Organisation of Eastern Caribbean States

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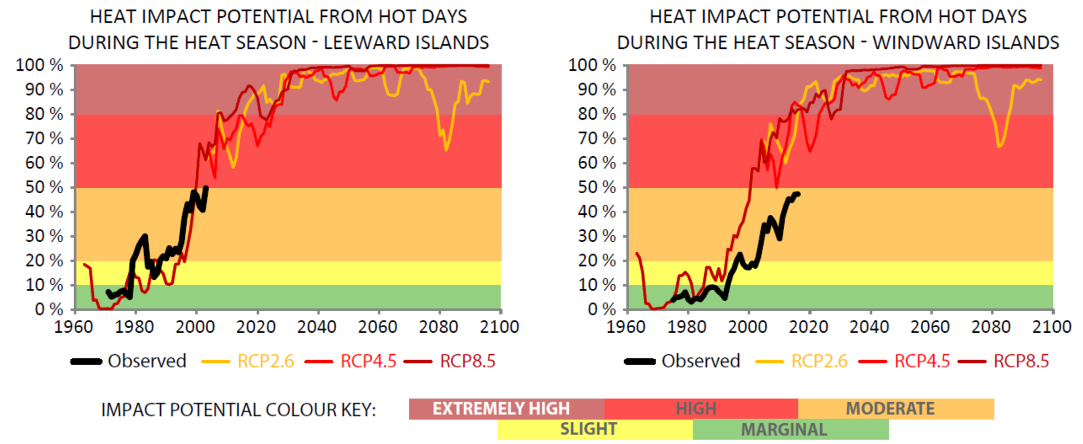
AFD AGENCE FRANÇAISE DE DÉVELOPPEMENT · EXPERTISE FRANCE · Adapt'Action

OECS CLIMATE CHANGE ADAPTATION STRATEGY & ACTION PLAN

Climate Trends and Projections for the OECS Region

April 1, 2020



Recent and future heat impact potential in the Leeward Islands (left) and Windward Islands (right) as measured by the percentage of hot days during the annual heat season (May to October) - Source: IPCC scenarios by CIMH

Implemented by:

ARTELIA

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This technical assistance programme operation is financed by the French Development Agency (AFD) within the framework of the Adapt'Action Facility. This Facility, which began in May 2017, supports African countries, LDCs and SIDS in implementing their commitments under the Paris Climate Agreement, through the financing of studies, capacity-building activities and technical assistance, especially in the adaptation sector. The authors assume full responsibility for the contents of this document. The opinions expressed do not necessarily reflect those of AFD or its partners.

This first CCASAP climate report (Deliverable 2) delivers all the work requested under this agreement except information regarding sex-disaggregated data that are technically not available nor considered when running IPCC RCP climate scenario[1]. The analysis was produced by:

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The second CCASAP climate report will be produced based on the "Findings" described in Section 4 of this Deliverable 2 report and include all information available on sex-disaggregated data and gender sensitive climate change impacts

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ACRONYMS

AFD	Agence Française de Développement
CARICOM	Caribbean Community
CC	Climate Change
CCA	Climate Change Adaptation
CCASAP	Climate Change Adaptation Strategy and Action Plan
CCCCC	Caribbean Community Climate Change Centre
CIMH	Caribbean Institute for Meteorology & Hydrology (St. James, Barbados)
COMES	Council of Ministers of Environment and Sustainability
COSEFIN	Council of Ministers of Finance of Central America, Panama and the Dominican Republic
CSGM	Climate Studies Group Mona of the University of the West Indies
DFID	United Kingdom Department for International Development
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
EbA	Ecosystem-based Adaptation
ENSO	El Niño–Southern Oscillation
FbA, RFbA	Forecast-based early Actions and Regional Forecast-based early Actions
GCF	Green Climate Fund
GDP	Gross Domestic Product
GST	Global Stocktake of the Paris Agreement
IPCC	Intergovernmental Panel on Climate Change
LDC	Least Developed Country
M&E	Monitoring and Evaluation
NAP-GN	National Adaptation Plan – Global Network
NDC	Nationally Determined Contributions
NOAA	US National Oceanic and Atmospheric Administration
OECS	Organisation of Eastern Caribbean States
PRECIS	Providing Regional Climates for Impacts Studies
RSC	Regional Steering Committee
SIDS	Small Island Developing State(s)
SPI	Standard Precipitation Index

EXECUTIVE SUMMARY

The Organisation of Eastern Caribbean States (OECS) region of Small Islands are among the most vulnerable areas to hydro-meteorological hazards. Many of these hazards are being exacerbated by climate change and the associated sea level rise. In 2017, category 5 hurricanes Irma and Maria stormed through the region, causing at least 3191 deaths and a cumulative damage of $12 billion. Similarly, damaging floods, landslides, droughts and coastal erosion have continued to cause substantial damage and loss, as excessive heat emerges as a new and important threat to the region. Future climate projections point to rising temperatures and increased evapotranspiration, as well as continued sea level rise, altered precipitation patterns, and increasing hurricane intensity. These projected changes will impact the region's coastal ecosystems and fisheries, water supplies, agriculture, biodiversity, human health, tourism and critical infrastructure.

In 2015, the Agence Française de Développement (AFD) launched the Adapt'Action programme to support countries seeking technical assistance for the institutional, methodological and operational implementation of their Nationally Determined Contributions (NDCs) containing commitments to implement the UNFCCC Paris Agreement. In July 2018, the Organisation of the Eastern Caribbean States (OECS), AFD and Expertise France signed an MoU under the Adapt'Action Facility. This OECS Adapt'Action Facility project, *Climate Change Adaptation Strategy and Action Plan* (CCASAP), supports the strengthening of institutional capacities and climate governance. One objective of CCASAP is the development of a consolidated climate profile for the OECS region. Previous analyses on variability and trends in hydro-meteorological hazards integral to understanding climate risk were not designed with a high enough spatial resolution to suit the needs of policy makers, sector planners and the environment in the OECS region in their aim of achieving climate resilience. This CCASAP technical climate report details the development of a regional scale, fit-for-purpose climate risk profile for the OECS region.

Climate risk can be quantified as the product of climate hazards (including their probability and severity), vulnerability and exposure. The climatological analyses reported here characterises and quantifies the major climate-related hazards that the OECS region faces. This is done through "climate-related hazard impact potential", which is defined as "*the frequency or proportion of time that a climate condition crosses a threshold beyond which significant impacts are expected to occur if striking in a vulnerable area/community with exposed assets*." The report relies on observational data time series, as well as output from new high-resolution future climate projections run with a regional climate model (RCM). To account for uncertainty in global development scenarios, several global emissions scenarios are examined: a low (Representative Concentration Pathway 2.6 – RCP2.6), mid-range (RCP4.5) and high (RCP8.5).

In summary, the available evidence for the region outlines the following priority climate hazards for the OECS:

- ***Heat Stress*** - Heat stress arising from excessive heat exposure has started affecting the OECS region. Heat stress increases mortality and morbidity in both humans and livestock, reduces children's learning ability at school, increases cooling demand, decreases labour productivity, exacerbates drought, and requires a re-envisioning of the urban environment. Heat impact potential has increased year-round from marginal to moderate across the OECS region after 1995, as shown by an observed positive trend in the annual number of hot days and nights and a decrease in the number of cool days and nights. During the heat season – when most heatwaves occur (May to October) –, the heat impact potential will very likely be high to extremely high as soon as the 2020s, meaning more than 50% of days to more than 80%, respectively, will be hot days, irrespective of the future scenario.

- ***Extreme rainfall*** - Flash floods occur when the rainfall intensity exceeds the rate of soil infiltration and surface drainage. Quantifying the variability and changing nature of extreme rainfall thus helps characterising the impact potential from flash floods and flooding. Both the Leeward and Windward Islands experience extremely high potential (i.e. at least 80% chance of at least 1 flash flood per country/territory) from August to November – peaking in November with a 40% chance. The Leeward Islands also experience a smaller peak in April and May with moderate potential (20% to 50% chance). There is little sign of a trend in flash flood potential either in the observed record or in projections out to the 2040s (*medium confidence*). However, by the end of the 21st Century, heavy rainfall frequency could decrease by up to 25% (*low confidence*) and rainfall intensity may increase by 50-100% by the 2090s (*medium confidence*), implying increasing flash flood severity in the second half of the 21st Century.

- ***Dry spells and drought***- Periods of several consecutive dry days are called dry spells. The longer and the more frequent during the critical growth stage, the more water stress dry spells cause to plants. Dry spells can pose significant risk to rain-fed crop production, a common practice in the OECS region. Seasonal to multi-annual periods of rainfall deficits can result in drought. Impactful water deficits in soil can appear within less than 3 months – triggering agricultural drought. Within 6 months of cumulative rainfall deficits, large streams and water reservoirs can be affected – hydrological drought. Within 12 months, the largest rivers, surface water reservoirs and underground aquifers can be affected, limiting freshwater availability, triggering drought impacts across a multitude of socio-economic sectors. The impact potential of dry spells, which peaks from March to May, is much higher on smaller islands and in areas with low topography than in mountainous areas (*high confidence*). In the former areas, planting sensitive crops without protective measures or supplemental irrigation may be too risky at any time of the year. By contrast, in mountainous areas, the period from June to December is virtually risk-free (*high confidence*). A robust rising trend in dry spell impact potential is only expected after the 2040s (*high confidence*). Drought impact potential has often been moderate (i.e. 20% to 50% of the time characterised by drought) during the annual dry season, but mostly slight (10% to 20%) during the wet season. Since 1999, long-term drought impact potential has been higher than in the 20 preceding years, but no further robust trends emerge before 2050. Beyond 2050, drought trends depend on the emissions scenario, with long-term drought impact potential rising beyond 2050 to 50% and higher by the 2080s in the RCP8.5 scenario. Finally, regardless of future rainfall trends, drought impact potential is expected to rise because of higher evapotranspiration rates brought about by higher temperatures.

- ***Other climate-related hazards*** - This report emphasizes that, in the OECS region, other climate-related hazards – namely tropical cyclones, sea level rise and changes in ocean temperature and salinity – are associated with risk levels that are, at the very least, comparable in extent to those highlighted above. Hence, despite the limited scope of the climatological research affordable to the CCASAP project, a brief literature review was conducted to highlight any observed and expected future trends of critical importance to the region.

- In terms of ***tropical cyclones***, the activity and impact level of the Atlantic Hurricane Season (June to November) on the OECS region varies from year to year, but an average of 11.3 tropical storms, 6.2 hurricanes and 2.3 major hurricanes (category 3 or higher) is noted for the period 1966 to 2009, with an upward trend between 1850 and 2015. While the total number of named storms is not projected to rise in future (low confidence), the strongest storms are likely to become 2% to 11% stronger and possibly more frequent (medium confidence); rainfall rates inside hurricanes could increase by up to 30%, increasing flash flood potential; and rising sea levels combined with stronger winds in the strongest storms substantially increases the impact potential of storm surge and coastal inundation.

- ***Sea level*** has risen at a rate varying from 1 mm per year in Grenada, to around 2 mm per year in Guadeloupe, and up to 2.5 mm per year in the British Virgin Islands since 1950 and are projected to rise by 27 cm to 30 cm – with a 90% confidence range of between 20cm and 40 cm – by 2050 and could exceed 1 m by 2100. Among the major future impacts of sea level rise facing the OECS region are coastal erosion; reduction of land space near sea level, including urban space; saline intrusion into soils and aquifers.

- ***Sea Surface temperatures*** - Finally, trends in sea surface conditions include an observed temperature rise of 0.2°C and 0.3°C per decade between 1986 and 2016 and are projected to rise a further 0.77°C to 2.5°C by the end of the 21st Century. As such, the warmest years in history would correspond to the coolest years by 2100. While salinity tends to fluctuate between 36 parts per thousand in the dry season and 35.5 during the wet season, global salinity is projected to decrease as a result of glacial melt. Such environmental changes in the upper ocean is expected to impact on coral reefs through more frequent and intense bleaching episodes, marine animal habitat changes and fish species migrations, as well as, heat expansion of the water column as ocean temperatures rise, contributing to sea level rise and its associated hazards.

1. INTRODUCTION

The Eastern Caribbean Islands are highly vulnerable to a set of hydro-meteorological hazards including tropical cyclones, excessive rainfall, droughts, dry spells and heatwaves and associated climate-driven hazards such as floods or landslides, coral reef bleaching and coastal erosion. Many of these hazards are being exacerbated by climate change and the associated sea level rise. Severe damage from Hurricane Irma and Hurricane Maria in 2017 caused significant losses to several OECS member States, in some cases economic losses exceeding 200% of Gross Domestic Product (GDP). Hurricane Irma was the first Category 5 hurricane on record to strike the Leeward Islands and is the second-costliest Caribbean hurricane on record, after Maria that followed two weeks later. Irma caused catastrophic damage in Saint Martin, Anguilla, and the Virgin Islands resulting in at least 134 deaths. Hurricane Maria, also a Category 5 hurricane, devastated Dominica in September 2017. It is regarded as the worst natural disaster on record to affect the Eastern Caribbean and is also the deadliest Atlantic hurricane since Jeanne in 2004. Maria, estimated to have killed 3057 people, was the third consecutive major hurricane to threaten the Leeward Islands in two weeks after Irma had made landfall in several of the islands and José had narrowly missed the Islands. In the OECS islands and St Martin, these two hurricanes caused about $12 billion of damage. For most of these countries, having limited access to human, technical and financial resources, recovery from these extreme events will take several years.

Future climate projections point to several significant trends in the Eastern Caribbean. They include increasing average temperatures and evapotranspiration, sea level rise, changes in precipitation patterns, and increasing hurricane intensity, which will very likely impact coastal ecosystems and fisheries, water supply, agriculture, biodiversity, human health, tourism and critical infrastructure. Extreme events are likely to become more frequent and/or more intense, resulting in continued shocks to society, the economy and vulnerable ecosystems and segments of society of OECS Member, Associate Member and Observer States.

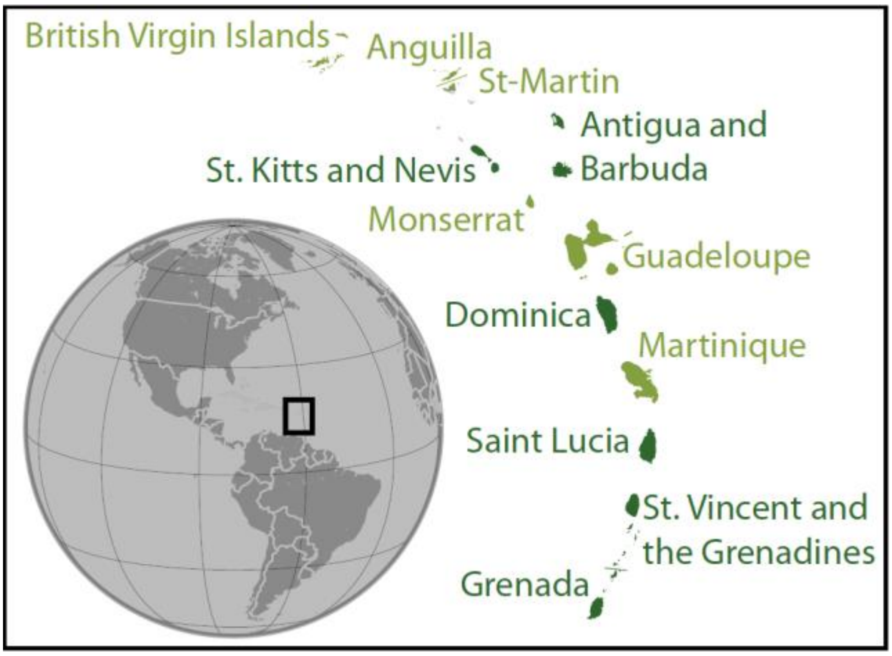
Following the conclusion of the *Paris Agreement* under the *United Nations Framework Convention on Climate Change* (UNFCCC) in 2015, the Agence Française de Développement (AFD) launched the Adapt'Action programme to support countries seeking technical assistance for the institutional, methodological and operational implementation of their Nationally Determined Contributions (NDCs) containing commitments to implement the *Paris Agreement*. With a goal of committing EUR 30m over a 4-year period, Adapt'Action will support 15 countries with a priority focus on Africa, the Least Developed Countries (LDCs), and Small Island Developing States (SIDS).

In July 2018, the Organisation of the Eastern Caribbean States (OECS), AFD and Expertise France signed a Memorandum of Understanding under the Adapt'Action Facility. The objective of the Adapt'Action project is to support OECS Members and the OECS Secretariat in:

- The consolidation of their climate governance for the successful implementation of their Nationally Determined Contributions (NDC) through capacity-building activities (component administrated by Expertise France).
- The translation of their NDC into sectoral public policies and action plans in the field of adaptation (component administrated by AFD).
- The design of priority climate change adaptation projects, to facilitate access to international climate finance (component administrated by AFD).

This OECS Adapt'Action Facility project, *Climate Change Adaptation Strategy and Action Plan* (CCASAP), supports the strengthening of institutional capacities and climate governance. The project will involve all Member States of the OECS, namely, six Independent States (Antigua, Dominica, Grenada, St. Kitts and Nevis, St Lucia, and St Vincent & the Grenadines), three UK Overseas Territories (Anguilla, British Virgin Islands and Montserrat), and three French Overseas Territories (Guadeloupe, Martinique and St. Martin). It aims at providing OECS countries/territories (both Leeward Islands and Windward Islands) critical technical and institutional tools they need to strengthen climate governance and mobilise international climate finance to scale up their action, and therefore produce a leverage effect.

Figure 1 : The OECS region with its Member States (dark green) and Territories (light green)



Source: modified from Wikimedia Commons

One objective of the Adapt'Action Facility project is to support OECS Commission and Member States in their transition to climate-compatible development to be achieved, in part, through the development of:

(i) a consolidated and comprehensive climate profile (impacts, vulnerabilities, risks and capacities) for the OECS region highlighting common issues and differences.

(ii) a gender-and climate vulnerability baseline comprising a compilation of data to highlight particular gender-specific vulnerabilities and opportunities in the OECS region.

(iii) an OECS Regional Climate Change Adaptation Strategy and Action Plan that prioritises interventions required to address climate change vulnerabilities and capacity constraints (human, technical and financial) within the context of the Paris Agreement commitments and National Climate Change Adaptation Policies of OECS States.

(iv) an effective and institutionalised tool for adaptation monitoring, reporting and reviewing results against commitments made under the Paris Agreement.

The outputs of the CCASAP component will also take into account the findings from two other components funded under the OECS Adapt'Action Facility project, namely:

- A Scoping Study for Regional Forecast – based Early Action in the OECS; and
- Guidelines for Mainstreaming Ecosystem Based Adaptation & Gender Equality into Climate Change Adaptation

The aim of this report is to describe the overall methodology carried out for the elaboration of the climate change risk profiles as well as a regional climate risk profile for the OECS States/Territories, namely for:

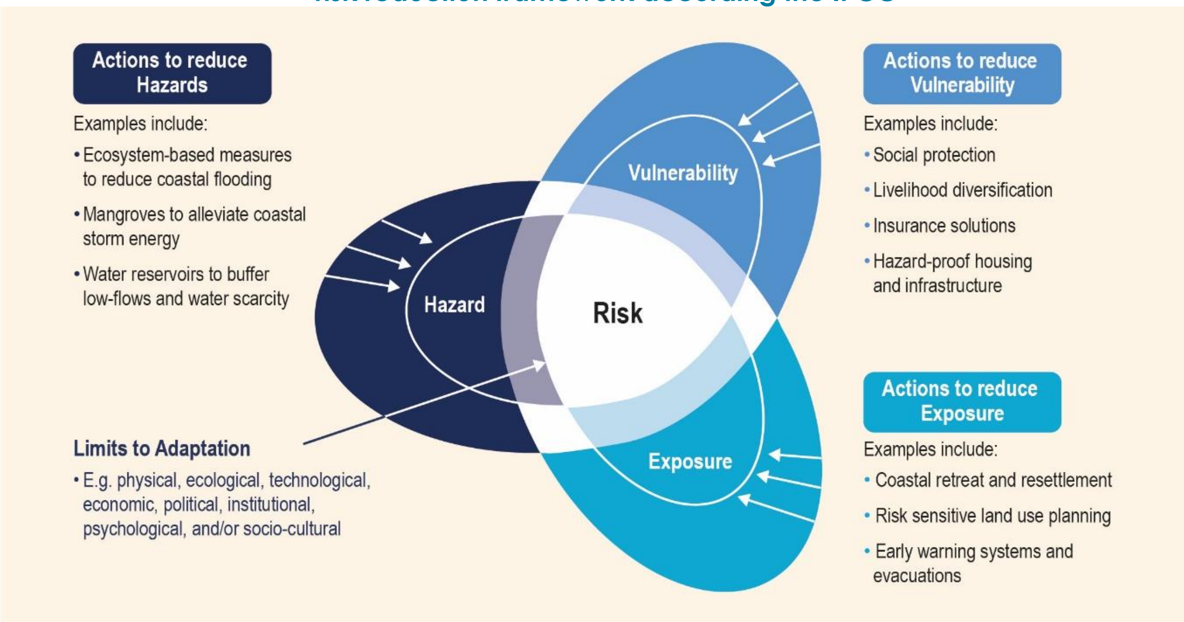
- The Leeward Islands: Anguilla, Antigua and Barbuda, British Virgin Islands, Guadeloupe, Montserrat, St. Kitts and Nevis, St-Martin; and
- The Windward Islands: Dominica, Grenada, Martinique, Saint Lucia, St. Vincent and the Grenadines.

2. METHODOLOGY

2.1 Climatological Analysis

The climatological analyses performed under the Terms of Reference of the CCASAP project involved the development of detailed historical climatological normals – henceforth referred to as historical climatologies , an assessment of observed climate variability and recent, observed trends, as well as an assessment of the highest resolution future climate projections available for the OECS region. In the analysis, emphasis was placed on climate indices that are closely tied to the occurrence of major climate-related hazards facing the region, namely excessive heat exposure, drought, extreme rainfall – engendering hazards such as flash floods1, flooding and landslides , sea level rise, tropical cyclones, as well as, changes in sea surface conditions (temperature and salinity), impacting coastal communities and marine-based livelihoods. As described in the IPCC SREX report "climate extremes, exposure, and vulnerability are influenced by a wide range of factors, including anthropogenic climate change, natural climate variability, and socioeconomic development. Disaster risk management and adaptation to climate change therefore focus on reducing exposure and vulnerability and increasing resilience to the potential adverse impacts of climate extremes, even though risks cannot fully be eliminated" (See Figure 1 below).

Figure 1: Relationship between climate hazard, vulnerability and exposure in a conceptual risk reduction framework according the IPCC



Source: IPCC (in press)

Based on those conclusions from the Intergovernmental Panel on Climate Change (IPCC, 2012), climate risk can be calculated as follows:

[1] Flash floods are sudden, local floods, typically due to heavy rain (*Source:* Oxford Dictionary). Flash floods occur when the rainfall accumulation rate exceeds the rate of soil infiltration and surface drainage.

Risk = hazard (probability and severity) x vulnerability x exposure Where, - a **hazard** is defined as the potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources, - **vulnerability** is defined as the propensity or predisposition to be adversely affected, and - **exposure** is the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected.

