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DOMINICAN REPUBLIC CLIMATE CHANGE VULNERABILITY ASSESSMENT REPORT

SEPTEMBER 2013

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ARCC



African and Latin American
Resilience to Climate Change Project

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Prepared by:

1. Ms. Patricia Caffrey, Team Leader
2. Mr. Leif Kindberg and Mr. Carter Stone, Deputy Team Leaders
3. Mr. Juan Carlos de Obeso and Dr. Sylwia Trzaska, Climate Scientists
4. Mr. Ruben Torres, Marine Scientist
5. Mr. Gerald Meier, Environmental Management Specialist

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Tetra Tech Contacts:

Cary Farley, Ph.D.

Chief of Party

African and Latin American Resilience to Climate Change (ARCC)

Arlington, VA

Tel.: 703-822-5668

Cary.Farley@alarcc.com

Anna Farmer

Project Manager

Burlington, VT

Tel.: 802-658-3890

Anna.Farmer@tetrattech.com

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AFRICAN AND LATIN AMERICAN RESILIENCE TO CLIMATE CHANGE (ARCC)

SEPTEMBER 2013

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ACRONYMS AND ABBREVIATIONS

ARCC	African and Latin American Resilience to Climate Change
BCRD	Dominican Republic Central Bank
CCU	Climate Change Unit
CEBSE	Centro para la Conservación y Ecodesarrollo de la Bahía de Samaná y su Entorno, Inc.
CODIA	Colegio Dominicano de Ingenieros, Arquitectos y Agrimensores
CODOPESCA	Consejo Dominicano de Pesca y Acuicultura
COE	Centro de Operaciones de Emergencias
COOPRESCA	Cooperativa de Pesca y Prestadores de Servicios Turísticos de La Caleta
CORAASAN	Santiago Water and Sewerage Company
CMIP5	Coupled Model Inter-comparison Project Phase 5
CNE	National Energy Commission
DGODT	Dirección General de Ordenamiento y Desarrollo Territorial
DR VA	Dominican Republic Climate Change Vulnerability Assessment
EGEHID	Empresa de Generación Hidroeléctrica Dominicana
ENSO	<i>El Niño</i> Southern Oscillation
FEDOMU	La Federación Dominicana de Municipios
Fundezurza	Fundación por el Saneamiento de La Zurza
FUNDEMAR	Fundación Dominicana de Estudios Marinos
GCM	General Circulation Models
GPA	Global Programme of Action for the Protection of the Marine Environment from Land-based Activities
GRID	Global and Regional Integrated Data
GRUMPvI	Global Rural-Urban Mapping Project, Version I
GTZ	German Agency for Technical Cooperation
IDDI	Instituto Dominicano de Desarrollo Integral
IGER	Municipal Institute of Risk Management
INAPA	The national water and sewerage authority
INDRHI	National Institute of Water Resources in the Dominican Republic

INFOTEP	Instituto Nacional de Formación Técnico Profesional
IPCC	Intergovernmental Panel on Climate Change
LAPOP	Latin American Public Opinion Project
MARENA	Ministry of Environment and Natural Resources
MPA	Marine Protected Area
MSD	Mid-Summer Drought
NAPH	North Atlantic High Pressure
NCE	National Emergencies Council
NGO	Nongovernmental Organization
OFDA	Office of U.S. Foreign Disaster Assistance
ONAMET	National Meteorological Office
PES	Payment for Ecosystem Services
PSA-CYN	Pago por Servicios Ambientales Hídricos en la Cuenca del Río Yaque del Norte
RCDR	Reef Check Dominican Republic
RCP	Representative Concentration Pathway
SLR	Sea-Level Rise
STRM	Shuttle Radar Topographic Mission
SST	Sea-Surface Temperatures
TNC	The Nature Conservancy
UNEP	United Nations Environment Programme
USAID	U.S. Agency for International Development

I.0 EXECUTIVE SUMMARY

The U.S. Agency for International Development (USAID)/African and Latin American Resilience to Climate Change (ARCC) Project conducted the Dominican Republic Climate Change Vulnerability Assessment (DR VA) from December 2012 to May 2013 in response to requests from the USAID/Latin America and Caribbean Bureau and USAID/Dominican Republic. The overall DR VA approach has six steps: a desk review of all relevant literature, a scoping visit, a field assessment phase, data compilation and analysis, a presentation of results, and a participatory analysis and definition of climate adaptation options. The assessment seeks to improve understanding of climate change impacts on watersheds and coastal resources — as well as the people dependent on them — in the four climate-sensitive hotspots that the assessment targets. The methodology for the integrated assessment is multi-scalar and multi-localational (it focuses on four climate-sensitive hotspots — urban and coastal — encompassing Punta Cana/Bávaro; Yaque del Norte [Montecristi/Santiago]; Bajo Yuna [Samaná Bay and Peninsula]; and Santo Domingo). Its organizational structure follows the major components of the widely accepted proposition that vulnerability is a function of three things: **exposure to a stress** (in this case climatic); the **sensitivity** of a community, livelihood, or natural system to that stress; and their **adaptive capacity** to recover from the impacts of that exposure. The most vulnerable communities/households are those with high exposure, high sensitivity, and low adaptive capacity. To assess these factors, climate, watershed, marine and coastal resources, and institutional analyses were conducted in the targeted hotspots.

EXPOSURE

The climate analysis methodology involved a literature review of climate in the Caribbean Region and in the Dominican Republic; an analysis of historical climate variability and trends in selected areas in order to provide a context for projected changes in the future climate; and climate projections for the same areas. The analysis of variability and trends compared two periods, 1960-1984 and 1985-2012, to assess changes in mean and frequency of precipitation, temperature and wind, and the amplitude of rainfall decadal variability in the Dominican Republic. Climate projections were developed by downscaling output of eight General Circulation Models (GCM)¹ under two emission scenarios (high and low emissions) from the latest projection archive (Coupled Model Inter-comparison Project Phase 5 [CMIP5], Taylor et al., 2012) to meteorological station level, resulting in mean projected climate conditions (temperature and precipitation) in two 30-year periods ending in 2030 and 2050. A complete methodology of this analysis appears in Annex A of the complete report.

The findings of the literature review of climate and analysis of historical climate variability and trends in rainfall, temperature, and wind lead to the following conclusions:

- Strong regional differences in seasonal and annual rainfall exist; temperature is mainly defined by altitude.

¹ Ten different general circulation models with different resolutions and different architectures were used, and the two outliers were discarded.

- All regions experience strong inter-annual rainfall variability linked to El Niño-Southern Oscillation (ENSO) as well as a decadal variability related to the Tropical Atlantic; decadal variability in the Tropical Atlantic also strongly affects the frequency of hurricanes.
- No robust and consistent long-term changes in rainfall variability were found. Temperature, on the other hand, exhibits a consistent increasing trend on the order of 0.5-1 °C during past decades.
- There is an indication of fewer extreme rainfall events in the Yaque del Norte watershed, in addition to more extreme events in the Santo Domingo watershed in the recent period, but no consistent pattern related to changes in flood patterns could be isolated.
- Analyses of changes in wind speed and direction did not yield robust and significant results; therefore, observed changes in beach erosion rates cannot be directly attributed to changes in wind.

Climate projections for temperature and precipitation reveal medium- and long-term potential for:

- A decrease in rainfall in May (a rainy month in all stations) and an increase in December (a dry month in all stations); and
- Temperature increases for 2030 and 2050, which are projected to be 0.5-1.0 °C and 1.0-2.5 °C respectively and will increase evaporation and induce additional water stress.

Furthermore:

- Sea-level rise will likely exacerbate coastal flooding and beach erosion; and
- The intensity of tropical storms and their accompanying precipitation will increase as ocean and global temperatures continue to rise. Combined with environmental degradation, tropical storm damage will worsen.

SENSITIVITY

Sensitivity is the degree to which a system will be affected by, or responsive to climate stimuli (Smit and Pilifosova, 2001). The current and anticipated climate impacts will increase the sensitivity of communities and natural systems in the four studied areas, making them increasingly vulnerable to these elements of exposure. The assessment found that, while sensitivity varies slightly among the studied areas, principal points of sensitivity are where flooding, storm surge, and coastal zone degradation affect populations and natural systems. Communities susceptible to flooding and storm surge are adversely and directly affected by the impact of flooding on roads, housing, businesses, and farm fields. Marine habitats suffer climate and non-climate induced impacts that have an indirect impact on the well-being of coastal communities by diminishing livelihoods that depend on fishing and the tourism industry. The study found that sensitivity to climate change manifests in the following ways:

- Increasing temperatures will continue to strain agricultural systems and groundwater availability and quality due to the possibility of hotter and drier conditions in Yaque del Norte, where precipitation is projected to slightly decrease.
- Increased frequency and intensity of flooding due to the combination of more intense storms and environmental degradation is likely to disproportionately affect already sensitive systems (e.g., livelihoods on the edge, people in poverty, coastal infrastructure).
- Populations on the margin of the economy (particularly those located in urban areas of Los Mina, Hoyo de Puchula, Fracatán, La Esperanza, and el Hoyo de Elias) as well as rural small farmers are

more sensitive to impacts of disasters (floods, dry periods, landslides) because they have limited resources with which to influence and increase adaptive capacity.²

- Coastal zones (particularly mangroves and coral reefs) are particularly sensitive to sea-level rise and more extreme storms because of existing problems with critical habitat destruction from development pressures, overfishing, and other threats.
- Local communities are very sensitive to these same factors, which will likely increase the risk to coastal communities of flooding, diminish fisheries stocks, and degrade natural tourist attractions in the absence of more comprehensive resource management planning.
- Residential households and the agriculture and tourism sectors heavily depend on ground and surface water supply, which are sensitive to localized land use and likely to experience decreasing recharge and quality due to evaporation and salt water intrusion. Inadequate sewage management further compromises water quality. In the absence of adequate sewage treatment facilities, most raw sewage is dumped into the aquifer through injection wells called “pozos filtrantes” or directly into rivers and the ocean, worsening water quality and increasing health risks.

Non-climate stressors, including population, land, and economic pressures, exacerbate these manifestations of sensitivity and will continue to impede efforts to reduce vulnerability of communities and natural systems. Populations inadvertently increase their vulnerability as they exploit natural resources to support their livelihoods (e.g., unsustainable fishing, forestry and agriculture practices) causing irreversible damage to natural systems.

ADAPTIVE CAPACITY

Adaptive capacity is the inherent ability of a livelihood system, or community, to absorb climate change shocks and to buffer the impacts of those shocks. It is often described as recovery power or as a set of assets and strategies that result in resilience. For this assessment, adaptive capacity was gauged by reviewing the existing capacity and potential of communities, institutions, policies, and programs to address the sensitivities. The limited assessment of adaptive capacity and the collection of local adaptive responses included a secondary literature review in addition to an institutional analysis at the national and sub-national levels triangulated with focus group discussions and key informant interviews conducted in the four climate-sensitive hotspots. Overall findings from the institutional analysis follow:

- Climate change policy and plans have been developed at the national level.
- The National Meteorological Office (ONAMET) and the National Institute of Water Resources in the Dominican Republic (INDRHI) have established a solid foundation with which to strengthen and expand their capacity to collect data and analyze and disseminate climate information.
- Climate change action is emerging at the national level, but has not yet reached sub-national levels.
- Guidelines, capacity, and resources to support implementation of adaptation measures are still weak at all levels and across ministries.
- There is a lack of coordination and integration across ministries and policies.

² **Adaptive capacity** refers to the potential or capability of a system to adjust to climate change so as to moderate potential damages, to take advantage of opportunities, or to cope with consequences (Smit and Pilifosova, 2001).

- It is anticipated that capacity, guidance, coordination, and collaboration will improve when the new climate change law takes effect.
- To ensure that the law is effective, other actions will need to follow, such as the development and dissemination of clear guidelines; the effective enforcement of the law; and capacity building to ensure that the public is informed and capable of complying.
- Locally generated adaptive responses exist but are not leveraged to bring to scale.
- Institutional capacity to respond to disasters and improve the management of watersheds and water exists within some public agencies and NGOs but is not implemented to scale or linked with climate change policy and programs.
- As the devolution of the National System for Prevention, Mitigation and Response to Disasters takes place, inter-institutional coordination and citizen awareness of the relationship between climate change and risk and disaster management pose challenges.
- Inadequate land-use and development planning and enforcement increase disaster risk in areas prone to flooding.

ADAPTIVE PATHWAYS AND RECOMMENDATIONS

Key donors and decision-makers participated in multi-stakeholder options analysis meetings in April in Santo Domingo, Samaná, Montecristi, Santiago, and Punta Cana. Participants discussed results, validated pathways, and defined strategies and recommendations based on evidence generated from the assessment. The adaptation pathways, strategies, and an overview of key recommendations are described herein (detailed recommended actions are provided in the recommendations section of the report).

Given the factors of exposure and sensitivity and gaps in adaptive capacity felt across the four hotspots, adaptive strategies need to be defined to improve policy and guidance, develop institutional capacity, and engage citizens (individuals, civil society organizations, and private businesses) to prevent, mitigate, and manage potential damage caused by flooding. To reduce the vulnerability of populations, livelihoods, and natural systems exposed to increases in extreme rainfall events and sea-level rise that will induce flooding (combined with storm surges), three adaptive pathways guide the direction that institutional actors can follow to strengthen resilience and adaptive capacity:

1. Disaster Risk Reduction and Early Warning Systems;
2. Development Planning: Infrastructure and Land Use; and
3. Management and Conservation of Coastal Habitats and Watersheds.

Much work has already been done in the Dominican Republic in this regard; therefore recommendations to improve adaptive capacity build on the policies, guidance, institutional capacity, and engagement platforms that already exist – at the national and local levels. These three pathways provide a higher-level framework with which to define and prioritize options for action – or recommendations for strengthening resilience and adaptive capacity. The pathways are distinct in dealing with climate vulnerability at different temporal scales.

The development planning and habitat management and conservation pathways are intended to develop adaptive capacity over the long term by shifting how development, land use, and natural resource management and conservation currently take place. It is envisioned that recommendations for these pathways would establish physical infrastructure, improve land use, and revive critical habitats that will

protect communities, livelihoods, and natural systems from the anticipated sea-level rise and increased intensity of rainfall events that will exacerbate flooding. On the other hand, the pathway to reduction of disaster risk related to flooding is primarily aimed at protecting populations and improving their resilience in response to increasing flood risks in the short term. All three pathways depend on a cross-cutting recommendation to build capacity to collect, analyze, and use climate information, and leverage existing analysis, communications, and local networks to support the development of effective early warning systems and long-term planning processes for resource use, as well as land and infrastructure development.

DISASTER RISK REDUCTION AND EARLY WARNING SYSTEMS PATHWAY

Strengthen the capacity of stakeholders to improve preparedness and response to flood-induced disaster:

- Increase awareness about vulnerability to climate change and the need for natural disaster preparedness (*Centro de Operaciones de Emergencias* [COE], municipal governments, neighborhood associations, mothers' clubs, private businesses, and tourism clusters).
- Strengthen the capacity of organizations best placed to improve both disaster risk preparedness and response in populations susceptible to flooding (National Council for Climate Change, *Instituto Nacional de Formación Técnico Profesional* [INFOTEP], Ministries of Labor and Public Administration, academic institutions, Red Cross, ONAMET, National Emergencies Council [NCE], COE).
- Link local actors and agencies on the “front-lines” of disaster risk preparedness and reduction with national agencies that can support their development and ability to respond (NCE, COE, nongovernmental organizations [NGOs], municipal and provincial governments, private businesses, neighborhood associations, tourism clusters, academic institutions, etc.).

Improve development and communication of climate and natural disaster information:

- Strengthen the national network of meteorological stations and staff capacity to produce long-term climate records and improve tropical storm tracking (INDRHI and ONAMET).
- Produce climate information tailored to specific sectors (INDRHI, ONAMET, ministries of Agriculture, Environment and Natural Resources, Trade and Industry, CNE, etc.).
- Develop a national system to communicate incoming climate-related risks (ONAMET, INDRHI, NCE/COE, academic institutions, and sub-national governments).

Strengthen inter-institutional and international collaboration to improve coordinated preparation and response to flood-induced disaster risk:

- Strengthen the application of the *Ley de Gestión de Riesgos a Desastres* (NCE, COE, NGOs, municipal and provincial governments, private businesses, neighborhood associations, tourism clusters, academic institutions, etc.).
- Define and implement coordinated plans for disaster risk response and early warning among key lead national and sub-national agencies (ONAMET; INDRHI; The Climate Change Unit; Ministries of Agriculture, Environment and Natural Resources, and Trade and Industry; COE/CNE; academic institutions; neighborhood associations; and sub-national governments).
- Establish local multi-sectoral working groups to improve coordination for prioritizing, planning, and implementing climate change and disaster risk response activities (COE, municipal governments, neighborhood associations, mothers' clubs, private businesses, and tourism clusters).

DEVELOPMENT PLANNING: INFRASTRUCTURE AND LAND USE

Strengthen the capacity of professionals and institutions to prevent and mitigate climate change risk exposure:

- Develop university courses to train specialized personnel on climate change, planning, and risk management (academic institutions such as the Autonomous University of Santo Domingo, *Dirección General de Ordenamiento y Desarrollo Territorial* [DGODT], etc.).
- Train officials and other technical personnel to facilitate the development of land-use plans that integrate climate change adaptation (CCA) (personnel from the local governments and the Dominican Federation of Municipalities, among others, would be targeted for the trainings).

Improve urban and land-use planning to minimize exposure to climate change and risks to natural disasters:

- Approve and apply the new *Ley de Ordenamiento Territorial* (DGODT, Ministry of Economic Development and Planning, and sub-national governments).
- Provide guidance and capacity building on how to integrate climate change adaptation into planning processes at national and sub-national levels (DGODT; Climate Change Unit; NGOs; Federations of Local Government including *La Federación Dominicana de Municipios* [FEDOMU]; Ministries of Economic Development and Planning, Environment and Natural Resources, and Agriculture; *Consejo Dominicano de Pesca y Acuicultura* [CODOPESCA]; etc.).
- Stabilize and control flooding by building physical barriers and restoring natural barriers (Ministry of Environment and Natural Resources, sub-national governments, neighborhood associations, NGOs, private businesses, etc.).

Strengthen environmental assessment and licensing policies, guidance, and enforcement in order to prevent and mitigate environmental degradation and flooding:

- Continue to strengthen the environmental permitting process (NGOs and the Ministry of Environment and Natural Resources).
- Educate NGOs, the academic community, and citizens about the *Ley del Medio Ambiente* and regulations for the environmental permitting process (environmental impact assessments) (Ministry of Environment and Natural Resources, NGOs, and sub-national environmental offices).
- Support establishment of independent monitoring and reporting mechanisms for process/compliance (academic institutions and NGOs).
- Evaluate infrastructure and plans to ensure their soundness in the face of anticipated climate change vulnerabilities (*Colegio Dominicano de Ingenieros, Arquitectos y Agrimensores* [CODIA], Risk Management Municipal Institute, Municipal Institute of Risk Management [IGER] in Santiago, Ministry of Public Works and Communications, etc.).

MANAGEMENT AND CONSERVATION OF COASTAL HABITATS AND WATERSHEDS

Strengthen institutions and create awareness related to climate change and the conservation of coastal-marine resources and watersheds:

- Train environmental and natural resource management professionals in climate change and improve understanding of climate change and conservation at the community level (the Climate Change Unit, academic institutions, ministries of Education and Agriculture, NGOs, etc.).
- Strengthen inter-institutional coordination across all related ministries and sectors to plan, coordinate, and address climate change through improved management and conservation of coastal-marine resources and watersheds (National Council for Climate Change, Ministries of Environment and Natural Resources and Agriculture, INDRHI, sub-national governments, neighborhood associations, private businesses, and NGOs).

Improve the management and conservation of watersheds:

- Promote forest conservation (Ministries of Environment and Natural Resources and Agriculture, academic institutions, provincial and municipal governments, NGOs, and others).
- Promote implementation of good agricultural and soil/water conservation practices (same as above and INDRHI).

Improve the integrated management of coastal-marine resources:

- Create awareness about and enforce laws that reduce the discharge of contaminants into coastal habitats (sub-national governments – environmental officers and neighborhood associations).
- Create awareness about and enforce laws that regulate fishing (CODOPESCA, *Marina de Guerra*, fishing associations, and NGOs).
- Promote the establishment and improved management of coastal/marine protected areas (public/private alliances, Ministry of Environment and Natural Resources, and NGOs).
- Restore coastal-marine ecosystems: coral reefs, mangroves, estuaries, and soft-bottom habitats (public/private alliances, Ministry of Environment and Natural Resources, CODOPESCA, and NGOs).
- Identify and promote environmentally-neutral income generation alternatives to fishing and salt harvesting (Ministries of Environment and Natural Resources, Trade and Industry; sub-national governments; federations of local governments; private businesses; and NGOs).

Promote the efficient use and management of water related to potable use, structures for divergence and storage (e.g., dams), irrigation for agriculture, and groundwater management:

- With the collaboration of government and NGO partners, support the Ministry of Environment to lead the promotion of best adaptation practices in water management and use.
- Strengthen local governance/enforcement, including capacities to control water management and use as an adaptation practice at the national and sub-national levels (Ministry of Environment and Natural Resources, INDRHI, the national sewage and water authority [INAPA], water service agencies, water user associations, and sub-national governments).

- Support INDRHI, INAPA, and local water service agencies to enhance water distribution systems, including water quality and waste reduction.
- Improve monitoring and management of watersheds during seasons of low runoff to mitigate floods and sedimentation (INDRHI and CNE).
- Continue to support promising payment for ecosystem services interventions (such as water funds) that promote watershed protection, improved water use, and management of solid waste (national and local utilities including water and energy service agencies, Ministry of Environment and Natural Resources, and NGOs).

2.0 BACKGROUND

2.1 PURPOSE AND APPROACH

The U.S. Agency for International Development (USAID)/African and Latin American Resilience to Climate Change (ARCC) Project conducted the Dominican Republic Climate Change Vulnerability Assessment (DR VA) from December 2012 to May 2013 in response to requests from the USAID/Latin America and Caribbean Bureau and USAID/Dominican Republic. Significant work had been completed in recent years, such as a USAID-funded vulnerability assessment conducted by the Instituto Dominicano de Desarrollo Internacional (IDDI) and The Nature Conservancy (TNC), as well as regional institutions that laid a foundation for understanding vulnerability in the Dominican Republic. These precursor studies not only identified major vulnerabilities of the Dominican population to climate change, but also uncovered major gaps in knowledge with respect to potential climate futures and the resulting impacts on people and the ecosystems on which they depend. As such, this assessment seeks to further our understanding of climate change impacts, both current and future, on resources that are critical to human safety, security, and prosperity—namely watersheds and coastal resources—in four climate-sensitive hotspots. The DR VA design has six steps: a desk review of all relevant literature, a scoping visit, a field assessment phase, data compilation and analysis, a presentation of results, and a participatory analysis and definition of climate adaptation options. The assessment relied on existing information and did not involve original field research. While large and diverse datasets were collected and reviewed, in some cases there was insufficient data over a long-enough record to provide the detailed analysis that would have been desirable. There were also some limitations with regard to the completeness of qualitative information.³The methodology for the integrated assessment is multi-scalar (national and sub-national) and multi-locational (it includes four climate-sensitive hotspots — urban and coastal — encompassing Punta Cana/Bávaro, Yaque del Norte [Montecristi/Santiago], Bajo Yuna [Samaná Bay and Peninsula], and Santo Domingo).

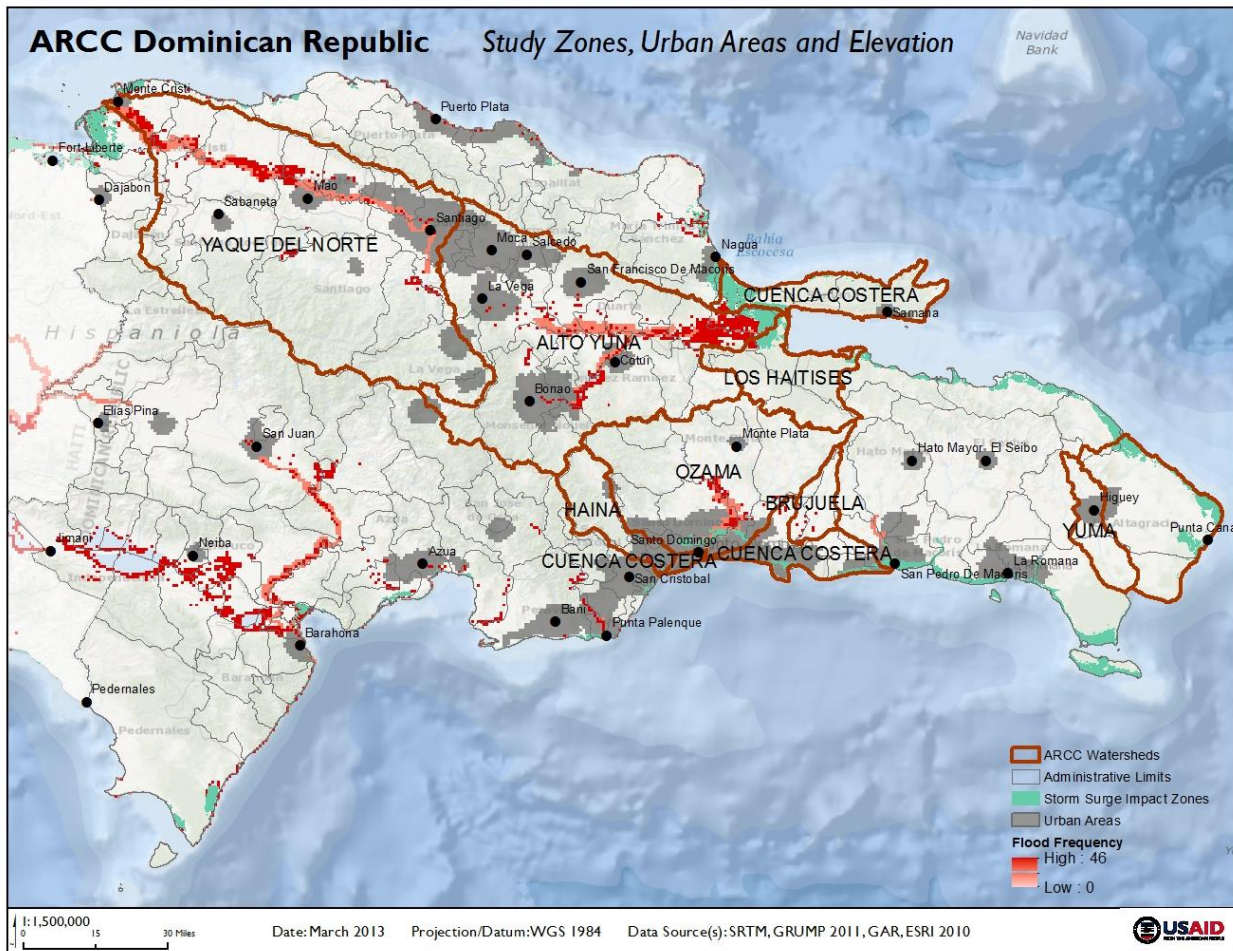
The criteria for identifying the assessment focus and, ultimately, the four climate-sensitive hotspots were based on a gap analysis of existing vulnerability studies and information; areas where sensitivity to climate exposure impacts such as flooding and storm surge are high with potential for significant repercussions on the economy and populations (climate-sensitive hotspots); and a representative range of hotspots from across the country (the South-West was not included) that improve understanding of climate change exposure, sensitivity and adaptive capacity within different bio-physical, socio-economic, and ecological contexts.

Flooding analysis was conducted to identify areas most susceptible to alluvial flooding and storm surge. Figure 1 on the following page demonstrates areas most susceptible to alluvial flooding (pink and red) and storm surge (green). Economic and population criteria were then broadly assessed to define susceptible areas with extensive populations and important economic activities that are known to be sensitive to climate (exposure) and its manifestations such as flooding and sea-level rise. Many of the larger coastal populations are co-dependent on critical habitats – watersheds and marine habitats, which regulate and mitigate flooding while supporting livelihoods through agriculture, tourism, and fisheries.

³ This assessment made use of available information triangulated with one to two focus group discussions per population center and key informant interviews with representatives of government and civil society. To develop a more detailed understanding of the specific sensitivities of the communities, livelihoods, and natural systems studied will require additional field research in the form of surveys and data mining.

ARCC chose to focus on four areas where coastal populations, marine habitats, and adjoining watersheds were determined to be sensitive to flooding and other climate manifestations through information gathered during the literature review and scoping phases (key informant interviews and a review of relevant vulnerability assessment information). The four areas are Punta Cana/Bávaro, Yaque del Norte [Montecristi/Santiago], Bajo Yuna [Samaná Bay and Peninsula], and Santo Domingo. Each hotspot has a unique set of bio-physical, socio-economic, and ecological characteristics in various stages of development, which collectively will contribute a diversity of information and experiences to enrich our understanding of climate change vulnerability and how to develop resilience in a variety of contexts.

FIGURE 1. AREAS MOST SUSCEPTIBLE TO ALLUVIAL FLOODING (PINK AND RED) AND STORM SURGE (GREEN).



The assessment approach follows the widely-accepted notion that vulnerability is a function of: exposure to a stress (in this case climatic); the sensitivity of a community, livelihood, or natural system to the stress associated with that exposure; and their adaptive capacity to recover from the impacts of that exposure. The key research questions were defined after the scoping visit and literature review gap analysis were conducted; they reflect the criteria and focus described above. The key research questions are aimed at understanding the causal relationships between anticipated climate changes (exposure); the importance of impacts from these changes on coastal communities, marine habitats, and watersheds within the targeted areas (sensitivity); and how the affected populations and systems will respond to these impacts (adaptive capacity):

1. How has/will climate change have an impact on water and marine resources?
2. How will these impacts affect natural systems and society, including water quality and quantity; urban settlements vulnerable to disasters (primarily flooding); and coastal communities, also vulnerable to flooding and dependent upon marine resources for their livelihoods?
3. How do/can people and institutions respond or adapt to these impacts?

The methodology entailed a multi-component analysis to assess climate, flooding dynamics, marine and coastal resources, and institutions in the targeted climate sensitive hotspots. Component methodologies are described in more detail at the beginning of the presentation of component results in Sections 3.1 and 4.1.

The climate analysis entailed a historical review of temperature and rainfall data and trends from the past 50 years, and down-scaled projections for 2030 and 2050. This analysis was supplemented by a literature review of extreme rain events and a wind analysis. The flooding analysis was completed geospatially by layering information related to river and ocean storm-surge flooding; administrative divisions and population centers; major physical features (rivers, roads, wetlands, mountains, etc.); and land use. The marine and coastal resources analysis was based on secondary data, a literature review, and key informant interviews. To implement the institutional analysis, multi-disciplinary teams conducted focus group discussions and key informant interviews, also supplemented by a literature review.

All components were designed to collect information related to the research questions and, after being compiled by component, were integrated into two sets of results: overall findings and climate-sensitive hotspot findings. The findings were presented to various audiences in the Dominican Republic: decision-makers, donors, and other stakeholders in Santo Domingo and the five communities visited in the climate-sensitive hotspots during the assessment phase. After presenting results, the assessment team facilitated six options analysis workshops and achieved the following objectives:

- Generated awareness of the issues and potential implications of climate change on the four climate change sensitive hotspot areas that the assessment targets;
- Improved understanding of constraints and opportunities for addressing adaptation; and
- Identified potential adaptation strategies and developed recommendations.

Fifty-five decision makers representing national and sub-national government, donors, academic institutions, and NGOs participated in the workshops and generated many recommendations for local and national consideration. The recommendations in this report reflect the thoughtful and informed input of the options analysis participants, who represent a variety of sectors and institutions.

2.2 CONTEXT

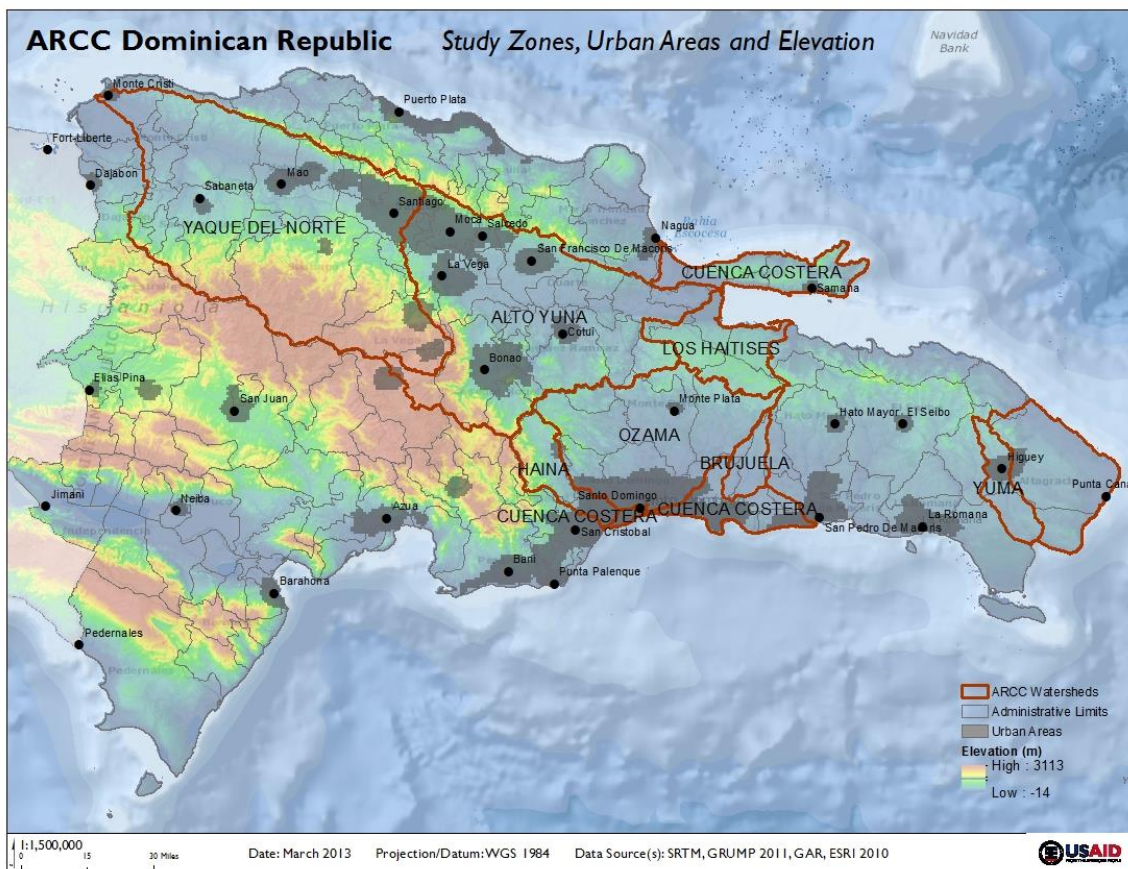
The Dominican Republic shares the Caribbean island of Hispaniola with Haiti and has a territorial extension of approximately 18,792 square miles (48,670 square kilometers), covering the eastern two-thirds of the island. The island belongs to the Greater Antilles and is located roughly in the center of the Antillean Arc. The Island of Hispaniola exhibits a broad altitudinal range, from 0⁴ to 3,175 meters above sea level (Pico Duarte in the Cordillera Central); a great variety of soils; and a rainfall gradient ranging from 400 to 4,600 millimeters (mm). Running northwest to southeast, four mountain ranges (the largest

⁴ Enriquillo Lake's elevation ranges from 35 to 40 meters below sea level.

of which is the Cordillera Central) divide the national territory into three principal regions — northern, central, and southwestern — and contribute to the Dominican Republic’s bio-geographical diversity (see Figure 2).

As mentioned, each hotspot has a unique set of bio-physical and ecological characteristics that collectively enrich our understanding of climate change vulnerability and how to develop resilience in a variety of contexts. The four climate-sensitive hotspots represent four distinct bio-geographical areas (Carmona and Ortiz, 2012). The Yaque del Norte Watershed — the Cibao Valley area in the lower watershed, which includes Montecristi and Santiago — has a dry tropical xeric macrobioclimate characterized by plants from the *Agavaceae* and *Cactaceae* families. Much of the lower valley is irrigated with water from the Yaque del Norte River and supports agriculture production, primarily rice. The mountains of the Samaná Peninsula are characterized by humid broad-leaf forests, a tropical-pluvial macrobioclimate with high rainfall rates. On the rocky escarpments of the peninsula, where these humid forests grow atop reef-perforated limestone, the territory adopts a dry profile as a result of the heavy water loss through the permeable sub-surface. Similarly, much of the Bávaro/Punta Cana area is situated on reef-perforated limestone with dry forests. The lower portion of the Ozama watershed that empties into the ocean in Santo Domingo also shares these reef limestone and dry vegetative features; in contrast, the upper reaches of the watershed are characterized by the humid broad-leaf forests found in the Cordillera Central.

FIGURE 2. DOMINICAN REPUBLIC GEOGRAPHICAL ELEVATION, POPULATION CENTERS, AND STUDY ZONES



The different bio-physical and ecological characteristics of each hotspot, to some extent, define the characteristics of exposure, the sensitivity of natural systems to exposure, and their capacity to adapt. Similarly, socio-economic characteristics help define the sensitivity of populations and their ability to respond to climate change. The assessment team had limited access to socio-economic information for each hotspot through the focus group discussion and key informant interviews that were conducted on site, and this information has been included in the hotspot specific descriptions in Sections 4.2 and 5.1. National statistics related to socio-economic well-being contribute to an improved understanding of the sensitivity of the target populations and supplement the locally gathered information. According to the 2010 National Census, the population of the Dominican Republic is approximately 10 million and relatively young, with a median age of 26.5 years. Although the overall unemployment rate is 13 percent, the youth unemployment rate exceeds 30 percent. A majority of the population, close to 70 percent, lives in urban centers. The national literacy rate is estimated to be close to 90 percent, even though the quality of public education is considered low and there is a low rate of completion particularly at the secondary school level (National Census, 2010). Although the ethnic composition is primarily (75 percent) a mixture of European and African heritages, discrimination based on skin color is common. Dominicans of Haitian origin face discrimination and challenges to establishing Dominican nationality. Women also face discrimination, and gender-based violence is common (Latin American Public Opinion Project [LAPOP], 2010 and 2010).

The World Bank classifies the Dominican Republic as an upper middle-income country with a per capita income of about \$5,250. There is significant income distribution inequality, with more than 40 percent of the population living in poverty. The poorest 10 percent of the population receives 2 percent of family income, while the richest 10 percent receives 36 percent. Manufacturing (30 percent of gross domestic product [GDP]) and the service industry (60 percent of GDP), including tourism, have become increasingly dominant drivers of the national economy, outpacing the traditional agricultural sector (6 percent of GDP) (World Bank, 2013).⁵ The majority of residents of hotspot communities situated in flood-prone and storm surge areas fall within the poorest 40 percent of the population, have relatively lower levels of education, are situated in urban centers, and are landless; many are of Haitian origin. Their relatively lower socio-economic status makes them especially vulnerable because they do not have a reserve of capital — financial, social, and physical — with which to withstand and recover from climate shocks such as flooding.

⁵ The World Bank classifies as “upper middle income” those countries with a per capita gross national income between \$4,036 and \$12,475 in current U.S. dollars.

3.0 EXPOSURE

The Intergovernmental Panel on Climate Change (IPCC) (2007) defines exposure as “the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected.” In this assessment, exposure is determined according to multiple changes in climate. These changes can manifest as alterations in the amount and distribution of rainfall, temperature, and the frequency and severity of extreme events (e.g., hurricanes), in addition to the impacts of sea-level rise and the effects of wind on coastal erosion. Given the areas of interest of this assessment, the exposure analysis focused on rainfall and temperature evolution and changes in wind in coastal areas that may be related to coastal erosion within the climate-sensitive hotspots. The exposure section describes the methodology, findings, and conclusions related to the analysis of these changes, including: an overview of rainfall characteristics; long-term historical rainfall evolution and projections; mean temperature characteristics; temperature variability, long-term evolution, and projections; wind speed and direction to assess wind as a factor in beach erosion; and sea-level rise.

3.1 CLIMATE ANALYSIS

The main objectives of the climate analysis are to quantitatively assess past and potential future changes in climate characteristics in the Dominican Republic. Climate varies on a range of spatial and temporal scales, and the conditions observed in any location change substantially from one year to the other. It is therefore essential to assess if recent large floods or coastal flooding and severe beach erosion are beyond or within the range of past ‘normal’ year-to-year variability, and also whether or not they are exacerbated by other non-climatic factors. Similarly, it is important to assess if the projected changes in climate represent a true shift to different climatic conditions or remain within the current range of variability. The analysis comprises three analytical components:⁶

1. A literature review of climate in the Caribbean, Hispaniola Island, and the Dominican Republic to assess main climate characteristics, including description of the variability and potential causes based on previous studies;⁷
2. An analysis of observed long-term evolution of climate and its variability in selected areas, to assess potential on-going changes in exposure and provide a context for projected changes in climate; and
3. Downscaled climate projections for rainfall and temperature in the climate-sensitive hotspot areas for the time periods 2015-2045 and 2035-2065, under two emission scenarios.

⁶ More detailed methodology can be found in Annex A.

