# Future Caribbean Climates in a World of Rising Temperatures: The 1.5 vs 2.0 Dilemma

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## ABSTRACT

A 10-member ensemble from phase 5 of the Coupled Model Intercomparison Project (CMIP5) is used to analyze the Caribbean's future climate when mean global surface air temperatures are 1.5°, 2.0°, and 2.5°C above preindustrial (1861–1900) values. The global warming targets are attained by the 2030s, 2050s, and 2070s respectively for RCP4.5. The Caribbean on average exhibits smaller mean surface air temperature increases than the globe, although there are parts of the region that are always warmer than the global warming targets. In comparison to the present (using a 1971–2000 baseline), the Caribbean domain is 0.5° to 1.5°C warmer at the 1.5°C target, 5%–10% wetter except for the northeast and southeast Caribbean, which are drier, and experiences increases in annual warm spells of more than 100 days. At the 2.0°C target, there is additional warming by 0.2°–1.0°C, a further extension of warm spells by up to 70 days, a shift to a predominantly drier region (5%–15% less than present day), and a greater occurrence of droughts. The climate patterns at 2.5°C indicate an intensification of the changes seen at 2.0°C. The shift in the rainfall pattern between 1.5°C (wet) and 2.0°C (dry) for parts of the domain has implications for regional adaptation pursuits. The results provide some justification for the lobby by the Caribbean Community and Small Island Developing States to limit global warming to 1.5°C above preindustrial levels, as embodied in the slogan "1.5 to Stay Alive."

## 1. Introduction

Climate change poses a significant threat to the nations of the Caribbean. The Caribbean region (Fig. 1) consists of mostly small islands and other developing states and is classified as being among the most vulnerable regions of the world to climate change (Nurse et al. 2014). The vulnerability arises from an extreme sensitivity to climate due to (among other things) 1) the small sizes and/or complex topographies of the constituent

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territories, which limit where population centers and economic zones may be located; 2) a near-exclusive reliance on climate sensitive economic activities such as agriculture and tourism; 3) an overwhelming dependence on rainfall for water; 4) high public debt; and 5) limited hazard forecasting capabilities (Lewsey et al. 2004; Pulwarty et al. 2010; Cashman et al. 2010; Simpson et al. 2010; M. Taylor et al. 2012; Taylor et al. 2016).

The region has already experienced changes in its climate. There has been a mean warming in both air (Peterson et al. 2002; Stephenson et al. 2014; Jones et al. 2016) and ocean surface temperatures (Antuña-Marrero et al. 2016; Glenn et al. 2015) in excess of 0.5°C over the latter half of the last century to the present; increases in average daytime (nighttime) temperatures of approximately 0.19°C decade$^{-1}$ (0.28°C decade$^{-1}$) since 1960 (Stephenson et al. 2014); small but statistically significant increases in annual total precipitation, daily intensity of rainfall, maximum number of consecutive dry days, and heavy rainfall events particularly during the period 1986–2010 (Stephenson et al. 2014); an increase in the occurrence of extreme events including droughts and more intense hurricanes (IPCC 2012); and rising sea levels at a rate of 1.7–1.9 mm yr$^{-1}$ between 1950 and 2009 (Palanisamy et al. 2012; Torres and Tsimplis 2013). Impact studies provide growing evidence of adverse impacts on key socioeconomic activities and sectors that determine quality of life in the region, including water availability, agriculture and food production, health, natural resources and biodiversity, and tourism [see reviews in Rhiney (2015), Taylor (2015), and Taylor et al. (2016)]. The cumulative impact has been to hinder the attainment of regional development goals and slow the growth of Caribbean economies (Charvériat 2000; Haites et al. 2002; CCCCC 2009).

Studies premised on the Special Report on Emission Scenarios (SRES; Nakićenović and Swart 2000) and using the generation of models from phase 3 of the Coupled Model Intercomparison Project (CMIP3) suggest that the region's climate is likely to continue changing through the end of the current century. Under the higher-emissions SRES scenarios, the end-of-century projections exceed the magnitude and frequency of changes already seen in the recent past. For example, by the end of the century, the region is projected to be 1.0° to 3.5°C warmer (Karmalkar et al. 2013; Hall et al. 2013; Campbell et al. 2011), with 95% of all days and nights considered "hot" (i.e., exceeding the 90th percentile of current temperatures; McSweeney et al. 2010). Annual rainfall totals are projected to decrease by up to 30% with the most pronounced drying during the Caribbean wet season from May and October (Karmalkar et al. 2013; Campbell et al. 2011). Tropical cyclone related rainfall rates may increase by 20%–30% near the storm's center and 10% at radii of 200 km or larger (Emanuel 2007; Knutson et al. 2010; Bender et al. 2010) while maximum hurricane wind speeds are projected to increase by 2%–11%. Mean sea level rise is projected to be up to 1.4 m (Horton et al. 2008; Perrette et al. 2013).

It is against this background of present and future vulnerability to climate change that the Caribbean Community (CARICOM)—an economic grouping consisting of 15 member and 5 associate member states—and other small island developing states (SIDS) mooted the slogan "1.5 to Stay Alive." The threshold of 1.5°C, it is argued, represents the global mean end-of-century temperature change with respect to preindustrial times which must not be exceeded if Caribbean life is to remain "viable." The history behind the slogan and the contribution of the SIDS leading up to the 21st Conference of the Parties (COP21) to having 1.5°C recognized as a global warming threshold are chronicled by Benjamin and Thomas (2016).

The 1.5°C value is, then, a mean *global* temperature threshold on which *regional* viability is being premised. What the mean temperature of the Caribbean will be when the global target is attained is not clear. It is also not entirely clear the Caribbean's basis for using 1.5°C as a threshold but it likely arose from a combination of considerations including a factoring in of 1) the mean global surface air temperature change already observed over the last century (approximately 1°C) and the corresponding regional impacts already reported, 2) climate change projections for the Caribbean and other SIDS and the resulting future impacts on the most vulnerable in an already extremely vulnerable region [see, e.g., the Economic Commission for Latin American and the Caribbean (ECLAC) studies[1]], and 3) global tipping point arguments (IPCC 2014). To the best of our knowledge, there has, however, not been any research done to ascertain what a global warming target of 1.5°C will specifically mean for the Caribbean region.

The landmark agreement coming out of COP21 acknowledges the 1.5°C target as an "aspirational goal." The Paris Agreement pledges the 195 nation signatories to rally around a global effort to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels and [to pursue] efforts to limit the temperature increase to 1.5°C" (UNFCCC 2015, p. 2). The agreement intentionally or inadvertently posits 2.0°C as a "default" global target that might be tolerable should the 1.5°C goal be missed. There is growing

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[1] The Review of the Economics of Climate Change in the Caribbean (RECC) project assessed economic impact of climate change on critical sectors of Caribbean life using studies spread across a wide range of Caribbean nations. The studies can be accessed at http://www.caribbeanclimate.bz/2010-2011-review-of-the-economics-of-climate-change-recceclacc/.

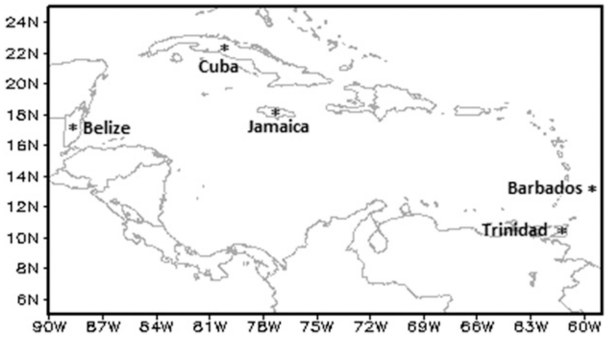

FIG. 1. Caribbean domain. Countries over which model data values are extracted are also indicated.

consensus, however, that a 2.0°C target will require 1) global commitments to achieving levels of greenhouse gas concentrations that do not yet seem possible under the cumulative reduction commitments presently being made by countries, and 2) widespread access to and use of mitigation technologies, some of which might not yet exist (IPCC 2014). The suggestion is that global end-of-century warming will likely exceed both the 1.5° and the 2.0°C targets without substantial effort and global coalescence around the mitigation cause (Meinhausen et al. 2015).

In this paper, future climate change profiles for the Caribbean region are developed for global warming targets of 1.5°, 2.0°, and 2.5°C. The primary question being investigated is whether there are differences between the climate of the Caribbean (temperature, rainfall, and climate extremes) for warming of 1.5° versus 2.0°C or higher above preindustrial levels to justify the region's call for the more stringent target. Section 2 of this paper outlines the approach taken and the data used in the investigation. Section 3 presents the results, while section 4 summarizes the major conclusions and discusses their significance.

## 2. Data and methodology

### *a. Data*

General circulation model (GCM) data from CMIP5 (K. Taylor et al. 2012), which are made available as a part of the IPCC Data Atlas, were accessed using the KNMI Climate Change Atlas web tool (https://climexp.knmi.nl/plot_atlas_form.py). Initially, near-surface temperature and rainfall data from 42 of 45 available GCMs with simulations spanning the period 1861 to 2100 are analyzed (Table 1). Where not specified in Table 1, the data used were from realization 1, initialization 1, and physics version 1 (r1i1p1) runs of the GCMs. The models had varying spatial resolutions and most simulated representative concentration pathways (RCPs) 2.6, 4.5, and 8.5. RCPs are defined by their total radiative forcing (cumulative measure of human emissions of greenhouse gases from all sources expressed in watts per square meter) pathway and level (i.e., 2.6, 4.5, 6.0, and 8.5 W m$^{-2}$) by 2100 (van Vuuren et al. 2011). Each RCP is considered

TABLE 1. CMIP5 models examined. Columns 3–6 indicate whether data were available for the model run using the respective RCP. Column 7 identifies models capturing the Caribbean bimodal precipitation pattern from Ryu and Hayhoe (2014). A capital bold X in column 7 indicates that the model is used in this study. (Expansions of acronyms are available online at http://www.ametsoc.org/PubsAcronymList.)

