**UNIVERSIDAD SAN FRANCISCO DE QUITO**

**Colegio de Posgrados**

# Prediction of Climate Change Impacts on Cocoa Crops in Trinidad and Tobago

**Karolina Andrea Argote Deluque**

**Richard Resl, Ph.Dc.,** Director de Tesis

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HOJA DE APROBACION DE TESIS

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## Karolina Andrea Argote Deluque

Richard Resl, Ph.Dc.
**Director de Tesis** ____________________________________

Anton Eitzinger, Ms.
**Miembro del Comité de Tesis** ____________________________________

Richard Resl, Ph.Dc.
**Director de la Maestría en Sistemas**
**de Información Geográfica.** ____________________________________

Stella de la Torre, Ph.D.
**Decano del Colegio de Ciencias**
**Biológicas y Ambientales** ____________________________________

Victor Viteri Breedy, Ph.D.
**Decano del Colegio de Posgrados** ____________________________________

Quito, febrero de 2014

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**Karolina Andrea Argote Deluque**

**Pasaporte: 53031983**

Quito, febrero de 2014

# AGRADECIMIENTOS

Este trabajo fue desarrollado en marco del proyecto “Crop Climate Impact in Trinidad & Tobago and Jamaica” ejecutado por el Centro Internacional de Agricultura Tropical (CIAT) y la Universidad de West Indies (UWI), cuyo objetivo principal es proveer información valiosa sobre los principales impactos del cambio climático sobre la producción de cultivos en Trinidad & Tobago y Jamaica.

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# RESUMEN

Hoy día, los efectos del cambio climático sobre la agricultura difieren alrededor del mundo, unas regiones son más vulnerables que otras. Tal es el caso de las pequeñas islas que hacen parte de la región Caribe, las cuales poseen características que las hacen especialmente vulnerables al cambio climático. A pesar de esto, existen grandes vacios al intentar evaluar y/o analizar la relación entre el cambio climático y la productividad de los cultivos, especialmente cuando no son de gran importancia económica en el mundo y cuando se trata de islas en los trópicos, ya que no hay suficientes datos ni modelos disponibles. Este estudio evalúa los impactos del cambio climático en Trinidad y Tobago especialmente sobre el cultivo de cacao, integrando conocimiento local de instituciones como el *Trinitario Cacao Resources* con la experiencia de organizaciones como el CIAT en la modelación de nicho ecológico usando modelos deterministicos como MaxEnt (Máximum Entropy), datos climáticos de la base de datos mundial WorldClim y modelos GCMs para el futuro.

Al analizar el impacto de los escenarios del IPCC SRES-A2 2020s, SRES-A2 2050s, SRES-A1B 2020s y SRES-A1B 2050s sobre la aptitud climática de los cultivos de cacao en Trinidad y Tobago, se obtiene en general un buen comportamiento de los modelos, con un coeficiente de variación promedio de las variables bioclimáticas entre el 5 y el 11% y una concordancia entre los modelos mayor al 60% en más del 70% del territorio. A partir del análisis climático regional se concluye que en términos generales, Trinidad y Tobago tendrá una potencial disminución progresiva de la precipitación anual promedio en 2020 y 2050, y un potencial aumento en la temperatura anual promedio. Esto se traduce en la predicción de hasta un 20% de pérdida en la aptitud climática en tierras bajas de municipios donde actualmente se cultiva cacao (Tobago, Piarco, parte sur de Sangre Grande y Talparo) y a su vez un incremento de la aptitud climática del cultivo en tierras altas, ubicadas en el noreste de Trinidad (norte del municipio de sangre grande), donde actualmente no hay presencia del cultivo. Esto sugiere que los pequeños agricultores de cacao en Trinidad y Tobago en el futuro cercano, deberán migrar hacia tierras altas, donde de acuerdo a los modelos; la aptitud climática del cultivo será mayor, para evitar importantes pérdidas económicas o cambios abruptos en su estilo y calidad de vida de los agricultores.

**Palabras Clave:** Cacao, Trinidad y Tobago, MaxEnt, precipitación, temperatura, cambio climático, aptitud y modelación.

# ABSTRACT

The impacts of climate change on agriculture will be spatially heterogeneous and certain regions, due to a combination of environmental and socio-economic factors are likely to be at a greater risk. For example, the small island nations found in the Caribbean region possess characteristics that make them particularly susceptible to the effects of climate change, with rising sea levels and a potential increase in extreme meteorological events an imminent threat. It can be noted that a knowledge gap linking the impacts of climate change to crop productivity exists and that this is particularly pertinent for crops of lower economic value, some of which are found in the Caribbean. Additionally, the Tropics, including the Caribbean nations, are often affected by a shortage of historic data which combined with a lack of established robust models can further inhibit agricultural research. This study is focused on the impacts of climate change on the cocoa crop in Trinidad and Tobago. We integrated knowledge reported by local experts such as Trinitario Cocoa Resources with CIAT's expertise in species habitat modeling. The deterministic model, MaxEnt, maximum entropy mode, combined with current climate data from the global database WorldClim and future climate data derived from GCMs, was used to drive the analysis.

The impacts of the SRES-A2 (2020s and 2050s) and SRES-A1B (2020s and 2050s) scenarios on the climatic suitability of cacao in Trinidad and Tobago were analyzed and it was found that in general the models performed well. The mean coefficient of variance of bioclimatic variables was between 5 and 11% and agreement between models was greater than 60% in over 70% of the countries. After conducting regional climate analysis, it was found that generally, Trinidad and Tobago will have a decrease in the average annual rainfall in 2020 and 2050, and a potential increase in mean annual temperature. Under such conditions it is estimated that a loss of up to 20% in climatic suitability could affect cacao producing municipalities located in lowland areas (Tobago, Piarco, south of Sangre Grande and Talparo part). In contrast, climatic suitability in highland regions will increase, mainly, in northeastern Trinidad (north of the municipality of large blood) where currently the crop is not present. This suggests that small cocoa farmers in Trinidad and Tobago in the near future should migrate to highland areas, where according to the models climatic suitability of the crop will be higher. Failure to migrate production could result in reduced output of cacao, significant economic loss, and damage to the survival of agricultural communities in Trinidad and Tobago.

**Key words:** Cocoa, Trinidad and Tobago, MaxEnt, precipitation, temperature, climate change, suitability, modeling.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ***ANUSPLIN*** | *Australian National University Spline* |
| ***CCAFS*** | *CGIAR Research Program on Climate Change, Agriculture and Food Security* |
| ***CIAT.*** | *International Centre for Tropical Agriculture* |
| ***FAO.*** | *Food and Agriculture Organization of the United Nations* |
| ***GCMs.*** | *General Circulation Models* |
| ***GHCN*** | *Global Historical Climatology Network* |
| ***GHG*** | *Greenhouse Gases* |
| ***ICAS*** | *Institute for Climatic and Atmospheric Science, UK.* |
| ***ICCO*** | *International Cocoa Organization* |
| ***ICGD*** | *International Cocoa Germplasm Database* |
| ***IPCC.*** | *Intergovernmental Panel on Climate Change* |
| ***Kg*** | *Kilogram* |
| ***mm*** | *Precipitation Value (amount of rain per square meter in one hour)* |
| ***NASH*** | *North Atlantic Subtropical High* |
| ***PAR*** | *Permanent Agriculture Resources* |
| ***R-HydroNet*** | *A Regional, Electronic Hydrometeorological Data Network for South America, Central America, and the Caribbean* |
| ***SIDS*** | *Small Island Developing States* |
| ***SRES*** | *Special Report on Emissions Scenarios* |
| ***SRTM*** | *Shuttle Radar Topography Mission* |
| ***T&T*** | *Trinidad and Tobago* |
| ***UNCTAD*** | *United Nations Conference on trade and development* |
| ***UNFCCC*** | *United Nations Framework Convention on Climate Change* |
| ***UTM*** | *Universal Transversal Mercator projection* |
| ***UWI*** | *University of West the Indies- St Augustine, Trinidad and Tobago* |
| ***WCF*** | *The World Cocoa Foundation* |
| ***WMO*** | *World Meteorological Organization* |

# 1. INTRODUCTION

There is growing consensus in the scientific community that climate change is occurring. The United Nations Intergovernmental Panel on Climate Change (IPCC) has concluded that the global atmosphere is warming, noting that the average global surface temperature has increased by nearly 1$^{o}$C over the past century and is likely to rise by another 1.4 to 5.8$^{o}$C over the current century. (IPCC, 2001b)

Climate is the primary determinant of agricultural productivity. At the same time, food production is essential for sustaining and enhancing human welfare. Therefore, agriculture has been a major concern in the discussions on climate change. The discussions concentrate in possible physical effects of climatic change on agriculture, such as changes in crop yields as well as the economic consequences of these potential yield changes.

The climate change effects on agriculture will differ across the world. However, it is clear that changes in temperature as well as changes in rainfall patterns and the increase in $CO_2$ levels projected to accompany climate change will have important effects on global agriculture, especially in the tropical regions.

In the tropics, the small islands that are part of the Caribbean Region have characteristics that make them especially vulnerable to the effects of climate change, such as sea level rise and extreme meteorological events (UNEP, 2008). This study is focused in the climate change impacts in Trinidad and Tobago especially in the Cocoa crops.

Even though the economy of Trinidad and Tobago is dominated by the petroleum industry, agriculture is an important sector and accounts for 16.7% of the land area, it contributes with the 5.0% of employed persons and is a key to the rural socio-economy. (FAO, 2006)

Of the most important crops in Trinidad and Tobago, the Cacao has contributed greatly to the socio-economic development of the country for over 200 years. Despite local production decreasing since the 1950s after the decline in world cocoa prices (Bekele 2004), but it continues to be an important crop that supports the rural economy. However, farmers have had to face major challenges, including climate risk and impacts of long term climate change.

Among them the fact that cocoa is highly sensitive to changes in climate, over exposure to sunlight, to rainfall and application of water, soil conditions and particularly to temperature due to effects on evapotranspiration. Climate change could also alter stages and rates of development of cocoa pests and pathogens, modify host resistance and result in changes in the physiology of host-pathogen/pests interaction. The most likely consequences are shifts in the geographical distribution of host and pathogen/pests, altered crop yields and crop loses which, will impact socio-economic variables such as farm income, livelihood and farm-level decision making. Hence the need for an understanding of climate change impacts on cocoa production and the potential for adaptation to climate change. (Anim-Kwapong & Frimpong, 2003)

This study aims to analyze the impact of climate change on Cocoa farms in Trinidad and Tobago in the present and in the near future (2020, 2050) using crop-climate modeling under SRES-A2 2020s, SRES-A2 2050s, SRES-A1B 2020s, SRES-A1B 2050s IPCC scenarios, GCMs and climate data of the global database WorldClim. Crop prediction models provide a useful tool visualizing the ways climate change could impact crop production. So far, the large majority of these models have been developed and employed outside of the Caribbean and are not necessarily applicable to the region, given the small geographic size of most regional states and the applicability of these models to a narrow range of crops. Also, the large majority of these models have been developed and employed outside of the Caribbean and are not necessarily applicable to the region, given the small geographic size of most regional states. The aim of this study is to improve on this situation by utilizing geographic information of crop presence, climate data and using crop suitability models such as Maxent. MaxEnt is one of the most popular tools for species distribution and environmental niche modeling, with over 1000 applications published since 2006. (Phillips, Anderson, & Schapire, 2006) MaxEnt, used as input a set of environmental variables (such as temperature, precipitation, etc.), as well as a set of geo-referenced occurrence locations. Using this data MaxEnt estimates a target probability distribution by identifying the probability distribution of maximum entropy.

# 2. LITERATURE REVIEW

## 2.1. Cocoa Cultivation

### *2.1.1. Cacao Taxonomy*

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Figure 1. Criollo Cacao tree

Table 1. Scientific Classification of Theobroma Cacao L. (National Plant Database, 2004)[1]

| Scientific Classification | |
|---|---|
| **Division** | *Magnoliophyta-Flowering plants* |
| **Class** | *Magnoliopsida-Dicotyledons* |
| **Subclass** | *Dilleniidae* |
| **Order** | *Malvales* |
| **Family** | *Sterculiaceae – Cacao Family* |
| **Genus** | *Theobroma L. - Theobroma* |
| **Specie** | *Theobroma Cacao L.-Cacao* |

The cacao tree – which produces the cocoa bean – is fragile, capable of growing only in a narrow band 15 degrees north or south of the equator. As with other "orchard" crops, cacao trees require time, yielding their first pods approximately two to three years after planting. The cacao tree grows well – and in harmony – with the surrounding forest, thriving under the shade canopy of taller, older trees. (CAOBISCO, 2010)

Of the 22 known species of the genus Theobroma, only Theobroma cacao is widely cultivated outside of its native range of distribution. However, it is noteworthy that several other species are cultivated or wild-harvested on a relatively small scale for human consumption, Theobroma bicolor (mocambo, pataste), Theobroma grandiflorum (cupuaçu), and to a lesser extent, Theobroma speciosum and Theobroma subincanum. (Hebbar, Bittenbbender, & O'Doherty, 2011) All cultivated cacao is classified into a single species Theobroma cacao and

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[1] National Tropical Botanical Garden, USA
http://www.ntbg.org/plants/plant_details.php?plantid=11101

subdivided into three well-defined groups of cacao: Forastero, Criollo, and Trinitario which is a hybrid of Forastero and Criollo. (Jurgen Pohlan & Díaz Pérez, 2010)

Cacao[2] (*Theobroma cacao* L.) has contributed to the socio-economic development of Trinidad and Tobago for over 200 years. The Spaniards first planted the *Criollo* (native) variety in Trinidad in 1525, but the cocoa trade only became operative in the colony at the beginning of the 18th century. The industry was almost completely destroyed in 1727 by a 'blast' (a hurricane or *Ceratocystis* wilt or bark canker, a *Phytophthora* infection). Consequently, *Forastero* (exotic) cacao was introduced from Venezuela in 1757, and eventually inter-bred with the remnant *Criollo* to produce hybrid cacao referred to as *Trinitario*. (Bekele, 2004)

### *2.1.2. Global Cocoa Cultivation*

The Latin name for cocoa -*Theobroma*- literally means, "Food of the gods". It comes mainly from three regions – Southeast Asia, Latin America and West Africa (CAOBISCO, 2010) and played an important role in many ancient South American cultures. In its earliest forms, the Mayans used cocoa to create a ritual beverage that was shared during engagement and marriage ceremonies, providing one of the first known links between chocolate and romance. In Europe, the drink "*chocolha*" only gained popularity after the 1600s. (Neleman, 2011)

Globally, the Ivory Coast is the single largest producer of cocoa, accounting for approximately 40 percent of the world's supply. Other leading cocoa farming countries include Brazil, Cameroon, Ghana, Indonesia and Nigeria. Furthermore, in Latin America, highlights the recent increasing of high quality cocoa market of Ecuador as a result the investment in new big scale plantations, higher production yields, intensive campaigns by the Ecuadorian Government, NGOs and the private sector encouraging the small holder farmer to rehabilitate their old cocoa farms in order to improve their income. (Doi, 2013)

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[2] The word ***cacao*** is used for the tree and its parts, and the word ***cocoa*** for the dried beans and products of manufacture.

In these countries, the cocoa production is a complex system of intermediaries that purchases and transports the cocoa from the farm to the port. The vast majority of cocoa farms are not owned by the companies that make chocolate products or supply cocoa. In some countries, companies that purchase cocoa in bulk are, in fact, prohibited from purchasing cocoa directly from farmers; in other countries, cocoa is purchased from farmers through a national cocoa organization. Much as it was 100 years ago, cocoa farming remains a small, family enterprise, very different to the larger "agribusiness" farms that produce other crops. (CAOBISCO, 2010)

### *2.1.3. Cocoa Cultivation in Trinidad and Tobago*

A few decades ago, Cocoa, derived from the cacao plant, was along with sugarcane the major crop in Trinidad and Tobago. From the late 1880s until the 1930s, cocoa was the most important crop on both islands, and in the late 1980s it remained the leading crop on Tobago. In fact, Trinidad and Tobago was once the second leading global producer of cocoa. Introduced by the Spanish in the 1700s, cocoa still occupied more agricultural land than sugar in the 1980s, although it was frequently cultivated with bananas and coffee. Over half the cacao farms were small, but large estates accounted for over 80 percent of output. Trinidad and Tobago's cocoa crop was ravaged for decades by successive diseases. The government formulated numerous rehabilitation schemes for the industry, the most recent one in 1980, but they were generally unable to meet their goals, and production continued to fall. The 1980 program was no exception, as production declined beginning in 1982. For example, in 1985 cocoa output was 1.3 million kg, or under 50 percent of the 1981 output. Falling yields were another major problem the industry faced as average yields declined from 275kg per hectare in the 1930s to under 100kg per hectare in the 1980s. Furthermore, virtually all cocoa was exported.[3]

Over the last three decades, cocoa production, exports, acreage under cultivation and farmer participation in Trinidad and Tobago have been declining steadily (De

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[3] Mongabay Website.
http://www.mongabay.com/history/caribbean_islands/caribbean_islands-crops.html

Vries, 2000). However, since 2002 the production has begun to stabilize at 1.2-2.3 million kg (3-5 million pounds) per year. (Bekele, 2004)

Despite the state of depressed international cocoa prices throughout history, nowadays, Trinidad and Tobago produces a superior quality cocoa, which fetches a premium price on the world market. This cocoa is known in the cocoa trade as fine or flavour cocoa, and is produced from *Trinitario* beans. Some manufacturers consider this cocoa as superior and of the highest quality and purity. There is a niche market for such cocoa, which is mainly used in specialty products. It thus commands a premium price, but there are higher production, processing and material costs associated with the production of such cocoas.

In recent years, the outlook for the industry has been bleak. Currently, there are approximately 3,500 farmers (45 in Tobago) growing cocoa and coffee in Trinidad and Tobago compared to 10,000 in 1966. Less than 9.8% of the labour force is involved in agriculture. During the last five years, total local production has not exceeded 1.6 million kg (metric tons) per year. With low cocoa yields (less than 200 kg/ha), production costs are cited as TT$7-11/kg (Anon, 1999). It is obvious that without proper intervention, the illustrious history of cocoa in Trinidad may be heading to an abrupt end. (Bekele, 2004)

### *2.1.4. Ecology and Growing Conditions of Cacao*

#### Climate Requirements

As shown in the table 2, the optimal conditions for cacao cultivation include uniformly distributed high rainfall (1,500-2,800mm) and temperatures of 18-21˚C minimum and 30-32˚C maximum. However, cacao can also be grown in areas with long periods (3months) of dry weather such as those that occur in West Africa and Rondonia state in Brazil. An exception to the rule is Ecuador, which has even longer dry periods (5-6 months), but quite unique environmental conditions such as lower temperature, high humidity, and cloud cover during the drier periods. (Hebbar, Bittenbbender and O'Doherty 2011)

Table 2. Growing Climatic conditions of Cacao.

| Variable | Range or pattern |
|---|---|
| **Elevation** | **Lower:** sea level<br>**Upper:** 500-600m. Exceptions include Colombia (1,400m) and Uganda (1,200m) |
| **Mean annual rainfall** | **Lower:** 1,500 mm<br>**Upper:** 2,800 mm |
| **Rainfall pattern** | Cacao grows well in climates with summer, bimodal and uniform rainfall. |
| **Dry season duration** | 3 months, exception Ecuador with 6 months. |
| **Mean annual temperature** | **Lower:** 18˚C<br>**Upper:** 32˚C |
| **Minimum temperature tolerated** | 10-15˚C (Bahia, Brazil) and will not tolerate frost. |

**Source:** (Hebbar, Bittenbbender, & O'Doherty, 2011)

### Soil Requirements

Not all soils are suitable for cocoa cultivation. Cacao trees grow well only in good quality soil. Cacao is a forest crop suited to forest soils therefore it is exceptionally demanding in its soil requirements. Most tropical forest soils consist of accumulated plant nutrients in the top few centimetres. Hence, when planting cocoa in a field that has been used to grow other crops, farmers should remember to apply recommended mineral fertilizer or compost to the planting hole to improve soil fertility. (Asare & David, 2010)

Cultivation of cocoa at the farm level is a delicate process as crops are susceptible to various conditions including weather patterns, diseases, and insects. Unlike larger, industrialized agribusinesses, the vast majority of cocoa still comes from small, family-run farms, who often confront outdated farming practices and limited organizational leverage. A steady demand from worldwide consumers draws numerous global efforts and funds committed to support and improve cocoa farm sustainability. (WCF, 2012)

## 2.2. Climate Change

Global warming is the observed increase in the average temperature of the earth's atmosphere and oceans in recent decades. Global surface temperature increased 0.74 ± 0.18°C during the last century. The IPCC concludes that most of the observed temperature increases since the middle of the 20th century was caused by increasing concentrations of GHG resulting from human activity such as fossil fuel burning and deforestation. A rise in the earth's temperatures can in turn root to other alterations in the ecology, including an increase in sea levels and a change in the quantity and pattern of rainfall. (Suryavanshi, Babu, Baghel, & Suryavanshi, 2012)

### *2.2.1. Evidence of Impact of Climate Change on Cocoa Crop*

Cocoa production is highly sensitive to changes in weather conditions. According to the last Annual Report issued by ICCO, during the 2010/2011 season, the weather in Africa was excellent for crop development and harvesting, and consequently the largest output on record was achieved. Thanks to ideal weather conditions, production held up very well despite the political crisis in the Ivory Coast. In Ghana, conductive weather conditions were supported by the continuous introduction of improved farming techniques which resulted in record harvest levels. While in Indonesia, the La Niña weather related pattern caused wetter than normal conditions, where heavy rains impacted negatively on cocoa production. (ICCO, 2012)

Several studies confirm the important role normal variability in climate plays in cocoa production. Cocoa is highly susceptible to drought conditions, which are often associated with high temperatures. Thus with the projected decrease in mean monthly rainfall amount and the rise in mean temperatures the vulnerability of cocoa production to adverse climatic condition will be exacerbated. ( (Anim-Kwapong & Frimpong, 2003), (Ajewole & Iyanda, 2010), (Abayomi, 2012)). Also, the amount of sunlight falling on the cocoa tree will affect its growth and yield, the most marked effect of humidity on cocoa is on the leaf area, the other effects of humidity concern the spread of fungal diseases and the difficulties of drying and storage of the product. (Ajewole & Iyanda, 2010)

### *2.2.2. Modelling Climate Change*

Predicting the impacts of climate change on cacao cultivation in Trinidad and Tobago using GCMs that produce results with low uncertainty is a challenge. Most Caribbean islands are too small to be identified with a grid point in global climate models, limiting the ability to generate future projections for climate change. Even though this is the case, most projections at the regional level are reasonably robust and suggest that permanent climate shocks to the Caribbean countries are expected to include sea level rise, and higher surface air and sea temperatures; extreme weather events, such as tropical storms and hurricanes, and more "El Niño-like" conditions are also expected to become either more frequent or more severe, or both; rain intensity is also expected to increase, leading to both more frequent as well as more severe flooding events. (World Bank, 2003)

The methods adopted to calculate the effects of climate change on the agricultural sector can be classified into two approaches: structural and spatial. The first combines the physical responses of crops with the economic responses of agricultural producers, while the second is characterized by analyzing agricultural production and the climate of the different regions and then, the differences are estimated. (Ordaz, Ramirez, Mora, Acosta, & Serna, 2013)

### *2.2.3.* Special Report on Emissions Scenarios

The Special Report on Emissions Scenarios (SRES) is an IPCC report that was published in 2000. The greenhouse gas emissions scenarios described in the Report have been used to make projections of possible future climate change. The SRES scenarios, as they are often called, were used in the IPCC Third Assessment Report (TAR), published in 2001, and in the IPCC Fourth Assessment Report (AR4), published in 2007.

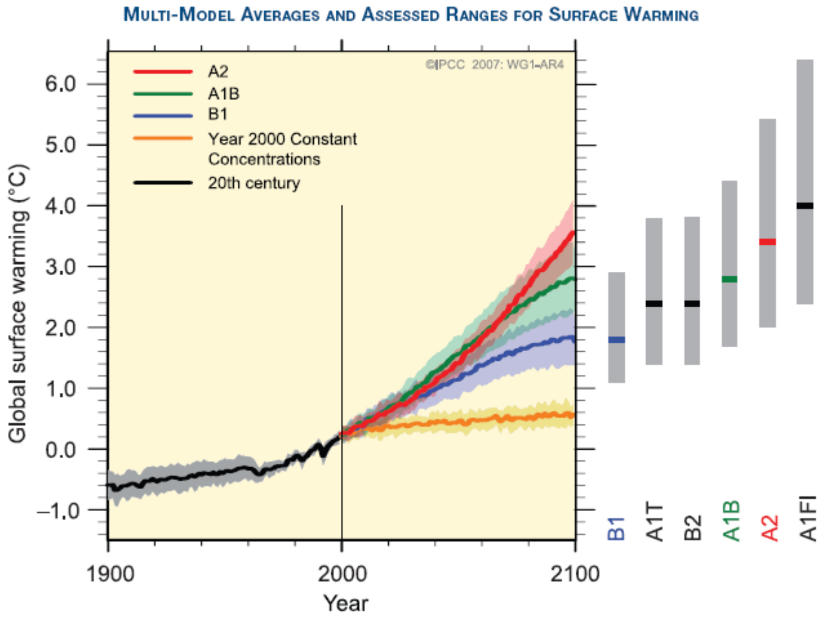

Figure 2. IPCC Future Scenarios.