Any quantification of hazard, vulnerability or exposure is bound by uncertainty[2], which the IPCC defines as such:

> "*a state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts*)" (IPCC, 2013)

One could refer to climate hazard probability and severity as hazard impact potential, i.e. the climate component of risk. This section on climatological analysis will outline:

1. Climate data availability.
2. Methods employed for the calculation of historical climatologies, variability, recent and future trends in climate indices.
3. Relationship between some of the climate indices and climate risk through the concept of hazard impact potential.

A climatology is defined as a **statistical description of the typical climate conditions at a given location**. Section **4. Key Findings** provides an overview of the key results of the climatological analysis in terms of historical climatologies, variability, recent and future trends across the OECS region found in **ANNEX II** and, where spatially differentiated, per sub-region, geographic setting, or country/territory. It further summarises the hazard impact potential for the different hazards assessed. A detailed description of the climate indices employed in the climatological analysis is found in **ANNEX I**.

[2] The Intergovernmental Panel on Climate Change (IPCC) defines **uncertainty** as an expression of the degree to which a value or relationship is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. Uncertainty may originate from many sources, such as quantifiable errors in the data, ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures, for example, a range of values calculated by various models, or by qualitative statements, for example, reflecting the judgment of a team of experts. (IPCC 2017)

2.2 Climate Data Availability

Historical climatologies, climate variability and recent trends were calculated using observational data mostly from manual/manned weather stations and rain gauges, while projection data on temperature and rainfall-based climate indices relied on a new generation of high-resolution regional climate projections produced by Caribbean researchers for the Caribbean.

2.2.1 Observed Climate Data

Three main sources of observational climate data were pooled to enable as detailed and robust a climatological analysis as possible under the time and budgetary constraints of the CCASAP project.

- Under the Caribbean Meteorological Organisation agreement, the Caribbean Institute for Meteorology and Hydrology (CIMH) operates, amongst others, as a Regional Climate Data Centre. As such, climate data is stored in support of its 16 member states, including all independent states and the British Overseas Territories of the OECS. Climate data remains the property of the National Meteorological Services in the respective CMO Member States.
- Under an informal agreement between all National Meteorological Services that participate in the Caribbean Climate Outlook Forum, each Service shares a limited amount of their own national climate data. As the WMO designated Regional Climate Centre (RCC) for the Caribbean, the CIMH coordinates the CariCOF, including the data sharing and product delivery. Hence, most of the daily and monthly data utilised in the climatological analysis from non-CMO, OECS Associate Members draws on data shared by CariCOF. The latter are stored in the CariCOF Outlook Generator (CAROGEN) online data access and climate outlook production platform. Météo France regularly provides a limited set of sub-daily, daily and monthly climate data to the CAROGEN, but retains property of the data shared.
- Additional observational climate data has been published and are freely available in the form of climate indices by Stephenson et al. (2014).

As can be seen from **Table 1**, observational data from land-based weather stations are available and quality-controlled for all countries and overseas territories, with the exception of the British Virgin Islands (BVI). That said, depending on the territory, more or less data could be utilized for assessments of the climatological norm and recent observed trends. For the heat-related extreme indices, the so-called Heat Index requires hourly time-series (identified as sub-daily in **Table 1**), which are only available for seven countries. Most of the heat-related and rainfall extremes-related indices are calculated based on daily time series, for which at least one station record is available in all countries and territories, except Anguilla, the BVI and St-Martin. Most drought- and dryness-related indices rely only on time-series of monthly rainfall totals, which are available in all countries and territories, except for the BVI. Long time-series of data records (at least 20 years) are needed to produce robust statistical analysis and develop relevant historical climatologies.

Table 1 details the availability of data for every country or territory, including Montserrat, where less than 20 years of data are available. In general, the availability of data records from automatic weather stations across all OECS Members are much shorter than 20 years – or, even under the more restrictive benchmark of 30 years recommended by the World Meteorological Organization (WMO) for the calculation of robust climatological averages. This problem has been remediated by using available records from manual/manned weather stations and rain gauges. However, the only available data for Montserrat has a record which does not reach 10 years. Therefore, any decision made based on the historical climatological averages for Montserrat should be informed by the much larger uncertainties as compared to places with much longer records.

Table 1 : Available quality controlled observational data from land-based weather stations

Territory / Island	Sub-daily data		Daily data		Monthly data	
	variables	# of stations	variables	# of stations	variables	# of stations
Anguilla					RR	1
Antigua and Barbuda	T, RH, HI	1	RR, TX, TN, HImax	1	RR, TX, TN, TM	1 (RR: 3)
British Virgin Islands						
Dominica	T, RH, HI	2	RR, TX, TN, HImax	2	RR, TX, TN, TM	2
Grenada	T, RH, HI	1	RR, TX, TN, HImax	1	RR, TX, TN, TM	1 (RR: at least 3, TM: 2)
Guadeloupe			RR, TX, TN	1	RR	8
Martinique	T, RH, HI	1	RR, TX, TN, HImax	1	RR, TX, TN, TM	1 (RR: 12)
Monserrat			RR, TX, TN	1*/**	RR, TX, TN, TM	1*/**
St. Kitts and Nevis	T, RH, HI	1	RR, TX, TN, HImax	1	RR, TX, TN, TM	1 (TM: 2)
Saint Lucia	T, RH, HI	2	RR, TX, TN, HImax	2	RR, TX, TN, TM	2 (RR: 4)
St-Martin					RR	2
St Vincent and the Grenadines	T, RH, HI	1	RR, TX, TN, HImax	1	RR, TX, TN, TM	1 (RR: 3)

*	less than 20 years of data	TX	maximum temperature
**	no quality control	TM	mean temp.
T	dry bulb temperature	TN	min. temp.
RH	relative humidity	Himax	daily max. heat index
HI	heat index	RR	precipitation

2.2.2 *Climate Projections*

Climate change puts pressures on societies and natural ecosystems by driving them closer to or beyond the thresholds of their coping ranges. Therefore, climate projections are utilized to help provide the scientific evidence base for societies to adapt to climate change in future and hence build climate resilience for future generations. Such projections provide necessary insight to support long term planning for infrastructure, societal activities and the protection of environmental resources. The most widely used tools to assess and simulate future or projected climates are Global Climate Models (GCMs, which in climate science are technically called General Circulation Models or Earth System Models). These models simulate to a great level of detail and reasonable accuracy how the climate is likely to behave around the world provided a scenario of socio-economic development or external physical factors that would affect the energy balance of the earth's climate system. The three emissions and development scenarios most recently elaborated by the Intergovernmental Panel on Climate Change (IPCC) are the RCP2.6 (scenario based on a low carbon emissions future), RCP4.5 (medium level of emissions) and RCP8.5 (high emissions). The major advantage of GCMs for the purpose of assessing how climate may change through time in future, is that they provide a full spatio-temporal coverage of earth's atmosphere.

However, for the purposes of small islands in the OECS region, the spatial resolution of GCMs is far too coarse to allow detailed sub-regional analysis of future heat, drought and other climate extremes. Regional Climate Models (RCMs), a downscaled version of GCMs at the regional level, offer finer spatial resolutions for Islands and sub-regional analysis. Among the projections run by a multitude of different GCMs and used in the IPCC's Fifth Assessment Report and many studies thereafter is the HadGEM2 earth system model. To enable sub-regional analysis of trends in extremes, downscaled simulations can be performed using the PRECIS regional climate model. Partnerships with the Climate Studies Group Mona (CSGM) of the University of the West Indies and the Cuban Instituto de Metereologia (INSMET) enabled the utilisation of new projections of trends in a number of climate extreme indices as closely consistent with the observed trends as possible. Downscaled simulations of RCP2.6, RCP4.5 and RCP8.5 were run using the PRECIS regional dynamical climate model at a ~25km x 25km horizontal resolution. The PRECIS simulations were forced by CMIP5 global projections using the HADGEM2 global climate model and were run from 1961 to 2098. A set of three scenarios using the finest resolution available to date presents a substantial advancement in terms of representing the small islands of the OECS region over any previous set of projections. This enables the calculation of indices with detail at sub-regional levels. Downscaled regional model outputs had been post-processed and made available by CSGM for the entire period of 1961-2098, with the exception of the calculated Standardized Precipitation Index (SPI) – an index which is elaborated on below and in **ANNEX I** – for which outputs from 2020 till 2090 were calculated. A special emphasis is placed on two-time horizons: a short-term horizon, namely the 2020s (relevant within the current political context), and a mid-term horizon, namely the 2040s, relevant for infrastructure planning and many other societal and environmental systems.

2.2.3 *Tropical Cyclones, Sea Level Rise and Sea Surface Conditions*

With respect to recent and future trends in tropical cyclones, sea level rise, sea surface temperature and salinity, this desktop review was produced using the best available data and science-based knowledge. A CSGM- and CIMH-led report entitled '***The State of Caribbean Climate in 2017:***

Information for Resilience Building.' which is expected to be published in 2020, served as the main basis and starting point for the desktop review.

2.3 Calculation of Historical Anomalies, Variability and Trends and Projections

While it is often said that data paucity hampers detailed climatological analysis in the region, a sufficiently high number of local stations is available to reproduce the major spatial differences in heat-related or drought/dryness-related climate indices. This is because both heat and, even more so, drought and dryness are large scale processes with limited local variability. In addition, temperatures are also temporally far less variable than rainfall. The analysis of excessive heat in terms of hot and humid days (i.e. days with a maximum daily heat index among the top 10% of the historical record) formed a particular case, however. Hourly temperature and relative humidity records were required for the analysis. Because such records are only available from 6 airport locations and in 5 of 6 cases for a period significantly shorter than 30 years, no analysis of variability or trends was pursued.

Ongoing research - obviously proving to be a gap in the analysis - suggests that there is strong correlation between hot and humid days, on the one hand, and hot days (i.e. days with a daytime maximum temperature among the top 10% of the historical record), on the other.. With such strong correlation, and **ANNEX II – Figure 2** showing strong resemblance of the average seasonality between hot and humid days and hot days, it is a fair assumption that trends in hot days, which are analysed in this report, may be indicative for expected trends in hot and humid days (see also **Gap 4** in section 5 Gaps, Conclusions and Recommendations). By contrast, for robust rainfall- and extreme rainfall-related climatological analyses, a larger data sample is required, because heavy shower activity is inherently a small-scale process. This means that there is large spatial variability in extreme rainfall. In addition, temporal variability is much larger for rainfall than for heat-related climatic conditions. This means that much longer records are required to compute robust climatologies and trends for rainfall- and extreme rainfall-related climatic conditions.

In comparison, rainfall occurrence largely depends upon the presence or absence of rainfall producing weather disturbances, which are typically much larger in spatial extent than isolated, heavy showers. This means that the spatial variability of rainfall occurrence tends to be much lower than rainfall intensity. Hence, climatological analysis on rainfall occurrence can produce robust results representative of a region with fewer records than rainfall intensity. This is one of the main reasons why conclusions on trends and variability of rainfall occurrence-related indices can be made with higher confidence given a relatively small number of daily rainfall records which were calculated from within the context of this project. Rainfall totals are the product of rainfall occurrence, rainfall duration and rainfall intensity. Several climate-related hazards of interest in the OECS region are related to seasonal rainfall totals. Since rainfall intensity is much more spatially variable than rainfall occurrence, drawing confident conclusion based on robust regional climatological analysis must rely on a larger data sample than for the rainfall occurrence-related indices. To that end, a larger number of monthly rainfall records were utilised than the number of daily rainfall records, as indicated by **Table 1**. This section further details how climatologies, variability and trends were computed, analysed and/or visualised.

2.3.1 *Climatologies*

As previously noted, a climatology is defined as a **statistical description of the typical climate conditions at a given location**. Most commonly, historical climatologies represent recent, monthly and annual averages of temperatures (either mean, or daytime maximum versus daytime minimum) and rainfall as found in a local, long term record of weather observations from a weather station or rain gauge. However, historical climatologies can encompass long-term averages, extremes, and probabilities of occurrence of any given weather condition or climate event. It is important to note that climatologies need not necessarily be computed from historical records of observed weather variables but can also be produced using GCM simulated records of past or future time periods, as well as from proxy records such as those derived from satellite products. In the context of the CCASAP project's climatological analysis, historical observed climatologies were primarily computed based on the observational records of daily rainfall, daytime maximum and night-time minimum temperature available from land-based weather stations in the OECS region as given in **Table 1** above. For seasonal rainfall-related analysis, as mentioned before, a larger number of monthly rainfall records were utilised. In order to produce climatologies of observed, monthly average rainfall totals and monthly average daytime maximum and night-time minimum temperatures most representative of the current climate, WMO currently recommends the reference period of 1981-2010 – the recommended period being updated every 10 years, so in 2021 the recommended period will be 1991-2020. That said, for climate change studies, the recommended, ideal reference period is 1961-1990, to capture the inherent decadal and variability of rainfall. A 1961-1990 climatology is hardly achievable for any location in the OECS region with the available data. Several Members and Associate Members have no daily rainfall or temperature records predating the 1980s. Only Martinique's Lamentin Airport station and Antigua's V.C. Bird Airport station data record available to the project date back to before and in the early 1960s, respectively. Hence, the decision was made to compute, wherever possible, 1981-2010 historical climatological averages. Where data time series did not start in the early-1980s or before and at least 30 years of record was needed for robust analysis, any subsequent 30-year period as close as possible to 1981-2010 was utilised. **ANNEX II – Figure 1** summarises the basic seasonality of temperature and rainfall across the OECS region. Records of daily rainfall and temperature which were shorter than 20 years (e.g. all stations in Montserrat, automatic weather station-based records in Saint Lucia and St. Vincent and the Grenadines) were not incorporated in the calculation of Leeward Islands and Windward Islands sub-regional averages. No sufficiently long record of daily temperatures or rainfall are available for Anguilla, the British Virgin Islands, Montserrat or St-Martin, and records from those territories were therefore not used so as not to bias the sub-regional climatologies of the Leeward Islands. However, it was decided that robustness should be prioritised to ensure the evidence-base for climate adaptation coming out of the climatological analysis, which follows the appropriate scientific norms and standards.

Preliminary analyses were performed on Montserrat alone, with the notion that confidence in the analysis for Montserrat is much reduced. Somewhat similarly, monthly rainfall records from automatic weather stations are available for the larger inhabited islands of the Grenadines but span less than 8 years. Therefore, country-wide climatologies of rainfall seasonality across St. Vincent and the Grenadines will be much more robust for St. Vincent than for the Grenadines. Since rainfall seasonality in the Grenadines is very similar to other smaller islands and other coastal areas with low topography across the OECS region, monthly average rainfall totals from one station in Bequia and one in Union Island were added to the same group in **ANNEX II – Figure 1, bottom right panel**. Finally, for the calculation of the historical average seasonality of hot and humid days, the entire period of record was used to calculate station climatologies and, then aggregated into a Leeward Islands average (though only represented by one station in Antigua) or a Windward Islands average (represented by two stations in Dominica, one in Martinique, one in Saint Lucia and one in St. Vincent). This was done in view of the relatively short available period of record of hourly temperature and humidity.

2.3.2 *Variability*

One of the most important sources of climate variability in the tropics and around the world is the El Niño Southern Oscillation, where the El Niño warm phase is characterised by anomalously warm sea surface temperatures in the equatorial Eastern Pacific and the La Niña cold phase by anomalously cold temperatures in that same region. It is well established that El Niño is one of the foremost drivers of drought in the Caribbean (e.g. Giannini et al., 2000). The historical temperature and rainfall record in the OECS further suggest strong correlation between strong El Niño events and temperature as well as the frequency of heatwaves and, to a certain extent, dry spells. Wherever patterns of variability and extreme value recurrence appear to be linked to strong El Niño events, mention is made in **ANNEX II**.

2.3.3 *Observed and Future Trends*

2.3.3.1 Observed Trends

Though the climate record does not go back more than three to four decades in most countries and territories of the OECS region, this should be a sufficiently long period to distinguish whether trends in heat-related climate indices have manifested.

For rainfall-related climate indices, this is potentially too short, since year-to-year variations (i.e. interannual variability) are much larger than the trends across the entire Caribbean (e.g. Stephenson et al., 2014).

- For the Leeward Islands, observed climate data records with at least two records containing observations at any time during that interval span the years 1969 to 2008.
- For the Windward Islands – using the same minimum requirement of at least two stations with observation at any time –, the climate records span 1973 to 2018.

As recommended by the WMO Expert Team on Sector-specific Climate Indices ET-SCI, climate indices (see **ANNEX I** for an overview) were produced using their statistical platform CLIMPACT2, written in R (which can be accessed at https://climpact-sci.org/) to analyze decadal trends. Other trends were calculated using least square regression in Microsoft Excel.

2.3.3.2 Projected Future Trends

Given that the main time periods of interest within the CCASAP project are the short-term (2020s) and mid-term (2040s), the most appropriate climate prediction method to estimate future trends are utilising future climate projections, where climatic changes are mainly driven by external forcing (such as increased atmospheric greenhouse gases concentrations). While decadal predictions, which are mainly driven by initial conditions of the atmosphere, ocean and vegetation, are being developed, their skill levels have not proven to be enough to provide robust and useful information for an entire upcoming decade. (More information on decadal predictions can be found at https://www.wcrp-climate.org/gc-near-term-climate-prediction.) Therefore, the CCASAP did not include information from the latest decadal predictions for the 2020s.

- Projected trends at the sub-regional scale were done by averaging grid cell outputs between 15.7°N to 19°N, 65°W to 61°W for the Leeward Islands, 11.9°N to 15.7°N, 62°W to 60.7°W for the Windward Islands.
- Projected trends are presented either as changes in decadal average values for the 2020s and 2040s compared to the simulated 1961-1990 climatology or 1981-2010 observed climatology, or visually as projection curves (where interannual variability is large, a five-year moving average is applied to emphasise the longer-term trend over the short-term variability).

2.4 Climate Hazard Potential

Climate extremes can be hazardous when conditions go beyond thresholds that bound a coping range. As recognised by the IPCC in their equation for risk calculation, the extremes pose a risk to a system if the system is exposed and vulnerable to these hazards. Building resilience to climate, including climate variability and climate change, therefore entails adapting our systems such that our coping ranges extend to envelop both ends of the extremes (e.g. drought and excessive rainfall, extreme heat and cold), leading to strong reduction in risk. To help facilitate climate risk estimation for the range of climate-related hazards assessed in this study, a partly quantitative, partly qualitative analysis of hazard impact potential was performed using the available climate data. That is, wherever possible – given data availability constraints – quantitative estimates of hazard impact potential have been calculated. This is the case for heat, flash floods, drought and dry spells at the (sub-)regional scale. **Hazard impact potential** can be defined in simple terms as below.

> ***the probability of a hazard to strike in an area at a certain level of severity/intensity that would cause socio-economic and/or environmental impacts if there are vulnerable and exposed persons or assets in that area.***

For the purpose of this study, **climate-related hazard impact potential** is defined as below.

> ***the frequency or proportion of time that a climate condition crosses a threshold beyond which significant impacts are expected to occur if striking in a vulnerable area/community with exposed assets***"

In an ideal case – i.e. without the existing climate data limitations –, quantitative estimation of hazard impact potential would be possible in terms of the historical average seasonality of the potential, as well as, its temporal and spatial variability and observed, recent / projected trends for all hazards except drought. In the sub-sections below, the method for quantitative estimation of heat, flash flood, drought and dry spell impact potential at the (sub-)regional scale is illustrated. Depending on the nature of the hazard, this estimation is differentiated by sub-region (i.e. Leeward vs. Windward Islands) or topography (i.e. small islands and areas with limited topography vs. larger islands and areas surrounded by steep hills or mountains). In many cases, however, a quantitative analysis-based, categorical scale of hazard impact potential may be more useful in communicating risk level and, thereby, deciding upon priorities in adaption. To facilitate such, the table below outlines how the potential is formulated for all hazards at the regional and, wherever relevant, country/territory level in the **FINDINGS – Climatological analysis** section. Selected potential climate impacts findings are analysed at the end of the Section 4 Findings.

Table 2 : Report's classification structure for hazard impacts

Potential level	Colour code	Frequency or proportion of time of hazard occurrence
extremely high		>80%
high		50-80%
moderate		20-50%
slight		10-20%
marginal		0-10%
none		0%

3. KEY FINDINGS FOR THE OECS REGION

3.1 Heat Trends

Highlights

Regarding the **current nature of heat as a hazard**:

- The **heat impact potential is moderate on average** during the peak of the heat season for hot days (as well as, for hot nights, uncomfortably hot days and nights, hot and humid days, and heatwaves, see **ANNEX II – Figure 2**).
- There is a clear, **observed positive trend** in the number of hot days (as well as, hot nights, uncomfortably hot days and nights, hot and humid days heatwaves, see **ANNEX II – Table 1**), with an additional 10-30 hot days per year each new decade**;**
- Regionally, there has been a **four- to five-fold increase in the annual heat impact potential** between the observed period before 1995 and after that year (see also **ANNEX II – Figure 3**), increasing from mostly marginal before 1995 to slight or moderate after 1995, testifying that heat is a relatively new hazard.

Regarding the **future nature of heat as a hazard**

- Despite the slower observed rise in heat impact potential compared to the projected rise for the Windward Islands, the **future will hold high to extremely high heat potential**.
- High to extremely high heat potential during the heat season will very likely manifest **as soon as the 2020s**, regardless of the future climate change scenario, and is virtually certain to **remain during the 2040s**.
- **ANNEX II – Figure 4** tells us both conclusions above hold true for **daytime and night-time heat**.
- With the devastating heat impacts on public health, national productivity and agriculture, being seen where such risk quantification was done, and given the heat impact potential in the region, it should be quite obvious that adequate climate change adaptation in the OECS region will require significant investment to tackle this relatively new problem called heat.

3.1.1 Observed Trends in Heat

Increasing heat exposure is among the first and fastest climate-related hazards to manifest with as climate changes. Heat stress – through excessive heat exposure – can affect many aspects of our society and our environment, see section 2. Methodology – Climatological Analysis – Hazard Impact Potential – Heat Impact Potential.

Heat stress tends to be most acute during the Caribbean heat season (May to October), during which most heat waves occur. Heat waves are the climate extreme that increases fastest in terms of intensity, frequency and duration across the OECS region. Before 1995, not many heat waves occurred in the region and the heat season in the OECS region was mostly restricted to August – September – October. Nowadays, while heat waves are even more frequent during those three months than before, they occur between May and July as well – particularly on leeward sides of islands sheltered from trade winds.

With respect to day-time heat, Table 3 summarises key elements of the current heat climatology, variability and recent trends at both the sub-regional and, where the available data permits, country/territory levels. The threshold temperature in the second column refers to the daytime maximum temperature of the top 10% warmest days in the historical record between 1981 and 2010 – statistically known as the 90th percentile. A hot day is any day with a daytime maximum temperature exceeding the 90th percentile. The peak season refers to the timing in the year of the most frequent hot days. Annual average numbers of hot days were calculated for the existing data in the records between 1971 and 1994 (fourth column), and between 1995 and 2018 (sixth column). Variability is also computed for those two periods as given by the range between the bottom and top 10% of the number of hot days per year in the record (fifth column and seventh column, respectively). Observed trends per decade in the annual number of hot days are given in the eighth column with robust warming trends in bold red font. A robust trend is defined here as statistically significant at the 95 % confidence level. Cell colouring follows the Table 2 hazard impact potential levels. For the Associate Members Anguilla, BVI, Montserrat and St-Martin – for which no calculations were possible due to data unavailability –, colouring follows that of the sub-region in which they are situated as a low confidence best estimate. A more detailed overview of the heat analysis can be found in **ANNEX II**.

