CLIMATE RISK COUNTRY PROFILE

PANAMA

WORLD BANK GROUP

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This profile is part of a series of Climate Risk Country Profiles developed by Climate Change Group of the World Bank Group (WBG). The country profiles aim to present a high-level assessment of the climate risks faced by countries, including rapid-onset events and slow-onset changes in climate conditions, many of which are already underway, as well as summarize relevant information on policy and planning efforts at the country level.

The country profile series are designed to be a reference source for development practitioners to better integrate detailed climate data, physical climate risks and need for resilience in development planning and policy making.

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Unless otherwise noted, data is sourced from the WBG's Climate Change Knowledge Portal (CCKP), the WBG's designated platform for climate data. Climate, climate change and climate-related data and information on CCKP represents the latest available data and analysis based on the latest Intergovernmental Panel on Climate Change (IPCC) reports and datasets. The team is grateful for all comments received from climate and development specialists, as well as climate research scientists and institutions for their advice and guidance on the use of climate related datasets.

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FOREWORD

Climate change is a major risk to good development outcomes and presents an existential threat to the World Bank Group's (WBG) twin goals of ending extreme poverty and promoting shared prosperity in a sustainable way. The WBG is thus committed to supporting client countries to invest in a low-carbon and climate-resilient future.

Our approach is outlined in the *WBG Climate Change Action Plan (CCAP) 2021–2025*, which focuses on helping countries integrate climate into their development agendas, with the goal to combine mitigation and adaptation with economic growth and poverty reduction. Guided by the *CCAP*, the WBG prioritizes climate action across five key systems: energy; agriculture, food, water, and land; cities; transport; and manufacturing. Only through transforming these systems can we begin to address climate change, achieve a resilient and low-carbon future, and support natural capital and biodiversity, while achieving development goals.

A key element of this strategy relies on the capacity to systematically incorporate and manage climate risks in development operations. We are thus investing in processes and tools that allow us to inform lending with climate data.

The Climate Change Knowledge Portal (CCKP) is an online 'one-stop-shop' for foundational climate data at the global, regional, and country levels. CCKP provides inputs to the WBG's Climate and Disaster Risk Screening Tool, which contributes to assessing short- and long-term climate and disaster risks in operations as well as national or sectoral planning processes.

Supplementing this effort, the *Climate Risk Country Profile* you are about to read is a signature product of CCKP which supports a better understanding of the impacts of physical climate risks. Guided by the Climate Risk Country Profile, WBG, key external partners, and development practitioners may conduct initial assessments of climate risks and opportunities that will eventually inform upstream country diagnostics, policy dialogue, and strategic planning for developing countries.

It is my hope that these efforts will spur the prioritization of long-term risk management and deepen the WBG's commitment to integrate adaptation planning into strategic country engagements and lending operations.

Jennifer J. Sara
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KEY MESSAGES

- **Observed Climate:** Panama has a moist tropical and subtropical climate with one rainy and dry season annually, regionally influenced by the march of the Intertropical Convergence Zone (ITCZ), changes in elevation and coastal proximity, and the El Niño Southern Oscillation (ENSO).
- **Observed Temperature:** Between 1971 and 2020, Panama's mean temperature increased by 0.23°C per decade.
  - The **eastern provinces** observed the greatest changes over this period during the summer months.
- **Projected Temperature:** Under the SSP3-7.0 ensemble, Panama's annual mean temperatures nationwide are projected to increase homogeneously from the historical reference period (1995–2014) to 26.02°C (25.75°C, 10th percentile, 26.50°C, 90th percentile) for the period 2020–2039, and to 26.65°C (26.24°C, 27.28°C) for the period 2040–2059.
- **Extreme Heat Risk:** By midcentury, Panama is likely to experience higher minimum and maximum temperatures. The following key metrics for temperature illustrate these risks under the SSP3-7.0 scenario for the period of 2040–2059, compared to the historical reference period of 1995–2014.
  - Number of Tropical Nights, T-min >20°C: The number of tropical nights with a minimum temperature >20°C is projected to increase in higher elevation regions across all four seasons. An increase in high Heat Index days or warm spell days coupled with the rise in the number of tropical nights with high minimum temperature thresholds magnify human health risks.
    - The **western provinces** are projected to experience the greatest increases by midcentury year-round.
  - Number of Tropical Nights, T-min >26°C: The number of tropical nights with a minimum temperature >26°C, an even higher minimum threshold, is projected to increase year-round. The combination of increased high heat days and tropical nights disproportionately concern: the elderly, pregnant women, children and newborns, people with chronic illnesses and disabilities, outdoor workers, low-wage earners, and people living in areas with poorly equipped and ill-prepared health services.
    - **Provinces along the central and eastern parts of the isthmus** are projected to experience increases by midcentury, especially during spring and summer months.
  - Warm Spell Duration Index (WSDI): This annualized index indicates the number days with consecutive daily maximum temperatures greater than the 90th percentile of daily maximum temperature calculated over a five-day window annually. Warm spell anomalies, measured in number of days annually, are projected to increase 144.14 days by 2040–2059. This shift reflects a longer-term change in daily maximum temperatures.
    - **Provinces in the southern Arco Seco region** experience the greatest increases in warm spell days by midcentury.
- **Observed Precipitation:** Over the 50-year period of 1971–2020, Panama experienced significant decreases in precipitation nationally (–28.18 mm per decade), but precipitation trends varied seasonally across Panama's regions. Over this period:
  - **Central Pacific and eastern provinces** were significantly drier, especially during summer months.
  - **Western and central Caribbean provinces** were significantly wetter annually, especially during fall months.