The SRES scenarios were designed to improve upon some aspects of the IS92 scenarios, which had been used in the earlier IPCC Second Assessment Report of 1995. [4] The SRES scenarios are reference scenarios, which means that they do not take into account any current or future measures to limit greenhouse gas (GHG) emissions (e.g., the Kyoto Protocol to the United Nations Framework Convention on Climate Change). (IPCC, 2000)

Emissions projections of the SRES scenarios are broadly comparable in range to the baseline emissions scenarios that have been developed by the scientific community.[5] The SRES scenarios, however, do not encompass the full range of possible futures: emissions may change less than the scenarios imply, or they could change more. (Karl, Melillo, & Peterson, 2009)

Scenario families contain individual scenarios with common themes. The six families of scenarios discussed in the IPCC's Third Assessment Report (TAR)

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[4] IPCC SRES 2000, Section 1.5: Why new IPCC Emissions Scenarios? http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=27#anc1

[5] IPCC AR4 SYR 2007. Synthesis Report, 3.1. Emissions Scenarios, http://www.ipcc.ch/publications_and_data/ar4/syr/en/mains3.html#3-1

(IPCC, 2001a) (IPCC, 2001a) and Fourth Assessment Report (AR4) (IPCC, 2007) are A1FI, A1B, A1T, A2, B1, and B2. In this study the impact of climate change is modeled with A1B scenario and A2.

**A1 Scenario:** The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (**A1FI**), non-fossil energy sources (**A1T**), or a balance across all sources (**A1B**) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).[6]

**A2 Scenario:** The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.[6]

**B1 Scenario:** The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on

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[6] IPCC TAR 2001, Working Group I: The Scientific Basis, The Emissions Scenarios of the Special Report on Emissions Scenarios (SRES), http://www.ipcc.ch/ipccreports/tar/wg1/029.htm#storya1

global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives. [6]

**B2 Scenario:** The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels. [6]

### *2.2.4.* Species Distribution Models (SDM)

Maps of actual or potential species distributions or habitat suitability are required for many aspects of environmental research, resource management, and conservation planning. For that reason in recent years a burgeoning number of statistical and related methods have been used with mapped biological and environmental data in order to model, or, in some way, spatially interpolate species distributions, and other bio-spatial variables of interest, over large spatial extends. This practice is known as species distribution modeling (SDM). It has also been referred to as environmental, bioclimatic, or species niche modeling, and habitat suitability modeling.  Species distribution models estimate the relationship between species records at sites and the environmental and/or spatial characteristics of those sites. (Franklin, 2009)

The elements of SDM are: (1) A conceptual model of the abiotic and biotic factors controlling species distributions in space and time; (2) data on species occurrences in geographical space; (3) digital maps of environmental variables representing those factors thought to control species distributions; (4) a quantitative or rule-base model linking species occurrence to environmental predictors; (5) a geographic information system for applying the model rules to the environmental variable maps in order to produce a map of predicted species occurrence; and (6) data and methods for evaluating the error or uncertainty in the predictions.

#### *2.2.4.1. EcoCrop*

The database was developed in 1992 by the Land and Water Development Division of FAO (AGLL) as a tool to identify plant species for given environments and uses, and as an information system contributing to a Land Use Planning concept. After publishing several versions, in October 2000 Ecocrop went on-line under its own URL. Since then more than 2 300 species have been added, volume 4 of the "Land and Water Digital Media Series" has been published in two new revisions and many species has been updated.[7]

In 2001 Hijmans developed the basic mechanistic model (also named EcoCrop) to calculate crop suitability index using FAO Ecocrop database in DIVA-GIS. The DIVA-GIS software allows analysis of gene-bank and herbarium databases to elucidate genetic, ecological and geographic patterns in the distribution of crops and wild species. It helps improve data quality by assigning coordinates and can also be used to check existing coordinates using overlays of the collection-site and administrative boundary databases. In addition, DIVA can extract climate data for all terrestrial locations, which can be used to describe the environment of collection sites. (Hijmans, Guarino, Cruz, & Rojas, 2001)

And the most recent development in the Ecocrop Suitability Modeling was undertaken by CIAT-CCAFS and ICAS (Ramirez-Villegas, Jarvis, & Läderach, 2013), the calibration and evaluation procedures used in the EcoCrop Model can be seen in a recent study that focused on modeling the suitability of sorghum (Ramirez-Villegas, Jarvis, & Läderach, 2013). They use current climate data from the WorldClim[8] database along with a calibrated set of growing parameters and

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[7] ECOCROP FAO
http://ecocrop.fao.org/ecocrop/srv/en/home

[8] WorldClim Database
http://www.worldclim.org

develop a set of metrics and specific calculations to determine current suitability on a geographic basis over Africa and South-east Asia.

### *2.2.4.2. MAXENT*

MaxEnt is a software based on the maximum-entropy approach for species habitat modeling. This software[9] takes as input a set of layers or environmental variables (such as elevation, precipitation, etc.), as well as a set of geo-referenced occurrence locations, and produces a model of the range of the given species. (Phillips & Dudík, 2004)

The idea of MaxEnt is to estimate a target probability distribution by finding the probability distribution of maximum entropy (i.e., that is most spread out, or closest to uniform), subject to a set of constraints that represent our incomplete information about the target distribution. The information available about the target distribution often presents itself as a set of real-valued variables, called “features”, and the constraints are that the expected value of each feature should match its empirical average (average value for a set of sample points taken from the target distribution). When MaxEnt is applied to presence-only species distribution modeling, the pixels of the study area make up the space on which the MaxEnt probability distribution is defined, pixels with known species occurrence records constitute the sample points, and the features are climatic variables, elevation, soil category, vegetation type or other environmental variables, and functions thereof. (Phillips, Anderson, & Schapire, 2006)

Maxent have a lot of advantages such as: (1) It requires only presence data, together with environmental information for the whole study area. (2) It can utilize both continuous and categorical data, and can incorporate interactions between different variables. (3) It uses efficient deterministic algorithms. (4) The output is

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[9] The software is available to download in old to current version in : http://www.cs.princeton.edu/~schapire/MaxEnt/

continuous, allowing fine distinctions to be made between the modeled suitability of different areas. If binary predictions are desired, this allows great flexibility in the choice of threshold.  (Phillips, Anderson, & Schapire, 2006)

However, like all the distribution models had some disadvantages such as: It uses an exponential model for probabilities, which is not inherently bounded above and can give very large predicted values for environmental conditions outside the range present in the study area. Extra care is therefore needed when extrapolating to another study area or to future or past climatic conditions. Furthermore, MaxEnt is not available in standard statistical packages, special-purpose software is required. (Phillips, Anderson, & Schapire, 2006)

# 3. STUDY AREA AND DATA OVERVIEW

## 3.1. Study Area

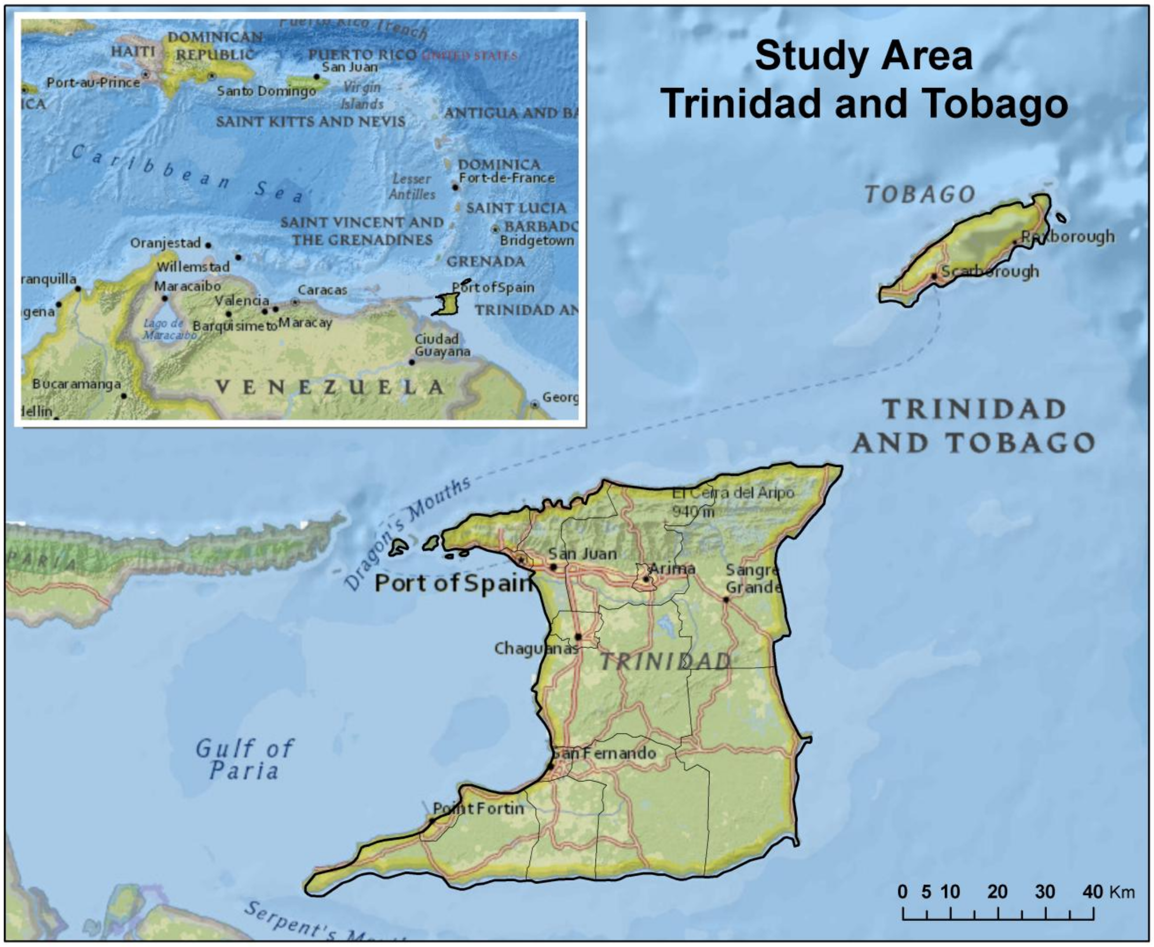

Figure 3. Trinidad and Tobago Location.

**Location**

The Republic of Trinidad and Tobago is a twin island nation located at the south-eastern end of the Caribbean archipelago lying roughly between 10 degrees north and 11.5 degrees north latitude and between 60 degrees west and 62 degrees west longitude. It comprises a total land area of 5,126km$^2$, with Trinidad having an area of 4,826km$^2$ and Tobago (the smaller), an area of 300km$^2$. Trinidad is the most southerly of the Caribbean Islands, bounded on the north by the Caribbean Sea; on the west by *the Gulf of Paria*; on the east by *the Atlantic Ocean* and on the south by *the Columbus Channel*. Tobago lies approximately 32km north-east of Trinidad, and is separated from Trinidad by a channel, the Tobago Sound which is nearly 12km in width. (WRA, 2001)

### Physiography

Trinidad features three (3) mountain ranges, the main one in the north extending from the east-west boundaries (maximum height of 900 m), the smallest one in the centre (maximum height of 300 m) and the other in the southern part of the island characterized by low hills. Undulating land, plains and swamps separate the ranges. The ranges decrease in altitude from north to south. These features allow for the division of the island into five (5) physiographic regions, namely, the Northern Range, the Northern Basin, the Central Range, the Southern Basin and the Southern Range. The dominant relief feature of Tobago is a metamorphic and volcanic mountain, the Main Ridge, which runs for about two-thirds of the length of the island in a south-west to north-east direction. Running parallel to the coastline, it attains a maximum elevation of 550 metres above mean sea level. This ridge slopes off steeply to the north-east and more gently to the south-west. The south-western end of the island is occupied by a flat coral limestone platform that extends seaward to form the off-shore coral reefs. (WRA, 2001)

### Administration Division

Trinidad and Tobago is split into 14 regional corporations and municipalities of Trinidad; consisting of 9 regions and 5 municipalities and Tobago.

- Trinidad (14): Arima, Chaguaranas, Couva-Tabauite-Talparo, Diego Martin, Penal-Debe, Point Fortin, Port of Spain, Princes Town, Rio Claro-Mayaro, San Fernando, San Juan-Laventille, Sangre Grande, Siparia, Tunapuna-Piarco,
- Tobago (1): Tobago

## Climate

The climate in the Caribbean region is characterized by dry winters and wet summers and is strongly influenced by the North Atlantic subtropical high (NASH). During winter the NASH lies further south with strong easterly trade winds modulating the climate and weather in the region, which is usually at its driest with reduced atmospheric humidity. Island climates in the Indian Ocean region are dominated to a large extent by the Asian Monsoon system, composed of the southwest or summer monsoon and the northeast or winter monsoon. (UNFCCC, 2007)

Trinidad and Tobago experience a climate that is tropical, warm and humid with two (2) major seasons. From January to May is the dry season with the wet season in June to some areas. In Tobago the average rainfall ranges from 3,800mm in the Main Ridge to less than 1,250mm in the south-western lowlands. The average annual minimum temperature varies between 22 and 25$^{o}$C at night and the maximum between 29 and 31$^{o}$C during the day. (WRA, 2001) A short dry spell of two (2) to three (3) weeks called the "*Petit Careme*" occurs in the middle of September or October. The prevailing winds are the North-East Trades which bring the heaviest rains to the highland areas of north-east Trinidad and in Tobago which lies along a south-west to north-east axis; there is no clear cut distribution between the windward and leeward districts. The average annual rainfall of Trinidad is 2,000mm. The evapotranspiration rate is very high accounting for up to 60% of the total rainfall received.

These climate characteristics and their particular socio-economic situations make Trinidad and Tobago and in general the SIDS, are some of the most vulnerable countries in the world to climate change. This combined with the fact that the SIDS produces extremely low levels of GHG, means that they will suffer disproportionately from the damaging impacts of climate change. (UNFCCC, 2007)

## 3.2. Data Overview

### *3.2.1. Current Climate Data (~1950-2000)*

The historical climate data were obtained from the database ***WorldClim***[10]***,*** downloaded by tile***.*** The data layers were generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (about 1km at Equator). Variables included are monthly total precipitation, and monthly mean, minimum and maximum temperature, and 19 derived bioclimatic variables. (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005)

The WorldClim interpolated climate layers were made using:

- ✓ Major climate databases compiled by GHCN, FAO, WMO, CIAT, R-HydroNet, and a number of additional minor databases for Australia, New Zealand, the Nordic European Countries, Ecuador, Peru, Bolivia, among others.
- ✓ The SRTM[11] elevation database (aggregated to 30 arc-seconds, "1 km")
- ✓ The ANUSPLIN software. ANUSPLIN is a program for interpolating noisy multi-variant data using thin plate smoothing splines. We used latitude, longitude, and elevation as independent variables.

A set of ***Bioclimatic variables***[12] were derived from the monthly temperature and rainfall data. These variables represent annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). They are coded as follows:

**BIO1 =** Annual Mean Temperature

**BIO2 =** Mean Diurnal Range (Mean of monthly (max temp - min temp))

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[10] WorldClim – Global Climate Data
http://www.worldclim.org/current

[11] The CGIAR Consortium for Spatial Information, SRTM 90m Digital Elevation Data
http://srtm.csi.cgiar.org/

[12] BIOCLIM Variables
http://www.worldclim.org/bioclim

**BIO3** = Isothermality (BIO2/BIO7) (* 100)

**BIO4** = Temperature Seasonality (standard deviation *100)

**BIO5** = Max Temperature of Warmest Month

**BIO6** = Min Temperature of Coldest Month

**BIO7** = Temperature Annual Range (BIO5-BIO6)

**BIO8** = Mean Temperature of Wettest Quarter

**BIO9** = Mean Temperature of Driest Quarter

**BIO10** = Mean Temperature of Warmest Quarter

**BIO11** = Mean Temperature of Coldest Quarter

**BIO12** = Annual Precipitation

**BIO13** = Precipitation of Wettest Month

**BIO14** = Precipitation of Driest Month

**BIO15** = Precipitation Seasonality (Coefficient of Variation)

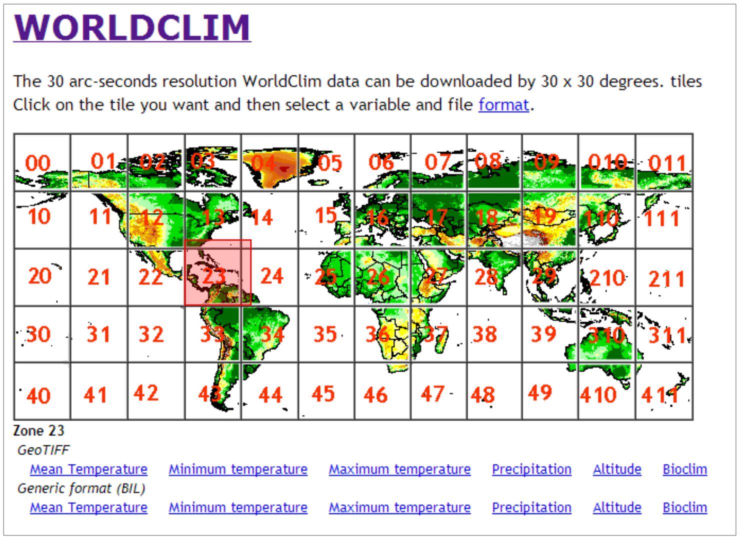
**BIO16** = Precipitation of Wettest Quarter

**BIO17** = Precipitation of Driest Quarter

**BIO18** = Precipitation of Warmest Quarter

**BIO19** = Precipitation of Coldest Quarter

The bioclimatic variables of Trinidad and Tobago were downloaded from WorldClim website (www.worldclim.org). The tile 23 corresponds to the Caribbean region was downloaded. (Figure 5)



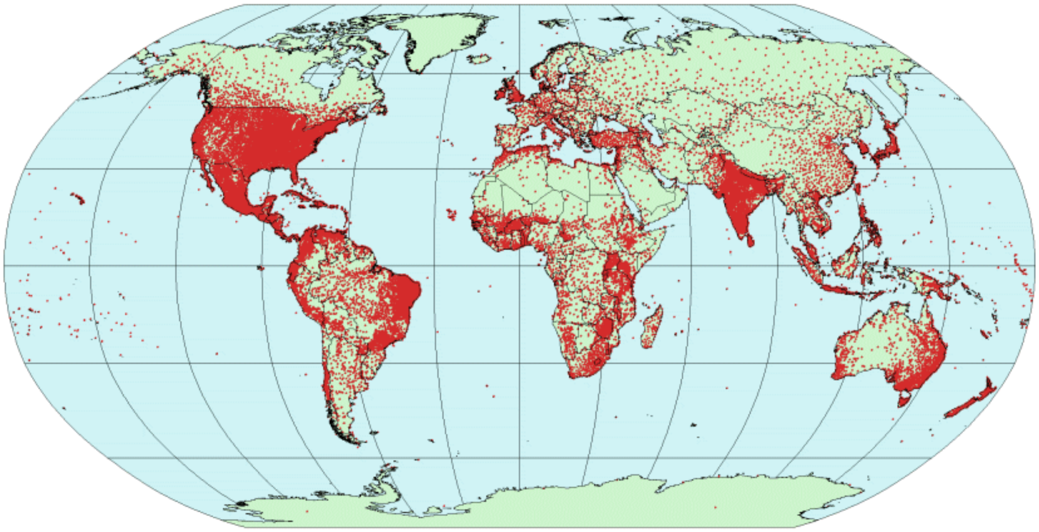
WORLDCLIM

The 30 arc-seconds resolution WorldClim data can be downloaded by 30 x 30 degrees. tiles Click on the tile you want and then select a variable and file format.

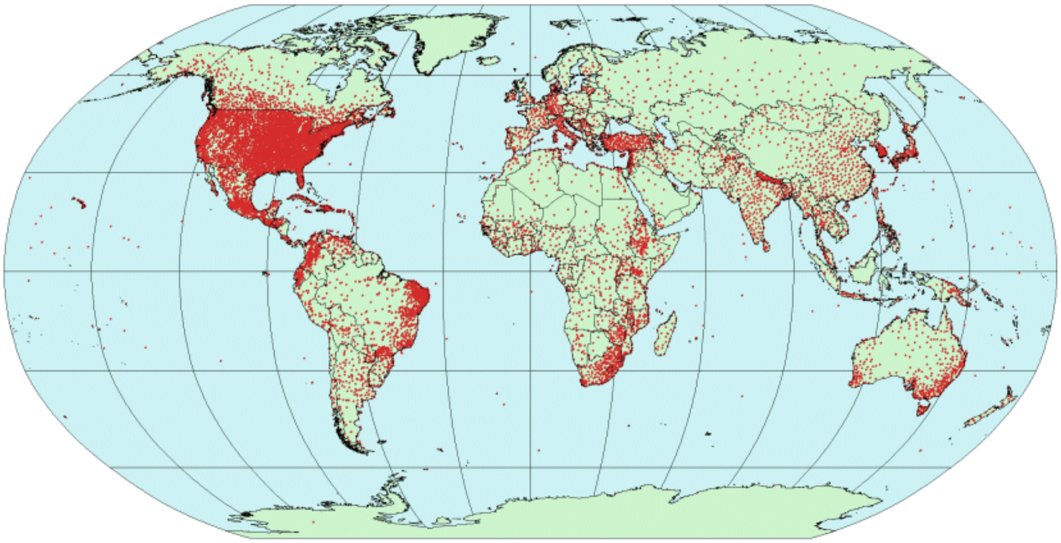
**Figure 4. Screenshot from process of data download.**

On this page it is possible to obtain the mean temperature, minimum temperature, maximum temperature, precipitation, altitude, and bioclimatic variables of the selected tile in 30 arc-seconds of spatial resolution and in *GeoTIFF* format.

The maps **(Figure 4)** below show the spatial distribution the climate stations for which WorldClim had data.



**(A)**



**(B)**

**Source:** (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005)

**Figure 5. Spatial Distribution of weather stations of WorldClim database. (A) Preciptation (47 554 stations); (B) Maximum or minimum temperature (14 930 stations).**

### *3.2.2. GCMs for Future Climate*

Emission scenarios impose conditions for climate models to calculate the future projection . To estimate the effects of emissions established by emission scenarios have on the global climate, the Global Climate Models (GCMs) are used.The GCMs, representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. GCMs depict the climate using a three dimensional grid over the globe, typically having a horizontal resolution of between 250 and 600 km, 10 to 20 vertical layers in the atmosphere (IPCC, 2007). Their resolution is thus quite coarse relative to the scale of exposure units in most impact assessments,[13] for that reason in this study the downscaled data produced by CIAT (Ramirez-Villegas, Jarvis, & Läderach, 2013) will be used. This data provides 24 future scenarios at the same spatial resolution of WorldClim data (2.5arc-min).

Most GCMs simulate extensive characteristics of climate and they can display large-scale changes observed in the recent past , so it can be used with some confidence to give projections of the climate response to the current and future human activity.

Climate scenarios based on the output of the GCMs are the major source of information for climate research today. GCMs are the best currently available scientific tool to simulate global climate system response to a change in the composition of the atmosphere. However, they differ in terms of: Formulation (equations), resolution, inputs, accuracy (validation) availability.