Table 3 : Heat climatology and recent trends across the OECS region as represented by Hot Days (measured in days)

OECS sub-region / Member / Associate Member	Threshold Temperature	Peak Season	Annual Average *(Until 1994)*	Variability *(Until 1994)*	Annual Average *(From 1996)*	Variability *(From 1995)*	Observed Trend *(per decade)*
Leeward Islands		Aug. to Sept.	13	0 to 30	60	40 to 100	**+19**
Windward Islands		Aug. to Oct.	10	5 to 20	47	20 to 75	**+13**
Anguilla							
Antigua & Barbuda (Antigua)*	31.6°C	Aug. to Sept.	20	0 to 50	31	10 to 75	+2
British Virgin Islands							
Dominica (wind sheltered)	32.6°C	May to Oct.	9	0 to 20	57	20 to 100	**+24**
Dominica (wind exposed)	31.4°C	Aug to Oct.	6	5 to 10	47	5 to 105	**+21**
Grenada*	31.7°C	Aug. to Sept.	17	5 to 40	37	20 to 65	+3
Guadeloupe (Basse Terre)	30.9°C	Aug. to Oct.	2	0 to 5	70	35 to 110	**+26**
Martinique	31.8°C	Aug. to Oct.	14	0 to 30	49	15 to 95	**+11**
Monserrat							
Saint Lucia (wind sheltered)**	32.2°C	May + Sept. to Oct.	2	0 to 5	28	5 to 65	+8
Saint Lucia (wind exposed)	31.6°C	Aug. to Oct.	11	0 to 25	61	30 to 105	**+16**
St. Kitts and Nevis (St. Kitts)	32.2°C	Jul. to Oct.	32	15 to 50	67	40 to 90	**+30**
St-Martin							
St Vincent and the Grenadines (St. Vincent south coast)	31.5°C	Aug. to Oct.	9	5 to 15	56	40 to 90	**+21**

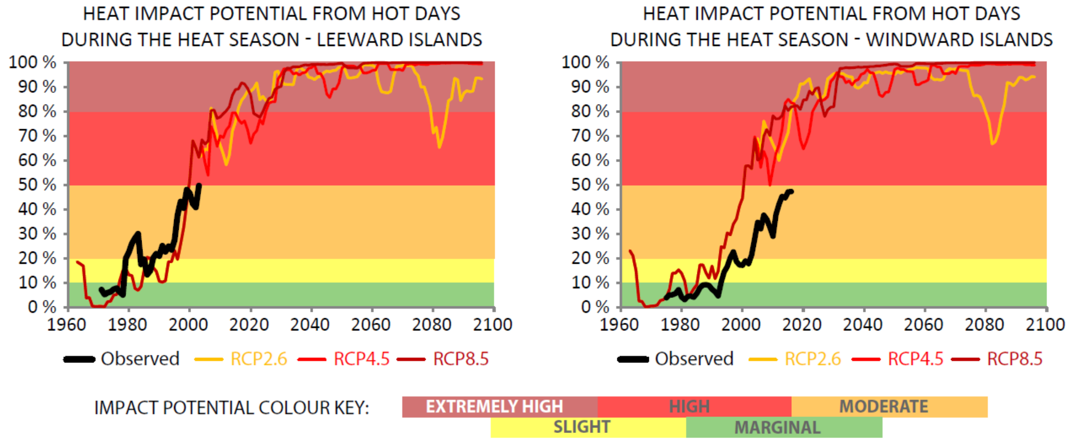
* reduced confidence in the number of hot days due to an apparent inhomogeneity in the day-time temperature record

** reduced confidence in the number of hot days prior to 1995 with only 3 years of data prior to 1995

3.1.2 Projected Changes in Heat

Given the observed, strong warming trend in heat indices, and the IPCC suggesting that warming will continue throughout the 21st century, it should not come as a surprise that the projections of heat indices follow that trend. **Figure 2** below shows the heat impact potential during the **heat season of May to October** as measured by the percentage of hot days during those six months. Shown in black is an average for stations located in either the Leeward Islands or the Windward Islands. In yellow, red and dark red are the RCP2.6, RCP4.5 and RCP8.5 projections, respectively. The observed, sub-regional averages have only been calculated where data was found for at least two stations per sub-region. A 5-year running mean smoothing has been applied to all curves to highlight trends and multi-annual to decadal variability. The different levels of heat impact potential are defined according to **Table 2** and colour-coded for visual aid.

Figure 2 : Recent and future heat impact potential in the Leeward (left) and Winward (right) islands as measured by the percentage of hot days during the annual heat season (May to October)



3.2 Extreme Rainfall

Highlights

Regarding the current nature of extreme rainfall as a trigger for flash floods:

- The **seasonality of extreme rainfall and flash flood potential** is **different between the Leeward**[3] **and the Winward**[4] **Islands** (*high confidence*). The Leeward Islands experience two distinct seasons for such, with moderate potential during April to May and high to extremely high potential during August to November. By contrast, the Windward Islands only experience one main season, with high to extremely high potential during August to November, during which typically one or two extreme wet spells occur.
- **Mountainous islands** are associated with **higher rainfall thresholds to produce extreme wet spells** compared to areas with low topography (*high confidence*). For areas with similar topography, the threshold does not, however, appear to differ between the Leeward Islands and the Windward Islands.
- The **highest flash flood potential** appears to be during the month of **November**, with around 40% in a majority of countries and territories.
- There is virtually no to only marginal flash flood potential from January to March (*high* confidence) across the region and only marginal potential during June and July in the Leeward Islands (*medium confidence*).
- There have been no observed, robust, recent trends in any extreme rainfall index, suggesting the **nature of extreme rainfall may not yet have changed** across the OECS region (*medium confidence*).

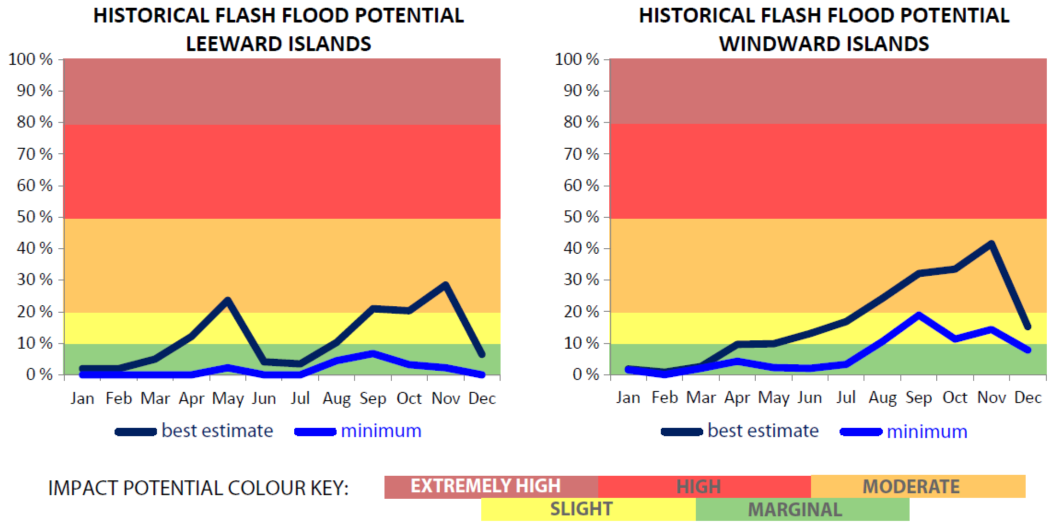
Regarding the future nature of extreme rainfall as a trigger for flash floods:

- There is **little sign that robust changes** in the nature of extreme rainfall will manifest **by the 2020s or the 2040s**. Rather, the projections suggest that year-to-year variability in the frequency and severity of extreme rainfall is likely to remain similar to that observed in recent decades (*medium confidence*).
- As a direct consequence of conclusion 1, the **seasonality of flash flood potential** is expected to remain **similar in the 2020s and 2040s as it is at present** (*medium confidence*);
- There is *low confidence* that the **frequency of heavy rainfall could decrease by up to 25%**, but *medium confidence* that the **contribution of extreme rainfall to annual rainfall totals will increase by up to 50%** by the end of the 21st century.
- Concomitantly, projections suggest that **extreme rainfall intensity may increase by 50-100%** by the end of the 21st Century (*medium confidence*).
- Conclusions above imply that the **severity of flash floods may increase** while the **frequency of flash floods may decrease towards the 2090s** (*low confidence*).

3.2.1 Trends in Extreme Rainfall

As opposed to trends in heat (**ANNEX II - Table 1**), there are no sub-regional robust, observed trends in extreme rainfall (**ANNEX II – Table 4**). Therefore, it is not an unreasonable assumption to state that the climatology of extreme wet spells is not changing dramatically. Given this assumption, the best way to differentiate flash flood[3] potential temporally is looking at its observed, average seasonality. The seasonality of flash flood potential shown in **Figure 3** for the Leeward[4] and Windward[5] Islands was calculated from the sub-regional averages of both (1) reported floods, which is virtually certainly an underestimate of the actual number of floods, since not all floods are reported; and (2) **extreme wet spells** (*i.e. periods of 3 consecutive days with rainfall totals exceeding the 99th percentile of historical 72-hour rainfall totals*) occurrence within each island, which can be regarded as a best estimate, as based on the hit score of 45-100% for the largest island in 5 of 6 OECS Member States. The flood reports across the largest island of each of the OECS Member States were compiled from the Caribbean Climate Impacts Database (cid.cimh.edu.bb). In contrast with the heat impact potential, the calculated flash flood potential does not look at the percentage of time spent in the hazard. Unlike excessive heat, a relatively slow onset event, in which the impacts of the hazards tend to continue to aggravate with longer exposure, flash floods are a fast onset event. Even though damage and losses tend to aggravate depending on the duration of inundation, flash floods tend to recede relatively fast as well. Hence, one could argue that the flash flood potential is not as much linked with the percentage of time spent in flash floods, but rather the frequency of flash floods during a given period. That is why **Figure 3** presents flash flood potential as the expected probability of flash floods per month. One advantage of this representation is that the total flash flood potential over a given number of months equals the sum of the monthly potentials for all months in that period.

Figure 3 : Climatological average seasonality of flood impact potential in the Leeward Islands (*left*) and Windward Islands (*right*).



As can be seen from the left panel of **Figure 3**, the Leeward Islands experience two periods per year with moderate potential for flash floods – one in May and in one from September to November. By contrast, moderate potential only occurs on average during one season – each month from August to November – in the Windward Islands. The discrepancy is mainly related to the seasonality of rainfall occurrence, with an early-season peak only found in the Leeward Islands, rather than rainfall intensity when it rains – of which annual cycle is quite similar in both the Leeward and Windward

[3] A flash flood is defined by the Oxford dictionary as a sudden local flood, typically due to heavy rain.
[4] Leeward islands include : St. Lucia, Saint Vincent and the Grenadines, Grenada, Martinique and Dominica.
[5] Winward islands include: The British Virgin Islands, Anguilla, Saint Martin, Saint Kitts and Nevis, Antigua and Barbuda, Montserrat and Guadeloupe.

Islands. This discrepancy forms the main argument for the separate calculation of the flash flood potential for the Leeward and the Windward Islands.

Table 4 elaborates on **Figure 3**; in that it further specifies the seasonality of the best estimate flash flood potential by country/territory. In the *second column*, the 99th percentile of 72-hour rainfall totals in the historical record per country/territory is identified for all available records between 1981 and 2010 within that country/territory. This is done to get a sense of the extreme rainfall intensity needed to engender a flash flood within a given country/territory. Finally, the third, fourth and fifth columns detail the historical average frequency of extreme wet spells per year, for the early extreme rainfall/flash flood season in the Leeward Islands – i.e. April to May – and for the main flash flood season – i.e. August to November. Note that the total flash flood potential over each of those two seasons can be easily calculated by summing the potentials of the months comprised in them. When the seasonal potential exceeds 100%, this means there are more than 1 expected extreme wet spells during that season. Finally, for the Associate Members Anguilla, BVI, Montserrat and St-Martin – for which no calculations were possible due to data unavailability –, colouring follows that of the sub-region in which they are situated as a *low confidence* best estimate.

Table 4 : Extreme wet spells climatology and the seasonality of flash flood potential.

OECS sub-region / Member / Associate Member	Threshold 3-day rainfall	Annual frequency	Apr. to May frequency	Aug. to Nov. frequency	Jan. %	Feb. %	Mar. %	Apr. %	May %	June %	July %	Aug. %	Sept. %	Oct. %	Nov. %	Dec. %
Leeward Islands	84 - 148 mm	1.4	0.4	0.8	2	2	5	12	24	4	4	10	21	20	29	7
Windward Islands	80 - 156 mm	2.0	0.2	1.3	2	1	3	10	10	13	17	24	32	34	42	15
Anguilla																
Antigua & Barbuda (Antigua)	84 mm	1.9	0.5	1.2	0	0	5	13	35	3	3	15	35	25	48	8
British Virgin Islands																
Dominica	156 mm	2.3	0.5	1.4	2	0	2	18	28	8	14	32	40	26	42	14
Grenada	80 mm	1.7	0.1	0.9	3	0	0	3	6	15	27	15	18	24	36	24
Guadeloupe (Basse-Terre)	148 mm	1.2	0.4	0.6	2	2	4	14	24	4	4	12	6	16	22	8
Martinique	111 mm	2.2	0.2	1.6	0	0	0	12	4	14	14	40	32	46	40	16
Monserrat																
Saint Lucia	105 mm	2.1	0.2	1.3	4	4	8	12	8	10	14	22	34	38	38	16
St. Kitts and Nevis (St. Kitts)	99 mm	1.1	0.2	0.6	4	4	6	10	12	6	4	4	22	20	16	4
St-Martin																
St Vincent and the Grenadines (St. Vincent)	123 mm	2.0	0.1	1.3	0	0	3	3	3	18	15	12	36	33	52	6

3.2.2 *Projected Changes in Extreme Rainfall*

The temporal focus in this study is on the short term (2020s) and medium term (2040s). Based on **ANNEX II – Table 4** and **ANNEX II – Figure 8**, neither the observed extreme rainfall records, nor the extreme rainfall projections indicate any robust changes before the 2050s. That said, projected changes in extreme rainfall beyond 2050 suggest that the heavy rainfall may occur 25% less frequently by the 2090s (RCP4.5 and RCP8.5), while the proportion of annual rainfall totals from extremely wet days is projected to increase by up to 50% by the 2090s (RCP2.6, RCP4.5 and RCP8.5). Should such trends indeed manifest, this would imply a doubling in rainfall intensity on extremely wet days compared to recent decades. Since, statistically and physically, there is a close link between extremely wet days and extreme wet spells, a strong increase in the former is likely to increase the severity of flash floods during the second half of the 21st Century. However, there could potentially be a reduction in the number of extreme wet spells that produce flash floods.

3.3 Dry Spells

Highlights

Regarding the **current nature of dry spell impact potential** on rainfed crops:

- The **dry spell impact potential** is **much higher on smaller islands and in areas with low topography** than in **mountainous areas** (*high confidence*). The annual cycle is very similar in both, with a peak season during the second half of the dry season (i.e. March to May), whereas the lowest potential typically is found between June and October.
- In **mountainous areas**, dry spells only pose a high enough risk level to crop growth between January and May, providing for a 7-month long, virtually risk-free period (*high confidence*).
- In **smaller islands and areas with low topography**, **planting sensitive crops without protective measures or supplemental irrigation may be too risky**, without any period where the potential is lower than moderate. In any case, with high to extremely high dry spell potential from at least January to April, rainfed crops – apart from varieties most resilient to wilting – may not give much yield without irrigation in at least 50% of years.
- There have been no observed, robust, recent trends in dry spell indices, suggesting the **nature of dry spells may not yet have changed** across the OECS region (*medium confidence*).

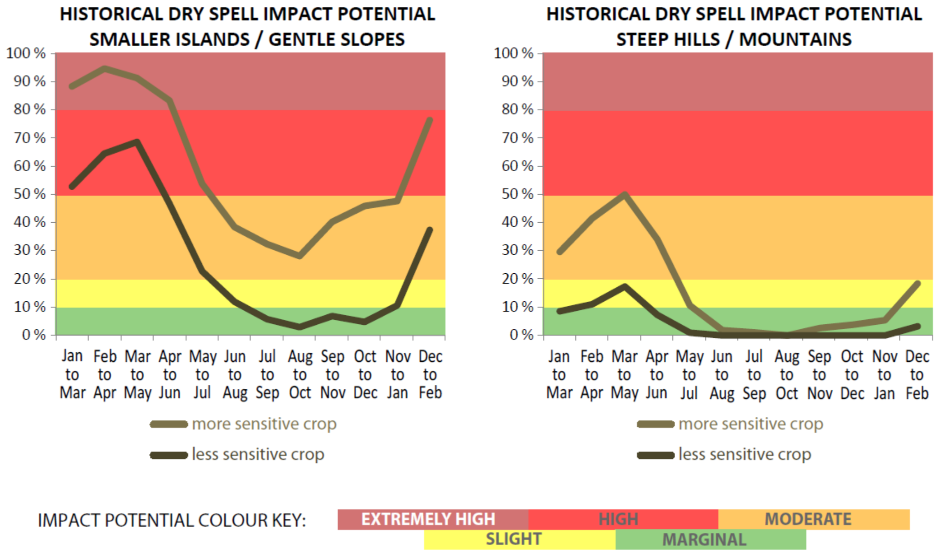
Regarding the **future nature of dry spells and their impact potential** on rainfed crops in the OECS region are:

- There is **little sign that robust changes** in the nature of dry spells will manifest **by the 2020s or the 2040s**. Rather, the projections suggest that year-to-year variability in the frequency and duration of dry spells is likely to remain similar to that observed in recent decades (*medium confidence*);
- As a direct consequence of conclusion 1, the **seasonality of dry spell impact potential** on rainfed crops is expected to remain **similar in the 2020s and 2040s as it is at present** (*medium confidence*).
- There is *high confidence* that the **frequency of dry spells could increase by between 10% and 30%**, and *medium confidence* that the **length of the longest dry spells will increase by 25% to 50%** by the end of the 21st Century.
- The conclusion above implies that the **dry spell impact potential will significantly increase between the 2040s and the 2090s** (*high confidence*).

3.3.1 Observed Trends in Dry Spells

Similar to extreme rainfall (**ANNEX II – Table 4**) – and therefore flash flood potential –, there are no sub-regional robust, observed trends in dry spells (**ANNEX II – Table 3**). Therefore, it is not unreasonable to assume that the climatology of dry spells is not changing dramatically. Given this assumption, the best way to differentiate dry spell impact potential temporally is looking at its observed, average seasonality. **Figure 3** presents the dry spell impact potential for crop damage in terms of the historical average probability of at least three or at least five 7-day dry spells per three-month period. The rationale for choosing two different thresholds (three versus five 7-day dry spells) in the calculation of potential is that some crops are more sensitive to dry spells than others. Rather than adopt a one-size-fits-all approach, two different possibilities are given. In displaying the potential at two different frequency thresholds, an attempt is made at visualising how the dry spell impact potential of a given crop can differ from another crop with a different tolerance level. All station records utilised to calculate the potential are taken from weather stations in coastal areas. As opposed to **Figure 1** and **Figure 2**, where the potential was differentiated into Leeward and Windward Islands, in the case of the historical average seasonal frequency of 7-day dry spells, differences are much more a function of topographic situation of a given location. In this case, two clusters of locations were selected for similar seasonality, namely: (i) areas that are relatively flat or are characterised by gentle slopes (e.g. the Maurice Bishop International Airport in the far south of Grenada), pooled with locations on the smaller islands (i.e. St. Kitts); and (ii) areas in the vicinity of steep hills or mountains (e.g. the old ET Joshua Airport on St. Vincent).

Figure 4 : Climatological average seasonality of dry spell impact potential for a more sensitive crop (light brown) or a less sensitive crop (dark brown).



Three clear observations are immediately apparent from **Figure 4**: (i) in areas surrounded by steep hills or mountains, dry spells are much less frequent than in relatively flat areas or smaller islands; (ii) the frequency of dry spells peaks in the March to May period; and (iii) in mountainous areas, the impact potential does not exceed 50% at any time of the year and is marginal at most during the wet season (June to November). By comparison, in smaller islands and areas surrounded by low topography, dry spell impact potential is high to extremely during much of the dry season. In such areas, the potential remains moderate throughout the wet season for crops that are highly sensitive to dry spells, meaning the risk of planting sensitive crops in such areas without rigorous protection against dryness or without supplemental irrigation may be too elevated. **Table 5** further details the historical seasonal dry spell potential for all OECS Members and Associate Members. In the *second column*, it also specifies the annual average number of 7-day dry spells. The latter confirms that areas with low topography or on smaller islands experience many more dry spells (14 on average) than mountainous areas (5 on average). For comparability with other hazard impact potential calculations, the table also highlights the potential for the Leeward Islands and Windward Islands. It should be noted that the annual average number of 7-day dry spells appears higher in the Leeward Islands. This is because the only two stations included in this sub-regional average both belong to the smaller island/low topography category. There is insufficient data to determine conclusively whether there is a robust difference in the climatology of dry spells between the Windward and Leeward Islands. However, when comparing the numbers of dry spells in areas on smaller islands or with low topography for which data are available across both subregions, no differences occur.