| | | RCP AR5 subset | | | | Bimodal precipitation |
|---|---|---|---|---|---|---|
| | CMIP5 models | 2.6 | 4.5 | 6.0 | 8.5 | |
| 1 | ACCESS1.0 | | X | | X | |
| 2 | ACCESS1.3 | | X | | X | |
| 3 | BCC-CSM1.1 | X | X | X | X | |
| 4 | BCC-CSM1.1-M | X | X | X | | |
| 5 | BNU-ESM | X | X | | X | |
| 6 | CanCM4 | | | | | x |
| 7 | CanESM2 | X | X | | X | |
| 8 | CCSM4 | X | X | X | X | |
| 9 | CESM1-BGC | | X | | X | |
| 10 | CESM1-CAM5 | X | X | X | X | **X** |
| 11 | CMCC-CM | | X | | X | |
| 12 | CMCC-CMS | | X | | X | |
| 13 | CNRM-CM5 | X | X | | X | **X** |
| 14 | CSIRO-Mk3.6.0 | X | X | X | X | **X** |
| 15 | EC-EARTH | X | X | | X | |
| 16 | FGOALS-g2 | X | X | | X | |
| 17 | FIO-ESM | X | X | X | X | |
| 18 | GFDL-CM3 | X | X | X | X | |
| 19 | GFDL-ESM2G | X | X | X | X | |
| 20 | GFDL-ESM2M | X | X | X | X | |
| 21 | GISS-E2-H | X | X | X | X | |
| 22 | GISS-E2-H, r1p2 | X | X | X | X | |
| 23 | GISS-E2-H, r1p3 | X | X | X | X | |
| 24 | GISS-E2-H-CC | | X | | | |
| 25 | GISS-E2-R | X | X | X | X | |
| 26 | GISS-E2-R, r1p2 | X | X | X | X | |
| 27 | GISS-E2-R, r1p3 | X | X | X | X | |
| 28 | GISS-E2-R-CC | | X | | | |
| 29 | HadCM3 | | | | | x |
| 30 | HadGEM2-AO | X | X | X | X | **X** |
| 31 | HadGEM2-CC | | X | | X | **X** |
| 32 | HadGEM2-ES, r2p1 | X | X | X | X | **X** |
| 33 | INM-CM4 | | X | | X | |
| 34 | IPSL-CM5A-LR | X | X | X | X | |
| 35 | IPSL-CM5A-MR | X | X | X | X | |
| 36 | IPSL-CM5B-LR | | X | | X | |
| 37 | MIROC4h | | | | | x |
| 38 | MIROC5 | X | X | X | X | **X** |
| 39 | MIROC-ESM | X | X | X | X | **X** |
| 40 | MIROC-ESM-CHEM | X | X | X | X | |
| 41 | MPI-ESM-LR | X | X | | X | **X** |
| 42 | MPI-ESM-MR | X | X | | X | **X** |
| 43 | MRI-CGCM3 | X | X | X | X | |
| 44 | NorESM1-M | X | X | X | X | |
| 45 | NorESM1-ME | X | X | X | X | |
| Total | | 32 | 42 | 25 | 39 | 13 |

as plausible and illustrative with no probabilities of occurrence attached to them. The set of GCMs analyzed was narrowed to 10 (see section 2b) from which surface air temperature and rainfall over the Caribbean and near-Caribbean region were extracted for the period 1861 to 2100.

Rainfall data from the Global Precipitation Climatology Project (GPCP) version 2.2 Combined Precipitation dataset (Adler et al. 2003) are used for comparison with model data. GPCP comprises monthly means of precipitation from observed and satellite measurements on a 2.5° × 2.5° global grid and covers the period January 1979 to January 2013.

### b. Methodology

A time sampling approach is used in this study. That is, the approximate future dates when the global mean surface air temperature attains increments of 1.5°, 2.0°, and 2.5°C above preindustrial times (hereafter $\Delta T_g1.5$, $\Delta T_g2.0$, $\Delta T_g2.5$) are determined from the GCM simulations, and the regional climate changes which occur at those dates are examined. James et al. (2017) note that a relative advantage of time sampling over other methodologies is that it facilitates a direct comparison of the climate signals and impacts between $\Delta T_g$ increments, even if the $\Delta T_g$ targets occur at differing times in the GCMs. A number of other studies to date have also used this approach to compare climate responses at 1.5°C versus 2.0°C for other regions of the world (see, e.g., Schleussner et al. 2016; Guo et al. 2016).

The analysis is undertaken for the 42 CMIP5 models running RCP4.5. The reasons for using RCP 4.5 include the following. First, most of the models run RCP4.5 and more data are therefore available for the analysis. Only RCP8.5 has comparable data availability; RCP6.0 is the least simulated scenario (see Table 1). Second, $\Delta T_g2.0$ is never achieved under RCP2.6 by 2100 (IPCC 2014), therefore precluding its use. Third, RCP4.5 represents a mitigation scenario (as opposed to RCP 8.5, which is seen as a business-as-usual scenario) and is therefore consistent with the argument mooted by the SIDS for global action, which forms the premise of this paper.

The methodology is divided into three tasks.

*Task 1—Determining $\Delta T_g$ years and model selection:* Annual surface air temperature anomalies time series from 1861–2100 are averaged for the world and the Caribbean for the 42 CMIP5 models that run RCP4.5 (Table 1). Anomalies are with respect to the preindustrial period 1861–1900. The Fifth Assessment Report of the IPCC similarly defines preindustrial as the period up to 1900 (IPCC 2014). For the Caribbean, averaging is done over 5.0°–25.0°N and 60°–90°W (Fig. 1), which is consistent with previous studies of the region (see, e.g., Giannini et al. 2000; Taylor et al. 2002). The time series plots are used to determine the years when each model and the multimodel mean, subject to a 10-yr running mean, first attains $\Delta T_g1.5$, $\Delta T_g2.0$, and $\Delta T_g2.5$ respectively with all subsequent years being higher. The use of a running mean instead of the annual mean is an attempt to minimize the impact of internal climate variability. The corresponding mean temperature change in the Caribbean with respect to preindustrial times is similarly determined for the three global warming targets. These results are presented in section 3a.

Ryu and Hayhoe (2014) identified 13 of the CMIP5 models that they suggest reasonably capture key features of the Caribbean's precipitation climatology (Table 1). Of the 13 models, 10 have data for RCP4.5 (indicated by a capital X in column 7 of Table 1). Figure 2 confirms that these 10 models reasonably capture the characteristic bimodal rainfall pattern of the Caribbean with peaks in June and September (Giannini et al. 2000; Spence et al. 2004; Taylor et al. 2002). The pattern is often used as a key metric for model studies of the region (see, e.g., Campbell et al. 2011; Centella-Artola et al. 2015). The models are therefore capturing the onset and demise of the rainy seasons and the midsummer drying. They have, however, a tendency to better simulate the first peak (the early rainfall season) than the second and to underestimate the GPCP monthly rainfall amounts. It is these 10 models that are used for further analysis. The impact of reducing the model ensemble on the timing of the attainment of the $\Delta T_g$ targets is examined in section 3a.

*Task 2—Characterizing the Caribbean's future climate:* Maps of mean change in annual precipitation and surface air temperature over the Caribbean are generated for each of the 10 GCMs for $\Delta T_g1.5$, $\Delta T_g2.0$, and $\Delta T_g2.5$. For each model, averaging is done over an 11-yr period (5 yr before and 5 yr after) centered on the years each model attains the global warming targets. Because the models have different spatial resolutions (see Table S1 in the online supplemental material), the monthly temperature and precipitation fields are first regridded to a common 1.4° latitude–longitude grid, which is the highest resolution grid among the 10 models. A multimodel ensemble (MME) is then calculated using equal weights. Results for the MME are presented with respect to a more recent baseline period (1971–2000) to facilitate interpretation of the results in the context of present-day climate, and for

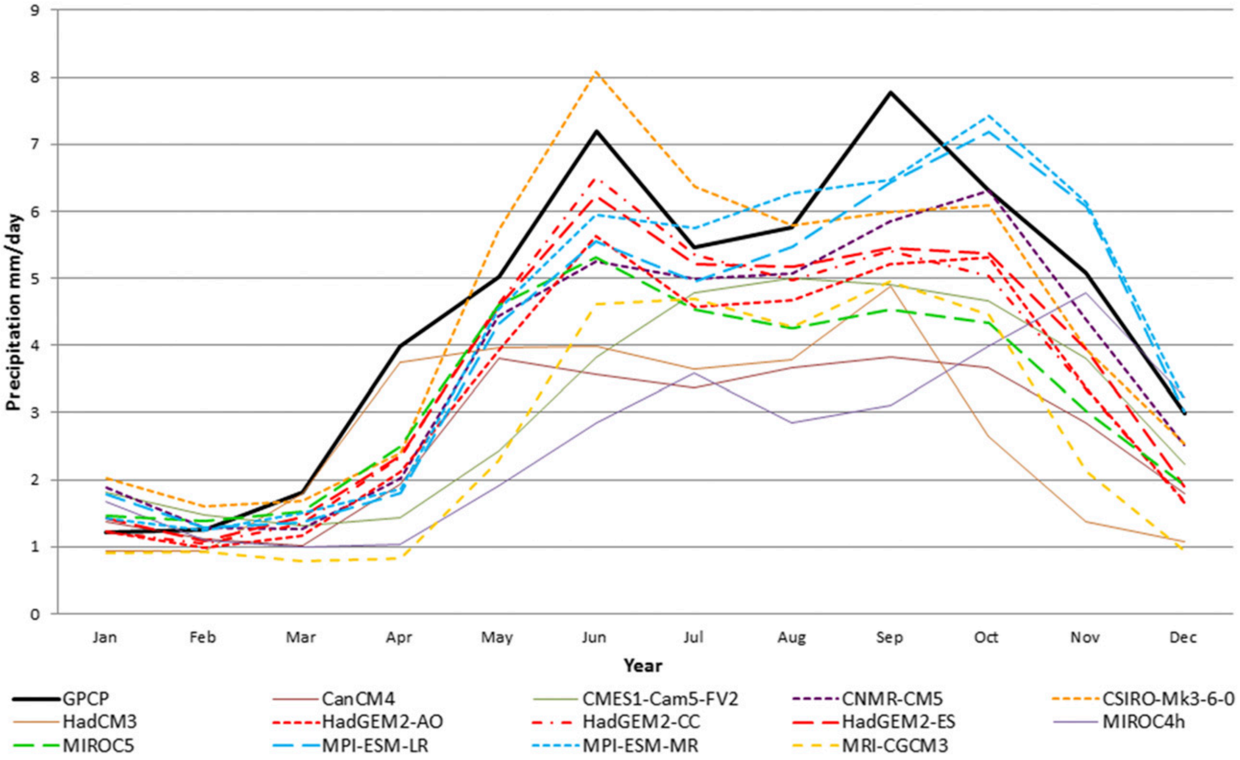

FIG. 2. Caribbean precipitation climatology (1980–2005) for 13 CMIP5 models identified by Ryu and Hayhoe (2014) (see Table 1) and from the GPCP dataset. Averaging is done over the Caribbean domain (Fig. 1).

the Caribbean domain previously defined. For each climate variable, results are shown for $\Delta T_g1.5$, $\Delta T_g2.0$, and $\Delta T_g2.5$ and for the difference between the 1.5° and 2.0°C states.

The average percentage change in precipitation is also determined for the grid boxes that fall over where landmasses exist in the domain. This means that for the smallest islands in the eastern Caribbean, values are still determined even if the GCM land mask did not indicate the presence of a land point. Results are presented for the Caribbean as a whole (land points) and for five countries: Cuba and Jamaica in the far north (13 and 3 grid boxes respectively), Trinidad in the southeast (2 grid boxes), Belize in the west (4 grid boxes), and Barbados (1 grid box) in the eastern Caribbean. These territories represent both mainland (Belize) and island states of various sizes (Fig. 1).