Table 3 shows the existing models and their resolutions:

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[13] IPCC Website
http://www.ipcc-data.org/guidelines/pages/gcm_guide.html

Table 3. Available Global Circulation Models

| Model | Country | Resolution (Atmosphere) |
|---|---|---|
| **BCCR-BCM2.0** | Norway | T63, L31 |
| **CCCMA-CGM3.1 (T47)** | Canada | T47(3.75x3.75), L31 |
| **CCCMA-CGM3.1 (T63)** | Canada | T63(2.8x2.8), L31 |
| **CNRM-CM3** | France | T63(2.8x2.8), L45 |
| **CSIRO-Mk3.0** | Australia | T63, L18 |
| **CSIRO-Mk3.5** | Australia | T63, L18 |
| **GFDL-CM2.0** | USA | 2.5x2.0, L24 |
| **GFDL-CM2.1** | USA | 2.5x2.0, L24 |
| **GISS-AOM** | USA | 4x3, L12 |
| **GISS-MODEL-EH** | USA | 5x4, L20 |
| **GISS-MODEL-ER** | USA | 5x4, L20 |
| **IAP-FGOALS1.0-G** | China | 2.8x2.8, L26 |
| **INGV-ECHAM4** | Italy | T42, L19 |
| **INM-CM3.0** | Russia | 5x4, L21 |
| **IPSL-CM4** | France | 2.5x3.75, L19 |
| **MICROC3.2-HIRES** | Japan | T106, L56 |
| **MICROC3.2-MEDRES** | Japan | T42, L20 |
| **MIUB-ECHO-G** | Germany/Korea | T30, L19 |
| **MPI-ECHAM5** | Germany | T63, L32 |
| **MPI-CGCM2.3.2.A** | Japan | T42, L30 |
| **NCAR-CCSM3.0** | USA | T85L26, 1.4x1.4 |
| **NCAR-PCM1** | USA | T42(2.8x2.8), L18 |
| **UKMO-HADCM3** | UK | 3.75x2.5, L19 |
| **UKMO-HADGEM1** | UK | 1.875x1.25, L38 |

# 4. METHODOLOGY

The methodology of this study is based on the deterministic model, MaxEnt, described in the literature review. The figure 6 shows the methodology scheme:

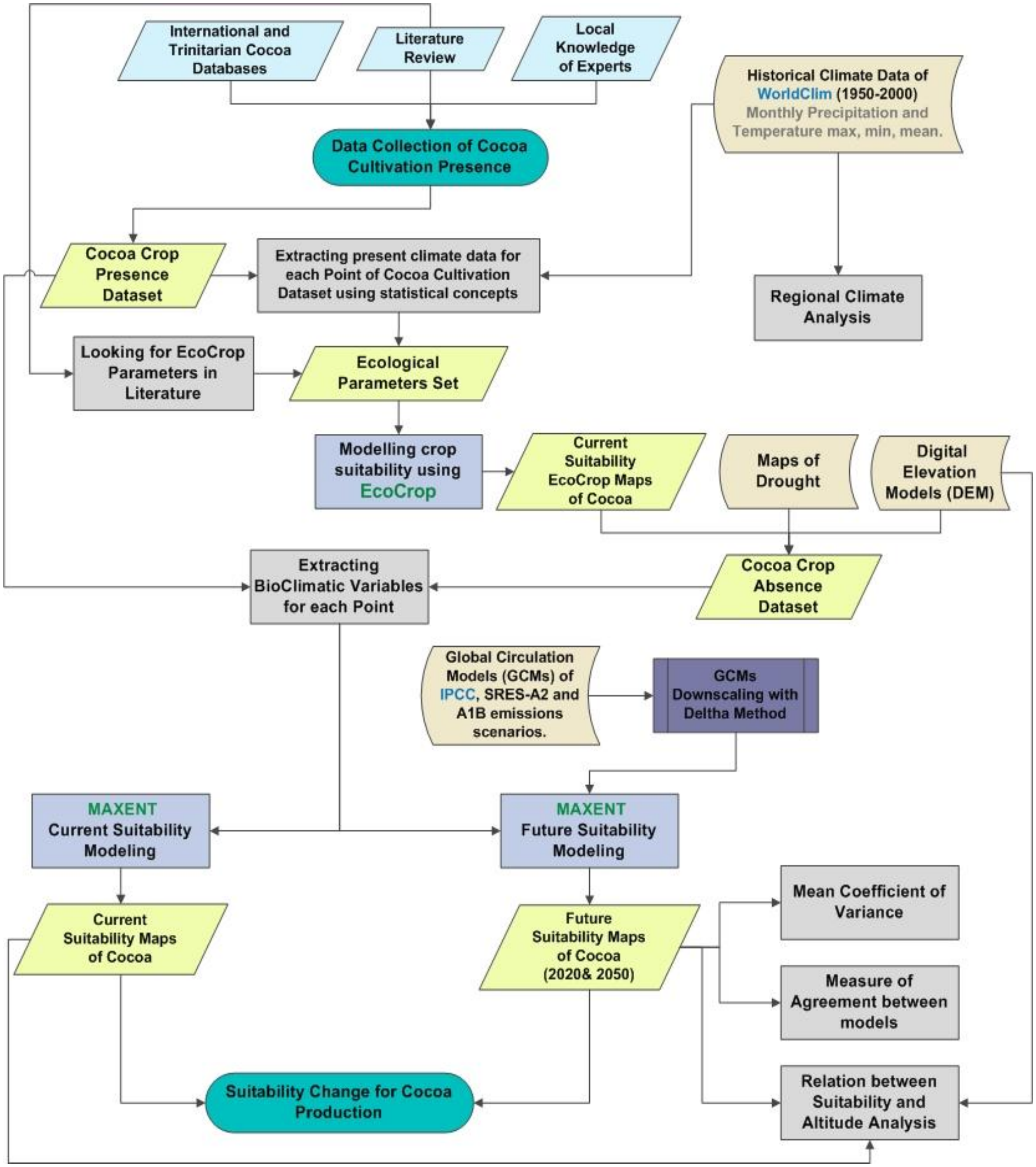


Figure 6. Methodology Scheme.

As show in the figure 6, the first step, was collected the presence points of the crop in Trinidad and Tobago. For this purpose a detailed literature review was conducted. Unfortunately, it is not easy to find information. Twenty six coordinates of cocoa farms across Trinidad and Tobago have been compiled from “Trinitario Cocoa Resources” website. The municipalities included Tobago, Piarco, Sangre Grande, Talparo, Princes Town and Siparia. The coordinates were distributed between an altitudinal range of 34 to 200 masl.

For the second step, current climate data was extracted for each point of Cocoa Cultivation Dataset. As current climate (baseline) we used historical climate data from the WorldClim database (Hijmans *et al*., 2005). WorldClim data are generated through interpolation of average monthly climate data from weather stations on a 30 arc-second resolution grid (often referred to as "1 km" resolution). Variables included are monthly total precipitation, and monthly mean, minimum, and maximum temperature, and 19 bioclimatic variables (Hijmans *et al*., 2005). Furthermore, within the WorldClim database, there are bioclimatic variables that were derived from the monthly temperature and rainfall values to generate more biologically meaningful variables, which are often used in ecological niche modelling. The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation), seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wettest and driest quarters).

After that, future climate data was extracted using GCMs. Global circulation models (GCMs) are a computer-based model that calculates and predicts what climate patterns will be like in a number of years in the future. GCMs use equations of motion as a numerical weather prediction model, with the purpose of numerically simulating changes in the climate as a result of slow changes in some boundary conditions (such as the solar constant) or physical parameters (such as the concentration of greenhouse gases).

The third step was the downscaling process, due to the spatial resolution of the GCM results is inappropriate to analyse the impacts on agriculture in the Caribbean islands as in almost all cases the grid cells measure more than 100km a side. Downscaling is therefore needed to provide higher-resolution surfaces of expected future climates if the likely impacts of climate change on agriculture are to be more accurately forecasted. A simple downscaling method (named delta method) was performed, based on the sum of interpolated anomalies to high-resolution monthly climate surfaces from WorldClim (Hijmans*et al*., 2005). The method, basically, produces a smoothed (interpolated) surface of changes in climates (deltas or anomalies) and then applies this interpolated surface to the baseline climate (from WorldClim), taking into account the possible bias due to the difference in baselines. (Ramirez & Jarvis, 2010)

The fourth step was the modelling crop suitability using MaxEnt. Maximum entropy-MaxEnt is a general-purpose method for making predictions or inferences from incomplete information. The idea is to estimate a target probability distribution by finding the probability distribution of maximum entropy, subject to a set of constraints that represent incomplete information about the target distribution. (Phillips, Anderson, & Schapire, 2006). The probability distribution is the sum of each weighed variable divided by a scaling constant to ensure that the probability value ranges from 0 to 1. The program starts with a uniform probability distribution and iteratively alters one weight at a time to maximize the likelihood of reaching the optimum probability distribution.  MAXENT is generally considered to be the most accurate model (Elith, et al., 2006)

Finally the results were analysed and two measurements of uncertainty were computed: (1) the agreement among models calculated as percentage of models predicting changes in the same direction as the average of all models at a given location and (2) the coefficient of variation among bioclimatic variables.

# 5. RESULTS

## 5.1. Regional changes in the mean annual precipitation

### Regional changes under A2 scenario

To obtain the regional changes in the annual mean precipitation the average of the climatic variable BIO12 (Annual Mean Precipitation) of the future (2020, 2050) and the present were subtracted. The data obtained are shown in the table 3:

**Table 4. Change of Annual mean precipitation in the future under A2 scenario.**

| **BIO 12: Annual Precipitation 2020** | | | | |
|---|---|---|---|---|
| **Region** | **Mean_min** | **Max** | **Min** | **Mean_max** |
| **Arima** | -63.47 | -63.11 | -63.53 | -63.21 |
| **Chaguanas** | -62.97 | -62.37 | -63.32 | -62.48 |
| **Diego Martin** | -61.62 | -59.05 | -62.05 | -60.55 |
| **Point Fortin** | -60.01 | -59.53 | -60.21 | -59.63 |
| **Port Of Spain** | -61.86 | -61.32 | -61.95 | -61.43 |
| **Princes Town** | -63.89 | -62.26 | -64.37 | -62.99 |
| **San Fernando** | -62.49 | -61.63 | -62.68 | -61.95 |
| **Sangre Grande** | -64.99 | -63.89 | -65.53 | -64.37 |
| **Siparia** | -61.13 | -55.95 | -61.84 | -58.66 |
| **Tobago** | -64.26 | -63.47 | -64.53 | -63.92 |
| **All region** | -62.67 | -61.26 | -63.00 | -61.92 |

| **BIO 12: Annual Precipitation 2050** | | | | |
|---|---|---|---|---|
| **Region** | **Mean_min** | **Max** | **Min** | **Mean_max** |
| **Arima** | -115.97 | -115.53 | -116.11 | -115.63 |
| **Chaguanas** | -113.79 | -112.68 | -114.37 | -112.89 |
| **Diego Martin** | -112.05 | -106.58 | -112.58 | -109.67 |
| **Point Fortin** | -107.32 | -105.58 | -107.68 | -106.03 |
| **Port Of Spain** | -112.23 | -111.26 | -112.37 | -111.64 |
| **Princes Town** | -115.35 | -111.58 | -116.79 | -113.03 |
| **San Fernando** | -112.17 | -110.79 | -112.42 | -111.18 |
| **Sangre Grande** | -118.40 | -116.37 | -118.89 | -117.32 |
| **Siparia** | -109.47 | -98.84 | -110.74 | -104.09 |
| **Tobago** | -117.42 | -116.37 | -117.89 | -116.88 |
| **All region** | **-113.42** | **-110.56** | **-113.98** | **-111.84** |

In table 4 the negative value indicates that the average annual precipitation is greater today than the annual precipitation predicted for the years 2020 and 2050 under the A2 scenario. The mean annual precipitation will decrease progressively, with a mean reduction in 2020 of 62mm, and a mean decline of 113mm by 2050.

In Figure 7 the edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

According with the results in the future, the province that represent the highest decrease in precipitation is Siparia; approximately between 56 and 62mm in 2020 and between 99 and 111mm in 2050. Siparia is located in the southern of Trinidad.

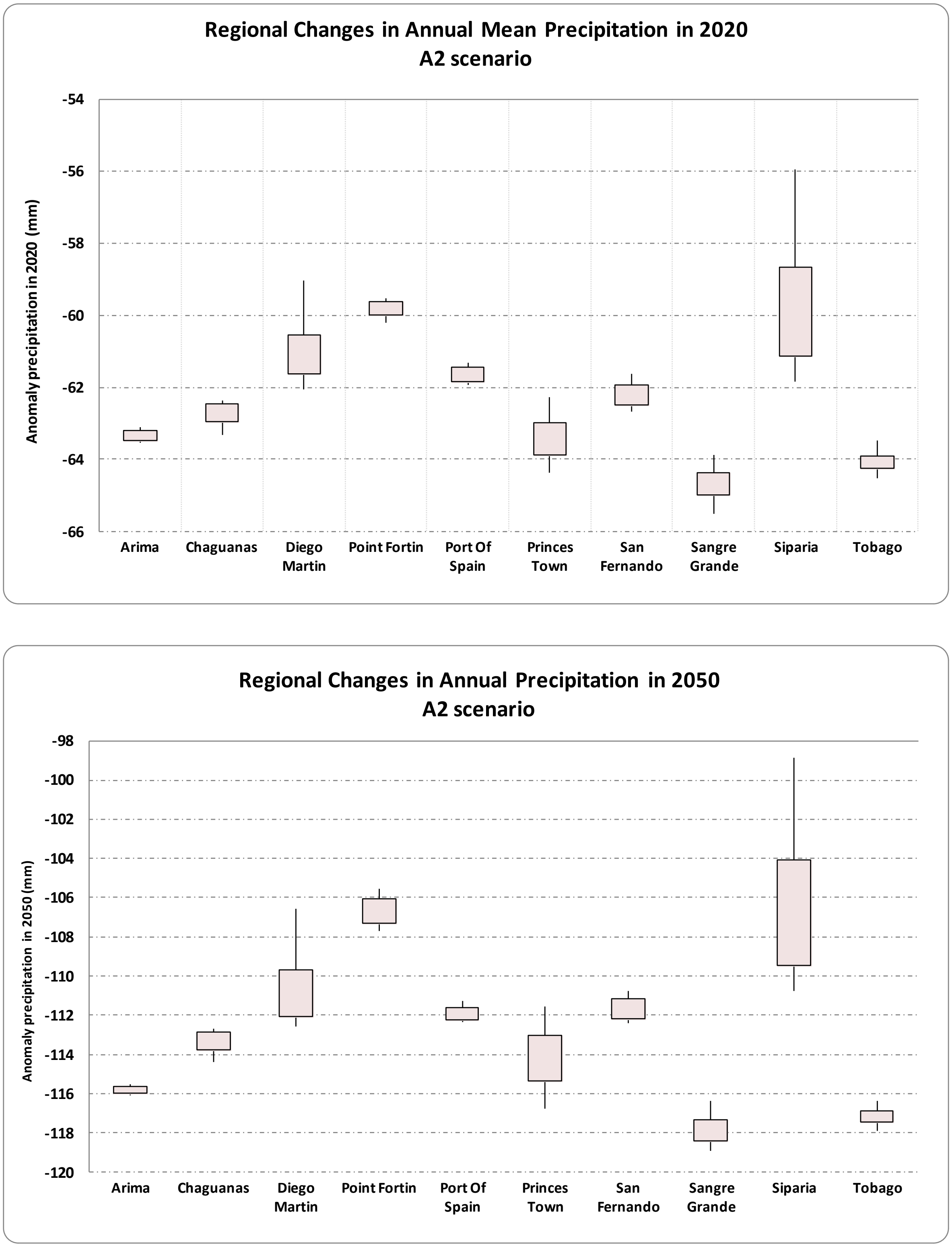


Figure 7. Regional Changes in Annual Precipitation in the future under A2 scenario.

## Regional changes under A1B scenario

To obtain the regional changes in the annual mean precipitation the average of the climatic variable BIO12 (Annual Mean Precipitation) of the future (2020, 2050) and the present were subtracted. The data obtained are showed in the table 4:

**Table 5 Change of Annual mean precipitation in the future under A1B scenario.**

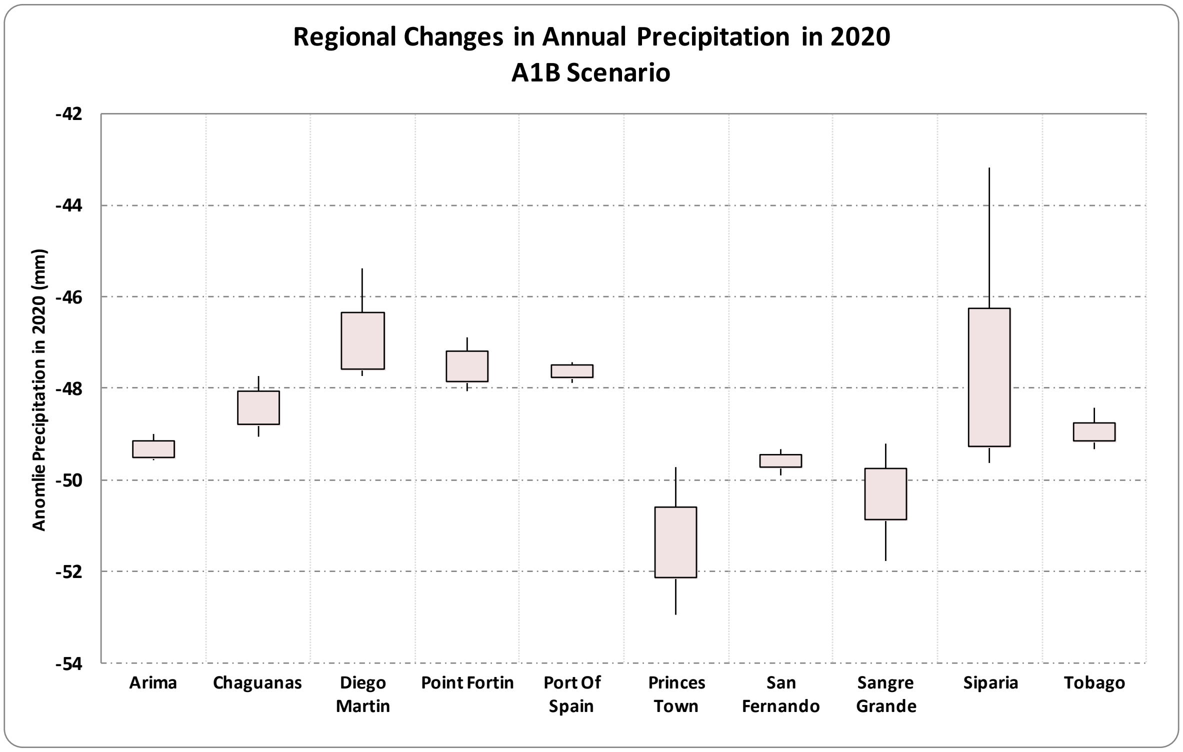
| BIO 12: Annual Precipitation 2020 | | | | |
|---|---|---|---|---|
| **Region** | **Mean_min** | **Max** | **Min** | **Mean_max** |
| **Arima** | -49.51 | -49.00 | -49.58 | -49.16 |
| **Chaguanas** | -48.79 | -47.74 | -49.05 | -48.07 |
| **Diego Martin** | -47.57 | -45.37 | -47.74 | -46.34 |
| **Point Fortin** | -47.86 | -46.89 | -48.05 | -47.18 |
| **Port Of Spain** | -47.76 | -47.42 | -47.89 | -47.48 |
| **Princes Town** | -52.14 | -49.74 | -52.95 | -50.60 |
| **San Fernando** | -49.73 | -49.32 | -49.89 | -49.47 |
| **Sangre Grande** | -50.88 | -49.21 | -51.79 | -49.74 |
| **Siparia** | -49.28 | -43.16 | -49.63 | -46.25 |
| **Tobago** | -49.14 | -48.42 | -49.32 | -48.75 |
| **All region** | **-49.27** | **-47.63** | **-49.59** | **-48.30** |

| BIO 12: Annual Precipitation 2050 | | | | |
|---|---|---|---|---|
| **Region** | **Mean_min** | **Max** | **Min** | **Mean_max** |
| **Arima** | -108.70 | -108.21 | -108.84 | -108.35 |
| **Chaguanas** | -107.55 | -105.63 | -108.11 | -106.31 |
| **Diego Martin** | -104.42 | -100.00 | -104.84 | -102.54 |
| **Point Fortin** | -103.17 | -101.68 | -103.68 | -102.16 |
| **Port Of Spain** | -104.55 | -103.89 | -104.84 | -104.00 |
| **Princes Town** | -111.16 | -107.26 | -112.42 | -108.88 |
| **San Fernando** | -107.34 | -106.21 | -107.74 | -106.63 |
| **Sangre Grande** | -111.65 | -108.63 | -112.68 | -110.12 |
| **Siparia** | -105.71 | -96.11 | -106.68 | -100.84 |
| **Tobago** | -109.78 | -108.68 | -110.00 | -109.10 |
| **All region** | **-107.40** | **-104.63** | **-107.98** | **-105.89** |

In the table 5 the negative value indicates that the average annual precipitation is greater today than the annual precipitation predicted for the years 2020 and 2050 under the A1B scenario. The mean annual precipitation will decrease progressively. By 2020 an average decline of 49mm and by 2050 an average decline of 106mm.

In the Figure 8, the edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

According with the results in the future, the province that represent the highest decrease in precipitation is Siparia; approximately between 43 and 49.6mm in 2020 and between 96 and 107mm in 2050.



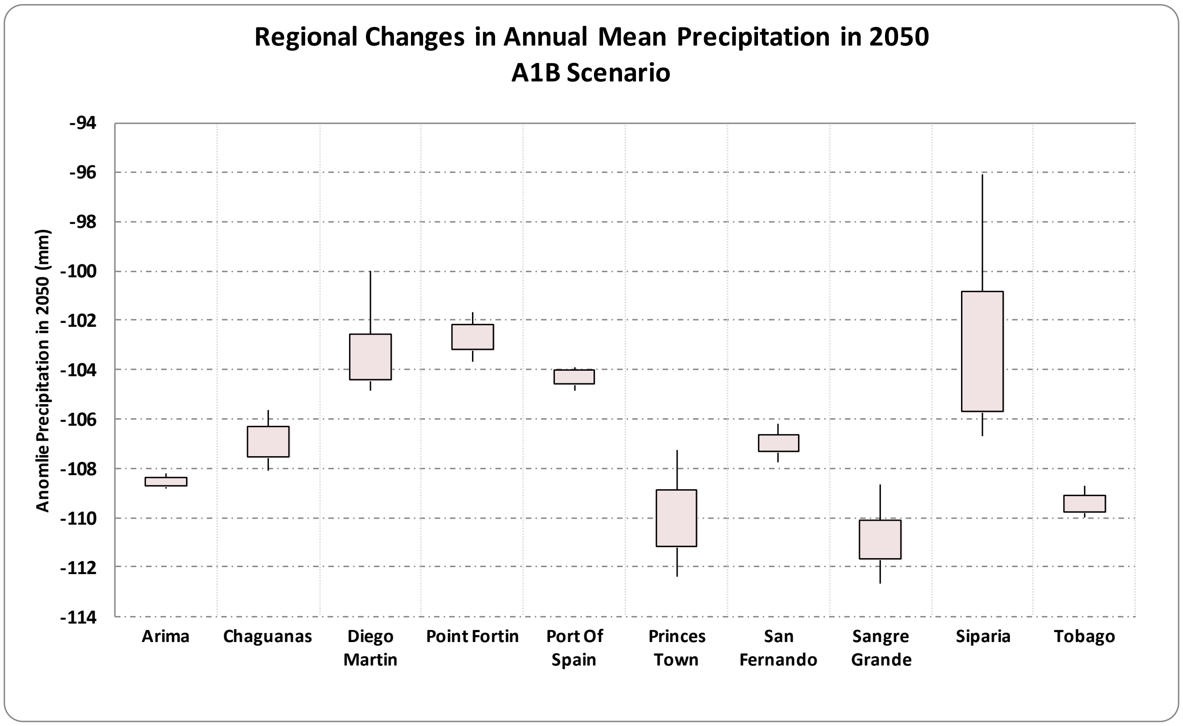


Figure 8. Regional changes in annual mean precipitation in the future under A1B scenario.

## 5.2. Regional changes in the mean annual temperature

### Regional changes in 2020 under A2 scenario

To obtain the regional changes in the annual mean temperature in 2020 the average of the climatic variable BIO1 (Annual Mean Temperature) of the future and the present were subtracted. The data obtained are shown in the table 5:

Table 6. Change of annual mean temperature in the future.

| BIO 1: Annual Mean Temperature in 2020 | | | | |
|---|---|---|---|---|
| **Region** | **Mean_min** | **Max** | **Min** | **Mean_max** |
| **Arima** | 0.85 | 0.90 | 0.83 | 0.89 |
| **Chaguanas** | 0.84 | 0.94 | 0.82 | 0.90 |
| **Diego Martin** | 0.83 | 0.91 | 0.79 | 0.88 |
| **Point Fortin** | 0.87 | 0.95 | 0.84 | 0.94 |
| **Port Of Spain** | 0.83 | 0.91 | 0.82 | 0.88 |
| **Princes Town** | 0.87 | 0.96 | 0.84 | 0.93 |
| **San Fernando** | 0.86 | 0.93 | 0.84 | 0.92 |
| **Sangre Grande** | 0.83 | 0.94 | 0.80 | 0.90 |
| **Siparia** | 0.88 | 0.97 | 0.84 | 0.95 |
| **Tobago** | 0.80 | 0.89 | 0.78 | 0.87 |
| **All region** | **0.85** | **0.93** | **0.82** | **0.91** |

| BIO 1: Annual Mean Temperature in 2050 | | | | |
|---|---|---|---|---|
| **Region** | **Mean_min** | **Max** | **Min** | **Mean_max** |
| **Arima** | 1.91 | 1.97 | 1.89 | 1.97 |
| **Chaguanas** | 1.94 | 2.04 | 1.93 | 2.00 |
| **Diego Martin** | 1.91 | 2.01 | 1.86 | 1.96 |
| **Point Fortin** | 2.06 | 2.14 | 2.03 | 2.13 |
| **Port Of Spain** | 1.92 | 2.02 | 1.92 | 1.97 |
| **Princes Town** | 2.01 | 2.14 | 1.97 | 2.09 |
| **San Fernando** | 2.00 | 2.09 | 1.99 | 2.07 |
| **Sangre Grande** | 1.87 | 2.01 | 1.82 | 1.97 |
| **Siparia** | 2.07 | 2.20 | 2.02 | 2.14 |
| **Tobago** | 1.72 | 1.84 | 1.69 | 1.79 |
| **All region** | **1.94** | **2.05** | **1.91** | **2.01** |

In table 6 the positive values indicate that according to the model the average annual temperature is greater in the future than today. Annual mean temperature will increase progressively. By 2020 on average increase of 0.88ºC, and by 2050 an average increase of 1,97ºC.