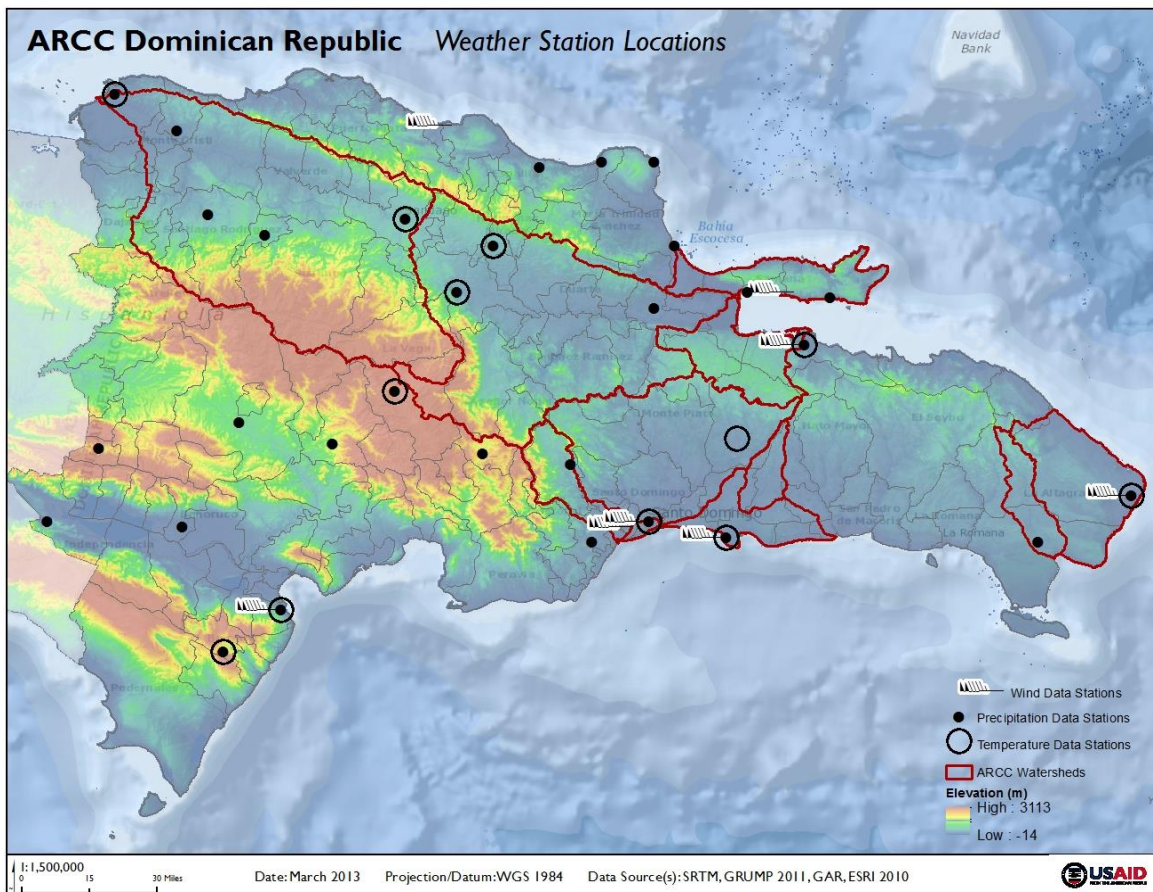
⁷ Detailed analysis of current climate variability and its causes is beyond the scope of this study.

3.1.1 DATA AND METHODS

Historical Climate Analysis

All data used for the historical climate analysis and the downscaling of projections are in-situ observations obtained from the *Oficina Nacional de Meteorología* (ONAMET). After a thorough quality control of more than 70 daily rainfall and over 40 temperature records received from ONAMET, 30 stations for precipitation and 12 for mean temperature were retained as a best trade-off between the spatial coverage (number of stations) and the length and quality of the records necessary for robust climate characteristics assessments.⁸ Eight stations contained wind information relevant to the coastal erosion study. Figure 3 shows the location of the selected stations; more details on the selection criteria, a station list, and a complete climate analysis methodology can be found in Annex A.

FIGURE 3. LOCATION OF NATIONAL METEOROLOGICAL OFFICE (ONAMET) STATIONS USED IN THE ANALYSIS OVERLAID ON TOPOGRAPHY AND FOCUS WATERSHEDS



⁸ Changes in station location or the physical environment surrounding the stations were not assessed as part of the study. However, the statistical methods used for the climate analysis helped to reduce the possible error in any individual station results.

Historical analyses assessed the average conditions at station level, the amplitude of current year-to-year variability, and long-term changes in these characteristics. Traditionally, 30-year periods are used to describe climatic characteristics. Given the maximum length of the records (52 years for rainfall, 50 for temperature), data were split into two samples of 26 years for rainfall and 25 for temperature. Average annual and monthly rainfall and temperature, as well as the amplitude of inter-annual variability (expressed as standard deviation), were computed for the two periods spanning 1960-1985 and 1986-2012. Those characteristics were further compared between the two periods to evaluate long-term changes, with their statistical significance assessed using standard tests (Student t-Test and Fisher-Snedecor F-test).

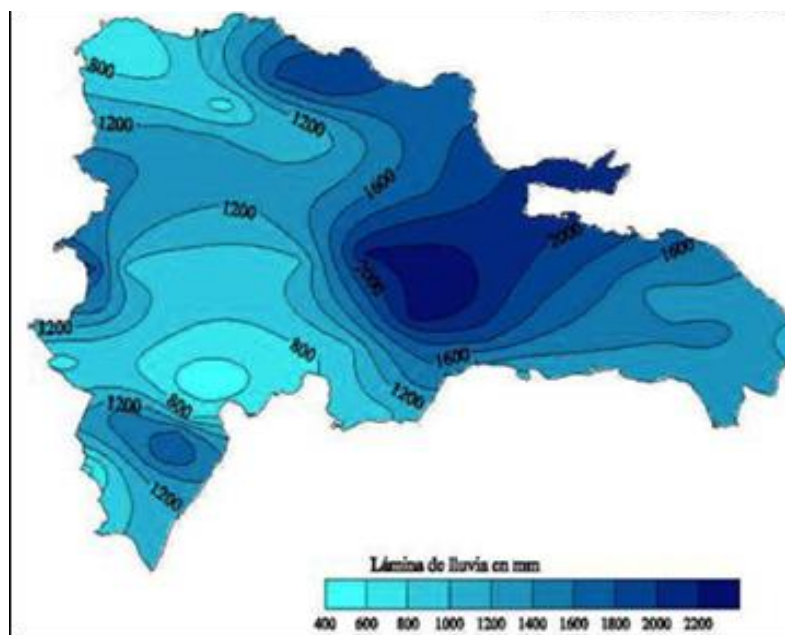
In addition, to assess potential decadal changes in rainfall, a similar analysis was performed with the pivotal year 1970 linked to documented changes in sea-surface temperatures (SST). Changes in the frequency of extreme events were similarly assessed by computing average frequency for each sub-period and comparing them using the Mann-Whitney U-Test. A similar approach was used to evaluate long-term changes in wind characteristics for the eight coastal wind records.

Climate Projections

Potential changes in rainfall and temperature in selected locations were obtained based on projections from the latest projection archive (CMIP5, Taylor et al., 2012). The range of potential changes was documented by using two different climate change scenarios (RCP4.5, a lower greenhouse gas [GHG] emissions scenario; and RCP8.5, a higher GHG emissions scenario) and 10 different models (of which two were discarded as outliers), following the multi-model approach recommended by IPCC (2007).⁹

The coarse resolution model outputs were downscaled to station level, and the bias was corrected using historical observations and model simulations for the period 1976-2005. Simulated average conditions and amplitude of inter-annual variability were computed for the periods 1976-2005, 2015-2045, and 2035-2065, and compared to the

FIGURE 4. AVERAGE ANNUAL RAINFALL FROM 1960-1991



Source: UNDP 2012.

⁹ Because GCMs are an imperfect representation of reality (cf. Annex A) and because different modeling groups have developed slightly different solutions to the challenges posed by climate modeling, the characteristics of climate projected under any given emission scenario may vary from model to model. It is not advisable to select the 'best' model, as they all have their strengths and weaknesses; thus the current practice recommended by IPCC (2007) is to look at the full range of available projections and consider their average or median, and an estimate of the spread. We looked at 10 different models and provided a multi-model average and the values from eight individual models.

historical 1976-2005 period. Statistical significance of simulated long-term changes vs. inter-annual variability was also assessed (see detailed methodology in Annex A).

The results of the historical and projections analyses are summarized in the following section.

3.2 RAINFALL

3.2.1 REVIEW OF RAINFALL CHARACTERISTICS

Annual Averages

Average annual precipitation in the Dominican Republic varies considerably throughout the country, with differences of up to 2400 mm (Izzo et al., 2010). The spatial distribution is primarily determined by trade wind direction and the orientation of mountain chains, which are typically elongated from northwest to southeast. The winds carry moisture from the Atlantic Ocean to the northeast of the country and release it upon encountering orographic barriers (the Cordillera Central), causing the heaviest precipitation in the northeast of the country (where it exceeds 2500mm), while the far western and southwestern valleys remain relatively dry with less than 760 mm of annual precipitation (see Figure 4) (UNDP, 2012).

Seasonality

In addition to regional differences in average annual precipitation, distinct seasonal rainfall patterns also exist. Garcia et al. (1978) identified five different rainfall zones that can be categorized into two main rainfall regimes:

1. In the north of the country, the rainy season is bi-modal, with two rainy seasons: May-June and September-October, separated by what has been termed a mid-summer drought (MSD) in July and August.
2. The south has two main seasons: a dry winter and a rainy summer.

The most widely accepted theory as to the cause of the MSD that characterizes regional seasonality of rainfall across the Caribbean is the intensification and expansion of the North Atlantic Subtropical High Pressure Cell into the region in July. The North Atlantic High Pressure (NAHP) is an atmospheric high-pressure system that causes stronger trade winds and lower sea-surface temperatures (SST), leading to increased atmospheric subsidence and diminished rainfall in the Caribbean (Gamble et al., 2008). These two main rainfall regimes are corroborated with ONAMET data used for this study and shown in Annex A.

Variability

In addition to spatial differences in average annual rainfall amounts and seasonality, rainfall in the Dominican Republic shows strong inter-annual and decadal variability. The main driver of the inter-annual variability appears to be *El Niño* Southern Oscillation (ENSO) in the equatorial Pacific at frequencies of approximately three to six years. While *El Niño* and *La Niña* events are known to affect coastal regions of the Tropical Pacific, they impact more remote areas by disturbing atmospheric circulation. In the case of the Caribbean, the location and strength of the NAHP, responsible for the MSD, are affected (Giannini et al., 2000; Gamble et al., 2008). An *El Niño* event is accompanied by atmospheric conditions leading to a drier and longer MSD, leading to an anomalously dry summer in the Caribbean. Conversely during *La Niña* events, the NAHP and MSD are less well expressed and cause anomalously wet summers.

A multi-decadal variability is also present in rainfall in the Dominican Republic. It has been associated with changes in the SST of the Atlantic Ocean. For example, colder SST during the 1970s to mid-1990s led to a decrease in precipitation in the region, while warmer SST, prevailing since the mid 1990's, resulted in increased precipitation in the region. The effect of this multi-decadal oscillation on the Atlantic Ocean is evidenced by the increase in hurricane activity in the Caribbean basin (Goldenberg et al., 2001). The multi-decadal oscillations are thought to be related to oceanic processes,¹⁰ independent of the global surface temperature increase induced by anthropogenic climate change, and should be considered in projections of near future climate. However, the predictions of related changes in SST are still in their infancy (Meehl et al., 2009; Ruiz-Barradas et al., 2013)

The inter-annual and decadal variations described are inherent to the climate system and fairly well understood. In the tropics they arise from interactions with the SST in adjacent and more distant oceanic basins, irrespective of changes in the atmospheric composition that drive long-term climate change. The strong amplitude of the inter-annual variability of rainfall and the presence of decadal variability mask long-term trends and make their detection difficult. If the trends are small relative to the inter-annual variability, they may appear as simple variations and not as shifts in climate regimes. These types of variability need to be accounted for, however, especially if their amplitude is strong. Rainfall and temperature behave very differently. Inter-annual variability is dominant for rainfall, while in the case of temperature, statistically significant long-term trends are manifestations of ongoing climate change. Interventions and adaptive strategies should develop resilience to inter-annual variability in the near future, in addition to improving adaptive capacity to address long-term climate change. Note that models used to project climate poorly capture inter-annual and decadal variability and are not reflected in the projections described in the next section.

Projections

Projections of future climate in the Caribbean and Dominican Republic have been made by various institutions and climate researchers at various spatial scales and time horizons for different emission scenarios. The IPCC (2007) provided Caribbean-wide projections in which different models projected a wide range of rainfall outcomes, both increases and decreases. The median value of those projections was a decrease of about 12 percent by 2080. Estimates of future rainfall for the Dominican Republic gave a range of changes in annual rainfall of -55 percent to +20 percent (McSweeney et al., 2009) by 2060 based on coarse-resolution General Circulation Model (GCM) outputs. Finer resolution analysis based on downscaled outputs from 2 GCMs did not reach a consensus and pointed to no change in one case and a decrease in the other (Simpson et al., 2012). A much finer scale analysis, at the level of the Yaque del Norte watershed (González Meza, 2012), pointed to a decrease by 18.5 percent of rainfall in the watershed but was based on one scenario and one GCM. Therefore, it is difficult to draw conclusions on potential changes in rainfall in the Dominican Republic based on the literature review alone.

Hurricanes

Hurricanes in the Dominican Republic are important events in the country's history, with devastating impacts due to the combined effects of high winds and heavy rainfall. They occur primarily during the months of August, September, and October; with greatest intensity in the southeast and southwest regions of the country. They form in the western part of tropical North Atlantic Ocean, where high SSTs and low pressure prevail and intensify as they travel westward over warm waters.

¹⁰ The Atlantic Multi-decadal Oscillation (AMO) is a North Atlantic basin-wide sea-surface temperature fluctuation on multi-decadal time scales, involving connections between the surface and the deep ocean. AMO has wide-ranging climate impacts and is linked to variability of Sahel rainfall, North and South American hydro climate, and the Indian monsoon. Additional information on the AMO can be found at http://www.aoml.noaa.gov/phod/amo_faq.php.

Analysis of inter-annual variability of hurricanes shows an increase in hurricane landfall probability for the whole Caribbean during *La Niña* years and a decrease during *El Niño* years, with a more than 3:1 ratio of hurricane landfalls between the two periods, per season (Targatliane et al., 2003).

In addition to inter-annual hurricane variability, multi-decadal changes in frequency have also been observed. Hurricane activity was relatively high from the 1940s to the late 1960s and in the late 1990s, while the period from the early 1970s until the mid-1990s, by contrast, was fairly quiet (Pielke et al., 2003). These longer-term fluctuations in Atlantic tropical cyclone activity follow the multi-decadal-scale changes in Atlantic SSTs (explained in the sections on variability and seasonality); hurricane activity is above average during the phases when the tropical North Atlantic is warmer (Goldenberg et al., 2001). The year 1995 is considered to be pivotal, marking the return to a more active regime last seen from the 1940s to the 1960s. It is important to continue to monitor the decadal variability in hurricane activity. If the current SST conditions in tropical North Atlantic persist, high levels of hurricane activity may prevail for the next decade (Pielke et al., 2003) irrespective of climate change linked to changes in atmospheric composition.

While it is impossible to make projections of individual events and landfall, recent projections of hurricane activity indicate that under various greenhouse gas emission scenarios, the frequency of hurricanes may not change but the global average intensity of tropical storms might increase by 2 to 11 percent by 2100, with an increased precipitation rate of 20 percent within 100 kilometers from the storm centers (Knutson et al., 2010). This increase in intensity could result in more devastating impacts, and should be considered along with the decadal and inter-annual changes in hurricane frequency described above.

3.2.2 LONG-TERM HISTORICAL RAINFALL EVOLUTION AND PROJECTIONS

Observed Long-term Evolution of Monthly Rainfall

The analysis of long-term rainfall changes assessed through a comparison of rainfall patterns for two non-overlapping periods, 1960-1985 and 1986-2012, in individual stations within the climate-sensitive hotspots did not show a robust and statistically significant trend in monthly precipitation. All records exhibit a very high inter-annual variability, as measured by the standard variation of monthly values in each of the periods, even after the removal of the most intense events related to tropical cyclones. This very high inter-annual variability makes the detection of statistically significant trends very challenging. In fact, in only a few instances (individual months) does rainfall appear to have significantly changed in individual stations. Figures R2, R3, R6, R7, R10, R11, R14, and R15 in Annex A show examples of inter-annual variability and long-term evolution of rainfall in selected individual stations in the targeted watersheds (Punta Cana/Bávaro, Yaque del Norte [Montecristi/Santiago], Bajo Yuna [Samaná Bay and Peninsula], and Santo Domingo). This preliminary analysis did not reveal robust and significant changes in rainfall across all the stations analyzed. However, in some instances, changes in rainfall seasonality in several stations were observed, indicating that changes may be influenced by large-scale dynamics (e.g., regional topography illustrated in Figure A2 in Annex A). Additional analysis is required to improve understanding of these dynamics. These changes are presented in the more detailed description of the results below.

In the northwest section of the Yaque del Norte watershed, among the driest regions in the Dominican Republic, all analyzed stations exhibit a bi-modal seasonal rainfall pattern with two rainy seasons (April/May and September/October) separated by the MSD (June and July) and followed by a longer dry season in winter. Only in very few instances do individual stations show long-term changes that are significant relative to inter-annual variability. A general pattern emerges of a decrease in rainfall during the April-December period and an increase in January; pointing to a change in seasonality.

In Bajo Yuna and Samaná the precipitations are generally higher than in Yaque del Norte, and the MSD is less well defined. Here again long-term changes are rarely significant, but the main emerging long-term rainfall pattern is that of a consistent (though not statistically significant at individual stations) increase in precipitations in the western section of the Yuna watershed (La Vega, Salcedo) while the East — Villa Riva and Sanchez — experienced a decrease in precipitation, especially during the latter part of the year. Samaná shows a very distinct pattern that might be related to its location: east on the coast of the peninsula and potentially benefitting from changes in wind direction.

In Punta Cana/Bávaro, the only significant change is an increase in rainfall in January, also present in the Samaná/Alto Yuna stations. Though they are located relatively close together, both stations experience very different rainfall change patterns, indicating the importance of orography and location of the station relative to the prevailing winds.

In the Santo Domingo and Ozama watersheds, rainfall shows primarily one longer rainy season in summer and one dry season in winter. Although not statistically significant, it is worth noticing that, unlike stations in other areas, all three analyzed stations experienced an increase in precipitation during most months of the year.

Observed Long-term Evolution of Extreme Rainfall Events

Changes in frequency of extreme rainfall events¹¹ between the periods 1960-1985 and 1986-2012 were also analyzed to assess if there is an evolution in the characteristics of individual rainfall events. An increase in the frequency of heavy precipitation events that led to flooding was reported in focus group discussions, and the analysis of actual rainfall events contributes to an understanding of what has occurred.

The analysis showed a tendency for fewer extreme rainfall events in Yaque del Norte watershed and more extreme events in the Santo Domingo watershed, where the increase in frequency of heavy rainfall was significant in the coastal areas (Santo Domingo and Las Américas). Changes in the Samaná and Yuna Region are inconsistent, with some stations showing an increase and some a decrease.

Projections through 2030 and 2050

Projected changes in rainfall for both, 2030 and 2050, point to a change in the seasonality rather than a strong change in the annual precipitation, with a potential decrease in rainfall in May (a rainy month in all stations) and an increase in December (a dry month in all stations). Due to high inter-annual variability and the presence of decadal variability in rainfall in the region, however, those changes might not be noticeable in the near future.

Most stations in the four climate-sensitive hotspots are projected to experience a statistically significant decrease in rainfall of about 10 percent¹² of rainfall in May, which is usually a month of high precipitation in stations especially on the north coast. There is also a projected decrease throughout the summer months, but the magnitude of decrease is less than that projected for May, with the exception of August

¹¹ An extreme rainfall event was defined as 90 percentile or more of the distribution of rainfall after removing days with no precipitation and precipitation associated with tropical storms and hurricanes. This analysis was split in two: frequency of rainfall above the 90 percentile and frequency of rainfall above the 95 percentile. The analysis was conducted for 16 stations, with seven of those located within the four climate sensitive hotspots. Complete results appear in Annex A.

¹² We estimated as multi-model average of projections by eight models, following IPCC (2007) recommendations. Note that there is a wide range of projected values by individual models that can be larger than the multi-model anomalies, thus the confidence in the exact values of projected changes in rainfall is low. The range of different projections and different time-horizons for a given model, station, and month is, however, much narrower and does not exceed 5 percent.

and September in a few stations where the deficit can exceed 10 percent of monthly values. In addition, rainfall is projected to increase in all stations for the months of November and December, sometimes by more than 20 percent. This increase points to a potential slight shift extending the rainy season, with a possibility of flooding in the later part of the year. But given the strong spread among the models and general uncertainty of the projections and high inter-annual and decadal variability, it is important to keep in mind that the projected climatological changes presented in this paragraph may or may not occur. Figures R4, R8, R12, and R16 in Annex A illustrate expected changes in precipitation as anomalies based on projections from individual models and the multi-model mean under each pathway.

Statistical downscaling procedures were used in this study to obtain station-level projections from 10 GCMs available in the CMIP5 archive. The projections of mean precipitation were performed for two 20-year periods: 2010 to 2030, and 2030 to 2050; under two greenhouse gas emission scenarios (Representative Concentration Pathway RCP4.5 [low emissions] and RCP8.5 [high emissions]).¹³ Multi-model averages as well as values from eight individual models (two outliers were discarded) were considered.

3.2.3 SUMMARY

Rainfall in the Dominican Republic shows high spatial variability (total amounts) and well defined seasonality, with two distinctive seasons in the South — rainy summer and dry winter — while in the North the summer rainy season is split into two by the MSD. Year-to-year variations are very strong and the region in general is also subject to decadal variability in rainfall and hurricane activity.

Longer-term trends, potentially attributable to climate change, are both masked by the amplitude of inter-annual and decadal variability and difficult to detect. No robust, spatially consistent trends emerge in annual rainfall from the current analysis. However, in a few instances, spatially coherent changes over limited areas point to changes in the seasonal cycle of rainfall, with a decrease in rainfall in summer and an increase in January. Changes in rainfall projected by models and statistically downscaled to the stations of interest show a wide range of values for each location and often do not agree on the sign of the change (increase vs. decrease). A multi-model average of these projections shows a potential decrease in rainfall in May by about 10 percent (and in some locations throughout the summer), in addition to an increase in November and December, pointing to a change in seasonality similar to what the historical analysis shows is already occurring. A reduction in rainfall in the peak of the rainy season can have consequences for agriculture and water quality, especially in more arid areas such as the northwest section of the lower Yaque del Norte watershed, which experiences the MSD. An increase in rainfall in January can lead to late-season flooding.

Few previous studies of observed and projected long-term changes in seasonality of rainfall in the Dominican Republic have been conducted to corroborate these findings. It is recommended that additional studies be conducted to assess their robustness and further contribute to the growing body of climate information and knowledge.

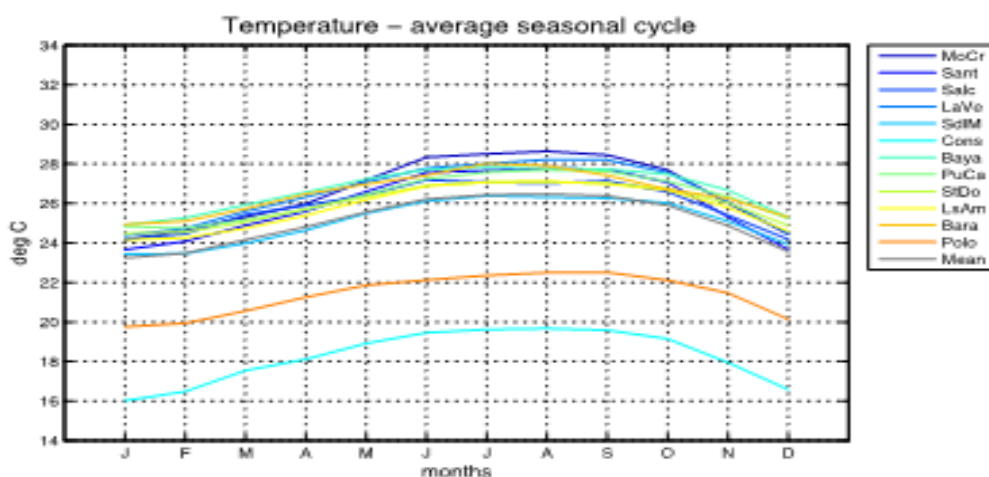
¹³ RCP stands for representative concentration pathway. 4.5 and 8.5 are the expected radiative forcing (W/m^2) associated with that pathway.

3.3 MEAN TEMPERATURE

3.3.1 MAIN MEAN TEMPERATURE CHARACTERISTICS

Altitude is the primary determinant of variations in temperature across the country, and all records analyzed exhibit a very similar seasonal cycle as well as limited inter-annual variations. The average seasonal cycle for mean temperature is uniform across all stations (Figure 5, following page) with a peak in the summer on the order of 26-28 °C for stations close to sea level, and the lowest temperatures in winter averaging 23-25 °C. Constanza and Polo, located at 1,164 meters and 703 meters above sea level respectively, experience lower average temperatures than stations in regions closer to sea level.

FIGURE 5. AVERAGE SEASONAL CYCLE OF TEMPERATURE IN THE 14 SELECTED STATIONS



Note: Monthly average values were computed over the 1960-2012 period.

3.3.2 VARIABILITY, LONG-TERM EVOLUTION, AND PROJECTIONS

Unlike for rainfall, inter-annual variations of temperature are small and consistent with the lack of dependency of temperature on atmospheric circulation and its seasonal and inter-annual variations (see Figure T2 in Annex A). The amplitude of inter-annual variability, expressed as a standard deviation, ranges between 0.5-1 °C in different locations and months. These limited inter-annual variations in temperature allow an easier detection of long-term trends. The long-term temperature increase between the 1960-1985 and 1986-2012 periods is statistically significant in most of the locations and months, even if it represents only 2 to 5 percent of the monthly average temperature. However, these trends cannot be attributed directly to climate change because other factors, such as a modification in the environment around the station (urbanization and urban heat effects), also can contribute to the recorded temperature increase. To further assess the magnitude and nature of the change, additional investigation and information is needed.

Previous estimates of future temperature changes focused on slightly longer horizons (2060, 2080, and 2090) and estimated the temperature increase in the Dominican Republic by 2060 to range between 0.5-2.3 °C (McSweeney et al., 2009). The multi-model estimated increase by 2080 (IPCC 2007) was about 2 °C and above 3 °C according to other estimates (Simpson et al., 2012). Our estimates of temperature change are in the order of 0.5-1 °C by 2030 and 1.0-2.5 °C by 2050 for all stations. This warming will increase evapotranspiration and induce further water stress, especially in arid or semiarid areas (51

percent of the country, Izzo et al., 2010). The northern stations are expected to experience a greater temperature increase than those in the south (see Annex A, Figures T3 and T3bis).

3.3.3 SUMMARY

Temperature in the Dominican Republic closely follows altitude and, unlike rainfall, experiences little seasonal and inter-annual variation (less than 5 percent). Unlike rainfall, long-term changes in temperature consist of a coherent increase among most of the stations and significant in most months, ranging between 0.5-1 °C. Models agree that temperature will continue to increase at a similar rate in the coming decades (with greater increases in the Northern region), increasing water stress in arid and semi-arid areas and also during drier months.

3.4 OTHER FACTORS: WIND AND SEA-LEVEL RISE

3.4.1 WIND

Analysis of changes in wind speed and direction did not yield robust and significant results. Therefore, the observed changes in beach erosion rates cannot be directly attributed to changes in atmospheric circulation. This analysis was conducted to better understand the relationship between changes in wind dynamics and increased beach erosion, which communities identified as an observable environmental change during focus group discussions. A significant, albeit small, change in wind speed was found for some stations. Barahona and Sabana de la Mar experienced an increase of 3 km/hour and 2 km/hour between the two time periods, respectively. A decrease of 2.5 km/hour was found in Santo Domingo. However, these statistically significant changes are most likely attributed to factors not related to climate change. For example in Santo Domingo, urban sprawl has occurred around the station and is most likely the cause of the statistically significant decrease in wind speed in the later time period. In Punta Cana, a significant decrease was found in the number of days with wind speeds above 12 knots, highlighting the fact that the strong beach erosion in that region is most likely due to factors not related to wind changes.

Differences between average wind characteristics for 1960-1985 and 1986-2012 as well as statistical tests were studied to assess changes in average wind speed, mean number of days with average wind speeds above 12 knots, and mean number of days with a particular wind direction. This threshold was determined to be the wind speed that could produce enough sand movement to exacerbate erosion.

3.4.2 SEA-LEVEL RISE

Sea-level rise (SLR), an impact of climate change, will likely exacerbate beach erosion and should be monitored closely.¹⁴ Climate change-induced SLR poses a threat to the coast of the Dominican Republic via thermal expansion and the melting of land-based ice. Literature reviews found that GCMs predict a 6-8 cm rise in sea level by 2020, a 23-25 cm rise by 2050, and a 42-50 cm rise by 2080 (Horton et al., 2008). In many locations, small increases in sea level during the past few decades have increased the height of storm surge and wind-waves (Parris et al., 2012). The observed sea-level rise exceeds what has

¹⁴ Of the 44 operational sea-level monitoring stations location in the Caribbean region, most are located in Puerto Rico and the U.S. Virgin Islands and operated by the National Ocean and Atmospheric Administration (NOAA) and the Puerto Rico Seismic Network (PRSN). There is at least one station managed jointly by ONAMET and PRSN located near Barahona. More information on this station and others located in the Caribbean is available at <http://www.ioc-sealevelmonitoring.org/station.php?code=bara>. A second station is known to be operated by Fundación Punta Cana but the data may not be publically available. An additional six stations are expected to be commissioned by INDRHI but do not appear to be operational at the time this report was written (UNESCO, 2009).

been predicted by models (best estimates) by approximately 50 percent for the periods 1990–2006 and 1961–2003 (Vermeer and Rahmstorf, 2009).

A more detailed study of potential impacts of the sea level rise on various coastal segments, including changes in storm surges, requires detailed observational data that are not available for the Dominican Republic.¹⁵

3.5 CONCLUSIONS

The Dominican Republic experiences great heterogeneity in annual rainfall and seasonal cycles across the country. Total annual rainfall is greatest in the northeast, while it is the lowest in the southwest. A bi-modal seasonal rainfall regime exists in the North, in which a mid-summer drought occurs between two months of high rainfall. In the South, the seasonal cycle is characterized by a wet summer and a dry winter. Consequently, the analysis of long-term rainfall changes in historical rainfall as well as estimation of projected changes needs to take into account the spatial variability in rainfall – its annual totals and seasonality. In addition, all regions experience very strong inter-annual rainfall variability; the Caribbean as a whole also experiences decadal changes in rainfall, potentially masking longer-term evolution.

The findings of the literature review of climate and analysis of historical climate variability and trends in rainfall, temperature, and wind lead to the following conclusions:

- Rainfall in the Dominican Republic shows spatial and seasonal contrasts as well as documented inter-annual and decadal variations. The detection of past and projected longer-term trends is made challenging by the presence of this natural variability. Long-term trends in historical rainfall are not statistically significant, but in a number of stations there seems to be a slight reduction of rainfall during the peak of the rainy season and an increase at the end of the season in late fall. Individual models tend to disagree on the amplitude and even the direction of projected changes, but there is some indication of a potential reduction of rainfall in the peak of the rainy season and an increase during what is traditionally the dry season.
- On the other hand, a consistent and significant upward trend has been found in temperature, which is also projected to continue increasing at the same or slightly faster rate in the near future.
- Increased heat combined with decreased rainfall can exacerbate water stress, especially in the drier areas of the country and in areas subject to the mid-summer drought. Conversely, increased rainfall over already-saturated areas at the end of the rains could exacerbate flooding in the flood-prone locations. The analysis of extreme rainfall events, excluding hurricanes and tropical storms, did not show consistent evidence of change in extreme rainfall frequencies; in certain watersheds they seem to have increased, while in others they decreased.
- The most devastating climate phenomena — hurricanes and tropical storms — also show strong seasonality and inter-annual and decadal variability. These variations are not easily predictable. But there is consensus about the fact that while the number of storms may not change, they may intensify in a warmer atmosphere, becoming more devastating due to anthropogenic climate change. Combined effects of higher intensity in warmer environments, along with changes in frequency

¹⁵ The high-resolution study recently published by UNDP-CARIBSERVE (Simpson, et al., 2010) used data that are not very reliable at the local scale. To produce models that inform the impact of SLR on different coastal segments with sufficient precision and reliability, local data including bare Earth topography and bathymetry, gravity-corrected benchmarks to provide true elevation, and records from calibrated tide gauges are necessary.

related to decadal variations in tropical Atlantic SSTs, may result in greater hurricane impacts in coming years. These effects will be experienced inland and on the coast, with increased storm surges in a higher sea-level context. No significant changes in high-speed wind events (outside of hurricanes) responsible for storm surges and beach erosion were found.

- While this study confirmed a consistent warming of the island, it did not find strong climate change signals in rainfall and wind. In general there is little peer-reviewed literature on climate variability and change that both specifically focuses on the Dominican Republic and captures all the complexity of its climate in order to back and contextualize current results. Further investigation, particularly focusing on atmospheric phenomena and mechanisms specific to the island, could shed more light on past and future possible evolution of climate with greater details.

4.0 SENSITIVITY

4.1 OVERVIEW OF SENSITIVITY

Sensitivity is the degree to which a system will be affected by, or responsive to, climate stimuli (Smit and Pilifosova, 2001). Sensitivity in this assessment refers to how anticipated climate changes and manifestations outlined in the exposure chapter (sea-level rise, increasing temperatures, strong inter-annual rainfall variability, intensifying tropical storms, and changes in rainfall seasonality) will affect the coastal communities, marine habitats, and watersheds that are identified as climate-sensitive hotspots. Many communities living within the study area are susceptible to the combined effects of alluvial flooding and storm surge, which will worsen as sea level rises, rainfall variability continues, and tropical storms intensify (these issues are further discussed in Section 4.2). These communities depend heavily on the health of coastal and watershed habitats to maintain their livelihoods (fisheries and tourism) and to mitigate potential natural disasters due to river and coastal flooding (as determined from focus group discussions). This section describes the sensitivity of these natural systems and the communities that depend on them, first describing common factors such as flooding/storm surge dynamics and the state of marine and coastal habitats across the climate sensitive hotspots, and then in more detail within the context of each hotspot.

It is important to note that stresses associated with climate change may be either slow (when there is a gradual increase in climate events, as is the case with sea-level rise), or sudden in onset (as is the case with severe storms that may cause significant flooding). The most vulnerable communities, livelihoods, and natural systems will be those that most directly suffer these impacts (the measure of sensitivity) and are less able to rebound over time (the measure of adaptive capacity). Significant non-climate-related stressors such as declining soil fertility, conflict, land, and population pressure — combined with climate stressors — will increase the challenges communities, livelihoods and natural systems face in responding to climate-induced changes and events. Those that are less vulnerable will be able to buffer the immediate impacts of such crises, recover in a timely fashion, and ensure the continued viability of the natural systems upon which they depend (e.g., coastal habitats that ensure that fish populations thrive, and healthy coral reefs that produce white sand and protect beaches from erosion).

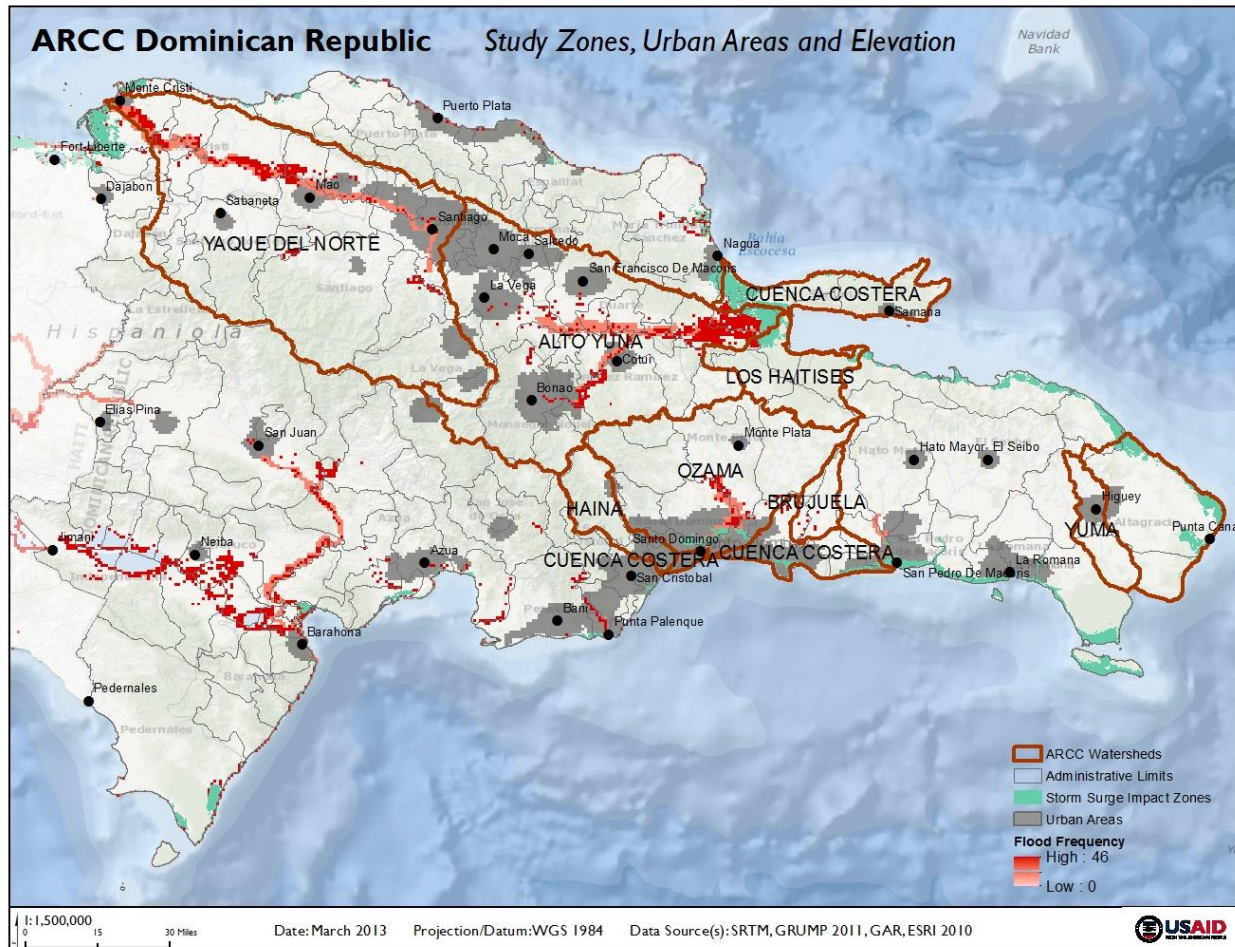
4.1.1 CLIMATE AND NON-CLIMATE STRESSORS

The climate stressors identified in the climate analysis (increasing temperature, more intensive tropical storms, projected slightly wetter dry seasons and drier peak rainy seasons, strong variability in rainfall, and continuing sea-level rise) will combine with the impact of non-climate stressors to further exacerbate the vulnerability of natural systems, people, and their communities. Significant non-climate stressors are well known and documented in the Dominican Republic. A population growing at a steady rate of 1.3 percent, with 70 percent living in urban areas (many looking for economic opportunity after having recently migrated from rural areas or from Haiti) puts pressure on scarce available land and a diminishing natural resource base. Economic efforts to make ends meet and develop industry put additional pressure on the exploitation of forests, fisheries, inner-city development, and agriculture lands, which then contributes to deforestation, overfishing, degradation of agriculture areas and marine environments, as well as the pollution and irrational use of water resources. Well-conceived and enforced planning practices as well as technical and financial support to promote sustainable livelihoods would help prevent and mitigate the negative consequences of development. Weak governance, however, makes it difficult to plan, enforce, and promote these efforts. If these non-climate stressors are not addressed in conjunction with the climate stressors, then efforts to increase adaptive capacity will

be undermined. The environmental degradation of the country's fertile valleys, extensive riverine systems, forested watersheds, and coastal habitats diminishes the ability of natural regimes and systems to buffer and mitigate the impacts of the anticipated increase in intensity of storms, temperatures, and sea-level rise.

4.1.2 SPATIAL ANALYSIS: FLOODING, LAND USE, POPULATION CENTERS, AND PRIMARY PHYSICAL CHARACTERISTICS (RIVERS, MOUNTAINS, VALLEYS, ETC.)

FIGURE 6. DOMINICAN REPUBLIC FLOOD FREQUENCY ANALYSIS AND CLIMATE-SENSITIVE HOTSPOTS



The purpose of the spatial analysis was to better understand current and historical manifestations of climate-related risk and the potential sensitivity of communities, livelihoods, and natural systems to those risks. Assuming that tropical storms will intensify, and that sea-level rise and patterns of rainfall variability will continue, a flooding analysis was conducted to identify areas most susceptible to alluvial flooding and storm surge (Figure 6). Economic and population criteria were then applied to define susceptible areas with extensive populations and important economic areas that are moderately to highly sensitive to flooding risks. Climate changes (exposure) including increasing localized temperature and precipitation changes were cross-referenced with medium- to high-risk flood areas and areas susceptible to storm surge and sea-level rise. Using these criteria and anecdotal information collected during focus group discussions and key informant interviews, the team could then focus on the

communities, livelihoods, and natural systems that are geographically located in the highest risk areas. Four areas — situated in partial or multiple watersheds — were identified and designated as climate-sensitive hotspots to be studied further (Figure 6).

The sensitivity of certain ecosystems and livelihoods to floods, storm surge, and other risks was analyzed using data for slope; elevation;¹⁶ watershed; population density; existing infrastructure such as tourism destinations, roads, buildings, irrigation canals, and dams; and important ecosystems such as mangroves and estuaries.¹⁷ Publicly available imagery was used to demonstrate the potential manifestations of climate change induced impacts within communities and across the landscape, and to demonstrate, where evidence existed, the non-climate drivers of risk such as land degradation.

Flooding is a major disaster risk in the Dominican Republic, and this analysis looked at flooding across all climate sensitive hotspots. Flooding risk was broken up according to event frequencies of ‘Low’ (0 – 2 floods), ‘Medium’ (3 – 24 floods), and ‘High’ (25 – 46 floods) in a 100 year period.¹⁸ The analysis demonstrated the geographical extent of flooding risk within the watersheds and overlaid secondary demographic and biophysical data (focus group discussion results, census, and land use) were reviewed to identify sensitive populations, livelihoods, and natural systems within the areas affected. The analysis found:

- Certain communities experience a ‘High’ frequency of flooding, such as the town of Montecristi in the lower watershed of the Yaque del Norte, in addition to numerous smaller populations in the lower watershed of the Yuna River. Coupled with the effects of sea-level rise the increasing intensity of storms, these communities are likely to have higher exposure in November and December due to an increase in precipitation within the watersheds during these months.¹⁹
- Spatial analyses also confirmed that land-use change (further discussed in the Surface and Groundwater Management Section) from forested to agriculture and other uses, which often leads to higher runoff, is present throughout the upper reaches of the Yuna, Yaque del Norte, and Ozama Rivers. The conversion of the natural landscape to less absorptive surface materials is likely to exacerbate future flooding risk. Furthermore, new construction and rebuilding of flooded homes and businesses in flood-prone areas are likely to increase the risk of communities situated along the major rivers that flow through the urban centers of Santo Domingo (e.g., Los Mina and neighborhoods in the northern district) and Santiago.