Table 5 : Dry spell impact potential for a more and a less sensitive crop

a) DRY SPELL IMPACT POTENTIAL - MORE SENSITIVE CROP

Topographic grouping / OECS sub-region / Member / Associate Member	Annual frequency	Jan. to Mar. (% of years)	Feb. to Apr. (% of years)	Mar. to May (% of years)	Apr. to Jun. (% of years)	May to Jul. (% of years)	Jun. to Aug. (% of years)	Jul. to Sep. (% of years)	Aug. to Oct. (% of years)	Sep. to Nov. (% of years)	Oct. to Dec. (% of years)	Nov. to Jan. (% of years)	Dec. to Feb. (% of years)
Smaller island / low topography	14	88	94	91	83	54	39	33	28	40	46	48	76
Steep hills / mountains	5	29	41	50	34	11	2	1	0	3	4	5	18
Leeward Islands*	15	91	94	92	87	73	59	44	33	51	49	48	76
Windward Islands*	8	52	63	66	52	20	8	9	9	13	20	22	42
Anguilla													
Antigua & Barbuda (Antigua)	15	92	92	90	85	67	58	50	38	50	50	25	81
British Virgin Islands													
Dominica	3	13	25	35	26	11	3	3	0	0	0	0	16
Grenada (low topography)	16	100	100	100	93	41	17	28	38	52	55	83	79
Guadeloupe (Basse-Terre)													
Martinique	6	48	61	65	50	13	2	0	0	4	4	9	24
Monserrat													
Saint Lucia (low topography)	10	71	91	80	66	29	18	14	9	7	32	13	74
St. Kitts and Nevis (St. Kitts)	14	89	95	94	89	78	61	39	28	53	47	71	71
St-Martin													
St Vincent and the Grenadines (St. Vincent)	5	28	38	48	25	7	0	0	0	3	7	7	15

b) DRY SPELL IMPACT POTENTIAL - LESS SENSITIVE CROP

Topographic grouping / OECS sub-region / Member / Associate Member	Annual frequency	Jan. to Mar. (% of years)	Feb. to Apr. (% of years)	Mar. to May (% of years)	Apr. to Jun. (% of years)	May to Jul. (% of years)	Jun. to Aug. (% of years)	Jul. to Sep. (% of years)	Aug. to Oct. (% of years)	Sep. to Nov. (% of years)	Oct. to Dec. (% of years)	Nov. to Jan. (% of years)	Dec. to Feb. (% of years)
Smaller island / low topography	14	52.8	64.5	68.5	46.8	23.0	12.2	6.1	3.3	7.2	5.1	10.9	37.6
Steep hills / mountains	5	8.5	11.0	17.2	7.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2
Leeward Islands*	15	50.6	62.3	67.8	48.9	35.8	24.5	12.2	4.8	9.7	6.8	9.8	29.2
Windward Islands*	8	27.1	33.2	38.0	22.2	4.7	0.0	0.0	0.7	1.8	1.4	4.8	20.3
Anguilla													
Antigua & Barbuda (Antigua)	15	53.8	61.5	63.5	42.3	32.7	21.2	7.7	9.6	7.7	7.7	1.9	23.1
British Virgin Islands													
Dominica	3	0.0	3.1	9.7	5.9	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grenada (low topography)	16	83.3	86.7	86.2	62.1	13.8	0.0	0.0	3.4	6.9	6.9	24.1	48.3
Guadeloupe (Basse-Terre)													
Martinique	6	15.2	19.6	28.3	8.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2
Monserrat													
Saint Lucia (low topography)	10	26.8	46.5	52.3	27.3	6.7	0.0	0.0	0.0	2.3	0.0	0.0	43.6
St. Kitts and Nevis (St. Kitts)	14	47.4	63.2	72.2	55.6	38.9	27.8	16.7	0.0	11.8	5.9	17.6	35.3
St-Martin													
St Vincent and the Grenadines (St. Vincent)	5	10.3	10.3	13.8	7.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.4

* too little evidence to suggest that differences exist in the seasonality of 7-day dry spells in topographically similar locations between the Leeward and Windward Islands

3.3.2 *Projected Changes in Dry Spells*

The temporal focus in this study is on the short term (2020s) and medium term (2040s). Based on **ANNEX II – Figure 6**, **ANNEX II – Table 3** and **ANNEX II – Figure 7**, neither the observed dry spell records, nor the dry spell projections indicate any robust changes before the 2050s. That said, a projected increase in the annual number of 5-day dry spells of between 10% and 30% in the Leeward Islands and between 20% and 30% in the Windward Islands by the end of the Century indicates increasing dry spell potential after 2050. Furthermore, though there were no observed trends for the longest dry spell per year, by the 2090s, the longest spell per year is projected to be up to 25% longer in RCP4.5 and up to 50% longer in RCP8.5. Should such trends indeed manifest, this would imply a further increase in dry spell impact potential.

3.4 Drought

Highlights

Regarding the **current nature of drought impact potential**

- The average **drought impact potential** has often been **moderate during the dry season**, and **slight or moderate during the wet season**.
- the **20 years of observations since 1999 show an increase in long-term drought impact potential** over the 20 preceding years in both the Leeward and Windward Islands.
- **No robust change** has been seen **in the frequency of short-term drought** since the late 1970s.

Regarding the **future nature of drought and its impact potential** on water availability**:**

- **No robust trend in drought impact potential** is seen **before 2050**.
- A **very clear, projected increasing trend** emerges for long-term drought **beyond the 2050s in the RCP8.5 scenario**, with the **2080s** characterised by **high or extremely high potential**.
- An **upward trend beyond the 2050s** is also seen in the **RCP8.5 scenario for short-term drought potential**, with **at least moderate and high potential during the 2080s in the wet and dry seasons**, respectively.
- A **significant, though less discernible upward trend in long-term drought** is also seen in the **Windward Islands during the dry season in the RCP4.5** scenario.
- With the drying trends in SPI-6, **long-term flooding potential may progressively decrease after 2050**.

3.4.1 Observed Trends in Drought

As mentioned previously, drought is an inherent feature of climate variability in the OECS region. In the Caribbean, two of the worst droughts on record occurred within the last period of 10 years of observations – i.e. the 2009-10 and 2014-16 Caribbean droughts – (Trotman et al., 2010), which begs the question whether the nature of drought as a hazard has changed in recent times in the OECS region.

Table 6 provides an overview of the observed drought impact potential per 10-year period at both the short term (*i.e. based on the SPI-6*) and long term (*i.e. based on the SPI-12*) in the dry and wet seasons across the OECS region. The drought impact potential is given as the historical percentage of time spent in impactful drought during each decade.

Table 6 : Observed variability in drought impact potential across the OECS region expressed as the percentage of time spent in drought expressed as the historical percentage of time spent in impactful drought during each decade.

a) SHORT TERM DROUGHT

OECS sub-region / Member / Associate Member	Dry Season					Wet Season				
	1969-78	1979-88	1989-99	1999-2008	2009-18	1969-78	1979-88	1989-99	1999-2008	2009-18
Leeward Islands		21.7	23.7	22.7		9.8	4.2	5.0	14.0	
Windward Islands		9.1	20.7	19.3	21.4		5.1	8.1	9.0	14.0
Anguilla										
Antigua & Barbuda (Antigua)	23.3	15.0	30.0	30.0	32.8	10.0	3.3	8.3	13.3	1.9
British Virgin Islands										
Dominica (wind sheltered)			15.0	28.3	18.3			10.0	15.0	6.7
Dominica (wind exposed)			21.7	25.0	25.0		10.0	11.7	8.3	16.7
Grenada			28.3	3.3	17.5			10.0	3.3	14.8
Guadeloupe (Basse Terre)		28.3	13.3	18.4		9.6	5.0	0.0	14.6	
Martinique	31.7	8.3	16.7	31.7		28.3	1.7	5.0	15.0	
Monserrat										
Saint Lucia (wind sheltered)			11.1	11.7	23.6			10.0	6.7	24.1
Saint Lucia (wind exposed)		9.8	22.2	21.7	16.4		3.7	10.0	6.7	9.3
St. Kitts and Nevis (St. Kitts)			27.8	19.6				6.7		
St-Martin										
St. Vincent and the Grenadines (St. Vincent south coast)			30.0	13.3	27.5			0.0	8.3	12.5

b) LONG TERM DROUGHT

OECS sub-region / Member / Associate Member	Dry Season					Wet Season				
	1969-78	1979-88	1989-99	1999-2008	2009-18	1969-78	1979-88	1989-99	1999-2008	2009-18
Leeward Islands		16.7	23.5	33.5			6.7	3.9	18.5	
Windward Islands		2.9	17.4	21.7	27.5			9.5	11.9	13.0
Anguilla										
Antigua & Barbuda (Antigua)	28	16.7	28.3	38.3	20.8	11.7	8.3	10.0	18.3	11.3
British Virgin Islands										
Dominica (wind sheltered)			18.3	20.0	30.0			8.3	16.7	1.7
Dominica (wind exposed)			23.3	21.7	28.3			10.0	11.7	20.0
Grenada			18.3	1.7	21.1			10.0	0.0	14.8
Guadeloupe (Basse Terre)		16.7	21.7	28.6			5.0	1.7	18.8	
Martinique	31.7	0.0	20.0	35.0		28.3	1.7	10.0	21.7	
Monserrat										
Saint Lucia (wind sheltered)			5.6	18.3	32.7			5.6	10.0	25.9
Saint Lucia (wind exposed)		5.9	13.0	30.0	29.1			11.1	18.3	9.3
St. Kitts and Nevis (St. Kitts)			20.4					0.0		
St-Martin										
St. Vincent and the Grenadines (St. Vincent south coast)			23.3	25.0	23.5			11.7	5.0	6.3

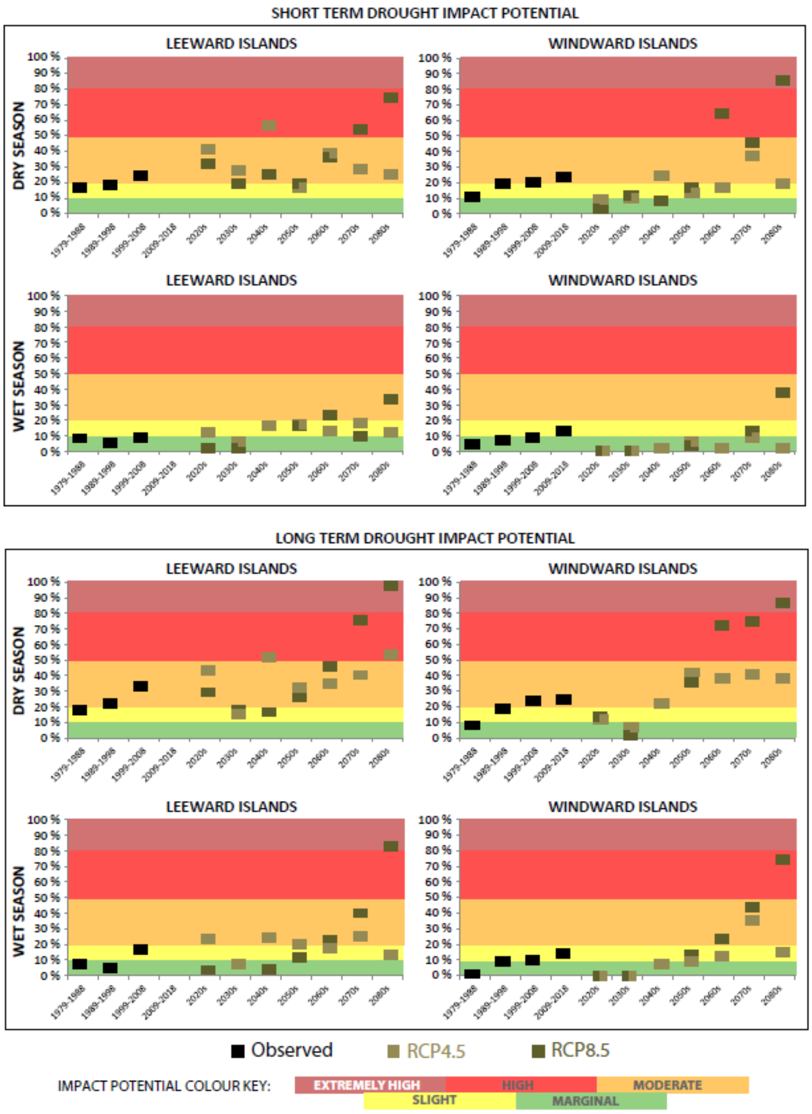
Table 6 indicates a greater frequency of long-term drought – and an associated increase in long term drought impact potential – in the OECS in the 20 years since the late 1990s as compared to 20 years before. This difference is seen both in the Leeward and Windward Islands irrespective of time of year – dry or wet season. In terms of year-to-year variability, **ANNEX II – Figure 9** shows that years characterised by the presence of moderate or stronger El Niño events appear to be strongly correlated with short term and long-term impactful droughts in the Leeward and Windward Islands. Both the 2009-10 and 2014-16 droughts coincided with a strong El Niño (with the 2014-16 El Niño being among the 3 strongest El Niño events since 1950). Finally, in theory, impactful drought should occur close to 20% of the time during the dry season, and less than 10% of the time during the wet season. However, when looking at all 10-year periods of observations for all individual locations in **Table 6**, the potential was more often moderate than not during the dry season and often slight or moderate during the wet season. This implies that the prevalence of impactful drought in the OECS region versus milder drought is relatively high.

3.4.2 *Projected Trends in Drought*

Whereas **Table 6** identified an uptick in long term drought between 1999 and 2018, **ANNEX II – Figure 10** suggests that the projections do not see a continued, robust increase in the prevalence of drought between the 2020s and 2040s. That said, after 2050, the average projected six-month and twelve-month rainfall totals seem to decrease sharply towards the end of the Century. This begs the question how drought impact potential is projected to change in time.

Figure 5 plots the observed and projected trends in drought impact potential as calculated by the proportion of time per decade spent in SPI-6-based short term, impactful drought and SPI-12-based long term, impactful drought. Drought is considered impactful with SPI values below -0.8 during the dry season and below -1.3 during the wet season. Projected trends in SPI were not available for the RCP2.6 scenario but were available for the RCP4.5 and RCP8.5 scenarios. The left panels depict the potential for the Leeward Islands, the right panels for the Windward Islands. The observed trends are coloured black, while the RCP4.5 projection is coloured light brown and the RCP8.5 projection darker brown.

Figure 5 : Observed and projected trends in short term and long-term drought impact potential.



3.5 Tropical Cyclones

Highlights

Regarding the **current nature of the Atlantic Hurricane Season:**

- The historical average **Atlantic Hurricane Season activity** in numbers of tropical cyclones from 1966 to 2009 is: **11.3 tropical storms**, among which **6.2 hurricanes** and **2.3 major hurricanes** (major hurricanes are category 3 or stronger on the Saffir-Simpson scale)
- The **number of storms varies widely between years**, with the El Niño Southern Oscillation in the Pacific and sea surface temperatures (SSTs) in the Tropical North Atlantic (TNA) driving much of the variations from the average.
- Between 1980 and 2016**, 30 hurricanes** have passed within a 200km radius of Anguilla, Antigua and Barbuda, British Virgin Islands, Dominica, Montserrat, St. Kitts and Nevis, Saint Lucia and St. Vincent and the Grenadines, as well as the French territories. Of those 30, 14 were of category 1, 3 of category 2, 2 of category 3, **9 of category 4 and 2 of category 5** (CSGM and CIMH, 2020). In a non-peer reviewed publication by Garnier et al. (2015), the reconstructed number of hurricanes affecting the French Antilles (Guadeloupe, Martinique, St-Barth's and St-Martin) based on historical damage data found in French archives for those territories between 1950 and 2007 was 12: 4 category 1, 2 category 2, **4 category 4 and 0 category 5** hurricanes;
- The **2017 category 5 hurricanes Irma and Maria** impacted all of the countries and territories in conclusion (3), with the inclusion of Saint Lucia and St. Vincent and the Grenadines.
- **A clear upward trend in numbers of named storms** is seen between 1850 and 2015, albeit with ample variability at the multi-decadal time scale. For instance, a marked uptick in Atlantic Hurricane Season activity is noted **since 1995**, with the number of category 4 and 5 hurricanes increasing.

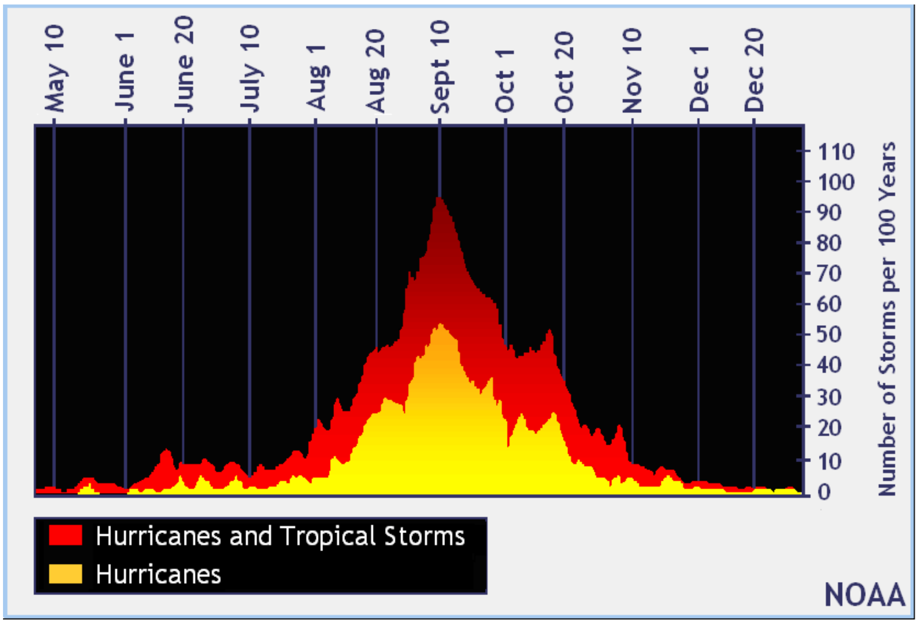
Regarding the **future nature of tropical cyclones:**

- While the total number of named storms is not projected to rise in future (*low confidence*), the **strongest storms** are **likely** to become **2% to 11% stronger in terms of maximum wind speeds** and **possibly more frequent** (*medium confidence*)
- **Rainfall rates** inside hurricanes could **increase by up to 30%**, **increasing flash flood potential**.
- Rising sea levels combined with stronger winds in the strongest storms substantially **increases the impact potential of storm surge and coastal inundation**.
- There is *low confidence* regarding changes in tropical cyclone genesis, location, tracks, duration, or areas of impact.

3.5.1 Observed Variability and Trends in the Atlantic Hurricane Season

As part of the Lesser Antilles, which, latitudinally, are within the **Atlantic Hurricane Belt**, the entire OECS region is prone to the passage of tropical cyclones, including tropical depressions, named tropical storms and hurricanes. As seen in the left panel of **Figure 6**, the **Atlantic Hurricane Season** (officially running from June 1st to November 30th), **peaks between mid-August and mid-October** and is centred around September 10th. The main reason for the timing of the peak is the annual peak of warm sea surface temperatures (SSTs) in the Caribbean Sea, the Gulf of Mexico and the tropical and sub-tropical North Atlantic Ocean around that time. The high SSTs from August to October provide ample heat energy to fuel the formation and intensification of tropical cyclones. During years when the tropical North Atlantic Ocean SSTs are below-average, less heat energy is available in the water to support hurricane activity. Conversely, the **busiest years** corresponded with North Atlantic Ocean and Caribbean Sea SSTs that were far above-average, e.g. 2005 and 2017. In addition, **El Niño** tends to decrease the numbers, while **La Niña** tends to increase them by altering wind patterns in the upper levels of the troposphere over the Caribbean Sea and tropical North Atlantic (i.e. altering the so-called vertical wind shear), where most storms form.

Figure 6 : The climatological seasonality of the Atlantic Hurricane Season



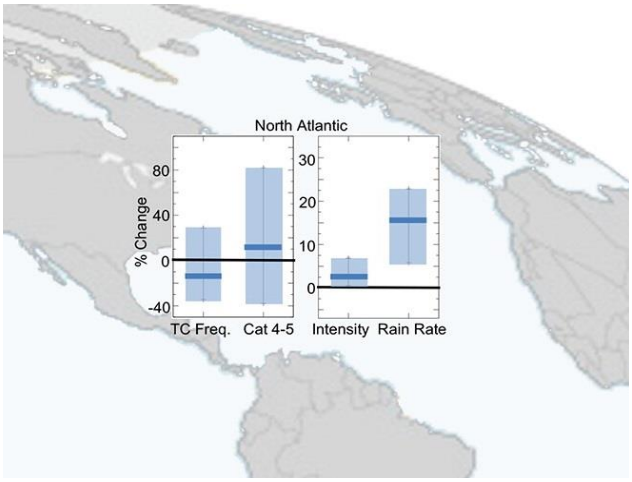
3.5.2 *Projected Trends in Tropical Cyclones*

The IPCC Special Report on Extremes (SREX – IPCC, 2012) mentioned five major conclusions with respect to trends in tropical cyclones:

1. There is low confidence in projections of changes in tropical cyclone genesis, location, tracks, duration, or areas of impact.
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.
3. It is likely that the **global frequency of tropical cyclones** will either decrease or remain essentially unchanged.
4. An increase in mean **tropical cyclone maximum wind** speed is likely, although increases may not occur in all tropical regions.
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.

Alongside these general conclusions, Knutson et al. (2013) estimated, based on RCP4.5 projections run with CMIP-3 and CMIP-5 global climate models, that the **rainfall rates** in the inner core of hurricanes could increase by 20% to 30% by the end of the 21st Century, and by around 10% outside 200km from the core. Increased rainfall rates during the passage of hurricanes in future would increase flash flood and pluvial flooding potential associated with them. Also, based on consistent findings between Knutson et al. (2010), Bender et al. (2010) and Emanuel (2007), it appears that the **maximum wind speed** in storms may increase by 2% and up to 11%. Finally, CMIP-5 models indicate a possible increase in the **frequency of category 4 and 5 hurricanes** by up to 45% for the first part of the 21st Century (Knutson et al., 2013), but there is only low confidence in the rate of this change. In a scientific consensus, Knutson et al. (2019) summarised the most recent findings, which is represented for the North Atlantic basin in **Figure 7**.

Figure 7 **Estimated changes in tropical cyclone activity in a 2°C warmer world in the Caribbean.**



Source: Modified from Knutson et al. (2019)

With increasing wind speed, it can be expected that wind-induced damage potential from the strongest storms could further increase as compared to present-day. Finally, the combination of rising sea levels (*virtually certain* – see sub-section below) and stronger winds around category 4 and 5 hurricanes (*medium confidence*), the impact potential of storm surge and coastal inundation greatly increases (*high confidence*).

3.6 Sea Level Rise

3.6.1 Observed Trends in Sea Level Rise

Global sea level has risen at an average rate of around 1.7 mm per year between 1901 and 2010, as measured by tide gauges, and, more recently, by around 3.2 mm per year from 1993 to 2010 (IPCC, 2013). In the Caribbean, the rate of sea level rise has been comparable to the global rate. **Sea level in the Caribbean** has been rising at rates of 1.8 mm per year between 1950 and 2009 (Palanisamy et al., 2012), as measured by tide gauges, or 2.5 mm per year between 1993 and 2010, as measured by satellite altimetry (Torres and Tsimplis, 2013). The tide gauge closest to **the OECS region** investigated in Torres and Tsimplis (2013) with data up to 2009 is near Lime Tree, US Virgin Islands (17.7°N, 64.8°W), where the gauge corrected sea level rise was measured at around 1.8 mm per year over 32 years. Correcting for global isostatic adjustment (i.e. topographic changes due to the receding ice sheets after the last Ice Age), the figure for the OECS region may be closer to 2.5 to 3.5 mm per year. The uncorrected value compares qualitatively well with Palanisamy et al. (2012) who estimates:

the rate in the Leeward Islands to be between 2 mm per year around Guadeloupe and up to more than 2.5 mm per year around the British Virgin Islands, and in the Windward Islands between

around 1 mm per year near Grenada and the islands of the Grenadines and gradually increasing northwards to near 2 mm per year near Dominica.

3.6.2 *Projected Sea Level Rise*

Projections of sea level rise around the Lesser Antilles north of Grenada suggest a mean increase of 11 cm (with a 90% confidence range of 6 – 17 cm) by 2020 and of 27-30 cm (90% confidence range of around 20 – 40 cm) by 2050 as compared to an 1986-2005 baseline (CSGM and CIMH, 2020). Those mean rates are marginally higher than the global sea level rise projections of close to 10 cm by 2020 and 25 cm by 2050 (IPCC, 2013). By the 2090s, local sea level rise may approach 1 m above 1986-2005 levels. The estimates for the Lesser Antilles north of Grenada provided for the end of the century may well be underestimated as they probably do not sufficiently account for glacial melt from Greenland and Antarctica (IPCC, 2019). Among the major future impacts of sea level rise facing the OECS region are coastal erosion, reduction of land space near sea level, including urban space, saline intrusion into soils and aquifers (CSGM and CIMH, 2020; Nicolas-Bragance and Saffache, 2016).

3.7 Sea Surface Temperature and Salinity

Highlights

- Globally, sea surface salinity is projected to decrease as a result of glacial melt, however, around the wider Caribbean and specifically the Lesser Antilles, local sea surface salinity may well increase.

3.7.1 *Observed Trends in Sea Surface Temperature and Salinity*

Climatologically, the seasonality of sea surface temperature (SST) in the OECS region fluctuates between about 26°C in the northern Leeward Islands to around 27°C in the southern Windward Islands in February and March to around 29°C in August and September. Between 1986 and 2016, the SSTs in the OECS region have warmed by between 0.2°C and 0.3°C per decade (CSGM and CIMH, 2020).