Results for the future climatic states of the Caribbean for $\Delta T_g1.5$, $\Delta T_g2.0$, and $\Delta T_g2.5$ are presented in section 3b.

*Task 3—Extremes and drought:* The processes of Task 2 are repeated for three variables—rx10mm, chdd, and wsdi—representing climate extremes relevant for the Caribbean. A description of each index is given in Table 2. Rx10mm is an indicator of heavy rainfall events, which often lead to landslides and flooding. More frequent occurrences of prolonged heat episodes are a growing challenge for the health (Méndez-Lázaro et al. 2015, 2016) and energy (Angeles et al. 2018) sectors of the Caribbean that is captured by wsdi (the warm spell duration index). Chdd (consecutive hot and dry days) recognizes that the combination of hot and dry also poses challenges for the water, agriculture, and health sectors in the region. In presenting the results for wsdi and chdd, the longest spells (in days) for each of the 11 yr centered on a future warming state are averaged and a similarly constructed average using the 1971–2000 baseline years is subtracted. The maps are therefore an indication of the mean extension (in days) of the extreme spells for $\Delta T_g1.5$, $\Delta T_g2.0$, and $\Delta T_g2.5$ over the present-day baseline. As before, The MME is determined and values extracted representing the entire domain (all points) and for the grid boxes over the five Caribbean territories previously noted. In producing the MME for the climate extremes variables, only 9 of the 10 models are used as daily values were not available for CSIRO-Mk3.6.0.

TABLE 2. Climate extremes indices.

| Index | Description | Method of calculation | Units |
|---|---|---|---|
| Rx10mm | Heavy precipitation index | Annual count of days when rainfall exceeds 10 mm. | Days |
| Wsdi | Warm spell duration index | Annual count of days with at least 6 consecutive days when TX > 90th percentile. The 90th percentile for each day is determined from the baseline years using a 5-day window centered on the day. | Days |
| Chdd | Consecutive hot and dry days | The longest number of consecutive hot and dry days in a year. Chdd is calculated by first deducing wsdi and then determining consecutive occurrences of rainfall below 1 mm during wsdi days. | Days |

Finally, recent prolonged droughts in the Caribbean (e.g., in 2009/10 and again in 2015) have significantly impacted (among other things) water availability, agricultural production, and the gross domestic product (GDP) within the region (Farrell et al. 2010). The Standard Precipitation Index (SPI) (McKee et al. 1993) is used as a measure of drought and SPI-12 (indicating drought occurrence over 12 months) is calculated using the average rainfall over the domain. For each model, the percentage of the domain under moderate ($-1.5 <$ SPI-12 $< -1$), severe ($-2 <$ SPI-12 $< -1.5$), and extreme drought (SPI-12 $< -2$) is determined for each year from 1890 through 2100, as well as the frequency of occurrence of each drought type during the 11-yr periods centered on $\Delta T_g1.5$, $\Delta T_g2.0$, and $\Delta T_g2.5$ target years. Results for the MME are given. SPI calculation is done using the CARiDRO (Caribbean Assessment Regional Drought) tool (http://caridro.caribbeanclimate.bz; Centella et al. 2017).

Results for the future Caribbean extremes are presented in section 3c.

## 3. Results

### a. Threshold dates and Caribbean mean temperatures

Figure 3a shows the smoothed anomaly time series for surface air temperature with respect to the preindustrial period for each of the 10 models (light blue lines), and the multimodel mean determined from the 42 (red line) and the selected 10 (dark blue line) CMIP5 models, respectively. Figure 3b is identical, but for the Caribbean averaged over the domain. All 10 models achieve $\Delta T_g1.5$ and $\Delta T_g2.0$ prior to the end of the century, but only 9 (MIROC5 being the exception) achieve $\Delta T_g2.5$ (Fig. 3a). The threshold attainment dates are 2028 for $\Delta T_g1.5$ (range of 2017 to 2038), 2046 for $\Delta T_g2.0$ (range of 2033 to 2062), and 2070 for $\Delta T_g2.5$ (range of 2047 to 2089) (Fig. 4a; see also Table S2 in online supplementary material file JCLI-D-17-0074s1). In comparison, the ensemble mean for the 42 CMIP5 models has somewhat later attainment dates of 2031 for $\Delta T_g1.5$ and 2055 for $\Delta T_g2.0$ and does not reach 2.5°C before the end of the century (Figs. 3a and 4a).

The 10-member ensemble mean suggests Caribbean temperatures of 1.2°C (range of 1.0°–1.4°C) for $\Delta T_g1.5$, 1.6°C (range of 1.4°–1.9°C) for $\Delta T_g2.0$, and 2.0°C (range of 1.7°–2.3°C) for $\Delta T_g2.5$, with respect to the preindustrial baseline (Fig. 4b and Table S2). For the three global warming targets, the equivalent temperature change for a mean Caribbean with respect to the preindustrial period is always less than the global mean state, by, respectively, 0.3°, 0.4°, and 0.5°C. Caribbean temperatures projected from the 42-member model mean are identical to those for the 10-member ensemble for both $\Delta T_g1.5$ and $\Delta T_g2.0$. Recall, however, that the 42-member ensemble never reaches $\Delta T_g2.5$.

It is also noted from Fig. 3b that the 10-member (42 member) ensemble indicates the following about present-day warming in the Caribbean: 1) a mean warming of 0.7°C (0.8°C) for the more recent decade 2001–10 with respect to the preindustrial period, 2) a mean warming of 0.3°C (0.4°C) for the baseline period 1970–2000 with respect to the preindustrial period, and 3) a warming rate of $0.015°\mathrm{C\,yr^{-1}}$ ($0.013°\mathrm{C\,yr^{-1}}$) based on a fitted linear trend over the baseline period 1971–2000, which is higher than for the preceding decades. These magnitudes and rates of warming are consistent with values previously reported for the Caribbean by Stephenson et al. (2014) and Jones et al. (2016) using observational datasets.

### b. Caribbean climate change profiles

Figure 5 shows the mean annual change in surface air temperature with respect to the 1971–2000 baseline for $\Delta T_g1.5$, $\Delta T_g2.0$, and $\Delta T_g2.5$ for the MME. In creating the MME maps, averaging is done over an 11-yr period centered on the years shown in Fig. 3a and given in Table S2 for each model and for each global warming

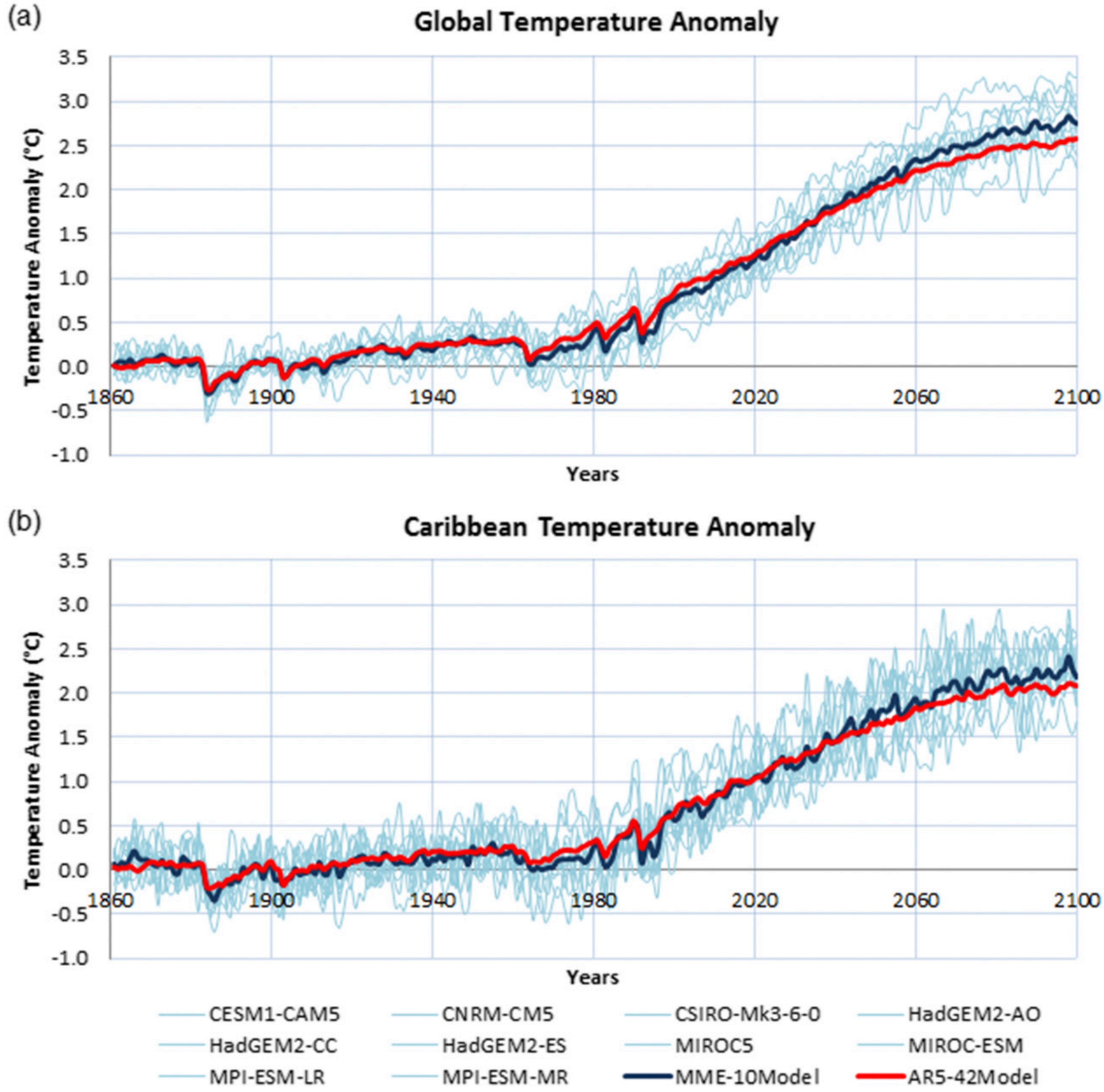

FIG. 3. Historical and future projections of annual near-surface air temperature anomalies with respect to a 1861–1900 (preindustrial) baseline for (a) the world and (b) the Caribbean for each of the 10 CMIP5 models (light blue) running RCP4.5. The ensemble mean for the 10 models (bold blue) and all 42 CMIP5 models (bold red) are also shown.

target. The fourth panel depicts $\Delta T_g 2.0$ minus $\Delta T_g 1.5$. For each panel, significant differences are tested using a difference of means. The changes were found to be significant at the 95% level everywhere in the domain for all panels in Fig. 5.