Storm surge is a risk in many coastal areas of the Dominican Republic. Storm surge is a manifestation of climate change including sea-level rise and more intense storms that lead to saltwater inundation in low-lying coastal areas. The dataset is based on estimated storm surges triggered by tropical cyclones between 1975 and 2007.²⁰ Preliminary analysis of the data indicated the following:

¹⁶ Slope and elevation affect ‘orographic rainfall,’ where warm moisture-laden air decreases its carrying capacity as it moves up in elevation. This effect results in a ‘rain-shadow’ on the Southwest side of the Cordillera Septentrional and Cordillera Central. Elevation and slope are derived from the Shuttle Radar Topographic Mission (STRM) with a spatial resolution of 90 meters by 90 meters.

¹⁷ Population density was obtained from the Global Rural-Urban Mapping Project, Version 1 (GRUMPv1) published in 2011, which uses census tract data and night-time satellite imagery to determine populated areas.

¹⁸ Flooding frequency data from the United Nations Environment Programme (UNEP)/Global and Regional Integrated Data (GRID)-Europe was reclassified from 46 values into three levels of risk (‘Low’ = 0 – 2 events, ‘Medium’ = 3 – 24 events, and ‘High’ = 25 – 46 events over a 100 year period) using natural statistical breaks.

¹⁹ Climate projections suggest an increase of rainfall in November and December with a potential decrease during the rainy season.

²⁰ Storm surge is based on data from UNEP/GRID-Europe and triggered by tropical cyclones between 1975 and 2007. It is based on three sources (discussed in annex A) and modeled using global data.

- The tourism areas of Bávaro and Punta Cana; the communities and agricultural land in the lower Yuna watershed; and other low-lying coastal infrastructure, such as roads and bridges in Santo Domingo and Montecristi and irrigation canals in the coastal area of the Cibao, are at significant risk.
- Risk is greater for certain coastal communities and ecosystems, such as mangroves located within a few feet of sea-level, such as in Montecristi and Samaná Bay;²¹ and for livelihoods such as agriculture, where the combination of river and coastal flooding is likely in the future.
- Risks are likely to become greater as continued sea-level rise, increasing temperatures, and more intense storms contribute to more extensive flooding and coastal surges which, in turn, increase the sensitivity of people, livelihoods, and natural systems due to an increasing frequency in ‘shocks’ to the system (Frankenberger et al., 2012).

4.1.3 MARINE AND COASTAL ANALYSIS

The communities in the coastal climate sensitive hotspots of Montecristi, Las Terrenas, Samaná, Bávaro, and Punta Cana reported that coastal flooding, salt water intrusion, pollution, fish and shrimp stock depletion, eroded beaches, and dying reefs were increasingly evident concerns that might be associated with climate change. Marine and coastal habitats such as coral reefs, sea grass beds (soft-bottom habitats), mangroves, and estuarine areas are crucial to many tropical coastal areas because of their economic and ecological functions; some of these serve to mitigate the negative effects of increasing sea-level rise, temperatures, and more intense storms. All of these habitats provide natural barriers and ecological services to protect from storm surge and to regulate water flow (fresh and salt water). They additionally provide economic benefits such as critical spawning grounds for fish, as well as healthy, attractive beaches and reefs for tourists to enjoy. Coral reefs and mangroves are the foundation of coastal protection, tourism, and subsistence economies. In many areas, they serve as focal points for cultural and community heritage (Maragos et al., 1996).

The combined effects of sea-level rise, increasing temperatures, and more intense storms will challenge the ability of coastal habitats to reduce the effects of flooding and the degradation of vital marine ecosystems in ways that will have negative impacts on human security and livelihoods (agriculture, tourism, and fisheries). Key findings related to the impacts of climate change on coastal habitats — relevant across the four hotspots — are described as follows:

- **Beach erosion, which is an irreversible coastline retreat due to increased sea level, will be exacerbated by climate impacts** (Peduzzi et al. 2011, UNEP). It is widely evidenced that Dominican beaches are eroding at rates comparable to similar locations across the region. Erosion rates have been recorded at 0.5 meters/year in some Caribbean islands (G. Cambers, 2009). In many locations, small increases in sea level during the past few decades have increased the height of storm surge and wind-waves (Parris et al., 2012). The observed sea-level rise exceeds model predictions (best estimates) by ~50 percent for the periods 1990–2006 and 1961–2003 (Vermeer and Rahmstorf [2009]). Observations like these do not bode well for Caribbean beach destinations like the Dominican Republic, especially when sea-level rise projections range from 75 to 190 cm for the period 1990–2100.
- **The prospect of more intense storms will increase wave action (adding additional stress to marine environments like soft-bottom habitats, coral reefs, and mangroves) and contribute to additional beach erosion.** Depending on the health and resiliency of habitats,

²¹ Mangrove data was provided by the Nature Conservancy (2009).

they might naturally restore themselves. Eroded beaches will take days to weeks, mangrove and soft bottom habitats will take weeks to months, and coral reefs will take years. For example, intense wave action generated from a passing tropical storm can greatly erode a beach, but given natural sand replenishment from nearby sources of sand such as coral reefs and sea grass beds, the beach can recover most of the lost sand in a matter of days or weeks. The increased intensification of storms and sea-level rise, however, will hinder the ability of beaches to establish themselves before the next storm hits. Other factors such as infrastructure development, intensive tourism activities, etc. also hamper their ability to recuperate.

- **In the Caribbean (with a total reef area of approximately 20,000 km², or 9 percent of the world's mapped reefs), nearly two-thirds of the reefs are considered 'at risk,' while almost one-third are characterized as highly threatened** (Bryant et al., 1998). Threats to coral reefs in the Dominican Republic include overfishing, destruction of co-dependent habitats such as estuaries and mangroves (freshwater intrusion), ocean acidification, and unregulated development and tourism. Coral reefs have been recognized for their biological, economic, and cultural services including the provision of natural physical barriers to protect coastlines (particularly beaches) from erosion; spawning habitats for a diverse assemblage of species (including commercially valuable species); white sand from coral; recreational diving and snorkeling; and a primary food source for local communities (Chiappone et al., 2000). Among the principal features that have made Caribbean islands like the Dominican Republic popular destinations for tourists are the tropical climate and the wide, sandy beaches (Beekhuis, 1981; Uyarra et al., 2005; Cambers, 2009), which are produced by local coral reefs (Thorp, 1935; UNEP/ Global Programme of Action for the Protection of the Marine Environment from Land-based Activities [GPA], 2003).
- **Ocean acidification will put marine ecosystems, particularly coral reefs, at even greater risk of rapid and permanent degradation.** Coral reefs are also vulnerable to effects of ocean acidification, which is referred to as the silent killer of marine organisms. As CO₂ from the atmosphere, generated by increasing global emissions, is absorbed by the oceans, pH drops and water becomes slightly more acidic (NOAA, n.d.). The increase in acidity is sufficient to upset the balance of entire marine ecosystems. Coral reefs are particularly at risk because their delicate coral organisms are sensitive to changes in acidity. If the organisms do not thrive, they will not build the skeletons that create immense and beautiful natural coral reef structures that support the coral reef ecosystem and provide natural barriers along coastlines. Coral reefs do more than supply sand to adjacent beaches; the barrier reef structures control the rates of beach erosion by reducing the energy of incoming oceanic waves (Weilgus et al., 2010).
- **Increased levels of freshwater flooding — either short-term during a storm or longer-term from alteration of mangroves and estuaries — can increase the mortality rate of coral organisms.** It has been documented that coastlines subjected to freshwater flooding generally do not support structural reefs (Longhurst and Pauly, 1987). Freshwater flooding occurs in Montecristi, Santo Domingo, and Samaná Bay, where coral reef organisms cannot tolerate variation in salinity levels. Heavy sedimentation and excessive storm and wave action combine with the freshwater flooding to increase the mortality rate of coral organisms.

Non-climate stressors (such as human exploitation of resources and development of infrastructure to support tourism and growing urban populations) combine with the climate-related stressors described above to increase the sensitivity of coastal populations and natural systems. Even though all of these stresses are inter-related, and it is difficult to differentiate between the climate and non-climate drivers, key findings associated with non-climate stressors follow:

- **Human dependency on coral reefs as a food source often leads to over-fishing, which, if not regulated, upsets the delicate balance of the reef ecosystem.** Fishermen prefer larger

fish, but when those fish stocks are depleted, they fish down the food chain (Pauly et al., 1998). When fishermen deplete the herbivore stocks (third and fourth levels down the food chain), marine ecosystems lose the ability to control fast growing algae, which leads to a proliferation of algae that dominate and upset the coral reef ecosystem (common throughout the Caribbean).

- **Beach loss is related to human impacts, such as alteration of natural coastal processes and systems by excessive construction in coastal areas and activities that have been described above, which contribute to coral reef degradation (Cambers, 1999).** In recent years, beaches in the Dominican Republic and other places in the Caribbean have seen accelerated erosion (UNEP/GPA, 2003). This long-term loss of beaches differs from the naturally occurring cycles of sand erosion and deposition. Beach quality plays an important role in the selection of the Dominican Republic as a travel destination for many international tourists (Mercado and Lassoie, 2002; Coles, 2004). In a survey conducted in 1999 (BCRD, 2000) at the country's international airports, 25 percent of respondents named "beach quality" as the main reason for visiting the Dominican Republic, second to "climate" (according to 37 percent of respondents). To maintain the quality of beaches that tourists demand, beach enhancement projects have been implemented throughout the region, including placing artificial structures in shallow water to mitigate wave impact and depositing sand from other sites on severely eroded beaches (UNEP/GPA, 2003). However, most beach enhancement interventions in the Dominican Republic are costly and temporary. For instance, the Dominican government recently invested over US\$20 million in beach enhancement, but this program did not address the root causes of the problem.
- **Many acres of mangrove, estuarine, and soft-bottom habitats have been and continue to be altered, filled in, or cut down to make way for development of agriculture, tourism infrastructure, and shrimp farms.** These habitats—along with coral reefs—play a significant role in protecting coastlines, fostering marine life, and regulating natural water regimes. These areas, when filled in and developed, are at high risk for flooding – and for potential permanent inundation with SLR. Historically, mangroves, estuaries, and soft-bottom ecosystems have been valued for their role in coastal protection; support of aquatic and terrestrial biota such as spawning for fish and shrimp; recreational and educational uses; and production of directly marketable products such as wood for construction and fuel (mangroves), crabs, and shellfish. Unfortunately, these habitats are also seen as areas that hinder development because they harbor mosquitos and are a site of frequent flooding, which impedes access.
- **There is strong evidence that coastal environments are increasingly fragile to human perturbations above and beyond those that have occurred throughout geologic time (Brown and Howard, 1985; Birkeland, 1997).** Major impacts to these coastal marine environments have been documented near major centers of human population and economic activity. Destruction of these habitats is driven by land use change for development and agriculture, coastal development, land-based sources of pollution, increased recreational use, and over fishing. Most of the changes recently observed in the world's coastal marine environments are linked to human activities (Lang et al., 1998; Smith et al., 1998). In the Dominican Republic, there is growing evidence of:
 - Mass mortality of reef organisms²² (Lessios et al., 1984);

²² Ninety-five percent of long-spine black urchins in the Caribbean have disappeared due to a disease. Urchins happen to be an effective bio control of algae on reefs; this effect combined with an increase in nutrient run-off resulted in many reefs covered mostly with algae.

- Increased incidences of diseases²³ and coral bleaching (Dustan, 1977; Williams and Bunkley-Williams, 1990; Goreau, 1992);
- Increased observations of algal-dominated reef communities (Dustan and Halas, 1987; Liddell and Ohlhorst, 1992; Porter and Meier, 1992; Shulman and Robertson, 1996);
- Increased bio-erosion, a natural process by which habitats, like a coral reefs, are eroded by animals like urchins (Hallock et al., 1993); and
- Low recruitment by corals to replace lost colonies (corals settling into available habitat to replace lost corals in the process of continuing the construction of the coral reef) (Dustan, 1977; Porter and Meier, 1992).

Community-Based Management of La Caleta Marine Park

A case study on marine ecosystems management.

The Dominican Republic has 1,389 km of coastline with biologically diverse marine resources that are important to the economies of coastal communities. La Caleta Marine Protected Area (MPA) is small and located 20 kilometers east of Santo Domingo. The area is a popular dive and fishing destination that once had healthy coral reefs. As population growth has increased pressure on this protected area, the reef has suffered a decline in overall health due to illegal fishing, coral bleaching, sedimentation, pollution, and other factors.

Reef Check Dominican Republic (RCDR) along with the *Cooperativa de Pesca y Prestadores de Servicios Turísticos de La Caleta* (COOPRESCA) and the Ministry of Environment and Natural Resources (MARENA) are developing a public-private partnership to establish a community-based marine resource management, sustainable fishing, and eco-tourism program within the MPA. The program aims to restore reef health and fish populations.

A healthy reef ecosystem appears to improve the resilience of reefs in coping with rising water temperature, sea-level rise, and acidification. For example, the presence of herbivore fish populations to graze on algae assists coral re-colonization, and healthier reefs are able to “keep up” with rising seas as new larvae colonize and build upon old limestone structures (L. Burke, et al., 2011).

The MPA management model establishes a self-regulated no-take zone and supports a business model for tourism and other income-generating activities. The program is designed to reduce local stressors that will allow fish and coral populations to recover, and provide the basis for non-extractive income-

Location of Coral Reefs in the Dominican Republic.



Source: World Resources Institute.

²³ Black-band, white-band, yellow band, aspergilosis, etc.

generating activities including kayaking, paddle boarding, snorkeling, and scuba diving. A study conducted in 2010 estimated that fishermen dependent on the reef could earn 90 percent of their current income through tourism activities (J. Wielgus, et al., 2010).²⁴

The groundwork is being laid for replication of the La Caleta MPA management model in other areas of the Dominican Republic. Recently a National Coral Reef Initiative was created, composed of more localized efforts for coastal marine conservation and restoration in Samaná, Puerto Plata, Montecristi, and La Altagracia. Local and independent financing will be generated through voluntary and user-fee donations from businesses and tourists to support long-term conservation and restoration of damaged coastal marine habitats that, in the long-run, will provide environmental services for the people and visitors of the Dominican Republic.

Key Contact: Rubén Torres, Reef Check Dominican Republic, Parque Nacional Submarino La Caleta

4.2 SENSITIVITY IN EACH CLIMATE-SENSITIVE HOTSPOT

The previous section described findings related to two key components of the assessment that examined sensitivity to climate change (the flooding and marine/coastal analyses) that are found across climate sensitive hotspots. The following sections describe the findings of the assessment that are relevant to the distinct characteristics of each hotspot. Each section provides an overview of contextual information; a summary of exposure or anticipated climate characteristics for the area; descriptions of sensitivity based on the flooding and marine/coastal analyses; and findings related to livelihoods based on visits to each site. This assessment made use of available information triangulated with one to two focus group discussions per population center and several key informant interviews with local representatives of government and civil society. To develop a more detailed understanding of the specific sensitivities of the communities, livelihoods, and natural systems studied will require additional field research in the form of surveys and data mining.

4.2.1 YAQUE DEL NORTE—MONTECRISTI/SANTIAGO

Context

MONTECRISTI AREA

The 1,885.81 km² Montecristi Province is situated in the Cibao Region near the Haitian border, flanked by the Atlantic Ocean to the north and west. To the east lie the provinces of Valverde and Puerto Plata; to the south, Santiago Rodríguez and Dajabón. The province has approximately 110,000 inhabitants, almost evenly divided between urban (Montecristi) and rural inhabitants. The population is relatively young, with 52 percent of the population under the age of 29. Seventy-nine percent of the population is literate, while only 50 percent have graduated from secondary school.

Montecristi is located at the end of the Duarte highway which runs from the south to the north of the country originating in Santo Domingo. The Province has a network of secondary roads that connect the municipal capital – San Fernando de Montecristi, with the other municipalities and surrounding provinces. The Yaque del Norte River empties into the Montecristi Bay after running 296 kilometers from the Dominican Republic's Central Mountain Range (*Cordillera Central*). Montecristi Bay is home to

²⁴ For additional information regarding the impact of marine conservation efforts in the Dominican Republic, visit: http://programaecomar.webs.com/Coastal_fisheries_of_Dominican_Republic.pdf.

several protected areas important to the country and the Caribbean, including the *Parque Nacional Submarino Montecristi* and the reef *Cayos Siete Hermanos*.

SANTIAGO AREA

Santiago is located in the Central Cibao Region, which occupies an area of 2,806.29 km² and is bordered in the North by the provinces of Valverde and Puerto Plata; in the West by Santiago Rodríguez; in the East by Espaillat and La Vega; and in the South by San Juan and La Vega. Approximately 690,000 people live in the municipality of Santiago, with 84 percent living in the City of Santiago. The population is generally better educated than the citizens of Montecristi, with a literacy rate of 88 percent. Its primary school completion rate is 100 percent, with 56 percent completing secondary school.

The Yaque del Norte River runs through the Province and City of Santiago. The entire watershed encompasses 7044 km² and is divided into the upper (between its origin in the mountains and Jarabacoa), middle (between Jarabacoa and Santiago), and lower watersheds (between Santiago and Montecristi Bay). Several water management structures, such as the Taveras Dam, have been constructed to manage the river flow in the middle watershed, which is intense during peak rain events and diminishes significantly during dry periods. Santiago, situated at the base of the middle watershed, depends on well regulated flows to meet the population's water needs and control flooding.

Exposure

MONTECRISTI AREA

Annual rainfall recorded at the Montecristi meteorological station and averaged for the period 1960-2012 is 660 mm, which makes it one of the driest stations in the country, with high inter-annual variability. The area experiences two rainy seasons during the year: the first one occurs between March and May, with monthly rainfall around 60 mm; the second one lasts from October to January, with similar rainfall levels and a peak in November at about 120 mm. Summer months are the driest of the year, with rainfall levels below 30 mm/month. The average annual temperature is 26.7 ± 0.7 °C. The temperature varies throughout the year, with the temperature during the coolest months of December to February in the vicinity of 24 ± 0.9 °C, increasing until it reaches a peak in summer (June to September), exceeding 28 ± 0.6 °C.

Climate projections in Montecristi point to a potential slight reduction in rainfall in April (wet month) and then in July to September (dry season), with an increase in November and December. The multi-model assessment shows that the average monthly temperature could increase by 0.7 – 1.0 °C through 2030, and by 1.0-1.5 °C through 2050, under the lower and higher emission scenarios, respectively. Individual models project an increase in average monthly temperatures exceeding 2 °C. One of the consequences of increasing atmospheric temperature is the changing thermodynamics, which lead to more intense rainfall events. More intense storms will result in additional incidences of severe flooding and, combined with sea-level rise, greater storm surges. It is also likely the sea levels will continue to rise, flooding coastal areas that are susceptible to storm surge. Decreased rainfall during the first rainy season and the following dry season could increase water stress and impact water quality in the area.

SANTIAGO AREA

Annual rainfall recorded at the meteorological station Santiago and averaged for the period 1960-2012 is 1,080 mm with high inter-annual variability. The region experiences two peak rainy seasons during the year: the first one during April and May, with monthly amounts around 110 and 150 mm, respectively; and the second one during September to December, with peaks in October and November around 100mm/month. The driest month is February, with average rainfall around 40mm. These amounts are long-term averages and, due to high inter-annual variability, the actual amounts may differ substantially. In particular, higher than normal precipitations have repeatedly led to landslides in the past. The average

annual temperature in Santiago, which is slightly cooler than in Montecristi, is 26.1 ± 0.7 °C. The temperature varies throughout the year, with the temperature during the coolest months, December to February, in the vicinity of 24 ± 0.9 °C. Temperature increases until it reaches a peak in summer, June to September, when it averages just under 28 ± 0.5 °C.

Climate projections for Santiago show a potential slight reduction in rainfall in the months of April and May (peak of the rainy season) and in July and August, with an increase in November and December (end of the second rainy season). The models show that average monthly temperature may increase between 1.2 -1.5 °C through 2030, under the lower and higher emission scenarios respectively; and by about 1.6-2.5 °C through 2050, under the lower and higher emission scenarios respectively. Individual models predict a temperature increase exceeding 3 °C by 2050 under the higher emission scenarios. One of the consequences of the increase in temperature is that storms (including hurricanes) may become more intense and result in additional incidences of severe flooding. The potential change in rainfall seasonality with increased precipitations at the end of the year could potentially lead to increased risk of flooding and landslides.

River Flooding and Storm Surge

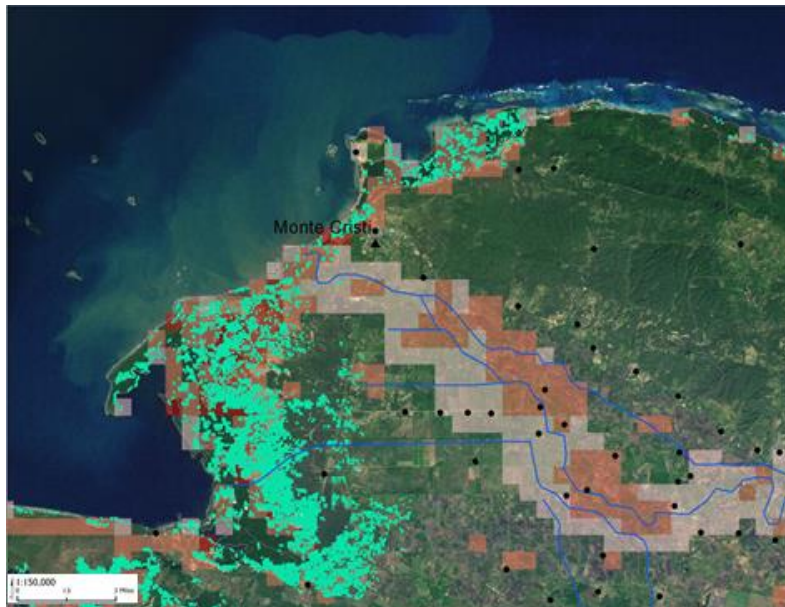
MONTECRISTI AREA

Flooding in low-lying coastal areas is the norm and is expected to increase due in part to the increased intensity of storms and sea-level rise. River flooding — a manifestation of rainfall patterns and non-climate factors such as upper watershed land-use change and poorly managed reservoirs — are likely to result in greater risk to populations, livelihoods, infrastructure, and ecosystems located in the floodplain, assuming that there is no significant change in current land-use practices.

The flooding dynamics in the Montecristi area are characterized as follows:

- Flooding with medium to low frequency along the Yaque del Norte riverbed, affecting agricultural lands and small rural communities in the Cibao Valley (see Figure 7 – black dots represent communities).
- A high frequency of flooding occurs at the mouth of the Yaque del Norte River due to the combined impacts of river flooding and storm surge during extreme rain events affecting the communities of Montecristi, Valverde, and Villa Vasquez.
- The negative impacts of flooding in the Yaque del Norte River delta are augmented by sediment entering the river channel due to upstream land-use change, primarily due to logging, urban development, and agriculture.

FIGURE 7. FLOODING ANALYSIS ON THE LOWER PORTION OF THE YAQUE DEL NORTE WATERSHED



- Projected higher temperatures in the region will likely lead to higher evaporation rates and possibly higher evapotranspiration rates,²⁵ affecting availability of river and ground water for irrigation during the dry seasons.
- An increase in levels of storm surge combined with the degradation of natural barriers (mangroves, dunes, and coral breaks) and the drawing down of the ground water table may lead to saltwater intrusion and contamination of the groundwater supply in aquifers near the coast.

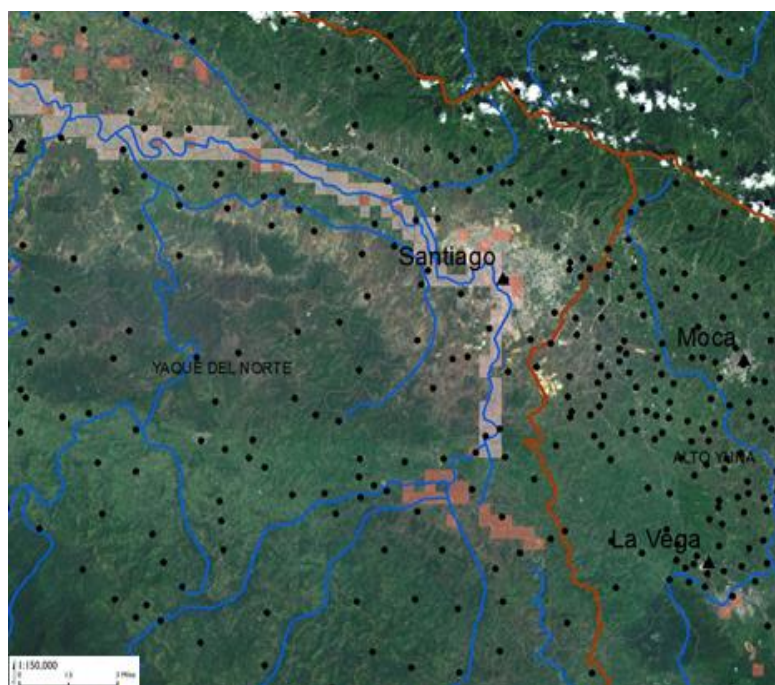
SANTIAGO AREA

Santiago is already negatively affected by flooding, which is anticipated to worsen due to the combined effects of more intense storms and continued degradation of watersheds:

- As noted in Figure 8, river flooding along the Yaque del Norte River occurs with low to medium frequency, and the flooding zone goes through the center of the populated city of Santiago.

- Due to the influx of rural people migrating to the city of Santiago to improve economic opportunities, make-shift communities have developed along the flood-prone riverbeds that are at repeated risk of flooding. Also noted are critical upstream dams that control the rate of water flow and protect the city from potentially harmful flooding. In November 2003, floods along the lower watershed of the Yaque del Norte and Yuna rivers forced the Taveras Dam to release 820 cubic meters per second, prompting the evacuation of 47,270 people, and causing US \$49,300,000 in damages. Hurricane Olga also caused an emergency operation resulting from the overflow of the Taveras dam, leading to losses of US\$105 million (GFDR, 2010).

FIGURE 8. FLOODING ANALYSIS ON THE UPPER PORTION OF THE YAQUE DEL NORTE WATERSHED



- The negative impacts of flooding in the Yaque del Norte River watershed are augmented by the downstream flow of excessive sediment and pollution caused by upstream land-use change, primarily deforestation and excessive use of agro-chemicals. The fertility of the soils in the upper watershed has been reduced in some areas and urban water and sanitation systems are affected, particularly during periods of extreme flooding. Sewage and industrial effluence affects the quality of the water downstream from Santiago.

²⁵ Evapotranspiration is the liquid water to water vapor phase change that occurs inside plants.

Coastal Habitats

Several coastal habitats are critical for maintaining flood regimes and ecological services that protect coastal areas and sustain livelihoods in Montecristi. The Montecristi Barrier Reef (Figure 9) is located on the northern coast near Haiti. It includes coral reefs and associated sea grass, mangrove, and estuarine ecosystems. Each habitat faces specific challenges:

- **Mangroves:** The bright green areas in Figure 9 show where the mangroves (39 km²) are. Adjacent to the mangroves are extensive estuaries. The mangroves have begun to dry out due to changes in land use, such as roads that cut off drainage areas for the mangroves.
- **Estuaries:** At the western end of the barrier reef, the coast changes due to the presence of the largest delta on the island, the mouth of the Yaque del Norte River, characterized by a mangrove-estuarine setting (39 km²) (Gerald and Vega, 2002; Garza and Ginsburg, 2007). As mentioned above, sedimentation and pollution due to more intense rainfall events and upstream land-use change has altered the health of the delta. An extensive plume of sediment stemming from the mouth of the river can be seen in Figure 9.
- **Coral reefs:** The largest reef formation in the country can be found in the Montecristi area, with a length of 64.2 km and an average live coral cover of 35 percent (Gerald and Vega, 2002). Historical fishing pressure and lack of enforcement of sustainable practices and protection of the large spawning grounds have degraded the mangroves and reefs and severely depleted the fish population. Reef Check surveys conducted in 2005 show that live coral cover is 30 percent in some areas which, though low, are not as depleted as in Bávaro/Punta Cana and Samaná. Specific actions must be taken to protect spawning areas (reefs, mangroves, and estuaries) to halt further degradation of the ecosystems (Garza and Ginsburg, 2007).

FIGURE 9. ECOSYSTEMS IN THE LOWER PORTION OF THE YAQUE DEL NORTE WATERSHED



Livelihoods

Livelihoods in the Yaque del Norte watershed focus on tourism, agriculture and fisheries. In the upper watershed agroforestry, traditional agriculture (coffee production and sustainable agriculture), crop production in greenhouses, and ecotourism (hiking and white water rafting in protected areas) are sources of income. Three competitiveness clusters²⁶ in Jarabacoa (tourism, coffee and greenhouse production) are promoting sustainable practices. In the large Cibao Valley banana, rice, cassava, and

²⁶ Competitiveness clusters are local associations of producers and/or business people engaged in similar sustainable economic development activities.

plantains are grown. Raising livestock including cattle, goats, and sheep helps to diversify farm-based livelihood strategies. In the delta region and along the coast, rural households rely on fisheries and salt production to sustain livelihoods. The area near San Fernando de Montecristi is being developed as a coastal tourist destination, but tourist infrastructure to date (hotels, restaurants, and recreational services) is limited. A new tourism cluster is engaged in developing and promoting tourism in Montecristi. Most residents in the City of Santiago engage in industry, administrative services, and trade. People living in the low-lying areas susceptible to flooding primarily engage in the informal sector (selling goods in markets and unskilled labor).

Livelihoods that are potentially negatively affected by climate change in the area include fishing, agriculture, and tourism. The adverse impacts of climate change, including an increase in flooding/storm surge and compromised coastal habitats, may affect livelihoods in the Yaque del Norte as follows:

- Degradation of fish and shellfish spawning areas: As mentioned above, reef, sea grass, estuarine, and mangrove ecosystems that serve as spawning areas for fish and shellfish are being degraded by climate and non-climate stressors such as sedimentation, pollution, altered natural drainage due to flooding, inadequate development planning, and lack of protection from human intervention. As the spawning areas degrade, fish and shellfish populations decline.
- Evaporation and saltwater intrusion affecting water supply, agriculture, and habitat health: The area hatched in orange in Figure 10 represents 180 km² of irrigated agriculture land (primarily rice) at risk of seawater inundation and longer-term salinization. The degradation of natural barriers such as the mangroves and estuaries to the west of the agriculture area combined with the predicted increase in temperatures in the area will likely increase seepage of saltwater and evaporation of freshwater, altering soil and water currently used for cultivation. Also, the delicate balance of salt and fresh water that maintains estuarine and mangrove health will be upset, causing the ecosystems to break down.
- Coastal tourism: The nascent tourism in the area will be negatively affected by the increasing quantity of heavy sediment and polluted drainage coming from mouth of the Yaque del Norte River and the decline in reef and beach health.
- Increased risk for low-lying marginalized neighborhoods in Santiago: Many households in the low-lying flood prone neighborhoods along the riverbed are already socially and economically vulnerable. Many are recent migrants, are landless, have lower levels of education, and have low incomes from unstable jobs in the informal sector. They are more vulnerable to the negative impacts of climate change, mainly flooding, largely because they lack economic and social reserves to recover from shocks.

FIGURE 10. LIVELIHOODS IN THE LOWER PORTION OF THE YAQUE DEL NORTE WATERSHED



4.2.2 BAJO YUNA–SAMANÁ BAY AND PENINSULA

Context

The Province of Samaná covers an area of approximately 845 km² in the Northeastern Region. The Province is comprised of the municipalities of Samaná, Sánchez, and Las Terrenas and three municipal districts: El Limón, Arroyo Barril, and Las Galeras. It is populated by approximately 100,000 inhabitants, with half living in the rural areas and half in the urban centers of Las Terrenas and Samaná. The majority of the population is relatively young, with 56 percent under the age of 29. The literacy rate is 84 percent, and only 53.8 percent of the population has completed secondary education. Three-quarters of the population are engaged in the informal agriculture sector, producing rice, cocoa, coffee, and coconut; gardening intensively; and raising livestock. The formal sector is comprised primarily of businesses that provide services, many linked to the growing tourist industry and real estate.

Samaná is a coastal area comprised of a peninsula and bay with significant marine biodiversity. Extensive mangroves that harbor a rich variety of wildlife (birds, fish, and mammals) are located in the National Park *Los Haitises* in the southern part of the Bay. The Province's marine habitats provide an important refuge for whales, sea turtles, and manatees. The soft bottom habitats and mangroves of the Bay serve as spawning grounds for fisheries important to the economy of the Province, shrimp in particular. The bio-physical characteristics of the Peninsula are diverse, including beaches, hillside forests, valleys, and bays, which are attractive to tourists. The lower watershed and delta of the Yuna River, which empties into the Bay, and the karstic characteristics of the *Los Haitises* influence the hydrology of the Province. The karstic limestone formations, which extend for 82 km from the Sabana del Mar to Cevicos, and 26 kilometers from the south of the Bay to Bayaguana, are punctuated by peaks and valleys that have been formed by coral reefs and years of erosion.

Exposure

The two ONAMET stations of Sanchez and Samaná have complete rainfall data for the period 1960 – 2012. These stations receive abundant rainfall during an extended rainy season: on the order of 1900mm/year for Samaná and 2200mm/year for Sanchez. Between May and December the stations receive in excess of 150mm, up to 200mm/month, (250mm for Sanchez in November). Even during the driest months of February and March, the rainfall still remains in the vicinity of 100mm/month. Both stations experience high inter-annual rainfall variability, with rainfall in individual months of individual years exceeding 300mm or falling below 50mm/month.

The only ONAMET station within the province that has a complete record for temperature is Sabana de la Mar, which is located in the southern part of the Bay. The average annual temperature is 25.3 ± 0.5 °C. The coolest period is during the winter months with temperatures around 23.5 ± 0.5 °C, increasing during the summer months, July to September, to 26.5 ± 0.4 °C.

Climate change projections for Sanchez and Samaná point toward a potential slight reduction in precipitation in the rainy periods of May then July, August and September and an increase in the dry periods of November and December. The models indicate that monthly average temperature in the area will increase by approximately 0.8-1.0 °C by 2030 and 1.0-1.5 °C by 2050 for low and high emissions scenarios, respectively. Individual models project changes exceeding 2 °C for 2050 under high emission scenarios.

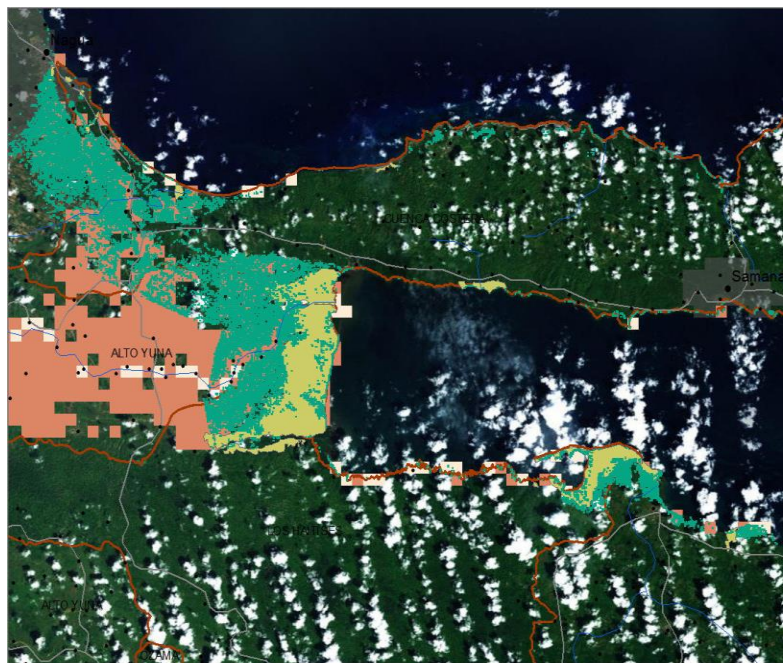
As in the case of Yaque del Norte, one of the consequences of increasing atmospheric temperature is the changing thermodynamics, which lead to more intense rainfall events. More intense storms will result in additional incidences of severe flooding and, combined with sea-level rise, greater storm surges. It is also likely the sea levels will continue to rise, which will flood coastal areas susceptible to storm surge. An increase in rainfall towards the end of the year could also contribute to local flooding.

River Flooding and Storm Surge

As illustrated in Figure 11, flooding from the River Yuna may occur with medium frequency throughout the extensive lower delta of the river (potentially susceptible areas illustrated in pink). Flooding from the river and a high potential for storm surges (which results from the rising sea level and more intense storms between the mainland and the Samaná Peninsula [highlighted in green]) create a large area with a high risk of flooding. The characteristics of the flooding dynamics follow:

- Multiple population centers (primarily small rural agricultural communities), infrastructure (e.g., homes and businesses, and irrigation canals for rice production, the Santo Domingo-Samaná road), and economic activity (primarily rice agriculture, but also vegetables) along the lower part of the Yuna River are frequently exposed to river flooding events.
- Local practices have been implemented to decrease livelihood sensitivity to this flooding, including the construction of dikes and elevated homes, and the production of vegetable crops on elevated locations such as along roadways. Additional investment to cope with the possibility of more severe flood events will be necessary.
- The large extension of land with very low elevation between highway #7 (Carretera Juan Pablo II) and the Samaná Bay may experience storm surges of up to 3.1 meters over a 50-year period, which will bring floodwaters significant distances inland (CDMP, 2010). If this happens, the resilience of natural estuaries, marine health, and inland agriculture will be adversely affected.
- Other sensitive infrastructure, including roads and drainage systems, are constructed along flood-prone areas of the Samaná Peninsula (characterized by porous subterranean limestone, in comparison to sand and gravel imbedded with clay in lower-lying delta areas mentioned above). Inefficient management of runoff might decrease groundwater recharge, collapse subterranean structures (causing sinkholes in urban areas), and impede groundwater storage that is critical to people and livelihoods in the area (Harlan et al., 2002).

FIGURE 11. FLOODING ANALYSIS AND COASTAL ECOSYSTEMS, SAMANÁ BAY AND PENINSULA



Coastal Habitats

Several coastal habitats are critical for maintaining flood regimes and ecological services that protect coastal areas and sustain livelihoods in the Samaná Peninsula and Bay. Figure 11 illustrates a large extension of mangroves (yellow). Less visible are the extensive beaches and coral reefs along the northern coast, the estuaries throughout the Yuna River delta, and the soft-bottom habitats that line the bottom of much of the Bay. Each habitat faces specific challenges:

- **Mangroves, estuaries, and soft bottom habitats:** The mangroves, along with estuaries, serve not only as natural barriers and regulators of complex water regimes in the area; they also serve as very fertile spawning areas for many marine species – fish and shellfish, protected in the Samaná Bay from the open ocean. The mangroves, estuaries, and water in the Bay also receive polluted discharge from the expansive Yuna watersheds. A significant portion of the country’s rice is produced in the lower watershed, discharging agro-chemicals and altering natural water regimes that negatively affect the health of different habitats. The lower Yuna and Samaná Bay is also at risk of heavy metal contaminants coming from upstream mining operations (e.g., gold and iron/nickel mines) (Reynoso, 2010). As pollution levels in the Bay increase, the contamination affects the quality of the shellfish, which adversely affects the health of consumers and, ultimately, the viability of the industry. Destructive fishing practices, mainly the use of trawl nets (locally called *licuadoras*, or blenders), are destructive to habitats and spawning because they tend to “blend” everything that is caught in the nets. This practice, which also encourages overfishing, has taken a toll by destroying these spawning habitats, thereby diminishing fishing productivity.
- **Coral reefs:** The coral reefs are found along the northern coast of the Peninsula. Although tourism is less developed in Samaná than in the Punta Cana/Bávaro area, it is more developed than the Montecristi area. Reef Check estimates that 90 percent of the reefs are dead.
- **Beaches:** The beaches, also found along the northern coast, are extensive and attract many Dominicans and tourists throughout the year. As the reefs degrade due to overfishing, acidification/bleaching, and human-induced impacts (development) combined with gradually rising sea levels, the beaches are at risk of eroding and gradually disappearing.

Livelihoods

Livelihoods in the Samaná Peninsula and Bay are based on agriculture and fisheries. Three-quarters of the population are engaged in the informal agriculture sector, producing rice, cocoa, coffee, and coconut; gardening intensively; and raising livestock. The formal sector is comprised primarily of businesses that provide services, with many linked to the growing tourism industry and real estate.

Livelihoods that are potentially negatively affected by climate change in the area include fishing, agriculture, and tourism. The Samana Tourism Cluster is working with stakeholders to implement sustainable tourism in the region, including an increase in cruise ship tourism. The adverse impacts of climate change — increase in flooding/storm surge and compromised coastal habitats — may affect livelihoods in the Samaná Bay and Peninsula as follows:

- **Degradation of fish and shellfish spawning areas:** The Samaná Bay and Peninsula’s spawning habitats and reefs, along the northern coast of the Samaná Peninsula, are important livelihood sources for 9,000 fishermen and their families. Currently, the Dominican fishing industry produces approximately 11,000 tons/year, representing approximately 0.5 percent of gross domestic product (GDP). The Samaná area contributes significant fish and shrimp to that figure. Unfortunately, the degradation of these critical habitats is rapidly depleting fish and shrimp stocks.
- **Coastal tourism:** The Samaná reef system, on the northern coast of the Peninsula, protects important beach areas that are being developed for tourism around Las Terrenas and El Portillo. The reefs and, ultimately, the beaches are being degraded due to decades of overfishing and uncontrolled sediment runoff. Studies conducted in that area show that local live coral coverage of that reef system ranges from 5 to 11 percent (Geraldés and Vega, 2002; Reef Check, 2005 data).

- Low-lying population centers at risk of flooding: Small rural populations that depend on agriculture and live in the delta of the Yuna River, in addition to urban populations situated along the coast (Las Terrenas and Samaná), are all at risk of significant flooding during extreme rain events and as the sea levels rise.

4.2.3 BÁVARO/PUNTA CANA

Context

Punta Cana is located on the eastern tip of the island, in the Altagracia Province, which is part of the Southeastern Region. Approximately 44,000 people live in the Veron-Punta Cana Municipal District, with 82 percent living in the urban centers of Bávaro and Punta Cana. The area is relatively flat, with a geological foundation of karstic limestone characterized by porous alkaline soil and subterranean aquifers. These aquifers are the only source for freshwater in the area. Mangroves, coastal lagoons, white sand beaches, and coral reefs are found along the extensive coastline. The mangroves and reefs protect the coast from strong currents and winds that prevail from the east, coming off the Atlantic Ocean.