Sea surface salinity (SSS) tends to fluctuate between around 36 parts per thousand during the dry season and 35.5 parts per thousand during the wet season. The latter seasonality is mainly due to increased evaporation rates (caused by increased wind speeds and solar radiation) and lower precipitation rates during the dry season as compared to the wet season.

3.7.2 *Projected Trends in Sea Surface Temperature and Salinity*

There are **few regional projections of sea surface temperature** around the Antilles. Antuña-Marrero et al. (2015) provides two estimates using a business-as-usual scenario and a low-CO_2 emissions scenario. According to them, SSTs around the Antilles would **increase by between 0.77°C** (with a 68% confidence range of 0.4-1.2°C) **for the low-CO2 emissions scenario** and **1.8°C** (with a 68% confidence range of 1.4-2.2°C) **for the business-as-usual scenario from 2000 to 2099**. By comparison, Nurse and Charlery (2014) estimated a **decadal warming rate of 0.13°C from 2000 to 2029**, **0.31°C from 2030 to 2059 and 0.41°C for 2070 to 2099**. In addition, they suggest that **the entire Caribbean Sea would maintain SSTs above 28°C year-round** and that the **annual cycle of SSTs decreases from around**

3.3°C between the coolest and warmest month, to 2.9°C in the 2030s and 2.3°C in the 2090s. In terms of variability, the SSTs during the **warmest years in recent history would equate to the SSTs of the coolest years** by the end of the 21st Century. In terms of future sea surface salinity, **global salinity is projected to decrease as a result of glacial melt** (Fu et al., 2016). However, with the area around the Lesser Antilles and the wider Caribbean Sea and tropical North Atlantic Ocean likely to show a future drying trend, local SSS may well increase.

4. Key Findings with Regards to Climate Hazards of Relevance to the OECS

4.1 Heat

Air temperature does not vary much between seasons and years across the OECS region. The heat – being moderated by a prevalent easterly breeze – has historically not been regarded as a major hazard but, at best, a cause of discomfort at times. However, with rising temperatures year-round, a more pronounced Caribbean Heat Season (May to October) with more frequent and intense heatwaves are becoming a new norm (see **ANNEX II – Table 1**). Heat discomfort and heat stress have started affecting society and the environment. Vulnerability to heat is currently not monitored in the OECS region – nor is it in the entire Caribbean – to the level of detail or with the spatial coverage required for detailed heat risk quantification. However, such risk quantification has been done in a multitude of areas of the world, including the tropics. Important impacts of increasing heat exposure (supported by research findings from around the world, including tropical regions and, where references are given, Caribbean countries) include:

- **Human health**: increased heat-related mortality and morbidity (suspected, but not measured in the OECS region – note that heatwaves are the most deadly weather-related hazard in the US), in particular in persons with lower fitness; increased apathy and aggression; accelerated proliferation of vector borne diseases such as Dengue, etc. (e.g. Lowe et al., 2018);
- **Water management**: increased evapotranspiration rates reduce availability of surface water.
- **Education**: children's learning ability significantly decreases with increased heat exposure.
- **Energy**: increased cooling demand and reduced efficiency in energy production.
- **National productivity**: loss of tens to hundreds of thousands of man-hours per country/territory.
- **Environment**: exacerbation of drought; facilitation of wildfires; stress on animal populations.
- **Food security**: crop failure due to wilting; severe heat stress related mortality and morbidity in livestock (e.g. Lallo et al., 2018).
- **Urban environment**: increased need for shading and green spaces, and for cooling centres for communities at risk; increased need for cool construction and home cooling techniques (e.g. roofing, efficient ventilation, A/C).

4.2 Flash Floods

A significant proportion of annual rainfall occurs when spells of intense showers occur in a rapid succession over a small number of days and associated with weather disturbances. The recurring heavy rains during such wet spells can be beneficial for replenishing major water reservoirs. However, extremely intense showers often lead to flash-flooding. Flash floods occur when the rainfall accumulation rate exceeds the rate of soil infiltration and surface drainage. There are rainfall intensity thresholds beyond which the occurrence of wet spells correlates well with the occurrence of flash floods across much of the Caribbean. Caribbean-wide, such extreme wet spells are defined as a three-day period during which the rainfall totals are among the top 1% (i.e. exceed the 99th percentile) of all 72-hour rainfall totals in the historical record at a weather station (CSGM and CIMH, 2020). Preliminary research at CIMH (2019) suggests that, for five of the six independent states of the OECS (the exception being St. Kitts), between 45% and 100% of all reported floods between 1988 and 2011 on their largest island – as recorded in the Caribbean Climate Impacts Database (cid.cimh.edu.bb) –, were dated within 2 days of an extreme wet spell at their airport station(s). This score of 45-100% is commonly known as a hit score – i.e. the number of times an event was expected and it did happen –, where the event is a flash flood occurrence and the expectation is based on the occurrence of an extreme wet spell. The flood record is incomplete and the number of recorded floods too low for robust statistical analysis in some of the countries and no reported flood data was available for the territories to run any such analysis. However, the apparent, strong quantitative relationship between extreme wet spell occurrence and flash flood occurrence makes extreme wet spell occurrence a promising proxy for flash flood potential.

4.3 Dry Spells

Each food crop grown in the Caribbean has a specific tolerance to recurrent water deficits during critical stages growth. When faced with severe deficits to the plant's water demand, water stress appears and may, if severe enough, hamper growth and hence, crop productivity. One way of engendering water deficits is the occurrence of many successive dry days – defined 24-hour periods with less than 1.0 mm of rain. Such periods of several consecutive dry days are called dry spells. It may appear obvious that, the longer the dry spell, the more water-stressed the crops become. However, perhaps also obvious, is the fact that a recurrence of short dry spells, for instance 7-day dry spells, may also exacerbate water stress. This will particularly be the case if the so-called wet days (i.e. days with rainfall amounts being at least 1.0 mm over a 24-hour period) in between 7-day dry spells do not receive much rainfall. Dry spell impact potential can thus be estimated by calculating the probability that at least a given number of 7-day dry spells occur during one growing season. Several commonly grown food crops in the OECS region – e.g. pumpkin, sweet potato, Irish potato, cucumbers and cassava – have a growing season with a critical growth period of about 3 months. Furthermore, each of these crops may have different tolerances to 7-day dry spell frequency during the growing season. Moreover, the sensitivity of a crop will further depend on variety, soil type and structure, drainage, mulching and other management techniques. Finally, cropping may not occur during the same months across the region. Therefore, in this study, the dry spell impact potential is estimated for each 3-month rolling period – i.e. January to March, February to April, March to May, April to June, July to September, October to December, November to January and December to February. The advantage is that this estimate allows an agricultural stakeholder to decide whether the risk of planting a given crop in each season may be too elevated in view of the many dry spells expected during that period. As for extreme rainfall, there are no robust observed or projected trends before the 2050s in dry spell duration or numbers of dry spells per 3-month period or per year across the OECS region (see ANNEX II – Table 2 and ANNEX II – Figure 7). Hence, it is a reasonable assumption that dry spell impact potential is not likely to change in the short-term or medium-term future compared to the recent past.

4.4 Droughts

Meteorological drought can be defined as a deficit of rainfall over a period of several weeks to years. When drier-than-normal conditions are significant and extend as long as to reduce the amount of available soil moisture, this can lead to crop wilting. Such droughts are called agricultural drought. If drought extends as long as to affect streams, rivers and water reservoirs above and below ground, one can refer to such droughts as hydrological drought. With reduced freshwater availability during prolonged hydrological drought, other socio-economic sectors are affected, e.g. firefighting, household water provision, construction, tourism, etc, this may be referred to as socio-economic drought. Typically, reduced soil moisture and reduced flow in streams and small rivers takes anywhere between several weeks and about 6 months of rainfall deficits – i.e. short-term drought – to manifest. After 6 months of significant meteorological drought, flow in larger rivers and water levels in large reservoirs are affected. Finally, after about 9 to 12 months of rainfall deficits – i.e. long-term drought –, water levels in the largest surface reservoirs and in aquifers tend to lower and flow in the largest rivers tends to decrease.

As introduced in **ANNEX I – Climate Indices – Rainfall-based Drought Indices**, a relatively simple and practical WMO-recommended drought index is the Standardized Precipitation Index (SPI), which calculates standardized rainfall deficits or surpluses as fitted to a statistical gamma distribution. The SPI indices analysed in the CCASAP project were the SPI-6 – indicative of short-term drought – and SPI-12 – indicative of long-term drought. The most relevant temporal analysis of drought impact potential is looking at recent and future trends in the proportion of time spent in drought at a severity level beyond which significant impacts are expected. This is because meteorological drought – and the associated agricultural, water and socio-economic impacts – is inherently a recurrent pattern of rainfall variability. Therefore, a climatological average seasonality of drought impact potential does not make sense. In conclusion, while strongly positive SPI values are indicative of excessive rainfall accumulations on monthly to interannual timescales (in case of an SPI-6 over 6 months, SPI-12 over 1 year) which is certainly linked to long-term flooding, it should be noted that a number of additional triggers are often needed to engender long-term flooding rather than seasonal rainfall excesses alone. Hence, while linked to long term flooding potential, no attempt is made here at calculating the long-term flooding potential.

5. GAPS AND RECOMMENDATIONS

Highlights

The climate of the OECS region is projected to continue warming in the future, implying:

- Increased heat stress as the local expression of global warming (*high confidence*).
- Warmer oceans along with steadily rising sea levels, even if global warming is halted in the foreseeable future (*high confidence*).

In addition to the above, recently observed and virtually certain future changes in climate conditions and the hazards they engender, some additional climate-related hazards are expected to potentially change in the future with:

- More frequent and more intense droughts (*high confidence*), as well as more frequent dry spells (*medium confidence*).
- More intense and more frequent major hurricanes (i.e. categories 4 and 5) (*medium confidence*), accompanied by a strong increase in storm surge due to sea level rise.
- Possible increases in flash flood producing extreme rainfall (*low confidence*), including from wetter tropical cyclones (*medium confidence*), but also a reduction in the frequency of flash floods and long-term flooding (*low confidence*)

5.1 Gap 1: Depending on the territory, varying amounts of observational data were utilized for assessments of the climatological norm and recent observed trends.

- *Assumption*: The observed recent and present-day nature of climate-related hazards investigated appears to often be spatially differentiated according to topographic setting - i.e. leeward versus windward side of the island, steepness of topography, overall island size - rather than by political borders. Hence, the assumption is made that station records from locations with a given topographic setting will be representative of an area without station records but a similar topographic setting.
- *Limitation*: There is increased uncertainty in country/territory-specific results for countries/territories in which observed data utilised to calculate hazard impact potential was not available for each of the topographic settings present in that country/territory. Hence, estimating the risk of a hazard in any given area based on the results of the CCASAP climatological analysis may require the use of the calculated hazard potential for a station found in a similar geographic setting, but on another island or in another part of the country/territory.
- *Recommendation*: Countries/territories need to continually invest in their National Meteorological and Hydrological Service (NMHS)'s capacity to observe weather - through the deployment and maintenance of a sufficiently dense observation network - and maintain climate databases, especially with respect to daily and sub-daily rainfall and air temperature data, but also sea level and water temperature data. Where applicable, the NMHS's mandate as the national authority for doing such needs to be established or amended.

5.2 Gap 2: Climate projection data are not always available for the necessary climate variables utilised in the climatological analysis.

- *Assumption*: Due to the unavailability of some projected climate variables, a close proxy was utilised when the expected implications for hazard impact potential could at least be qualitatively assessed.
- *Limitation*: In such cases, future risk estimation - for a hazard of which the any of the projected time series data of relevant climate variables is not available - would have to be based primarily on the present, quantitative impact potential, with addition of qualitative future trends.
- *Recommendation*: For fully quantitative estimates of hazard impact potential, both past and future data time series need to be available for all required climate variables.

5.3 Gap 3: In most cases, climate projections cannot yet be produced at the spatial scale at which vulnerabilities can be differentiated.

- *Assumption*: Projected trends in hazard impact potential presented in this report assume that the highest sensible resolution is at the sub-regional level at this time - i.e. Leeward Islands versus Windward Islands, despite a 25 km by 25 km horizontal grid in the regional climate model. That said, the spatial differentiation of hazard impact potential remains more a factor of topographic setting than geographic coordinate location within either the Leeward Islands or the Windward Islands of the OECS region.
- *Limitation*: Whether or not the model resolution does reach a similar spatial resolution as the spatial analysis of vulnerabilities, uncertainties related to the model setup itself or the assumed development scenarios prevent a one-to-one mapping of model grid box and assessed vulnerability in the same geographic space. That said, to estimate future hazard impact potential for a location with a specific topographic situation, prudent extrapolations can be made based on the present hazard impact potential in locations with the same topographic situation plus the trend in the respective sub-region.
- *Recommendation*: If site-specific hazard potential is needed, future studies could consider additional climate projection tools, including the use of so-called weather generators. Weather generators produce statistics of weather at a single spot based on those that are currently observed, but in a different climate. This is, however, only possible for locations for which sufficiently long observed data time series are available.

5.4 Gap 4: The climatology of dry heat versus humid heat in the OECS region is not yet well constrained. Neither are heat thresholds quantified beyond which human mortality or morbidity significantly increase. Time series of hot and humid days, defined based on a heat index or an "apparent heat" are only available at locations where hourly records of relative humidity and temperature are maintained. Traditionally, time series of observed relative humidity are only available at the international airport stations.

- *Assumption*: Despite that hot and humid days do not necessarily occur at the same time as hot days, the analysis of their present-day seasonality suggests that, on a monthly timescale, their frequencies correlate strongly. Hence, while heat stress is exacerbated when humidity is high, the CCASAP analysis uses hot days as a proxy for hot and humid days in its analysis of heat impact potential. With respect to health-related heat thresholds, the climatological analysis compares a set of different heat indices. Since the seasonality of these indices shows strong covariance, there is at least an indication that the definition of hot days may be stable enough to serve as a first order proxy to heat exposure.
- *Limitation*: There is some level of uncertainty associated with the quantification of heat impact potential based on the frequency of hot days, arising from the imperfect correlation between hot and hot and humid days on a monthly timescale. The greater uncertainty pertains to the assumption of hot day frequency as a quantitative estimator of heat impact potential, as opposed to another index, given that the heat threshold is not based on human physiological heat response.
- *Recommendation*: In future, from a meteorological perspective, hourly measurements need to be made and their records maintained at many more locations than is presently the case. This requires some additional investment in NMHSs to cover the minor cost of instrumentation deployment, but also the sustained cost of instrument maintenance. In addition, the capacity of the NMHSs in the maintenance of quality-controlled time series of hourly temperature and relative humidity needs to be built, mostly in terms of procedural capacity.

6. Glossary of Terms

Glossary Source: (1) IPCC, 2012: Glossary of terms. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 555-564; (2) WMO Caribbean Climate Centre rcc.cimh.edu.bb

Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate.
Adaptive Capacity	The combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities.
Anthropogenic	Resulting from or produced by human beings.
Capacity	The combination of all the strengths, attributes, and resources available to an individual, community, society, or organization, which can be used to achieve established goals.
Climate	Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. In various chapters in this report different averaging periods, such as a period of 20 years, are also used.
Climate Change	A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.
Climate Extreme	The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as 'climate extremes.'
Climate Model	A numerical representation of the climate system that is based on

the physical, chemical, and biological properties of its components, their interactions, and feedback processes, and that accounts for all or some of its known properties. The climate system can be represented by models of varying complexity, that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical, or biological processes are explicitly represented, or the level at which empirical parameterizations are involved. Coupled Atmosphere-Ocean Global Climate Models (AOGCMs), also referred to as Atmosphere-Ocean General Circulation Models, provide a representation of the climate system that is near the most comprehensive end of the spectrum currently available. There is an evolution toward more complex models with interactive chemistry and biology. Climate models are applied as a research tool to study and simulate the climate, and for operational purposes, including monthly, seasonal, and interannual climate predictions.

Climate Projection	A projection of the response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/ concentration/radiative-forcing scenario used, which are based on assumptions concerning, e.g., future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.
Climate Scenario	A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate.
Climate System	The climate system is the highly complex system consisting of five major components: the atmosphere, the oceans, the cryosphere, the land surface, the biosphere, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations, and anthropogenic forcings such as the changing composition of the atmosphere and land use change.
Climate threshold	A critical limit within the climate system that induces a non-linear response to a given forcing. See also Abrupt climate change.
Climate variability	Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate at all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal

processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). See also Climate change.

Cold days/Cold nights	Days where maximum temperature, or nights where minimum temperature, falls below the 10th percentile, where the respective temperature distributions are generally defined with respect to the 1961-1990 reference period.
Coping	The use of available skills, resources, and opportunities to address, manage, and overcome adverse conditions, with the aim of achieving basic functioning in the short to medium term.
Disaster Risk	The likelihood over a specified time period of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.
Downscaling	Downscaling is a method that derives local- to regional-scale (up to 100 km) information from larger-scale models or data analyses.
Drought	A period of abnormally dry weather long enough to cause a serious hydrological imbalance. Drought is a relative term (see Box 3-3), therefore any discussion in terms of precipitation deficit must refer to the particular precipitation-related activity that is under discussion. For example, shortage of precipitation during the growing season impinges on crop production or ecosystem function in general (due to soil moisture drought, also termed agricultural drought), and during the runoff and percolation season primarily affects water supplies (hydrological drought). Storage changes in soil moisture and groundwater are also affected by increases in actual evapotranspiration in addition to reductions in precipitation. A period with an abnormal precipitation deficit is defined as a meteorological drought. A megadrought is a very lengthy and pervasive drought, lasting much longer than normal, usually a decade or more.
Emissions Scenario	A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as technological change, demographic and socioeconomic development) and their key relationships. Concentration scenarios, derived from emissions scenarios, are used as input to a climate model to compute climate projections. In the IPCC 1992 Supplementary Report, a set of emissions scenarios was presented, which were used as a basis for the climate projections in the IPCC Second Assessment Report. These emissions scenarios are referred to as the IS92 scenarios. In the IPCC Special Report on Emissions

	Scenarios, new emissions scenarios, the so-called SRES scenarios, were published. SRES scenarios (e.g., A1B, A1FI, A2, B1, B2) are used as a basis for some of the climate projections.
Exposure	The presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected.
Extremes	See Climate Extreme
Flood	The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods.
Hazard	The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources
Impacts	Effects on natural and human systems. In this report, the term ‘impacts’ is used to refer to the effects on natural and human systems of physical events, of disasters, and of climate change.
Likelihood	A probabilistic estimate of the occurrence of a single event or of an outcome, for example, a climate parameter, observed trend, or projected change lying in a given range. Likelihood may be based on statistical or modelling analyses, elicitation of expert views, or other quantitative analyses.
Projection	A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasize that projections involve assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty. See also Climate projection and Climate prediction.
Proxy	A proxy climate indicator is a local record that is interpreted, using physical and biophysical principles, to represent some combination of climate-related variations back in time. Climate-related data derived in this way are referred to as proxy data. Examples of proxies include pollen analysis, tree ring records, characteristics of corals, and various data derived from ice cores. The term ‘proxy’ can also be used to refer to indirect estimates of present-day conditions, for example, in the absence of observations.
Radiative Forcing	Radiative forcing is the change in the net, downward minus upward, irradiance (expressed in W m–2) at the tropopause due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun. Radiative forcing is computed with all tropospheric properties

	held fixed at their unperturbed values, and after allowing for stratospheric temperatures, if perturbed, to readjust to radiative-dynamical equilibrium. Radiative Glossary of Terms Annex II 563 forcing is called instantaneous if no change in stratospheric temperature is accounted for. For the purposes of this report, radiative forcing is further defined as the change relative to the year 1750 and, unless otherwise noted, refers to a global and annual average value. Radiative forcing is not to be confused with cloud radiative forcing, a similar terminology for describing an unrelated measure of the impact of clouds on the irradiance at the top of the atmosphere.
Scenario	A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections but are often based on additional information from other sources, sometimes combined with a narrative storyline.
Sea Level Change	Changes in sea level, globally or locally, due to (i) changes in the shape of the ocean basins, (ii) changes in the total mass and distribution of water and land ice, (iii) changes in water density, and (iv) changes in ocean circulation. Sea level changes induced by changes in water density are called steric. Density changes induced by temperature changes only are called thermosteric, while density changes induced by salinity changes are called halosteric.
Sea Surface Temperatures (SST)	The sea surface temperature is the temperature of the subsurface bulk temperature in the top few meters of the ocean, measured by ships, buoys, and drifters. From ships, measurements of water samples in buckets were mostly switched in the 1940s to samples from engine intake water. Satellite measurements of skin temperature (uppermost layer; a fraction of a millimeter thick) in the infrared or the top centimeter or so in the microwave are also used but must be adjusted to be compatible with the bulk temperature.
Storm Surge	The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place.
Uncertainty	An expression of the degree to which a value or relationship is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. Uncertainty may originate from many sources, such as quantifiable errors in the data, ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures, for example, a range of values calculated by various models, or by qualitative statements, for example, reflecting the judgment of a team of experts

Vulnerability	The propensity or predisposition to be adversely affected.
Warm Days/warm nights	Days where maximum temperature, or nights where minimum temperature, exceeds the 90th percentile, where the respective temperature distributions are generally defined with respect to the 1961-1990 reference period.

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8. ANNEXES

Annex I – Climatological Analysis

Climate indices are indices derived from one (or a combination of) climate variable(s) such as temperature, rainfall, wind speed, etc., and calculated in a way that knowledge of their numerical values can add value to evidence-based decision making.

A useful climate index that can support decision making in a climate adaptation context will be constructed to have the intensity (in terms of severity and/or duration) threshold correspond to a level beyond which significant impacts are expected to occur.

At the global level through the World Meteorological Organization (WMO), the Commission for Climatology's Expert Team of Sector-specific Climate Indices (ET-SCI) has been charged with developing and delivering a range of relevant indices for climate sensitive sectors, such as water resources management, agriculture and food production, health. The aim is to present climate monitoring (and, to a certain degree, projection) information in a concise and practical way to support climate adaptation within such socio-economic sectors. The complete list of climate indices recommended by the ET-SCI is found on https://climpact-sci.org/indices/.

This study draws heavily on the climate indices recommended by the ET-SCI and adds a number of region-specific indices used within the Caribbean for operational climate monitoring and prediction through the Caribbean Drought and Precipitation Monitoring Network (CDPMN - http://rcc.cimh.edu.bb/climate-monitoring/caribbean-drought-and-precipitation-monitoring-network/) and the Caribbean Climate Outlook Forum (CariCOF - http://rcc.cimh.edu.bb/caricof/). The climate indices utilized in this study are introduced, defined and bundled below under several themes: heat exposure, rainfall-based drought indices, rainfall occurrence-based extreme indices, other indices.

Heat exposure

Heat exposure in humans (and animals) is mainly a factor of temperature, humidity, wind speed, radiation from direct sunlight or other sources, activity and fitness level, type of ground cover and buildings, as well as, body insulation (e.g. clothing). While physical infrastructure and land cover can control temperature, humidity, shading and wind exposure at the micro-scale to some extent, ambient temperatures and humidity are mostly climate controlled at the large spatial scale. Therefore, they represent the meteorological variables most often used in defining heat index as a measure of apparent (or 'feels-like') temperature. A major challenge to defining reference climatologies for a heat index is that its calculation requires a decade long, complete set of quality controlled hourly weather observations. However, most national meteorological services in the OECS region have not been in the position to maintain such datasets. Hence, analysis on variability, trends and extremes in heat exposure are mostly limited to temperature-only based indices. Nevertheless, wherever there is a strong temporal correlation between the heat index and temperature, those indices robustly reflect the level of heat exposure and associated heat stress.