- **<u>Projected Precipitation:</u>** Projected precipitation patterns under SSP3-7.0 increase from the reference period at the national level by an anomaly of 45.09 mm (–307.60 mm, 298.70 mm) annually to 3,217 mm (2,707.55 mm, 3,716.96 mm) by midcentury, but exhibit divergent regional and seasonal shifts.
  - **Western provinces** are expected to experience an annual decrease in precipitation, mostly during fall and winter months.
  - **Pacific-facing provinces** are expected to experience an annual increase in precipitation, mostly during the summer and fall months.
  - **Caribbean-facing provinces** are expected to experience approximately no net annual change in precipitation, with summer and winter decreases generally balancing spring and fall increases.
- **<u>Precipitation Risk:</u>** By midcentury, Panama is likely to experience an overall increase in annual precipitation intensity with regional and seasonal trends corresponding to projected precipitation volumes. The following key metrics illustrate these shifts for the period of 2040–2059 under SSP3-7.0, compared to the historical reference period of 1995–2014.
  - <u>Average Largest 5-Day Precipitation:</u> Increases in the average largest precipitation amount over a 5-day period, which rise by an anomaly of 11.98 mm (–81.77 mm, 81.00 mm) nationwide from the reference period to 228.08 mm (165.58 mm, 321.58 mm) by midcentury, pose risks for flood management.
    - **Western provinces** are expected to experience the least annual change in precipitation intensity, with the greatest decreases during winter months.
    - **Pacific-facing provinces** are expected to experience an annual increase in precipitation intensity, with the greatest increases during fall months.
    - **Caribbean-facing provinces** are expected to experience only slight increases in precipitation intensity, with the greatest increases during fall months.
- **<u>Extreme Precipitation Occurrence:</u>** By midcentury, Panama is likely to more frequently experience extreme precipitation event occurrence. These conditions pose risks for food security, flood-related safety, disease ranges, biodiversity, and living conditions.
  - **Provinces along the central and eastern Pacific coast** are projected to be nearly twice as likely to experience the largest 1-day precipitation amounts associated with 100-year historical return periods by midcentury under SSP3-7.0.
- **<u>Climate-Related Hazards:</u>**
  - Sea level rise and coastal inundation will increasingly threaten Panama's **Caribbean coast and parts of the Pacific coast**. Warmer sea surface temperatures south of the Gulf of Panama (**Pacific coast)** would likely result in a southward migration of ITCZ precipitation.
  - The frequency of intense floods and droughts associated with ENSO will likely become more common in the future and are especially critical to monitor in the **Panama Canal watershed and Arco Seco**, respectively.
  - Climate variability is an important contributor to seismic risk conditions, which particularly affect the **westernmost, easternmost, northernmost, and southernmost extents of the Isthmus of Panama**.

For National Policies, see key documents linked at the end of this profile.

COUNTRY OVERVIEW

The Republic of Panama, located on the Isthmus of Panama connecting North America with South America, is a strategically positioned country subdivided into ten provinces and three semiautonomous indigenous-led *comarcas* between 7°N-10°N latitude (**see Figures 1a and 1b**). Panama's land area covers 74,180 km^2 and borders Costa Rica to the west, Colombia to the east, the Caribbean Sea to the north, and the Pacific Ocean to the south. Two primary mountain ranges – the Cordillera Central (Tabasará) in the west and the Cordillera de San Blas in the east – bisect the isthmus into Pacific-facing and Caribbean-facing slopes split by the 65 km-long Panama Canal. The taller Cordillera Central contains the country's highest point, Volcán Barú (Chiriquí Province) at 3,475 meters (m) above sea level, while smaller mountain chains occupy portions of the Azuero Peninsula (Veraguas, Los Santos, and Herrera Provinces) in the southwest and the Majé (Panamá and Darién Provinces) and Jungurudó (Darién and Emberá Provinces) in the east.[1] However, as illustrated in **Figure 1b**, most of Panama comprises coastal lowlands below 700 m in elevation. Of the country's 1,600 islands, the largest include Coiba (Veraguas), the Perlas Archipelago (Panamá), and Bocas del Toro Archipelago (Bocas del Toro).

According to the World Bank's DataBank,[2] Panama has an estimated 2022 population of 4.4 million with an annual population growth rate of 1.3% and fertility rate close to the worldwide average (**see Table 1**). Approximately two-thirds of the population live in urban areas as of 2022, with a majority residing in the Panama City-Colón metropolitan region and settlements in Panama's southwest (Pacific) quadrant. Overall, Panama ranks relatively high on the Human Development Index (61 out of 191) for 2021, considering factors such as life expectancy, education, and income per capita.[3] As an upper-middle-income country, it has a 2022 Gross Domestic Product (GDP in current $US) of $76.52 billion, an annual GDP growth rate of 10.8%, and GDP per capita of roughly $17,000 (current $US). Panama's economy grew more than four times the average for the Latin America and Caribbean region between 2014–2019 and experienced a strong economic rebound from the COVID-19 pandemic.[4] This reflects the fact that most of the country's GDP and employment revolves around service sector activities related to trade and offshore financing since the 1970s and 1980s, transportation and logistics (the government took full control of the Panama Canal from the U.S. in 1999), and more recently tourism.[5] Most commerce and key industries, including construction, brewing, cement, sugar milling, and oil refining are centered around the Panama Canal corridor. Cultivation of sugarcane, bananas, rice, and maize comprise a relatively small portion of GDP, but such agricultural activities disproportionately provide employment in rural areas. Livestock raising is centered in the southwest savannas while fish and shrimp harvesting occurs primarily in the shallow (Pacific) Gulf of Panama. Although Panama is a rapidly growing economy and dedicates substantial

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1 Anguizola, G., Gordon, B. L., and Millett, R. L. (2023). Panama. Encyclopedia Britannica. URL: https://www.britannica.com/place/Panama
2 World Bank (2023). DataBank – World Development Indicators. URL: https://databank.worldbank.org/source/world-development-indicators
3 UNDP (2022). Human Development Report 2021/2022. URL: https://hdr.undp.org/system/files/documents/global-report-document/hdr202122pdf_1.pdf
4 World Bank (2023). Panama Overview. URL: https://www.worldbank.org/en/country/panama/overview#1
5 Anguizola, G., Gordon, B. L., and Millett, R. L. (2023). Panama. Encyclopedia Britannica. URL: https://www.britannica.com/place/Panama; Beaton, K., and Hadzi-Vaskov, M. (2017). Panama's growth prospects: Determinants and sectoral perspectives. International Monetary Fund Working Paper. URL: https://www.imf.org/en/Publications/WP/Issues/2017/07/07/Panamas-Growth-Prospects-Determinants-and-Sectoral-Perspectives-45030

funding to social programs, poverty and income inequality remain high. About one-fifth of Panama's (2019) population lives below the national poverty line. Many indigenous minorities located in isolated areas in the country's east and Caribbean west experience extreme poverty that contrast living conditions in the capital region, which help explain why Panama has the 12th highest levels of inequality globally (2021) according to the Gini Index. These factors contribute to the country's vulnerability to changing climates and physical climate risks.