Exposure

From 1960 to 2012, the Punta Cana ONAMET station reported an average of 1,000 mm of rainfall per year with very high inter-annual variability. Punta Cana receives rain throughout the year with bi-modal rainy seasons peaking in May (averaging 130 mm) and September and October (averaging 260 mm). The summer is relatively drier. The average annual temperature is 26.5 ± 0.6 °C. The coolest period is during the winter months with temperatures increasing during the summer months reaching a peak in August, with an average temperature of 28 ± 0.5 °C.

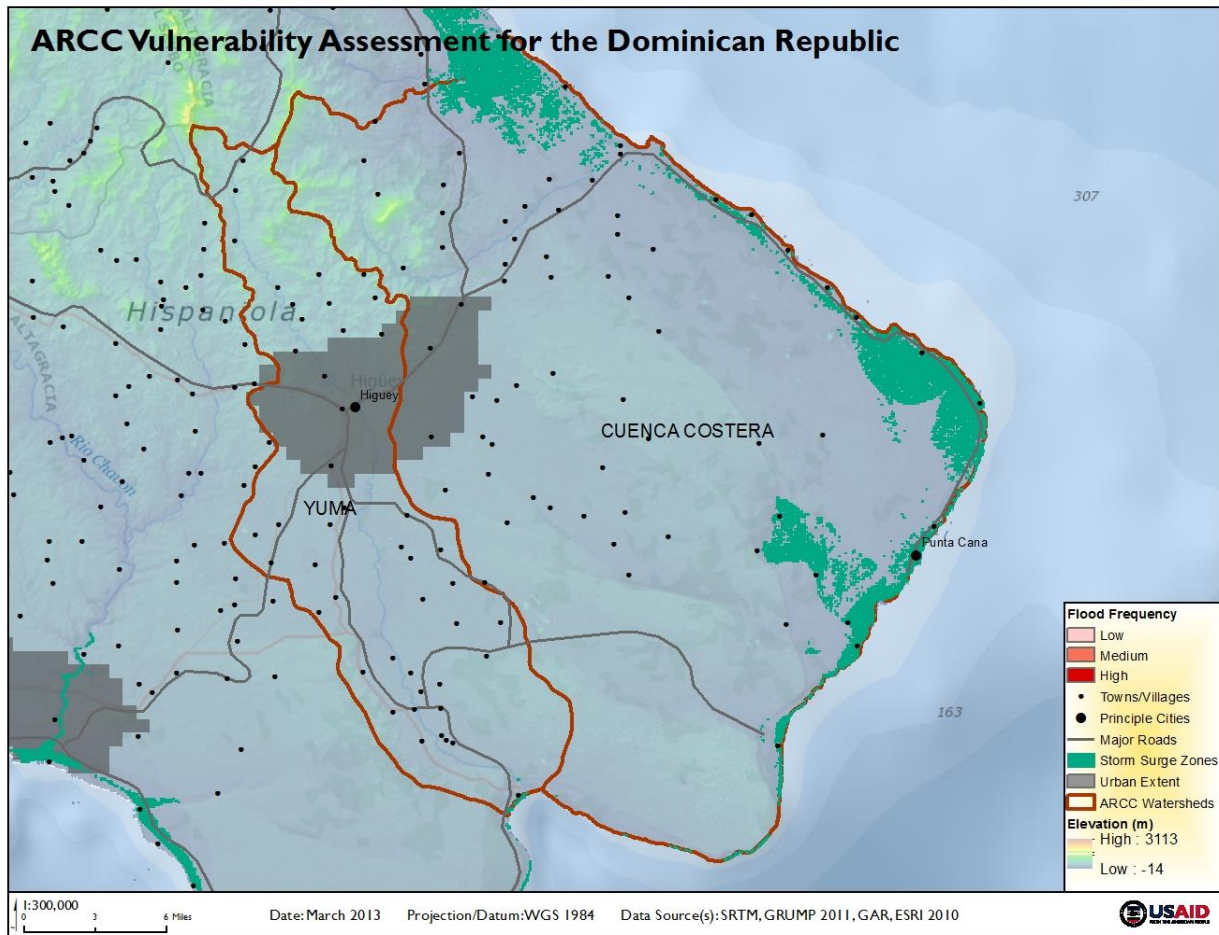
Climate change projections for Punta Cana point to a consistent increase in rain in the months of November, December, and January, with a consistent decrease in the months of May, July, and August that indicates a slight shift in seasons. Multi-model estimates project a monthly average temperature increase by approximately 0.5-0.7 °C by 2030 and 0.8-1.2 °C by 2050 for low and high emissions scenarios, respectively. Individual models project increases up to 1.5 °C and 2.5 °C for 2030 and 2050, under the high emission scenarios.

As in the case of the other areas, one of the consequences of increasing atmospheric temperature is the changing thermodynamics, which lead to more intense rainfall events. More intense storms will result in additional incidences of severe flooding and, combined with sea-level rise, greater storm surges. It is also likely that the sea levels will continue to rise, which will cause flooding in coastal areas susceptible to storm surge.

Storm Surge Induced Flooding

As illustrated in Figure 12, the Altagracia Province is relatively flat, and the coastal areas are susceptible to storm-surge-induced flooding along the coast (represented in green). Coastal flooding is predicted to worsen as a consequence of sea-level rise, increased intensity of tropical storms coming from the east, and degradation of natural barriers such as coral reefs and mangroves. Figure 13 shows how potential storm surge areas along the Bávaro coast overlap with the area that has been developed for tourism, which demonstrates a risk that the infrastructure will be flooded.

FIGURE 12. FLOODING ANALYSIS, BÁVARO/PUNTA CANA



Coastal Habitats

The Punta Cana and Bávaro area can best be described as a coral-reef-protected beach that, in the past, was also an important mangrove area. The mangroves have since been reduced to a small protected area. Given the tendency for prevailing strong winds and ocean currents coming from an easterly direction over the Atlantic Ocean, both mangroves and coral reefs play a critical role as natural buffers protecting the coastline. Issues related to each of these habitats follow:

- **Mangroves:** Figure 13 shows how tourism infrastructure (hotels, restaurants, and roads) has been built over the former coastal mangrove forest (Figure 14). The destruction of the mangroves makes the coastal area more vulnerable to coastal flooding, especially with sea-level rise and more intense storms.
- **Coral reefs:** The Punta Cana reef system, visible in Figures 13 and 14, is the second largest in the Dominican Republic (Geraldes and Vega, 2002) and serves as an active natural barrier that protects this important beach destination from erosion. The reef system provides habitat for many marine species that serve as a food source for Dominicans and tourists. The coral reefs are also the primary source of white sand for Punta Cana's and Bávaro's prized beaches. Unfortunately, due to the influx of tourism, and poor planning, the benefits provided by the reefs are rapidly diminishing. The reefs in Punta Cana support, on average, 9.7 percent coverage by live coral. When compared to other areas across the Caribbean, the Punta Cana values are second to lowest (Brandt et al., 2003; Reef Check, 2004).

Livelihoods

The majority of people living in Punta Cana/Bávaro maintain their livelihoods by providing services for the area's well developed and thriving tourist industry. Many are employed in the resorts, hotels, and restaurants that the tourists frequent. Others offer services to

FIGURE 13. STORM SURGE AND TOURISM, BÁVARO/PUNTA CANA



FIGURE 14. COASTAL HABITATS AND TOURISM, BÁVARO/PUNTA CANA



tourists including transport, guide, and recreation services. Fishing to provide seafood to the tourist industry is also a common livelihood strategy. More intense storms, sea-level rise, and increasing temperatures are likely to have a negative impact on the tourism industry. Other non-climate stressors compound the long-term negative impacts to livelihoods, including inadequate planning of infrastructure, overfishing, and destruction of coastal ecosystems that regulate water flow and provide natural barriers to storm surge:

- **Coastal tourism:** The tourism industry in the Dominican Republic annually receives 5 million visitors who occupy 66,000 rooms and generate US\$5 billion per year. The Bávaro/Punta Cana area receives a majority of the tourists. Tourism infrastructure along the coastline is threatened by flooding as a result of the degradation of the natural buffers (reefs and mangroves) and climate change, rising sea levels, and more intense tropical storms. Prevailing easterly winds coming off the Atlantic Ocean also make the coastline more susceptible to hurricanes, furthering the risk of coastal flooding. With the destruction of the reefs, the white sand beaches (the coastline's primary tourist attraction) are at risk of disappearing. The beach is eroding at a rate of 50 cm per year; approximately 90 percent of the reefs are dead, fish stocks are diminishing, and flooding of tourist infrastructure is already a reality (severe flooding along the Bávaro coast occurred during Hurricane Jeanne in 2004.).
- **Fisheries:** The fish populations along the coast have diminished as a result of the degradation of the reef and mangrove habitats and overfishing. A comparison of Punta Cana fish densities with those of 15 other countries/regions shows that Punta Cana has some of the lowest recorded fish density and biomass values (Brandt et al., 2003).
- **Availability of freshwater:** The effects of sea-level rise and coastal flooding, combined with increasing temperatures, will alter the balance between salt and freshwater regulation, which is particularly critical with the porous karstic geology and the high demand for freshwater from the tourism industry. The mangroves and coral reefs naturally help regulate water flows and to some extent can mitigate the negative effects of climate change.

Groundwater Management

Groundwater is a very important resource for the communities, livelihoods, and natural systems in the Dominican Republic, particularly so in the tourism communities of Bávaro and Punta Cana in the La Altagracia Province where it is the principal water resource in the area. Factors contributing to groundwater quality and availability in the region include aquifer depletion and increased sea water intrusion and salinization caused by unsustainable extraction practices and sea level rise; a decrease in water infiltration in the groundwater system caused by land-use change; and the disposition of untreated sewage into the aquifer and introduction of sanitary discharge, landfill waste, and other contaminants picked up by rainwater as it drains to the subsurface. Moreover, the groundwater recharge area is entirely localized, while withdrawal rates are believed to be at unsustainable levels. In the 1980s, estimated water availability was believed capable of supporting a maximum of around 20,000 rooms for the tourism sector; but the current amount of development is much higher,²⁷ as is the permanent population (World Bank, 2004).

Of the 18 watersheds in the Altagracia Province, there are likely two that serve as the groundwater recharge catchment for Bávaro and Punta Cana, which were identified in focus group discussions and key informant interviews to be significantly impacted by saltwater intrusion (discussed below). The karstic limestone geological system present in the area — also common on the Samaná Peninsula, Boca

²⁷ In 2012 total hotel rooms was estimated at 35,000 according to Lissette Gil, Director of the Sustainable Tourism Empowerment Program.

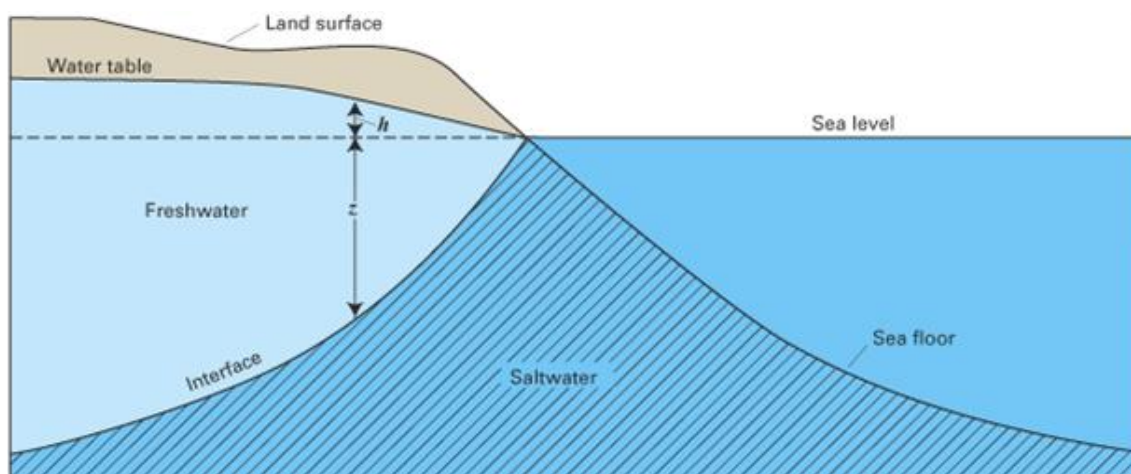
Chica/Juan Dolio, and other locations — is highly porous and forms caves and channels through which rainwater infiltrates and flows (Harlan et. al., 2002). Groundwater recharge requires rainfall to penetrate the surface and migrate through the soil to the subsurface, where it is collected. Although infiltration is rapid in the porous karstic geology, the time required also depends on the permeability of the soils and is greatly impacted by land use.

The introduction of impervious surfaces and the capture and redirection of surface runoff significantly affects groundwater recharge and behavior of surface water. Forest cover offers the greatest reduction in runoff potential with respect to land use, while grasslands and impervious surfaces produce the greatest runoff during storm events. In watersheds that experience significant degradation of land cover (leading to increased runoff), the effect is manifested by streams that are dry when there is no rainfall and in a flood condition during rainfall events, which increases the risk of flash floods that destroy infrastructure and private property. As surface runoff increases, groundwater recharge and therefore surface stream base flows decrease.

Land development and prevalence of impervious surfaces also affect water quality in that any surface activity or infrastructure, such as roads and buildings that intercept rainwater draining to the subsurface will impact the suitability of that resource for human use. Research has indicated that *E. coli* contamination found in drinking water wells in the area may be caused by infiltration of fecal matter and other organic waste (Grady and Younos, 2010). Sediment discharge is largely a function of land use and correlates directly with surface runoff.

The karstic system stores water in unconfined aquifers before it is naturally discharged along the coast or withdrawn for human consumption through wells. In this system, groundwater collects and migrates to the coast at negligible velocities (velocities can range from low to surface stream velocities, depending on geological characteristics), where it encounters saltwater systems. The aquifer behaves as a Ghyben-Herzberg system, with storage capacity and subterranean flows mediated by fresh-saltwater interchange from the sea (see Figure 15). In this system, the density difference between freshwater and saltwater maintains a two-phase regime, with freshwater collecting above the underlying saltwater layer. The system heavily depends on the volume of rainfall for recharge in order to maintain the mass of subsurface water required to maintain the fresh-saltwater relationship. Groundwater withdrawal is gradually lowering the freshwater in the Ghyben-Herzberg relation, resulting in a gradual inland migration of saltwater as it seeks equilibrium with local groundwater. This process may speed up due, in part, to the degradation of a number of climate-dependent natural systems that protect inland aquifers, including coral reefs and mangroves. The salinization of groundwater has already been reported in Bávaro, with wells moving further back from the coast and salinity of freshwater lagoons in Punta Cana increasing (Grady and Younos, 2010).

FIGURE 15. GHYBEN-HERZBERG RELATION



Note: h = freshwater hydraulic head above sea level, z = freshwater displacement of intruding saltwater.

Source: Barlow, 2003

Due to increasing demand from the local population and tourism industry in Bávaro and Punta Cana, human activities in the area and climate change are likely to have far-reaching consequences for groundwater availability and quality. Bávaro and Punta Cana are likely to experience further altered surface stream flow and reductions in subterranean water supply for human consumption.

4.2.4 SANTO DOMINGO

Context

The populations within the City of Santo Domingo most susceptible to the adverse impacts of climate change are the communities located along the Ozama and Isabela Rivers, which are exposed to flooding and storm surge (see Figure 16). Much of the land situated close to the rivers is not intended to be developed because it is prone to flooding and should serve as river easements. Nevertheless, people who are in need of shelter and lack resources to set up permanent residences settle in these areas. With an urbanization rate of 2.1 percent change annually (2010-2015 est.) (CIA World Factbook, 2013), people continue to migrate from the rural areas and neighboring Haiti to Santo Domingo in search of economic opportunity. Neighborhoods along the rivers comprise a mix of semi-permanent and permanent structures to house families and set up small shops. Most residents are engaged in the informal sector, providing unskilled labor and services and are of modest means. Generally, they are actively trying to improve their economic opportunities and create a better living environment by sending their children to school and engaging in neighborhood associations (IDDI, 2013). The municipal government and NGOs work with these communities to improve infrastructure and access to services.

Exposure

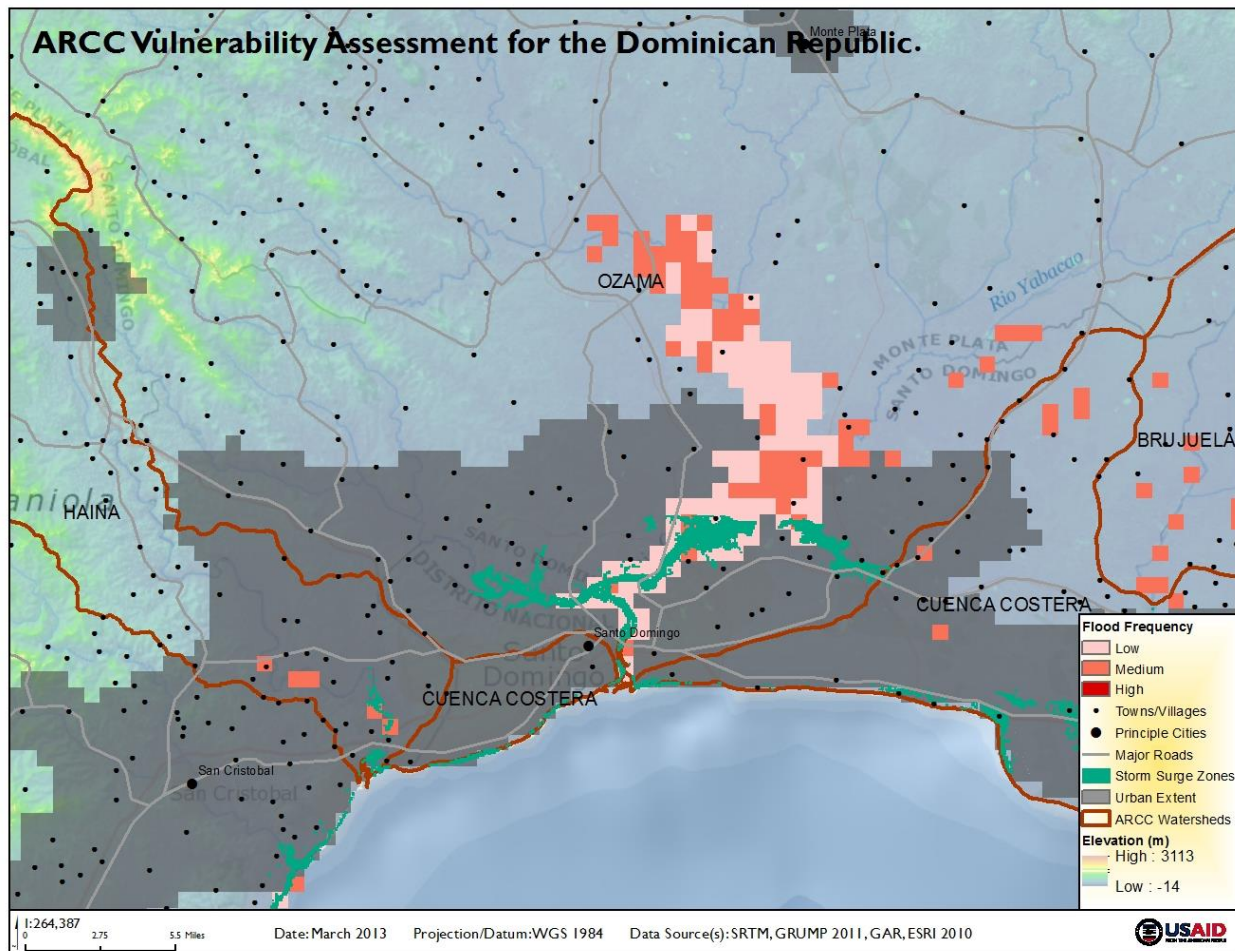
During the period of 1960 to 2012, the Santo Domingo ONAMET station reported an average of 1,500 mm of rainfall per year with very high inter-annual variability. Santo Domingo receives the bulk of its annual rainfall between May and October, when monthly rainfall exceeds 150mm/month, with the peak between August and October with rainfall reaching 90 mm/month. During the driest months of the year, February and March, rainfall drops to 50mm/month.

The average annual temperature is 26.3 ± 0.7 °C. The coolest period is during January and February, with average temperatures just below 25 °C, increasing during the summer months, June to October, when the temperatures exceed 27 ± 0.7 °C.

Climate change projections for Santo Domingo show a potential decrease in rainfall in August and September (high precipitation months), with an increase in November and December, traditionally drier months. This shift indicates a potential change in the seasonality of the rainfall. Models consistently project an increase in temperature on the order of 0.6-0.8 °C by 2030 and 0.9-1.3 °C by 2050 as estimated from the multi-model projections for low and high emissions scenarios, respectively. Individual models project changes exceeding 1.5 °C by 2030 and up to 2.5 °C by 2050 under high emission scenarios.

As in the case of the other areas, one of the consequences of increasing atmospheric temperature is the changing thermodynamics, which lead to more intense rainfall events. More intense storms will result in additional incidences of severe flooding and, combined with sea-level rise, greater storm surges. It is also likely that the sea levels will continue to rise, which will flood coastal areas susceptible to storm surge. Increase of rainfall at the end of the rainy season may also result in increased incidence of flooding, while the decrease in rainfall in the middle of the rainy season might affect water availability when combined with increased temperature at the 2050 horizon.

FIGURE 16. FLOODING ANALYSIS, SANTO DOMINGO



River Flooding and Storm Surge

As illustrated in Figure 16, Santo Domingo is susceptible to flooding from water coursing down the Ozama River from the upper watershed (pink areas on the map) and storm surge coming from the ocean and traveling up the Ozama River (green on the map). Flooding from both of these sources happens during heavy rainfall events and creates extensive flooding throughout the Ozama riverbed in the heart of the city. Storm surge is controlled to some extent by the construction of physical barriers – particularly at the mouth of the river. The large size (343 hectares) and steep relief of the Ozama watershed, along with the fact that 80 percent of the watershed lies below 200 meters in elevation exacerbates the impact of normal annual precipitation patterns. During more intense storm events and as the sea level rises, the populations living along the river is at increased risk of being subjected to high flooding events. The Risk Reduction Index Project (Fundacion DARA, 2011) stated that in the case of Santo Domingo, “floods pose a serious threat to the population and infrastructure, especially in the many slums of Santo Domingo located near the Ozama and Isabela River and connected creeks and streams. In these areas, the size of the vulnerable population has increased due to rural-urban migration and the construction of improvised shelters with no urban planning or basic water supply and drainage.” Community members interviewed in the focus group discussions reported flooding during extreme rainfall events that resulted in roads and pathways inundated with dirty water (garbage and sewage) that damaged structures and threatened their health.

Livelihoods

Highly sensitive populations — many of them poor, landless migrants that have come to Santo Domingo in search of economic opportunity — are exposed to these flooding events with the following consequences:

- Damage to housing, public buildings, and shops: Neighborhoods with modest housing, shops, schools, and clinics have experienced repeated flooding events and have been relocated or rebuilt.
- Health risks: Poor drainage and infrastructure for water and sanitation leads to an influx of sediment from the upper watershed and uncontrolled human waste from the urban area, which spreads into the water supply and puts human health at risk.
- Lack of economic reserves: Most of the households in the area lack resources (assets and cash) to recover after a flooding event. With repeated disasters, they become increasingly vulnerable and at risk.

4.3 OVERALL CONCLUSIONS RELATED TO SENSITIVITY

The previous sections explain how communities, livelihoods, and natural systems are affected by climate change exposure and the sensitivity of these systems in general. An integrated analysis of sensitivity across the hotspots provides the following overarching conclusions:

- Increasing temperatures will continue to strain agricultural systems and groundwater availability and quality due to the possibility of hotter and drier conditions in Yaque del Norte, where precipitation is projected to decrease slightly.
- Increased frequency and intensity of flooding due to the combination of more intense storms and environmental degradation is likely to disproportionately affect already sensitive systems (e.g., livelihoods on the edge, people in poverty, coastal infrastructure).

- Populations on the margin of the economy (particularly those located in urban areas of Los Mina, Hoyo de Puchula, Fracatán, La Esperanza, and el Hoyo de Elias) as well as rural small farmers are more sensitive to impacts of disasters (floods, dry periods, and landslides) because they have limited resources with which to influence and increase adaptive capacity.
- Coastal zones (particularly mangroves and coral reefs) are particularly sensitive to sea-level rise and more extreme storms because of existing problems with critical habitat destruction from development pressures and overfishing, among other threats.
- Local livelihoods are very sensitive to these same factors, which will likely increase the risk to coastal communities of flooding, diminish fisheries stocks, and degrade natural tourist attractions in the absence of more comprehensive resource management planning.
- Agriculture and tourism sectors, as well as residential households, are highly dependent on ground and surface water supply, which are sensitive to localized land use and likely to experience decreasing recharge and quality due to evaporation and salt water intrusion. The quality of the water is worsened by inadequate sewage management, where most raw sewage is dumped into the aquifer through injection wells called “pozos filtrantes” or directly into rivers and the ocean.

5.0 ADAPTIVE CAPACITY

Adaptive capacity is the inherent ability of a livelihood system, or community, to absorb climate change shocks and to buffer the impacts of those shocks. It is often described as recovery power or as a set of assets and strategies that result in resilience. The most vulnerable communities/households are those with high exposure, high sensitivity, and low adaptive capacity. For this assessment, adaptive capacity was gauged by reviewing the existing capacity and potential of communities, institutions, policies, and programs to address the sensitivities described in the previous section. Information was gathered via literature review and supplemented by focus group discussions and key informant interviews conducted in the four climate-sensitive hotspots. It is important to note that adaptive capacity can exist and is important at various levels, from the individual to the neighborhood community, to the national government. However, the adaptive capacity presented and discussed in this section focuses primarily on the ability of institutions to improve adaptive capacity within key sectors (public, civil society, academic, and business) and levels (national and local). Adaptive capacity related to natural systems (coastal ecosystems) is presented and discussed in section 4.1.3 – Marine and Coastal Analysis. To gain an in-depth understanding of individual and household-level adaptive capacity it would be necessary to conduct additional household-level research.

This section presents an overview of findings of the institutional analysis at national and sub-national levels, followed by additional detail on sub-national capacity relevant to each climate-sensitive hotspot. At the sub-national level, it was found that a number of organizations — NGOs, local government, academic institutions, and businesses — implement programs and activities that provide a foundation for strengthening local resilience and adaptive capacity to climate change. Many of the activities aim to improve disaster risk response and environmental/natural resource management and have not necessarily been conceived to address anticipated impacts of climate change; they do provide, however, a foundation with which to develop strategies for improving adaptive capacity.

With a better understanding of existing adaptive capacity, the assessment team defined three adaptive pathways. These pathways are presented in the recommendation section and guide the direction in which institutional actors can build on and improve existing policy and programs, along with developing new initiatives, to strengthen resilience and adaptive capacity.

5.1 INSTITUTIONAL ANALYSIS

5.1.1 NATIONAL LEVEL AND SUB-NATIONAL OVERVIEW

The assessment team did a rapid analysis of institutional capacity related to climate change adaptation within government, civil society, and private sector organizations at national and sub-national levels. Focus group discussions and key informant interviews were conducted with approximately 80 organizations. The purpose of the institutional analysis is to understand progress made to date and current institutional capacity with which to develop and strengthen adaptive capacity. In the focus group discussions, which took place in six communities within the four climate-sensitive hotspots, the assessment team also learned about how community members perceive climate change impacts; how these impacts affect their livelihoods; and what, if anything, they have been able to do about addressing them.

At the national level, the government and NGOs have made significant progress in establishing a policy framework and institutions with which to address climate change. The recently developed National Development Strategy for 2030 outlines four primary strategies, one of which envisions a society that is

productive and consumes sustainably in a way that manages risks and natural resources, protects the environment, and addresses climate change adaptation in an efficient and equitable way. The development of a Climate Change Policy is in progress, and a Strategic Plan for Climate Change and a National Action Plan for Climate Change Adaptation have recently been developed. The National Council for Climate Change²⁸ works closely with the Ministry of Environment and Natural Resources to spearhead the development and establishment of the national climate change policy. Under the new policy, the Ministry of the Environment and Natural Resources will lead the national climate change efforts with the support of the Council. Presently, the Council and the Ministry lead the establishment of climate change policy and planning, promote inter-institutional coordination, and represent the country's position on climate change to the international community. The Ministry of the Environment and Natural Resources and the Climate Change Unit conducts relevant research and promotes policy and programming related to climate change. There is also a unit within the Ministry of Agriculture that is dedicated to working with climate change as it impacts agriculture and fisheries.

According to the new climate change policy, a diversity of sectors potentially affected by climate risk, including agriculture, transport and related infrastructure, housing, environment, health, education, energy, water/sanitation, and tourism are expected to address climate change risk. The capacity to address climate change will have to be mainstreamed into sector-specific plans and programs. Principal government institutions, some yet to be formed, that will be responsible for enforcing the climate change policy include the Ministry of the Environment and Natural Resources, the National Council for Climate Change, the Inter-institutional Commission on Climate Change, the Institute for Studies and Scientific Research related to Climate Change, and the Office on Information and Communication on Climate Change.

Other ministries and government institutions that currently play significant roles in addressing climate change include the National Office for Meteorology (ONAMET) and the National Institute for Water Resources (INDRHI), which both focus on compiling, analyzing, and, in some cases, communicating and/or acting on climate and hydrology-related information. Both organizations have a significant amount of climate-related information. The climate analysis that was conducted for this assessment required a long record of quality data (precipitation and temperature) gathered throughout the country. The ONAMET dataset was extensive and relatively well organized, but after cleaning and checking the data for inconsistencies and gaps, few data points (meteorological stations) were complete (30 for precipitation and 12 for temperature) over the past 50 year period. ONAMET and the Instituto Dominicano de Aviación Civil produce a monthly bulletin called the “Boletín de Vigilancia Climática” that shares relevant and up-to-date information on climate in the country. We were not able to access the complete INDRHI data set, so we cannot comment on breadth and quality. Both organizations have established a solid foundation with which to strengthen and expand their capacity to collect data and analyze and disseminate climate information.

The National Commission for Emergencies (CNE) and Center for Emergency Operations (COE) play crucial roles in disaster risk management. The CNE, an inter-institutional commission, has been the longstanding body (established as a civil defense institution within the military in 1981) for national emergency management. The *Ley de Gestion de Riesgos a Desastres*, adopted in 2002, establishes the legal framework for the National System for Prevention, Mitigation and Response to Disasters. The System is designed to reduce risks and prevent disasters, “socialize” the prevention and mitigation of risks,

²⁸ The Council is led by the Ministry of Environment and Natural Resources. Other represented ministries include Economic Planning and Development, Agriculture, Foreign Affairs, Tourism, Internal Affairs (Hacienda), Industry and Commerce, Health and Social Welfare, as well as members from the Central Bank, National Energy Commission, and the State-run Electric Company. The Executive Vice President of the National Council serves as the Secretary.

respond effectively to emergencies and disasters, and support rapid and sustained recuperation. The *Comité Técnico Nacional de Prevención y Mitigación de Desastres*, under the CNE, provides technical advice and guidance to the National System including the formulation of Risk and Disaster National Plans. The COE, which is also part of the CNE, promotes inter-institutional coordination for disaster management and implements the National Plan throughout the country.

The COE has become increasingly important as the national system devolves to sub-national levels. As the devolution takes place, coordination is a challenge with some CNE and COE implementation overlap and duplication. Evidence of this devolution was noted in Samaná and Santiago where focus group discussants noted that the COE, working in close collaboration with municipal and provincial governments, respectively, has contributed to the development of sub-national plans. It was also noted that inter-institutional engagement and citizen awareness of the relationship between climate change and risk and disaster management needs to be improved. The Risk Reduction Index Project (Fundación DARA, 2011) conducted a sub-national analysis of conditions and capacity for risk reduction. Territorial organization was identified along with environmental degradation, socioeconomic status, and poor governance as drivers of risk. Territorial organization was identified as a driver because of: 1) the inappropriate location of housing and land use in areas prone to flooding and extreme storms; 2) the lack of DRR strategies in land use plans and public projects; and 3) non-compliance with environmental and building codes that prevent effective risk reduction. These findings, corroborated by information from KIIs and FGDs, suggest that inadequate land-use and development planning and enforcement increase disaster risk in areas prone to flooding.

Nongovernmental organizations (NGOs) have played a significant role in raising awareness about climate change, assessing vulnerability, developing and implementing programs to address climate change, advocating for the government to improve their response to climate change and working in partnership with government and donors to develop and support the climate change policy. For example, the *Instituto Dominicano de Desarrollo Integral (IDDI)*, in partnership with The Nature Conservancy (TNC), conducted a national assessment on vulnerability to climate change; local NGOs PRONATURA, the *Fundación Dominicana de Estudios Marinos (FUNDEMAR)*, and the *Centro para la Conservación y Ecodesarrollo de la Bahía de Samaná y su Entorno, Inc. (CEBSE)* work closely with TNC in key watersheds and coastal areas to create awareness about climate change and implement activities to improve resilience and disaster risk response. Several civil society umbrella organizations play very important roles in disseminating and educating the public about the environment and climate change and in advocating for constructive action and accountability. These organizations include *Acción Verde*, the *Consorcio Ambiental Dominicana*, and *Climacción*. Universities such as the Technological Institute of Santo Domingo (INTEC) are implementing certificate training programs on climate change targeting municipalities and environment sector professionals.

The climate change policies and actions that have been recently initiated at the national level have not had a noticeable impact at the subnational level yet. The Dominican Republic is divided into 31 political districts, provinces, and the capital of Santo Domingo (National District). The decentralization of government is a fairly recent development in the Dominican Republic as defined in the new Constitution. The legislature is charged with transferring 10 percent of the total government budget to 161 municipalities throughout the country. The Dominican Municipal Federation manages the structure for decentralization. Both provincial and municipal governments should have environmental units, and CNE and COE units should be established at the provincial level. Forty-nine of the 161 municipal environmental units have been established so far, and the ability of these units to engage their constituencies in understanding and addressing climate change is very limited. In some cases, civil society, local government, and the private sector — independently and in partnership — were improving their ability to prepare and respond to disasters and manage flooding, watersheds, and coastal habitats at a local level. Most of these instances, however, were in immediate response to a crisis (e.g.,

controlling flooding with sand bags) or small-scale collaborations (e.g., a hotel collaborating with a conservation organization to protect a local reef) and led by concerned local NGOs and businesses. For example, in Montecristi the Consejo Dominicano de Pesca y Acuicultura (CODOPESCA), Marina de Guerra, fishing associations, and NGOs are working together to create awareness about and enforce laws that regulate fishing.

The provincial and municipal governments of Santiago and Santo Domingo are the largest and most active local governments. They are taking significant and innovative actions to improve resilience to climate change, urban planning, and environmental degradation in areas vulnerable to flooding. Santiago has developed a strategic plan, *Plan Estratégico*, which defines zones within the city that are vulnerable to flooding in addition to actions for improving planning and response within the zones. For a detailed description of this initiative and its relevance to addressing climate change see the Santiago Urban Planning Case Study (pg. 58). The Commonwealth of the Greater Santo Domingo (*Mancomunidad del Gran Santo Domingo*) offers a potential platform to address climate change in its 11 member municipalities. On the NGO front, in Santo Domingo, IDDI and other civil society group's work with local community foundations and the municipal government to address similar issues in poor, severely flood-prone neighborhoods situated along the Ozama and Isabel Riverbeds. The text boxes of this report present detailed descriptions of civil society, the academic community, local government, and, in some cases, private businesses working together to improve resilience and adaptive capacity to climate change.

Overall conclusions from the institutional analysis follow:

- Climate change policy and plans have been developed at the national level.
- ONAMET and INDRHI have established a solid foundation with which to strengthen and expand their capacity to collect data and to analyze and disseminate climate information.
- Guidelines, capacity, and resources to support implementation are still weak at all levels and across ministries.
- There is a lack of coordination and integration across ministries and policies.
- It is anticipated that capacity, guidance, coordination, and collaboration will improve when the new Climate Change Policy takes effect.
- To ensure that the law is effective other actions will need to follow such as: the development and dissemination of clear guidelines; the effective enforcement of the law; along with capacity building to ensure the public is informed and capable of complying.
- Sub-national levels of government have not yet begun to take significant climate change action.
- Locally generated adaptive responses exist but are not leveraged to bring to scale.
- Institutional capacity to respond to disasters and improve the management of watersheds and water exists within some public agencies and NGOs but is not implemented to scale or linked with climate change policy and programs.
- As the devolution of the National System for Prevention, Mitigation and Response to Disasters takes place, inter-institutional coordination and citizen awareness of the relationship between climate change and risk and disaster management pose challenges.
- Inadequate land-use and development planning and enforcement increase disaster risk in areas prone to flooding.

5.1.2 YAQUE DEL NORTE—MONTECRISTI/SANTIAGO

In Montecristi, NGOs such as Agrofrontera and Caritas, the municipal government, provincial representatives of the Ministry of the Environment, CODOPESCA, Ministry of Environment and Natural Resources (MARENA), and members of the Tourism Cluster are implementing a number of activities that mitigate to some extent the impacts associated with climate change, such as coastal and alluvial flooding, potential saltwater intrusion on agriculture fields in the Cibao Valley, and increasing temperatures. NGOs and the private sector develop and promote new strategies to retain moisture and to manage water more effectively to improve agriculture production. CODOPESCA and Agrofrontera work with local fishing associations to create awareness about the laws that regulate fishing and encourage fishermen to modify their practices to comply with laws and protect coastal habitats. Agrofrontera implements activities to promote the conservation and protection of marine ecosystems in the area. Interventions that have been implemented but are less effective in the long term include the construction of barriers to control flooding near the mouth of the Yaque del Norte River, the digging of channels to control water flow through the mangroves, and occasional campaigns led by the municipal government to clean up the mangroves and beaches.

Santiago, which is situated at the convergence of several rivers and downstream of manmade dams, is vulnerable to potential flooding, which may be exacerbated by climate change as rain events become more intense – particularly if uncontrolled development of urban growth and degradation of the surrounding watersheds continue. The provincial and municipal governments, in collaboration with the Ministry of Environment, the private sector, NGOs, research institutions, and academia are in the process of implementing programs to improve watershed management and disaster risk reduction. The Ministry of Environment, in partnership with Empresa de Generación Hidroeléctrica Dominicana (EGEHID) (a state-owned hydroelectric power-generating company) and the Corporación del Acueducto y Alcantarillado de Santiago (CORAASAN), have been implementing innovative watershed management programs for some time in the upper Yaque del Norte (see “Payment for Environmental Services Water Project: A Focus on the El Cercado Microbasin Case Study”). The “*Programa de Reforestación Social*” brings together local government, private businesses, academic institutions, NGOs, and communities to implement reforestation activities in the watersheds within the province. The Ministry of Agriculture is promoting agroforestry and integrated agro-silvo-pastoral systems in the middle and lower sections of the watersheds. In terms of disaster risk reduction, the Civil Defense, Red Cross, and municipal government have been working together to improve planning and preparedness for preventing and managing flood-induced disasters. The Provincial Government of Santiago, working with representatives from these sectors, has developed and begun to implement a Strategic Plan for 2010 to 2020 (*Plan Estratégico 2020*) that improves safety and security in the province and the City of Santiago. See “An Urban Planning Case Study from Santiago” in the Recommendations Section for an explanation of how this multi-stakeholder effort provides an innovative institutional structure for addressing the potential impacts of climate change in Santiago.

5.1.3 BAJO YUNA—SAMANÁ BAY AND PENINSULA

Local organizations in Samaná are also implementing promising activities:

- With USAID support, the Samaná Municipal Environmental Unit has investigated local capacity and begun to create awareness related to climate change.
- The Samaná Tourism Cluster has organized and implemented activities to address local environmental issues such as over-fishing and improve management of solid waste. They have organized “clean up” events in town and along the beaches and raised awareness of the importance of protecting coral reefs.

- Through the provincial government, the Ministry of Environment is promoting reforestation activities.
- CEBSE is working with local municipalities to restore mangroves and with fish cooperatives to improve fishing practices and promote alternative livelihoods.
- CEBSE and other NGOs also promote coral reef conservation and restoration, and raise climate change awareness.
- A network of local NGOs and municipal government are working together to improve land-use planning based on anticipated climate impacts.

In Las Terrenas, NGOs, the municipal government, and local businesses have formed the *Alianza Arrecifal de Las Terrenas* to promote protection of the coral reefs and economic alternatives to fishing. The hotel *Balcones del Atlantico* collects a surcharge of one U.S. dollar per night to fund reef conservation and dune stabilization.

5.1.4 BÁVARO/PUNTA CANA

The *Fundación Ecológica Punta Cana* is one of the most prominent local organizations implementing programs related to coastal habitat protection in the Bávaro/Punta Cana area. The Foundation was established by a group of private investors developing sustainable tourism in the region, called the *Grupo Puntacana*. The activities of the Foundation include raising awareness about the potential causes and consequences of climate change; promoting corporate social and environmental responsibility to improve planning and action to mitigate and reduce negative impacts; protecting areas where fishing is prohibited (e.g., a co-management agreement with CODOPESCA); and improving the management of solid waste. Other activities implemented by local organizations include the creation of an alliance between NGOs and businesses to conserve and protect the coral reefs, as well as raising the awareness of members of local fishing cooperatives to practice sustainable fishing and discontinue the use of nets for fishing. For example, the Punta Cana Tourism Cluster and the Ministry of Environment have entered into a co-management agreement to protect the Laguna Bávaro Protected Area.

5.1.5 SANTO DOMINGO

As described in the sensitivity section the assessment focused on neighborhoods within the city of Santo Domingo vulnerable to alluvial and storm surge flooding along the Ozama River. There are a number of institutions, NGOs and government, which are working with community-based organizations to reduce the vulnerability of these neighborhoods to flooding. Most of the activities aim to improve preparedness and response to disaster. Community-based foundations have been formed to organize and lead the communities to work together to keep their neighborhoods clean and improve disaster risk preparedness and response. The foundations are organized into an Association of Foundations and receive resources and technical assistance from the CNE/COE, municipal government, and NGOs such as IDDI and Caritas.

One of the community foundations, *Fundación por el Saneamiento de La Zurza* (Fundezurza), created an early warning system for neighborhoods along the riverbed. They installed water-level monitors in areas susceptible to flooding that warn the neighborhoods about rising water levels. Unfortunately, the first attempt failed because the communities needed additional organization and training to adequately manage and maintain the system. IDDI is piloting similar interventions in La Barquita de Los Mina, where a community-based early warning system shows promise. An innovative feature of this project is how IDDI, working with the municipal government, has formed a multi-institutional municipal-level platform that works together to reduce disaster risk. Members of the platform include the municipal government, emergency services, Red Cross and Civil Defense of Santo Domingo Este along with representatives

from the district health, education, and police units. See the following case study on “Community Coordination for Disaster Risk Reduction” for additional details regarding this project.