In Figure 9, the edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.

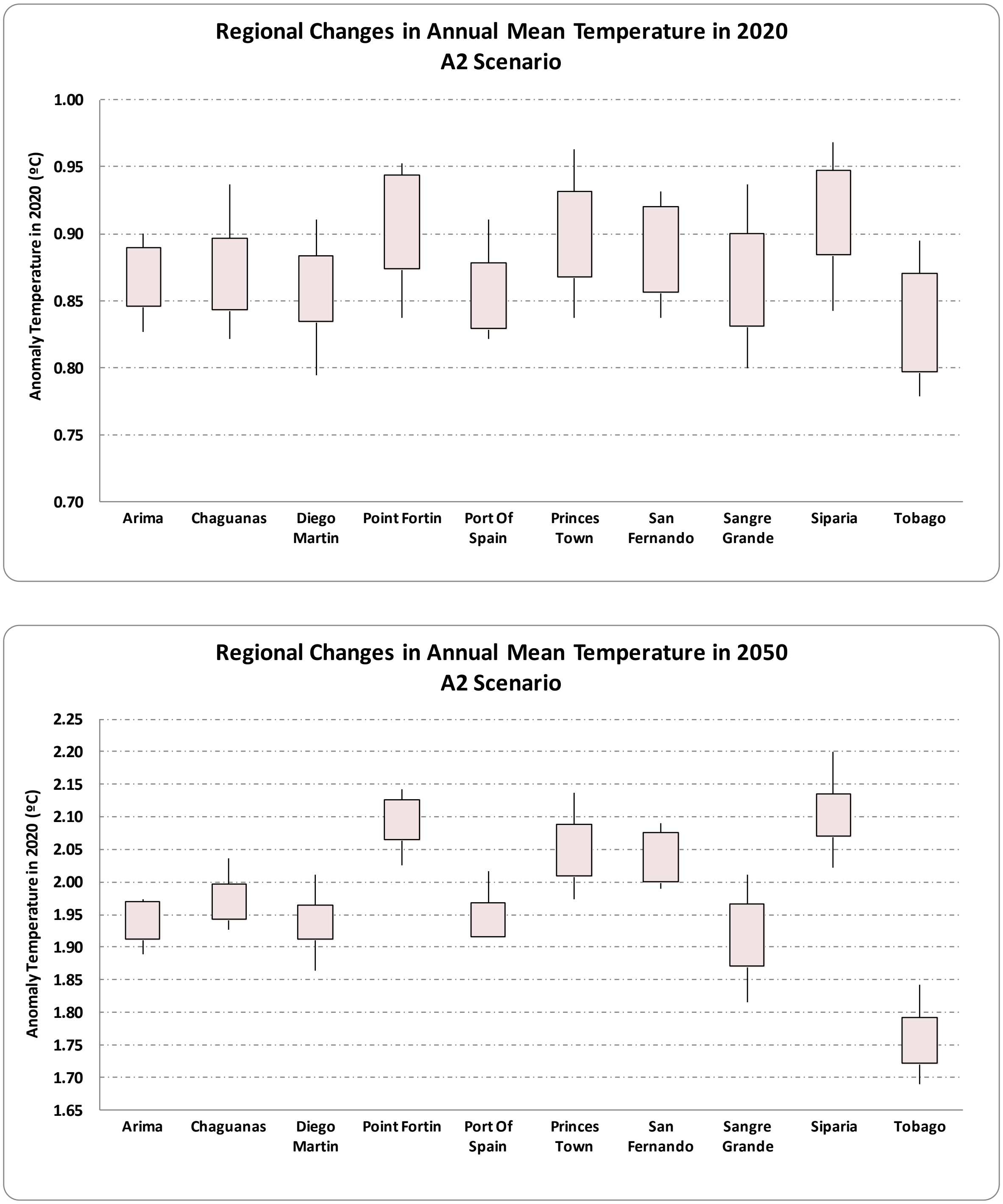


Figure 9. Regional changes in annual temperature in the future under A2 scenario.

## Regional changes under A1B scenario

To obtain the regional changes in the annual mean temperature the average of the climatic variable BIO1 (Annual Mean Temperature) of the future (2020, 2050) and the present were subtracted. The data obtained are shown in the table 6:

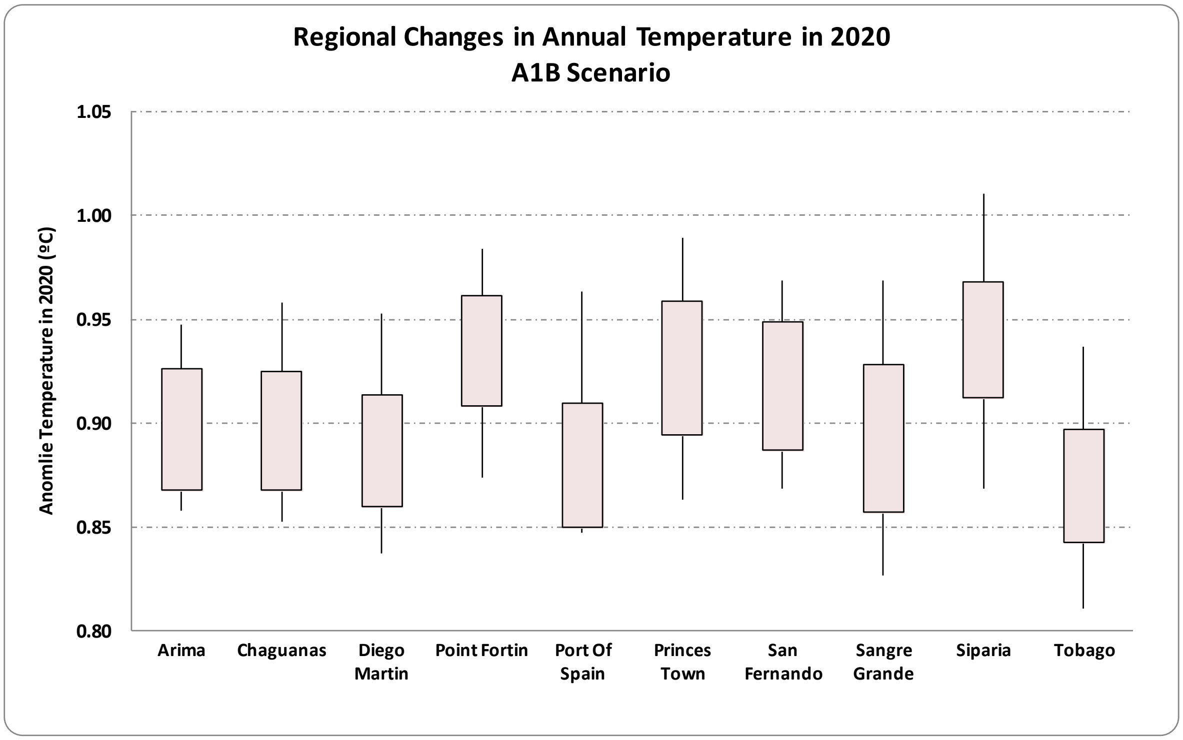
Table 7 Change of Annual mean precipitation in the future under A1B scenario.

| BIO 1: Annual Mean Temperature 2020 | | | | |
|---|---|---|---|---|
| **Region** | **Mean_min** | **Max** | **Min** | **Mean_max** |
| **Arima** | 0.87 | 0.95 | 0.86 | 0.93 |
| **Chaguanas** | 0.87 | 0.96 | 0.85 | 0.92 |
| **Diego Martin** | 0.86 | 0.95 | 0.84 | 0.91 |
| **Point Fortin** | 0.91 | 0.98 | 0.87 | 0.96 |
| **Port Of Spain** | 0.85 | 0.96 | 0.85 | 0.91 |
| **Princes Town** | 0.89 | 0.99 | 0.86 | 0.96 |
| **San Fernando** | 0.89 | 0.97 | 0.87 | 0.95 |
| **Sangre Grande** | 0.86 | 0.97 | 0.83 | 0.93 |
| **Siparia** | 0.91 | 1.01 | 0.87 | 0.97 |
| **Tobago** | 0.84 | 0.94 | 0.81 | 0.90 |
| **All region** | **0.87** | **0.97** | **0.85** | **0.93** |

| BIO 1: Annual Mean Temperature 2050 | | | | |
|---|---|---|---|---|
| **Region** | **Mean_min** | **Max** | **Min** | **Mean_max** |
| **Arima** | 2.03 | 2.12 | 2.02 | 2.10 |
| **Chaguanas** | 2.07 | 2.15 | 2.05 | 2.13 |
| **Diego Martin** | 2.03 | 2.13 | 2.00 | 2.09 |
| **Point Fortin** | 2.21 | 2.28 | 2.16 | 2.26 |
| **Port Of Spain** | 2.03 | 2.13 | 2.02 | 2.09 |
| **Princes Town** | 2.15 | 2.28 | 2.09 | 2.22 |
| **San Fernando** | 2.15 | 2.23 | 2.13 | 2.21 |
| **Sangre Grande** | 1.99 | 2.15 | 1.93 | 2.10 |
| **Siparia** | 2.22 | 2.36 | 2.16 | 2.28 |
| **Tobago** | 1.82 | 1.95 | 1.79 | 1.89 |
| **All region** | **2.07** | **2.18** | **2.03** | **2.14** |

In table 7 the positive values indicate that according to the model, the average annual temperature is greater in the future than today. Annual mean temperature will increase progressively. By 2020 an average increase of 0.9ºC, and by 2050 an average increase of 2,1ºC.

In figure 10, the edges of the boxes indicate the mean maximum and mean minimum values and the ends of the line the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation.



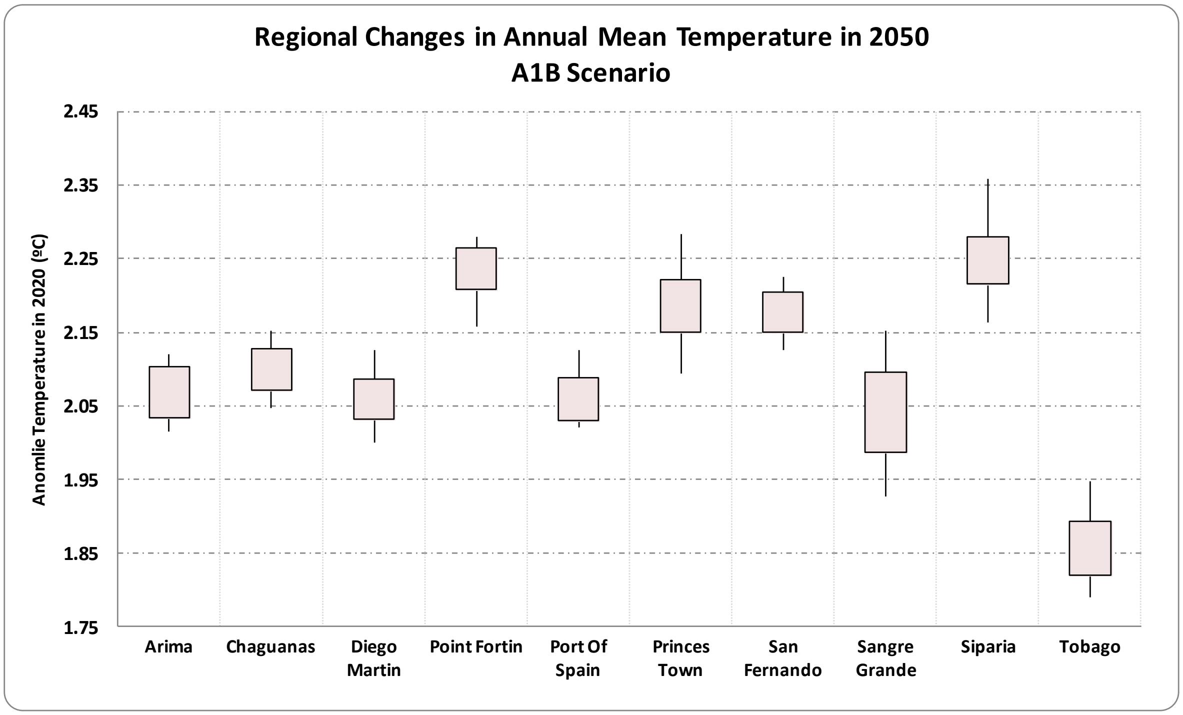


Figure 10. Regional changes in annual mean temperature in the future under A1B scenario.

## 5.3. Average Climate Change Trends for Trinidad and Tobago

Future climate data derived from 19GCM models from the 4th IPCC assessment (IPCC, 2007), run under the A2 scenario of 2020 (2010-2029) and 2050 (2040-2069) were compared with the historical climate data (1950-2000) from WorldClim Database. We obtained the following results:

In figure 11, monthly precipitation is represented by bars and monthly mean temperatures by lines for the three time points (present, 2020 and 2050). The figure illustrates a constant increase of temperature through time. In 2050, monthly precipitation in all months is reduced, affecting various annual crops, because as indicated in the literature review, the duration of dry season is a constraint on cocoa crop growth.

Through this analysis it is possible to conclude the following:

- For 2050 rainfall decreases from 2067 millimeters to 1953 millimeters passing through 2004 millimeters in 2020.
- For 2050 temperatures increase and the average increase is 2 ºC exceeding that found (0.9 ºC) in 2020.
- The mean daily temperature range increases from 8.5 ºC to 9 ºC in 2050.
- The maximum number of cumulative dry months remains constant, with a total of 3 months.

The extreme conditions are:

- The maximum temperature of the year increases from 30.8 ºC to 33.3 ºC while the warmest quarter gets hotter by 2.2 ºC in 2050.
- The minimum temperature of the year increases from 20.2 ºC to 21.8 ºC while the coldest quarter gets hotter by 1.8 ºC in 2050.
- The wettest month gets drier with 263 millimeters instead of 272 millimeters, while the wettest quarter gets drier by 41 mm in 2050.
- The driest month gets drier with 60 millimeters instead of 64 millimeters while the driest quarter gets drier by 9 mm in 2050.

Overall the climate becomes more seasonal in terms of variability through the year in temperature and more seasonal in precipitation.

And the variability between models:

- The coefficient of variation of temperature predictions between models is 2.1%.
- Temperature predictions were uniform between models and thus no outliers were detected.
- The coefficient of variation of precipitation predictions between models is 6%
- Precipitation predictions were uniform between models and thus no outliers were detected.

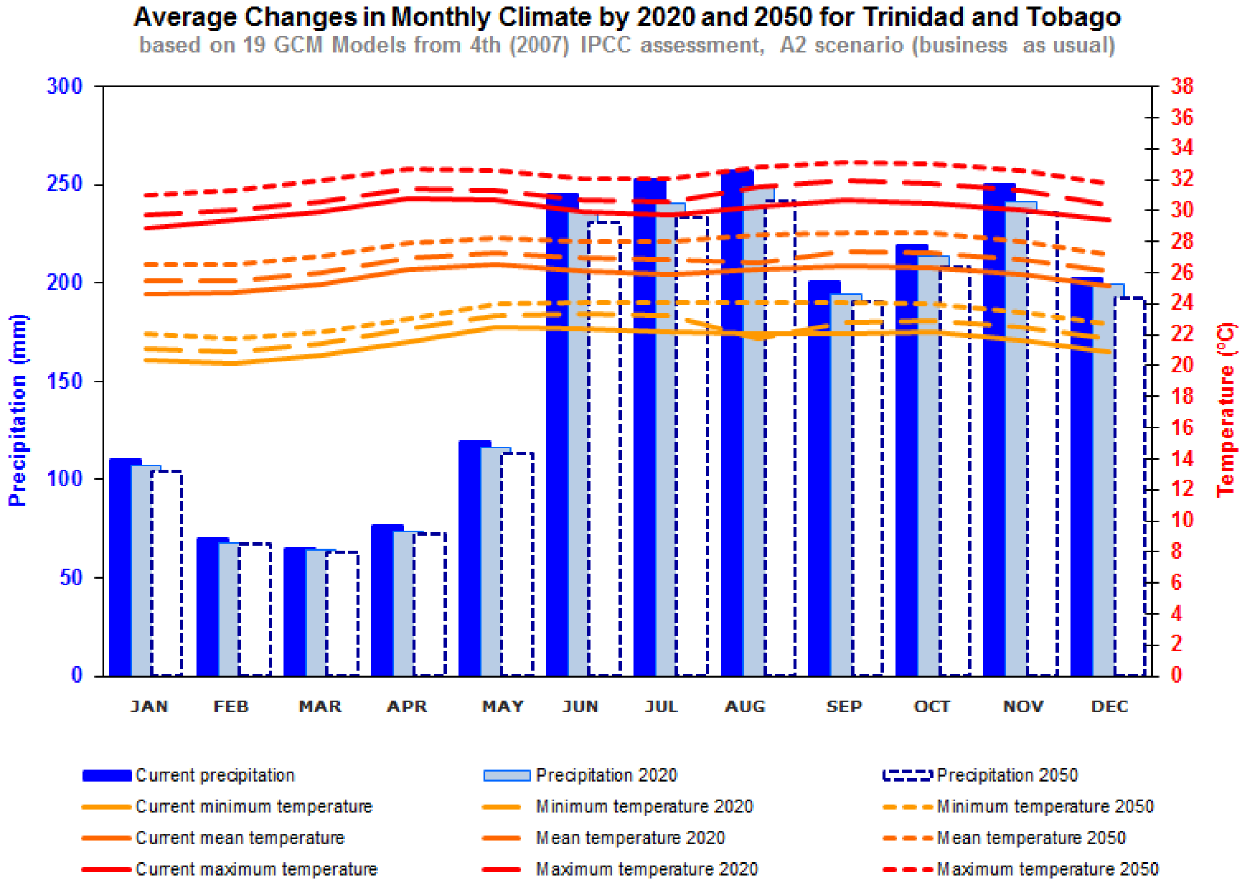


Figure 11. Averages Changes in Monthly Climate by 2020 and 2050 for T&T.

## 5.4. Current Suitability

### *5.4.1. EcoCrop Modeling*

To gain a general idea into the current suitability of cocoa crops in Trinidad and Tobago, the EcoCrop model was run.

As discussed in the literature review, EcoCrop requires that specific parameters are defined for the crop of interest, cacao. These parameters were developed based on the academic literature, for the species *Theobroma Cacao L* which grows in Trinidad and Tobago, in South America and in some parts of the African Continent.

Table 8. EcoCrop Parameters for Theobroma Cacao L.

| EcoCrop Parameters for Theobroma Cacao L. | | | | |
|---|---|---|---|---|
| **Parameters** | **FAO** | **Literature** | **Units** | **Source** |
| **Gmin** | 180 | 180 | Days | (ProAmazonía 2004) |
| **Gmax** | 365 | 365 | Days | (ProAmazonía 2004) |
| **Tkill** | 5 | 10 | ˚C | (Crane, Balerdi and Joyner 2006) |
| **Tmin** | 10 | 15 | ˚C | (ProAmazonía 2004), (Batista 2009) |
| **Topmin** | 21 | 18 | ˚C | (Hebbar, Bittenbbender and O'Doherty 2011), (Anim-Kwapong and Frimpong 2003), (Crane, Balerdi and Joyner 2006) |
| **Topmax** | 32 | 32 | ˚C | (Hebbar, Bittenbbender and O'Doherty 2011), (ProAmazonía 2004), (Anim-Kwapong and Frimpong 2003), (Crane, Balerdi and Joyner 2006) |
| **Tmax** | 38 | 36 | ˚C | (Borrero 2008) |
| **Rmin** | 900 | 1000 | mm | (Batista 2009) |
| **Ropmin** | 1200 | 1500 | mm | (Hebbar, Bittenbbender and O'Doherty 2011), (ProAmazonía 2004), (2005_Zuidema), (Borrero 2008) |
| **Ropmax** | 3000 | 2500 | mm | (ProAmazonía 2004), (Borrero 2008), (Batista 2009) |
| **Rmax** | 7600 | 2800 | mm | (Hebbar, Bittenbbender and O'Doherty 2011) |

Table 8 displays the FAO-EcoCrop[14] parameters used and provides details of the specific academic sources that were used in the parameterization process. It must be noted that the general FAO-EcoCrop parameters are more applicable to global studies; they are averages of crop conditions found throughout the world. For local studies this data is very broad and it is recommendable to look for specific parameters for the species in the study area.

With the local parameters and climate data extracted from WorldClim the following results were obtained:

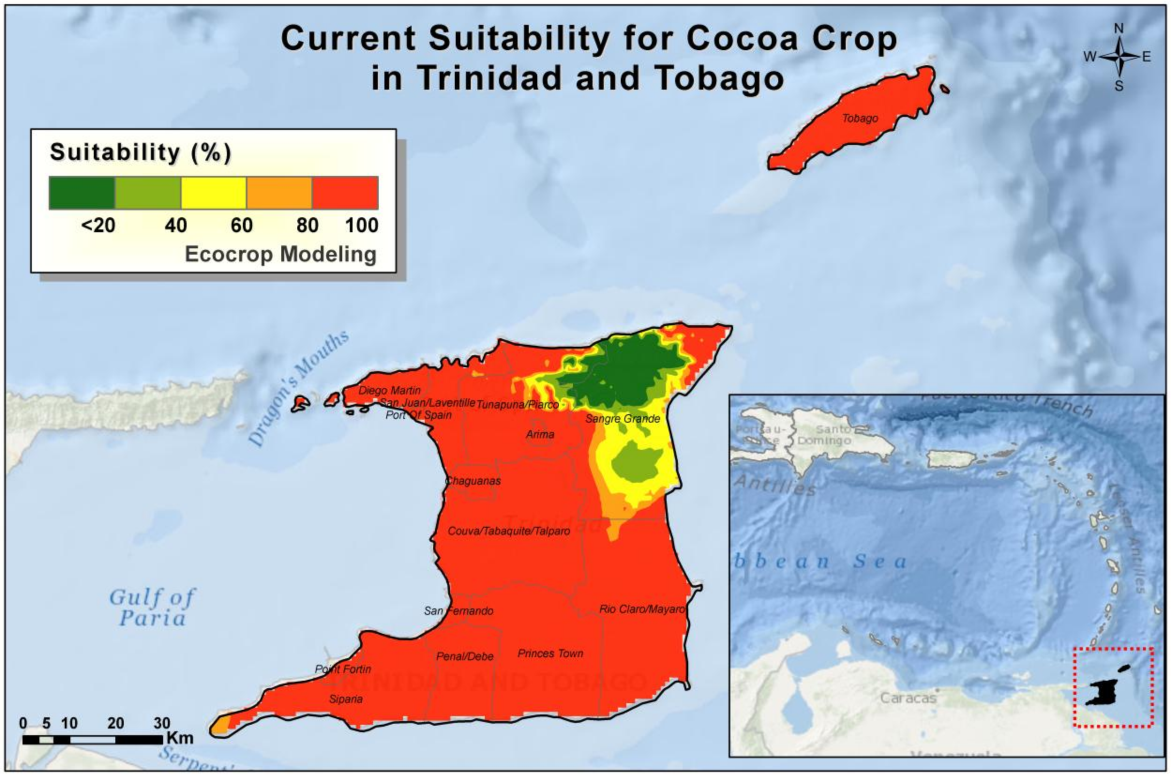


Figure 12. Map of Current suitability for Cocoa Crop in T&T using EcoCrop.

In figure 12, red and orange areas indicate higher predicted suitability whilst the areas in green are expected to have low future suitability, these areas are located mainly in north eastern zones. Therefore only those areas (red areas) with the optimal growing climate parameters (temperature and precipitation), is the cacao crop projected to have successful development.

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[14] FAO-EcoCrop Website
http://ecocrop.fao.org/ecocrop/srv/en/home

Table 9. Current Suitability using EcoCrop.

| Aptitud | Range | Area |
|---|---|---|
| **Low** | **0-40%** | 8% |
| **Medium** | **40-60%** | 5% |
| **High** | **60-100%** | 87% |

As shown table 9, EcoCrop predicts an aptitude up to 100%. Furthermore, 87% of the island possesses a high aptitude (>60%), 5% of the island possesses a medium aptitude (40-60%) and 8% of the island possesses a low or very low aptitude (<40%).

Low suitability is located mainly in the municipalities of Sangre Grande and Tunapuna in the north-east of the island. These areas correspond to high zones with an altitude greater than 200msnm. And high suitability is located in other parts of the island.

### *5.4.2. MaxEnt Modeling*

Modelling with MaxEnt requires presence and absence points of the crop. With this data it is possible to extract bioclimatic variables for each point in order to find the current and future suitability of the crop. The number of pseudo-absences and presences were equaled in order to keep prevalence constant. (Keenan, Serra, Lloret, Ninyerola, & Sabate, 2011)

#### Presence Data

In order to identify and collate all the known presence points of cacao, local information available online[15] from the Trinidad and Tobago Resource Institute was used, and maps of cacao occurrence were digitized.