There is a pattern of greater warming across the Caribbean for successive global warming targets. For $\Delta T_g 1.5$, temperatures across the domain are 0.5°–1.5°C warmer than the present-day baseline (1971–2000). For $\Delta T_g 2.0$ and $\Delta T_g 2.5$, the warming ranges are 1.0°–2.5°C and 1.5°–3.0°C, respectively. The largest warming occurs over the larger landmasses (which would also be captured as land by the GCMs), including Central America, northern South America, and the Greater Antilles in the north Caribbean. Over parts of Central America and northern South America, the magnitude of the anomaly maxima indicates that there are regions in the domain that are warmer than the global mean state (i.e., when warming from preindustrial to present is factored in). Using $\Delta T_g 2.0$ minus $\Delta T_g 1.5$ confirms that at the higher global

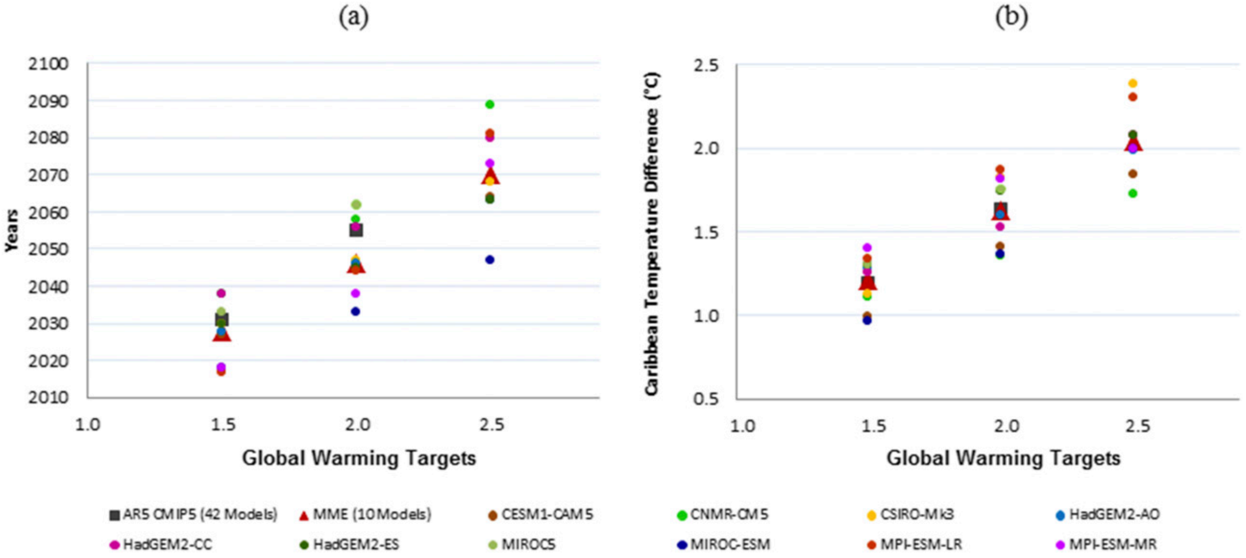

FIG. 4. (a) Years projected by the 10 models for the three global warming targets (1.5°, 2.0°, and 2.5°C). (b) Mean annual Caribbean temperature anomalies (°C) with respect to the preindustrial baseline projected by the 10 models for the three global warming targets. Values for the ensemble mean for the 10 models (red triangles) and the 42 CMIP5 models (black boxes) are also shown in each plot.

warming target there is statistically significant further warming ranging from 0.2° to 1.0°C across the basin. The largest additional warming occurs over northern South America (near the Caribbean coast of the Columbia–Venezuela border) and over Central America (Guatemala, Honduras, and Nicaragua). Using $\Delta T_g2.5$ minus $\Delta T_g2.0$ (not shown) also indicates additional warming over the entire domain for a further 0.5°C global warming increment, but with smaller magnitude change over the Caribbean Sea (~0.3°C) and along the Caribbean coastline of South America (~0.2°C). In the latter instance, maximum change occurs over Guatemala in Central America and over Venezuela near the domain's southern border.

Figure 6 is similar to Fig. 5, but for precipitation. Statistically significant changes at the 95% level are hatched. A general pattern of a progressively drying Caribbean emerges for the two higher global warming states, which is a reversal of the general pattern seen for $\Delta T_g1.5$. At 1.5°C, there are small changes (−5% to +5%) with respect to the present-day baseline over most of the basin and an overall tendency to be wetter. The dominant feature is a wet maximum (+10%–25%) in the southwestern Caribbean Sea in the vicinity of the Caribbean low-level jet (CLLJ), which extends across Central America (Nicaragua to Panama) and into the eastern tropical Pacific. Smaller wet maxima also occur between Jamaica and Haiti and in the far northeast corner of the domain. Dry regions, however, occur over the Bahamas and central Cuba (not statistically significant), in the northeast of the island chain (eastern Puerto Rico to Dominica), and in the south (Aruba, Bonaire, and Curacao) and southeast (in the vicinity of Trinidad and southward).

In comparison to $\Delta T_g1.5$, the domain is predominantly drier for $\Delta T_g2.0$. The drying originates in the southeastern quadrant and spreads north and westward so that it covers much of the eastern half of the Caribbean Sea, including Aruba, Bonaire, and Curacao (the ABC islands), the Caribbean coast of Venezuela, and the entire island chain from Puerto Rico to Trinidad. The largest magnitude drying (15%–20%) occurs over Trinidad and the nearby Caribbean coast of Venezuela. Central America (except Costa Rica and Panama) (−10%) and the Greater Antilles islands (−5%) also exhibit moderate drying and the wet maximum previously evident in the southwestern Caribbean Sea for $\Delta T_g1.5$ is diminished in extent and magnitude. There is, however, an expansion of the wet anomaly in the northeast of the domain. For $\Delta T_g2.5$, the dry anomaly emanating from the southeastern Caribbean expands farther westward and northward, and there is an intensification of the drying over the southern Caribbean Sea, the ABC islands, the Caribbean coast of Venezuela, and along the Venezuela–Guyana border. The wet maximum in the southwestern Caribbean Sea is even further diminished while that over the northeast of the domain is expanded to include the lower Bahamas and Turks and Caicos Islands. The wet anomaly over the eastern Pacific is also expanded northward.

The difference map ($\Delta T_g2.0 - \Delta T_g1.5$) emphasizes a regional drier state at 2.0°C versus 1.5°C. The entire

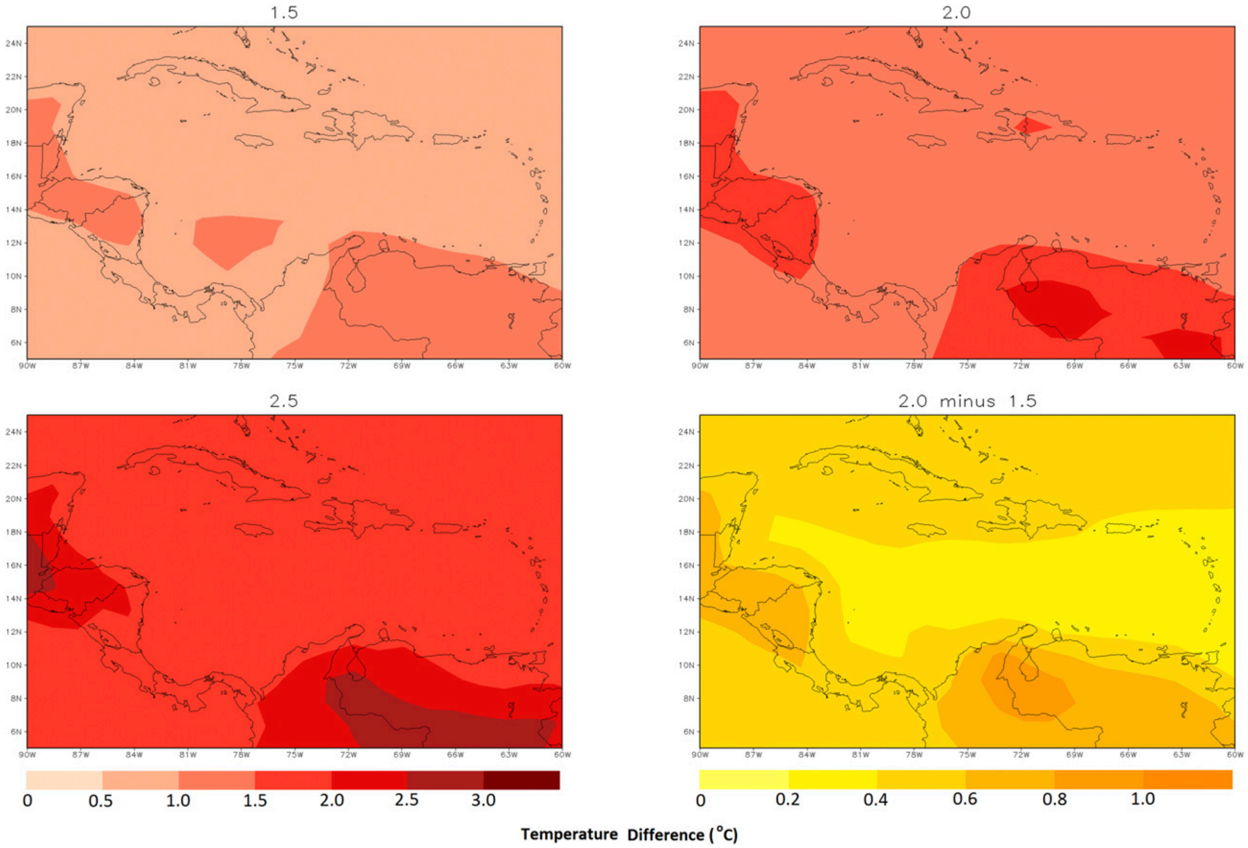

FIG. 5. Spatial distribution of surface air temperature (°C) anomalies relative to a 1971–2000 baseline projected by the MME for the 1.5°, 2.0°, and 2.5°C global warming targets. The bottom right panel shows difference between the 2.0° and 1.5°C maps. Changes were found to be significant everywhere at the 95% level.

domain between 10° and 20°N, encompassing Central America, the Caribbean coast of South America, and the entire island chain excepting the Bahamas in the far north, is between 5% and 20% drier. The area of largest magnitude change stretches northwestward from the southeastern Caribbean and into the Caribbean Sea south of Hispaniola. A similar magnitude of drying is also found over portions of Central America within the latitude band noted previously. Differences between $\Delta T_g 2.5$ and $\Delta T_g 2.0$ (not shown) are largely restricted to the central Caribbean basin (drier) and over Central America and the eastern Pacific below 14°N (wetter).

