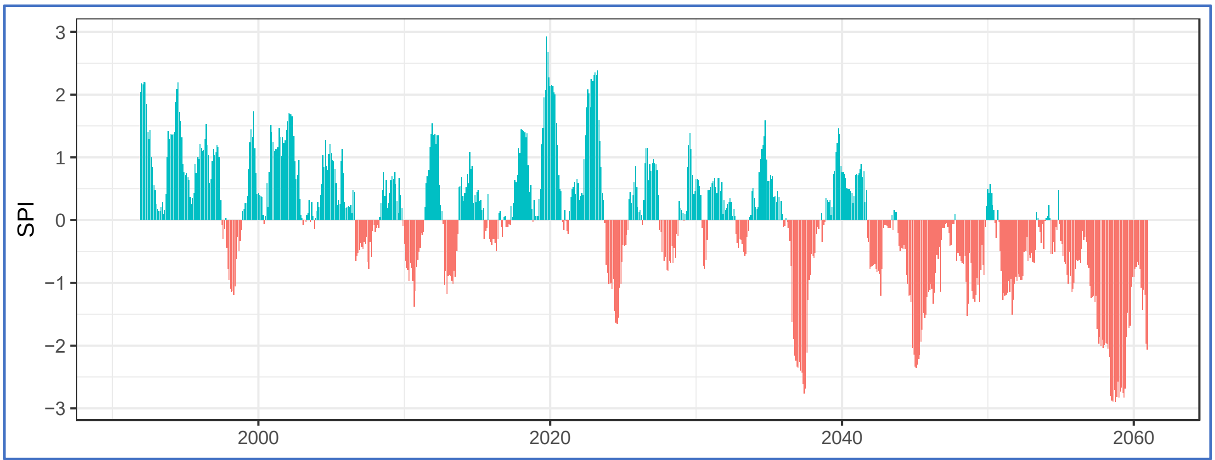

Figure 11: Standardised Precipitation Index (12-month period) from monthly precipitation as projected by an ensemble of CMIP6 models with the SSP2-4.5 scenario. The grey shaded area represents the current climatological normal. (Note that, as per CMIP6 procedures, the data in the period 1991 – 2013 is a hindcast; CMIP6 forecasts start in 2014.)