In the climatological analysis under the CCASAP project, historical climatologies, variability and recent and, where marked by an asterisk, future trends for the following heat-related indices were computed:

- Mean daytime maximum temperature (**TXM**)
- Mean night-time minimum temperature (**TNM**)
- Highest daytime temperature of the year (**TXX**)
- Highest night-time temperature of the year (**TNX**)
- Uncomfortably hot days = days with a daytime maximum temperature above a location-relevant threshold temperature of 32°C (**TXge32**)
- Uncomfortably hot nights = days with a night-time minimum temperature above a location-relevant threshold temperature of 26°C (**TNge26**)
- Hot days* = days with a daytime maximum temperature among the top 10% of all values (i.e. above the 90th percentile) (**TX90p**)
- Hot nights* = days with a night-time minimum temperature among the top 10% of all values (i.e. above the 90th percentile) (**TN90p**)
- Cool days* = days with a daytime maximum temperature among the lowest 10% of all values (i.e. below the 10th percentile) (**TX10p**)
- Cool nights* = days with a night-time minimum temperature among the lowest 10% of all values (i.e. below the 10th percentile) (**TN10p**)
- Heat waves = periods of at least two consecutive hot days

The abbreviated ET-SCI recommended indices are in bold.

Rainfall-based drought indices

Meteorological drought can be defined as a deficit of rainfall over a period of several weeks to years. As mentioned in the main text in section **2. Methods**, the impacts of drought across different drought-sensitive sectors tend to be differentiated in time. Hence, a proxy for the different types of drought should account for the different timescales involved. Furthermore, it should be scalable to the national context of water management. Its calculation should be possible given the climate record available within the country. One such proxy, recommended by the WMO is the **Standardized Precipitation Index (SPI**, McKee et al., 1993). The SPI is calculated as a normalized precipitation anomaly over 1 month to 48 months. Given that most droughts in the OECS are seasonal in nature, the most relevant indices are SPIs calculated over three-month (SPI-3), six-month (SPI-6) and twelve-month (SPI-12) periods. However, rainfall deficits can exceed 12 months as was the case during the 2014 to 2016 Caribbean drought. Finally, because freshwater availability from soils and surface reservoirs can be reduced due to enhanced evapotranspiration rates relative to rainfall, a similar index called the Standardized Precipitation Evapotranspiration Index (SPEI, Vicente-Serrano et al., 2010) can be very useful in monitoring drought. The index is constructed in the same way as the SPI and can therefore be calculated over any relevant time period (e.g. SPEI-3, SPEI-6 and SPEI-12). However, it offers the advantage of calculating a balance between rainfall (i.e. local water input onto the surface) and evapotranspiration (i.e. local water output from the surface). Drought in the Caribbean tends to typically be seasonal in nature. Therefore, in operational drought monitoring through the Caribbean Drought and Precipitation Monitoring Network (CDPMN), 1-month SPI (i.e. SPI-1), 3-month SPI (SPI-3), 6-month SPI (SPI-6), 12-month SPI (SPI-12) and 24-month SPI (SPI-24) are mapped each month. In operational drought prediction through the Caribbean

Climate Outlook Forum (CariCOF), SPI-6 based, suggested short term drought alert levels with a 3-month lead time are provided each month alongside SPI-12 based, suggested long term drought alert levels which target either the end of the Caribbean Water Year (i.e. 31 May), or the end of the Caribbean Wet Season (i.e. 30 November).

Importantly, besides the correlation of drought impact types to drought duration, impact levels also tend to correlate to the value of the calculated SPI – i.e. to drought severity. Therefore, to improve the interpretation and communication of SPI values, the CDPMN adopted a slightly modified categorical scale of drought severity. SPI values between -0.5 and -0.8 are indicative of slightly dry conditions, -0.8 to -1.3 moderately dry, -1.3 to -1.6 severely dry, -1.6 to -2.0 extremely dry and below -2.0 exceptionally dry. The impact level is also non-stationary with respect to rainfall seasonality. Since it rains more during the wet season, a larger rainfall anomaly – i.e. a larger negative SPI value – is required to impact on water availability to a similar level as during the dry season, when rainfall totals are somewhat reduced. The CDPMN uses the following rule of thumb: significant drought impacts are expected during the dry season when the SPI is below -0.8 (i.e. indicative of at least moderate drought), versus below -1.3 during the wet season (i.e. at least severe drought). Finally, since drought impact levels with relevance to surface water resources depend not just on water input (i.e. rainfall), but also output (i.e. evapotranspiration), the CDPMN offers experimental drought monitoring products using the SPEI-1, SPEI-3, SPEI-6, SPEI-12 and SPEI-24. Through the CDPMN and CariCOF programmes, awareness raising, education and outreach activities have led to some level of familiarity with relevant stakeholders throughout the Caribbean with the SPI. For consistency with ongoing drought monitoring and prediction practice in the Caribbean, the CCASAP project included the SPI-6 and SPI-12 drought indices to assess the variability and recent and future trends in drought frequency and severity.

Rainfall derived extreme indices

Besides impacting on the long term in terms of excessive seasonal rainfall or drought, intense rainfall or the relative lack thereof can also engender impacts on the much shorter term through so-called rapid onset events. The impact level of such rapid onset events, such as extreme rainfall triggering flash floods or dry spells triggering crop wilting, inevitably will be linked to the duration and intensity of the triggering event. However, extremely high rainfall intensity varies considerably between events. This makes robust statistical analysis based on relatively short data records of 3 or 4 decades hardly possible because sample sizes are typically very small. By contrast, when analysing occurrence and frequency of rainfall events beyond a given threshold intensity, sufficiently large samples can be utilised once the threshold is not as extreme as to have the event occur less than once a year. Hence, many extreme rainfall-related climate indices look at the occurrence or frequency of rainfall beyond a given threshold. The selection of extreme rainfall indices for this study adopts this reasoning to the extent that the occurrence of events as defined by two specific indices should strongly correlate with the occurrence of significant impacts – see main text 2. Methodology – Climatological Analysis – Climate Hazard Impact Potential.

In the climatological analysis under the CCASAP project, historical climatologies, variability and recent and, where marked by an asterisk, future trends for the following rainfall occurrence-related indices were computed :

- percentage of the annual rainfall total from extreme rainfall above the 95th percentile* = percentage of the annual rainfall total from all days in the year during which rainfall is among the top 5% of historical 24-hour rainfall totals (i.e. above the 95th percentile) (**R95pTOT**)
- percentage of the annual rainfall total from extreme rainfall above the 99th percentile = percentage of the annual rainfall total from all days in the year during which rainfall is among the top 1% of historical 24-hour rainfall totals (i.e. above the 99th percentile) (**R99pTOT**)
- maximum 3-day rainfall per year (**RX3day**)
- maximum 5-day rainfall per year** (**RX5day**)
- annual number of heavy rainfall days** = the annual number of days with 24-hour rainfall totals exceeding 10 mm (**R10mm**)
- extreme wet spells = periods of 3 consecutive days with rainfall totals among the top 1% of historical 72-hour rainfall totals (i.e. above the 99th percentile)
- dry days = days with 24-hour rainfall totals below 1.0 mm
- wet days = days with 24-hour rainfall totals being at least 1.0 mm
- 7-day dry spells = periods of 7 consecutive dry days
- consecutive dry days* = the number of days of the longest consecutive period of dry days per year (**CDD**)
- annual number of 5-day dry spells** = the number of 5-day dry spells in a given year (NDP)

The abbreviated ET-SCI recommended indices are in bold. The double asterisk denotes indices only available from the future projections.

Other Indices

While the Atlantic Hurricane Season's variability and changing nature, as well as sea level rise and sea surface conditions including temperature and salinity are investigated through a desk-top study within the context of the CCASAP project, variables discussed are quite straightforward and indices do not require specific introduction. This is except for sea level rise.

Hence, within the context of this study, two indices of sea level rise are utilised:

- global sea level rise = the global average total rise in the 0 m geodetic sea level over time.
- local sea level rise = the local net apparent rise in the mean tide 0 m level, as a function of global sea level rise, local uplift or subsidence, local ocean density and ocean currents.

Annex II. Climatological Analysis – Historical climatologies, climate variability, recent and future trends

Under the CCASAP project, one regional climate risk profile for the OECS region will be complemented by country climate risk profiles for the region's independent states and territories. The main results of the detailed climatological analysis preceding the authoring of the regional and country/territory climate risk profiles are discussed in detail in this annex.

Basic climatology

Detailed climatologies for the individual countries can be found here, as well as, on the RCC's web page rcc.cimh.edu.bb, where the current reference climatology (1981-2010) for rainfall and mean temperature at the main stations can be found. ANNEX II focuses on the current climate and its year-to-year variability, observed, recent trends and projected, near- and medium-term trends at the sub-regional scale. In other words, the analyses are broken up into the states and territories of the OECS region in the Leeward Islands on the one hand (henceforth – **Leeward Islands**) and in the Windward **Islands (henceforth – Windward Islands**) on the other hand. The climatological seasonality of rainfall, daytime high and night-time low temperatures is presented in **Figure 1**.

- With respect to the **temperature seasonality**, the annual average range of night-time low (minimum) temperatures is around 21-23°C from December to March (April in the Leeward Islands) and up to 25°C between June and August. Daytime high (maximum) temperatures tend to hover around 28-30°C between December and March and are typically between 30-32°C between May and October. Variations in temperature seasonality are determined by the exposure to Tradewinds. Stations located on the leeward side of steep slopes tend to record 1-2°C warmer temperatures. Rather than an annual peak, maximum temperatures are roughly constant between May and October. By contrast, areas more exposed to sea breeze tend to display a peak around August and September.
- **Annual precipitation** totals tend to average 1000-1500 mm in low lying areas of the smaller islands and areas without steep hills or mountains. This is the case for most locations in the Leeward Islands. However, areas surrounding the mountains of Basse-Terre in Guadeloupe are much wetter, as is reflected in bottom left panel of Figure 1, with annual totals exceeding 2000 mm and above 5000 mm in the highest elevations. In the Windward Islands, most locations feature steep hills and mountains with average rainfall totals of 1700-2700 mm in most places, or up to more than 3000 mm in the inhabited places at higher elevations. By contrast, northernmost Saint Lucia, northern- and southernmost Saint Lucia and Grenada, as well as, the Grenadines, have annual rainfall totals between 900 mm and 1200 mm.
- With respect **to rainfall seasonality**, on average, February and March form the driest part of the dry season. In the Windward Islands, a majority of years April and May are similarly dry, but, in some years, May – and, occasionally, April – is relatively wet. After the transition month of May, the wet season months of June to November carry, on average, upwards of 150 mm of rainfall, with the peak occurring between August and November and October being the wettest months on average. Then, in

most years, December and January mark the transition back into the dry season. The wet season months of June to November account for 66% of annual rainfall totals on average.

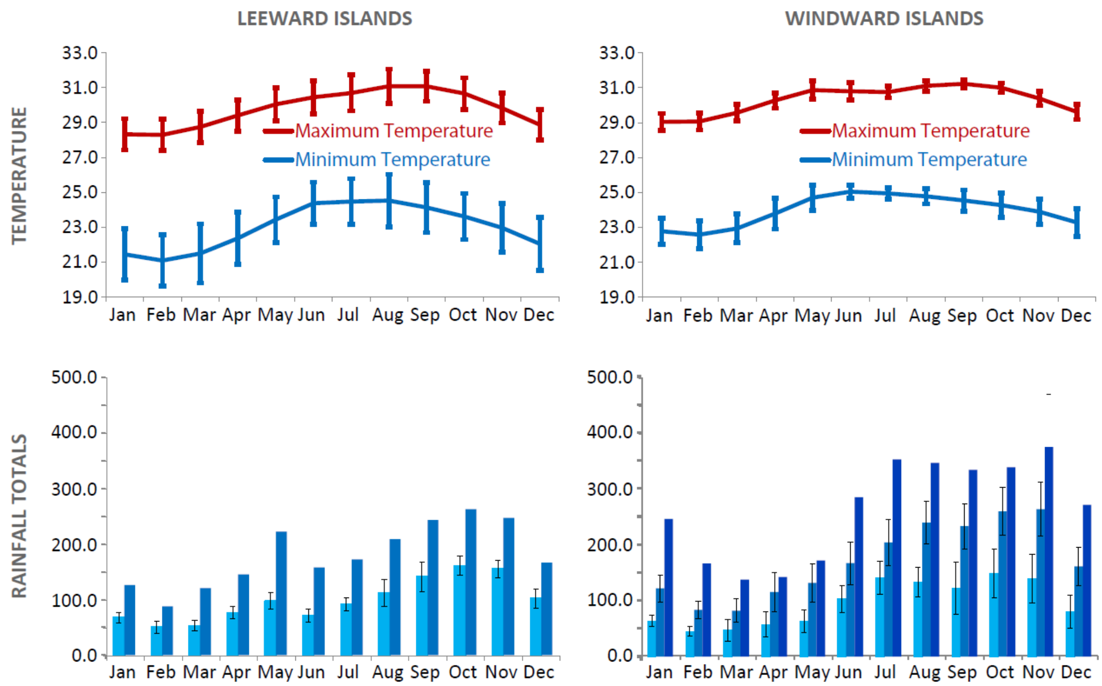

Figure 1 **Climatology of the seasonality of maximum temperature, minimum temperature (top panels) and rainfall totals (*bottom panels*) across the Leeward Islands (*left panels*) and Windward Islands (*right panels*) of the OECS region.**

Climatological averages were calculated per station for the years 1981 to 2010 (the current reference period recommended by the WMO). 3 and 7 stations were used to calculate sub-regional averages for temperature for the Leeward and Windward Islands, respectively, compared to 17 and 26 stations for average rainfall totals, respectively. Rainfall stations located on the smaller islands and islands with low topography are grouped (light blue) alongside low lying stations on islands with steep hills and mountains (blue) and high elevation stations (dark blue). Whiskers denote differences between stations as indicated by one standard deviation in categories with at least three available stations.

- An **early wet season** peak in May is much more frequent in the **Leeward Islands** with their wet season effectively starting a month earlier on average. A majority of years features such an early wet season peak (similar in behaviour to the Greater Antilles) whereas, in other years, the dry season appears to continue into July. It should be noted that the amplitude of the seasonal cycle is slightly reduced compared to the Leeward Islands, with around 60% of annual rainfall totals recorded during the months of June to November.
- A significant portion of **wet season rains** occurs during the passage of atmospheric disturbances such as tropical waves, tropical cyclones (including tropical depressions, tropical storms and hurricanes) and troughs. The more active those disturbances are

and the slower they move (i.e. the longer they take to cross the land area), the higher the associated rainfall accumulations.

- **Interannual variability** is largest in November, with the 10th percentile (i.e. the threshold rainfall total below which the 10% driest observations are found) being just below 120 mm and the 90th percentile (i.e. the threshold above which the 10% wettest observations are found) being around 510 mm.

HEAT CLIMATOLOGY

Figure 2 presents the current climatological norm for several heat-related extreme indices as averaged across three stations in the Leeward Islands (Antigua – VC Bird ; Guadeloupe – Petit Bourg ; St. Kitts – National Agricultural Station) and seven stations in the Windward Islands (Dominica – Canefield and Douglas Charles ; Grenada – MBIA ; Martinique – Lamentin Aéroport ; Saint Lucia – GFL Charles and Hewanorra ; St. Vincent – ET Joshua). A **heat season** – running from May to October – can be defined as the time of year during which most **hot days** occur. Hot days are defined as days with a maximum temperature among the top 10% of a historical record (i.e. above the 90th percentile). which is seen in **Figure 2** as a transparent red box.

Day-time heat

As indicated on **Figure 2**, the **heat season** lasts from May to October with a total of around 36 of an annual total of 40 hot days in the Leeward Islands and 37 of 43 days in the Windward Islands. The heat season peaks between August and October with more than 5 hot days each. If we considered days with a maximum temperature above 32C to be **uncomfortably hot days**, then the numbers are 20-25% lower, but the seasonality essentially unchanged. If we factor in humidity, then the numbers of **hot and humid days** (i.e. with a maximum daily heat index above the 90th percentile) are around 35 per year, but the seasonal cycle again remains nearly unchanged, apart from a slight shift to more hot and humid days towards the latter half of the heat season.

- On the opposite end, **cool days** (i.e. days with a maximum temperature below the 10th percentile) are mostly restricted to the period December to March, which may be referred to as the **cool season** during which on average 40 and 37 days are cool in the Leeward and Windward Islands, respectively.
- Heat exposure is more dangerous when the severity and duration of successive hot days increases. Hence, the occurrence of **heat waves** is of interest when it comes to heat stress. While an official definition for heat waves does not exist nationally, the Caribbean Climate Outlook Forum (rcc.cimh.edu.bb/caricof) utilizes one functional definition across the Caribbean region, thus making it comparable across the OECS region. In this context, a **heat wave is a period of at least two consecutive hot days**. As such, a **heatwave day** is any hot day that was preceded by or is followed by another hot day. The May to October heat season contains most of the historical heat waves. An important distinction is that, except for locations with a pronounced leeward effect (e.g. Canefield in Dominica), **August to October** are the only individual months during which more than half of all years have recorded heat.

Night-time heat

Because heat morbidity and mortality are often associated with night-time heat exposure during which the body cannot properly rest, it is also important to qualify the heat and cool seasons based on night-time temperatures. Using the **hot nights** (minimum temperature above the 90th percentile) and **uncomfortably warm nights** (minimum temperature above 26C) indices, the heat season once again appears to run from May to October, the peak night-time temperatures occur in June in the Windward Islands, when nights are shortest. There are on average around 37 and 35 hot nights in the heat season in the Leeward and Windward Islands, resp. Looking at **cool nights** (minimum temperature below the 10th percentile), the cool season runs from December to April, with an average total of around 39 and 33 cool nights in the Leeward and Windward Islands, respectively.

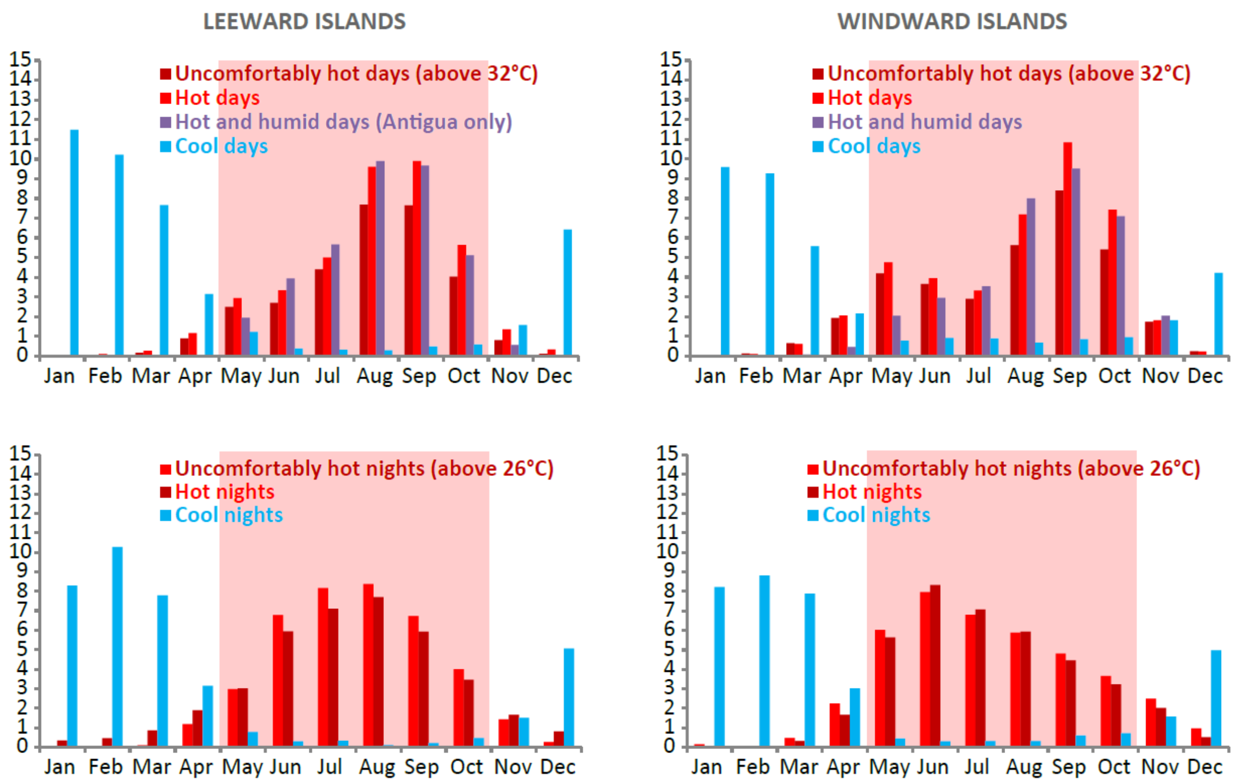

Figure 2 **Climatological seasonality of heat-related indices across the Leeward Islands (*left panels*) and Windward Islands (*right panels*) of the OECS region.**

The indices are defined throughout the text and calculated from daily maximum and minimum temperature records (except for hot and humid days which are calculated from hourly temperature and relative humidity). In the *top panels*, the seasonality of monthly day-time maximum temperature- and maximum heat index-based indices is plotted. Night-time minimum temperature-based indices are plotted in the *bottom panels*. The unit for all indices is in days per month. Indices based on daily data are calculated from daily maximum and minimum temperature time series from 1981 to 2010 wherever the record contained data covering at least 80% of this period. In other cases, as well as, for the hot and humid, a shorter period of record of no less than 15 years had to be selected. Note that, in all but one of the 6 stations where the statistics on hot and humid days could be calculated, less than 20 years of record, as opposed to more than 25 years for all other heat-related indices in most cases. Nevertheless, there is a strong correlation between hot days and hot and humid days. Hence, the climatology can be deemed robust.

OBSERVED HEAT TRENDS

A recent **Caribbean regional assessment of observed trends and extremes** was published in 2014 (Stephenson et al., 2014). It asserted that, for the Caribbean as a whole, the following heat-related trends between 1961 and 2010 were robust:

- >15% increase in annual frequency of hot days and hot nights.
- 7% decrease in the annual frequency of cool days and 10% decrease in cool nights.
- temperature of the coolest and hottest days and nights per year all increased by roughly 1°C.

These regional trends were calculated using the RClimdex software sanctioned by the World Meteorological Organization. Here, trends were calculated for ten stations across the OECS region using its successor software ClimPACT2. The readership is referred to climpact-sci.org for a detailed description of the scientific methods utilized in the calculation of the extreme indices. **Figure 3** shows that only four of the ten station records start before 1980 while nine stations provide data by 1990. If trends in heat extremes are to be statistically significant, the trends need to be pronounced.