Panama updated its first Nationally-Determined Contribution (CDN1) in 2020, released its Second Biennial Update Report (2IBA) in 2021, and submitted its Fourth National Communication (4CNCC) to the UNFCCC in 2023 as it pursues a carbon-neutral economy by 2050. The CDN1 makes 29 commitments across ten sectors, including mitigation targets to reduce its emissions from the energy sector by at least 11.5% by 2030 and 24% by 2050, in addition to restoring 50,000 hectares of national forests by midcentury. Key adaptation programs outlined by Panama's Ministry of Environment, established in 2015, tackle issues ranging from integrated water resource management, public health, and building climate resilience in coastal, rural, and urban communities.[6] The 2021 National Climate Action Plan (PNAC), among other instruments and strategies, lays out implementation guidelines across institutions for achieving its climate goals in the next five years.[7]

FIGURE 1A. Administrative Divisions of Panama

[6] Ministry of Environment (2018). Third National Climate Change Communication. URL: https://unfccc.int/sites/default/files/resource/Tercera%20Comunicacion%20Nacional%20Panama.pdf

[7] Ministry of Environment (2023). Fourth National Climate Change Communication. URL: https://unfccc.int/sites/default/files/resource/53792416_Panama-NC4-1-4CNCC_2023_PANAMA_H.pdf

FIGURE 1B. Physiographic Map of Panama with Largest Cities[8]

TABLE 1. Key Development Indicators[9]

Key Demographic Indicators	Most Recent Value	Global Rank
Population Density (people per sq km, 2021)	58.66	143 (out of 216)
Life Expectancy (for total population in years, 2021)	76.22	63 (out of 209)
Fertility Rate (total births per woman, 2021)	2.33	92 (out of 210)
Dependency Ratio (dependents per 100 working-age people, 2022)	53.62	117 (out of 217)
Key Economic and Social Development Indicators	**Most Recent Value**	**Global Rank**
GDP per Capita (in current $US, 2022)	$17,357.63	69 (out of 185)
% Population Below National Poverty Line (2019)	21.50%	89 (out of 157)
Unemployment Rate (% of total labor force, 2022)	8.79%	53 (out of 183)
% Employed in Agriculture (2021)	15.67%	96 (out of 185)
% Employed in Industry (2021)	16.82%	124 (out of 185)
% Employed in Services (2021)	67.51%	62 (out of 185)
% Population with Access to Electricity (2021)	95.25%	150 (out of 215)
% Population Using at Least Basic Sanitation Services (2022)	85.88%	118 (out of 191)

Data for each indicator's most recently measured year is ranked compared to all countries and entities globally in the far-right column, as tracked by the World Bank's DataBank. Global ranking for the population below national poverty line is ordered according to most recent value, not most recent year.

[8] GISGeography (2023). Map of Panama. URL: https://gisgeography.com/panama-map/

[9] World Bank (2023). DataBank – World Development Indicators. URL: https://databank.worldbank.org/source/world-development-indicators

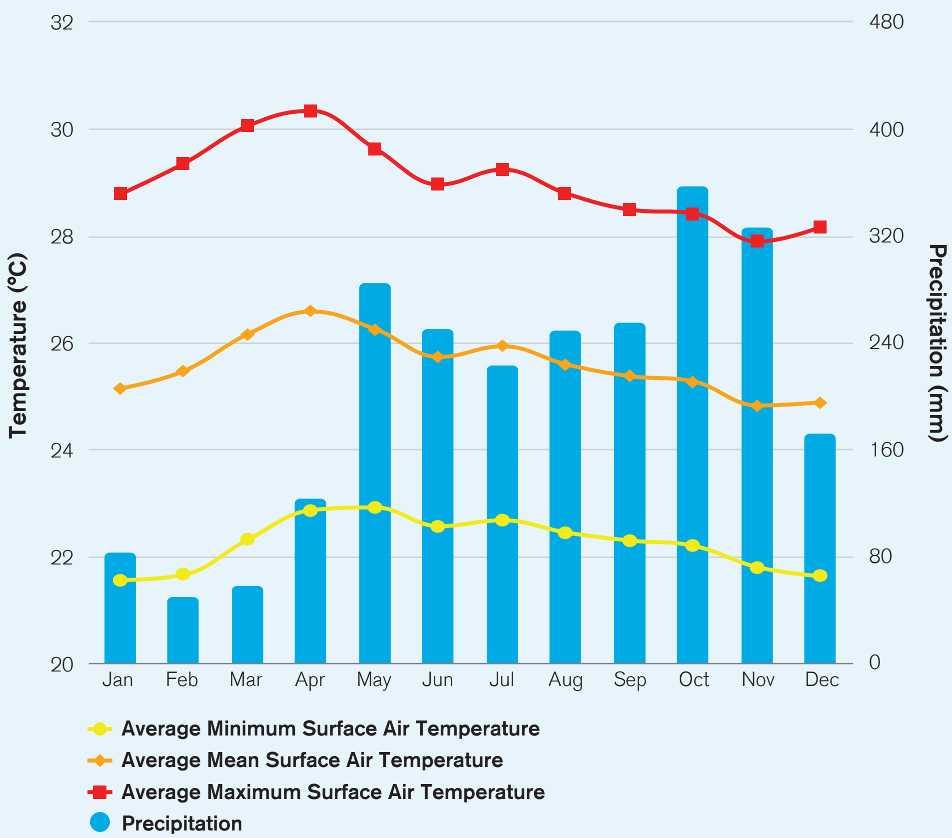
Data Overview

The data presented are from the World Bank Group's Climate Change Knowledge Portal (CCKP).[10] Historical, observed data is derived from the Climatic Research Unit, University of East Anglia (CRU), CRU TS version 4.07 gridded dataset (data available 1901–2022) and ERA5 reanalysis collection from ECMWF (1950–2020).

Climate Overview

Panama has a moist tropical and subtropical climate with one rainy and dry season annually, regionally influenced by the march of the Intertropical Convergence Zone (ITCZ), changes in elevation and coastal proximity, and the El Niño Southern Oscillation (ENSO). Over the current climatology (1991–2020, **see Figure 2**), Panama observed a mean annual temperature of 25.6°C. During the 1991–2020 period, the warmest

FIGURE 2. Observed Monthly Climatology of Panama's Temperature and Precipitation, 1991–2020



Note the midsummer precipitation minimum in July and minor temperature variations year-round coinciding with the timing of the wet season (May to December).

[10] World Bank Climate Change Knowledge Portal (2023). Panama Climatology. URL: https://climateknowledgeportal.worldbank.org/country/panama/climate-data-historical

month of April ranged from an average minimum temperature of 22.86°C to an average maximum temperature of 30.34°C, while the coolest month of November ranged from a minimum average temperature of 21.79°C to a maximum average temperature of 27.89°C. Temperature increases by approximately 0.56°C for every 100 meters gained in altitude, creating two altitude-driven temperature regimes – a hot, tropical, low-lying zone at elevations below 700 m, which make up the majority of the territory, and a subtropical montane zone at higher elevations.[11] As shown in **Table 2**, the warmest average temperatures occur in April nationwide before the onset of the rainy season. Los Santos on the central Pacific coast possesses the warmest mean temperature (27.92°C) in April and warmest annual mean temperature (26.48°C) in Panama. The coolest average temperatures occur in November and December at the end of the rainy season. Bocas del Toro on the northwest Caribbean coast, including the western highlands, possesses the coolest monthly average temperature (21.91°C in December) and coolest annual average temperature (22.69°C).