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[15] Trinidad and Tobago Resource Institute website:
http://www.trinitario-cacao.org/

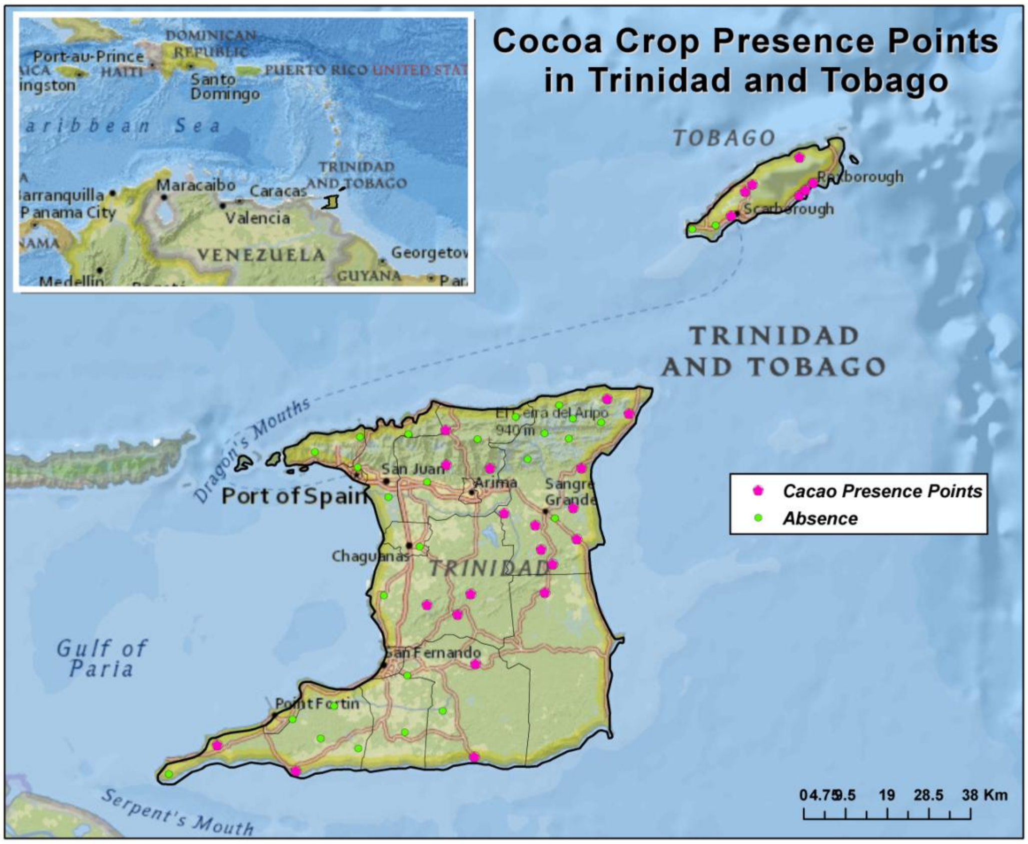


Figure 13. Cacao Presence Points in Trinidad and Tobago.

Pink points displayed in the map (Figure 13) represent places where cocoa farmer groups are located. It is possible that more presence points exist, but so far access to these 27 points collected by *Trinitaro Cocoa Resources* Organization remains the most comprehensive dataset available. These 27 points were used to determine the impact of climate change on national Cocoa Crop suitability using MAXENT.

Table 10 reveals the coordinates (longitude, latitude) of cacao presence points in T&T in the Universal Transverse Mercator (UTM) projection. These points were digitized from the map available on the website of Trinitario Cacao Resource. It is a Geo-map that reveals some of the sample areas of Cacao farms in Trinidad and Tobago taken by this institute.

Table 10. Presence Points of Theobroma Cacao L in T&T (UTM projection).

| ID | Longitude | Latitude |
|---|---|---|
| 1 | -60.609 | 11.299 |
| 2 | -60.706 | 11.245 |
| 3 | -60.721 | 11.230 |
| 4 | -60.749 | 11.181 |
| 5 | -60.609 | 11.222 |
| 6 | -60.597 | 11.233 |
| 7 | -60.581 | 11.247 |
| 8 | -60.958 | 10.784 |
| 9 | -61.003 | 10.813 |
| 10 | -61.056 | 10.674 |
| 11 | -61.243 | 10.674 |
| 12 | -61.333 | 10.680 |
| 13 | -61.334 | 10.751 |
| 14 | -61.214 | 10.583 |
| 15 | -61.150 | 10.559 |
| 16 | -61.073 | 10.593 |
| 17 | -61.065 | 10.531 |
| 18 | -61.138 | 10.510 |
| 19 | -61.115 | 10.480 |
| 20 | -61.131 | 10.423 |
| 21 | -61.282 | 10.420 |
| 22 | -61.310 | 10.379 |
| 23 | -61.372 | 10.399 |
| 24 | -61.273 | 10.280 |
| 25 | -61.275 | 10.092 |
| 26 | -61.641 | 10.063 |
| 27 | -61.802 | 10.116 |

### Absence Data

The green points displayed in the map (Figure 13) represent places where cocoa crops do not possess sufficient suitability to grow. These points were selected using a map of dry constant months in Trinidad and Tobago and an altitude map.

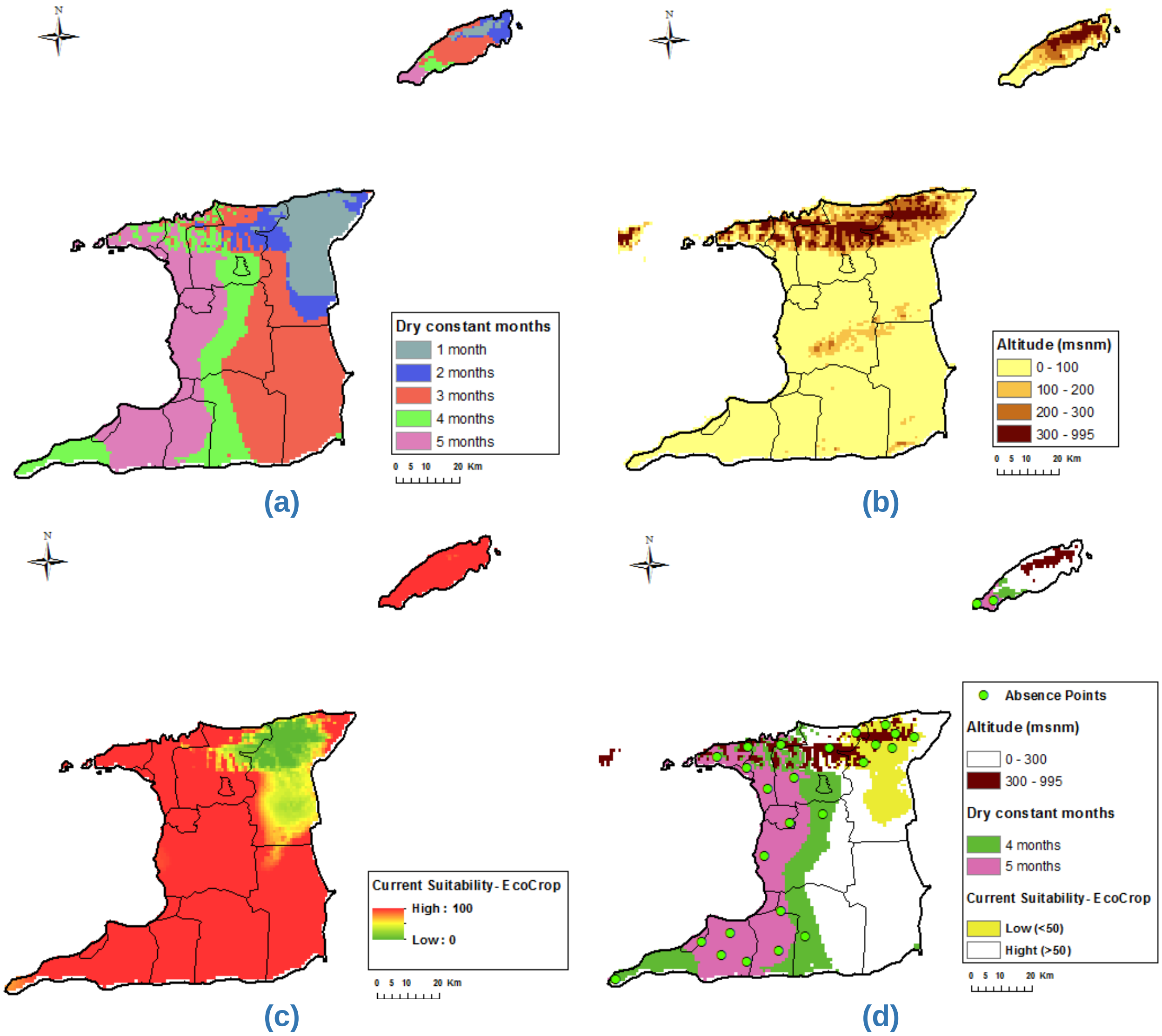
In accordance with the literature review, the four to six months of dry weather, results in a soil water deficit, and, since irrigation is not part of the farming system in Trinidad and Tobago, cocoa seedling mortality is high during the establishment phase. In bearing plants, the existence of the short dry season during main crop pod filling can affect bean size if it is sufficiently severe. In adult plantings, water deficits result in lower yields and an increase in the level of capsid damage. (Anim-Kwapong & Frimpong, 2003) (Batista, 2009) (Ofori-Boateng & Insah, 2011) (Abayomi, 2012)

Apart from drought, height is also a limiting factor in crop growth. The wind intensity may increase with the height and slope of the land and this can cause mechanical and physiological damage to the leaves, fruits, and general plant architecture. Globally cocoa crops are found in tropical humid forest, the average temperature is 24-25ºC and the altitude less than 300 meters above sea level. (Batista, 2009).

Additionally, the EcoCrop results of current suitability are used to select the non suitability areas.

As shown in Figure 14, we overlay different layers and find the non-suitability areas, with four and five dry constant months, altitude greater than 300 meters above sea level and current EcoCrop suitability less than 50%. Finally, in these areas the absence points were created randomly.

Finally with presence and absence coordinates the value of bioclimatic variables in each point was extracted. (**Annex 1, 2**)



(a) (b) (c) (d)

Figure 14. Absence points selection. (a) Dry constant months in T&T, (b) Altitude of T&T in meters above sea level, (c) Current suitability result using EcoCrop, (d) Overlay of layers to create the absence points.

Using the presence and absence points listed above, and climate data extracted from WorldClim for each point in the software MaxEnt the following results using MaxEnt were obtained:

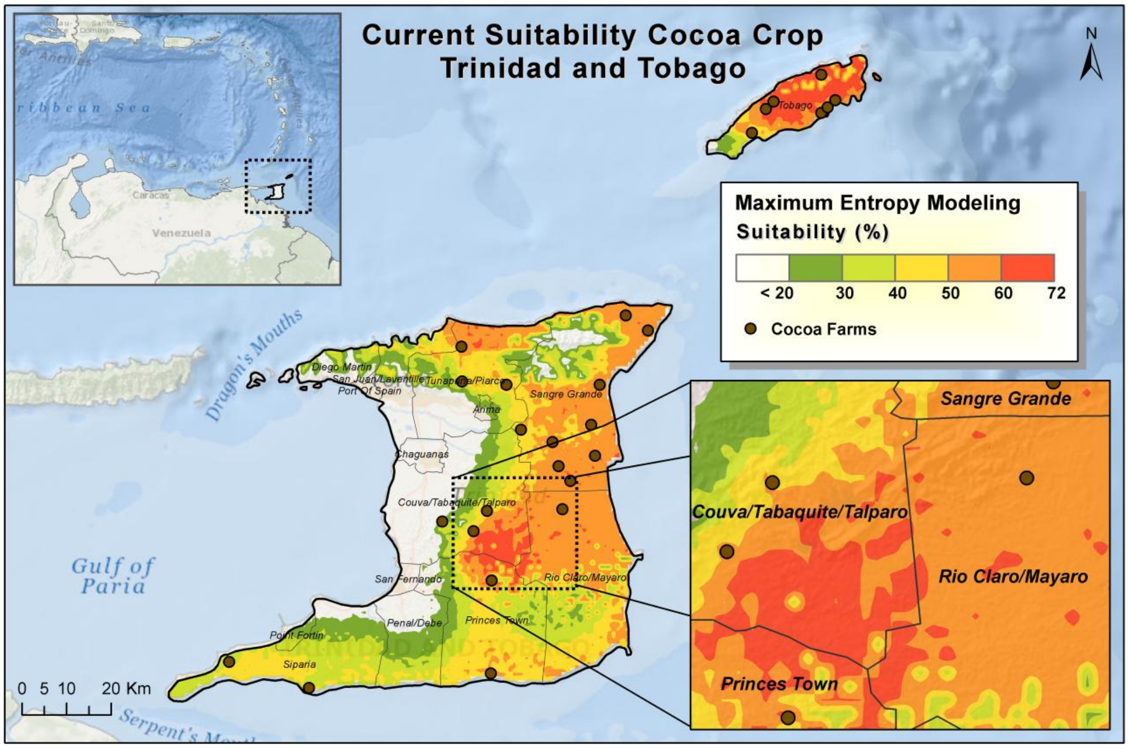


Figure 15. Map of Current Suitability for Cocoa crop in T&T using MAXENT.

Warmer colors show areas with better predicted conditions. Brown dots show the presence locations used for training. (Figure 15)

As displayed in the map, MaxEnt modeling predicts an aptitude up to 72%. Additionally, 7% of the island possesses a high aptitude (>60%), 43% of the island possesses a medium aptitude (40-60%) and 50% of the island possesses a low or very low aptitude (<40%). (Table 11)

Table 11. Current Suitability using MaxEnt.

| Aptitud | Range | Area |
|---|---|---|
| **Low** | **0-40%** | 50% |
| **Medium** | **40-60%** | 43% |
| **High** | **60-72%** | 7% |

Low suitability is located mainly in the municipalities of Diego Martin, San Juan, part of Tunapuna, Chaguanas, part of Talparo, San Fernando, Penal and Siparia in the west of the island and the high zones of Sangre Grande.

And high suitability (60-72%) is located in Tobago and in the center of Trinidad in the municipalities of Talparo, Princess Town and Mayaro.

Statistically, the MaxEnt model possesses an area under the curve (AUC) of 0.784 (See **Annex 3**).

Through the results of the Jackknife test, it is possible to know which environmental variables have a greater contribution to the MaxEnt Modeling. These variables were: BIO 14 (Precipitation of Driest Month), BIO 17(Precipitation of Driest Quarter), BIO12 (Annual Precipitation) and BIO 18 (Precipitation of Warmest Quarter) with a percent contribution of 42.7%, 23.4%, 16% and 10.4% respectively.

These results indicate that changes in precipitation influence the suitability of cacao, and as confirmed by the literature review, the duration of the period of drought is a limiting factor in the productivity of cacao. The temperature has no major influence on the suitability.

Overall, the EcoCrop model predicts more suitable areas than the MaxEnt model. However, the result of EcoCrop is based solely on climatic data and therefore their results are very general, mainly due to the fact that the study area is very small (T&T). For that reason this study doesn't seek to compare the modeled results of MaxEnt and EcoCrop, instead seeks ways to integrate the two models in order to obtain the best results.

### *5.4.3. Analysis of Maxent Prediction*

**Analysis of omission/commission**

Figure 35 shows the omission rate and predicted area as a function of the cumulative threshold. The omission rate is calculated both on the training presence records, and on the test records. The omission rate is close to the predicted omission.

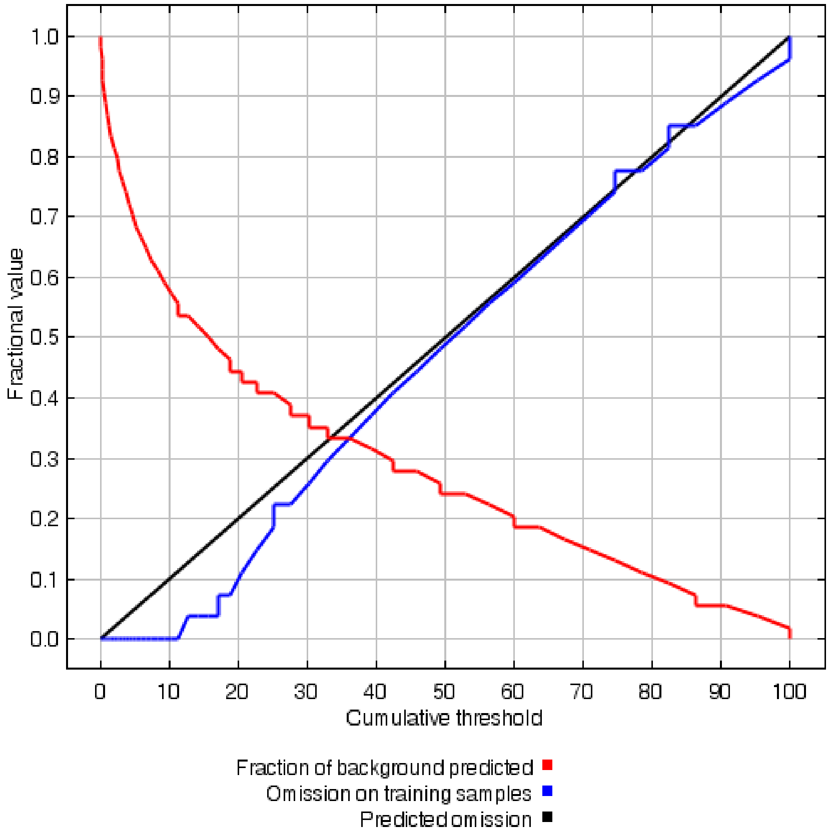


Figure 16. Omission and Predicted Area for Cacao.

Figure 36 is the receiver operating characteristic (ROC) curve for the same data. The specificity is defined using predicted area, rather than true commission. This implies that the maximum achievable AUC is less than 1. If test data is drawn from the MaxEnt distribution itself, then the maximum possible test AUC would be 0.717 rather than 1; in practice the test AUC may exceed this bound. In this case we obtained AUC=0.748.

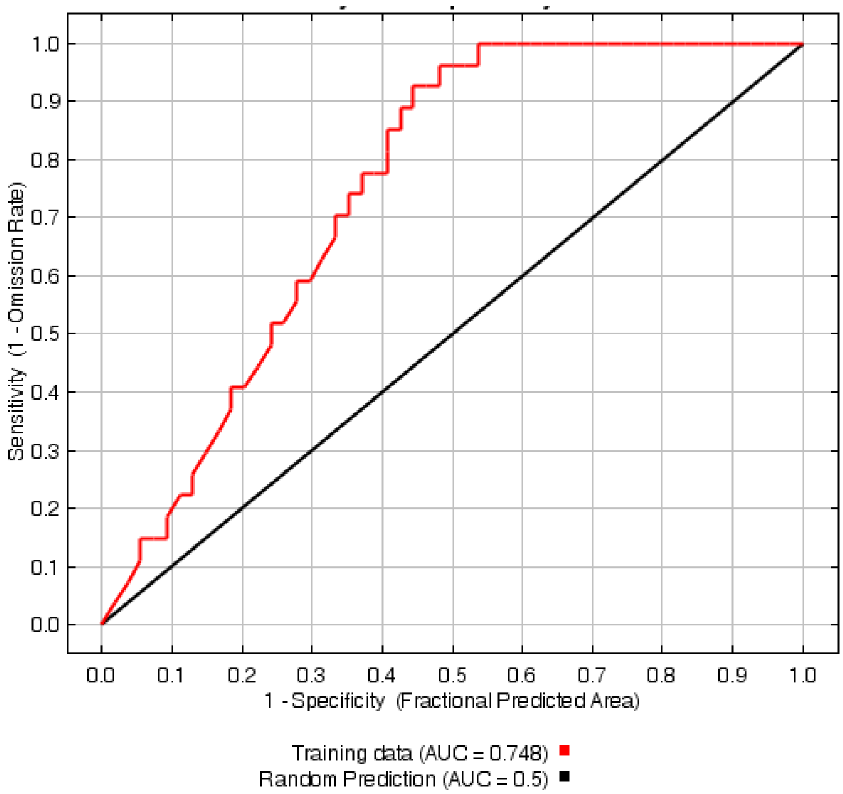


Figure 17. Sensitivity vs. Specificity for Cacao.

## Response curves

These curves (Figure 37) show how each environmental variable affects the MaxEnt prediction. The curves show how the logistic prediction changes as each environmental variable is varied, keeping all other environmental variables at their average sample value. Note that the curves can be hard to interpret if you have strongly correlated variables, as the model may depend on the correlations in ways that are not evident in the curves. In other words, the curves show the marginal effect of changing exactly one variable, whereas the model may take advantage of sets of variables changing together.

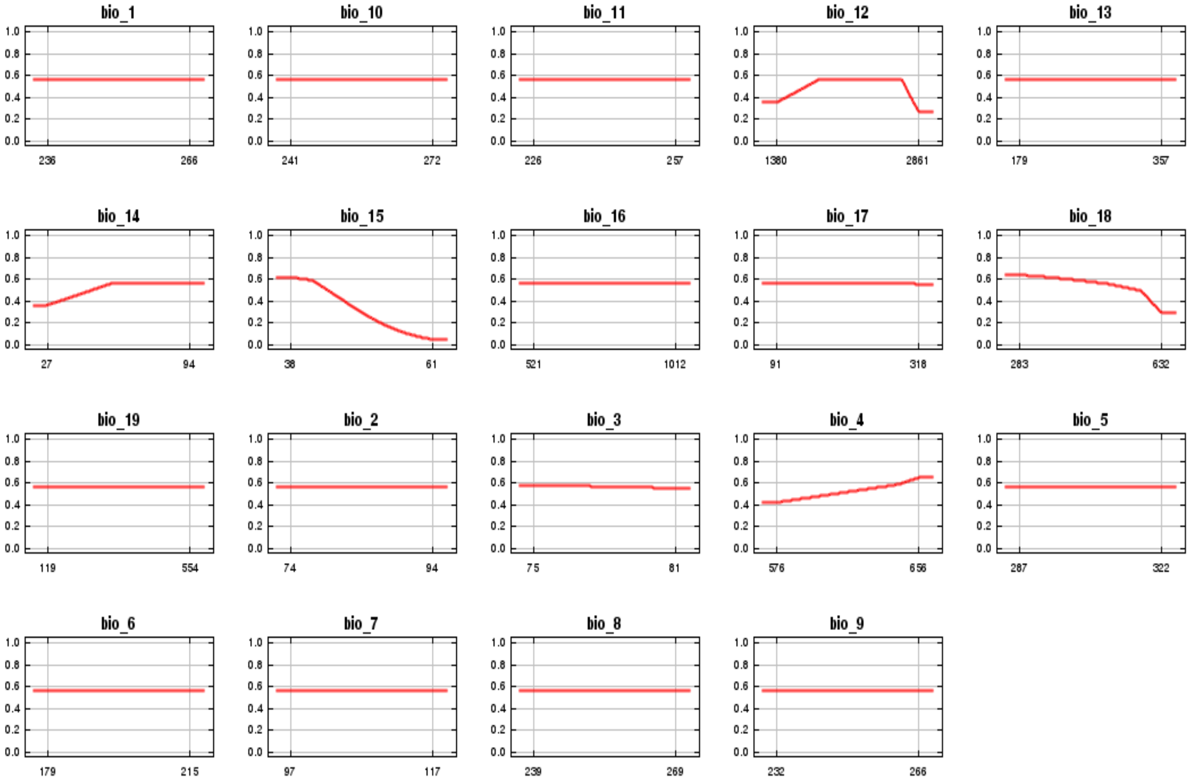


**Figure 18. Response curves of bioclimatic variables.**

In contrast to the above marginal response curves (Figure 38), each of the following curves represents a different model, namely, a MaxEnt model created using only the corresponding variable. These plots reflect the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables. They may be easier to interpret if there are strong correlations between variables.