Figure 7 depicts the average changes in precipitation for the three global warming targets over the entire domain (grid boxes situated over where land occurs in the domain) and for grid boxes over Barbados, Belize, Cuba, Jamaica, and Trinidad. Mean annual changes are shown as well as changes for the entire wet season spanning May through November (MJJASON), the main Caribbean early and late wet seasons [May–July (MJJ) and September–November (SON) respectively), the midsummer drought period [July–August (JA)], and the primary dry season from December through February (DJF). The following things are noted:

- There is less annual rainfall at higher global warming targets. The data indicate a change in sign from mean positive to negative anomalies (Barbados, Belize, and Jamaica), an intensification of already dry conditions (Trinidad), or a near-elimination of a positive anomaly (the Caribbean domain). Cuba shows no net change as increasing deficits in the early wet season (MJJ) at higher global warming targets are offset by increasing gains in the late wet season (SON).
- Changes in the early wet season (MJJ) and the midsummer drought period (JA) are always negative for $\Delta T_g 2.0$, and $\Delta T_g 2.5$ for all countries and for the entire domain.
- During the late wet season (SON), the northernmost countries (Jamaica and Cuba) experience positive anomalies ranging from 7% to 11% for $\Delta T_g 2.0$ and $\Delta T_g 2.5$, while the southernmost countries experience

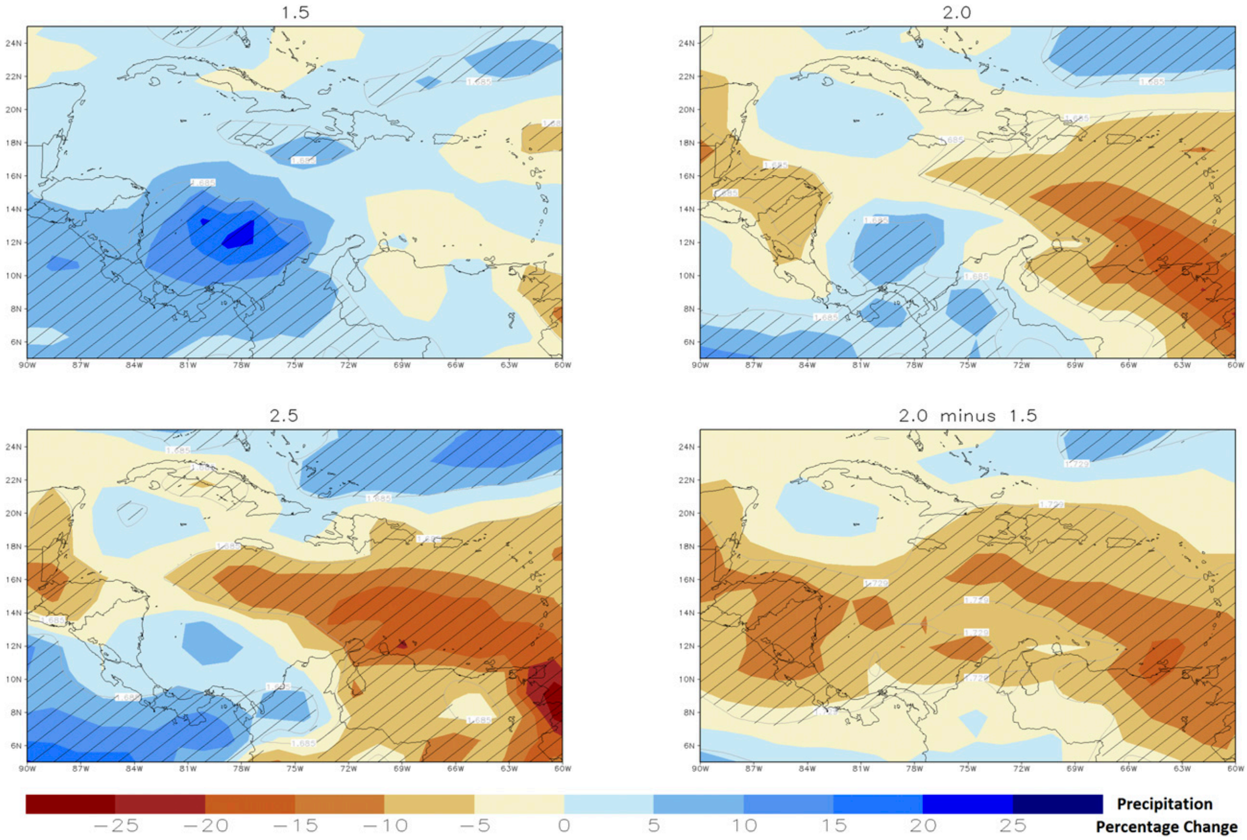

FIG. 6. As in Fig. 5, but for mean annual percentage change in rainfall. Significant differences at the 95% level are hatched.

negative anomalies (−5% to −7% for Barbados and −14% to −15% for Trinidad).

- The grid boxes over Barbados, Trinidad, and Belize show the largest magnitude changes during the wet season (MJJASON) for the three future states. This is consistent with Fig. 5, which shows that Central America and the eastern Caribbean see the largest changes in rainfall.
- The dry season (DJF) dries at higher global warming targets for the grid boxes over Belize, Barbados, and Trinidad (i.e., Central America and the southern Caribbean). For this season, largest magnitude drying occurs over Trinidad (−15%, −22%, and −35% for $\Delta T_g1.5$, $\Delta T_g2.0$, and $\Delta T_g2.5$, respectively). In the northern countries (Jamaica and Cuba), the magnitude of change is small (0%–4%) with no obvious pattern with respect to $\Delta T_g$ increments. Values averaged over the domain are similarly small but reflect larger dry anomalies for higher $\Delta T_g$.
- Changes between $\Delta T_g2.5$ and $\Delta T_g2.0$ are generally always smaller than for $\Delta T_g2.0$ and $\Delta T_g1.5$ for both annual rainfall amounts (except for Cuba) and for the wet season (MJJASON) (except for Cuba and Jamaica).

### *c. Caribbean climate extremes*

Figures 8, 9, and 10 follow the same structure as Figs. 5 and 6 but are for wsdi, rx10mm, and chdd, respectively. Statistically significant differences from the baseline at the 95% level are indicated. Significance for these maps is evaluated using the nonparametric Wilcoxon signed-rank test, given that the extreme indices are not normally distributed (Alexander and Arblaster 2009; Kharin et al. 2013). Recall also that for wsdi and chdd the maps show the mean extension (in days) for each future state of the longest mean occurrence of the extreme condition in the baseline years. An inset on each diagram provides the average values for the grid boxes over Cuba, Jamaica, Belize, Barbados, Trinidad, and the entire domain.

The wsdi value (Fig. 8) shows large magnitude increases over the entire domain relative to the present-day baseline, for all global warming targets. As with mean temperature (Fig. 5), the changes are statistically significant everywhere and intensifying for successively higher global warming targets. Irrespective of $\Delta T_g$ increment, the largest magnitude increases occur over the Caribbean Sea south of 20°N, with a maximum (>300 days) occurring just south of Jamaica for $\Delta T$ 2.0 and $\Delta T_g2.5$. Inset

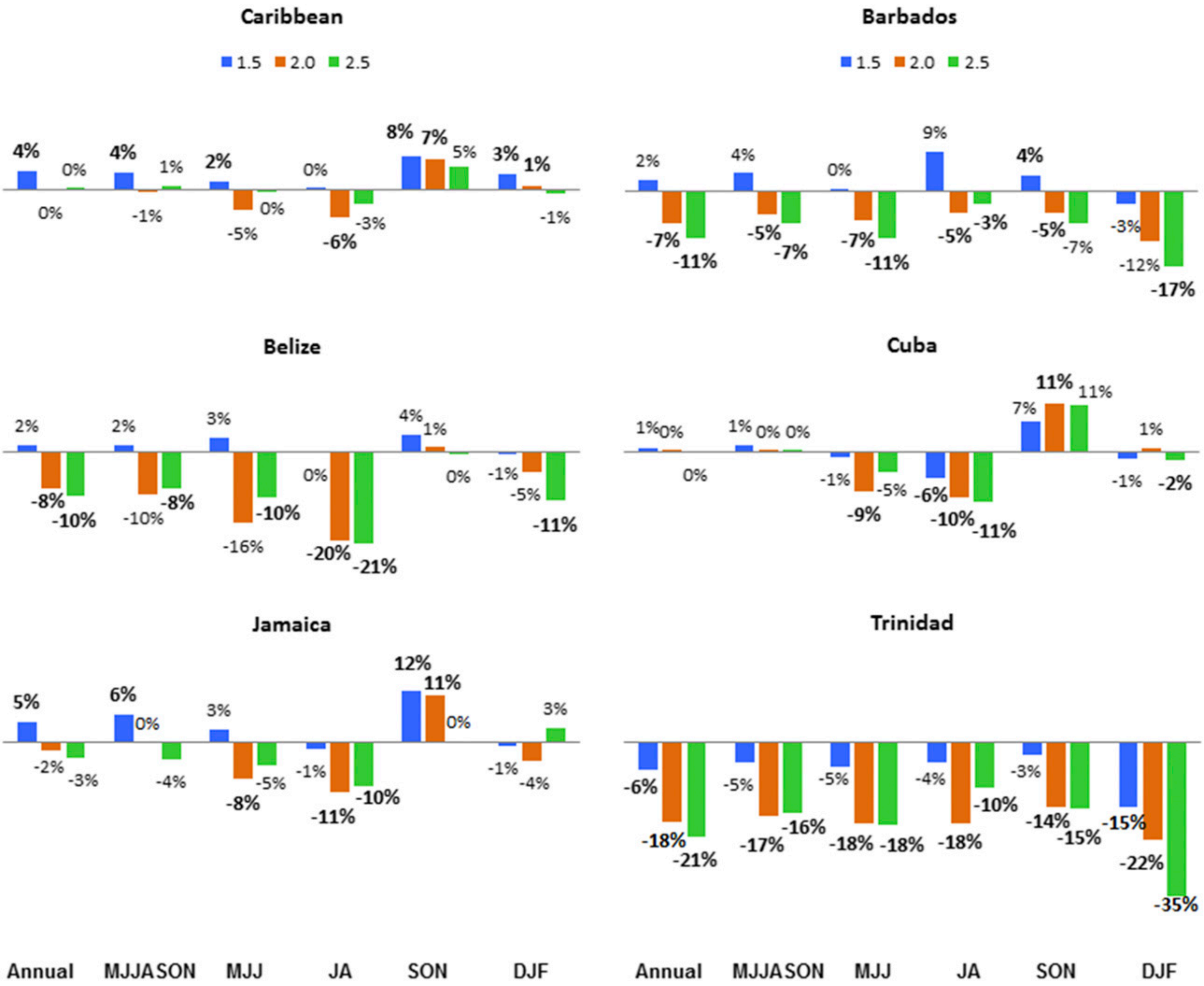

FIG. 7. Mean percentage change in rainfall relative to a 1971–2000 baseline projected by the MME for grid boxes over 5 Caribbean countries and over the entire Caribbean domain (Fig. 1) for global warming targets of 1.5°, 2.0°, and 2.5°C. Changes are shown for the annual mean, the Caribbean wet season from May to November (MJJASON), the early wet seasons from May to July (MJJ), the late wet season from September to November (SON), the midsummer drought period of July and August (JA), and the primary dry season from December to February (DJF). Significant changes at the 95% level are in bold.

values show grid boxes over Jamaica and Barbados as consistently experiencing the highest change. In comparison, Central America, northern South America, Cuba, and Hispaniola show smaller (but still large) increases. Cuba and Belize have wsdi anomalies that are generally smaller than for the other three countries. This may in part be due to differences in land versus sea warming (Sutton et al. 2007) and the fact that of the five countries singled out only the larger countries are generally represented as land points in most of the models.