Panama's mean annual precipitation over the current climatology (1991–2020) at the national level was 2,436.21 mm but varied regionally and seasonally. The forested Caribbean coast and eastern isthmus received the highest annual rainfall amounts due to moist trade winds and year-round precipitation (all greater than 2,300 mm per year). By comparison, most of Panama's Pacific-facing slopes, savannas, and coast did not record mean precipitation levels above 2,500 mm per year and exhibited the most distinct rainy and dry seasons.[12] **Table 2** illustrates Panama's precipitation patterns subnationally according to western, central, and eastern geographic regions. Panama's wet season begins in May with the northward migration of the ITCZ and ends in October or November when the ITCZ migrates southward. Stronger easterly trade winds in midsummer associated with the Caribbean low-level jet produce a 10–15% reduction in precipitation during July (*veranillo*), most evident over the most recent climatology in the northwest Caribbean region.[13] For example, Bocas del Toro observed Panama's wettest annual average precipitation over the most recent climatology (3,113.29 mm) with an average July minimum of 259.07 mm compared to nearly equivalent monthly maxima in May and October of approximately 400 mm or greater. The wettest months on average nationally occur at the end of the wet season in October or November, which coincide with the peak strength of the moist westerly Chocó low-level jet.[14] Chiriquí, which contains Panama's highest elevations, observed the heaviest monthly average (512.28 mm) during October. As the ITCZ migrates south, the northerly Panama low-level jet strengthens from January to April and crosses the isthmus, coinciding with the dry season that peaks in February or March.[15] The central Pacific region, in the rain shadow of the central mountain ranges, contains the driest monthly average precipitation (9.40 mm in Herrera during February), much lower than in the west (e.g., 64.54 mm monthly minimum in Chiriquí) and east (e.g., 31.87 mm monthly minimum in Colón). The driest annual average precipitation over the same time period (1,851.33 mm in Coclé) also occurred along the central Pacific coast.

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[11] Anguizola, G., Gordon, B. L., and Millett, R. L. (2023). Panama. Encyclopedia Britannica. URL: https://www.britannica.com/place/Panama; Ministry of Environment (2018). Third National Climate Change Communication. URL: https://unfccc.int/sites/default/files/resource/Tercera%20Comunicacion%20Nacional%20Panama.pdf

[12] However, one should note that while the label of dry season signifies a relative decrease in seasonal precipitation, annual precipitation totals in Panama are above average compared to other regimes globally.

[13] Magaña, V., Amador, J. A., and Medina, S. (1999). The midsummer drought over Mexico and Central America. Journal of Climate, 12(6), 15771588. DOI: https://doi.org/10.1175/1520-0442(1999)012<1577:TMDOMA>2.0.CO;2

[14] Valencia, J., and Mejía, J. F. (2022). Projected Changes of Day-to-Day Precipitation and Choco Low-Level Jet Relationships over the Far Eastern Tropical Pacific and Western Colombia from Two CMIP6 GCM Models. Atmosphere, 13(11), 1776. DOI: https://doi.org/10.3390/atmos13111776

[15] Ordóñez-Zúñiga, S. A., Correa-Ramírez, M., Ricaurte-Villota, C., and Bastidas-Salamanca, M. (2021). The Panama Low-Level Jet: extension, annual cycle and modes of variation. Latin american journal of aquatic research, 49(5), 750–762. DOI: http://dx.doi.org/10.3856/vol49-issue5-fulltext-2591

Panama's interannual rainfall variability is further influenced by ENSO. Anomalously warm sea surface temperatures and weaker easterly winds in the East Pacific characterize an El Niño phase, resulting in droughts and warmer weather that particularly impact water resources and the agricultural sector. Anomalously cool sea surface temperatures and stronger easterly winds in the East Pacific characterize a La Niña phase, resulting in floods and cooler weather that threaten human safety and critical infrastructure in urban and rural areas. For example, the 1997–1998 El Niño resulted in famine, water shortages, and agricultural losses in the drought-prone savannas of the western provinces and Arco Seco, and the La Niña in the later 2000s resulted in billions of dollars in economic losses in rural western and eastern provinces.[16]

TABLE 2. Observed Temperature and Precipitation Trends for 1991–2020 Climatology Across Panama's Regions

Climatic-Topographic Region and Province	Observed Warmest (Top) and Coolest (Bottom) Months by Mean Temp.	Duration of Wet and Dry Seasons	Observed Wettest and Driest Months per Season	Observed Annual Precip.
Western Mountains and Plains (Tropical, Subtropical, and Warm Temperate Moist)				
Bocas del Toro (Caribbean)	June: 23.28°C (20.00°C, 26.64°C)	W: May–Nov	W1: May (397.90 mm) W2: Oct (428.31 mm)	**3,113.29 mm**
	Dec: 21.91°C (18.58°C, 25.24°C)	D: Jan–Mar	D: Feb (112.26 mm)	
Ngäbe Buglé (Caribbean)	Apr: 24.70°C (21.12°C, 28.31°C)	W: May–Nov	W1: May (332.37 mm) W2: Oct (421.68 mm)	2,672.19 mm
	Dec: 23.23°C (20.05°C, 26.44°C)	D: Dec–Apr	D: Feb (66.21 mm)	
Chiriquí (Pacific)	**Apr: 25.10°C** (21.47°C, 28.88°C)	W: May–Nov	W1: May (355.84 mm) **W2: Oct (512.28 mm)**	2,922.75 mm
	Dec: 23.48°C (20.23°C, 26.76°C)	D: Dec–Apr	**D: Feb (64.54 mm)**	
Central Mountains and Plains (Tropical and Subtropical Moist)				
Veraguas (Pacific and Caribbean)	Apr: 26.82°C (23.24°C, 30.43°C)	W: May–Nov	**W: Oct (381.63 mm)**	2,144.81 mm
	Dec: 24.99°C (21.85°C, 28.18°C)	D: Dec–Apr	D: Feb (24.62 mm)	
Los Santos (Pacific)	**Apr: 27.92°C** (24.10°C, 31.76°C)	W: May–Nov	W: Oct (357.02 mm)	2,040.06 mm
	Nov: 25.39°C (22.36°C, 28.48°C)	D: Dec–Apr	D: Feb (11.60 mm)	

(*continues*)

[16] Global Facility for Disaster Risk Reduction (2011). Panama Climate Risk and Adaptation Country Profile. URL: https://climateknowledgeportal.worldbank.org/sites/default/files/201810/wb_gfdrr_climate_change_country_profile_for_PAN.pdf

TABLE 2. Observed Temperature and Precipitation Trends for 1991–2020 Climatology Across Panama's Regions (*Continued*)