Many of the communities most susceptible to flooding are newly established, temporary settlements of recent migrants to the city – people with limited economic means and assets. NGOs are helping them meet their needs, including improved community organization and representation, assistance with receiving basic services, and improving livelihood options. All of these interventions, though not directly related to climate change, are important strategies for reducing the vulnerability of these communities and improving their ability to engage in adaptive strategies.

6.0 RECOMMENDATIONS

6.1 ADAPTIVE PATHWAYS

The assessment team reviewed the major findings on exposure, sensitivity, and adaptive capacity, and based on these findings developed a preliminary set of adaptation strategies that fall along three pathways. In terms of exposure, there are several climate changes that are anticipated across the four hotspots: increasing temperature, sea-level rise, and intensity of storms, along with continued inter-annual rainfall variability. It is likely that the anticipated climate change will affect communities, livelihoods, and natural systems in ways that will vary in each hotspot but can be summarized as follows:

- Low-lying coastal areas and alluvial flood plains will be increasingly susceptible to flooding (alluvial and storm surge), which will adversely impact infrastructure (houses, roads, public buildings, and businesses); people living in the areas; natural habitats (forests, marine, and coastal); and land used for agriculture and grazing.
- Many of the populations living in these areas are already exposed to flooding during extreme rainfall events, and it is anticipated that their risk to flooding-induced disaster will increase.
- Erosion, destruction of natural vegetation and barriers caused by the flooding, and human-induced impacts (population pressure and development) will degrade the marine habitats and coastal areas, leading to a reduction in livelihood incomes generated from fishing and tourism.

Given these impacts, adaptive strategies need to be defined to improve policy and guidance, develop institutional capacity, and engage citizens (individuals, civil society organizations, and private businesses) to prevent, mitigate, and manage potential damage caused by flooding. Much has already been done in the Dominican Republic in this regard; therefore activities to improve adaptive capacity should build on the policies, guidance, institutional capacity, and engagement platforms that already exist – at the national and local levels.

In line with the strategic approach, the following three adaptive pathways guide the direction that institutional actors can follow to strengthen resilience and adaptive capacity.

1. Disaster Risk Reduction and Early Warning Systems;
2. Development Planning: Infrastructure and Land Use; and
3. Management and Conservation of Coastal Habitats and Watersheds.

These three pathways provide a higher-level framework with which to define and prioritize options for action – or recommendations for strengthening resilience and adaptive capacity. The development planning and habitat management and conservation pathways are intended to develop adaptive capacity over the long-term by creating a shift in how development, land use, and natural resource management and conservation currently takes place. It is envisioned that the recommendations defined in this section, if implemented, will succeed in establishing physical infrastructure, improving land use, and reviving critical habitats that will protect communities, livelihoods, and natural systems from the anticipated sea-level rise and increased intensity of rainfall events that will exacerbate flooding. On the other hand, the pathway to reduction of disaster risk related to flooding is aimed primarily at protecting populations and improving their resilience to prepare and respond to increasing flood risks in the short term. The activities proposed under this pathway also strive to improve climate information and early warning

systems to produce a shift in “business as usual” by institutionalizing local and national capacity to prepare for and reduce risk.

The recommendations presented below were developed during six options analysis workshops that took place in April, 2013. During those workshops, over 55 participants representing key government agencies, NGOs, private businesses, and academic institutions (see Annex B for a list of workshop locations and participants) learned about the findings of the assessment, improved their understanding of constraints and opportunities for addressing adaptation, and identified potential adaptation strategies and recommendations. These recommendations represent the thoughtful and informed input of the options analysis participants.

Overall planning, policy development, and investment to address climate change in the Dominican Republic is being led and coordinated at the national level. During the national level options analysis workshop held in Santo Domingo, participants who represented key public and private agencies that are engaged in climate change-related policy making and programming discussed and defined national-level strategies to strengthen resilience in the short term and adaptive capacity in the long term.

Adaptive capacity also needs to be developed at a local level because it is experienced there. Local experiences and examples of promising practices serve to influence the development of national policies and programs that are effective at all levels. Returning to the communities to conduct local workshops, the assessment team worked with sub-national actors to refine recommendations based on actual practice and the reality on the ground. They used the opportunity to further investigate and validate the promising nature of some of the local activities they had learned about during the assessment phase. The innovative local efforts and case studies highlighted in the following pages, show promise for strengthening adaptive capacity and merit further study as models for developing future climate adaptation programming. They provide a basis for understanding existing adaptive capacity. The recommendations described below reflect both national and subnational perspectives, with specific examples of existing experiences provided in the case studies.

6.2 PATHWAY I: DISASTER RISK REDUCTION AND EARLY WARNING SYSTEMS

Three strategies were defined to guide development of the Disaster Risk Reduction and Early Warning Systems pathway. The strategies are to strengthen the capacity of stakeholders (communities as well as technical and administrative agents) to improve preparedness and response to disasters; improve development and communication of climate and natural disaster information; and strengthen inter-institutional and international collaboration to improve coordinated preparation and response to disaster risk.

Strengthening the capacity of stakeholders to improve preparedness and response to disaster requires a three-pronged approach to: 1) increase awareness about vulnerability to climate change and the need for natural disaster preparedness among various sectors of society (general public, decision-makers, and members of communities exposed to climate change); 2) strengthen the capacity of organizations that are best placed to improve disaster risk preparedness and response (nationally and locally); and 3) link local actors and agencies on the “front-lines” of disaster risk preparedness and reduction with national agencies that can support their development and ability to respond. Broad activity areas were defined to address each approach.

Increase awareness about vulnerability to climate change and the need for natural disaster preparedness:

- Sensitize multiple stakeholders on how issues surrounding climate change will affect them. For example, in Punta Cana municipal government, private businesses, and the tourism cluster engage in dialogue to discuss related problems, reach consensus, and share responsibility for action.
- Improve awareness via local “charlas” and media.
- Support the design and implementation of comprehensive curriculum on climate change tailored for the Dominican Republic covering all education levels. The Ministry of Education and academic institutions are expected to play a major role.

Strengthen the capacity of organizations best placed to improve disaster risk preparedness and response in populations susceptible to flooding:

- Conduct training needs assessments for disaster risk management and climate risk awareness at national and subnational levels with the National Council for Climate Change and the Ministry for Labor and/or the Ministry of Public Administration taking a lead role technically supported by the *Instituto Nacional de Formación Técnico Profesional (INFOTEP)*, the Red Cross, and other organizations with relevant technical experience.
- Design and implement training for professionals based on the results of the needs assessments.
- Develop local public-private disaster risk management strategies that respond to climate related risks.
 - At the municipal level, share and use the disaster/vulnerability maps that have been prepared by the Civil Defense and climate information that has been prepared by ONAMET;
 - Link municipal-level disaster/climate vulnerability maps to develop a national-level map to be used for national-level planning;
 - Strengthen the capacity of ONAMET to collect, analyze, and disseminate relevant climate information at the national and local levels; and
 - Strengthen the capacity of the Civil Defense to access (via ONAMET) and disseminate information and warnings in a timely manner.
- Design and implement scenario disaster risk reduction contingency planning supported by the National Emergencies Council (NCE) and the Academy for Sciences of the Dominican Republic.
- Conduct emergency response simulations periodically at the community level, involving the municipal government and emergency responders such as the fire station, police, and ambulance staff; Civil Defense; and the Red Cross.

Link local actors and agencies on the “front-lines” of disaster risk preparedness and reduction with national agencies that can support their development and ability to respond:

- Establish community-based Climate Change Units (CCUs) and/or multi-sectoral working groups to strengthen local understanding of vulnerability and strengthen local capacity to respond (e.g., the multi-institutional municipal level platform developed in Los Mina – Santo Domingo).
 - At the national level, link them to the National Council for Climate Change, National Emergencies Council (NCE), and other institutional sources of support for capacity building, e.g., NGOs and/or academic institutions.

- At the local level, link to community-based groups, e.g., community foundations.
- Climate change resource organizations (government institutions, NGOs and academic institutions proficient in climate change) train community-based agents and technical staff.
- Develop alliances between national institutions and the local entities (CCUs and/or working groups and community-based groups) to establish and strengthen disaster preparedness and response in the communities at risk of flooding disaster.
- Design and implement community-based early warning systems in communities potentially affected by flooding.

To improve development and communication of climate and natural disaster information, the recommended approach is to: 1) improve the national network of meteorological stations and their capacity to produce long-term climate records and improve tracking of tropical storms; 2) produce climate information tailored to specific sectors; and 3) develop a national system to communicate incoming risks. Activities for each area are defined as follows:

Strengthen the national network of meteorological stations and staff capacity to produce long-term climate records and improve tracking of tropical storms:

- Strengthen the institutional capacity of both INDRHI and ONAMET.
 - Identify desired location of critical stations for monitoring precipitation, temperature, wind, and stream flow.
 - Equip and staff the stations.
 - Train staff in how to maintain the stations and equipment, collect and analyze data, and communicate information.
- Improve the capacity of INDRHI to monitor and communicate critical changes in river flow upstream for “early flood warning.”

Produce climate information tailored to specific sectors:

- Identify climate-related data and information useful at the national, provincial, and municipal levels and for each relevant sector (e.g., Trade and Industry, Agriculture, Environment and Natural Resources, CNE, etc.)
- Working with the organizations, collect and analyze the data relevant to each.
- Assist the organizations to generate information from the data, document it, and communicate it to necessary audiences.

Develop a national system to communicate incoming risks:

- Build on what has already been established for early warning systems (nationally and locally). Note that the assessment did not identify a functioning early warning system, but rather elements of attempts to establish systems (e.g., municipal-level mapping – Los Mina and Samaná, ONAMET’s monthly climate monitoring bulletin, and weather reports for farmers).
- Strengthen the capacity of ONAMET, INDRHI, CNE/COE, and local governments to communicate the relevant information in a timely way.
 - Develop and implement an early warning systems communication strategy.

- Communicate via mass media and networks (including community-based networks).

To strengthen inter-institutional and international collaboration to improve coordinated preparation and response to disaster risk, it is recommended that the application of the *Ley de Gestion de Riesgos a Desastres* be strengthened. This law clarifies mandates to all parties and encourages engagement across sectors and levels of government along with the development and implementation of a national disaster risk response plan that engages key institutional players. To foster learning and knowledge management in the areas of climate change and disaster risk response, it is recommended that inter-institutional networks and local multi-sectoral working groups be developed. Further description of these recommendations follows:

Strengthen the application of the *Ley de Gestion de Riesgos a Desastres*:

- Communicate a simple synopsis of the law to all citizens.
- Encourage community-based groups (NGOs, *juntas vecinales*, etc.) to monitor the application of the law and hold officials responsible for compliance.

Define and implement a coordinated plan for disaster risk response and early warning among key lead national agencies:

- Establish a climate and disaster response network of a variety of institutions that can offer specific information and expertise to the development and implementation of the plan.
 - Institutions included could be ONAMET, INDRHI, the Climate Change Unit, ministries of Agriculture, Trade and Industry and Environment, COE/CNE, academic institutions, NGOs, and associations of local government, among others.
- Participating institutions actively collaborate to build capacity and transfer relevant technology.

Establish local-level multi-sectoral working groups in order to improve coordination for prioritizing, planning, and implementing climate change and disaster risk response activities:

- Working groups can include private, public (municipal and provincial), and civil society organizations – similar to the tourism cluster model, but with a clear mandate and objectives.
- Working groups would actively engage *juntas vecinales* and *clubes de madres y jovenes* in local level disaster risk preparation, planning, and response, and in monitoring compliance with the *Ley de Gestion de Riesgos a Desastres*.

Disaster Preparedness to Improve Resilience Program A Case Study on Community Coordination for Disaster Risk Reduction

The Instituto Dominicano de Desarrollo Integral (IDDI) launched the Disaster Preparedness to Improve Resilience Program for the community of Los Mina North along the Ozama River in Santo Domingo East. This community is 90 percent Dominican, with an average income between DR\$1500–DR\$7000 per month. Most people work as day laborers or in other areas of the informal economy, and many live within the flood plain of the Ozama River.

The program was launched in 2011 with funding from IDDI and the Office of U.S. Foreign Disaster Assistance (OFDA). Los Mina faces severe flooding two to three times per year between June and November. Flooding is a major contributor to loss of property and life, and diseases such as leptospirosis. Standing flood waters also attract mosquitoes, which increases the incidence of dengue fever and a variety of skin diseases.

Program partners have established a municipal coordination platform for disaster risk reduction with the City of Santo Domingo Este, the Santo Domingo Fire Brigade, Dominican Red Cross and Santo Domingo Este Red Cross, Civil Defense, the province Area II Health Ministry, 10-03 school district, and the regional Eastern Santo Domingo National Police. This partnership has focused on improving communication of information on disasters, providing risk reduction training, and developing an informational webpage (<http://plataformarrd.com/>) for sharing early warning information with the community. Members of the municipal platform convene every 15 days and includes outreach to women and youth groups.

The four key areas supported by the project include: improving awareness about disaster risk reduction; creating and strengthening inter-agency coordination for rapid response; building and repairing infrastructure such as evacuation routes, shelters with provision of equipment to the disaster risk management unit (*Gestión de Riesgo* [UGR]); and establishment of early warning systems including community maps, signaling evacuation routes, and disaster monitoring. The program has organized work parties to channel waste water and rainwater, build retaining walls and shelters, and improve drinking water networks. The program has increased the ability of the Los Mina and other participating communities to adapt to climate change variability and increased flooding risks.

Public knowledge and response to flooding has improved as a result of greater awareness, better coordination, and strengthened relationships between the provincial and local authorities. At the end of the first year of the project, there were heavy rains. The people living within Los Mina Norte evacuated early from flood-prone areas, thus reducing the loss of life and property. Engagement by local government and community groups coupled with technical assistance from IDDI has built public awareness in disaster preparedness, and people now prioritize the urgency of evacuation over the personal belongings they have in their homes. In addition, two flood-prone communities that regularly experience severe flooding have been selected for permanent relocation by the government.

Community mapping exercise in Los Mina North



Source: Instituto Dominicano de Desarrollo Integral (IDDI)

Key Contact: Santa Sanchez, Project Coordinator, Instituto Dominicano de Desarrollo Integral (IDDI)

6.3 PATHWAY 2: DEVELOPMENT PLANNING: INFRASTRUCTURE AND LAND USE

Three strategies were identified to guide definition of the Development Planning: Infrastructure and Land Use pathway. The strategies are to strengthen the capacity of planning-related professionals and institutions to prevent and mitigate climate change risk exposure; improve urban and land-use planning to minimize exposure to climate change and risks to natural disasters; and strengthen environmental assessment and licensing policies, guidance, and enforcement to prevent and mitigate environmental degradation, flooding, and pollution.

Strengthening the capacity of professionals and institutions to prevent and mitigate climate change risk exposure can be accomplished by implementing two broad and ambitious activities:

- Develop university courses to train specialized personnel on climate change, planning, and risk management. Academic institutions such as the Autonomous University of Santo Domingo and private universities can be supported to develop these courses. Some climate change courses have already been developed and are given throughout the country (e.g., Samaná).
- Train officials and other technical personnel to facilitate the development of land-use plans that integrate climate change adaptation. Personnel from local governments, the Dominican Federation of Municipalities, and *Dirección General de Ordenamiento y Desarrollo Territorial*, to name a few, would be targeted for the training.

Improving urban and land use planning to minimize exposure to climate change and risks to natural disasters involves three principal actions: approving the application of the *Ley de Ordenamiento Territorial* (a new law with which many people are not familiar); providing guidance and capacity building on how to integrate climate change adaptation into national planning processes; and stabilizing coastlines and controlling flooding by building physical barriers and restoring natural barriers:

Approve and apply the new *Ley de Ordenamiento Territorial*:

- Establish and apply regulations developed in a contextually realistic and climate-responsive way.
- The Ministry of Economic Development and Planning and local governments make land use information — studies and plans — available to the public.

Provide guidance and capacity building on how to integrate climate change adaptation into planning processes at national and sub-national levels:

- The Ministry of Economic Planning and Development and the *Dirección General de Ordenamiento y Desarrollo Territorial* strengthen and scale-up their work with the municipalities such as the Climate Change Unit, NGOs with appropriate expertise, and federations of local government (e.g., *La Federación Dominicana de Municipios* [FEDOMU]), to develop and provide this guidance and capacity building.
- Strengthen the capacity of provincial and municipal governments to develop strategic plans that are climate responsive and enforce land-use regulations that take climate change vulnerability into consideration and are in line with the new *Ley de Ordenamiento Territorial*.
- The ministries of Economy, Planning and Development, Environment, Agriculture (CODOPESCA), and Tourism, working with local governments, improve coastal land use management and zoning to protect populations from storm surge.

- Identify communities extremely vulnerable to climate change and improve urban planning to prevent and mitigate risk (integrate with the recommendation in the Disaster Risk Reduction Pathway to improve disaster risk mapping.)
 - Draft vulnerability maps for each community along the river flood plain with the participation of community organizations (this activity initially can be informed by the results of this assessment).
 - Based on the maps define strategic risk reduction and urban development plans for each community with the participation of community organizations (e.g., community foundations, community-based organizations, local churches, etc.).
 - Link the climate risk reduction plans to municipal strategic plans and with organizations that can provide resources and technical assistance (e.g., local government and NGOs).
 - Include in the plans improvements in water systems and sanitation, which are often designed without taking extreme fluctuations of water flow (flooding and storm surge) into consideration.
 - Establish natural barriers (e.g., forests, wetlands, grass lands, etc.) to control flooding along the river.
 - Install waste filters at the opening of drainage pipes accompanied by training in the regular cleaning and maintenance of the filters to prevent clogging of drain pipes, especially in areas susceptible to flooding.
 - Relocate houses and other buildings that are situated in zones vulnerable to flooding, as indicated in the vulnerability maps.
 - Improve the quality of local housing construction with permanent materials to resist major weather events and flooding.
- Prioritize public investment in line with improved climate change adaptation and responsive planning.

Stabilize and control flooding by building physical barriers and restoring natural barriers:

- Flood retention barriers and walls can be built; but as the sea level rises, storms become more intense, and natural barriers are degraded. Construction of these barriers is temporary and can be costly.
- In some strategic areas, such as at the mouth of the Yaque del Norte, artificial reefs can be built to serve as a water break and control the encroachment of sediments.
- It is more cost effective and better for the environment if natural barriers such as coral reefs and dunes are maintained and restored.

Strengthening environmental assessment and licensing policies, guidance, and enforcement in order to prevent and mitigate environmental degradation and flooding can be achieved by implementing a two-pronged approach to ensure that infrastructure and plans are compliant and sound in the face of anticipated climate change vulnerabilities. The two approaches are to educate NGOs, the academic community, and citizens regarding the *Ley de Medio Ambiente* and regulations for the permitting process and support the establishment of independent monitoring and reporting mechanisms to monitor and report on compliance.

Support continued strengthening of the environmental permitting process:

- Continue to provide training and support to maintain and update as necessary the Ministry of Environment's environmental permitting tracking system including the on-line GIS based screening tool – NEPAAssist.
- Work with the Ministry to incorporate CCA considerations into the environmental permitting process.
- Support the drafting, adoption, and application of guidelines for the incorporation of CCA considerations for four priority sectors: housing, tourism, mines, and agriculture.

Educate NGOS, the academic community, and citizens about the *Ley del Medio Ambiente* and regulations for the environmental permitting process (environmental impact assessments):

- The Ministry of the Environment and NGOs can inform citizens of their rights and how they can monitor and engage in the process (Samaná-Ministry of Environment and NGOs).
- The Ministry of the Environment and NGOs can also ensure that officials are well trained, defending the environment and the rights of citizens.

Support establishment of independent monitoring and reporting mechanisms regarding process/compliance:

- Identify academic institutions and NGOs that are interested in performing this role.
- Provide support including training, appropriate technical assistance and funding.

Evaluate infrastructure and plans to ensure their soundness in the face of anticipated climate change vulnerabilities:

- Build capacity in this area by providing training and technical support to local institutions and consultants (e.g., *Colegio Dominicano de Ingenieros, Arquitectos y Agrimensores* [CODIA], Risk Management Municipal Institute, IGER in Santiago, Ministry for Public Works and Communications, etc.) in planning and architectural design to reduce risks.

Implementation of Plan Estratégico at the Municipal Level

An Urban Planning Case Study from Santiago

The Province of Santiago is one of the most populous regions in the Dominican Republic, with a population of 1.8 million. Growth is most notable in the capital city of Santiago de los Caballeros (“Santiago”), located along the Yaque del Norte River. The city has expanded by 60.5 percent between 1988 and 2006, and the population has grown from 585,000 in 2006 to 1.2 million in 2012. Population density increased from 7,344 inhabitants/ km² to 8,744 inhabitants/ km² from 1988 to 2006 (Oficina Nacional de Estadística, 2011), leading to the proliferation of urban settlements; many situated in areas affected by floods and other manifestations of climate change.

To address the need for environmentally sustainable, integrated, and inclusive planning that ensures the security and safety of this growing population, the *Consejo para el Desarrollo Estratégico de la Ciudad y el Municipio de Santiago*, comprised of leadership from provincial and municipal government, private businesses, nonprofit organizations, the Catholic church, and other civil society organizations, developed *Plan Estratégico 2020*. *Plan Estratégico* is comprehensive and includes some goals and activities that address issues related to the potential impacts of climate change on Santiago’s most at-risk communities: those that live close to the Yaque del Norte riverbed.

A number of projects — many of them forged through public-private alliances — address disaster risk management including the development of a municipal-level land-use plan (*Plan de Ordenamiento Territorial de Santiago*) that identifies and prioritizes risk management activities by geological threats, location of infrastructure and political boundaries, and socio-economic and environmental factors. Illustrative projects that improve resilience and adaptive capacity in these vulnerable communities include:

- A partnership between the municipal government, *Instituto de Gestión de Riesgos (IGER)*, and the *Secretaría de Trabajo* improves urban stream flow by removing solid waste from the stream channels while raising awareness about sanitation and flood control.
- The municipal government and the *Secretaría de Urbanismo* relocated 500 families living in flood-prone areas in the communities of Larga and Oyo de Julia.
- A partnership between the municipal government, the *IGER*, and *Caritas* (a faith-based NGO) works to reduce the risk of floods and to develop communication to improve local preparation and

Time-series urban expansion of Santiago.



Source: Google Earth

response to disasters in the communities of Oyo de Puchula, Fracatán, La Esperanza, and el Oyo de Elias. Activities include the construction of pedestrian bridges in flood-prone areas and development of flood-risk maps outlining evacuation routes and disaster ‘meetup’ points in the event of flooding.

- The communities of Cañada de Nevaje and Cañada del Diablo have constructed flood walls in flood-prone areas with technical assistance from the IGER.
- The *Fundación Dominicana de la Gestión de Riesgos* is developing awareness on climate change adaptation and other disaster risk reduction activities and strategies by launching and maintaining a website to share relevant information.

Key Contact: Luis Peña, Director of IGER, Municipality of Santiago. Email: fundoger@gmail.com. Phone: 809-276-1112.

6.4 PATHWAY 3: MANAGEMENT AND CONSERVATION OF COASTAL HABITATS AND WATERSHEDS

Four strategies were defined to guide development of the Management and Conservation of Coastal Habitats and Watersheds pathway. The strategies are to strengthen institutions and create awareness related to climate change and the conservation of coastal-marine resources and watersheds; improve the management and conservation of watersheds and coastal-marine resources – separate strategies for each; and promote the efficient use and management of water related to potable use, structures for divergence and storage (e.g., dams), irrigation for agriculture, and groundwater management.

Strengthening institutions and creating awareness related to climate change and the conservation of coastal-marine resources and watersheds can be accomplished by: 1) training environmental and natural resource management professionals to understand the relationship between management and conservation of the environment and natural resources and climate change; and 2) strengthening inter-institutional coordination across all related ministries and sectors to plan, coordinate, and address climate change through improved management and conservation of coastal-marine resources and watersheds.

Train environmental and natural resource management professionals in climate change and improve understanding of climate change and conservation at the community level:

- Improve awareness of how good management/conservation of the environment/natural resources reduces vulnerability to climate change.
- Train professionals from NGOs, universities, Ministry of Agriculture, Ministry of Environment, Ministry of Education, and others on climate change and the environment. Conduct a training needs assessment to help define training objectives, curriculum, and target audiences.
- Introduce environmental and climate change education in primary and secondary curricula so that young citizens improve their understanding of climate change and what they can do to help address it.
- Train NGOs, municipal officials, and the Department for Coastal and Marine Management (in the Ministry of the Environment) in climate change and the environment – perhaps working through climate change working groups and community foundations.

Strengthen inter-institutional coordination across all related ministries and sectors to plan, coordinate, and address climate change through improved management and conservation of coastal-marine resources and watersheds:

- Improve collaborative planning, decision making, and action between private, public, and civil society groups (e.g., National Council for Climate Change, Ministry of Environment, Ministry of Agriculture, and INDRHI).

Improving the management and conservation of watersheds is ambitious, and the Dominican Republic already has significant experience throughout the country in improving the management of watersheds. The recommendations below draw on this experience and are organized into two areas of work: forest conservation and the promotion of good agricultural and soil/water conservation practices.

Promote forest conservation by working closely with the Ministry of Environment, Ministry of Agriculture, provincial and municipal governments, NGOs, and others:

- Support the further development and implementation of the *Programa de Reforestacion Social*, in which communities work closely with provincial government and academic institutions or NGOs to reforest watersheds.
- Develop and fund watershed management programs (payment for environmental services, possibly with the private sector) to improve capacity in watershed management with an emphasis on targeting farmers.
- Through the Ministry of Agriculture, promote agro-forestry on farmland to stabilize slopes and retain soil moisture in the Yaque del Norte River (where rising temperatures will dry out soils).
- Promote reforestation using native species along the lowest part of the Yaque del Norte River to control flooding.
- Encourage land-use change practices from cattle ranching to forestry to prevent downstream flooding due to high rainfall events.
- Promote reforestation of the upper watershed, including management for sedimentation in riparian buffer zones to prevent downstream flooding/high sediment load during high rainfall events.
- Support farmers with education and capital resources to improve the promotion of adaptive activities in the upper watershed, as outlined above.
- Restore the Rio San Juan watershed in Samaná to serve as a possible model for integrated and climate change management; pre-studies exist including plant identification and the establishment of coastal plant nurseries. The current project is being implemented by CEBSE, TNC, the Ministry of the Environment, and communities within the watershed. USAID should continue supporting the project.
- Improve planning, restoration, and management of vegetative buffer zones in the urban lower watersheds, such as along the Ozama River in Santo Domingo and Yaque del Norte River in Santiago.
 - Establish and manage river easements, both natural and restored.
 - Teach community members about the importance of maintaining these areas and keeping them clean (in possible alliance with the private sector).
 - Improve the management of solid waste and promote recycling.

Promote implementation of good agricultural and soil/water conservation practices:

- Improve integrated management by promoting agro-silvo-pastoral systems, led by the Ministry of Agriculture and supported by NGOs and private agri-businesses.

- Promote the use of environmentally-friendly alternatives to agro-chemicals, and educate farmers and agro-businesses on the use of alternatives and the proper use of agro-chemicals.
- Improve the management of toxic waste – human, industrial, and agricultural.
- Hold agro-chemical producers responsible for promoting environmentally-friendly products and for improved application and disposal of chemical receptacles that pollute the environment; garner support from agri-businesses.

Improving the integrated management of coastal-marine resources is also an area where the Dominican Republic has significant experience throughout the country. The recommendations below draw on this experience and are organized into four areas of work: creating awareness about laws that control the discharge of contaminants into coastal habitats and regulate fishing; consolidating the conservation and protection of critical habitats (mangroves, coral reefs, and soft-bottom habitats); restoring these habitats; and identifying and promoting environmentally-neutral alternative livelihoods to fishing and salt harvesting.

Create awareness about and enforce laws that reduce the discharge of contaminants into the coastal habitats:

- As part of the first strategy, raise awareness among citizens about the negative impacts of discharging contaminants into coastal environments and how to understand and enforce related laws.
- Implement campaigns to regularly clean the beaches and critical habitats of garbage (implemented by municipal governments and neighborhood brigades).

Create awareness about and enforce laws that regulate fishing working with CODOPESCA, *Marina de Guerra*, fishing associations, and NGOs:

- Explain how fishing is regulated (no spear fishing and regulation of size and maturity of catch).
- Educate fishermen about alternatives to spear fishing.
- Train the *Marina de Guerra* in the conservation of marine habitats, climate change, and sustainable practices.
- Introduce improved methods for fishing and salt-harvesting that are less damaging to the environment.

Promote the establishment and improved management of coastal/marine protected areas:

- Create and support the establishment of co-managed protected areas, (e.g., La Caleta where Reef Check co-manages with the government).
- Improve the management and protection of coastal protected areas.
 - Support additional training of park guards.
 - Provide additional resources (boats, etc.) and staff.
 - Establish community monitoring.
 - Implement anchor buoys.
 - Reduce boat traffic.

- Educate visitors on how to protect the habitats, particularly coral reefs.

Restore coastal-marine eco-systems (coral reefs, mangroves, estuaries, and soft-bottom habitats):

- Restore and plant mangroves (NGOs, Ministry of Environment, and public/private alliances).
- Restore coral reefs (NGOs, Ministry of Environment, and public/private alliances).
 - Establish coral nurseries.
 - Control boat traffic.
 - Educate visitors by showing them coral restoration projects.

Identify and promote environmentally-neutral income generation alternatives to fishing and salt harvesting:

- Conduct a market survey of alternatives.
- Build appropriate skills.
- Make investment capital available.

Recommendations for promoting the efficient use and management of water related to potable use, structures for divergence and storage (e.g., dams), irrigation for agriculture, and groundwater management overlap in some places with the watershed management recommendations. They have been addressed by the following approaches: promoting best adaptation practices in water management use (e.g., monitoring and management of dams and infrastructure, maintenance of drainage systems, establishment of native plant species on river easements to control erosion and siltation, controlling water quality and reducing waste, educating users to reduce water waste, and increasing the number and use of pressurized systems including drip irrigation and small dams, etc.); strengthening local governance and enforcement to control water management and promote adaptation practices; enhancing water distribution and treatment systems; improving monitoring and management of watersheds during seasons of low runoff to mitigate floods and sedimentation; and introducing payment for environmental services in support of adaptation practices.

Promote best adaptation practices in water management and use, led by the Ministry of Environment and supported by NGO partners:

- As part of the first strategy, raise awareness among citizens about the best adaptation practices.
- Train citizens and technical experts on how to better adapt to reduced surface water availability and flooding.

Strengthen local governance/enforcement, including capacities to control water management and use as an adaptation practice at the national and sub-national levels (Ministry of Environment, INAPA [the national sewage and water authority], and local government):

- As part of the first strategy, train professionals in best adaptation practices to control water.
- Promote best adaptation practices through local and neighborhood organizations.

Enhance water distribution systems, including water quality and waste reduction, by working with INDRHI, INAPA, and CORAASAN:

- Educate users to reduce water waste as an adaptation strategy.

- Create awareness about improved water use at the farm and household levels.
- Install water meters where feasible.
- Increase the number and use of pressurized systems, including drip irrigation and small dams.
- Improve treatment of water in aqueducts.
- INDRHI and CORAASAN analyze and report on water quality related to decreased/increased surface water flow.
- Enhance distribution systems in agriculture (Ministry of Agriculture).
- Substitute some agricultural crops for crops that require less water.
- Clean out the irrigation drainage canals flowing from the Yaque del Norte River to improve water flow and re-channel water to improve use.
- Clean water, irrigation, and waste drains in rural areas to reduce flooding during precipitation events.
- Channel the draining system in the lower watershed and maintain the system to improve water use efficiency.

Improve monitoring and management of watersheds during seasons of low runoff to mitigate floods and sedimentation led by INDRHI and CNE:

- Enhance the quality of climate and hydro-meteorological information to better monitor precipitation, temperature, stream flow, and other climate change impacts.
- Establish ongoing monitoring and evaluation of dams.

Continue supporting payment for environmental services that support adaptation practices such as watershed protection, improved water use, and management of solid waste.

Payment for Environmental Services Water Project: The El Cercado Microbasin A Watersheds Case Study

The Northern Yaque is one of the most important watersheds in the Dominican Republic, supplying water to 17 municipalities, supporting six hydro-electric dams (Taveras, Bao, Lopez-Angostura, Monción, Chacuey, and Maguaca), and supplying water for a large percentage of the country's agricultural production. The Northern Yaque River stretches 296 km from the headwaters in the Cordilla Cenrale to Montecristi, with the upper and middle watersheds located above Santiago. Rural livelihoods depend primarily on coffee production, timber harvesting, and other small-scale agriculture.

The *Empresa de Generación Hidroeléctrica Dominicana* (EGEHID) funds 41 percent (2012) of the payment mechanism for the Payment for Environmental Services Water Project (*Pago por Servicios Ambientales Hídricos en la Cuenca del Río Yaque del Norte [PSA-CYN]*), which encompassed five municipalities in the upper watershed.²⁹ The payment mechanism supported adaptation of natural systems to climate change and sustainable livelihoods for basin inhabitants by financing the development of forest management plans; protection and restoration of native forest ecosystems that maintain permanent forest cover; improved production practices for shade-grown coffee; and agroforestry management for sustainable logging. The planting of tree species that are resilient and able to cope with climate change provide adaptation benefits including reduced evapotranspiration, which also leads to healthier terrestrial and aquatic ecosystems. The establishment of riparian vegetation increases water retention, thus mitigating downstream flooding during high precipitation events and reducing sedimentation; retention of nutrient-rich sediment is a win-win to maintain a functional ecosystem and reduce operational costs for the hydroelectric dams.

The Ministry of Environment supports the program through the National Reforestation Program (*Plan Nacional Quisqueya Verde*) with the supply of trees and labor. Funding is appropriated through the Ministry of Environment (located in the water resources office in Santiago), which has not received consistent appropriations for the program. Transparency in how these funds are appropriated remains a consideration in order to maintain landowner confidence in the program. However, results have demonstrated that farmers participating in the program have often maintained their conservation plans even when payments were not provided due to the co-benefits they receive through improved timber management and coffee production.

The Nature Conservancy (previously responsible for developing agroforestry and shade coffee and forest management plans) is launching a follow-on program called the Water Fund focused on restoration of riparian vegetation along selected micro-watersheds and cloud, broadleaf, and coniferous forests; additional support to the Environmental Services Payment Program; an environmental education

Water in El Cercado supports small hydroelectric systems.



Source: Francisco Núñez Henríquez, *The Nature Conservancy*.

²⁹ The Ministry of Environment funds 43 percent of the program, and CORAASAN funds 16 percent. Although the program was officially completed in 2012, it is not clear whether payments are still being provided by the Ministry of Environment. It is also worthwhile to note that the Payment for Ecosystem Services (PES) scheme in the upper Yaque started in 2002 under the direction of the German Agency for Technical Cooperation (GTZ) with PROCARYN expanding the program reach and providing follow-on support.

program on the issues of water quality and quantity; design and implementation of an aquatic and terrestrial monitoring program; and restoration of aquatic systems in Jarabacoa, upstream of the Tavernas Dam.

Key Contacts: Santa Rosario, PSA-CYN Director, Ministry of Environment.
Francisco Núñez Henríquez, Conservation Science Director, The Nature Conservancy Dominican Republic Program. Email: fnunez@tnc.org.

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8.0 ANNEXES

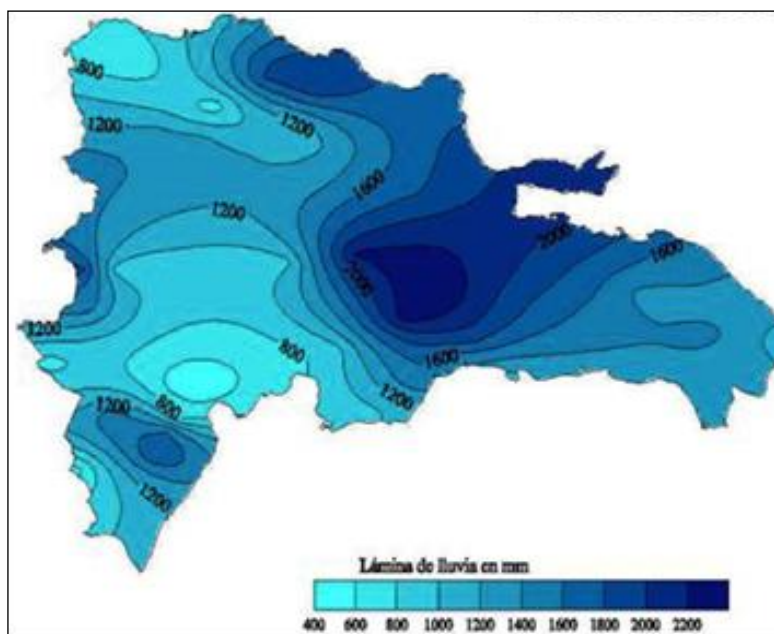
8.1 ANNEX A: CLIMATE ANALYSIS – DOMINICAN REPUBLIC

AVERAGE CLIMATE

Rainfall

Average annual precipitation in the Dominican Republic is primarily determined by trade wind direction and the orientation of mountain chains, which are typically elongated from northwest to southeast. The winds carry moisture from the Atlantic Ocean to the northeast of the country and release it upon encountering orographic barriers causing large differences in annual rainfall, up to 2,400 mm (Izzo et al., 2010). The heaviest precipitation is in the northeast (with an average annual rainfall of 2,540 mm), while the far western and southwestern valleys remain relatively dry (with less than 760 mm of annual precipitation; see Figure A1) (UNDP, 2012).

FIGURE A1: AVERAGE ANNUAL RAINFALL OVER 1960-1991 PERIOD



Source: UNDP, 2012.

In addition to regional differences between average annual precipitations, distinct differences in seasonal rainfall patterns also exist. Garcia et al. (1978) analyzed average monthly rainfall during the 1960-1967 period and defined five regions across the Dominican Republic with distinct seasonal rainfall patterns (see Figure A2).³⁰ Region 1 experiences two rainfall maxima, in November and April, and a dry summer season. The monthly rainfall distribution for region 2 is similar to that of region 1, except that the maxima occur in November and May. On the other hand, regions 3, 4, and 5 are mostly characterized by a dry winter and a rainy summer. In summary, southern regions experience only two well defined seasons (dry winter and rainy summer) while in the north, the summer rainy season is split into two seasons, separated by a short dry season.

³⁰ Further analysis over a more recent and longer time period should be performed to validate these regional seasonal rainfall patterns.

FIGURE A2: RAINFALL REGIONALIZATION BASED ON THE SEASONAL CYCLE

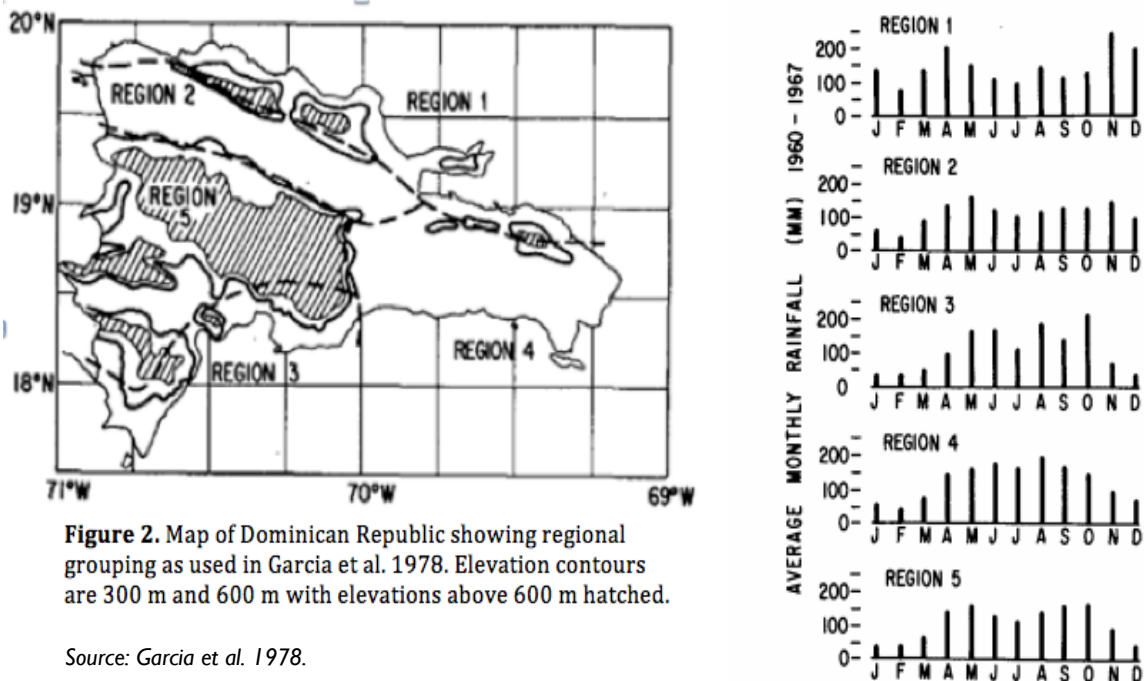


Figure 2. Map of Dominican Republic showing regional grouping as used in Garcia et al. 1978. Elevation contours are 300 m and 600 m with elevations above 600 m hatched.

Source: Garcia et al. 1978.

The main reason for the existence of this long dry spell in the middle of the summer, also called mid-summer drought (MSD), which exists in some parts of the Caribbean in July-August, remains poorly understood. The most widely accepted theory as to the cause of the MSD is the intensification and expansion of the North Atlantic Subtropical High Pressure Cell (NAHP) into the region in July. The NAHP is an atmospheric high-pressure system that causes stronger trade winds, lower sea-surface temperatures (SST), increased subsidence, and diminished rainfall in the Caribbean (Gamble et al., 2008).

Temperature

The Dominican Republic has primarily a tropical climate with little seasonal temperature variation; although August tends to be the hottest month, and January and February the coldest. The average annual temperature is 25 °C, with a range between 18 °C at altitudes of 1,200 m and greater to 28 °C at altitudes of 10 m. Valleys experience highs of 40 °C and lows of zero are common in mountainous areas (UNDP, 2012).