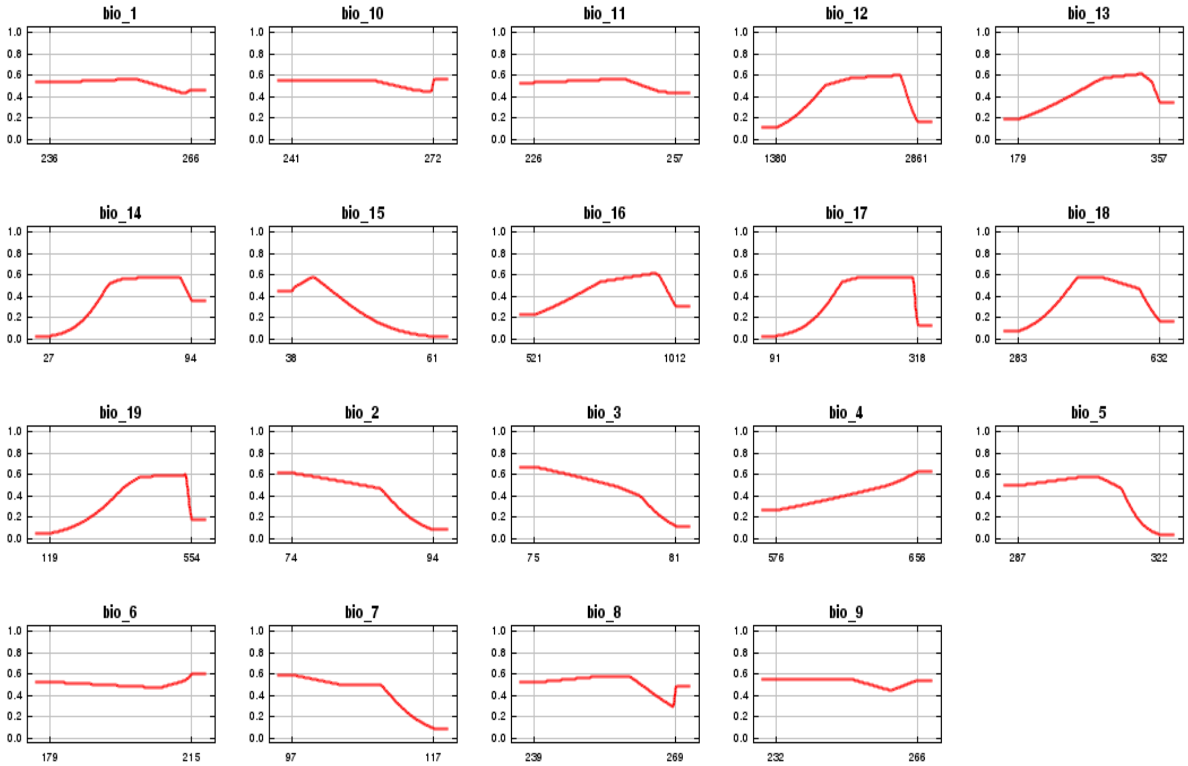


**Figure 19. Response curves of bioclimatic variables (Maxent Model using only the corresponding variable).**

### Analysis of variable contributions

The table 12 gives estimates of relative contributions of the environmental variables to the MaxEnt model. To determine the first estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative. For the second estimate, for each environmental variable in turn, the values of that variable on training presence and background data are randomly permuted. The model is reevaluated on the permuted data, and the resulting drop in training AUC is shown in the table, normalized to percentages. As with the variable jackknife, variable contributions should be interpreted with caution when the predictor variables are correlated.

The bioclimatic variables with highest contribution in the modeling were BIO 14 (Precipitation of Driest Month), BIO 17 (Precipitation of Driest Quarter), BIO 12 (Annual Precipitation) and BIO 18 (Precipitation of Warmest Quarter). This means that the precipitation in the warmer months is a limiting factor for growing cocoa in Trinidad, and temperature has no major influence on crop growth.

**Table 12. Bioclimatic variables with relative contribution greater than 0.**

| Variable | Percent Contribution | Permutation Importance |
|---|---|---|
| **BIO 14** | 42.7 | 0 |
| **BIO 17** | 23.4 | 0.6 |
| **BIO 12** | 16 | 9.6 |
| **BIO 18** | 10.4 | 19.2 |
| **BIO 15** | 4.4 | 58.2 |
| **BIO 4** | 1.8 | 3.4 |
| **BIO 2** | 0.9 | 0 |
| **BIO 19** | 0.3 | 0 |
| **BIO 3** | 0.1 | 0 |

Figure 39 shows the results of the jackknife test of variable importance.

The environmental variable with highest gain when used in isolation is BIO 17, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is BIO 15, which therefore appears to have the most information that isn't present in the other variables.

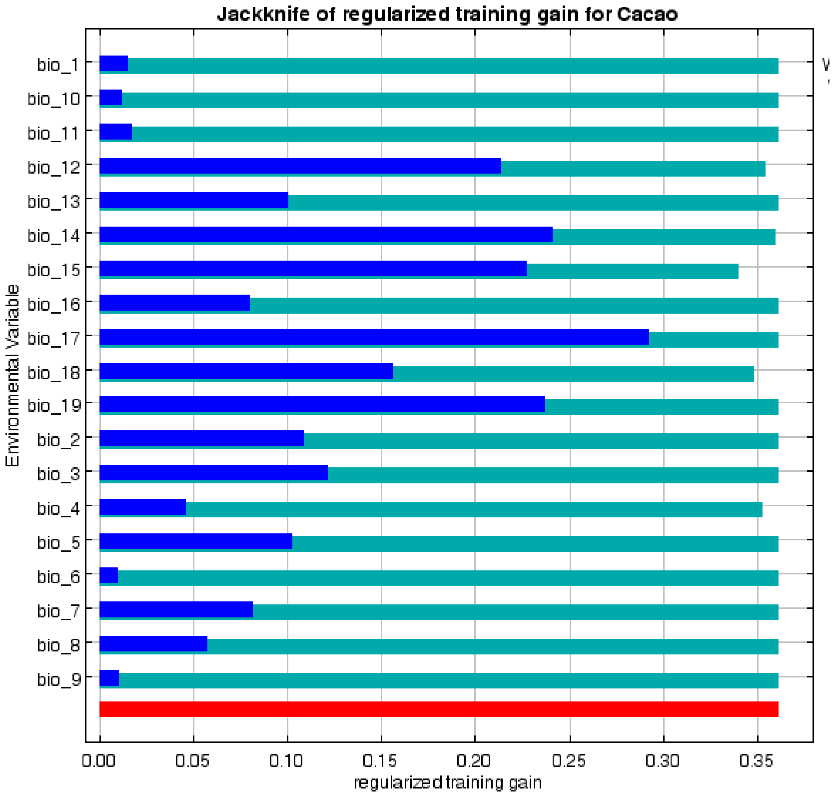


**Figure 20. Jackknife of regularized training gain for Cacao.**

## 5.5. Future Suitability

### *5.5.1. SRES A2*

As shown in the figures (Figure 21 and 17), in 2020 Tobago decreases its suitability in 10-15% going from a current suitability of 72% to 40%-60% by 2020. In contrast, in Trinidad, the municipality of Sangre Grande increases suitability (10-15%) in the highlands of the island (>300 meters above sea level) by 2020 and continue increasing by 2050 with 15% more suitability than current (Figure 18 and 19). At the same time the south of the municipalities of Rio Claro/Mayaro and Princes Town show a big increment of suitability (15-23%) compared with the present. The others municipalities of the island (Diego Martin, San Juan, Port of Spain, Chaguanas, Piarco, Arima, Talparo, San Fernando and Penal) in general have a decrease in the suitability (Figures 17 and 19).

On the other hand, the south of Sangre Grande, Talparo and the north of Rio Claro/Mayaro for 2020 showed the highest loss of suitability (5-24%). Those zones coincide with most of the current presence points of the crop (Figure 21). This means that the cacao producers in Trinidad and Tobago will have to adapt to not suffer the effects of climate change on their crops.

The major impact would be for Tobago due to the high loss of suitability (>15%) particularly as this is currently the main area of high quality Cocoa production in the country.

According to the scenario A2, the majority of the areas continue to be slightly suitable for cacao production presuming similar climatic conditions as today. It is estimated that in 2050 the high suitability of cacao production will be mainly concentrated in the municipalities Princes Town, Rio Claro and Siparia (Figure 23). In this zone, the most suitable areas will even expand in the highest areas, which are located approximately between 200 and 500 masl. It would be a possible migration zone for cocoa production in the future; nevertheless, it would imply necessary social and economic arrangements.

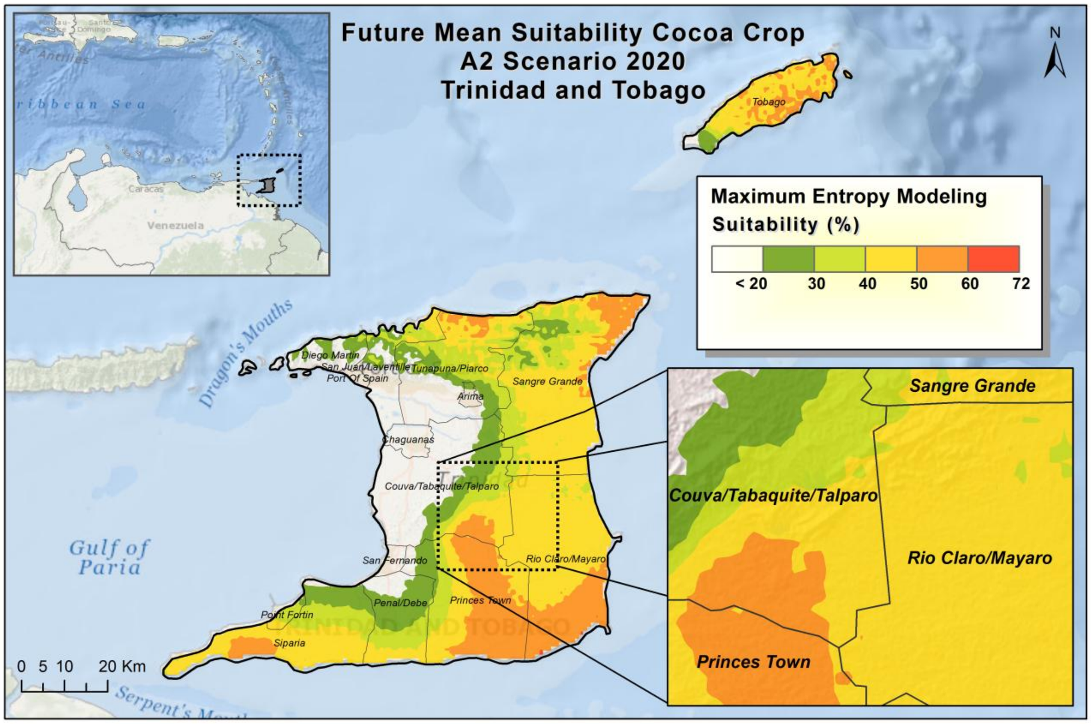


Figure 21. Map of Future Mean Suitability, A2 Scenario 2020 for Cocoa crop in T&T using MaxEnt.

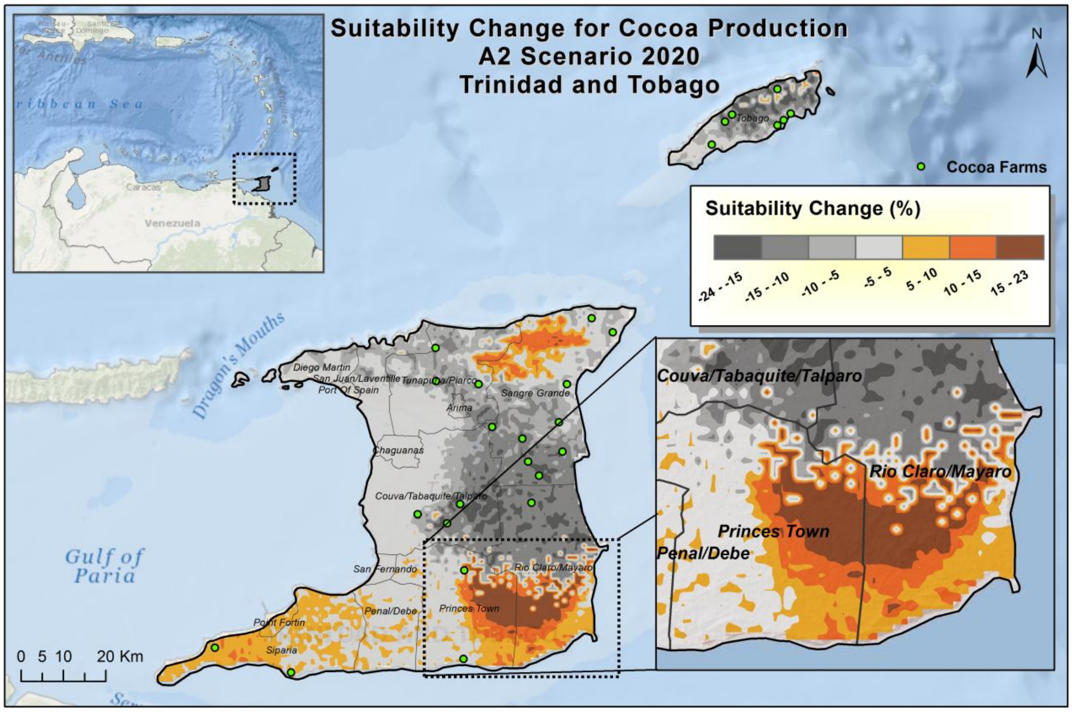


Figure 22. Suitability change for cacao production in 2020 under A2 scenario.

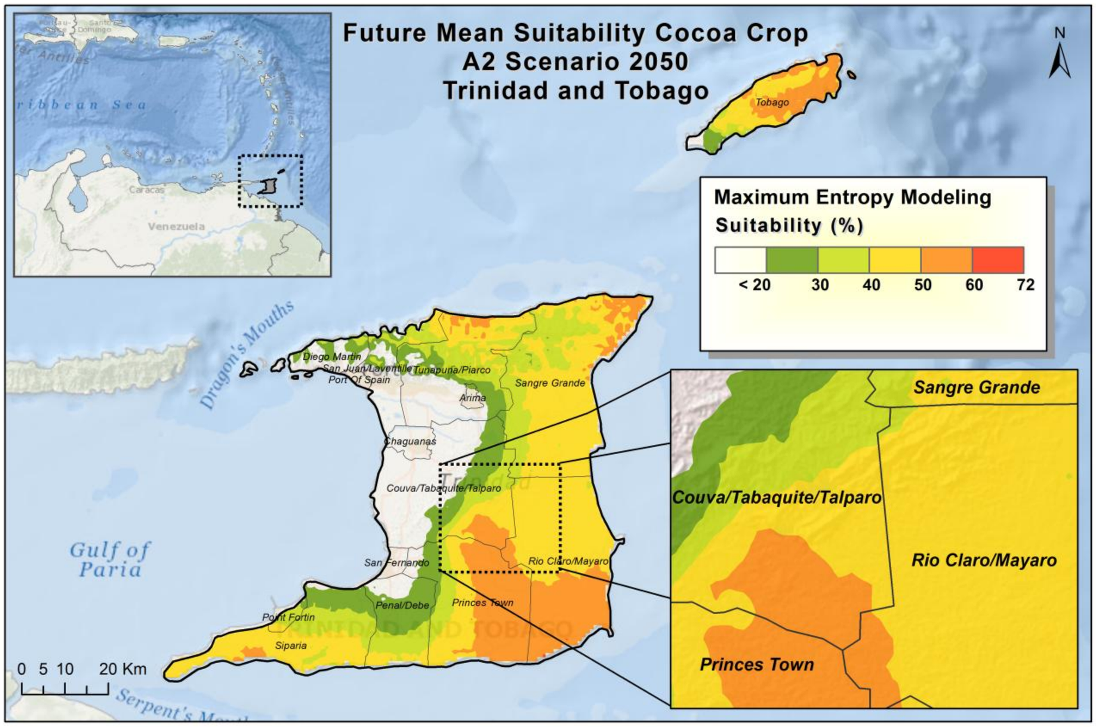


Figure 23. Map of Future Mean Suitability, A2 Scenario 2050 for Cocoa crop in T&T using MaxEnt

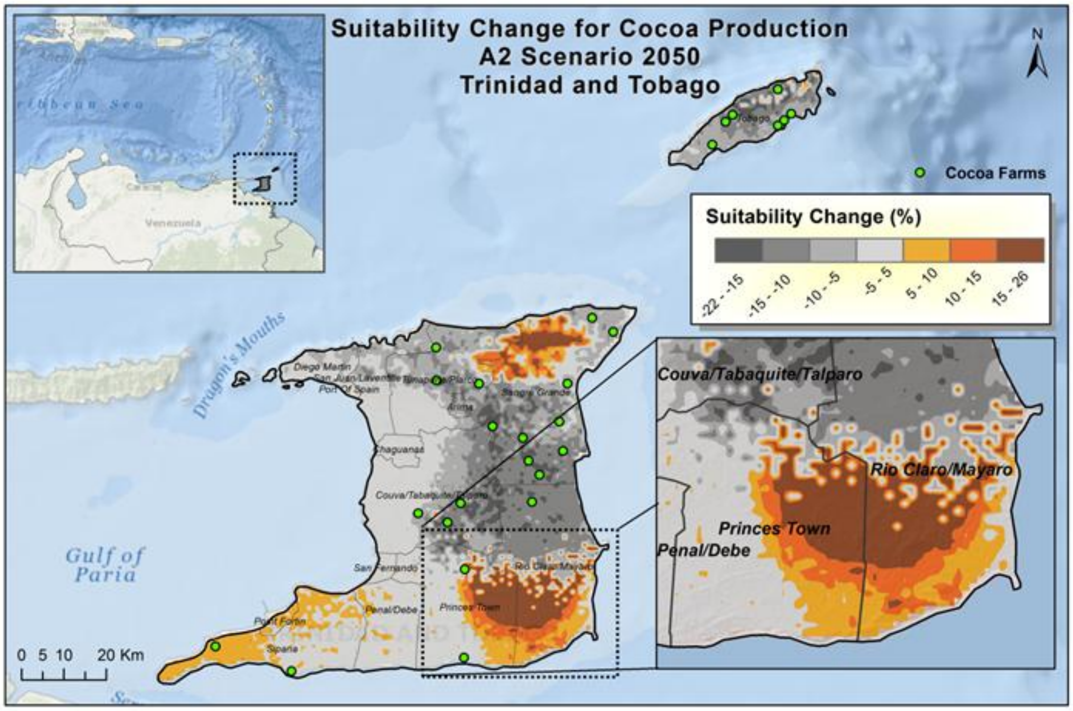


Figure 24. Suitability change for cacao production in 2050 under A2 scenario.

Although the regional analysis suggest a mean annual decrease in precipitation and increase of temperature through time (by 2020 and 2050), this could mean that the dry season will be more pronounced in the future and could have serious consequences for the crop and as mentioned above the cocoa crop is very sensitive to the duration of the dry season, especially when it lasts more than 4 consecutive months.

### Mean Coefficient of Variance of Bioclimatic Variables

Figure 25 shows the degree of similarity between the model predictions. There is a low mean coefficient of variance for bioclimatic variables both 2020 and 2050 in the area of study (between 5% and 11%), this means a high certainty in climate suitability response where most of the models coincide.  The major agreements in the models for the A2 scenario is in Tobago with a coefficient of variance lower than 7. However, the agreement within models for 2020 is lower in the North-East of Trinidad for Sangre Grande and Piarco municipalities; this difference in agreement is especially in the highlands of Sangre Grande.

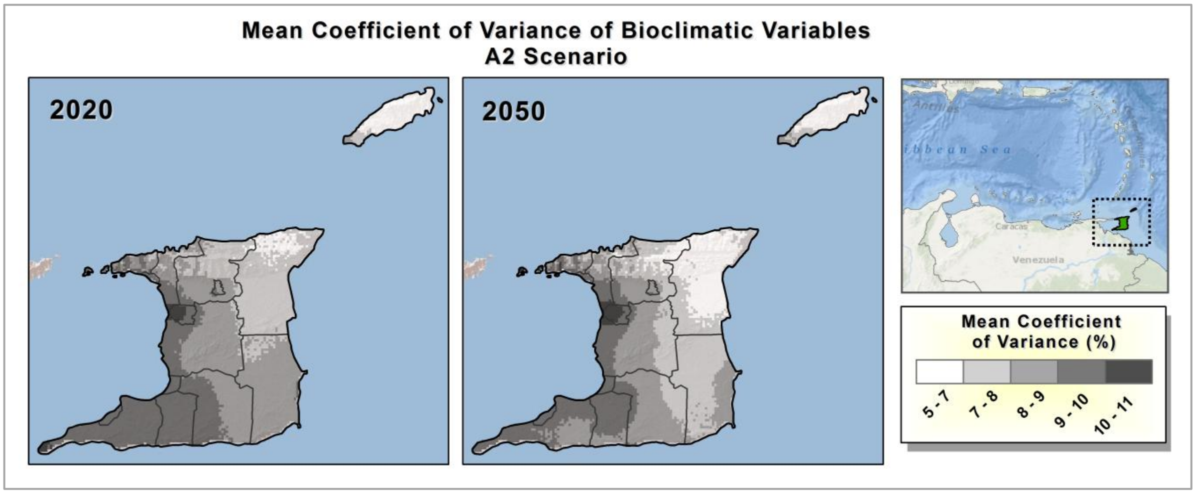


Figure 25. Mean coefficient of variance of bioclimatic variables in 2020 and 2050.

### Measure of Agreement between models

In general under A2 scenario there is a good agreement between models. By 2020 and 2050 approximately in the 70% of Trinidad and Tobago may obtain a good or excellent agreement between models. (Figure 21)

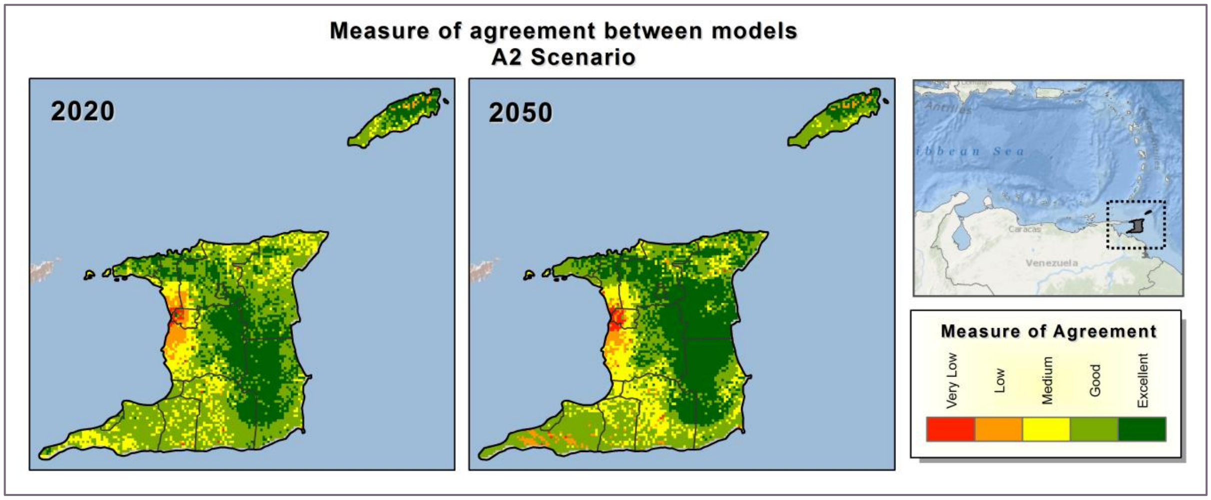


Figure 26. Measure of agreement between models under A2 scenario.

### *5.5.2.SRES A1B*

A1B scenario describes a future where there is a balance across all sources of energy.

The results of modeling the future under A2 and A1B scenarios were very similar. In 2020, Tobago losses more than 15% of suitability mainly in highlands (figure 22 and 23). In 2050 the suitability increases a little to 50%-60%.

On the other hand, in 2020, the highlands of Trinidad (>300 meters above sea level) gain suitability from 0% to 20%, mainly in the north of the municipality Sangre Grande and the south of Rio Claro/Mayaro and Princes Town. In contrast the lowlands in the municipalities Diego Martin, Piarco, east of Talparo, south of Sangre Grande and north of Rio Chlaro/Mayaro loss more than 5% of current suitability in the future.

By 2050 (figures 24 and 25), the lowlands of Diego Martin, Piarco, Arima, south of Sangre Grande, Talparo and north of Rio Claro/Mayaro that lose suitability in 2020, continue to lose suitability between 5 and 23%. In contrast, the areas that gain more in 2020 (north of Sangre Grande, Rio Claro/Mayaro and Princes Town) continue to gain, resulting in a 23% increase in the suitability compared to the present.

Figures 23 and 25 clearly show that the areas are that lose suitability are precisely the areas where small farmers producing cocoa are located. This indicates that farmers must necessarily perform a migration of agriculturally suitable lands in the south of Rio Claro/Mayaro, east of Princes Town and north of Sangre Grande or implement specific mitigation strategies.

The regional analysis described above, suggest a mean annual decrease in precipitation by 2050 and a mean annual increase in temperature. This will mean a more pronounced dry season. This suggests that according to the predictions, cocoa crops could suffer the impacts of climate change in the near future if the country does not implement any kind of adaptation or mitigation strategy.