Climatic-Topographic Region and Province	Observed Warmest (Top) and Coolest (Bottom) Months by Mean Temp.	Duration of Wet and Dry Seasons	Observed Wettest and Driest Months per Season	Observed Annual Precip.
Herrera (Pacific)	Apr: 27.42°C (23.71°C, 31.16°C)	W: May–Nov	W: Oct (360.98 mm)	1,952.84 mm
	Nov: 25.30°C (22.29°C, 28.34°C)	D: Dec–Apr	**D: Feb (9.40 mm)**	
Coclé (Pacific)	Apr: 27.09°C (23.57°C, 30.64°C)	W: May–Nov	W: Oct (308.00 mm)	**1,851.33 mm**
	Dec: 25.16°C (22.07°C, 28.29°C)	D: Jan–Apr	D: Mar (18.30 mm)	
Panamá Oeste (Pacific)	Apr: 27.84°C (24.20°C, 31.52°C)	W: May–Nov	W: Nov (309.34 mm)	2,006.05 mm
	Nov: 25.41°C (22.54°C, 28.31°C)	D: Jan–Apr	D: Mar (18.98 mm)	
Eastern Mountains and Plains (Tropical and Subtropical Moist)				
Colón (Caribbean)	Apr: 27.46°C (24.18°C, 30.79°C)	W: May–Nov	**W: Nov (399.05 mm)**	2,515.67 mm
	Dec: 25.49°C (22.55°C, 28.47°C)	D: Jan–Apr	**D: Mar (31.87 mm)**	
Kuna Yala (Caribbean)	Apr: 27.56°C (23.84°C, 31.33°C)	W: May–Nov	W: Nov (297.87 mm)	2,313.16 mm
	Nov: 25.60°C (22.69°C, 28.56°C)	D: Jan–Apr	D: Feb (44.84 mm)	
Panamá (Pacific)	**Apr: 27.66°C** (23.94°C, 31.42°C)	W: May–Nov	W: Nov (319.96 mm)	2,433.01 mm
	Nov: 25.38°C (22.49°C, 28.31°C)	D: Jan–Apr	D: Mar (41.22 mm)	
Darién (Pacific)	Apr: 27.03°C (22.95°C, 31.15°C)	W: May–Dec	W: Nov (324.44 mm)	**2,575.76 mm**
	Nov: 25.47°C (22.26°C, 28.73°C)	D: Jan–Apr	D: Feb (76.09 mm)	
Emberá (Interior)	Apr: 27.08°C (23.03°C, 31.17°C)	W: May–Nov	W: Nov (308.05 mm)	2,469.18 mm
	Nov: 25.57°C (22.37°C, 28.80°C)	D: Jan–Apr	D: Feb (68.87 mm)	

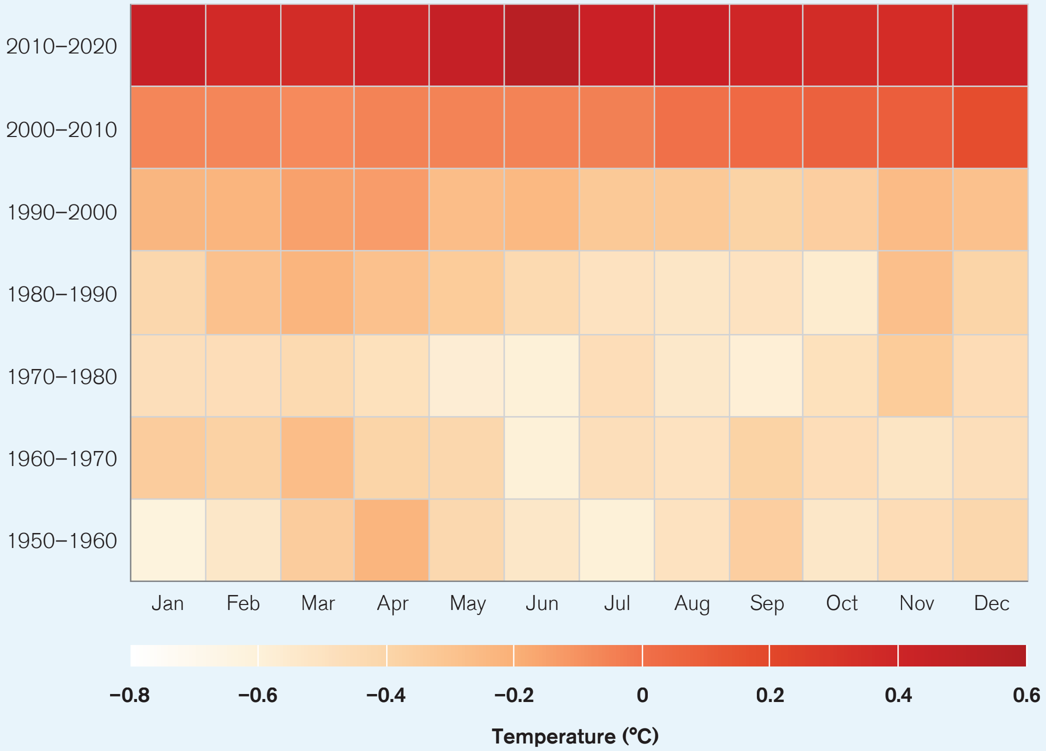
Climatic zones are classified according to characteristics in Sayre et al. and grouped by topo-geographic region (west shaded green, central shaded yellow, and east shaded blue).[17] Each province's warmest month generally corresponds with the period before the onset of the rainy season and the coolest month with the end of the rainy season. For the column listing mean monthly temperatures, the minimum (left) and maximum (right) temperatures are shown in parentheses. Precipitation regimes indicate wettest (W) and driest (D) months and first (W1) and second (W2) peaks if relevant, both further interpreted in the text.

[17] Sayre, R., Karagulle, D., Frye, C., Boucher, T., Wolff, N. H., Breyer, S., et al. (2020). An assessment of the representation of ecosystems in global protected areas using new maps of World Climate Regions and World Ecosystems. Global Ecology and Conservation, 21, e00860. DOI: https://doi.org/10.1016/j.gecco.2019.e00860

Temperature

Between 1971 and 2020, Panama's average mean temperature increased by 0.23°C per decade (see Figure 3), with the greatest changes observed in the eastern provinces and most widespread warming during the summer months. Nationwide, average minimum temperatures increased 0.22°C per decade between 1971–2020, while average maximum temperatures increased 0.24°C per decade over the same period. The eastern provinces of Darién and Emberá recorded the highest annual average mean temperatures increases per decade (0.31°C), minimum temperature increases per decade (0.29°C), and maximum temperature increases per decade (0.37°C and 0.36°C, respectively). By comparison, the lowest significant temperature increases over this period occurred in the western provinces. For example, Bocas del Toro observed a 0.15°C mean increase per decade, 0.18°C minimum increase per decade, and 0.10°C maximum increase per decade. Summer months exhibited the greatest seasonal mean increase in temperature per decade, with changes greater than 0.20°C extending to nearly all provinces. During summer months, Darién recorded a minimum temperature increase of 0.30°C per decade, an average mean temperature increase of 0.31°C per decade, and average maximum temperature increase of 0.35°C per decade. Average maximum temperature increases above 0.30°C per decade also extended to many of the central Pacific provinces (Arco Seco) during these months. Observed single-day minimum of daily minimum temperatures from 1971–2020 significantly increased 0.22°C per decade nationally.