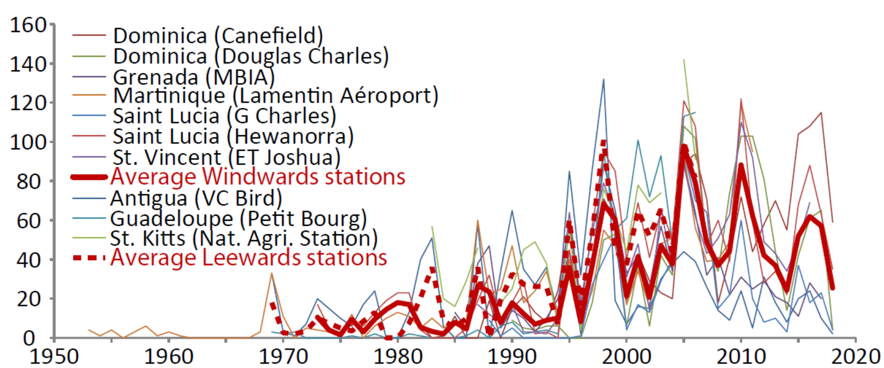

Figure 3 **<u>Interannual variability of the annual number of hot days during the heat season (May to October) is shown for all available stations with daily records of maximum temperature with more than 10 years of record.</u>** Averages were calculated for the stations in the Leeward Islands and Windward Islands for all years where the sub-region had values for at least 2 stations.

As can be seen from **Table 1**, and consistent with the findings of Stephenson et al. (2014), nearly all heat-related indices are indicative of a warming local climate, with a majority of stations showing significant warming trends in 19 out of 24 heat extreme indices (8 out of 12 in the Leeward Islands and 11 out of 12 in the Windward Islands). The fact that the significant recent warming of heat extremes is perhaps less evident in the Leeward Islands is, in part, possibly due to an inhomogeneity in Antigua's VC Bird record of maximum temperatures early in the 21st Century. Indeed, after a period of rapid increase in hot days from the 1980s to the late 1990s, the trend is reversed thereafter, which is opposed to the continued rising trend post 1998 in Guadeloupe's Petit Bourg station and in St. Kitts's National Agricultural Station record. The overall trend in the number of hot days is one of robust warming in both the Leeward Islands and the Windward Islands. (i.e. statistically significant to the 95% confidence level).

Hot days – trends vs. variability

The warming climate of the OECS region is reflected in a significant increase of the annual number of hot days, as shown in **Figure 3**. This is in line with the Caribbean, region-wide trend, in which significant warming trends are seen in most heat indices (Stephenson et al., 2014).

Apart from a strong upward trend, another interesting feature of Figure 3 is the interannual variability. Specifically, it appears that there is a relationship between moderate and strong El Niño events and hotter heat seasons. This was especially so during the years associated with the 1968-69, 1986-87, the 1994-95, the 1997-98, the 2009-10 and the 2014-2016 El Niño events. Warmer than usual sea surface temperatures around the Leeward and Windward Islands drive anomalous heat in the OECS region – for instance in 2005, the year with the most intense heat season in many places –, excessive heat appears to be exacerbated during El Niño years. This is because of an interrelationship between drought driven by El Niño (Giannini et al., 2000) and heat.

Table 1 **Observed trends per decade in heat-related indices for the Leeward and Windward Islands from all stations in the OECS region with daily temperature records spanning over 25 years and starting latest in the 1980s.** The estimated averages were calculated from 3 stations in the Leeward Islands (one in Antigua, one in Guadeloupe, one in St. Kitts), 5 in the Windward Islands (one in Dominica, one in Grenada, one in Martinique, one in St. Lucia, one in St. Vincent). Robust trends (i.e. same trend direction across all stations and trend statistically significant at the 95% confidence level in least two stations) are bold. Trends coloured red are indicative of warming or blue if indicative of cooling.

Heat-related index (*abbreviated name*)	Trend per decade Leeward Islands	Trend per decade Windward Islands
mean day-time maximum temperature (*TXm*)	**+0.39°C (2 of 3)**	**+0.16°C (4 of 5)**
mean night-time minimum temperature (*TNm*)	**+0.17°C (2 of 3)**	**+0.15°C (3 of 5)**
temperature of the warmest day of the year (*TXx*)	**+0.36°C (2 of 3)**	**+0.21°C (4 of 5)**
temperature of the warmest night of the year (*TNx*)	-0.02°C	**+0.19°C (4 of 5)**
Annual number of uncomfortably hot days (*TXge32*)	**+11.8 (2 of 3)**	**+12.6 (4 of 5)**
Annual number of uncomfortably warm nights (*TNge26*)	+4.7	**+9.4 (3 of 5)**
Annual percentage of hot days (*TX90p*)	**+9.0% (2 of 3)**	**+3.4% (4 of 5)**
Annual percentage of hot nights (*TN90p*)	**+2.5% (2 of 3)**	**+3.1% (5 of 5)**
Annual percentage of cool days (*TX10p*)	**-4.3% (2 of 3)**	**-2.7% (4 of 5)**
Annual percentage of cool nights (*TN10p*)	**-2.7% (2 of 3)**	**-1.8% (4 of 5)**
Annual number of days in long heatwaves (WSDI)	+15.1 (1 of 3)	+4.9 (1 of 5)
Cooling degree days per year (*CDDcold*)	+12.1 (1 of 3)	**+19.4 (4 of 5)**

Projected heat trends

Table 2 provides a first window into how heat extreme indices are expected to evolve in future. Striking are the **very strong projected shifts** from a 1961 to 1990 simulated climatological average, to the 1981 to 2010 period (used as climatological reference period for our observations), and to the short term 2020s and mid-term 2040s futures. This is irrespective of the RCP scenario. Indeed, simulated **hot days and hot nights**, when baselined for 1961-90 in the model, have already become three times more frequent by the 1981-2010 period. This compares qualitatively well to an observed doubling of hot days and hot nights in the Leeward and Windward Islands, indicating that the projections simulate past trends in heat at least qualitatively well.

Table 2 **Simulated heat trends from three downscaled projections in the Leeward and Windward Islands.** The projections were run by downscaling the RCP2.6, RCP4.5 and RCP8.5 HadGEM2 projections with the PRECIS model for 1961 to 2098. Model climatology is set to 1961-90 and calculated indices are shown for the periods 1981-2010, the 2020s (short term) and the 2040s (midterm). The ranges reflect the different values seen in the different RCPs.

Leeward Islands	1961 - 1990	1981 - 2010	2020 - 2029	2040 - 2049
Annual percentage of hot days (*TX90p*)	**10%**	**31% to 33%**	**81% to 86%**	**93% to 98%**
Annual percentage of hot nights (*TN90p*)	**10%**	**32% to 33%**	**78% to 85%**	**91% to 97%**
Annual percentage of cool days (*TX10p*)	**10%**	**3.9%**	**0%**	**0%**
Annual percentage of cool nights (*TN10p*)	**10%**	**4.2%**	**0.1%**	**0%**
Annual number of heatwave days in long heatwaves (WSDI)	**13**	**76-83**	**255 to 280**	**320 to 325**
Windward Islands	**1961 - 1990**	**1981 - 2010**	**2020 - 2029**	**2040 - 2049**
Annual percentage of hot days (*TX90p*)	**10%**	**29% to 31%**	**79% to 88%**	**92% to 97%**
Annual percentage of hot nights (*TN90p*)	**10%**	**31% to 32%**	**76% to 88%**	**90% to 98%**
Annual percentage of cool days (*TX10p*)	**10%**	**2.3%**	**0.1%**	**0%**
Annual percentage of cool nights (*TN10p*)	**10%**	**2.4%**	**0.1%**	**0%**
Annual number of heatwave days in long heatwaves (WSDI)	**14**	**68-75**	**245 to 285**	**310 to 320**

Figure 4 shows that the increase in frequency of hot days and nights is further accelerated into the 2020s, when frequency is eight-fold, to end up close to a 100% of all days in the year in most years during the 2040s. However, given the recent observed increase rate appears to be slower for hot days and hot nights – both increasing less than 10% per decade, one might expect a delay in reaching a near 100% frequency.

- For **cool days and nights**, one can see that, from a 1961-1990 model baseline of 10% frequency, a decrease of over 75% was already noted by 1981-2010. Cool days and nights become virtually absent from the projected future as early as the 2020s. With observed decrease rates of 2% to 4% per year as compared the 1981-2010 period average of 10%, it is plausible that the projected scenarios are accurate in their rate of change, even if the disappearance of cool days and nights may potentially end up being delayed by a decade or two in reality if the slower decrease rate continues.

- Looking at the number of days of **heat waves** (at least six consecutive days according to the definition of the warm spell duration index or WSDI), a remarkable increase is noted across all three scenarios, again in qualitative agreement with observed trends. Whereas the simulated baseline period only recorded 18 such heatwave days per year on average, the numbers had already increased fivefold by 1981-2010 to further increase roughly 15-fold by the 2020s and becoming a nearly yearlong occurrence by the 2040s. It should be stressed that the very strong simulated trends in the heat-related indices after around 1980 only corresponds well qualitatively with the strong observed trend. But even with the downscaled projections overestimating the actual trends, hot days and hot nights will likely occur happen in most cases by mid-Century, while cool days will likely disappear much sooner. Unfortunately, this committed future change seems to be mostly unavoidable, because the conclusion is valid no matter what RCP scenario is considered.

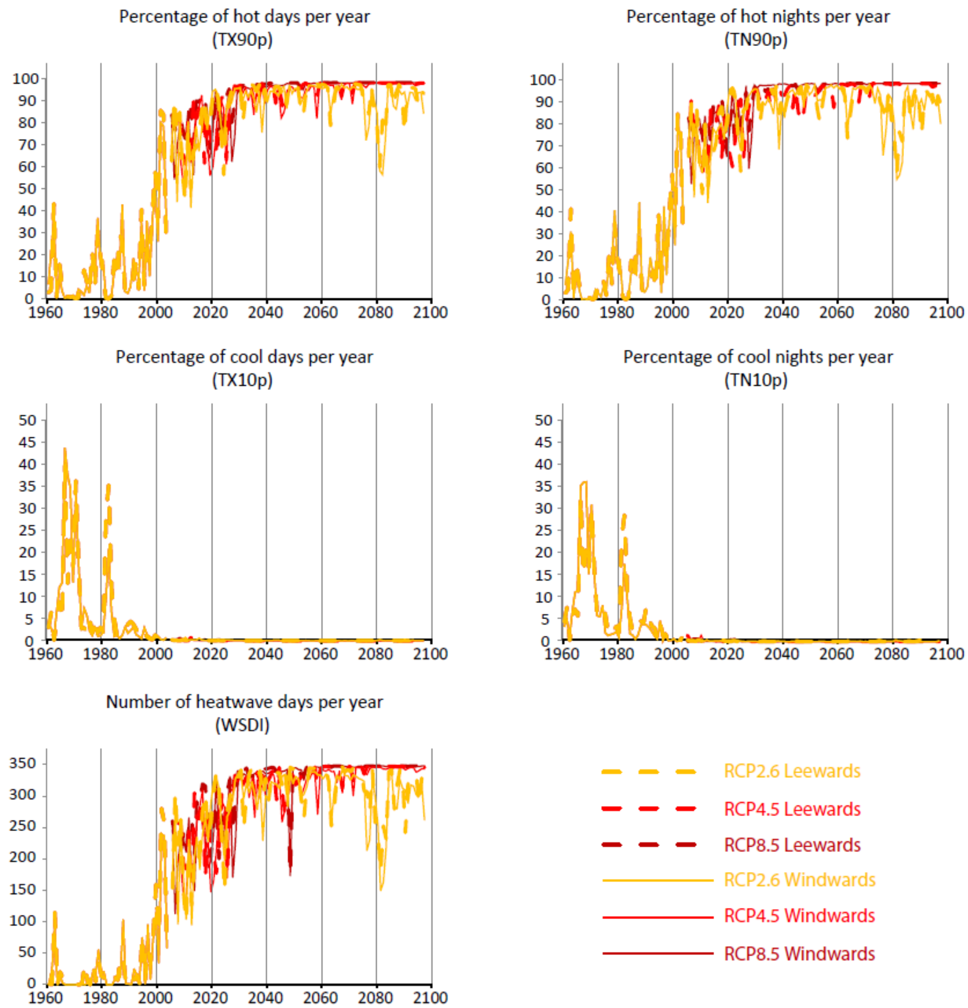

Figure 4 Simulated annual trends in the percentage of hot days (TX90p, top left), hot nights (TN90p, top right), cool days (TX10p, middle left) and cool nights (TN10p, middle right) per year in the vicinity of Martinique, as well as, trends in the annual number of heatwave days during long heat waves of at least six consecutive days (WSDI, bottom) from three downscaled projections.

Rainfall

RAINFALL SEASONALITY

The top left panel in **Figure 5** presents the historical average seasonality of rainfall indices and reported floods for the OECS region. When comparing the **number of wet days** per month to monthly rainfall totals in **Figure 1** across the region as subdivided in smaller islands and low-lying areas with gentle slopes on the one hand and hilly or mountainous areas on the other, the annual cycle shows a relatively strong resemblance. Smaller islands and low-lying areas with gentle slopes are characterised by a distinctly drier climate and shall be referred to as ‘**drier areas**’ throughout the remainder of this section. Those drier areas are the Leeward Islands (with the exception of Basse-Terre in Guadeloupe), northern- and southern-most Saint Lucia, the Grenadines and southern-most Grenada.

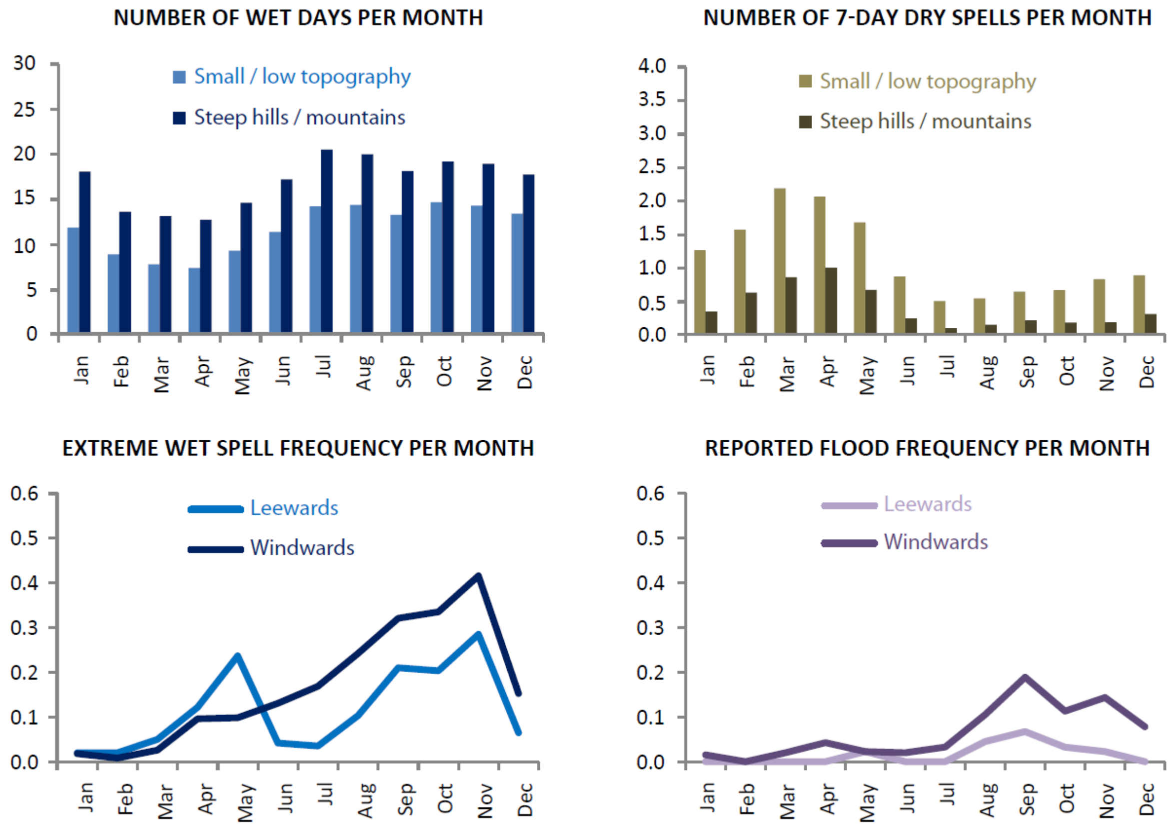

Figure 5 Climatology of the average seasonality of rainfall occurrence, rainfall extreme indices and reported floods. The *top panel*s illustrate the average monthly number wet days (*left*) and 7-day dry spells (*right*) across the OECS region. In these top panels, the OECS region is subdivided in smaller islands and areas with gentle slopes and low topography on the one hand, areas near or on steep hills and mountains on the other hand. Dry and wet days are days with less than and at least 1 mm of rainfall, respectively, while 7-day dry spells are period of seven consecutive dry days. The *bottom panels* illustrate the historical seasonality of extreme wet spells (*left*) and reported flood frequency (*right*) for the Leeward Islands (blue) and Windward Islands (dark blue).

RAINFALL OCCURRENCE

Rainfall totals are a product of **rainfall occurrence** and rainfall intensity when it rains. A commonly used definition to distinguish wet days from dry days is as follows: any day with rainfall totals of at least 1 mm is called a **wet day**. Any day with less than 1 mm is called a **dry day**. In terms of rainfall totals, the **peak of the dry season** is in February and March (with only around 5% of the annual rainfall total each) as seen in **Figure 1**. By contrast, the number of wet days appears to reach its minimum – and the number of dry days its maximum – slightly later in April (**Figure 5**). That said, February to May are the four months of the year with wet days occurring less than 1/3 of the time in the drier areas, and less than half the time in the hilly and mountainous areas. Between May and July, the number of number of wet days increases to remain around 12 to 14 for the rest of the year in the drier areas and around 17 to 20 in other areas.

RAINFALL EXTREMES: DRY SPELLS, EXTREME WET SPELLS AND FLASH FLOOD POTENTIAL

Rainfall tends to be concentrated into wet spells, with dry days and, at times, dry spells in between them. While **dry spells** may be a blessing for multi-day outdoor activities, **crop agriculture** can be affected when the frequency of dry spells is too high, or their duration becomes too long for crops to survive or be productive. Hence, crop farmers may benefit from knowledge of their occurrence. The bottom left panel of **Figure 4** illustrates that, in most years, the months of February to May each would record at least one 7-day dry spell. This makes those four months potentially unsuitable for the planting of rainfed crops that are sensitive to recurrent dry spells. By contrast, the remaining eight months of the year feature much fewer 7-day dry spells. Different than for the wet season peak in rainfall totals, the seasonality of 7-day dry spells shows a clear reduction much earlier in the year – with only one 7-day dry spell every ten years in July. In terms of **extreme wet spells,** the bottom right panel of **Figure 5** suggests that the seasonality is very similar to the seasonality in rainfall totals and rainfall intensity on wet days.

- In the **Leeward Islands** there is a distinct bimodal seasonality, i.e. exhibiting two peaks. Indeed, an extreme wet spell would, based on the historical record occur, on average, in 36% of years between April and May, and in 80% of years between August and November. Conversely, between December and March an extreme wet spell is expected once every 6 years and between June and July once every 12 years.
- By comparison, the seasonality in the **Windward Islands** is different and unimodal, i.e. just one annual peak on average. Between January and March, virtually none occur. Then, progressively, the probability of an extreme wet spell increases each month towards November, to drop rapidly by the end of December. One year out of two sees an extreme wet spell between April and July, while between August and November 1 or 2 extreme wet spells occur on average each year. While December is known as the first month of the dry season, **Figure 5** demonstrates that extreme wet spells do happen roughly once every six years in the Windward Islands. This is an important statistic, given that the so-called **2013 Christmas floods** – which form an archetypical example of how an extreme wet spell triggers flash flood, especially in locations with steep topography – took residents from Dominica all the way to St. Vincent totally off guard.

OBSERVED TRENDS IN RAINFALL EXTREMES

Dry spells

Between 1967 and 2018, the number of 7-day dry spells does not appear to have significantly changed in the Windward Islands, as seen in **Figure 6**. Even though the trend line of the normalized[6] 7-day dry spells averaged over the Windward Islands suggests a slow increase, the year-to-year variability is too large to make the trend significant for now. For the Leeward Islands, a trend should not be computed given the too small number of years for which an average could be calculated. This is because, though the Antigua

[6] Normalization of records – so as to scale the variability equally between the different records – is needed to compute average trends wherever a climate index is not associated with relative thresholds, such as percentiles. Since the number of dry spells is not associated with a relative threshold, Figure 6 shows normalized values and trends, with the units on the Y-scale being standard deviations about the mean and the mean of each record being set to 0.

– VC Bird airport record is long, no data were available from Guadeloupe and the St. Kitts National Agricultural Station. Instead, for St. Kitts, the RLB Airport station was used, but the record only spans 1999 till 2014. Hence, the sub-regional average – which requires at least one non-missing values from at least two different stations for each year – for the Leeward Islands is a record far too short to estimate trends.

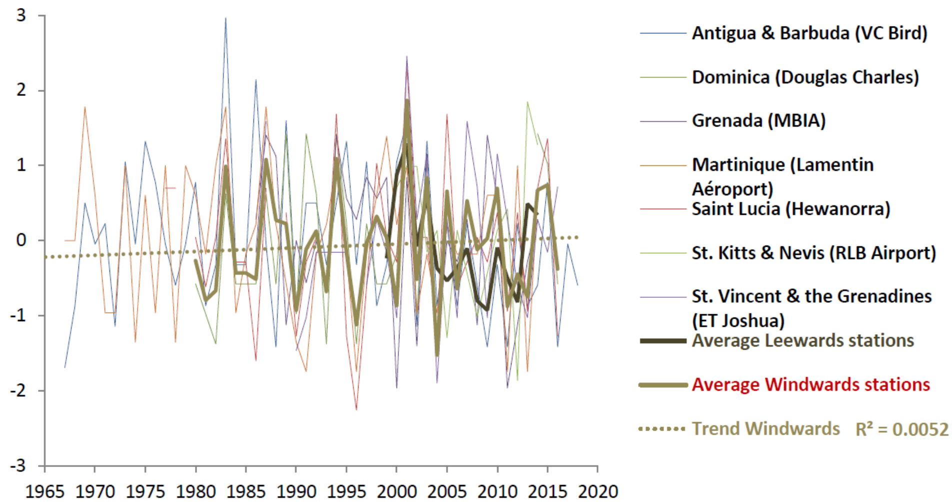

Figure 6 Interannual variability of the annual number of 7-day dry spells is shown for all available stations. Averages were calculated for the stations in the Leeward Islands and Windward Islands for all years where each sub-region had values for at least 2 stations.

Table 3 further illustrates the observed trends in dry spell-related indices, but here the actual values are shown (i.e. not the normalized values shown in **Figure 6**). In terms of 7-day dry spells, the number has increased by 1 spell per year per 24-year time span and, for the peak period of March to May, by 1 spell per year per century in the Windward Islands. Again, those trends are not yet significant due to the large interannual variability. The same goes for the duration of the longest dry spell each year: a non-significant rise of 1 day per 9 years is noted for the Windward Islands. By contrast, the duration seems to decrease – though not significantly – by 1 day per 7 years for the Leeward Islands.

Table 3 **Observed trends per decade in dry spells-related indices for the Leeward and Windward Islands from all stations in the OECS region with daily rainfall records spanning over 25 years and starting latest in the 1980s.** The estimated sub-regional averages were calculated from the same 3 stations in the Leeward Islands and 5 stations in the Windward Islands as in Table 1 above. Robust trends (i.e. same trend direction across all stations and trend statistically significant at the 95% confidence level in least two stations) are bold. Trends are coloured brown if indicative of increasing dryness or blue if indicative of decreasing dryness.