There is an extension in warm spell duration for $\Delta T_g 2.0$ versus $\Delta T_g 1.5$. Most of the domain exhibits increases of more than 70 additional days, except over Central and South America and western Cuba where the increases are slightly smaller (~20 to 50 additional days). The inset values are all positive, with country averages ranging from 36 (Belize) to 103 (Jamaica) additional days for the half a degree increment. Overall, the suggestion from Fig. 8 is of a significant portion of the year exhibiting consecutively warm days for $\Delta T_g 1.5$ (a range of 59 to 187 more days than for the present-day baseline for inset countries), with further extensions of warm spells (up to 100 or more days in some locations) at $\Delta T_g 2.0$°C.

Figure 9 showing rx10mm bears similarity to the rainfall maps of Fig. 6 with a general coincidence between areas showing decreased (increased) days of intense rainfall and dry (wet) anomalies, respectively. The suggestion is that changes in precipitation in the future may in part be due to changes in the number of days with intense rainfall.

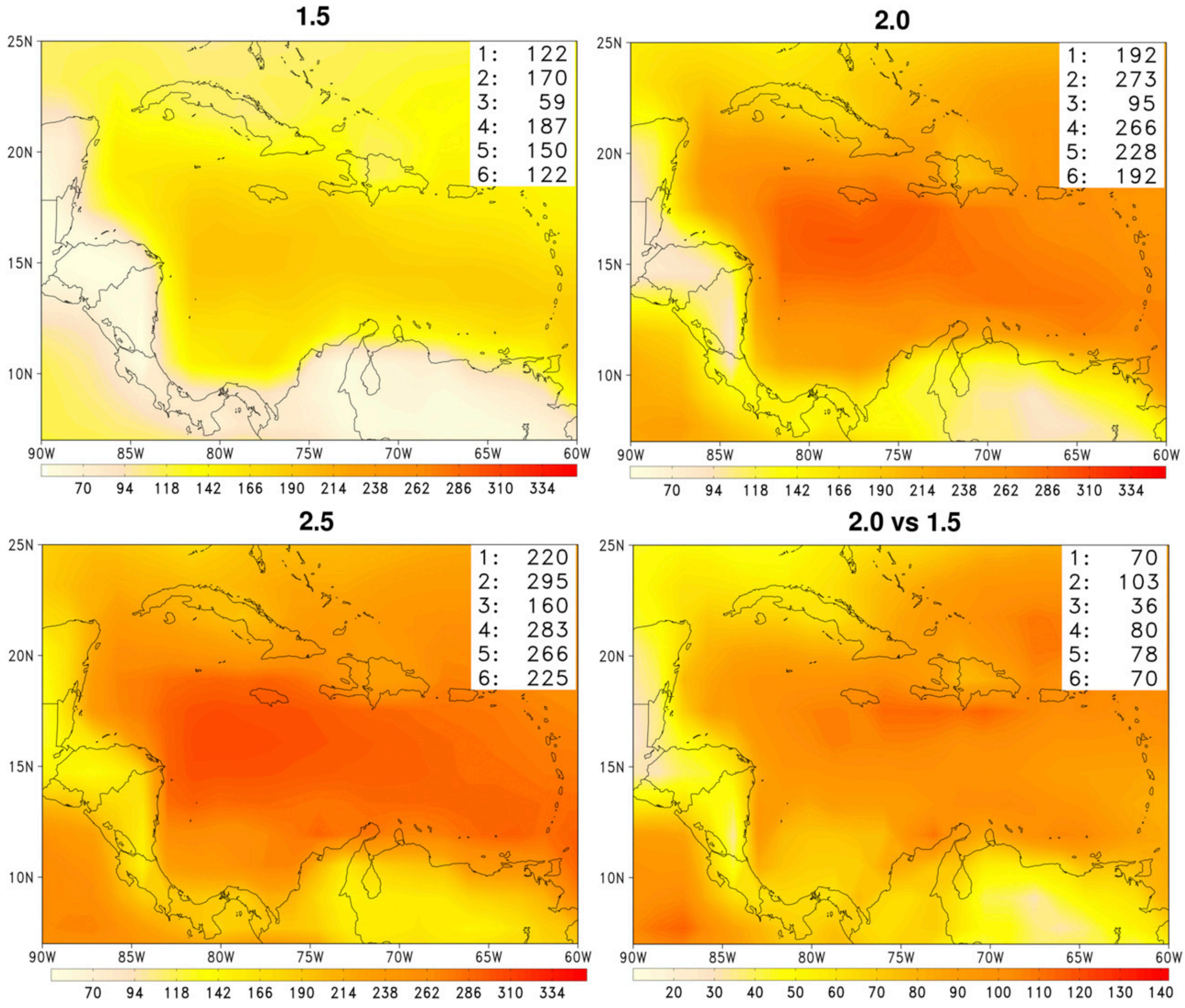

FIG. 8. As in Fig. 5, but for mean change in the longest annual warm spell duration (wsdi). Units are days. Inset on each map shows values averaged over grid boxes covering Cuba, Jamaica, Belize, Barbados, Trinidad, and the entire domain (1–6, respectively). The changes are significant at the 95% level everywhere in the domain.

Similar to the rainfall maps, the dominant feature for $\Delta T_g$1.5 is a positive maximum located in the southwest of the domain, indicating an increase in the daily occurrence (>10 days) of rainfall events exceeding 10 mm. Across the rest of the Caribbean, the change is of similar sign but smaller magnitude (although still statistically significant), with the only area of statistically significant decrease occurring southeast of Trinidad and along Venezuela's Caribbean Sea border. Except for Trinidad, the inset numbers show small positive increases of up to 2 more days of intense rainfall. There is a reversal in the general trend for $\Delta T_g$2.0°C and $\Delta T_g$2.5°C, with intense rainfall events decreasing across the southeastern Caribbean Sea, the eastern Caribbean islands, and northern South America (Venezuela). Except for Jamaica and Cuba, the country determined values for $\Delta T_g$2.0°C are all negative. The positive maximum in the southwestern quadrant of the domain also gradually diminishes in size for successively higher global warming targets, with significant values no longer appearing in the Caribbean Sea (but still over Panama and the eastern Pacific) for $\Delta T_g$2.5°C. Note that $\Delta T_g$2.0 minus $\Delta T_g$1.5 shows a statistically significant decrease in intense rainfall days over most of the domain south of 20°N, with the largest change over Central America. The inset numbers are all negative except over Cuba, which does not exhibit any change.

The maps depicting changes in chdd (Fig. 10) capture both the progressive warming for higher global warming targets and the intensification of areas of significant drying. The changes are statistically significant everywhere

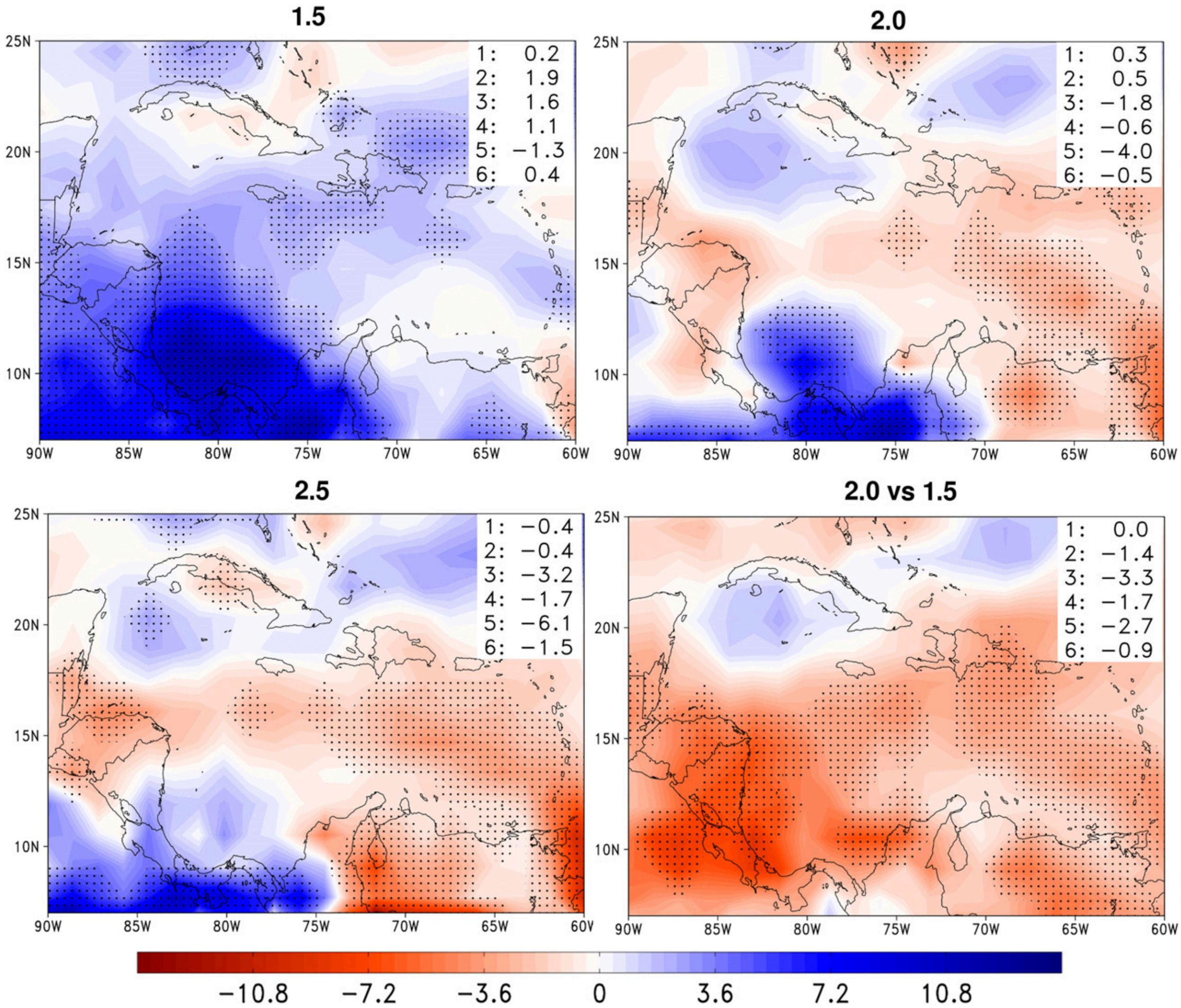

FIG. 9. As in Fig. 8, but for mean change in the number of days in a year when precipitation exceeded 10 mm (rx10mm). Significant differences at the 95% level are hatched.

for the three future states. The largest changes occur over a region just north of South America that extends to the southernmost islands of the eastern Caribbean for all global warming targets. Inset values suggest that, for the countries considered, hot and dry spells are 7–11 days longer for $\Delta T_g1.5$ and 9–22 (17–39) days longer for $\Delta T_g2.0$ ($\Delta T_g2.5$). Trinidad (Belize) consistently shows the largest (smallest) extension of warm dry spells of the five territories examined for all thresholds. The value of $\Delta T_g2.0$ minus $\Delta T_g1.5$ is always positive for the domain, with the country values reflecting an additional 2–11 days for the longest spells. Over the region of maximum change in the southwestern Caribbean Sea, there may be up to an additional 19 consecutive hot and dry days for 2.0° versus 1.5°C.