FIGURE 3. Heatplot of Historically Observed Average Mean Temperature Trends per Month Nationally (1951–2020)

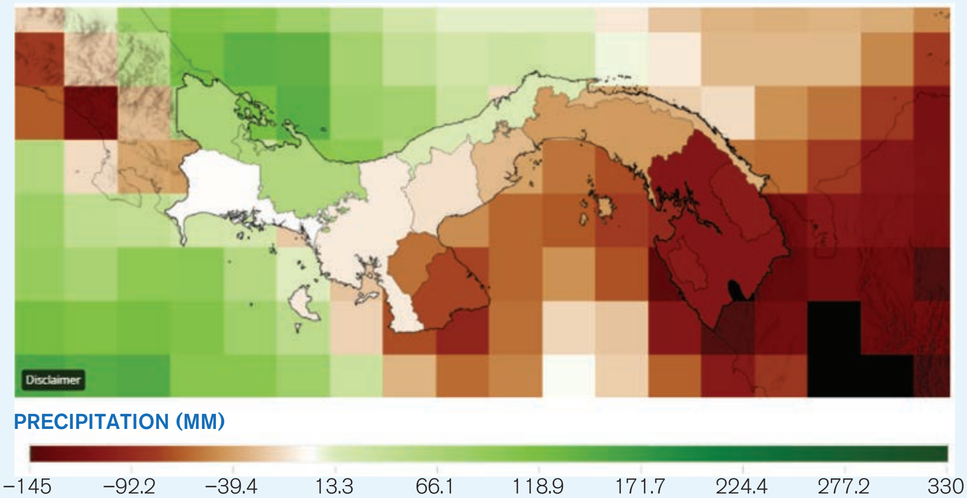


Note the increase in average mean temperature year-round during the last two decades (2000–2010 and 2011–2020) compared to previous decades.

Precipitation

Over the 50-year period of 1971–2020, Panama experienced seasonally varied and significant decreases in precipitation per decade across the eastern and central Pacific provinces but significant increases per decade along the western and central Caribbean provinces. During the 1971–2020 climatology (**see Figure 4**), the eastern provinces of Darién and Emberá observed the largest total decreases in precipitation per decade (–109.34 mm and –103.71 mm, respectively), with the strongest effects during summer months. The central Pacific (Arco Seco) provinces also observed a significant decline in precipitation per decade, with greater effects moving southward in Los Santos (–76.66 mm) and Herrera (–58.93 mm). While the western Pacific province of Chiriquí did not observe any significant change, the rest of the Pacific provinces and Kuna Yala (eastern Caribbean) also experienced precipitation decreases. However, western and central Caribbean provinces observed significant precipitation increases over the same time period, especially during fall months, including in Bocas del Toro (+63.07 mm per decade), Ngäbe Buglé (+59.63 mm per decade), and more modestly in Colón (+14.02 mm per decade). Overall, there were no significant observed changes for the largest 1-day and 5-day precipitation events, especially given the historical influence of interannual ENSO variability.

FIGURE 4. Observed Precipitation Trend per Decade (1971–2020) Annually



Note significant decreases in the eastern and central Pacific provinces but increases along the western and central Caribbean.

PROJECTED CLIMATE

Data Overview

Modeled climate data is derived from CMIP6, the Coupled Model Intercomparison Project, Phase 6. The CMIP efforts are overseen by the World Climate Research Program, which supports the coordination for the production of global and regional climate model compilations that advance scientific understanding of the multi-scale dynamic interactions between the natural and social systems affecting climate. CMIP6 is the foundational data used to present global climate change projections presented in the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC). CMIP6 relies on the Shared Socioeconomic Pathways (SSPs), which represent possible societal development and policy scenarios for meeting designated radiative forcing (W/m^2) by the end of the century. Scenarios are used to represent the climate response to different plausible future societal development storylines and associated contrasting emission pathways to outline how future emissions and land use changes translate into responses in the climate system. Model-based, climate projection data is derived from the Coupled Model Inter-comparison Project-Phase 6 (CMIP6). CMIP is a standard framework for the analysis of coupled atmosphere-ocean general circulation models (GCMs) providing projections of future temperature and precipitation according to designated scenarios. CMIP6 projections are shown through five shared socio-economic pathway (SSP) scenarios defined by their total radiative forcing (a cumulative measure of GHG emissions from all sources) pathway and level by 2100. These represent possible future greenhouse gas concentration trajectories adopted by the IPCC.

The following assessment explores projected climate conditions and changes under multiple scenarios[18] for the near (the 2030s; 2020–2039) and medium term (2050s; 2040–2059) using data presented at a 0.25° × 0.25° (25 km × 25 km) resolution.[19] This risk profile focuses primarily on SSP3-7.0. Other SSPs are highlighted where appropriate given different trends and outlooks that should be noted. Projections for extreme precipitation events use data presented at a 1.00° × 1.00° (100 km × 100 km) resolution.[20]

Temperature

Under SSP3-7.0, Panama's temperatures are projected to homogeneously increase further (see Figure 5). Mean temperature nationwide increases from the historical reference period of 1995–2014 to 26.02°C (25.75°C, 10th percentile, 26.50°C, 90th percentile) for the period 2020–2039, and to 26.65°C (26.24°C, 27.28°C) for the period 2040–2059. Minimum temperature nationwide increases from the historical reference period to 23.16°C (22.90°C, 23.68°C) for the 2020–2039 period, and 23.78°C (23.40°C, 24.51°C) for 2040–2059. Maximum temperature increases to 28.88°C (28.56°C, 29.31°C) for the 2020–2039 period, and 29.51°C (29.06°C, 30.12°C) for 2040–2059. However, projected temperature changes under SSP2-4.5 and SSP1-2.6 are lower.[21] Under SSP3-7.0, the largest seasonal change occurs during fall months, when Chiriquí's mean temperature increases 1.36°C from the reference period by midcentury, compared to 1.22°C in Los Santos. Minimum and maximum temperatures increase homogeneously with spatial and seasonal trends similar to projected mean temperatures.