Extreme events, such as hurricanes, in the Dominican Republic are an important element of climate and mark important events in the country’s history. These atmospheric phenomena occur with greatest frequency during the months of August, September, and October, and with greatest intensity in southeast and southwest regions of the country. Tropical cyclones form in oceanic areas of high temperature and low pressure. Table A1 identifies cyclones that affected the Dominican Republic over past 50 years by name, intensity, category, date, and wind velocity. It is usual to distinguish between: tropical depressions with a velocity of 62 km/h or less; tropical storms with a velocity of 63-117 km/h; and hurricanes with winds over 118 km/h. Cyclone and hurricane landfall frequencies over the Dominican Republic are variable with an average of one every two years, but can occur as frequently as two per year. There have been periods of inactivity of five to ten years (Ministerio de Medio Ambiente y Recursos Naturales, 2011).

Hurricanes can cause significant damage to coastal zones, vegetation, infrastructure, life, and property. Winds induce heavy seas, which result in storm waves, flooding, and coastal erosion. On land, sudden and massive tree mortality can occur, and community structures can converge (Lugo, 2000). Hurricane Georges was highly destructive and blew down many trees; shifted the Yaque del Norte River waterbed by several hundred meters; and destroyed crops, prime agricultural land, and houses (Schelhas et al., 2002). However, some positive effects on vegetation include opportunities for species change, diversity of age classes, faster biomass and nutrient turnover, and carbon sinks. Hurricanes cause billions of dollars in losses due to destruction of infrastructure, life, and property. Increases in population density, changes in age structure and population health, sprawl of urban areas, insufficient infrastructure, and human occupation of coastal and flood prone areas have increased the vulnerability of Caribbean countries (Lugo, 2000).

TABLE A1: CYCLONE NAME, DATE, INTENSITY, AND CATEGORY IN THE DOMINICAN REPUBLIC DURING THE 1960-2008 PERIOD

Name	Date	Intensity	Category
FRANCES	9/2-3/1961	Tropical Storm	
EDITH	9/26-27/1963	Hurricane	2
INEZ	9/28-29/1966	Hurricane	4
BEULAH	9/10-11/1967	Hurricane	4
ELOISE	9/16-17/1975	Tropical Storm	
CLAUDETTE	7/18-19/1979	Tropical Depression	
DAVID	8/31/1979	Hurricane	5
FREDERIC	9/5-6/1979	Tropical Storm	
LILI	12/23-24/1984	Tropical Depression	
EMILY	9/22/1987	Hurricane	4
CINDY	8/16/1993	Tropical Storm	
GORDON	11/11-14/1994	Tropical Storm	
HORTENSE	9/10-12/1996	Hurricane	1
GEORGES	9/22/1998	Hurricane	3
DEBBY	8/23/2000	Hurricane	1
MINDY	10/10/2003	Tropical Storm	
ODETTE	12/6/2003	Tropical Storm	
JEANNE	9/16-17/2004	Hurricane/Tropical Sto	1
ALPHA	10/23/2005	Tropical Storm	
CHRIS	8/3-4/2006	Tropical Storm	
ERNESTO	8/26-27/2006	Tropical Storm	
DEAN	8/18-19/2007	Hurricane	5
NOEL	10/27-30/2007	Tropical Storm	
OLGA	12/11-12/2007	Tropical Storm	
FAY	8/15-16/2008	Tropical Storm	
GUSTAV	8/25-26/2008	Tropical Storm	
HANNA	9/1-2/2008	Tropical Storm	
IKE	9/6-7/2008	Tropical Storm	

Source: Ministerio de Medio Ambiente y Recursos Naturales, 2011.

CLIMATE VARIABILITY

Rainfall Variability

Caribbean climate experiences the effects of *El Niño* Southern Oscillation (ENSO) that occurs in the equatorial Pacific at frequencies of three to six years. An *El Niño* event, with higher sea surface temperatures (SST) and lower sea-level pressure (SLP) in the Eastern Equatorial Pacific, is accompanied by an anomalously dry summer in the Caribbean. Conversely, anomalously wet summers are associated with *La Niña* events. The main mechanism by which ENSO seems to affect the Caribbean is an

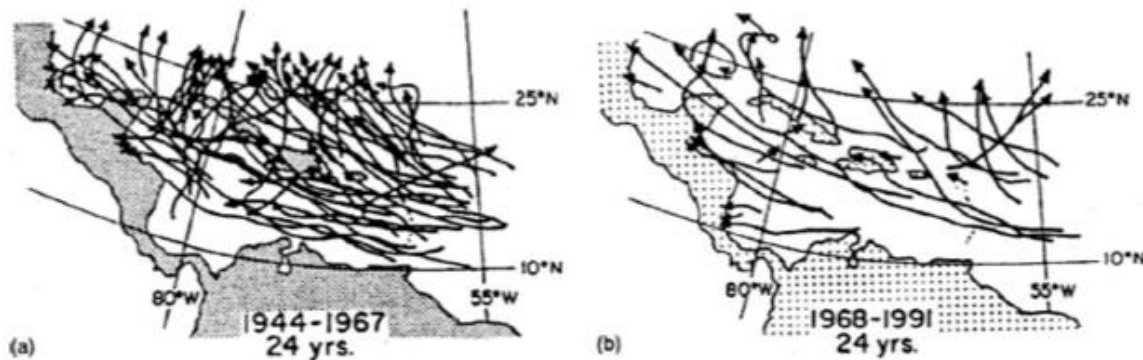
equatorward displacement of the NAHP linked to higher than normal SLP and lower SST in the Tropical Atlantic (Giannini et al., 2000).

Variability in Cyclonic Activity

Hurricane landfall probability is also affected by ENSO. Previous studies show an increase in hurricane landfall probability for the whole Caribbean during the *La Niña* phase and a decrease during *El Niño* phase, when compared to neutral years. A more than 3:1 ratio exists of hurricane landfalls per season between *La Niña* and *El Niño* years (Targatlione et al., 2003).

In addition to inter-annual variability, multi-decadal changes in frequency of hurricanes have also been observed. Hurricane activity was relatively high from the 1940s to the late 1960s and in the late 1990s, while the period from the early 1970s until the mid-1990s was by contrast fairly quiet (see Figure A3) (Pielke et al., 2003).

FIGURE A3: CONTRAST OF HURRICANE TRACKS IN THE CARIBBEAN FOR MULTI-DECADAL PERIODS OF: (A) 1944-1967; (B) 1968-1991



Source: Pielke et al., 2003.

Long-term fluctuations in Atlantic tropical cyclone activity closely follow the multi-decadal scale changes in Atlantic SSTs. During warmer Atlantic multi-decadal phase, major hurricane activity is above average (Goldenberg et al., 2001). The year 1995 marked a distinctive switch back to a more active regime last seen in the 1940s and 1960s. It is important to continue to document hurricane variability, because if conditions persist as they did last century, high levels of hurricane activity may prevail for the next two to three decades (Pielke et al., 2003).

CLIMATE ANALYSIS APPROACH

Rationale

The objective of the climate analysis is twofold:

1. Provide an assessment of past changes in climate — historical climate analysis — to be related to recorded and reported impacts in other sections of the vulnerability assessment (VA); in other words provide information on *past exposure* and relate it to outcomes in the recent past.
2. Provide estimates of potential future changes in climate — projection analysis — e.g., range³¹ of *future exposure* element of the vulnerability.

³¹ There is an uncertainty inherent to projections and only estimates and ranges of changes in climate can be provided.

Note that it is crucial to contextualize projected changes within climate variations experienced in the recent past to better appreciate their amplitude and potential impacts. Therefore, in addition to providing information on past exposure that can be related to recorded impacts, the historical climate analysis also provides a baseline for future changes.

The historical climate analysis was based on a relatively complete and comprehensive set of records of rainfall, temperature and wind over the period 1960-2012 provided by *Oficina Nacional de Meteorología* (ONAMET) and the analyses focused on determining past climate conditions, including the amplitude of inter-annual variability and frequency of extreme events (excluding hurricanes) and longer-term changes by comparing the main climate characteristics between two non-overlapping periods: 1960-1986 and 1986-2012 (cf. next section). The analysis of rainfall and temperature records provided information on climate for the subsequent vulnerability analysis of the watersheds while the analysis of wind was mostly intended to assess changes in low level atmospheric circulations that could be related to coastal erosion as reported by study respondents (focus group discussions and key informant interviews).

The projected climate analysis assessed potential changes in climate based on most recent simulations performed for the upcoming AR5 IPCC report (to be released in 2014) and focused on rainfall and temperature for two time slices centered on 2030 and 2050. In order to assess ranges of potential changes, projections for two different emission scenarios, as well as outputs from 10 different models, were considered. Coarse resolution projections were statistically downscaled and corrected for bias (cf. methods in the Climate Projections section).

HISTORICAL CLIMATE ANALYSIS

Data

Data for observed past climate were obtained from ONAMET for the period 1960-2012. The initial set included 74 stations with precipitation records, 45 stations for mean temperature, 16 stations for wind speed, and 13 stations for wind direction.

Prior to the analysis, data quality assessments and data selection were performed on all records. For a robust assessment of climate characteristics, the use of data spanning 30-year periods is general practice (WMO, 2011). Furthermore, for a monthly average value to be valid, fewer than five daily records can be missing. Not all the records fulfill those requirements and there are trade-offs between the spatial coverage (number of stations retained) and the length and completeness of the records. We strived to follow WMO recommendations yet provide enough information in each of the regions selected for the VA.³²

Precipitation: among 74 initial records, only 40 stations had 52 years of data and only 30 had fewer than 20% of missing months.³³ The final selection of 30 stations is shown in Table A2 and Figure A4. For all the rainfall analyses, daily rainfall amounts related to named hurricanes, tropical depressions and tropical storms³⁴ were removed based on dates compiled from the *Ministerio de Medio Ambiente y*

³² Longest possible records – 52 years – were considered in order to establish climate characteristics in two non-overlapping, quasi 30-year periods to document long-term historical climate changes.

³³ An incomplete month was defined as having more than five days of missing record in a calendar month.

³⁴ The classification into hurricanes, tropical depressions and tropical storms is made based on wind velocity: tropical depressions have a velocity of 62 km/h or less; tropical storms have a velocity of 63-117 km/h; and a hurricane has winds over 118 km/h. Cyclone and hurricane occurrences are variable with an average rate of one every two years, but they can occur as frequently as two per year. There have been periods of inactivity of 5-10 years (*Ministerio de Medio Ambiente y Recursos Naturales*, 2011).

Recursos Naturales (Table A1) to reduce bias in the amplitude of inter-annual variability. For the extreme rainfall analysis, 16 of these 30 stations were selected.

TABLE A2: SELECTION OF STATIONS FOR RAINFALL ANALYSIS

Station Name	Latitude	Longitude	Altitude
Barahona	18.2	-71.1	10
Cabrera	19.633	-69.9	15
Constanza	18.9	-70.733	1164
Gaspar Hdez	19.617	-70.267	15
Hondo Valle	18.717	-71.683	890
Jimani	18.483	-71.85	31
La Vega	19.217	-70.533	97
Las Americas	18.433	-69.667	17
Monción	19.4	-71.15	366
Monte Cristi	19.85	-71.633	7
Nagua	19.367	-69.833	3
P Las Casas	18.733	-70.933	510
Polo	18.067	-71.283	703
Punta Cana	18.567	-68.367	122
R Arriba	18.7	-70.45	678
R San Juan	19.633	-70.067	4
S de la Mar	19.05	-69.417	3
S R Yuma	18.417	-68.667	54
Salcedo	19.367	-70.417	196
Samaná	19.2	-69.333	7
San Cristobal	18.417	-70.1	44
San Juan	18.8	-71.233	415
Sanchez	19.217	-69.6	17
Santiago	19.45	-70.7	183
Santiago R	19.467	-71.333	129
Sto Domingo	18.483	-69.917	14
V Altagracia	18.667	-70.167	156

Station Name	Latitude	Longitude	Altitude
Villa Riva	19.167	-69.9	17
Villa Vasquez	19.733	-71.433	24
Neyba	18.467	-71.417	10

Mean Temperature: A similar quality control was performed for mean temperature data considering stations with 50 years of data. Readings exceeding three standard deviations from the mean were considered incorrect and discarded. For mean temperature, only stations with less than 25 percent of incomplete months were considered.³⁵ After this control, 12 stations were selected and are shown in Table A3 and Figure A4.

TABLE A3: SELECTION OF STATIONS FOR THE MEAN TEMPERATURE ANALYSIS

Station Name	Latitude	Longitude	Altitude
Barahona	18.2	-71.1	10
Bayaguana	18.75	-69.633	61
Constanza	18.9	-70.733	1164
La Vega	19.217	-70.533	97
Las Americas	18.433	-69.667	17
Monte Cristi	19.85	-71.633	7
Polo	18.067	-71.283	703
Punta Cana	18.567	-68.367	122
Salcedo	19.367	-70.417	196
Santiago	19.45	-70.7	183
Sto Domingo	18.483	-69.917	14
S de la Mar	19.05	-69.417	3

Wind: As the analysis was aimed to link changes in wind speed and wind direction to beach erosion, only the eight stations located in or near the coast were considered and are shown in Table A4 and Figure A4. All eight stations were individually analyzed to look for potential outliers. Mean winds above 60 km/h were cross checked with the NOAA hurricane database to assure reliable readings. All measurements above 60 km/h that were not consistently shown in several stations and could not be cross-referenced to a known storm were considered as missing data. All the stations had less than 25 percent of incomplete months and at least 20 years of data.

³⁵ An incomplete month on mean temperature was defined as one with more than 10 days of missing data in a calendar month.

TABLE A4: SELECTION OF STATIONS FOR THE WIND ANALYSIS

Station Name	Latitude	Longitude	Altitude
A Herrera	18.467	69.967	61
Barahona	18.2	71.1	10
La Union	19.75	70.55	5
Las Americas	18.433	69.667	17
Punta Cana	18.567	68.367	122
S de la Mar	19.05	69.417	3
Arroyo Barril	19.217	69.45	4
Sto Domingo	18.483	69.917	14

FIGURE A4: LOCATION OF WEATHER STATIONS USED IN THE ANALYSIS

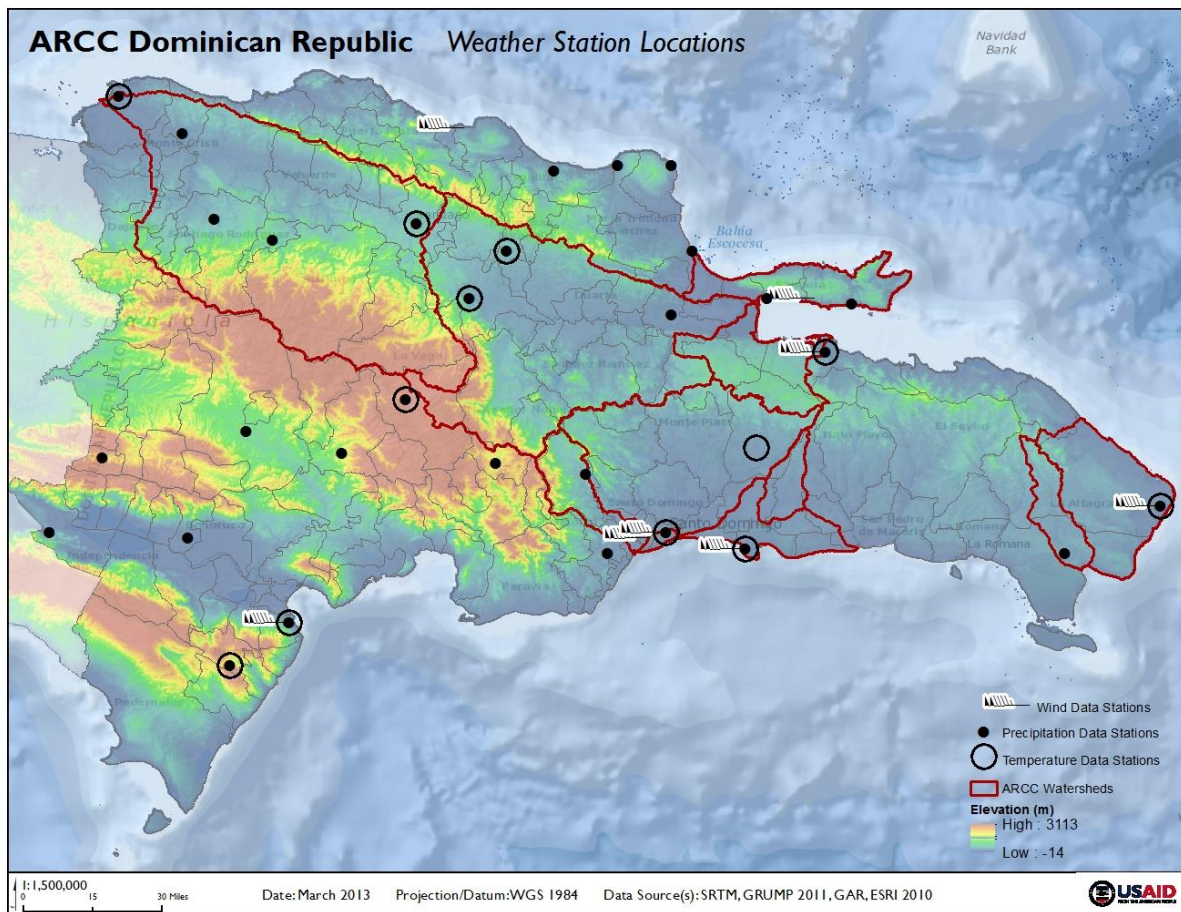


Figure A4 shows the location of the final selection of records for rainfall, mean temperature and wind, together with the delineation of the watersheds central to the study.

Historical Data Analyses

The following analyses were performed on the data selected above:

1. Monthly aggregates, seasonal cycle (rainfall, temperature):
 - a. Average and standard deviation on 1960-2012 period
 - b. Comparison between 1960-1985 and 1986-2012 average; Student t-test to assess significance of changes; Student t-test
 - c. Comparison between 1971-1995 and 1995-2012 (averages cold versus warm Tropical North Atlantic); Student t-test (rainfall only)
2. Daily rainfall:
 - a. Analysis of changes in frequency of occurrence of highest 10 percent and 5 percent daily rainfall events between 1960-1985 and 1986-2012; Mann-Whitney U test to assess significance of changes
3. Daily wind:
 - a. Analysis of changes in the frequency of occurrence of high intensity events; Student t-test
 - b. Analysis of changes in frequency of occurrence of given wind direction; Student t-test
 - c. Analysis of changes in average wind speed; Student t-test to assess the significance of changes

CLIMATE PROJECTIONS

Data

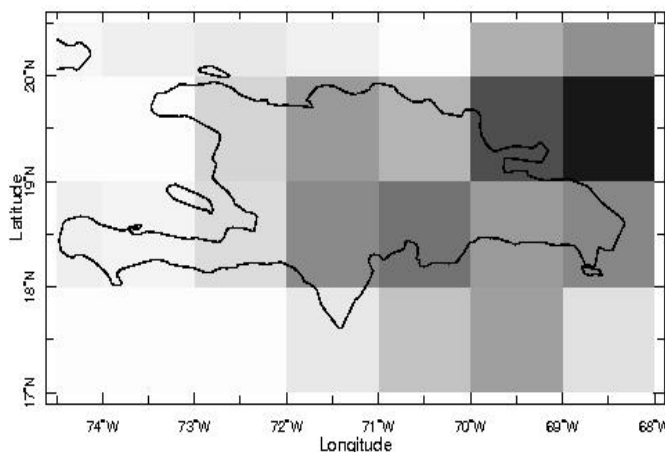
The information about projected evolution of climate is obtained using general circulation models (GCMs). GCMs are numerical representations of a number of processes that define atmospheric and oceanic state and circulation, exchanges between the surface of the Earth and the air (over ocean and land) as well as at the top of the atmosphere. The models use the information on GHG emissions to alter the composition of the atmosphere which in turn will affect energy budgets, atmospheric and oceanic behaviors, and ultimately local climate. This exercise represents a substantial scientific and computational effort as well as challenges (cf. below). To insure that best available estimates of future climate are included in this study we use the new climate projections, prepared for the next IPCC assessment and available since December 2011.³⁶ Despite constant progress in the scientific knowledge of climate and its processes, enhanced computational resources and innovative technical solutions, estimating changes in the future climates, especially at local scale, face a number of challenges:

³⁶ Note that the modeling effort goes beyond the projecting climate in response to changes in atmospheric composition; it includes, among others, the simulation of past climate as well as a number of other experiments. The full description of the archive can be found in Taylor et al., 2012.

- **Scale issues: downscaling approaches and systematic bias correction.**

Because of the need to solve thousands of equations in hundreds of thousands of locations over a period of 100+ years and constraints on current computational capacity, scientists need to prioritize the process that will be explicitly resolved in the models and those that will be approximated. They also need to make choices as to spatial resolution of the models. Currently the models that are used to project climate 100 years into the future rarely can be used with a resolution finer than $1^\circ \times 1^\circ$, a.k.a., approximately 100×100 km (an example of resolution of GCM typically used in climate projections is shown in Figure A5). Thus models are only approximate representations of the system, to the best of our current knowledge and technologies. Models may not represent well the influences of local features, such as mountains, water bodies, vegetation, etc., on atmospheric circulation. Thus models may not capture differences in climate — temperature and precipitation — between the bottom of the valley and the top of the mountain and simulate the correct values of climate variables for those locations, all important to local decisions. Therefore the outputs of GCMs need to be adjusted to local conditions, a process called ‘downscaling’ often coupled with ‘bias-correction.’ Two classes of approaches exist to derive finer spatial (and temporal) resolution information on climate based on GCM outputs: dynamical, e.g., using regional, finer resolution models that capture better local features; and statistical, that essentially adjust the GCM values to local observations. The first is physically consistent and allows simulation of events unseen in the past (such as very high rainfall events or heat waves) or inclusion of changes in land use, but is resource intensive (computational and technical) and even those outputs often need further adjustments. The second approach is not resource intensive; is easy to implement and interpret the results; and produces local outputs more compatible with decision scales. However, it relies heavily on the relationships between model outputs and historical records. Despite those drawbacks, and thanks to ease of implementation, the latter is often used in cases where local or fine scale information is needed.

FIGURE A5: TYPICAL GRID OF A GENERAL CIRCULATION MODEL



Note: A typical $2.5^\circ \times 2.5^\circ$ is overlaid over the island of Hispaniola to illustrate the challenge in the spatial scales of projections versus scales needed for national decisions.

- **Spread among models and scenarios: multi-model approach, two scenarios**

The technical challenges inherent to climate modeling and described above led different modeling groups to make different choices as to technical solutions which may lead to slightly different final results. At this stage it is impossible to select the ‘best’ model(s) as the performance of models can be evaluated based on a variety of criteria. Often models performing well at one do not perform well at another. Thus the current approach recommended by IPCC is to use all the projections provided by different groups and assess the spread among the results as a measure of uncertainty. This approach is called ‘multi-model’ approach and usually provides projected values for climatic variables in terms of an average (or median) of all the projections as well as a range of conditions projected by individual models. The current projection archive contains a large number of simulations by different modeling groups under different emission scenarios but also uses different versions of the same model. Accessing the data and further downscaling the simulations for such a large number of outputs is beyond the time limits of this assessment. Thus we have limited our focus to two scenarios (rcp 4.5 and rcp 8.5) and a selection of 10 different models developed by different

groups, with different resolutions and only one version per model. The selection includes three ‘coarse’ resolution models (resolution>2°), three ‘medium’ resolution (2°>resolution>1.5°) and four ‘high’ resolution models (resolution<1.5°) – cf. Table A5. We have considered one individual simulation for each model.

TABLE A5: MODELS USED IN THE MULTI-MODEL ASSESSMENT OF CLIMATE CHANGE IN THE DOMINICAN REPUBLIC

Model	CanE SM2	CCSM 4	CNRM -CM5	CSIRO- Mk3-6-0	GISS- E2-R	HadG EM2- ES	MIRO C-ESM	MIRO C5	MPI- ESM- LR	MRI- CGCM 3
Country of origin	Canada	USA	France	Australia	USA	UK	Japan	Japan	Germany	Japan
Institution	CCC MA	NCAR	CNRM- CERFA CS	CSIRO- QCCCE	NASA GISS	MOHC	MIROC	MIROC	MPI	MRI
Res. Lat. x Lon.	2.8° x 2.8°	0.9° x 1.25°	1.4° x 1.4°	1.87° x 1.87°	2° x 2.3°	1.25° x 1.87°	2.81° x 2.81°	1.4° x 1.4°	1.8° x 1.8°	1.125° x 1.125°

Methods

DETAIL OF THE ANALYSES OF THE PROJECTIONS

- i. Downscaling approach: statistical approach linking model outputs to observed monthly values.
Downscaling procedure: for each station and each model:
 - Average seasonal cycle computed over 30-year period (1976-2005) for in-situ and modeled rainfall and temperature, including standard deviations
 - Selection of the best matching grid point in terms of the seasonal cycle; metrics used: correlation between observed and simulated seasonal cycles
 - Two worst performing models were discarded
 - Linear regression model established between each model average seasonal cycle and each station (model-predictor, observation-predictor); similar for multi-model average
 - 30-year average seasonal cycles (rainfall and temperature) and related standard deviations computed for 2015-2045 and 2035-2065 for each grid point and model and multi-model average, to document climate around 2030 and 2050
 - Projected seasonal cycles were then rescaled using regression models established above and bias-corrected anomalies (projected value minus historical value) computed; statistical significance assessed for each model and for multi-model average using Student t-test on raw model values
 - Bias-corrected anomalies analyzed and/or added to observed values to present ‘the projected climate’

- ii. Results analyzed at country scale (for temperature) and by watershed (rainfall) in the context of current seasonal cycle

Note on the Figures

We have tried to provide synthetic figures including as much information as possible for comparison purposes. Most of the analyses done at the station level present the information in terms of monthly average values with the estimates of the spread around the average superimposed. Although representing the true data, the figures are more illustrative than providing the exact quantitative information, especially given the high uncertainty of the results of the projections. The figures presenting the long-term observed changes in rainfall or temperature show, for each station, the 26/25-year average monthly rainfall or average temperature as grey bars, the left bar reflects the earlier period, the right bar the latest. Stemming from the top of the bar are arrows whose amplitude reflects a measure of year-to-year variations within the respective periods, in terms of ± 1 standard deviation. In that way, the amplitude of changes between the long-term averages (between bars) can be directly, qualitatively compared to the amplitude of year-to-year variability in several stations. In addition, the quantitative statistical significance of the change for a given month is highlighted with the red dot on the X axis. In the case of temperature, the change between bars is comparable to the inter-annual variability (amplitude of the arrows) and, in most stations and most months, this change is statistically significant (red squares). In the case of rainfall, the amplitude of inter-annual variability is very high and can exceed 30 percent of the monthly total. The long-term change is very modest in comparison and statistically significant only in very few instances. We hope that this facilitates a quicker overview of the results and general conclusions rather than precise numbers for multiple months and stations, which are more difficult to synthesize.

A similar approach has been adopted for the representation of *projected estimates* of future rainfall and temperature. Current monthly conditions are presented as bars onto which conditions projected for the two horizons (2030 and 2050), and under two scenarios, are superimposed. All four projections are shown on the same plot with values for each horizon and scenario color-coded (lower emissions in 2030 and 2050 in blue and turquoise, respectively, and higher emissions for 2030 and 2050 in orange and yellow, respectively; significant values are marked with the red dot on the X axis). The use of the same scale as in the observations allows a direct qualitative comparison with historical long-term changes. For each scenario and horizon, multi-model average value (larger square) as well as the values projected by the eight individual models are shown (as smaller dots of the same color) to allow interpretation of the spread between models in the context of projected anomalies and current variability.

In the case of rainfall additional figures, showing the projected anomalies and allowing a more precise estimation of the anomaly range are also provided. It is easy to see that all the models simulate an increase in temperature with a modest spread between the model's results. The amplitude of the change comparable to the trend currently observed and the amplitude of inter-annual variability are significant. In the case of rainfall, the spread among models is larger than the changes projected by the multi-model average, giving little confidence in the projected values or even the sign of the changes. The multi-model change remains comparatively small to inter-annual variability, thus not all of the changes are significant.

It is important to note that this is the first analysis conducted at this scale (station level, detailing the seasonal cycle) and that some of the conclusions merit further in-depth investigation.

Figures are numbered as follows: General figures are named A1, A2, etc.; Figures related to temperature are named T1, T2, etc.; while figures related to rainfall are named R1, R2, etc. Some results are presented twice: the first time within the context of long-term averaged rainfall and temperature; and the second time as anomalies (departures from those long-term averages). The subsequent figures are labeled as BIS to highlight the different presentation of the same results.

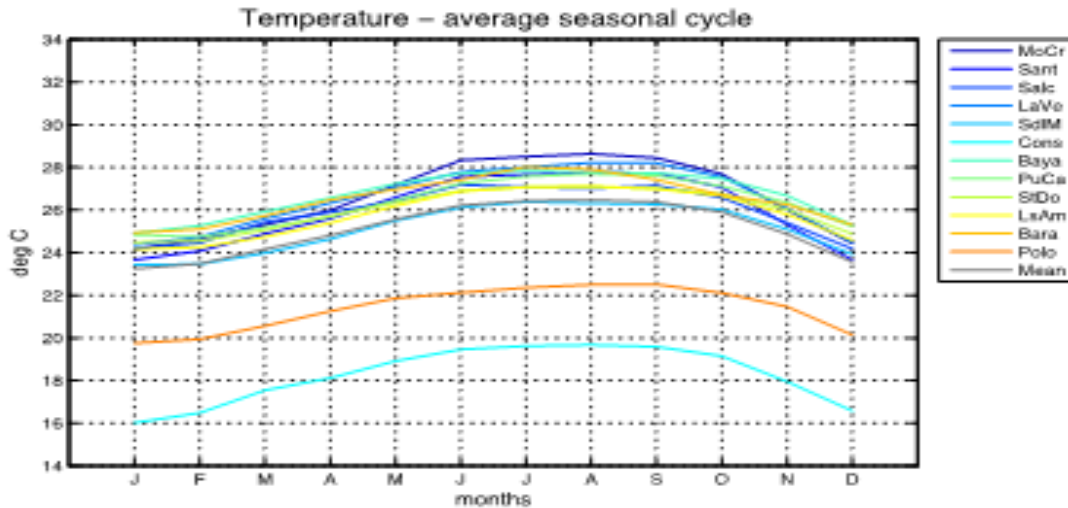
CLIMATE ANALYSIS RESULTS

Temperature

AVERAGE TEMPERATURE

Seasonal cycle

FIGURE T1: AVERAGE SEASONAL CYCLE OF TEMPERATURE IN THE 12 SELECTED STATIONS



Note: Monthly average values of mean temperature were computed over the 1960-2012 period.

All 12 stations (Figure T1) analyzed have a uniform mean temperature seasonal cycle with altitude being the main driver of differences. Stations close to sea level experience cooler mean temperatures in the winter months (23-25 °C), with an increase over the summer, reaching its peak in July-August (26-28 °C). Stations in mountain ranges with higher altitudes, like Constanza and Polo (1164 m and 703 m above sea level, respectively), experience lower average temperatures than regions closer to sea level, consistent with a decrease of 6-8 °C per 1,000 m of elevation.

VARIABILITY

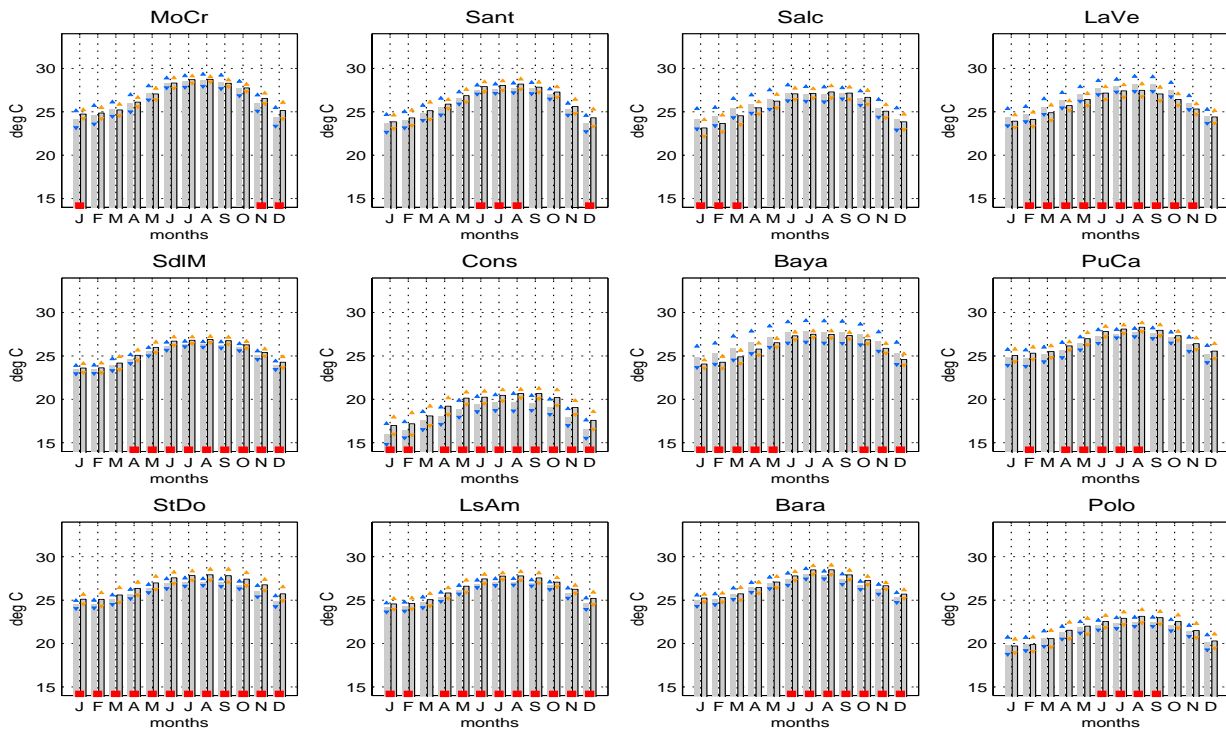
Inter-annual, Long-term Evolution

All stations analyzed in this study show an inter-annual variability (measured as one standard deviation) of around 1 °C. In order to assess long-term trends we compared the mean temperature of two time periods of each station using a standard Student t-test. The comparison between the 1960-1985 and 1986-2010 periods for all 12 stations is shown in Figure T2. Santo Domingo, Las Americas, and Constanza exhibit a statistically significant warming in at least 11 months of the year. Six stations (Monte Cristi, Santiago, S de la Mar, Punta Cana, Barahona, and Polo) show a statistically significant warming in some months of the year with no consistent pattern among stations.

The remaining three stations (Bayaguana, La Vega, and Salcedo) show statistically significant cooling in several months of the year. Further research on the history of events related to these stations is needed to understand the reasons behind these changes. Considering the warming trend in the majority of the

stations and in the projections, this cooling might be associated with a change in instruments or location of the stations, which were not known to this study.

FIGURE T2: DIFFERENCES IN THE SEASONAL CYCLE OF TEMPERATURE BETWEEN 1960-1985 AND 1986-2012 FOR SELECTED STATIONS



Note: Grey bars and grey bars with borders show the average monthly temperature for 1960-1985 and 1986-2012 period respectively, and the arrows indicate the amplitude of ± 1 standard deviation. Red squares denote months where changes are statistically significant at $p=0.05$.

PROJECTIONS

Downscaled projections at the station level are shown as absolute changes (Figure T3) and anomalies (Figure T3BIS). Both figures show projections of individual models and multi-model means under the selected emission scenarios. The projected anomalies are statistically significant and show that all stations are expected to have higher temperatures in the upcoming decades. Models project an increase in mean temperature between 0.5-1.0 °C by 2030 and between 1-2.5 °C by 2050. This increase appears to be larger in the northern stations than in the southern stations. However, this could be an artifact of the downscaling technique.

FIGURE T3: AVERAGE SEASONAL CYCLE OF TEMPERATURE OBSERVED IN SELECTED STATIONS OVER 1976-2005 AND PROJECTED FOR 2030 AND 2050 UNDER RCP4.5 AND RCP 8.5 SCENARIOS

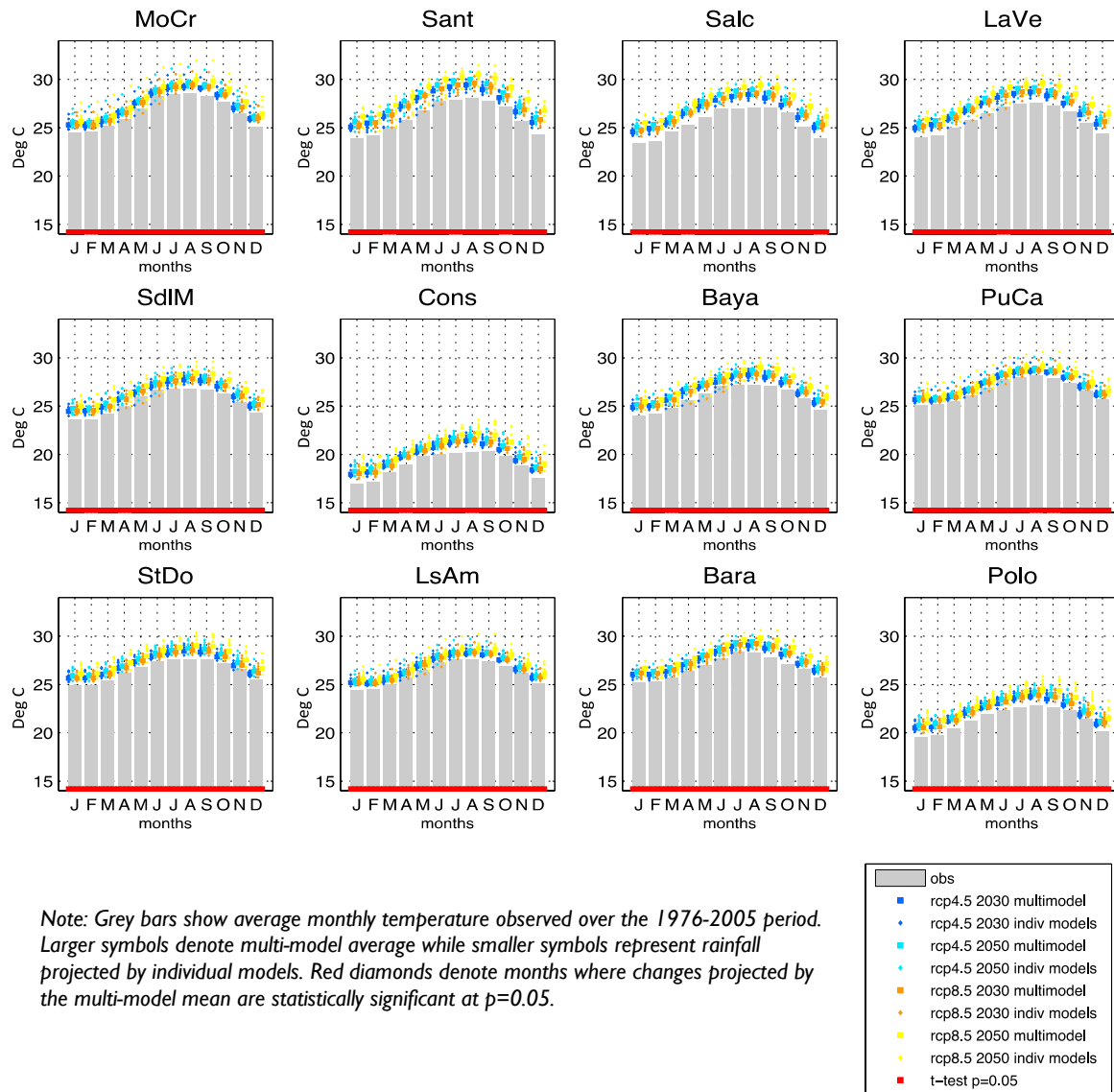
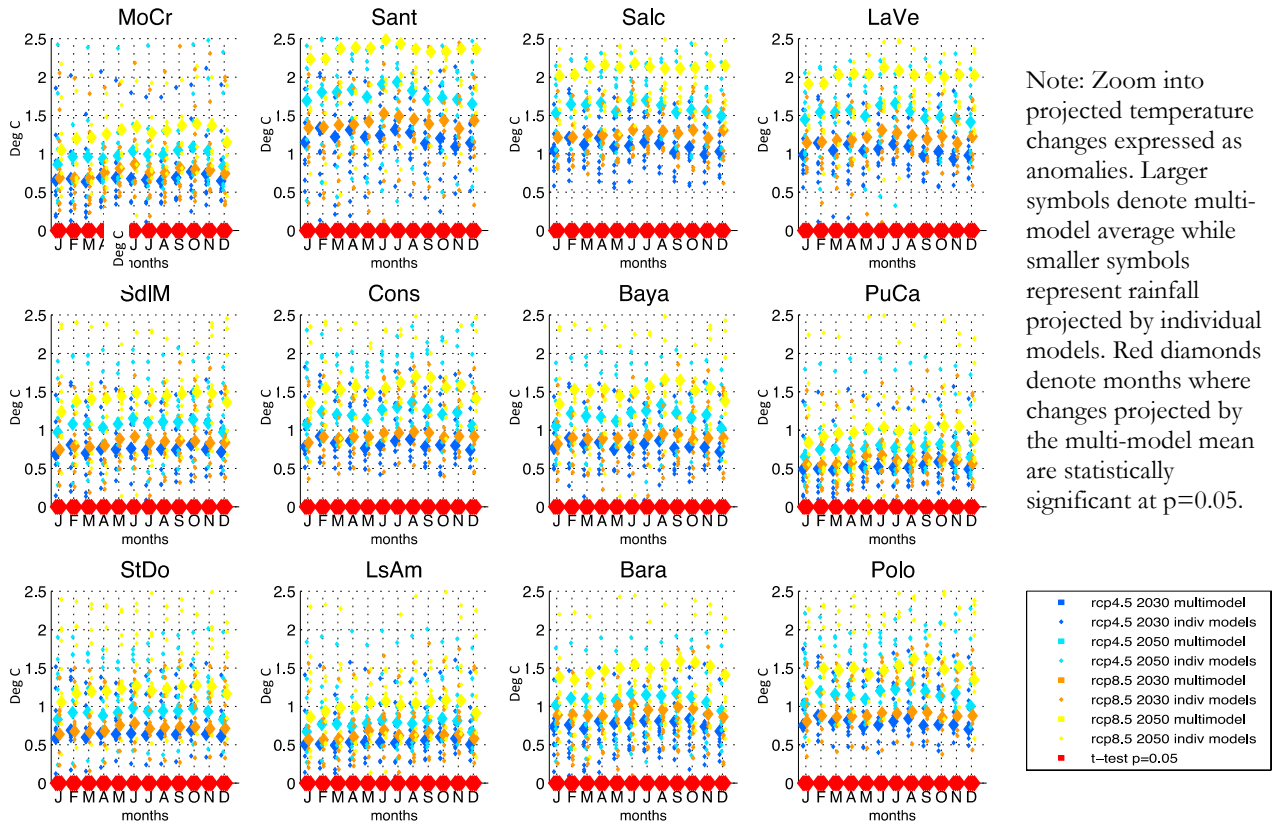


FIGURE T3BIS: PROJECTED MONTHLY TEMPERATURE ANOMALIES (MODELS ONLY)



Note: Zoom into projected temperature changes expressed as anomalies. Larger symbols denote multi-model average while smaller symbols represent rainfall projected by individual models. Red diamonds denote months where changes projected by the multi-model mean are statistically significant at $p=0.05$.