Finally, Fig. 11 shows the percentage of the domain that is subject to moderate (blue), severe (yellow), and extreme (red) drought, where drought categories are as previously defined in section 2. Results are shown for 1900–2100. In generating Fig. 11, SPI-12 was derived from the multimodel average precipitation time series for each grid box and the percentage of the domain covered by the different drought categories determined. Table 3 gives the relative occurrence of each drought category for each global warming target. The values in Table 3 were determined by applying the 11-yr time sampling approach to the SPI-12 index derived from a domain-averaged time series of the rainfall multimodel mean. The proportion of the sampling period (expressed as a percentage) when the index was in each drought category was then determined. The results of Fig. 11 and Table 3 suggest the following:

- There is a general increase in areas under drought (whether moderate, severe, or extreme) from 1900 to

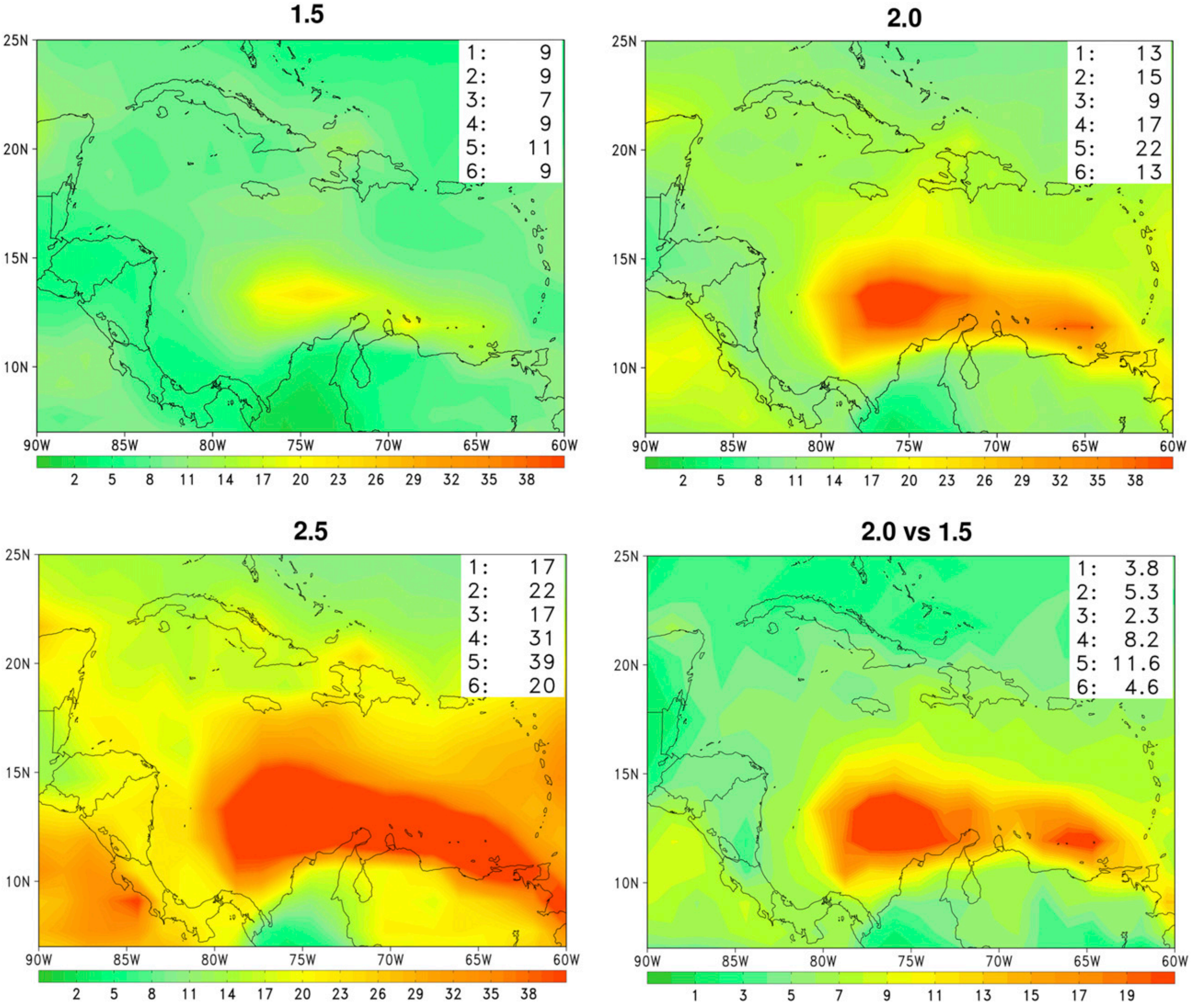

FIG. 10. As in Fig. 8, but for change in the duration of the longest annual number of consecutive hot and dry days (chdd) in a year. The changes are significant at the 95% level everywhere in the domain.

the end of the century. From 2050 to the end of the century, at least 10% of the domain experiences drought of one category or another.

- Moderate drought has the largest projected change between $\Delta T_g 2.0$ (occurring 10% of the time sampled) and $\Delta T_g 1.5$ (2% of the time). In comparison, the relative occurrences of severe droughts and extreme droughts show little or no change. Between $\Delta T_g 2.5$ and $\Delta T_g 2.0$ there is a small increase in the occurrence of moderate drought, no change for severe drought, and a 6% increase in the occurrence of extreme droughts.

## 4. Summary and discussion

The climatic conditions over a Caribbean domain are examined when the mean global surface air temperatures are 1.5°, 2.0°, and 2.5°C above preindustrial values. A time sampling approach is used to determine the future climatic states of the Caribbean. James et al. (2017) note a number of advantages to this methodology, including that it is computationally cheap and allows for the comparison of $\Delta T_g$ states while not necessarily assuming a linear relationship between the global temperature and the local change. One disadvantage of the method is that it is sensitive to multidecadal natural variability (James et al. 2017). To overcome this, an ensemble of 10 CMIP5 models was used (as opposed to examining, for example, a single model or just a few models) and the MME calculated. The 10 models used were among those that, according to Ryu and Hayhoe (2014), reasonably simulated Caribbean climate.

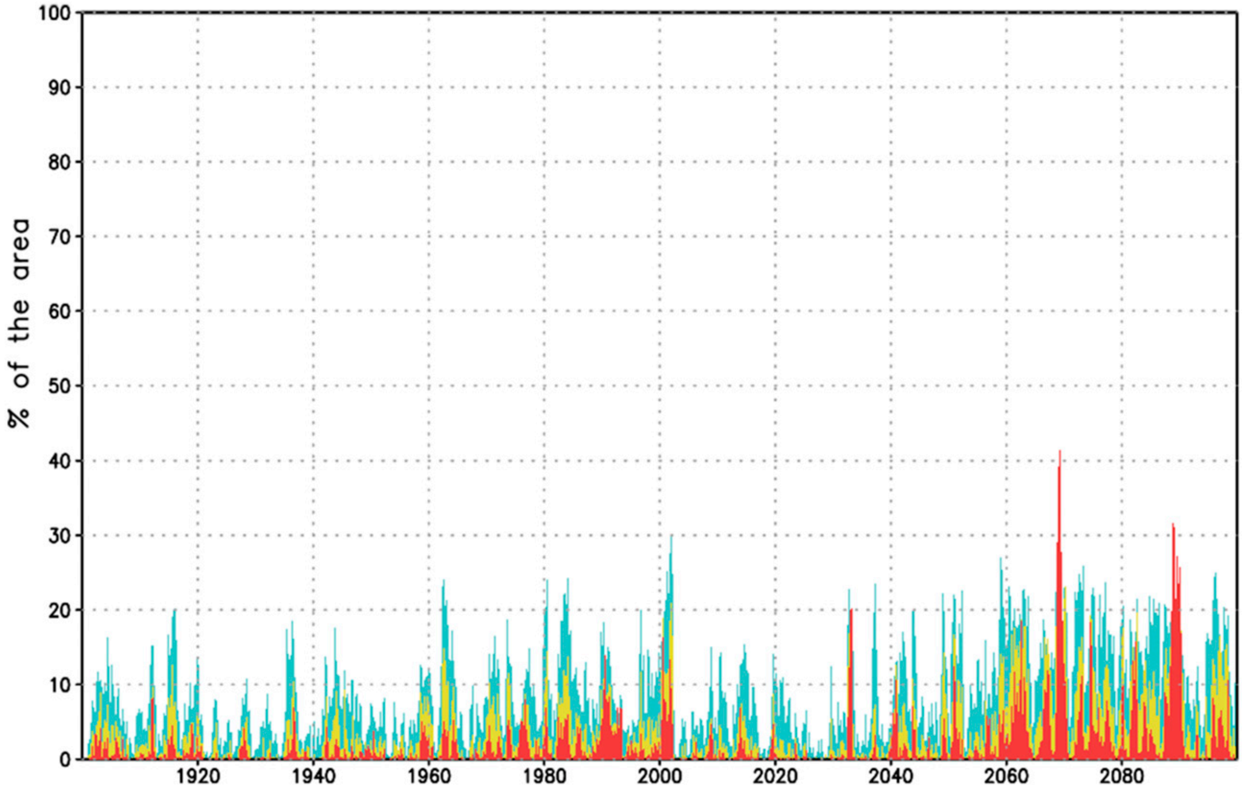

FIG. 11. The annual percentage of the domain that is covered by moderate (blue), severe (yellow), and extreme (red) drought between 1900 and 2100. Drought categories are determined using SPI-12 where $-1.5 < \text{SPI-12} < -1$ indicates moderate drought, $-2 < \text{SPI-12} < -1.5$ indicates severe drought, and $\text{SPI-12} < -2$ indicates extreme drought. The diagram was generated using the CARiDRO (the Caribbean Assessment Regional Drought Tool) (Centella et al. 2017).