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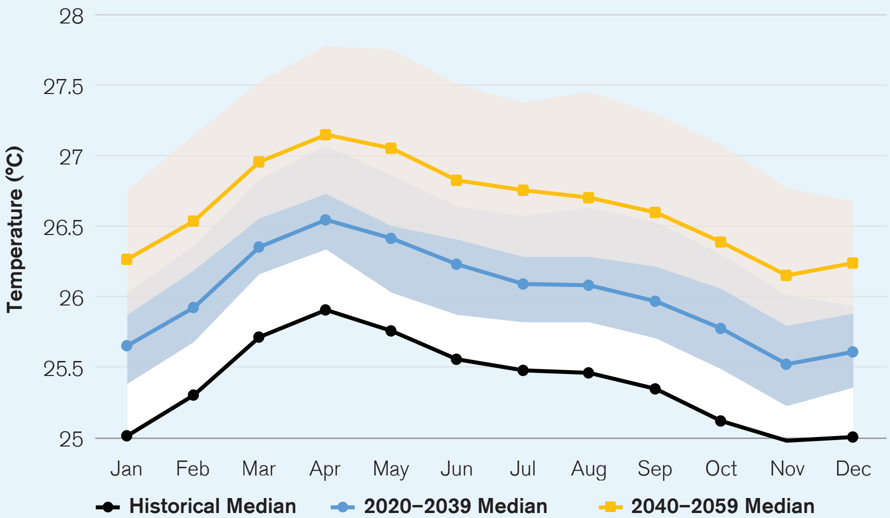
18 SSP3-7.0 represents a higher emissions scenario and is considered a more realistic worst-case scenario in which warming reaches ~3.5-4°C by 2100. When considering 'risk' it is most prudent to use higher scenarios in order to not dangerously under-estimate potential changes and risk conditions.

19 World Bank Climate Change Knowledge Portal (2023). Panama Climate Projections. URL: https://climateknowledgeportal.worldbank.org/country/panama/climate-data-projections

20 World Bank Climate Change Knowledge Portal (2023). Panama Extreme Events. URL: https://climateknowledgeportal.worldbank.org/country/panama/extremes

21 Under SSP1-2.6, minimum temperature nationwide only increases to 23.51°C (23.09°C, 24.12°C) and under SSP2-4.5, increases to 23.73°C (23.33°C, 24.28°C) by 2040–2059. Under SSP1-2.6, maximum temperature increases nationwide to 29.23°C (28.76°C, 29.77°C), and under SSP2-4.5, increases to 29.40°C (28.98°C, 29.94°C) by 2040–2059.

FIGURE 5. Projected Climatology of Mean Temperature Countrywide for 2020–2039 and 2040–2059 (Ref. Period 1995–2014) Under SSP3-7.0



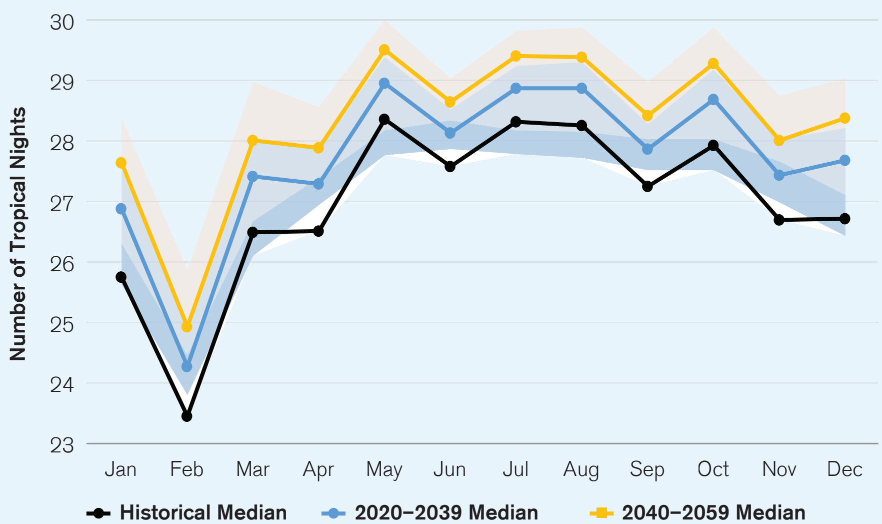
Areas shaded orange indicate 10th and 90th percentiles for 2040–2059, while areas shaded blue indicate 10th and 90th percentiles for 2020–2039. The projected climatology of mean temperature countrywide for each month (2040–2059 period) increases less than two times the projected climatology for 2020–2039 above the reference period, except for November and December.

Panama is projected to experience spatially and seasonally varied shifts to hotter conditions by midcentury. Higher atmospheric moisture content during the wet months makes the number of days surpassing the Heat Index >35°C increase by a greater extent in the Arco Seco region for the 2040–2059 climatology. For example, Herrera is projected to experience only 5.42 (0.31, 23.20) high Heat Index days annually over 2020–2039, but 29.80 high Heat Index days annually with a wide range of uncertainty (3.59, 92.00) over 2040–2059. Although heat stress will pose less of a threat in the immediate future, the magnitude would significantly rise later in the century. An escalating trend of the Warm Spell Duration Index (WSDI) over time, reaching more than 300 warm spell days across the country by 2100, illustrates a shift in long-term temperatures from the historical baseline.[22] Herrera and Los Santos on the southern Pacific coast are projected to experience the highest WSDI values, while Bocas del Toro and Ngäbe Buglé on the western Caribbean coast are projected to experience the lowest comparative WSDI values. This spatial pattern generally corresponds with topographic variations along the isthmus.

[22] This value indicates the number days with consecutive daily maximum temperatures greater than the 90th percentile of daily maximum temperature calculated over a five-day window annually. Warm Spell Duration Index projections use 1.00° × 1.00° (100 km × 100 km) data resolution.

Heat-related risks can be compounded when considering both day temperature conditions and night temperature conditions. On nights temperatures do not go below 20°C, the human body reaches a biophysiological threshold where it cannot adequately cool down to achieve restorative sleep. By midcentury, the number of tropical nights with a minimum temperature >20°C (**see Figure 6**) increases annually by a median of 16.29 (10.94, 23.47) nationally, with the highest increases in the western highland provinces. For example, the number of tropical nights in Ngäbe Buglé increases 50.94 (31.60, 76.97) by 2020–2039 and 93.88 (67.45, 118.42) nights by 2040–2059 under SSP3-7.0. But since Panama already has a high number of tropical nights >20°C annually, the number of tropical nights with a minimum temperature >26°C, an even higher threshold, illustrates a more widespread shift in future heat conditions. Compared to the historical reference period, such tropical nights increase the most in coastal areas during spring and summer months by midcentury (2040–2059). As illustrated in **Table 3**, Kuna Yala is projected to experience the largest annual increase of 115.48 (56.75, 223.41) nights by 2040–2059, followed by Panamá with an annual increase of 65.43 (25.41, 157.82) nights over the same time period. The SSP3-7.0 scenario forecasts a roughly similar number of tropical nights >20°C and >26°C by midcentury compared to the SSP1-2.6 and SSP2-4.5 scenarios, however the number of tropical nights >26°C diverges for each by the end of the century (see Annex).

FIGURE 6. Projected Climatology of Tropical Nights (No. Nights T-min > 20°C) Countrywide for 2020–2039 and 2040–2059 (Ref. Period 1995–2014) Under SSP3-7.0



Areas shaded orange indicate 10th and 90th percentiles for 2040–2059, while areas shaded blue indicate 10th and 90th percentiles for 2020–2039. The projected climatology of tropical nights countrywide (for both 2020–2039 and 2040–2059 periods) increase from the reference period twice as much during winter months compared to summer months. Note the minimum mean number of tropical nights countrywide during the month of February.