RAINFALL

As mentioned in the data section above, this study used data from 30 stations distributed throughout the Dominican Republic. Rainfall events associated with tropical storms and hurricanes were removed to reduce bias in the inter-annual variability.

Results below are shown in the context of the four areas of study areas: Punta Cana/Bávaro; Yaque del Norte [Montecristi/Santiago]; Bajo Yuna [Samaná Bay and Peninsula]; and Santo Domingo. For all areas, the following analyses were performed: assessment of seasonal cycle and variability of rainfall in the watershed. This was conducted in two phases; the first one to analyze long-term trends (two 25-year periods), and the second to analyze decadal variability associated with the shifts in SST of the Tropical Atlantic Ocean, with the “warm” phase covering the period 1995-2012 and the “cold” phase 1971-1995.

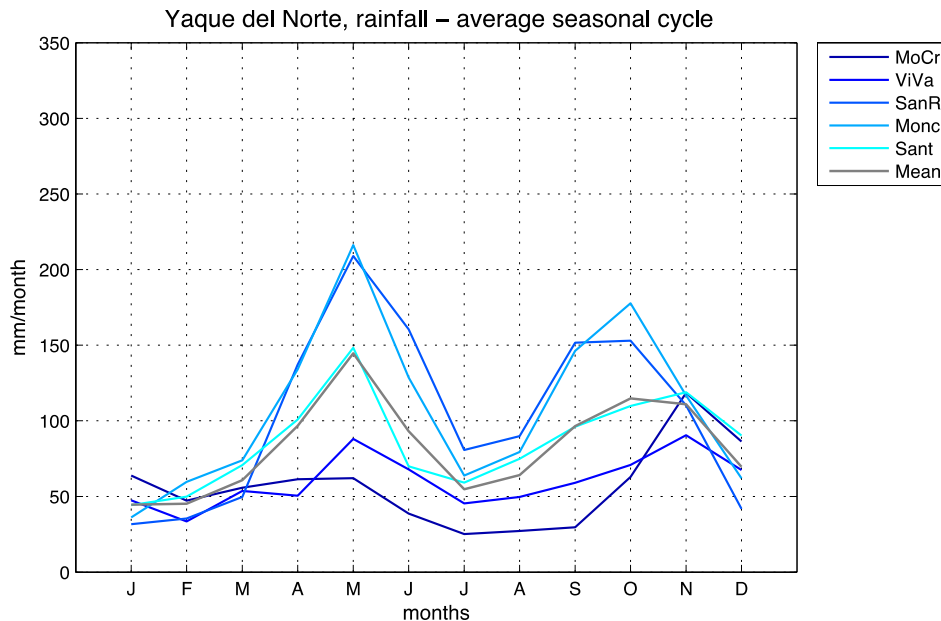
YAQUE DEL NORTE

The six stations used in this study are within the boundaries of this watershed: Montecristi (MoCr), Villa Vazquez (ViVa), Santiago R (SanR), Monción (Monc), and Santiago (Sant).

Average Rainfall

SEASONAL CYCLE

FIGURE R1: AVERAGE SEASONAL CYCLE OF RAINFALL IN STATIONS LOCATED IN YAQUE DEL NORTE WATERSHED. MONTHLY AVERAGE VALUES COMPUTED OVER 1960-2012 PERIOD



Note: Zoom into projected temperature changes expressed as anomalies. Larger symbols denote multi-model average while smaller symbols represent rainfall projected by individual models. Red diamonds denote months where changes projected by the multi-model mean are statistically significant at $p=0.05$.

Figure R1 shows the average rainfall for the six stations in the watershed. To some degree, all stations show a bimodal seasonal cycle with dry winter (December to March) and dry summer (July-August). Montecristi and Villa Vasquez, in the lower part of the watershed are among the driest in the Dominican Republic and even in the peak of the season, rainfall barely reaches 100 mm/month. Santiago R, Monción, and Santiago, higher up on the watershed, show higher precipitation during the peak rainy seasons, reaching 200 mm/month, with the first season (April to June) a little stronger than the second.

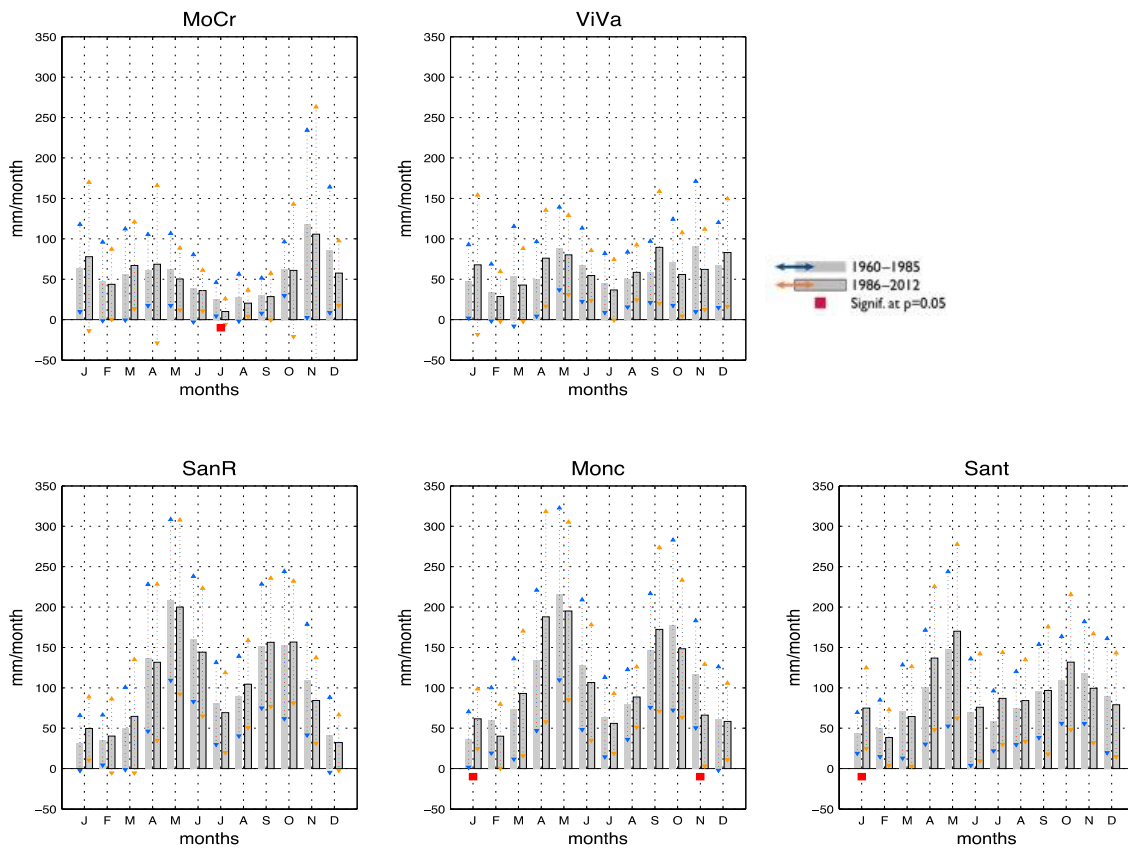
Variability

INTER-ANNUAL, LONG-TERM AND DECADAL

Figure R2 summarizes inter-annual variability and long-term evolution of rainfall in the five stations in the northwestern section of the Yaque del Norte watershed (Montecristi to Santiago). First, note very high inter-annual variability as measured by the standard variation of monthly values in each of the periods and depicted by arrows, even after the removal of the most intense events related to tropical cyclones. This very high inter-annual variability makes the detection of statistically significant trends very challenging. In fact, only in very few instances (individual months in individual stations) does rainfall appear to have significantly changed (red squares). The change is not consistent among all the stations even if decreased in October-November (second rainy season), increased in January and, with the exception of Santiago, decreased in April-May (first rainy season) and June-July (summer dry season). (Figure R2BIS)

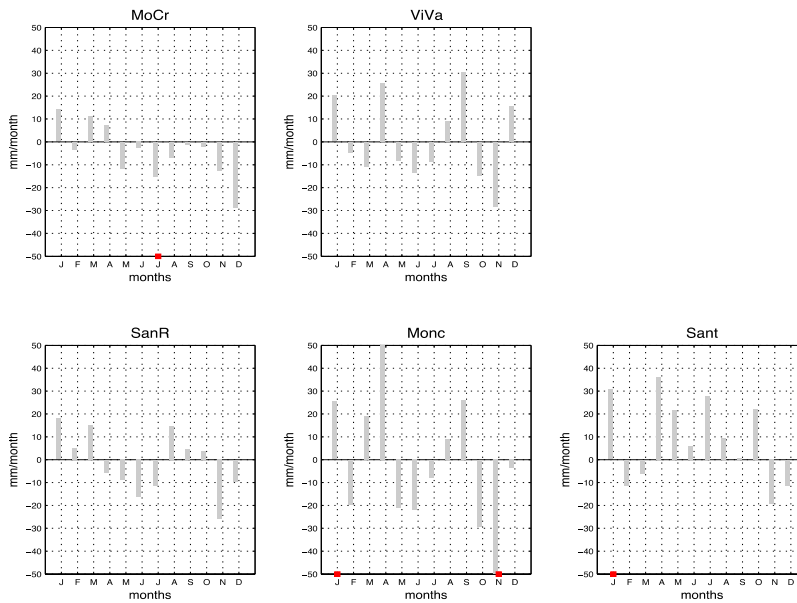
Figure R2 shows changes in rainfall in Yaque del Norte watershed related to the decadal variability in the Tropical North Atlantic. The period 1971-1995 experienced colder SSTs in the Tropical North Atlantic and a decrease in hurricane activity. While the periods 1960-69 and 1996-2012 experienced warmer SSTs in the Tropical North Atlantic and an increase in hurricane activity. During the more recent, warmer period, rainfall has increased in nearly all stations (with the exception of Monción in April-May-June). The amplitude of this decadal variability is similar, if not higher, than that of the longer-term trend and of opposite signs (Figure R3BIS).

FIGURE R2: DIFFERENCES IN SEASONAL CYCLE OF RAINFALL BETWEEN 1986-2012 AND 1960-1985 FOR STATIONS IN YAQUE DEL NORTE WATERSHED



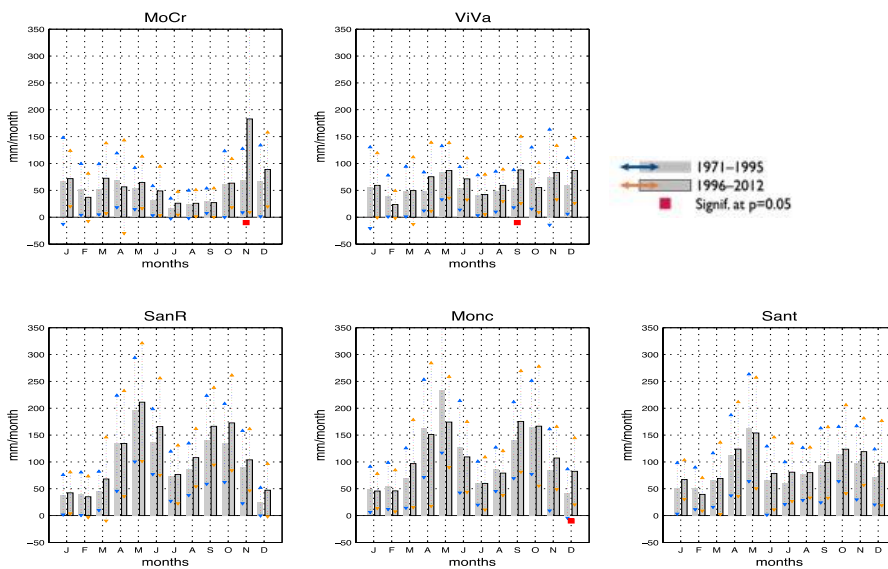
Note: Grey bars and grey bars with borders show the average monthly rainfall for 1960-1985 and 1986-2012 periods respectively and the arrows represent the amplitude of 1 standard deviation. Red squares denote months where changes are statistically significant at $p=0.05$.

FIGURE R2BIS: DIFFERENCES IN AVERAGE MONTHLY RAINFALL BETWEEN 1986-2012 AND 1960-1985 IN YAQUE DEL NORTE WATERSHED (SHOWN AS ANOMOLIES)



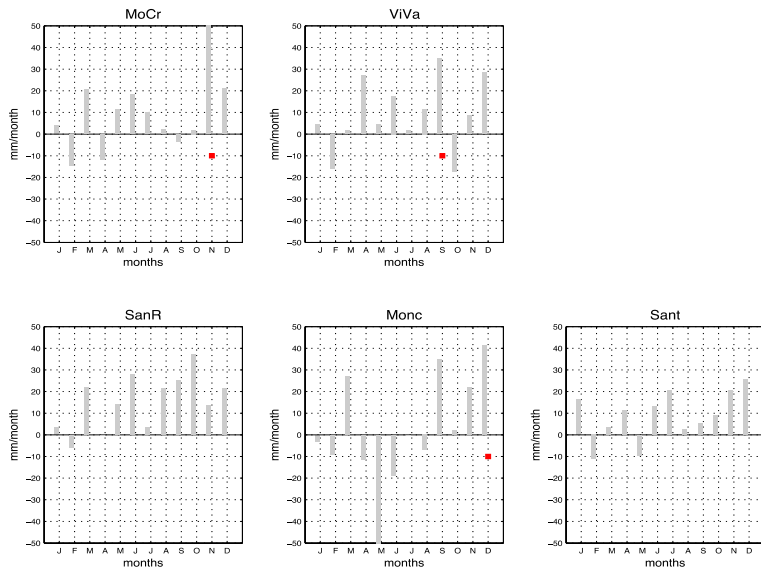
Note: Grey bars show the difference between average monthly rainfall observed in 1986-2012 and 1960-1985 (1986-2012 minus 1960-1985) and the red dot highlights the months where the difference is statistically significant at $p=0.05$.

FIGURE R3: SAME AS FIGURE R2 EXCEPT FOR DIFFERENCES IN SEASONAL CYCLE OF RAINFALL BETWEEN 1996-2012 AND 1971-1995 PERIODS



Note: This figure shows the average monthly rainfall during 1971-1995 (colder Atlantic - grey bars and blue arrows) and 1996-2012 (warmer Atlantic - grey bars with borders and orange arrows) to document potential impact of sea surface temperatures in the tropical Atlantic on rainfall. Red squares denote months where changes are statistically significant at $p=0.05$.

FIGURE R3BIS: DIFFERENCES IN AVERAGE MONTHLY RAINFALL BETWEEN 1996-2012 AND 1971-1995 PERIODS (SHOWN AS ANOMALIES)

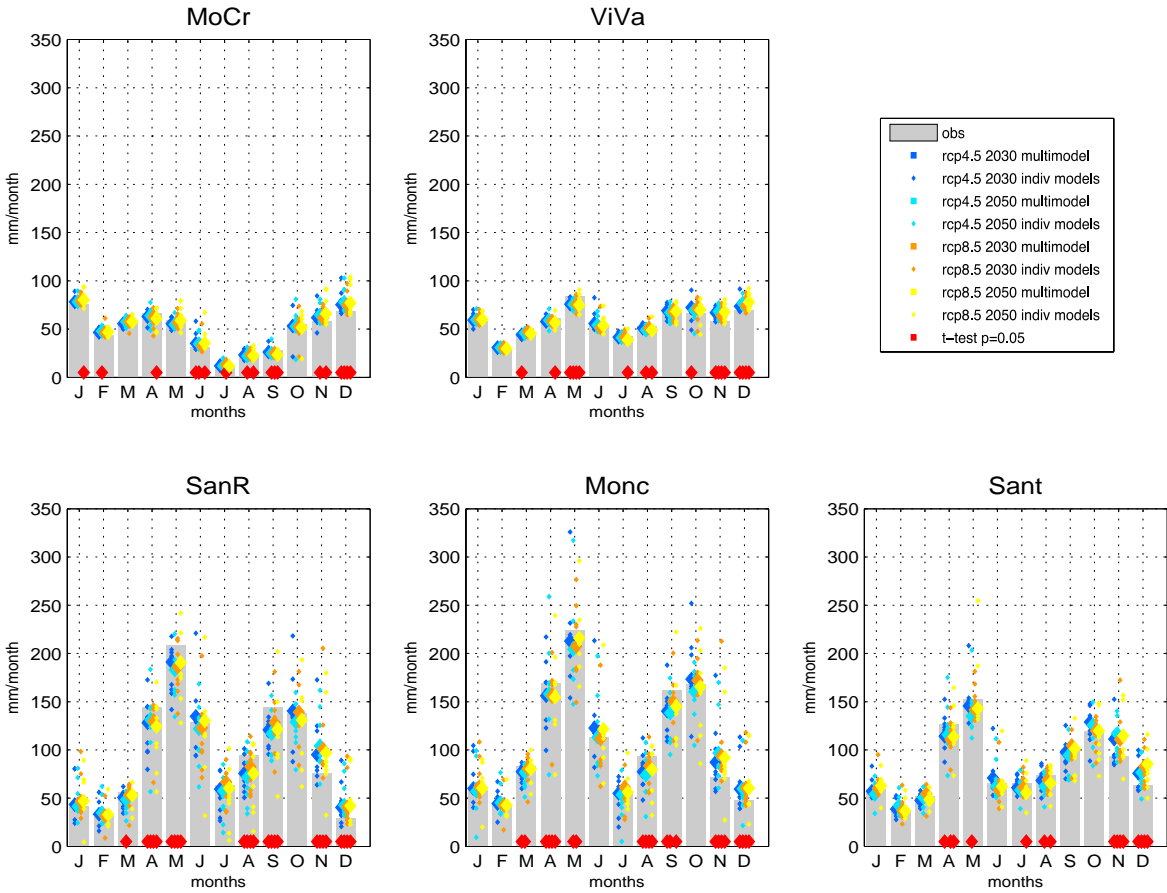


Note: Grey bars show the difference between average monthly rainfall observed in 1971-1995 (tropical North Atlantic colder) and 1996-2012 (tropical North Atlantic warmer), or 1971-1995 minus 1996-2012; the red squares highlights the months where the difference is statistically significant at $p=0.05$.

Projections

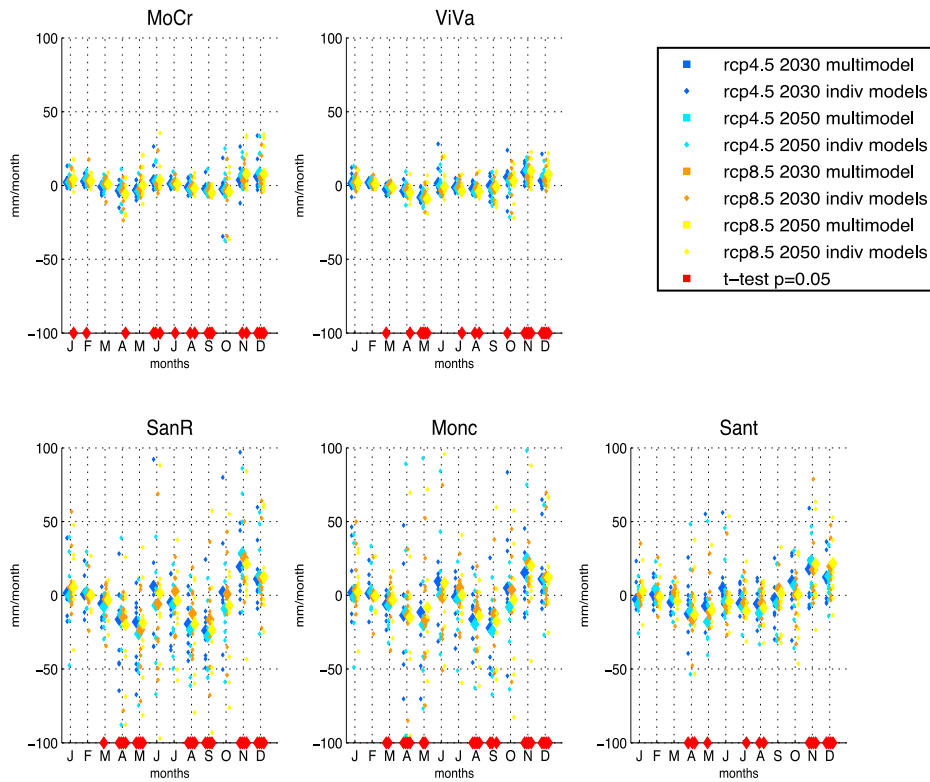
Figures R4 and R4BIS show projected levels of rainfall for 2030 and 2050 climates under RCP4.5 and RCP8.5 emissions scenarios. While the spread between the models is high, multi-model mean shows significant (albeit small) decrease in rainfall in April-May and August-September (rainy seasons) of the order of 10-20 mm/month, and a significant increase in rainfall of about the same monthly amount in November-December, traditionally the drier season. The anomalies are in line with observed long-term and decadal variability. The decrease in rainfall in April-May is consistent with the observed long-term trend, but the increase in November-December points to the role of warmer Tropical North Atlantic. Further studies are necessary to document the mechanisms leading to projected changes in rainfall in the Yaque del Norte watershed.

FIGURE R4: AVERAGE SEASONAL CYCLE OF RAINFALL OBSERVED IN STATIONS IN YAQUE DEL NORTE WATERSHED OVER 1976-2005 AND PROJECTED MONTHLY RAINFALL FOR 2030 AND 2050 UNDER RCP4.5 AND RCP8.5 SCENARIOS



Note: Grey bars show average monthly rainfall observed over the 1976-2005 period. Larger symbols denote multi-model average while smaller symbols represent rainfall projected by individual models. Red diamonds denote months where changes projected by the multi-model mean are statistically significant at $p=0.05$.

FIGURE R4BIS: SAME AS FIGURE R4 BUT SHOWN AS ANOMALIES (MODELS ONLY)



Note: Zoom into projected rainfall changes expressed as anomalies. Larger symbols denote multi-model average while smaller symbols represent rainfall projected by individual models. Red diamonds denote months where changes projected by the multi-model mean are statistically significant at $p=0.05$.

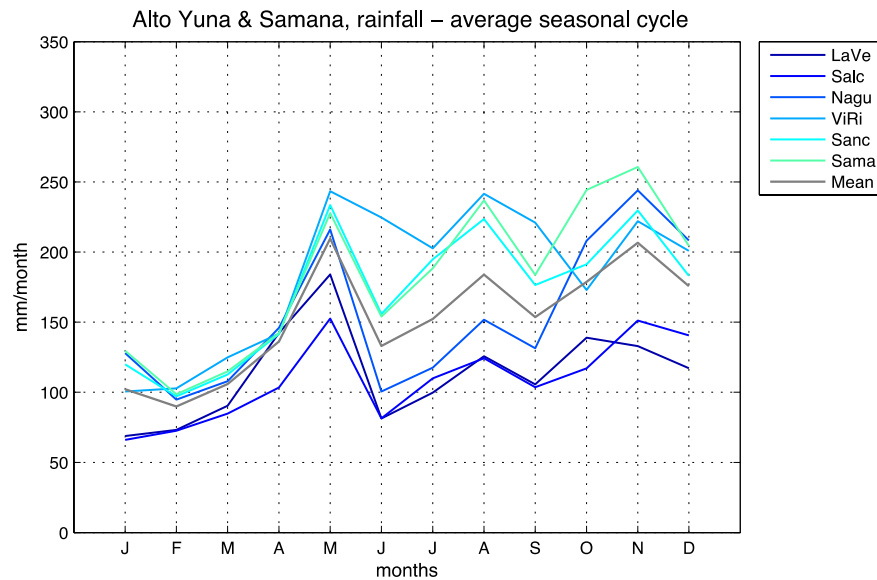
SAMANÁ BAY AND PENINSULA (BAJO YUNA)

Six stations used on this study are within or close of this area of study: La Vega (LaVe), Salcedo (Salc), Nagua (Nagu), Villa Riva (ViRi), Sanchez (Sanc), and Samaná (Sama).

Average Rainfall

SEASONAL CYCLE

FIGURE R5: AVERAGE SEASONAL CYCLE OF RAINFALL IN STATIONS LOCATED IN SAMANÁ AND BAJO YUNA WATERSHEDS



Note: Monthly average values computed over the 1960-2012 period.

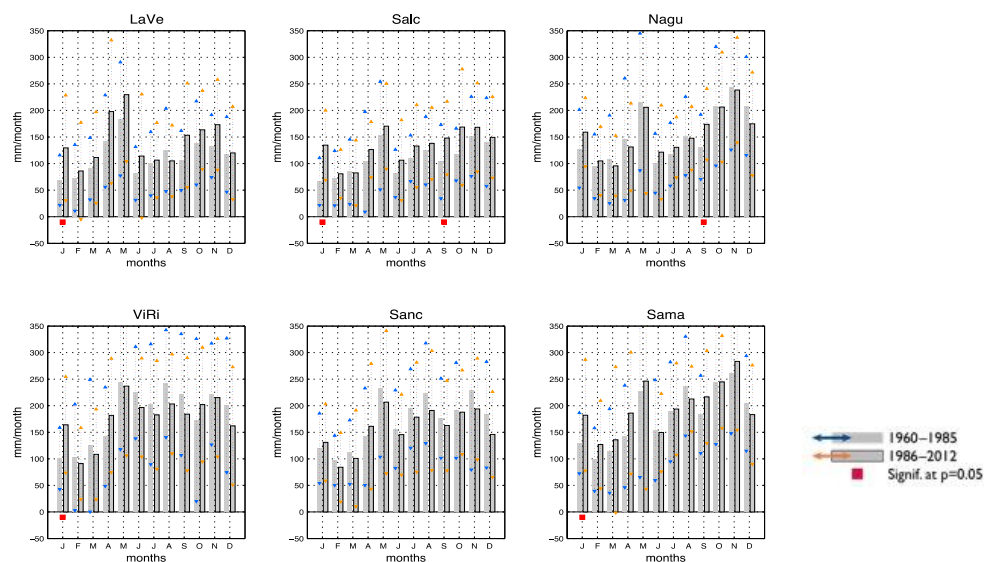
This area of study encompasses two watersheds that belong to a region with significantly higher rainfall and a slightly different seasonal cycle than Yaque del Norte. Figure R5 shows the average rainfall for the six stations in the area. This region also experiences peak rainfall in April-May and October-November seasons, with a third rainy peak in August when rainfall can reach the same levels as in the peak months. The region also experiences drier periods in June-July and September on average. Thus, there is no prolonged dry season in summer like the one in winter (January-March). Stations on or close to the Eastern coast (Villa Riva, Sanchez and Samaná) experience more rainfall than the stations higher up in the Alto Yuna watershed (La Vega, Salcedo) or on the Northern coast (Nagua).

Variability

INTER-ANNUAL, LONG-TERM AND DECADAL

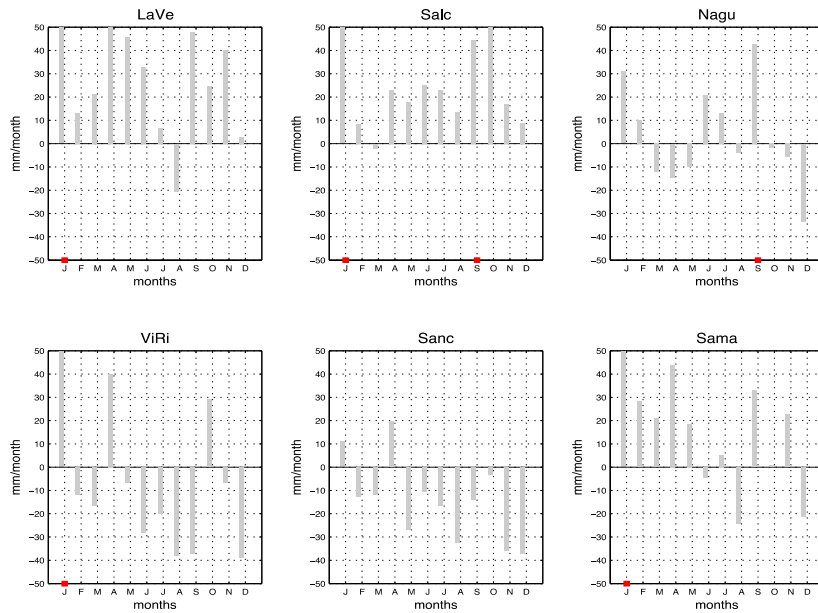
Figure R6 and R6BIS summarize inter-annual variability and long-term evolution of rainfall in the six stations in the Samaná/Alto Yuna area. First note that as in Yaque del Norte, there is very high inter-annual variability as measured by the standard variation of monthly values in each of the periods and depicted by arrows, even after the removal of the most intense events related to tropical cyclones. This very high inter-annual variability makes the detection of statistically significant trends difficult, with most changes not statistically significant. The main pattern emerging is that of a consistent increase in precipitations in the Upper Alto Yuna. The pattern in La Vega and Salcedo is stronger and more consistent than in Santiago which is in the Yaque del Norte watershed suggesting that similar phenomenon might be at play. Further to the East, Villa Riva and Sanchez experienced a decrease in precipitation, especially during the latter part of the year. Samaná shows a very distinct pattern that might be related to its location, furthest east on the coast of the peninsula (on slopes of the mountains to the north) and potentially benefitting from changes in wind direction. Figure R7 and R7BIS show the changes associated with decadal variability in the region. Samaná, Sanchez, Salcedo and LaVega seem to have experienced more or less a consistent increase in precipitation in the middle part of the year when the Tropical North Atlantic became warmer. The upper Alto Yuna stations show some sign of an increase also toward the end of the year, similar to that in Yaque del Norte, while the peninsula stations experienced a decrease. Villa Riva and Nagua, both at low altitude and not surrounded by significant slopes show a very different pattern of a decrease throughout the year. The amplitude of the main decadal changes is somewhat stronger than the long-term evolution.

FIGURE R6: DIFFERENCES IN SEASONAL CYCLE OF RAINFALL BETWEEN 1986-2012 AND 1960-1985 FOR STATIONS IN SAMANÁ AND ALTO YUNA WATERSHEDS



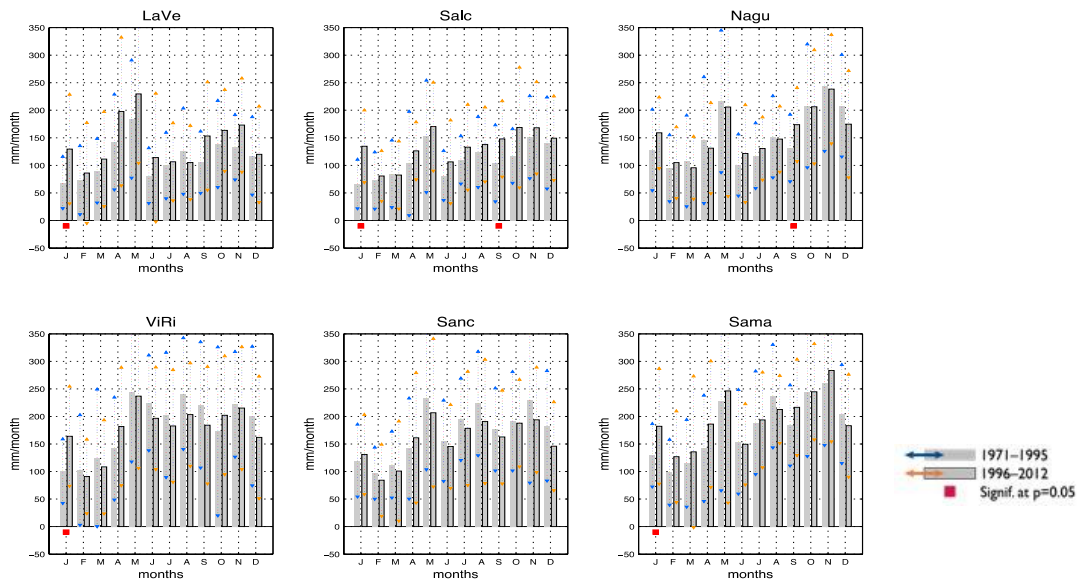
Note: Grey bars and grey bars with borders show the average monthly rainfall for 1960-1985 and 1986-2012 periods respectively and the arrows (blue and orange) show the amplitude of ± 1 standard deviation. Red squares denote months where changes are statistically significant at $p=0.05$.

FIGURE R6BIS: DIFFERENCES IN AVERAGE MONTHLY RAINFALL BETWEEN 1986-2012 AND 1960-1985 PERIODS SHOWN AS ANOMALIES



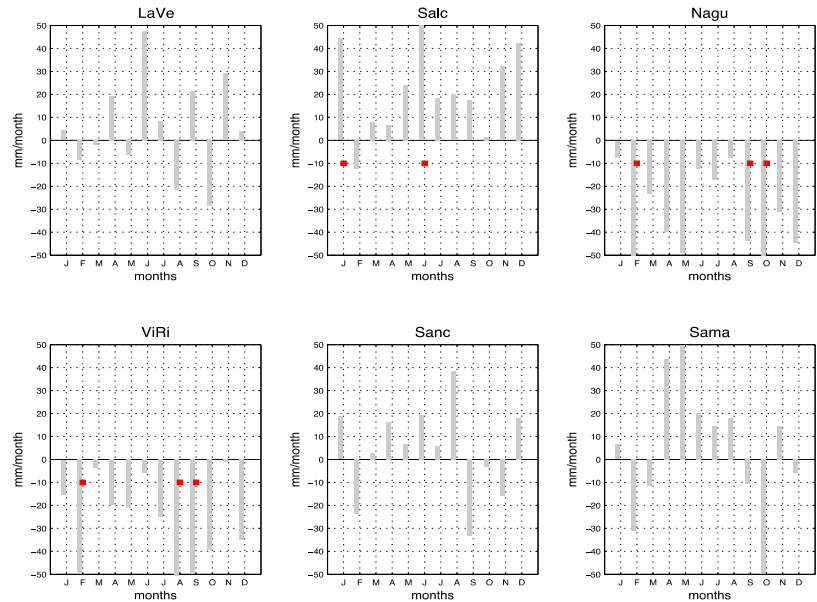
Note: Grey bars show the difference between average monthly rainfall observed in 1986-2012 and 1960-1985 periods and the red squares highlight the months where the difference is statistically significant at $p=0.05$.

FIGURE R7: DIFFERENCES IN SEASONAL CYCLE OF RAINFALL BETWEEN 1996-2012 AND 1971-1995 PERIODS



Note: This figure shows the average monthly rainfall during 1971-1995 (colder Atlantic - grey bars and blue arrows) and 1996-2012 (warmer Atlantic - grey bars with border and orange arrows) to document potential impact of sea surface temperatures in the tropical Atlantic on rainfall. Red squares denote months where changes are statistically significant at $p=0.05$.

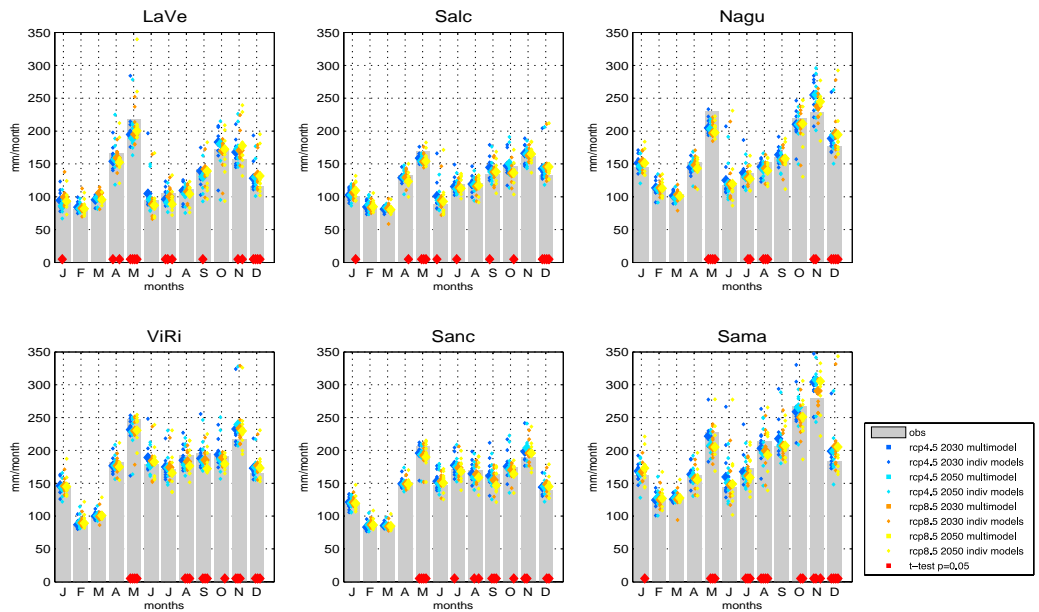
FIGURE R7BIS: DIFFERENCES IN AVERAGE MONTHLY RAINFALL BETWEEN 1996-2012 AND 1971-1995 PERIODS (SHOWN AS ANOMALIES)



Note: Grey bars show the difference between average monthly rainfall observed in 1996-2012 and 1971-1995 periods. The red squares highlight the months where the difference is statistically significant at $p=0.05$.

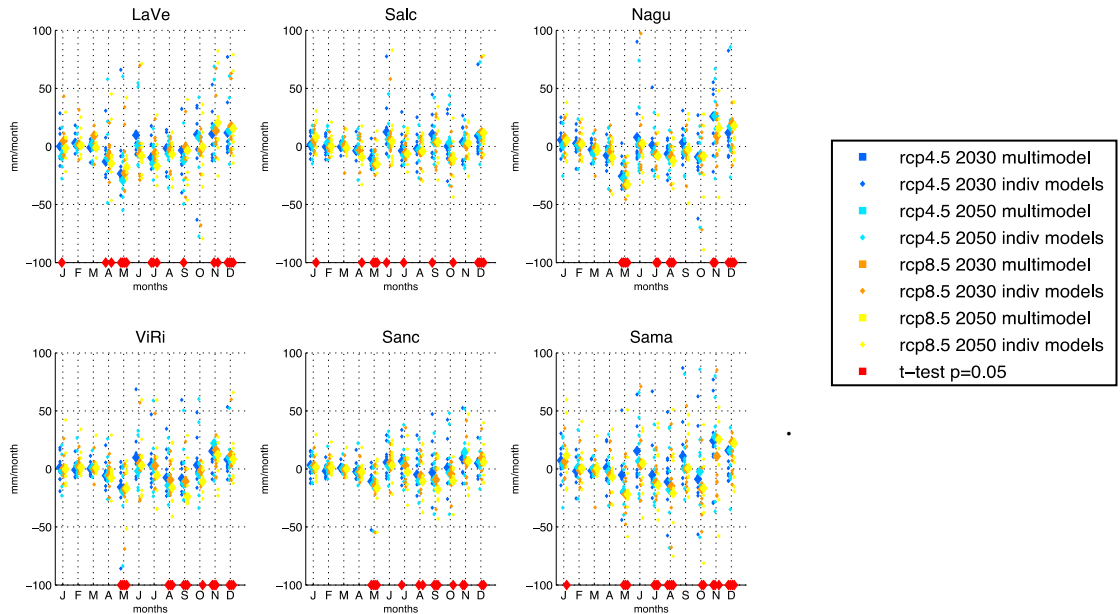
Projections

FIGURE R8: AVERAGE SEASONAL CYCLE OF RAINFALL OBSERVED AND PROJECTED FOR STATIONS IN SAMANÁ AND ALTO YUNA WATERSHED



Note: Grey bars show average monthly rainfall observed over the 1976-2005 period. Larger symbols denote multi-model average while smaller symbols represent rainfall projected by individual models. Red diamonds denote months where changes projected by the multi-model mean are statistically significant at $p=0.05$.

FIGURE R8BIS: SAME AS FIGURE R8 BUT SHOWN AS ANOMALIES (MODEL ONLY)



Note: Zoom into projected rainfall changes expressed as anomalies. Larger symbols denote multi-model average while smaller symbols represent rainfall projected by individual models. Red diamonds denote months where changes projected by the multi-model mean are statistically significant at $p=0.05$.

Figures R8 and R8BIS show projected levels of rainfall for 2030 and 2050 climates under RCP4.5 and RCP8.5 emissions scenarios. While the spread between the models is high, the most consistent and robust projected signal is a decrease in rainfall during the peak seasons, mostly in May then August-September and an increase in rainfall at the end of the year in November-December. This is similar to the Yaque del Norte signal which points to similar dynamics of rainfall changes. As mentioned in the Yaque del Norte section further studies are necessary to understand the mechanisms behind this dynamics.

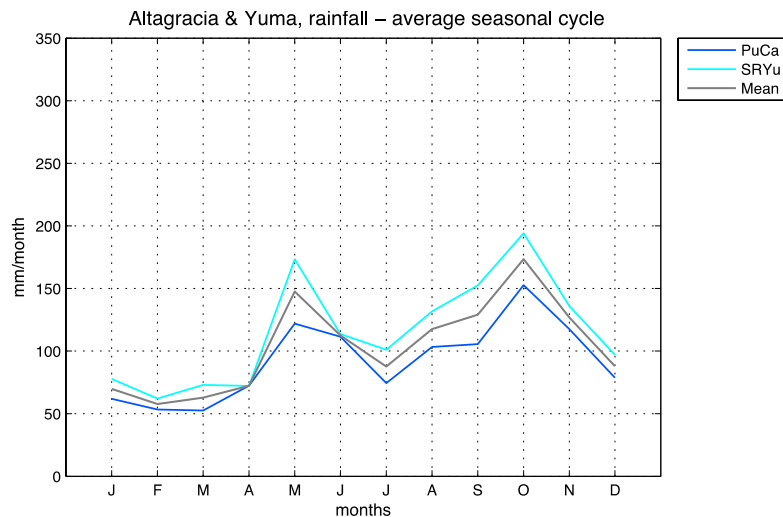
PUNTA CANA AND BÁVARO

Located in the Eastern portion of the country, this is the region with the fewest stations of this analysis. The ONAMET network only has two stations that fulfill the quality control criteria with Punta Cana (PuCa) and San R Yuma (SRYu).