Approximate dates of attainment for 1.5°, 2.0°, and 2.5°C were 2028, 2046, and 2070 respectively using the 10-member ensemble. Guo et al. (2016) report similar attainment dates of 2027, 2047, and 2075 using the same RCP and a 17-member CMIP5 ensemble. Karmalkar and Bradley (2017) do not report on $\Delta T_g 2.5$ but suggest attainment dates of 2030 and 2050 for 1.5° and 2.0°C, respectively, using a 32-member ensemble and RCP4.5. It is apparent that, whereas available studies suggest similar attainment dates for the first two global warming targets notwithstanding ensemble size, larger ensembles postpone the attainment of 2.5°C to later and later in the century. There is seemingly greater intermodel variability at higher warming targets as the climate system and models move farther away from current conditions (James et al. 2017), which is further enhanced for a larger spread of models. In this study, when all 42 CMIP5 models are used, 2.5°C is not achieved before the end of the century. Discussions that focus on when the global warming targets will be achieved for a given RCP should bear in mind the uncertainty introduced with respect to the highest targets when the ensemble size is varied.

The mean surface air temperature change averaged over the entire Caribbean domain (with respect to the preindustrial period) is always a few tenths of a degree smaller than the corresponding global warming target. The smaller comparative change does not, however, diminish the significance of the regional temperature change as there is generally lower variability in the tropics, particularly with respect to temperature ranges. This means that even small changes can move the tropics beyond the limits of historical extremes and precedents, resulting in unprecedented and unfamiliar climates (Frame et al. 2017) that threaten biodiversity (Mora et al. 2013) and resource-strapped economies. Within the domain, however, there are some regions (parts of Central America and northern South America) that experience change larger than the global averages.

The ensemble size facilitated the determination of a Caribbean climate profile for all three global warming targets for RCP4.5. Table 4 is a summary of the major results with respect to a present-day baseline (1971–2000). (Mean warming for present-day periods with respect to the preindustrial period was discussed in section 3a). For temperature and temperature related

TABLE 3. The relative occurrence (% of time sampled) per drought category for the global warming targets of 1.5°, 2.0°, and 2.5°C considering an 11-yr period centered on when the MME indicates the target is attained.

| | 1.5 | 2.0 | 2.5 |
|---|---|---|---|
| Moderate drought | 2 | 10 | 12 |
| Severe drought | 5 | 6 | 6 |
| Extreme drought | 10 | 10 | 16 |

extremes, there is a strengthening of warm anomalies and increased duration of warm spells for higher $\Delta T_g$ increments. James et al. (2017) suggest that an intensification of temperature anomalies at higher global warming targets is generally true for similar studies of other global regions. In contrast, however, both mean rainfall and heavy rainfall days show a reversal of the general trend seen at 1.5°C. Whereas small wet anomalies with respect to the present-day baseline predominate across most of the Caribbean and Central America for $\Delta T_g1.5$, they are replaced by dry anomalies for $\Delta T_g2.0$. There are, however, parts of the domain, particularly in the eastern and southeastern Caribbean, that already show dry tendencies for $\Delta T_g1.5$ and that further dry for $\Delta T_g2.0$. There is further intensification and spreading of the dry anomalies in the main Caribbean basin for $\Delta T_g2.5$ (see again Fig. 6). Previous SRES-based studies (e.g., Campbell et al. 2011; Karmalkar et al. 2013) also indicate the onset of mean drier conditions in the region after the middle of the century when surface temperatures are higher. The drying at higher $\Delta T_g$ increments, notwithstanding warmer temperatures, is likely associated with a number of interdependent factors including an intensification of the CLLJ in the south Caribbean Sea (Cook and Vizy 2010; Taylor et al. 2013), an intensification of the North Atlantic subtropical high (Rauscher et al. 2008), and the future prevalence of a sea surface temperature gradient state characterized by a relatively cooler tropical Atlantic and warmer equatorial Pacific (Taylor et al. 2011; Fuentes-Franco et al. 2015). The reversal in the rainfall pattern for 2.0° versus 1.5°C over some parts of the domain has implications for the pursuit of adaptation options in the region. For example, there is the danger of maladaptation if adaptation is premised on near-term projections and the global goal of limiting warming to 1.5°C by the end of the century is not met.

The results also suggest that particularly for rainfall the intensification of the dry anomalies with $\Delta T_g$ increment is not linear. For example, Fig. 7 shows that for most countries in the domain, except those in the north, the rainfall changes are larger between 1.5° and 2.0°C than between 2.0° and 2.5°C. This suggests that care must be taken in developing climate change projections for the Caribbean region as some methodologies (e.g., pattern scaling) may not be appropriate.

To have an idea of the robustness of the results, both the signal-to-noise ratio (SNR) and the standard deviation (SD) across the 10-member ensemble were calculated for each variable. The results (not shown) indicate that, notwithstanding the variations of SD with increased global warming, the changes in the temperature-related variables (mean temperature, wsdi, and chdd) always emerge over the intermodel noise. For mean rainfall and heavy rainfall days, however, there is a tendency for intermodel noise to dominate over the changes at the different warming targets in large parts of the domain, indicating less certainty in the results (than, e.g., for the temperature variables reported on). This is true even for small changes in SD. The exception is in the region close to Costa Rica, Panama, and Colombia where the intermodel differences tend to be largest and rainfall and rx10mm changes generally emerge over the intermodel noise. Figure S1 also provides an idea of the ensemble spread for the detailed regional precipitation patterns shown in Fig. 7. The figure generally suggests small intermodel spread in the annual mean and for most seasons for the Caribbean, Barbados, Cuba, and Jamaica for all three global warming targets. Belize shows greater model spread for 2.5°C across most seasons analyzed, whereas Trinidad has greatest spread for 2.5°C for SON.

Finally, this paper was motivated by 1) the lobby by CARICOM and other SIDS to limit further global warming as embodied in the slogan "1.5 to Stay Alive," and 2) the Paris Agreement, which posited 2.0°C as an upper target for global mitigation efforts. On the basis of the results presented, the following three things are noted about the Caribbean position:

1) *There needs to be greater global urgency if 1.5°C is indeed a limit for regional "viability" as suggested by the Caribbean slogan.* A 2030 attainment date for 1.5°C, as suggested by this and other similar studies, gives the Caribbean region less than 15 years to prepare for the consequences of a 1.5°C world and for the subsequent years when global temperatures move beyond this threshold. The attainment year may even be a few years earlier since the current rates of emission of greenhouse gases do not support adherence to the RCP4.5 pathway (Friedlingstein et al. 2014). For example, Guo et al. (2016) calculate the year to be 2024 (less than 10 years away) for the business-as-usual RCP 8.5. The call by the region and other SIDS to limit global warming at the end of the century to 1.5°C above preindustrial temperatures is then really a call to far greater global action to slow

TABLE 4. Summary of changes seen in the Caribbean domain for three global warming targets. Changes referred to are with respect to a 1971–2000 baseline.

| | 1.5 | 2.0 | 2.5 | 2.0 vs 1.5 |
|---|---|---|---|---|
| Temperature | 0.5°–1.5°C warming across the domain. | 1.0°–2.5°C warming across the domain. | 1.5°–3.0°C warming across the domain. | Additional warming of 0.2°–1.0°C. |
| Rainfall | Overall mean wetter tendency (~+4%). Maximum (+25%) in the southwestern Caribbean Sea. Drying tendency in the east, south and southeast Caribbean islands and the Bahamas. | Mostly drier (−15% to −20%). Maximum drying in the southeastern Caribbean. | Mostly drier (−15% to −25%). Intensification of drying in the southern Caribbean. | 5%–10% drier between 10° and 20°N. |
| Warm spells | Up to 50% of the year. | >300 days in south Caribbean. Central America, northern South America, Cuba and Hispaniola show smaller (but still large) increases | Much of the year (>200 days) excessively warm. | More than 70 additional days. |
| Intense rainfall | Small increases (~1 day), except for the southwest Caribbean Sea (up to +7 days) | Up to 4 fewer intense rainfall days | Up to 6 fewer intense rainfall days | Up to 3 fewer intense rainfall days |
| Hot and dry days | Moderate increases (up to ~15 days) for most of basin. | Increases >15 days over most of the basin. | Increases > 20 days for most of the basin. Maximum (>30 days) over the Caribbean coast of South America. | Up to 9 more days over most of basin. Increases by 15–20 days over the Caribbean coast of South America. |
| Drought | The domain experiences moderate to severe drought approximately 17% of the time. | The domain experiences moderate to severe drought approximately 26% of the time. | The domain experiences moderate to severe drought approximately 34% of the time. | ~8% increase in the occurrence of moderate drought |
| Seasonal changes | • The early wet season (MJJ) and the midsummer drought (JA) are most impacted, progressively drying at higher global warming targets.<br>• Late season (SON) dries in the southern Caribbean.<br>• The dry season (DJF) dries over Central America and the southern Caribbean but is not significantly altered over the northwest Caribbean (Jamaica and Cuba). | | | |

emissions even beyond what is currently proposed. To do otherwise means that the proposed viability threshold for the Caribbean, as indicated by the slogan, will be crossed much sooner rather than later this century.

2) *A global warming target of 1.5°C will still result in significant climatic change in the Caribbean.* Agreeing to 1.5°C as a global limit still represents a concession to some degree of change in the climatic regime of the Caribbean and the associated impacts those climatic shifts will bring. In a 1.5°C future, in comparison to the present, the Caribbean will be warmer, with longer warm spells and longer hot and dry spells, and will experience moderate to extreme drought approximately 16% of the time. Particularly, for temperature extremes, the changes seen at 1.5°C also suggest unfamiliar conditions compared to the present with which the Caribbean will have to contend (e.g., up to 120 more warm spell days). The call to limit global warming at the end of the century to 1.5°C above preindustrial temperatures is, then, also a call for more time to adapt to the accompanying significant shifts in regional climate that are still likely at 1.5°C.
3) *There are significant differences for the Caribbean between a global warming target of 1.5° and 2.0°C.* The differences between 2.0° and 1.5°C for the Caribbean include a further 0.2°–1.0°C warming, almost year-round warm spells, longer hot and dry spells, greater portions of the domain being under drought, increased occurrence of extreme drought conditions, and a transition to a mean drier regime across the entire domain. The general picture is of a significantly drier and hotter Caribbean than present for a transition from 1.5° to 2.0°C, with intensification of this state for 2.5°C. The potential impacts on the Caribbean way of life are still to be investigated but are likely to be larger for higher global warming targets. Burke et al. (2015) note that tropical countries

are the most affected when the differences in the impact of 1.5°C versus 2.0°C on global economic production are considered. The call to limit global warming at the end of the century to 1.5°C above preindustrial temperatures may finally, then, also be a call to a less risky regional climate state than that which further warming may yield.

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