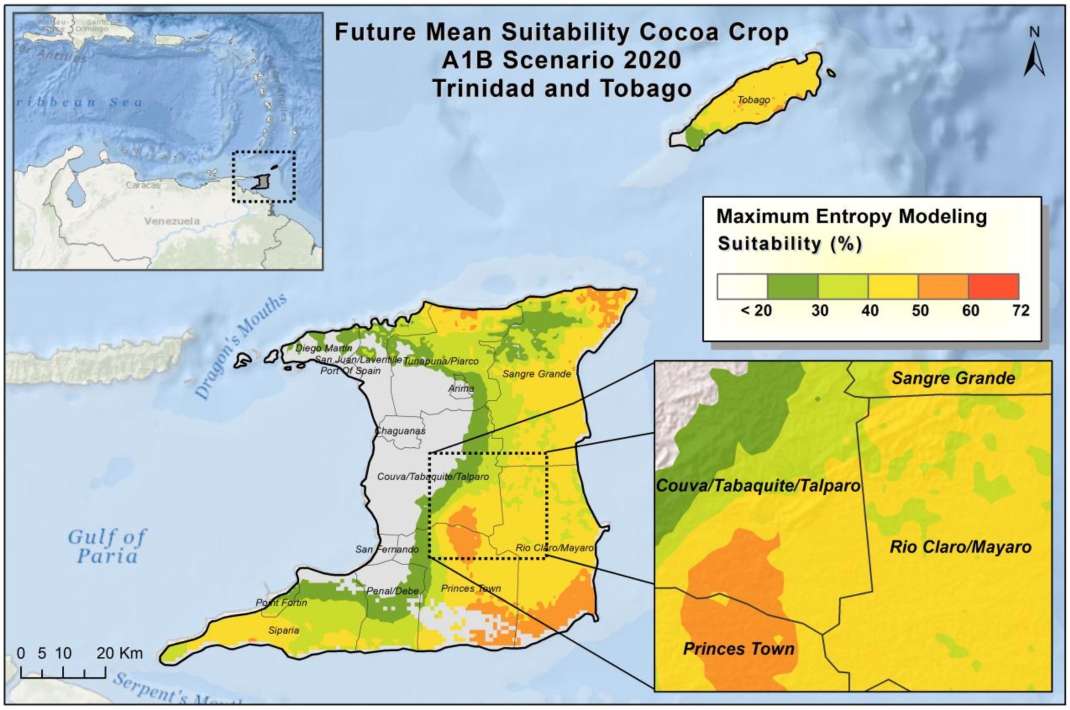


Figure 27. Map of Future Mean Suitability, A1B Scenario 2020 for Cocoa crop in T&T using MaxEnt.

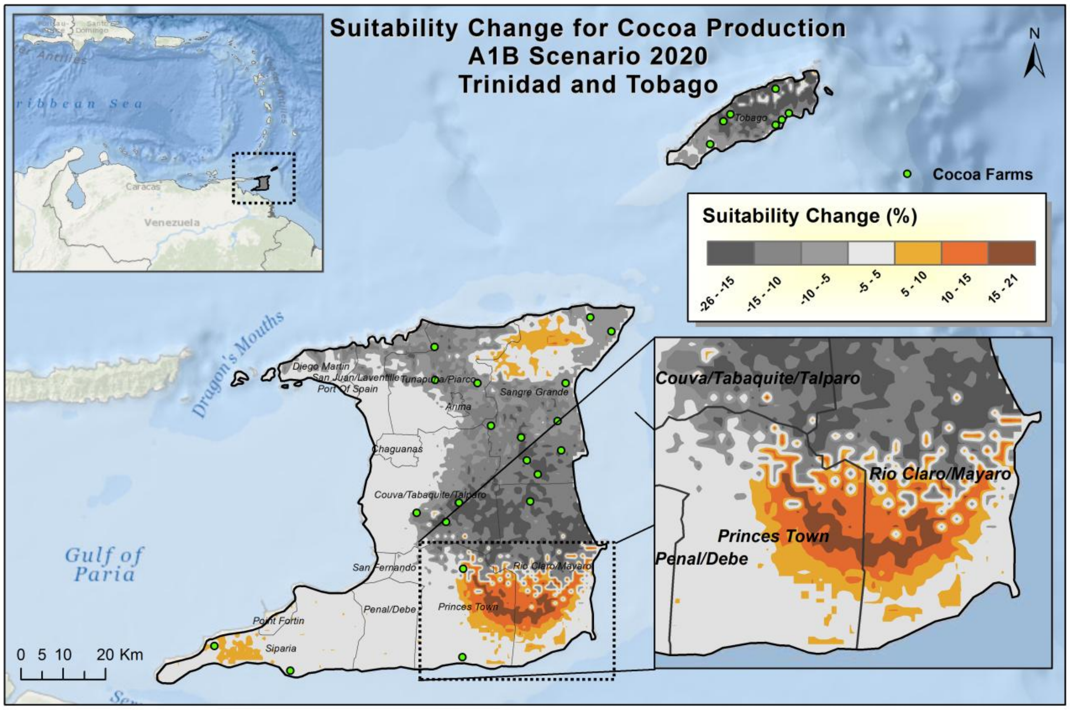


Figure 28. Suitability change for cacao production in 2020 under A1B scenario.

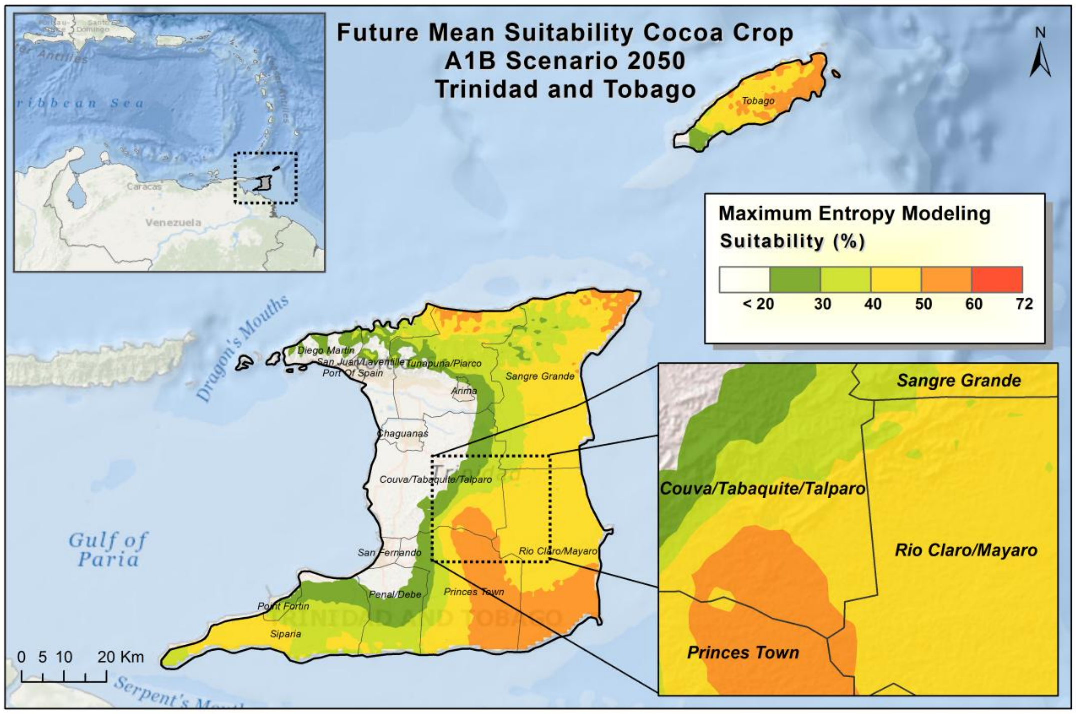


Figure 29. Map of Future Mean Suitability, A1B Scenario 2050 for Cocoa crop in T&T using MaxEnt.

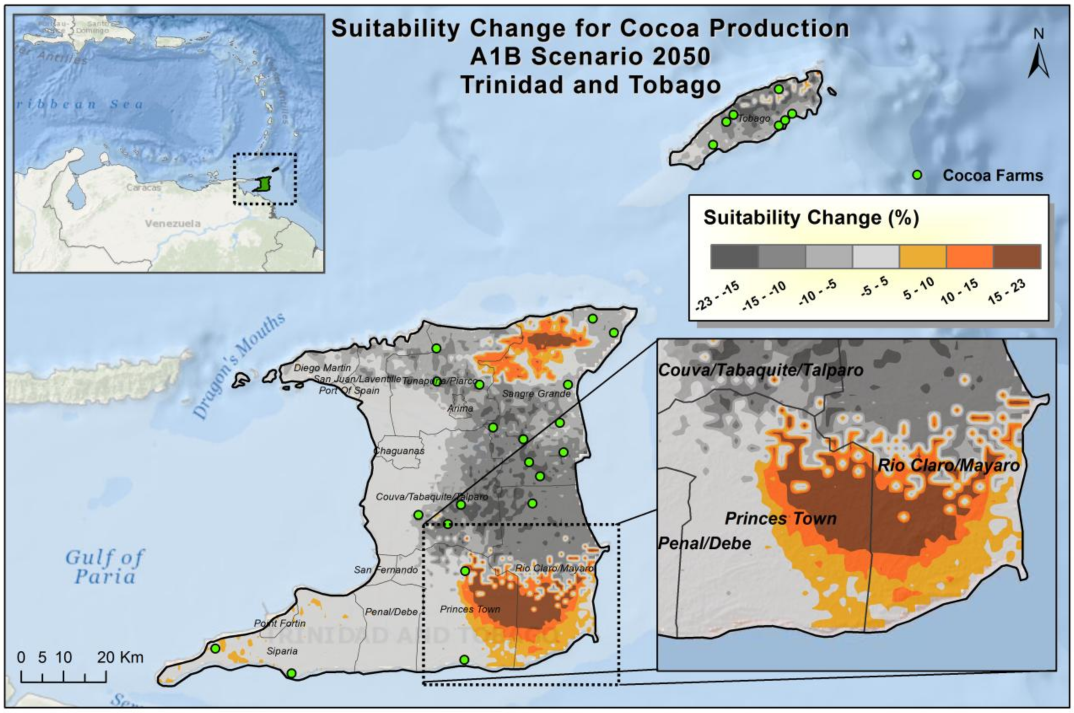


Figure 30. Suitability change for cacao production in 2050 under A1B scenario.

## Mean Coefficient of Variance of Bioclimatic Variables

The Figure 26 shows the degree of similarity between the model predictions under A1B scenario. There is a low mean coefficient of variance for bioclimatic variables both 2020 and 2050 in the area of study (between 5% and 15%), this means a high certainty in climate suitability response where most of the models coincide. As under A2 scenario, the major agreement in the models for the A1B scenario is in Tobago with a coefficient of variance lowers than 7. Furthermore, the agreement within models for 2020 is lower in the North-East of Trinidad for Sangre Grande and Piarco municipalities; this difference in agreement is especially in the highlands of Sangre Grande.

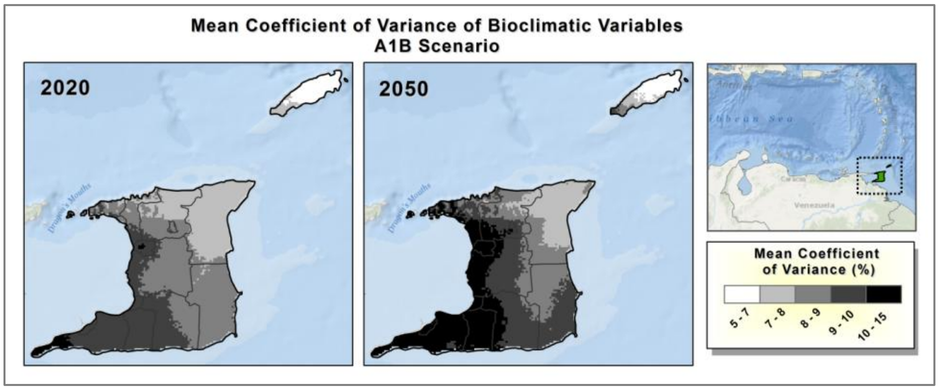


Figure 31. Mean coefficient of variance of bioclimatic variables in 2020 and 2050 under scenario A1B.

## Measure of Agreement between models

In general under A1B scenario there is a good agreement between models as in the A2 scenario. By 2020 and 2050 approximately in the 70% of Trinidad and Tobago may obtain a good or an excellent agreement between models. (Figure 27)

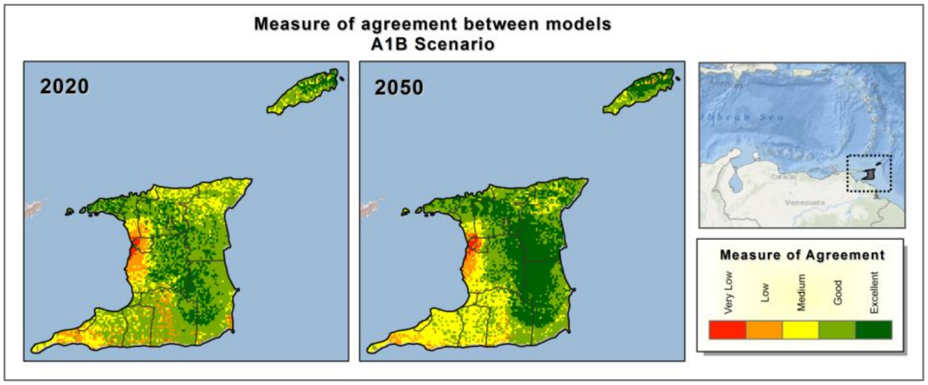


Figure 32. Measure of agreement between the models under A1B scenario.

## 5.6. Relation between suitability and altitude

Analyzing the relationship between suitability obtained for Cocoa Crops in Trinidad and Tobago for the present and the future (2020 and 2050) we found that:

Currently marginal suitability (0 to 20%) is located mainly at altitudes between 50m and 450m. In the future under the A2 and A1B scenarios the marginal suitability is located mainly between 50m and 250m altitude.

The graph (Figure 28) shows that the area with marginal suitability (0-20%) is mainly located in lowlands and do not change significantly in the future.

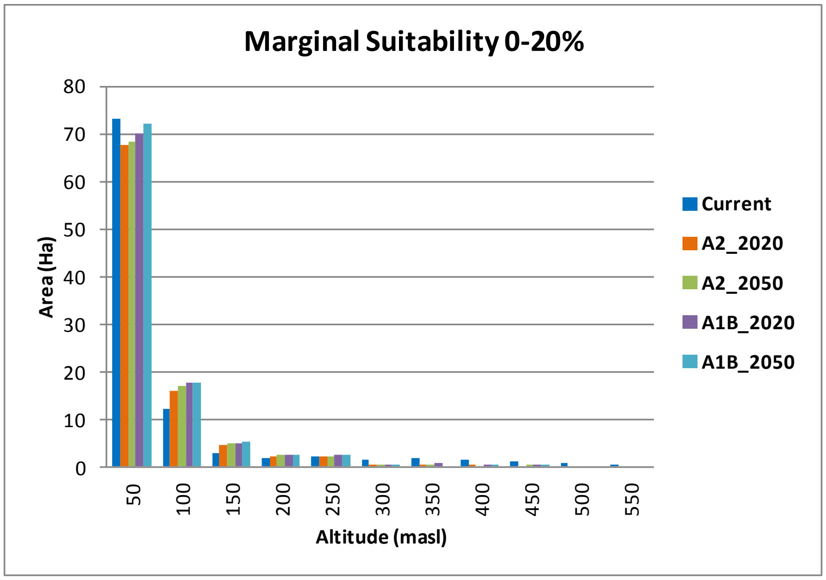


Figure 33. Altitude vs. Marginal Suitability (0-20%) Areas.

A marginal suitability (20 to 40%) is shown that currently is located between 50m and 400m. In the future under the A2 and A1B scenarios the marginal suitability is located mainly between 50m and 550m altitude. This means that some areas gain suitability in higher altitudes in the future.

The graph (Figure 29) shows that the currently marginal suitability (20-40%) areas gain suitability in the future between 350 and 550m.

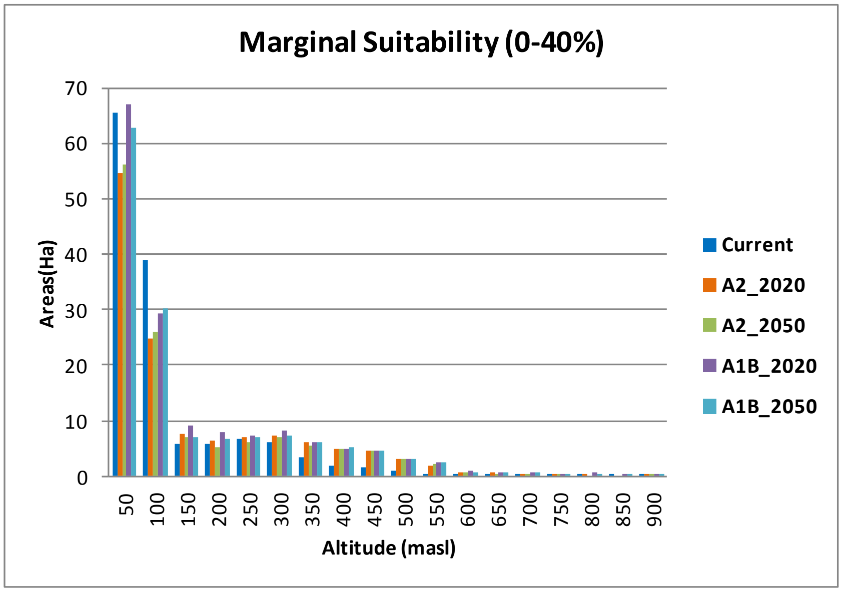


Figure 34. Altitude vs. Marginal Suitability (20-40%) Areas

A good suitability (20 to 40%) currently is located mainly between 50m and 550m. In the future under the A2 and A1B scenarios the good suitability 20-40% is located mainly between 50m and 450m altitude. This means that areas with good suitability today will not have significant changes in the future (2020 and 2050).

The graph (Figure 30) shows that the currently good suitability (40-60%) areas gain suitability in the future mainly in lowlands.

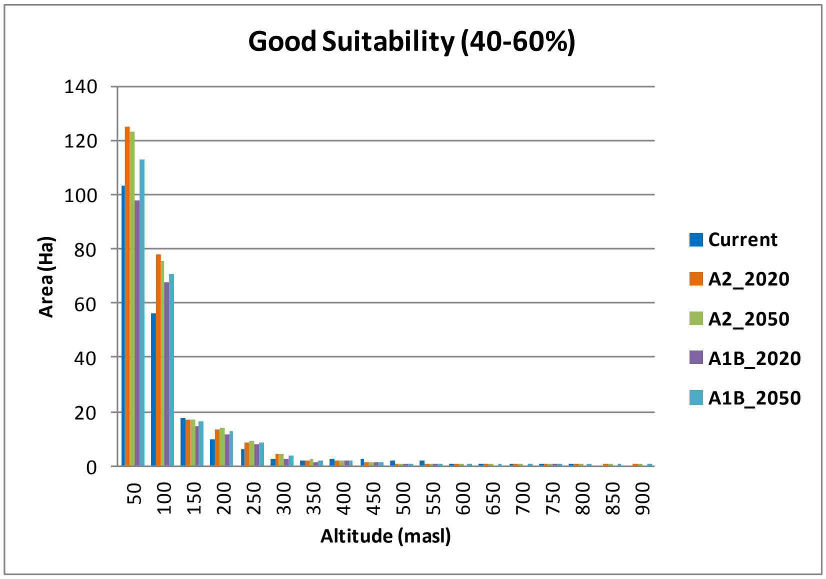


Figure 35. Altitude vs. Suitability. Marginal Suitability (40-60%)

Finally, also notes that areas that currently have a very good suitability (60-80%) are greater in the future. This means that in general the current very good suitability in the Island could be lost in the future.

### 5.6.1. Relation between suitability and altitude by scenario

Figure 31 shows the current climate in blue line, forecasts for 2020 in red line, and gray lines indicate the projection of the different GCMs. According with the prediction by 2020 under A2 scenario, in lowlands (between 200 and 300 masl) the suitability could decrease approximately 6% and in the highlands (between 600 and 900 masl) the suitability could increase approximately 1.3%.

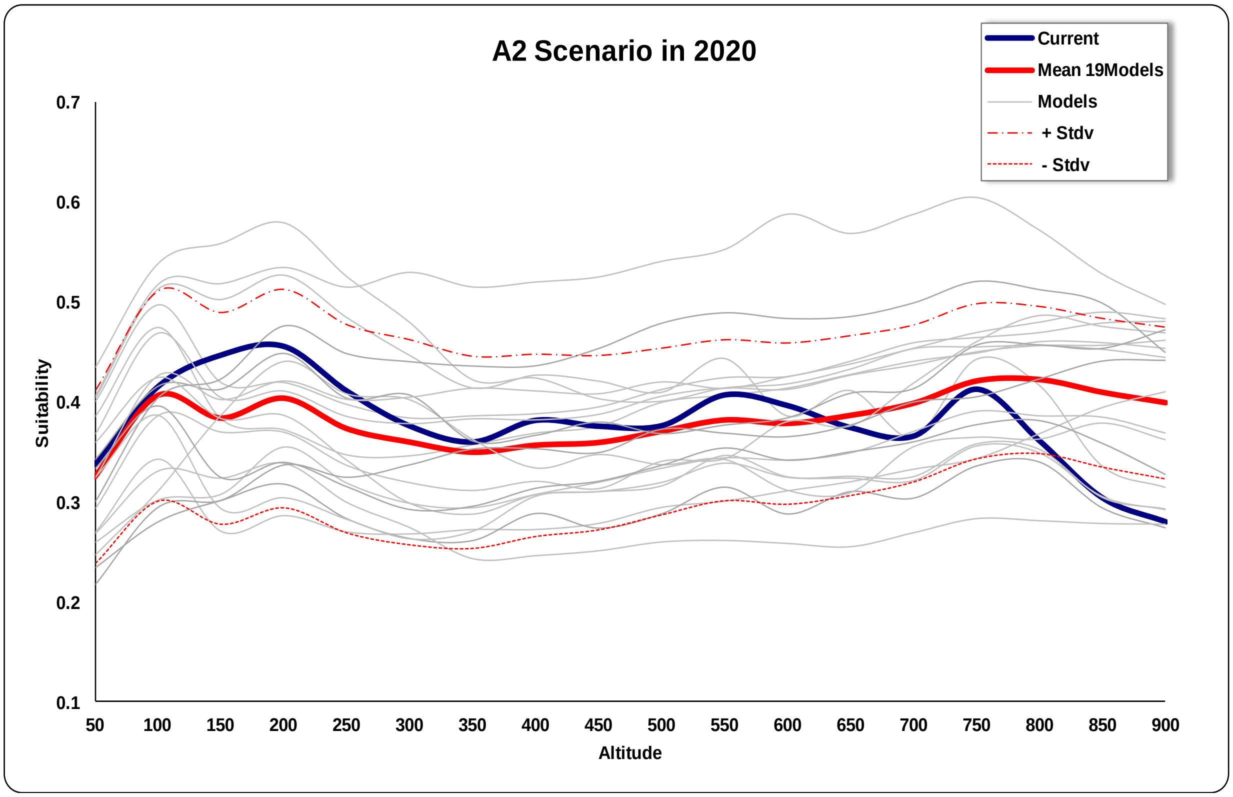


Figure 36. Relation between the cocoa suitability and the altitude, A2 scenario, 2020.

As shown in figure 32, according to the prediction by 2050 under A2 scenario, in lowlands (between 100 and 300 masl) the suitability could decrease approximately 5% and in the highlands (between 600 and 900 masl) the suitability could increase approximately 1%.

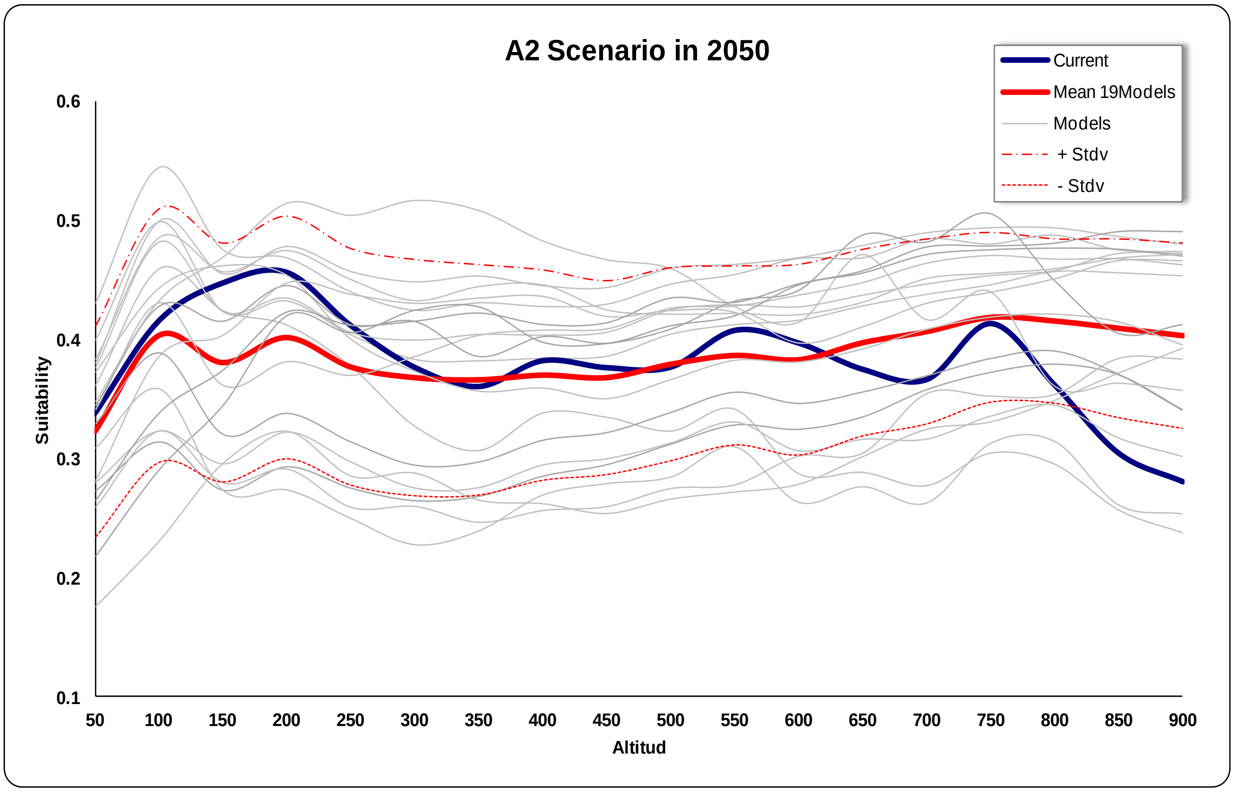


Figure 37. Relation between the cocoa suitability and the altitude, A2 scenario, 2050.