Average Rainfall

SEASONAL CYCLE

FIGURE R9: AVERAGE SEASONAL CYCLE OF RAINFALL IN STATIONS LOCATED IN ALTAGRACIA AND YUMA WATERSHEDS



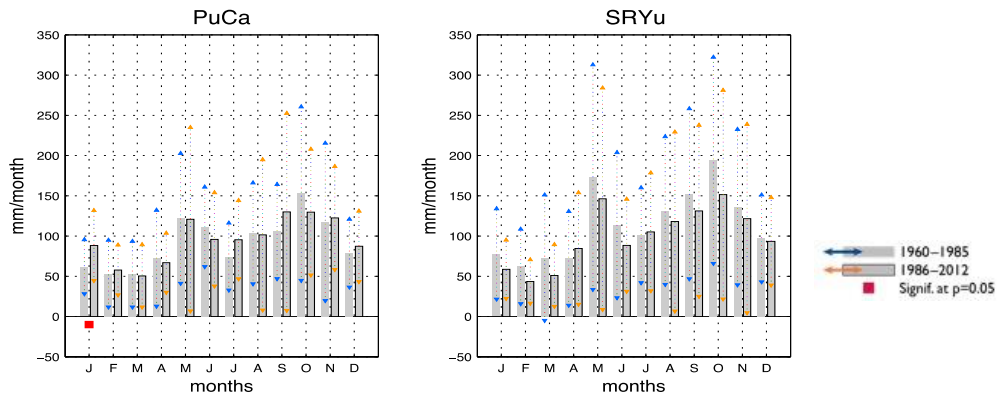
The two stations in this region share a bimodal seasonal cycle with peaks in April-May and September-October (Figure R9). The September-October peak has larger amplitude in both stations, making these two months the rainiest in the region. A dry summer is characteristic of the region similar to the one in Yaque del Norte Stations; it is still, however, wetter than the extended dry season covering December to March.

Variability

INTER-ANNUAL, LONG-TERM AND DECADAL

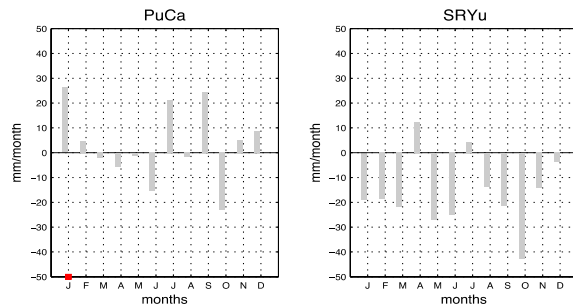
As for the other watersheds the amplitude of the inter-annual variability overrides the potential long-term changes. The only significant change shown in figure R10 and R10BIS is the rainfall increase in January for Punta Cana, also present in some of the Samaná/Alto Yuna stations. SR Yuma shows a consistent, albeit not significant, decrease in rainfall during nearly all months, similar to that of Sanchez and Villa Riva. Both stations although located relatively close to one another experience very different variability patterns pointing to the importance of orography and location of the station relative to the prevailing winds.

FIGURE R10: DIFFERENCES IN SEASONAL CYCLE OF RAINFALL BETWEEN 1986-2012 AND 1960-1985 FOR STATIONS IN ALTAGRACIA AND YUMA WATERSHEDS



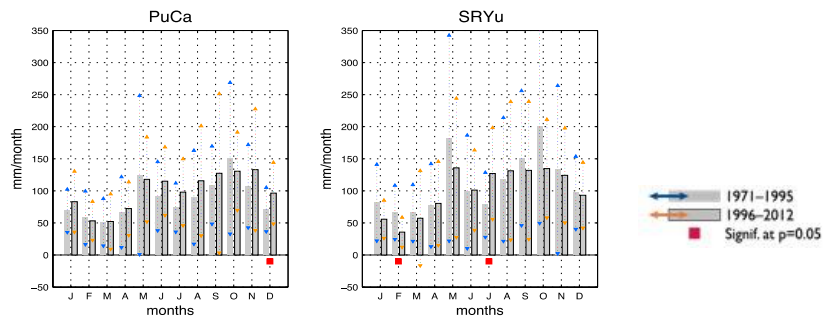
Note: Grey bars and grey bars with borders show the average monthly rainfall for 1960-1985 and 1986-2012 periods, respectively. The arrows show the amplitude of ± 1 standard deviation. Red squares denote months where changes are statistically significant at $p=0.05$

FIGURE R10BIS: DIFFERENCES IN AVERAGE MONTHLY RAINFALL BETWEEN 1986-2012 AND 1960-1985 SHOWN AS ANOMALIES



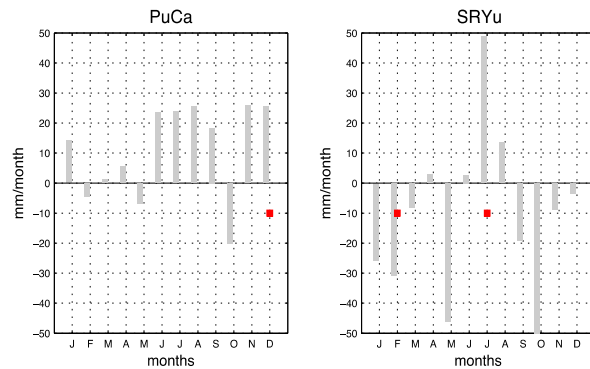
Note: Grey bars show the difference between average monthly rainfall observed in 1986-2012 and 1960-1985 periods. The red squares highlight the months where the difference is statistically significant at $p=0.05$.

FIGURE R11: SAME AS FIGURE R10, BUT FOR DIFFERENCES IN SEASONAL CYCLE OF RAINFALL BETWEEN 1996-2012 AND 1971-1995 PERIODS TO DOCUMENT POTENTIAL INFLUENCE OF THE ATLANTIC OCEAN ON RAINFALL



Note: Grey bars and grey bars with borders show the average monthly rainfall for 1971-1995 (colder tropical North Atlantic) and 1996-2012 (warmer tropical North Atlantic); the arrows show the amplitude of ± 1 standard deviation. Red squares denote months where changes are statistically significant at $p=0.05$

FIGURE R1 IBIS: SAME AS FIGURE R1 I BUT SHOWN AS ANOMALIES



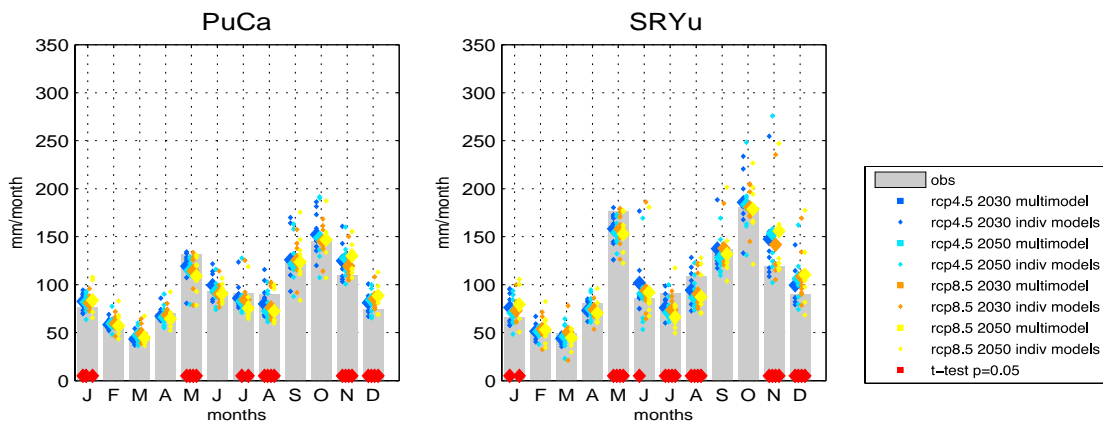
Note: Grey bars show the difference between average monthly rainfall observed in the periods 1996-2012 and 1971-1995. The red squares highlight the months where the difference is statistically significant at $p=0.05$.

Decadal variability analysis shows no relation between the two stations, although seasonal cycles are close (Figures R1 I and R1 IBIS). This decadal analysis shows an increase in the later part of the year in Punta Cana Station while S R Yuma mostly shows a decrease in fall/winter/spring season, when the Tropical North Atlantic is warmer.

Projections

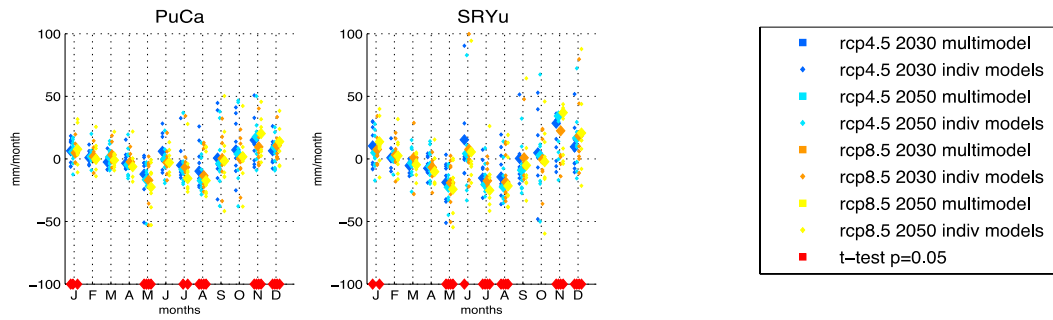
Under both emission scenarios (figures R12 and R12BIS) both stations show a strong and consistent increase in precipitations in November-December and January for 2030 and 2050. Models project a decrease in May-June and August in both stations. These projections point to a reduction of seasonal contrast with a decreased precipitation during the rainy season and increased precipitation during the dry season in the area.

FIGURE R12: AVERAGE SEASONAL CYCLE OF RAINFALL OBSERVED AND PROJECTED IN STATIONS IN ALTAGRACIA AND YUMA WATERSHED UNDER RCP4.5 AND RCP 8.5 SC



Note: Grey bars show average monthly rainfall observed over the 1975-2005 period. Symbols show projected values and larger symbols denote multi-model average while smaller symbols represent rainfall projected by individual models. Red diamonds denote months where changes projected by the multi-model mean are statistically significant at $p=0.05$.

FIGURE R12BIS: SAME AS FIGURE R12, BUT SHOWN AS ANOMALIES, MODEL ONLY



Note: Zoom into projected rainfall changes expressed as anomalies. Larger symbols denote multi-model average while smaller symbols represent rainfall projected by individual models. Red diamonds denote months where changes projected by the multi-model mean are statistically significant at $p=0.05$.

SANTO DOMINGO

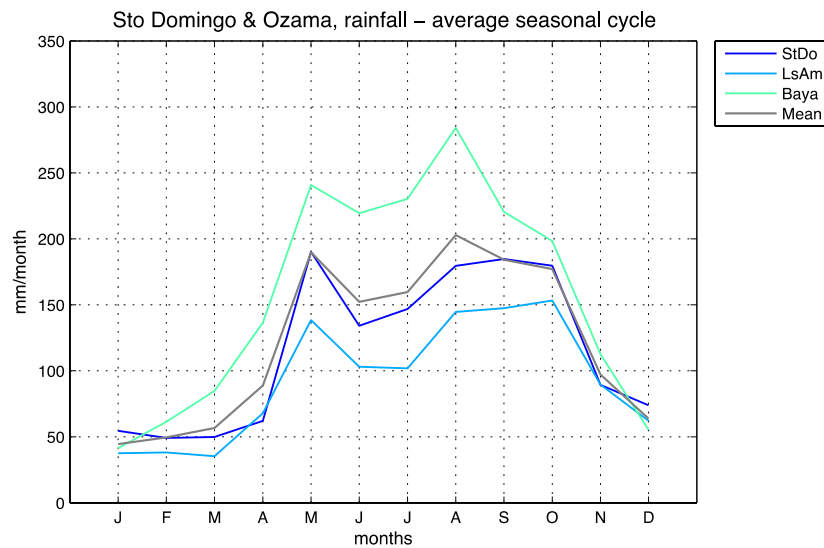
Under this region located in the southern coast of the country we analyzed three stations: Santo Domingo (SaDo), Las Americas (LaAm) and Bayaguana (Baya).

Average Rainfall

SEASONAL CYCLE

Located in some of the wetter areas of the Dominican Republic the southern coast and the Ozama watershed experience a mono-modal seasonal cycle. The region receives the bulk of the precipitations in summer, between May and October, with rainfall above 100 mm/month and as high as 250 mm/month in the Bayaguana station, inland from (Figure R13). The region has a long dry season that extends from November to April.

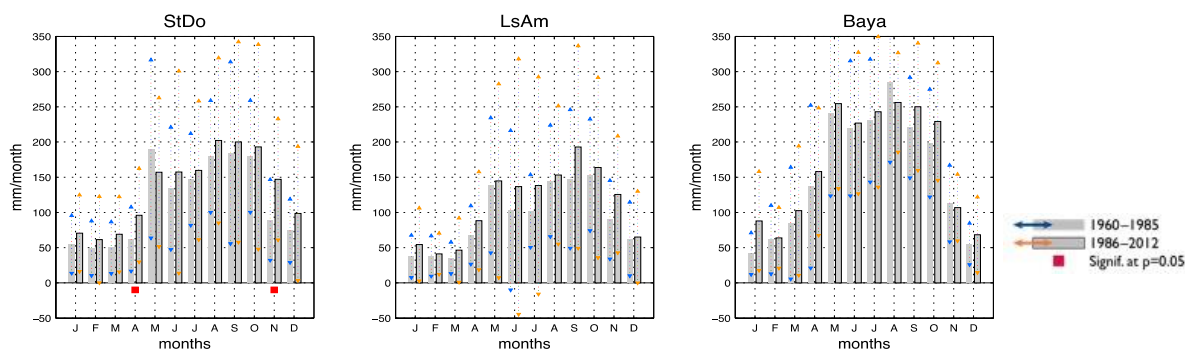
FIGURE R13: AVERAGE SEASONAL CYCLE OF RAINFALL IN STATIONS LOCATED IN SANTO DOMINGO AND OZAMA WATERSHED; MONTHLY AVERAGE VALUES COMPUTED OVER 1960-2012 PERIOD.



Variability

INTER-ANNUAL, LONG-TERM AND DECADAL

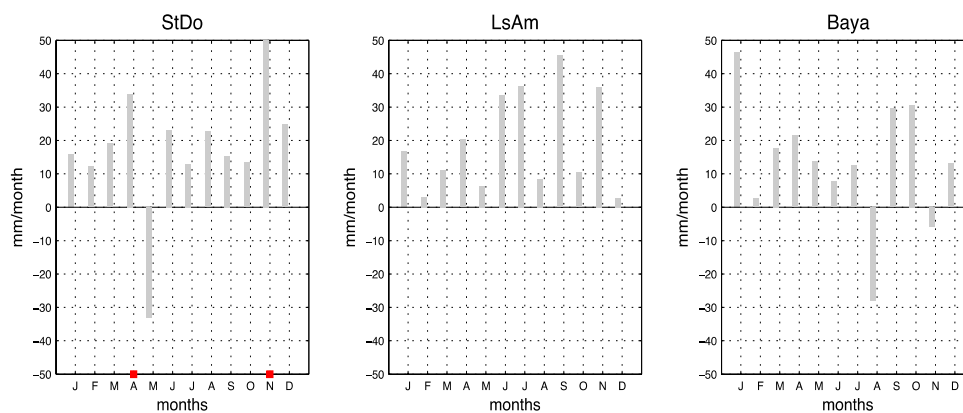
FIGURE R14: DIFFERENCES IN SEASONAL CYCLE OF RAINFALL BETWEEN 1986-2012 AND 1960-1985 FOR STATIONS IN SANTO DOMINGO AND OZAMA WATERSHED



Note: Grey bars and grey bars with borders show the average monthly rainfall for 1960-1985 and 1986-2012 periods respectively; the arrows show the amplitude of 1 standard deviation. Red squares denote months where changes are statistically significant at $p=0.05$.

As in the other three regions of this study strong inter-annual variability in the three stations of the regions mask long term trends. Statistically significant changes only happen in Santo Domingo station with an increase in precipitation in April and November (Figure R14). Figure R14BIS shows that, although not statistically significant, there appears to be a slight increase in precipitation throughout the year in all three stations.

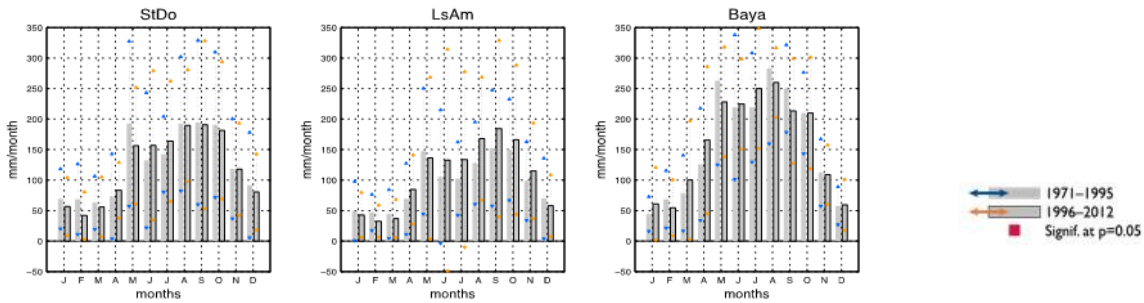
FIGURE R14BIS: DIFFERENCES IN AVERAGE MONTHLY RAINFALL BETWEEN 1986-2012 AND 1960-1985 PERIODS SHOWN AS ANOMALIES



Note: Grey bars show the difference between average monthly rainfall observed in 1986-2012 and 1960-1985 periods. The red squares highlight the months where the difference is statistically significant at $p=0.05$.

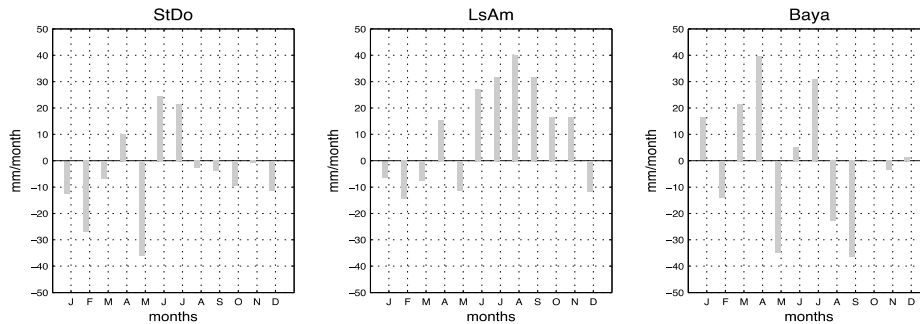
The decadal signal is not significant in this area (Figures R15 and R15BIS). With respect to long-term changes, the main difference is a potential decrease in rainfall in the earlier part of the year when the Tropical North Atlantic is warmer. This is an area that has experienced an increase in rainfall in the peak of the rainy season in both cases – long-term and decadal evolutions. These two signals are reversed in the early part of the year.

FIGURE R15: SAME AS FIGURE R14 BUT FOR DIFFERENCES IN SEASONAL CYCLE OF RAINFALL BETWEEN 1996-2012 AND 1971-1995 PERIODS



Note: Grey bars and grey bars with borders show the average monthly rainfall for 1971-1995 and 1996-2012 periods respectively; the arrows show the amplitude of 1 standard deviation. Red squares denote months where changes are statistically significant at $p=0.05$.

FIGURE R15BIS: SAME AS FIGURE R15 BUT SHOWN AS ANOMALIES

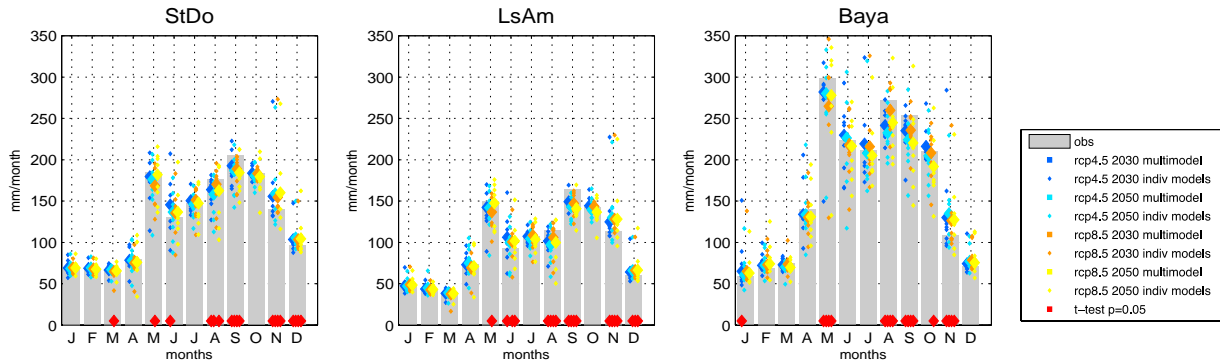


Note: Grey bars show the difference between average monthly rainfall observed in 1996-2012 and 1971-1995 periods. The red squares highlight the months where the difference is statistically significant at $p=0.05$.

Projections

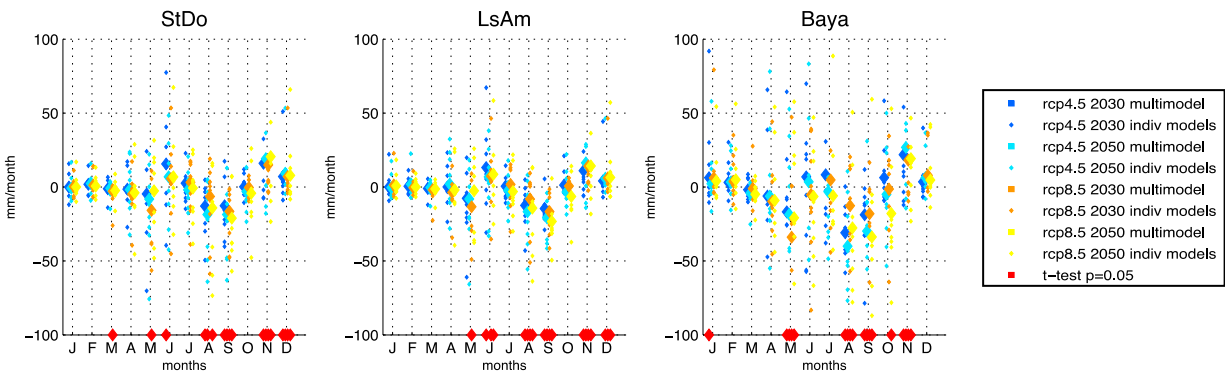
This region shares many of the same results in projections as the other three areas. These projections are shown in Figures R16 and R16BIS. The main signal is the decrease of rainfall during the main rainy season (in May then July-August) and a strong increase in the dry season. These changes will modify the seasonal contrast in the region with wetter winters and drier summers.

FIGURE R16: AVERAGE SEASONAL CYCLE OF RAINFALL OBSERVED AND PROJECTED IN STATIONS IN SANTO DOMINGO AND OZAMA WATERSHED



Note: Grey bars show average monthly rainfall observed over the 1975-2005 period. Symbols show projected values where larger symbols denote multi-model average and smaller symbols represent rainfall projected by individual models. Red diamonds denote months where changes projected by the multi-model mean are statistically significant at $p=0.05$.

FIGURE R16BIS: AS FOR FIGURE R16 BUT SHOWN AS ANOMALIES (MODEL ONLY)



Note: Zoom into projected temperature changes expressed as anomalies. Larger symbols denote multi-model average while smaller symbols represent rainfall projected by individual models. Red diamonds denote months where changes projected by the multi-model mean are statistically significant at $p=0.05$.

EXTREME RAINFALL EVENTS

The extreme rainfall events analysis was conducted in 16 stations distributed in the four areas of study. All days that reported no precipitation were removed from the datasets to reduce the skewed nature of the distributions. In order to remove outliers and incorrect recordings, the 1960-2012 daily rainfall data was carefully inspected. Days in which hurricanes occurred were excluded (Table A1) since these events are controlled by a different atmospheric phenomenon than the one that influences local daily rainfall. Values that appeared abnormally high (e.g., station values with daily rainfall above 150 mm) were also removed.

It was decided that only years that had a robust amount of data should be analyzed. For each station, years that did not contain enough data were excluded to ensure that the seasonal rainfall variations were properly captured in the analysis. Since daily rainfall varies greatly throughout the year, the analysis should not include values that represent only a portion of the year. Therefore, years that contained 5 percent or more missing data were excluded. If too few years remained after this removal, 10 percent missing data was used as the criterion.

The Mann-Whitney U-Test was used to assess changes in the frequency of rainfall events within the top 10 and top 5 percentile of the distributions applying the 1960-1985 and 1986-2012 time frames (Table A6).

Yaque del Norte stations experience an overall decrease in the number of extreme rainfall events with a higher trend of less events in the top 5 percent. Samaná and Alto Yuna show an inconsistent trend with some stations showing an increase and others a decrease. The two stations in Punta Cana/ Bávaro show inconclusive results. The two stations in the Santo Domingo Metropolitan area show a significant increase in extreme rainfall events.

TABLE A6: RESULTS ON FREQUENCY CHANGES OF EXTREME 10% AND 5% RAINFALL EVENTS BETWEEN 1960-1985 AND 1986-2012

WATERSHED	CHANGE in FREQUENCY	
	Extreme 10%	Extreme 5%
YAQUE DEL NORTE		
Monte Cristi	inconclusive	decrease
Villa Vasquez	decrease	decrease
Santiago R	decrease	decrease
Santiago	inconclusive	inconclusive
Moncion	inconclusive	inconclusive
SAMANA PENINSULA & ALTO YUNA		
Nagua	decrease	decrease
Sanchez	increase	increase
Samana	inconclusive	inconclusive
La Vega	increase	increase
Salcedo	decrease	decrease
Villa Riva	inconclusive	increase
ALTAGRACIA & YUMA		
Punta Cana	decrease	inconclusive
S R Yuma	inconclusive	inconclusive
CUENCA COSTERA (Sto Domingo & others)		
Sto Domingo	increase	increase
Las Americas	increase	increase
Bayaguana	inconclusive	inconclusive

WIND SPEED

Average Wind Speed

The average wind speed climatology for the eight stations over the complete record of each station is shown in Figures W1 and W2. Figure W1 depicts the four stations in the north coast; Figure W2 shows the four stations on the south coast.

FIGURE W1: AVERAGE WIND SPEED FOR THE NORTH COAST STATIONS

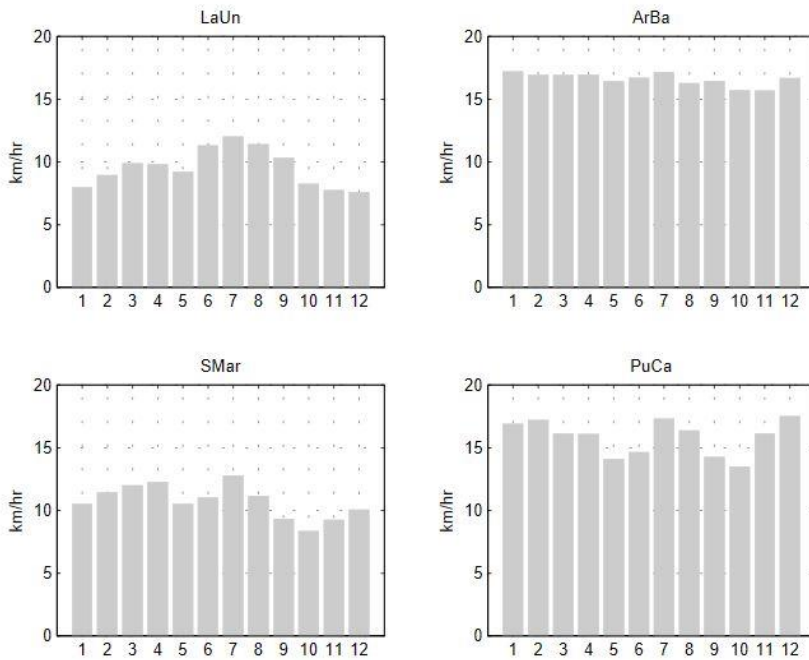
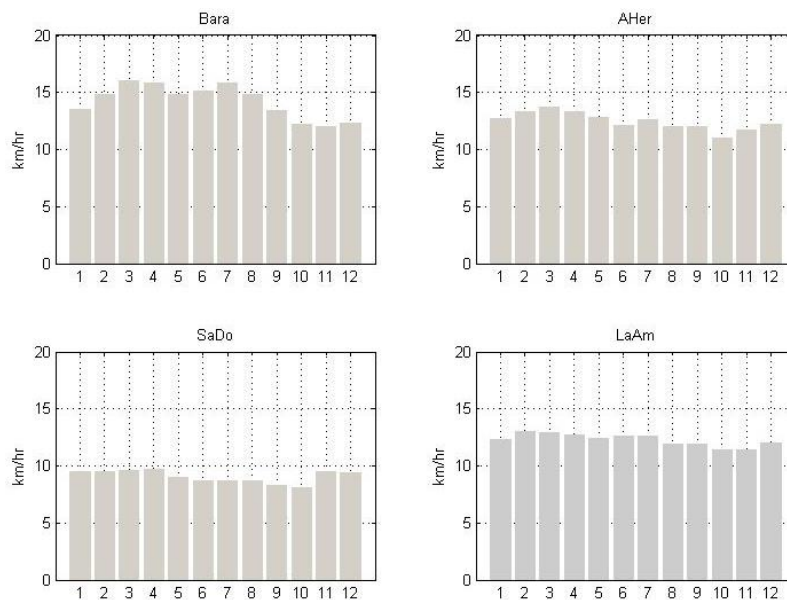


FIGURE W2: AVERAGE WIND SPEED FOR THE SOUTH COAST STATIONS



When comparing the two proposed timeframes, statistically significant changes were only present in three stations: Barahona in the southwest with an average increase of 3 km/h in all months, S de la Mar in the northeast with an average increase of 2km/h in 10 of the 12 months (April and July were the exception) and Santo Domingo, with an average decrease of wind speed of 2.4 km/h in all months except June. Santo Domingo changes are thought to be associated with urban sprawl in the area, which effectively lowers wind speed. For Barahona and S de la Mar further details of the station record (instruments, height of measurements, etc.) are needed to understand the nature of these increases.

Mean Number of Days with Wind Speeds above 12 Knots

Statistically significant changes in the mean number of days with average wind speeds above 12 knots were only found in Punta Cana. Eight months show a significant change in the mean number of days shown in Table A7.

TABLE A7: PUNTA CANA STATIONS - CHANGES IN MEAN NUMBER OF DAYS WITH AVERAGE WIND SPEED

Month	>12 knots	<12 knots
Mar	-2.19	2.23
Apr	-2.81	2.31
Jun	-0.70	0.96
Jul	-2.57	2.43
Aug	-1.67	1.86
Oct	-0.81	0.64
Nov	-2.43	2.35
Dec	-2.98	2.93

Note: Negative numbers represent a decrease in the number of days. Yellow represents statistically significant changes.

Wind Direction

The mean fraction of days with a particular cardinal or inter-cardinal wind direction for the stations in the north coast of the country is similar. Punta Cana, La Union and S de la Mar have predominant easterly winds throughout the year with a fraction of days always over 40 percent. This is consistent with the expectation given the location of the island on the trade wind belt. Arroyo Barril in the NW of the country but on the south of the Samaná Peninsula has more northerly wind than the other stations in the north.

Statistically significant changes in wind direction, with fractions above 20 percent when comparing the two time periods, occur in Punta Cana in January, March, April, June, July, August, and December when the mean number of days with easterly winds has decreased and with winds from ENE has increased. In S de la Mar, a decrease in the mean number of days with NE winds and an increase in the mean number of days with easterly winds, is statistically significant from January to October.

The south coast follows different wind direction seasonality. The three stations located close to or within Santo Domingo (A Herrera, Santo Domingo, and Las Americas) have a prevalence of N winds in the winter months; easterlies increase its incidence in over the summer months. Statistically significant

changes are only major in Las Americas with an increase of N and NNE winds in the winter and a reduction in NE winds.

Barahona in the southwest has predominant winds from the SE and SSE throughout the year. Statistically significant changes occur only in these two directions with an increase in the SSE and a decrease in SE indicating a southward shift on the winds.

CONCLUSIONS

The Dominican Republic experiences great heterogeneity in annual rainfall and seasonal cycles across the country. Total annual rainfall is greatest in the northeast, while it is the lowest in the southwest. A bi-modal seasonal rainfall regime exists in the North, in which a mid-summer drought occurs between two months of high rainfall. In the South, the seasonal cycle is characterized by a wet summer and a dry winter. Consequently, the analysis of long-term rainfall changes in historical rainfall as well as estimation of projected changes needs to take into account the spatial variability in rainfall – its annual totals and seasonality. In addition, all regions experience very strong inter-annual rainfall variability; the Caribbean as a whole also experiences decadal changes in rainfall, potentially masking longer-term evolution.

The findings of the literature review of climate and analysis of historical climate variability and trends in rainfall, temperature, and wind lead to the following conclusions:

- Rainfall in the Dominican Republic shows spatial and seasonal contrasts as well as documented inter-annual and decadal variations. The detection of past and projected longer-term trends is made challenging by the presence of this natural variability. Long-term trends in historical rainfall are not statistically significant, but in a number of stations there seems to be a slight reduction of rainfall during the peak of the rainy season and an increase at the end of the season in late fall. Individual models tend to disagree on the amplitude and even the direction of projected changes, but there is some indication of a potential reduction of rainfall in the peak of the rainy season and an increase during what is traditionally the dry season.
- On the other hand, a consistent and significant trend has been found in temperature, also projected to continue at the same or slightly faster rate in the near future.
- Increased heat combined with decreased rainfall can exacerbate water stress, especially in the drier areas of the country and those subject to the mid-summer drought. Conversely, increased rainfall over already saturated areas at the end of the rains could exacerbate flooding in the flood-prone locations. The analysis of extreme rainfall events, outside of hurricanes and tropical storms, did not show any consistent evidence of extreme rainfall frequencies – even if in certain watersheds they seem to have increased, while decreasing in others.
- The most devastating climate phenomena — hurricanes and tropical storms — also show strong seasonality and inter-annual and decadal variability. While they are not easily predictable, there is consensus about the fact that they may intensify in a warmer atmosphere without changing their frequencies, thus become more devastating. Combined effects of higher intensity in warmer environments with changes in frequency related to decadal variations in tropical Atlantic SSTs may result in greater hurricane impacts in coming years; inland and on the coast, with increased storm surges in a higher sea level context. No significant changes in high-speed wind events (outside of hurricanes) responsible for storm surges and beach erosion were found, pointing to the strong role of non-climatic factors in the observed increase in coastal erosion.

- While this study confirmed a consistent warming of the island, it did not find strong climate change signals in some of the other historical or projected climatic variables. Further investigation, particularly focusing on atmospheric phenomena and mechanisms specific to the island, could confirm or disprove current findings.

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8.2 ANNEX B: OPTIONS ANALYSIS PARTICIPANTS LISTS

Santo Domingo

1. Sésar Rodríguez, Consorcio Ambiental Dominicano (CAD) sesar_rodriguez@yahoo.com
2. Ian Pritchard, Fundación Dominicana de Estudios Marinos (FUNDEMAR) ianepg@gmail.com
3. Patricia Lamelas, Center for the Conservation and Eco- Development of Samaná Bay and its Surroundings (CEBSE) lamelasp@gmail.com
4. Fausto Gómez, PRONATURA fgomez@pronatura.org.do
5. Monserrat Acosta Morel, The Nature Conservancy (TNC) macosta-morel@tnc.org
6. Zoraida Zapata, Viceministerio Costeros Marinos (MIMARENA) Zoraida.zapata@ambiente.gob.do
7. Solangel González, Agro-Meteorología (ONAMET) sgonzalez@onamet.gov.do
8. Nathalie Flores González, Ministry of Environment nathalie.flores@ambiente.gob.com
9. Cecelia Viloría, ONAMET ceceliavH22@hotmail.com
10. Enrique Pugibet Bobea, Center of Marine Biology Research (CIBIMA-UASD) epugibet@gmail.com
11. Francisco Gerales, Center of Marine Biology Research (CIBIMA-UASD) franciscogerales@yahoo.es
12. Odalis Perez, USAID operez@usaid.gov
13. Luz Bonilla, Ministerio de Economía, Planificación, y Desarrollo (MEPyD/DGOT) luzpatria.bonilla@gmail.com
14. Francis Santana, Consorcio Dominicano Competitividad Turística (CDCT) francisdct@gmail.com
15. F. Abel Abreu, Instituto Nacional de Recursos Hidráulicos (INDHRI) abelabreu55@hotmail.com
16. Franklin Reynoso, Instituto Nacional de Recursos Hidráulicos (INDHRI) franklin_aquiles@yahoo.es
17. Carmen Bautista, DGOT dra_Carmen02203@yahoo.com.mx
18. Víctor García, Consultor DGOT vgarcia.pos@gmail.com
19. Mariaana Hypponen, Banco Mundial thypponer@gmail.com
20. Luis Tolentino, Fundación REDDOM luis@funacionreddom.org
21. Evaydeé Pérez, Instituto Dominicano de Desarrollo Integral (IDDI) eperez@iddi.org
22. Pedro García, Ministry of Environment pedro.garcia@ambiente.gob.do
23. Jose Martínez, Ayuntamiento del Distrito Nacional (ADN) josemartinez@adn.gob.do
24. Milagros Rodríguez, UNIBE mrodriguez5@unibe.edu.do

25. Roberto Suriel, UNPHU roberto.suriel@gmail.com
26. Karen Hedeman, CNCCMDL khederman@cambioclimatico.gob.do
27. Americo Martínez, ADORA adora@claro.net.do
28. Orlando Arias, El Nuevo Diario arias0617@gmail.com
29. Hugo Segura, ONAMET prodirector2008@yahoo.com
30. Amable Montas, CODIA amablemontas@hotmail.com

Montecristi:

1. Alsides Brea Franco, INCAP Mao alsidesbrea@yahoo.es
2. Frederick Payton, Agrofrontera Project Participants fpayton@agrofrontera.org
3. Olga Lovetti, Ministry of Environment olga.gomez@ambiente.gob.do
4. Anibal Cordero, Provincial Director Ministry of Agriculture (Northwest Region, Villa Vasquez) anibalcorder_2621@hotmail.com
5. Ramón Moran, Agrofrontera Project Participant casanoba007@hotmail.es
6. Eridania Hernández, Agrofrontera Project Participant fpayton@agrofrontera.org
7. Leoncio Pimentel, Agrofrontera Project Participant cdj@codetel.net.do
8. Felipe Pérez, Agrofrontera Project Participant fpayton@agrofrontera.org
9. Franklin Tatis, Asociación Productores de Arroz fpayton@agrofrontera.org
10. César Andújar, Agrofrontera Project Participant fpayton@agrofrontera.org
11. César Cruz, Agrofrontera Project Participant fpayton@agrofrontera.org
12. Carlos Jiménez, CODOPESCA
13. César Rafael, Agrofrontera Project Participant fpayton@agrofrontera.org
14. Vidal Cabrera, Cluster Turístico Grupo Literario
15. Luis Mercedes Reyes, Alcalde (Ayuntamiento) jackelinejimenez10@gmail.com
16. Soraya Rodríguez, Cluster Soraya y Santo Tours sory522000@yahoo.com
17. Laura García, Cluster Hotel El Morro laura.garcia@elmorro.com.do

Santiago

1. Luis Peña, Director of Instituto de Gestión de Riesgos (IGER) Municipality of Santiago fundoger@gmail.com
2. Mario Tejada, Ministry of Environment m.tejada@ambiente.gob.do
3. Juan Castillo, Fundación Solidaridad fsolidaridad@gmail.com
4. Walkiria Esteves, Corporación Santiago Solidario walkiria2020@yahoo.es
5. Zeneida Reynoso, Asociación para el Desarrollo (APEDI) apedi@claro.net.do

6. Alfredo Matías, Centro Integral para el Desarrollo Local (CIDEL) cidelocal@gmail.com
7. Esteban González, D.C. postorestebangozalez@hotmail.com
8. Bienvenida Cuevas, CEUR/PUCMM bcuevas@pucmmsti.edu.do
9. Luis Carballo, CEUR/PUCMM lrballo@pucmmsti.edu.do

Punta Cana

1. Albania Martinez Germosen, Punta Cana Bávaro Diving Operators albania20@hotmail.com
2. Christian Garrido, Punta Cana Recycling Project cgarrido@tecnologiaambiental.net
3. Juan Carlos Sánchez, Bávaro Hotel Cluster jcsvilla@yahoo.com
4. Omar Castillo, Ministry of Environment omar_castillo@hotmail.es
5. Peter Lorenz, Punta Cana Bávaro Diving Operators famlorenz@hotmail.com
6. Raysa Félix, Adompretur Filial Bávaro rayasfeliz@gmail.com
7. Luis José Chávez, Adompretur lj.chavez23@gmail.com
8. Gilberto Sosa, Assistant Director of Tourism gilbertososa@hotmail.com
9. Joel Castillo
10. Lourdes Ruiz, Reef Check Dominican Republic lourdesruizflaquer@yahoo.com

Samaná

1. Tomás Díaz, Center for the Conservation and Eco- Development of Samaná Bay and its Surroundings (CEBSE)-Fisheries Coordinator hradio2@yahoo.es
2. Oromayka Flores, Environmental Manager Bahia Cayacoa gerenteseguridadhigienebpcay@bahia-principe.com
3. Philippe Siebert, Las Terrenas- Samaná Diving Operators siebert.philippe@gmail.com
4. Fanny Jones, Directora Ejecutiva Cluster Turístico Samaná (CTS) fanjo_05@hotmail.com
5. Noelia Jerez, Center for the Conservation and Eco- Development of Samaná Bay and its Surroundings (CEBSE) noelajerez83@gmail.com
6. Corinne Siebert, Las Terrenas Samaná Diving Operators siebert.philippe@gmail.com
7. Luz del Alba Acosta, Ministry of Environment - Samaná Regional MARENA Director lalula_23@hotmail.es

Centro Bono

1. Fernando Santa, FUNDSAZURZA grannandor@hotmail.com
2. Carlos Arias, FUNSACO carlosarias@yahoo.com

U.S. Agency for International Development

1300 Pennsylvania Avenue, NW

Washington, DC 20523

Tel: (202) 712-0000

Fax: (202) 216-3524

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