Wet or dry extreme-related index (*abbreviated name*)	**Trend per decade Leeward Islands**	**Trend per decade Windward Islands**
Annual number of 7-day dry spells	-	0.42
Duration (in days) of the longest dry spell per year (*CDD*)	-1.4	1.1
Number of 7-day dry spells during March-April-May	-	0.10

Extreme rainfall

As can be seen in **Table 4**, none of the five extreme rainfall indices showed any significant trend. As with the dry spell indices, this should be interpreted mostly in terms of the large interannual variability in those indices, which thereby require very long records before a trend becomes significant. If a negative trend were to manifest, then the potential for flooding and flash floods would decrease in time. Conversely, were a positive trend to manifest, then the potential would increase, with significant risk implications.

Table 4 **Observed trend per decade in extreme rainfall-related indices for the Leeward and Windward Islands from all stations in the OECS region with daily temperature records spanning over 25 years and starting latest in the 1980s.** The estimated sub-regional averages were calculated from the same 3 stations in the Leeward Islands and 5 stations in the Windward Islands as in **Table 2** above. Robust trends (i.e. same trend direction across all stations and trend statistically significant at the 95% confidence level in least two stations) are bold. Trends are coloured brown if indicative of decreasing wetness or blue if indicative of increasing wetness.

Wet or dry extreme-related index (*abbreviated name*)	Trend per decade Leeward Islands	Trend per decade Windward Islands
Percentage of the annual rainfall total from all days with rainfall above the 95th percentile only (*Rp95TOT*)	-1%	0.55%
Percentage of the annual rainfall total from all days with rainfall above the 99th percentile only (*Rp99TOT*)	0.050%	0.16%
Maximum 3-day rainfall per year (*RX3day*)	-4.9 mm	4.1 mm
Maximum 5-day rainfall per year (*RX5day*)	-7.0 mm	3.8 mm
Annual number of days with at least 10 mm of rainfall (*R10mm*)	-0.53	0.59

Projected Changes in Extreme Rainfall

Whereas clear trends appear in downscaled projections of heat (RCP2.6, RCP4.5 and RCP8.5) and drought (RCP4.5 and RCP8.5) in coming decades, trends in short term rainfall extremes such as dry spell and wet spell frequency changes are hard to detect due to their large year-to-year variability as seen in **Table 2** and **Table 3**. In terms of future climate, at present, not all indices presented in **Table 2** and **Table 3** are available in the downscaled projections (see **ANNEX I**), but those that are may provide some insight into climate in the near-, mid- and longer-term future.

Dry spells

Figure 7 shows a significantly increasing trend in the projected duration of the longest dry spell per year (CDD) and the annual number of 5-day dry spells in both the RCP4.5 and RCP8.5 scenarios and in all projections, respectively. This is projected future drying trend is consistent with the projected drying signal seen in the drought projections The projected trend may not be detectable before the second half of the 21st Century. Note, however, that the trend in the RCP2.6 scenario is small, essentially leaving interannual variability as the primary source of temporal changes in dry spell impact potential. According to the RCP4.5 and RCP8.5 projections, the duration of the longest dry spell of the year may increase by up to 50% in the Leeward Islands and up to 40% in the Windward Islands by the end of the 21st Century.

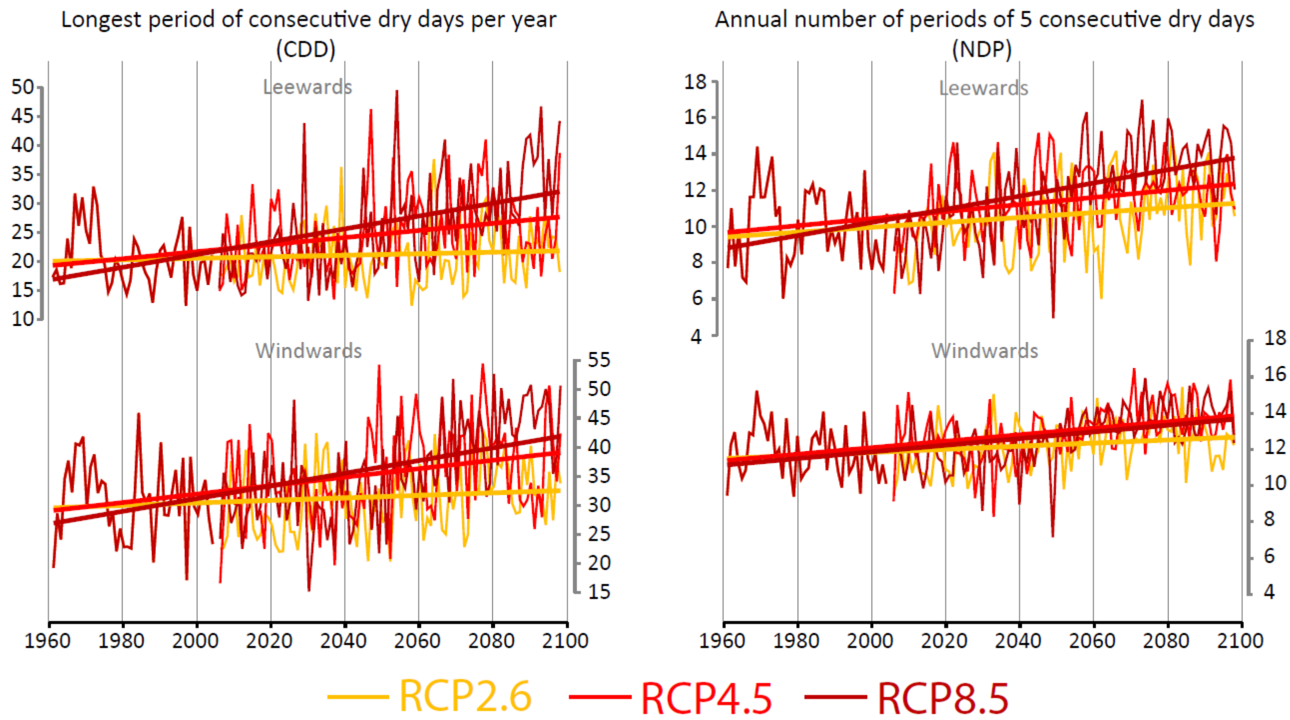

Figure 7 **Projections of dry spell indices across the Leeward and Windward Islands from 2006 to 2098, with the simulated hindcast for the period 1961 to 2005.** The longest period of consecutive dry days per year is shown in the *left panels* and the annual number of 5-day dry spells in the *right panels*. Least squares simple linear regression trend lines were plotted over the entire period 1961-2098. In yellow, red and dark red are the RCP2.6, RCP4.5 and RCP8.5 projections, respectively.

Note, however, that the duration of the longest dry spell is lower in the observed records, especially in areas with steep topography, which is not resolved in the models. The discrepancy is at least partly caused by the simplified topography in the model of an island with complex topography. In reality, the topography produces more frequent rains/less long dry spells – as can be seen in the top left panel of **Figure 5**. Hence, there is only *medium confidence* that the longest dry spells may indeed become longer in future decades.

Extreme rainfall

As can be seen from **Figure 8**, there are **signals in projected trends of extreme rainfall**, despite the year-to-year variability exceeding by far the long-term trend in both the proportion of annual rainfall totals from extremely wet days (R95pTOT) and the number of days with heavy rainfall (R10mm).

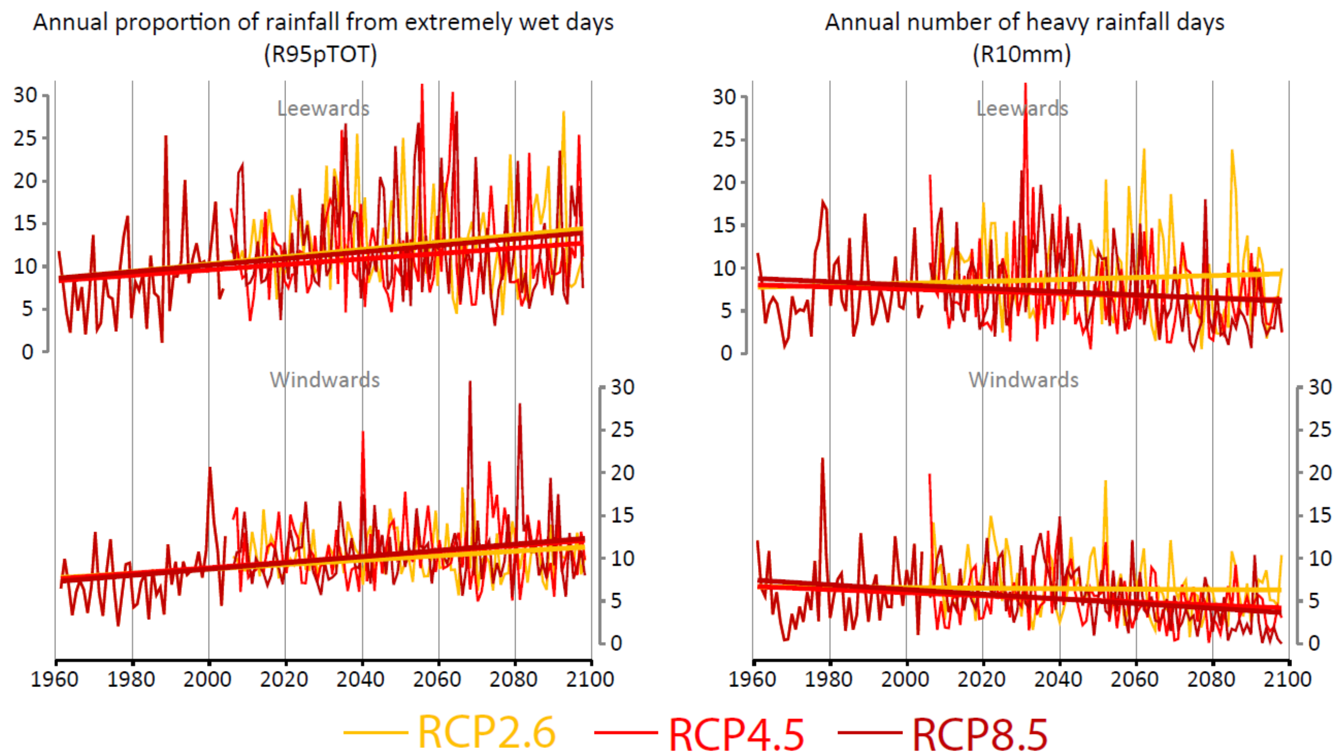

Figure 8 **Projections of extreme rainfall-based indices across the Leeward and Windward Islands from 2006 to 2098, with the simulated hindcast for the period 1961 to 2005.** The simulated annual proportion (in percent) of rainfall from extremely wet days (i.e. the top 5% wettest days in a record) (*left*) and annual number of heavy rainfall days (i.e. days with at least 10 mm rainfall) (*right*). Least squares simple linear regression trend lines were plotted over the entire period 1961-2098. In yellow, red and dark red are the RCP2.6, RCP4.5 and RCP8.5 projections, respectively.

The **annual proportion of rainfall from extremely wet days** appears to increase over time in all three scenarios from around 8% in the 1960s to between 11% and 13% in the 2090s in both the Leeward and Windward Islands. By contrast, the **annual number of days with heavy rainfall** decreases in both RCP4.5 and RCP8.5, but remains virtually unchanged in RCP2.6. If both opposing trends do manifest, this means extreme rainfall will become less frequent, but even more intense. This means that the **potential for flash flooding** and related hazards may increase throughout the 21st Century, though changes may be hardly detectable by the 2020s and 2040s. An indication of such increasing flash flood potential towards 2100 comes from the fact that, while the proportion of annual rainfall from extremely wet days will increase in all three projections, the RCP8.5 systematically projects fewer years with at least 5 days with heavy rainfall than RCP4.5 during the second half of the Century. The same is apparent when comparing RCP4.5 to RCP2.6. Indeed, the period 2050 to 2089 contains 27 and 25 years with at least 5 days with heavy rainfall in RCP2.6 in the Leeward and Windward Islands, respectively. By comparison, in RCP4.5 those numbers are 22 and 14, respectively, while in RCP8.5 those numbers are 19 and 12, respectively. For similar reasons as for the simulated number of dry spells, the model systematically underestimates the wetness of Martinique in that the observed number of days with heavy rainfall at Lamentin Airport is nearly 60 per year, versus only 6 to 7 in the model.

Drought

Though drought is a rainfall extreme, and most rainfall extremes are treated in a separate section, drought shall be treated in this section. The choice is motivated by the anomalous nature of drought. Being an anomaly means there is no sense in computing historical climatologies. Hence, the structure of the section is somewhat different than with the previous two sections.

OBSERVED DROUGHT VARIABILITY AND TRENDS

Drought has been and will remain an integral part of climate in the OECS region. This hazard, while physically dependent on both rainfall and evapotranspiration rates, is of lesser concern in the wetter islands with complex topography such as Martinique than in drier, low topography areas of the OECS region. However, where water consumption is intense due to high population density or high consumption by the islands' industries, the sensitivity of the environment and society to drought is significant.

Historical drought occurrence

As can be seen from **Figure 9**, severe or worse droughts and excessively wet periods have occurred, regardless of the timescale that is monitored.

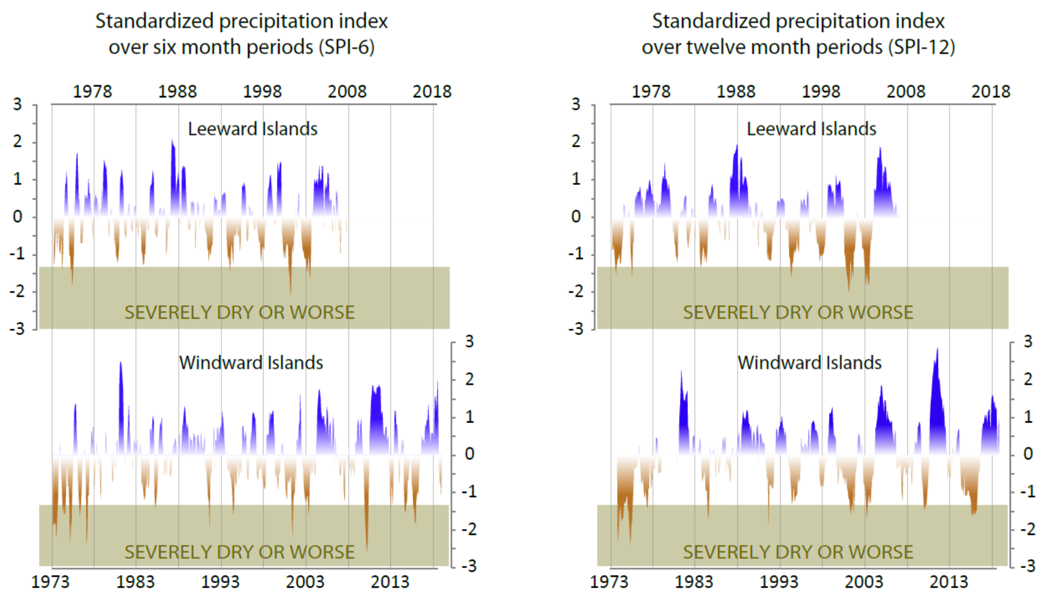

Figure 9 Interannual variability of 6-month and 12-month normalised rainfall totals as represented by the SPI-6 (*left panels*) and SPI-12 (*right panels*), respectively, for the Leeward (*top panels*) and Windward Islands (*bottom panels*). Negative values (red hues) depict rainfall deficits compared to average – which is called meteorological drought –, while positive values depict rainfall surpluses (blue hues). Brown boxes denote which values of the SPI are associated with severe or worse drought. Sub-regional averages are shown for all years where each sub-region had values for at least 2 stations.

An SPI value of less than -2 (i.e. exceptionally dry) should, theoretically, occur once every 40 to 50 years. However, at the 6-month timescales, the record shows exceptional **short-term droughts** have occurred three times in the mid-1970s in the Windward Islands and two times since, namely in 2001 and 2010, over a total time span of 56 years. In the Leeward Islands, where no data is available post 2008, an SPI-6 level indicative of exceptional short-term drought was only reached in 2001, over a total time span of 46 years. Looking at the frequency of severe or worse drought – which theoretically should occur less than once per decade –, it occurred in 5 consecutive years in the mid-1970s and 8 times since then, including 3 times since late 2009 in the Windward Islands. That is, on average, once per 4-5 years. In the Leeward Islands, severe or worse short-term drought occurred 5 times. As such, it appears that the Windward Islands have experienced more drought than expected since 1973, whereas the Leeward Islands were close to the expected frequency.

Looking at long term drought – as indicated by the SPI-12 –, three prolonged periods of nearly uninterrupted drought stand out in the Windward Islands: 1974-1978, 2001-2003 and 2014-2016. In the Leeward Islands, 2001-2003 stands out as well, but the mid-1970s dryness ended early into 1976. At the other end of the SPI scale, late 2010 to 2012 marked the wettest 24-month period in the Windward Islands, coming right after the worst short-term drought on record. This stark contrast within less than 12 months in 2010 translated into a period of high long-term flooding potential in the Windward Islands, with 2010 and 2011 being two of the wettest years on record in many locations across the sub-region. In general, pronounced periods of drought and excessive rainfall were well aligned in time between the Leeward and Windward Islands, which testifies to the relatively large spatial scale of drought as a hazard.

That said, the intensity of dryness or wetness differed between the two sub-regions, with the exception of the most extreme events. This finding suggests a common driver of rainfall extremes at the interannual timescales. Indeed, El Niño forms the strongest driver for regional drought (Giannini et al., 2000), while La Niña is a strong regional driver for excessive rainfall at the 6- to 12-month time scales. All moderate to strong **El Niño events** between 1973 and 2018 were, chronologically, in 1973, 1982-83, 1986-87, 1991-92, 1994-95, 1997-98, 2002, 2009-10 and 2015-2016. Of those events, only the 1982-83 and 1986-87 were not accompanied by pronounced drought. Finally, **long term drought, as expressed by the SPI-12, has been more frequent in the last two decades (1999-2018) compared to the previous two decades (1979-1998)**, but the trend may not be robust as yet. To conclude, **rainfall has not as yet seen major changes in nature – neither in its average nor its extremes, consistent with Stephenson et al. (2014) –, despite a potential increase in the frequency of long term drought since 1973 in the OECS region.**

Projected Changes in Drought

Projected trends in drought for RCP4.5 and RCP8.5 are shown in **Figure 10** from 2020 to 2090. An SPI value of around 0 is expected on average if rainfall totals are not changing from the 1961-1990 model climatology. Aside from a marked increase in heat exposure, the future projections also indicate that **drought will become more prevalent** and **seasons with extremely high rainfall** as compared to the model's 1961-1990 seasonal averages will virtually disappear. However, the trend may only clearly manifest from the 2050s onwards. In the RCP8.5 projections, the SPI-6 shifts from close to 0 in the 2020s and 2030s to -1.1 in both the Leeward and Windward Islands. By comparison, the SPI-12 decreases from 0 to -1.2 in the Leeward Islands and approaches -2 by the 2070s and 2080s. Over the same periods in RCP4.5, the SPI-6 shifts from near 0 to -0.6 in the Leeward and Windward Islands, while the SPI-12 from decreases from near 0 to -0.8 by the 2070s and 2080s in both sub-regions. Those significant trends stand out even with the large interannual variability in both the SPI-6 and SPI-12. A **clear drying shift** – i.e. away from frequent wet episodes and to more frequent dry episodes – stands out for both RCP4.5 and RCP8.5. On the wet side of the SPI scales, in both projections, SPI-6 indicative of moderately wet or wetter conditions occur around the 20% of the time in the Leeward and Windward Islands until around 2050, which is the expected percentage if no long-term seasonal rainfall shifts occur. After that, however, moderately wet or wetter conditions decrease to around 5% of the time in the Leeward Islands, and near 0% in the Windward Islands by the 2080s. Very similar results are seen in the SPI-12.

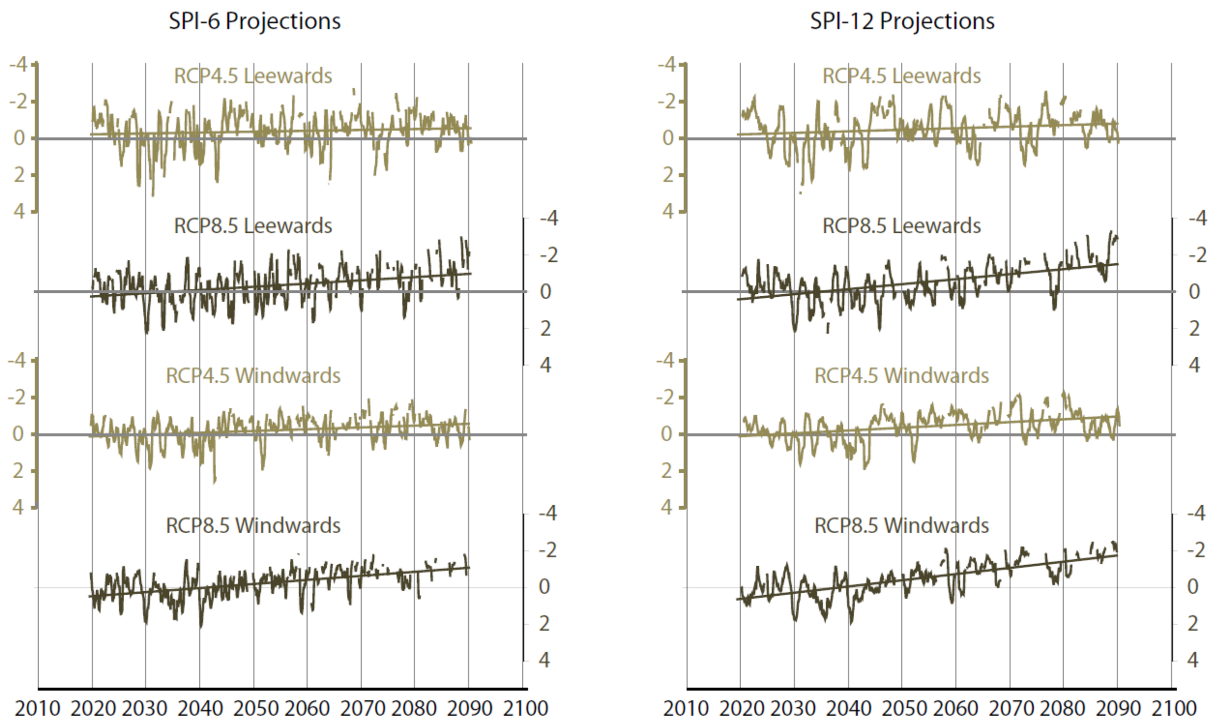

Figure 10 Simulated trends in the standardized precipitation index over six months (SPI-6, *left panels*) and twelve months (SPI-12, *right panels*) per year for the Leeward and Windward Islands from the RCP4.5 and RCP8.5 downscaled projections

The vertical scale has been inversed such that a trend towards more drought appears as an upward trend. The 0-line refers to the historical average rainfall totals, with negative values indicative of rainfall deficits and positive values as rainfall surpluses.

Towards the 2080s, very dry and worse conditions, which at present can be expected to lead to significant drought impacts in a variety of sectors even during the wet season, may occur once every three to five years following RCP4.5, but in as much as 60% of years in the high emissions scenario (RCP8.5). To conclude, the **projected reduction in seasonal excessive rainfall suggests a considerable reduction the long-term flooding potential**.