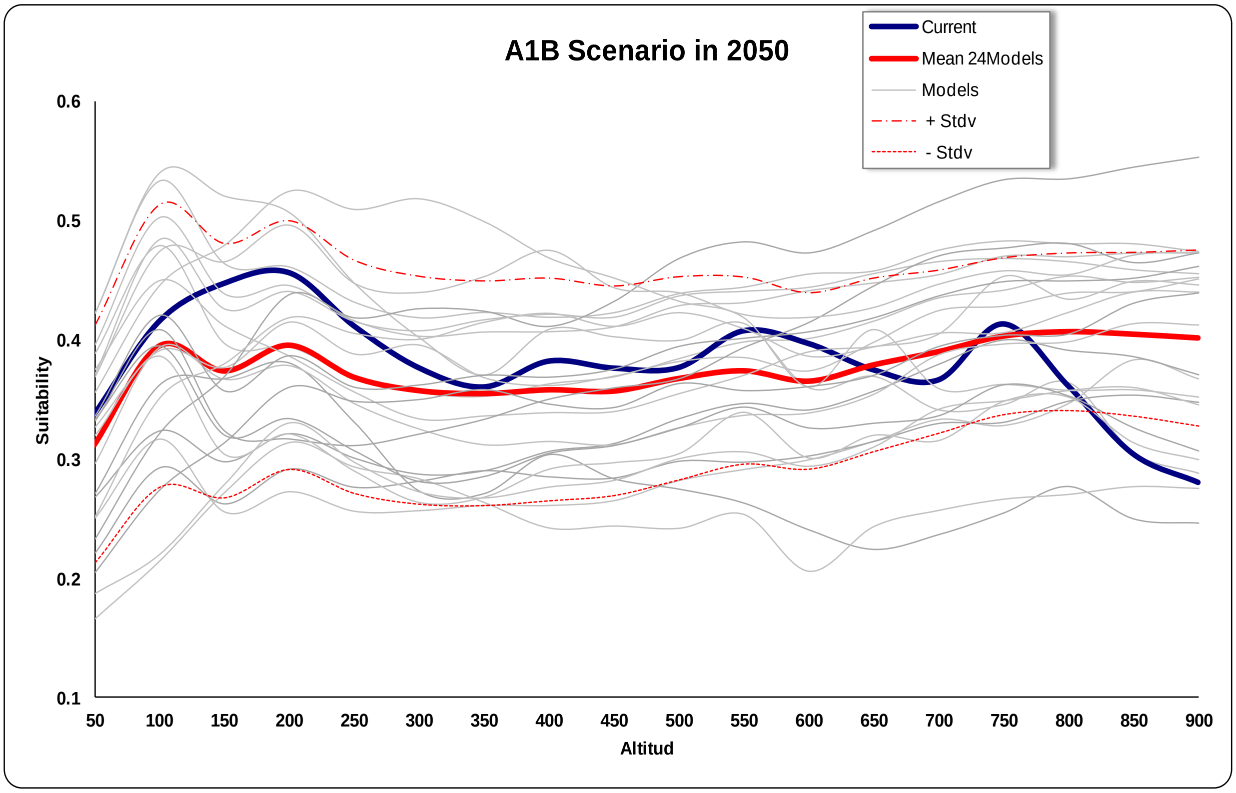


Figure 38. Relation between the cocoa suitability and the altitude, A1B scenario, 2050.

As shown in figure 33, according to the prediction by 2050 under A1B scenario, between 50 and 650 masl the suitability could decrease approximately 3% and in the highlands (between 650 to 900 masl) the suitability could increase approximately 10%.

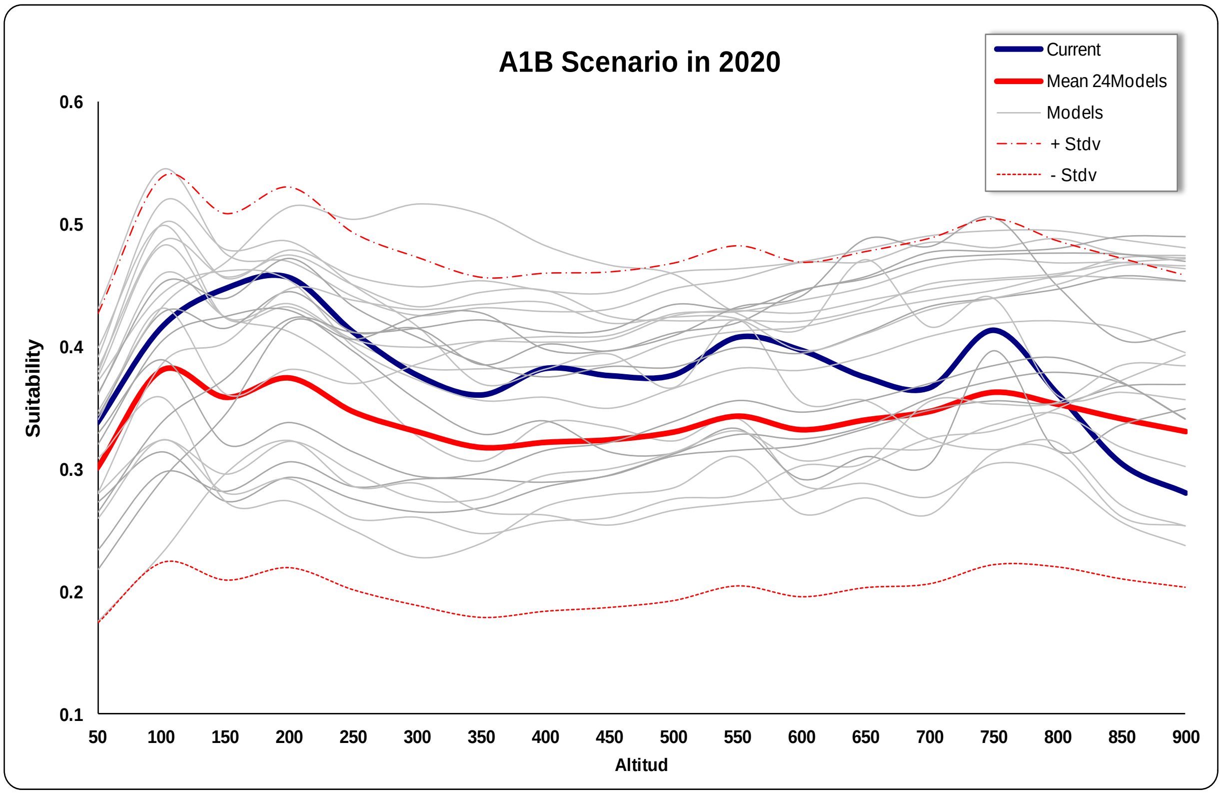


Figure 39. Relation between the cocoa suitability and the altitude, A1B scenario, 2020.

As shown in figure 34, according to the prediction by 2020 under A1B scenario, between 50 and 800 masl the suitability could decrease approximately 4% and in the highlands (between 800 to 900 masl) the suitability could increase approximately 5%.

# 6. DISCUSSION

According with the results, currently Trinidad and Tobago has a mean aptitude reaching a high of 72%. The municipalities with higher climatic suitability for growing cocoa are: Tobago, the east of Talparo, north of Piaro, Rio Claro/Mayaro and the south of Sangre Grande. And areas that show lower suitability (less than 20%) are: the highlands of Sangre Grande, west part of Piaro, Chaguanas, west part of Talparo, San Fernando and north of Penal. However, the prediction by 2020 and 2050 under SRES-A2 and SRES-A1B resulted in approximately 15% of suitability loss in areas where currently cocoa growing and also a gain of approximately 15% of suitability in highlands where currently there is not cacao and where currently the suitability is low.

By overlaying suitability change, present and future, it shows that just those areas for which future predicted greater suitability by 2020 and 2050 are areas of forest that even are part of the national network of protected areas. In the northern of Sangre Grande, where was predicted an increase of 10-26% of suitability are Eastern Extension Matura Forest Reserve, St David Reserve, Matura Swamp Reserve and Western Matura Forest Reserve. And in the southern of Princes Town and Rio Claro/Mayaro, where was predicted an increase of 15-26% of suitability are the Victoria Mayo Forest Reserve.

This suggest that small cocoa farms are located in areas where predicted a loss of suitability will not be able to migrate to these areas of higher suitability. Therefore, it will be necessary that the country implement specific mitigation strategies for farmers in order to reduce the impact that climate change will have on the small islands of the Caribbean Region.

Between these strategies, for small coca farmers in Trinidad and Tobago we could recommend the following:

- Not having monoculture farming systems, but instead implement Agroforestry Systems with cacao, in order to capture the water in the soils through the protection of the tallest trees in the system.

- Maintain natural barriers that protect water sources and protect the groundwater.

- Using plant genetic resources that have been present for centuries on the island, as these tend to be more diverse and adaptable. This way you can ensure greater resilience of cocoa to climate change. (Navarrete-Frias, et al., 2013)

- FAO suggests the combination of the development of robust crop varieties (modifying genomes of crops through breeding) with the introduction of sets of mitigating factors in agricultural management practices.

Finally, in order to increase the reliability of the predictions it would be fine to include more variables in the modelling such as soil data. And include more presence points because in this analysis the points are located in the east part of the country and in the same way the results tend to be skewed and predict higher suitability in these parts of the island.

# 7. CONCLUSIONS

Climate Change poses a problem to cocoa crops in Trinidad and Tobago. Adequate efforts by the government to address this issue are required in order to address present and future income losses from the problem.

The major direct effects of climatic change on cocoa production in T&T are through changes in precipitation and length of the dry season. Moreover, changes in temperature were found to be less influential. Specifically, sensitivity of cocoa production to hours of sunshine, rainfall, soil conditions and temperature makes it vulnerable to climatic change.

It is very important to understand that all is related. A changing climate can also alter the development of pests and diseases and modify the host’s resistance. Extended drought will cause the newly transplanted young cocoa plants and some cocoa trees to wither, while major pests and diseases of cocoa are promoted by unfavourable climatic situations.

It is also worthy to note that over the years, cocoa production in T&T has been marked by declining productivity. It is very important that the government of T&T works on adaptation strategies that reduce the impact of climate change on small farmers. And these strategies should be based on results from research like this.

The results of this research show that the impact of climate change on cacao crops will depend on extreme precipitation events and/or future changes in the maximum and minimum annual precipitations in the island. This is because the duration of drought season is a strong limitation to the crop. Furthermore, according with the results it can be concluded that the cocoa crops in T&T will lose suitability in lowland areas and gain suitability in highland areas. This means that farmers must begin to adapt to climate change by setting other species in lowland areas such as banana, or should move to highland areas of the island if they wish to continue to have high productivity in cocoa production.

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# 9. ANNEXES

## Annex 1. Bioclimatic data for each presence point.

| id | lon | lat | bio_1 | bio_2 | bio_3 | bio_4 | bio_5 | bio_6 | bio_7 | bio_8 | bio_9 | bio_10 | bio_11 | bio_12 | bio_13 | bio_14 | bio_15 | bio_16 | bio_17 | bio_18 | bio_19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | -60.609 | 11.299 | 253 | 76 | 76 | 638 | 300 | 200 | 100 | 252 | 249 | 258 | 243 | 2231 | 295 | 64 | 39 | 770 | 253 | 478 | 447 |
| **2** | -60.706 | 11.245 | 253 | 76 | 76 | 645 | 299 | 200 | 99 | 252 | 249 | 258 | 243 | 2167 | 283 | 64 | 41 | 754 | 238 | 454 | 426 |
| **3** | -60.721 | 11.230 | 257 | 75 | 76 | 617 | 304 | 206 | 98 | 257 | 254 | 263 | 248 | 2058 | 272 | 60 | 42 | 725 | 219 | 423 | 399 |
| **4** | -60.749 | 11.181 | 266 | 74 | 75 | 617 | 313 | 215 | 98 | 269 | 263 | 272 | 257 | 1797 | 240 | 51 | 45 | 651 | 174 | 357 | 332 |
| **5** | -60.609 | 11.222 | 265 | 75 | 76 | 626 | 312 | 214 | 98 | 264 | 261 | 270 | 255 | 2025 | 276 | 53 | 41 | 712 | 221 | 428 | 406 |
| **6** | -60.597 | 11.233 | 266 | 75 | 76 | 631 | 313 | 215 | 98 | 265 | 262 | 272 | 256 | 2030 | 278 | 53 | 41 | 716 | 224 | 428 | 411 |
| **7** | -60.581 | 11.247 | 266 | 75 | 77 | 625 | 312 | 215 | 97 | 265 | 262 | 271 | 256 | 2065 | 284 | 54 | 40 | 729 | 232 | 435 | 424 |
| **8** | -60.958 | 10.784 | 263 | 81 | 77 | 625 | 312 | 208 | 104 | 262 | 266 | 269 | 253 | 2265 | 284 | 65 | 41 | 814 | 266 | 449 | 498 |
| **9** | -61.003 | 10.813 | 253 | 82 | 78 | 628 | 303 | 198 | 105 | 253 | 250 | 259 | 244 | 2578 | 314 | 82 | 40 | 892 | 299 | 527 | 538 |
| **10** | -61.056 | 10.674 | 261 | 83 | 77 | 644 | 312 | 205 | 107 | 260 | 258 | 267 | 251 | 2646 | 336 | 89 | 40 | 920 | 310 | 527 | 541 |
| **11** | -61.243 | 10.674 | 245 | 86 | 78 | 643 | 296 | 187 | 109 | 248 | 241 | 250 | 235 | 2664 | 347 | 84 | 43 | 989 | 275 | 589 | 464 |
| **12** | -61.333 | 10.680 | 236 | 86 | 79 | 648 | 287 | 179 | 108 | 239 | 232 | 241 | 226 | 2554 | 332 | 81 | 43 | 959 | 266 | 574 | 444 |
| **13** | -61.334 | 10.751 | 254 | 89 | 79 | 629 | 308 | 196 | 112 | 257 | 251 | 260 | 245 | 2173 | 278 | 75 | 43 | 781 | 232 | 432 | 400 |
| **14** | -61.214 | 10.583 | 259 | 87 | 78 | 651 | 312 | 201 | 111 | 262 | 255 | 265 | 249 | 2445 | 325 | 79 | 46 | 919 | 241 | 488 | 423 |
| **15** | -61.150 | 10.559 | 260 | 85 | 77 | 651 | 312 | 203 | 109 | 263 | 256 | 266 | 250 | 2654 | 331 | 88 | 42 | 947 | 284 | 540 | 503 |
| **16** | -61.073 | 10.593 | 261 | 84 | 78 | 651 | 312 | 205 | 107 | 261 | 257 | 267 | 251 | 2697 | 350 | 92 | 40 | 927 | 311 | 547 | 535 |
| **17** | -61.065 | 10.531 | 261 | 84 | 79 | 640 | 311 | 205 | 106 | 260 | 257 | 266 | 251 | 2654 | 346 | 93 | 40 | 924 | 301 | 528 | 527 |
| **18** | -61.138 | 10.510 | 255 | 85 | 78 | 651 | 306 | 198 | 108 | 258 | 251 | 261 | 245 | 2607 | 325 | 88 | 42 | 920 | 276 | 539 | 499 |
| **19** | -61.115 | 10.480 | 251 | 85 | 79 | 651 | 302 | 195 | 107 | 254 | 247 | 257 | 241 | 2567 | 318 | 87 | 41 | 902 | 274 | 544 | 494 |
| **20** | -61.131 | 10.423 | 260 | 85 | 78 | 640 | 311 | 203 | 108 | 260 | 256 | 265 | 250 | 2546 | 322 | 86 | 42 | 887 | 268 | 503 | 515 |
| **21** | -61.282 | 10.420 | 252 | 86 | 78 | 655 | 303 | 194 | 109 | 254 | 247 | 257 | 242 | 2016 | 266 | 57 | 46 | 770 | 186 | 440 | 347 |
| **22** | -61.310 | 10.379 | 257 | 87 | 79 | 656 | 308 | 199 | 109 | 259 | 252 | 262 | 247 | 1883 | 243 | 53 | 45 | 680 | 171 | 394 | 342 |
| **23** | -61.372 | 10.399 | 253 | 87 | 79 | 650 | 304 | 194 | 110 | 256 | 248 | 258 | 243 | 1845 | 262 | 49 | 50 | 751 | 164 | 406 | 186 |
| **24** | -61.273 | 10.280 | 258 | 85 | 80 | 641 | 308 | 202 | 106 | 258 | 254 | 263 | 248 | 1914 | 252 | 65 | 40 | 667 | 202 | 412 | 394 |
| **25** | -61.275 | 10.092 | 262 | 83 | 79 | 620 | 311 | 207 | 104 | 265 | 258 | 267 | 253 | 1821 | 243 | 60 | 42 | 677 | 194 | 548 | 349 |
| **26** | -61.641 | 10.063 | 263 | 82 | 79 | 620 | 312 | 209 | 103 | 266 | 259 | 269 | 254 | 1533 | 204 | 54 | 42 | 595 | 182 | 452 | 298 |
| **27** | -61.802 | 10.116 | 263 | 80 | 80 | 605 | 311 | 211 | 100 | 266 | 259 | 269 | 254 | 1521 | 203 | 59 | 40 | 585 | 200 | 457 | 317 |

## Annex 2. Bioclimatic data for each absence point.

| id | lon | lat | bio_1 | bio_2 | bio_3 | bio_4 | bio_5 | bio_6 | bio_7 | bio_8 | bio_9 | bio_10 | bio_11 | bio_12 | bio_13 | bio_14 | bio_15 | bio_16 | bio_17 | bio_18 | bio_19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -61.433 | 10.140 | 262 | 84 | 80 | 612 | 311 | 207 | 104 | 265 | 258 | 267 | 253 | 1635 | 223 | 47 | 45 | 629 | 167 | 545 | 282 |
| 2 | -61.585 | 10.108 | 262 | 82 | 79 | 620 | 311 | 208 | 103 | 265 | 258 | 267 | 253 | 1609 | 208 | 54 | 43 | 619 | 181 | 497 | 295 |
| 3 | -61.479 | 10.222 | 263 | 85 | 80 | 612 | 312 | 207 | 105 | 266 | 259 | 268 | 254 | 1608 | 229 | 44 | 47 | 629 | 153 | 566 | 266 |
| 4 | -61.439 | 10.297 | 263 | 86 | 78 | 641 | 314 | 205 | 109 | 265 | 258 | 267 | 253 | 1611 | 232 | 41 | 50 | 647 | 140 | 345 | 254 |
| 5 | -61.462 | 10.371 | 262 | 87 | 80 | 622 | 313 | 205 | 108 | 265 | 258 | 267 | 253 | 1504 | 214 | 32 | 55 | 638 | 116 | 527 | 204 |
| 6 | -61.422 | 10.397 | 261 | 88 | 80 | 630 | 313 | 203 | 110 | 263 | 257 | 266 | 251 | 1567 | 226 | 33 | 54 | 667 | 122 | 363 | 140 |
| 7 | -61.451 | 10.493 | 263 | 90 | 80 | 630 | 316 | 204 | 112 | 265 | 259 | 268 | 253 | 1513 | 227 | 29 | 58 | 657 | 102 | 341 | 119 |
| 8 | -61.408 | 10.519 | 262 | 90 | 80 | 637 | 315 | 203 | 112 | 264 | 258 | 267 | 252 | 1574 | 242 | 30 | 58 | 669 | 103 | 327 | 226 |
| 9 | -61.430 | 10.544 | 263 | 90 | 80 | 629 | 316 | 204 | 112 | 265 | 259 | 268 | 253 | 1519 | 241 | 27 | 61 | 646 | 91 | 299 | 220 |
| 10 | -61.459 | 10.647 | 265 | 93 | 80 | 603 | 320 | 205 | 115 | 267 | 261 | 270 | 255 | 1628 | 240 | 32 | 55 | 664 | 131 | 333 | 240 |
| 11 | -61.561 | 10.721 | 266 | 93 | 81 | 576 | 321 | 207 | 114 | 268 | 263 | 271 | 257 | 1713 | 258 | 52 | 50 | 677 | 163 | 283 | 309 |
| 12 | -61.122 | 10.750 | 249 | 84 | 78 | 634 | 299 | 192 | 107 | 251 | 245 | 254 | 239 | 2861 | 354 | 94 | 40 | 999 | 318 | 612 | 551 |
| 13 | -61.056 | 10.765 | 240 | 83 | 79 | 645 | 290 | 185 | 105 | 243 | 236 | 246 | 230 | 2832 | 349 | 91 | 40 | 990 | 315 | 625 | 547 |
| 14 | -61.102 | 10.801 | 248 | 83 | 78 | 634 | 298 | 192 | 106 | 250 | 244 | 253 | 238 | 2814 | 343 | 93 | 40 | 972 | 316 | 595 | 554 |
| 15 | -61.133 | 10.778 | 241 | 84 | 80 | 645 | 291 | 186 | 105 | 244 | 237 | 247 | 231 | 2860 | 357 | 93 | 40 | 1012 | 314 | 626 | 543 |
| 16 | -61.513 | 10.678 | 266 | 94 | 80 | 588 | 322 | 205 | 117 | 268 | 262 | 271 | 257 | 1669 | 252 | 40 | 52 | 677 | 150 | 320 | 267 |
| 17 | -61.901 | 10.057 | 264 | 78 | 79 | 610 | 311 | 213 | 98 | 267 | 260 | 270 | 255 | 1380 | 179 | 52 | 38 | 521 | 179 | 389 | 306 |
| 18 | -61.005 | 10.322 | 262 | 83 | 79 | 625 | 311 | 207 | 104 | 261 | 258 | 267 | 252 | 1990 | 246 | 66 | 43 | 698 | 208 | 632 | 415 |
| 19 | -61.361 | 10.636 | 261 | 90 | 78 | 645 | 317 | 202 | 115 | 264 | 258 | 267 | 252 | 1745 | 248 | 32 | 55 | 728 | 127 | 389 | 248 |
| 20 | -61.286 | 10.603 | 261 | 88 | 78 | 628 | 314 | 202 | 112 | 263 | 257 | 266 | 251 | 1971 | 276 | 51 | 54 | 792 | 160 | 403 | 281 |
| 21 | -61.321 | 10.627 | 260 | 89 | 78 | 650 | 314 | 201 | 113 | 263 | 256 | 266 | 250 | 1867 | 265 | 43 | 54 | 767 | 144 | 400 | 267 |
| 22 | -61.277 | 10.633 | 260 | 88 | 78 | 637 | 313 | 201 | 112 | 262 | 256 | 265 | 250 | 2054 | 282 | 59 | 51 | 806 | 180 | 414 | 309 |
| 23 | -61.415 | 10.194 | 262 | 84 | 79 | 632 | 312 | 206 | 106 | 265 | 258 | 267 | 253 | 1619 | 228 | 44 | 47 | 631 | 155 | 552 | 274 |
| 24 | -61.556 | 10.177 | 262 | 84 | 80 | 620 | 311 | 207 | 104 | 265 | 258 | 267 | 253 | 1615 | 208 | 50 | 44 | 613 | 171 | 535 | 279 |
| 25 | -61.388 | 10.548 | 261 | 90 | 80 | 638 | 315 | 203 | 112 | 264 | 258 | 267 | 252 | 1635 | 244 | 33 | 58 | 684 | 109 | 336 | 238 |
| 26 | -61.413 | 10.340 | 260 | 87 | 80 | 637 | 311 | 203 | 108 | 263 | 256 | 265 | 250 | 1642 | 227 | 39 | 51 | 675 | 138 | 376 | 161 |
| 27 | -61.451 | 10.085 | 260 | 83 | 79 | 620 | 309 | 205 | 104 | 263 | 256 | 265 | 251 | 1681 | 219 | 54 | 43 | 641 | 181 | 530 | 303 |