TABLE 3. Projected Tropical Night Anomalies by Province for 2020–2039 and 2040–2059 (Ref. Period 1995–2014) Under SSP3-7.0

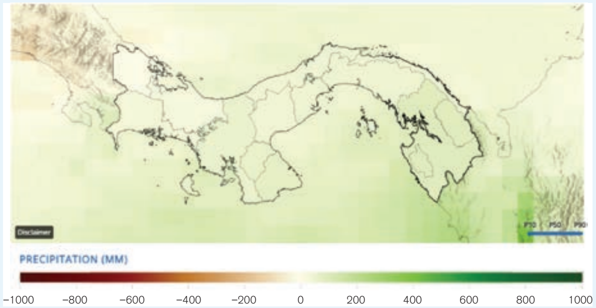
Province	2020–2039					2040–2059				
	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Fall (SON)	Annual	Winter (DJF)	Spring (MAM)	Summer (JJA)	Fall (SON)
Tropical Nights (No. Nights T-min >26°C)										
Bocas del Toro (Caribbean)	6.76 (2.95, 18.01)	0.15 (0.05, 0.44)	1.59 (0.75, 4.34)	2.80 (1.07, 6.77)	2.16 (0.95, 6.53)	20.59 (11.44, 36.31)	0.94 (0.27, 2.93)	4.41 (2.41, 8.72)	8.29 (4.32, 12.97)	6.96 (3.88, 12.35)
Ngäbe Buglé (Caribbean)	1.06 (0.51, 4.38)	0.07 (0.03, 0.19)	0.26 (0.12, 1.13)	0.39 (0.15, 1.59)	0.33 (0.18, 1.67)	4.83 (1.47, 17.30)	0.30 (0.13, 0.84)	1.17 (0.35, 4.12)	1.65 (0.47, 6.32)	1.43 (0.45, 5.97)
Chiriquí (Pacific)	**10.40** (4.96, 24.39)	2.05 (0.98, 4.68)	4.77 (2.65, 9.34)	2.18 (0.84, 6.02)	1.05 (0.34, 4.38)	**28.98** (16.61, 57.46)	6.10 (3.51, 11.09)	**10.70** (6.75, 17.55)	7.54 (3.24, 15.72)	4.68 (2.02, 12.51)
Veraguas (Pacific and Caribbean)	**13.91** (6.84, 33.90)	2.49 (0.92, 4.99)	5.37 (2.26, 11.95)	3.36 (1.35, 9.98)	2.31 (0.93, 6.96)	38.36 (20.65, 86.06)	6.12 (3.42, 12.99)	13.66 (6.86, 29.34)	10.73 (4.79, 25.13)	7.60 (3.96, 20.09)
Los Santos (Pacific)	10.57 (4.33, 35.56)	1.45 (0.47, 5.27)	**5.56** (2.72, 16.19)	2.27 (0.32, 8.32)	0.98 (0.06, 5.66)	38.31 (17.10, 100.73)	6.87 (2.95, 15.89)	17.15 (9.05, 38.19)	9.32 (2.82, 23.55)	5.97 (1.35, 18.95)
Herrera (Pacific)	3.98 (1.20, 15.86)	0.12 (0.00, 1.09)	2.88 (1.08, 9.49)	0.46 (0.02, 3.60)	0.10 (0.00, 2.24)	17.26 (4.87, 60.00)	0.89 (0.06, 6.47)	10.77 (3.89, 27.75)	3.38 (0.49, 15.55)	1.34 (0.02, 12.54)
Coclé (Pacific)	7.13 (4.36, 20.58)	0.82 (0.30, 2.76)	3.36 (2.20, 7.49)	1.77 (0.60, 5.96)	0.71 (0.18, 3.82)	24.45 (12.38, 60.26)	3.88 (1.37, 8.91)	9.78 (6.40, 17.69)	6.82 (2.68, 18.44)	3.73 (1.43, 13.23)
Panamá Oeste (Pacific)	8.52 (1.18, 41.58)	0.93 (0.03, 3.47)	3.94 (0.92, 12.58)	2.40 (0.28, 13.08)	0.67 (0.08, 8.02)	**46.27** (12.00, 137.08)	7.95 (1.30, 18.03)	**17.46** (5.84, 38.09)	15.35 (3.26, 42.60)	6.53 (1.63, 36.49)
Colón (Caribbean)	9.74 (3.61, 35.57)	1.27 (0.30, 3.66)	3.47 (1.64, 9.66)	2.86 (0.70, 12.22)	1.55 (0.59, 8.73)	45.67 (16.32, 120.14)	6.97 (2.48, 14.13)	14.36 (5.80, 29.22)	14.78 (4.35, 44.56)	9.27 (3.30, 35.61)
Kuna Yala (Caribbean)	**34.11** (14.67, 97.87)	6.83 (2.78, 17.01)	9.22 (3.93, 26.56)	**11.19** (4.27, 32.34)	6.13 (2.43, 24.52)	**115.48** (56.75, 223.41)	25.38 (11.53, 43.84)	30.26 (14.71, 57.28)	**35.90** (16.96, 63.86)	24.99 (11.36, 57.10)
Panamá (Pacific)	15.88 (6.48, 56.05)	2.48 (1.08, 5.87)	5.26 (2.11, 15.08)	5.18 (1.60, 20.24)	2.56 (0.97, 13.97)	65.43 (25.41, 157.82)	10.19 (3.48, 21.63)	18.64 (8.34, 40.57)	22.37 (8.31, 50.83)	12.61 (4.99, 42.84)
Darién (Pacific)	6.19 (2.47, 23.49)	1.16 (0.41, 4.00)	2.72 (1.02, 9.41)	1.58 (0.41, 6.99)	0.84 (0.19, 4.53)	27.65 (10.21, 78.95)	5.91 (1.66, 14.85)	10.64 (4.43, 26.88)	7.79 (2.37, 19.33)	4.73 (1.40, 17.26)
Emberá (Interior)	0.58 (0.13, 4.42)	0.09 (0.02, 0.67)	0.21 (0.02, 1.94)	0.16 (0.02, 1.37)	0.06 (0.01, 0.69)	5.70 (0.69, 30.71)	1.09 (0.12, 4.66)	2.50 (0.22, 12.21)	1.52 (0.19, 7.70)	0.67 (0.08, 6.23)

10th percentile and 90th percentile values shown in parentheses. Largest anomalies (>50 days) are shaded orange and smallest relative anomalies from the reference period are shaded gray. The largest anomaly in each region is bolded. Note tropical nights increase most along the central-eastern portions of the isthmus during spring and summer months. See text for interpretation.

Precipitation

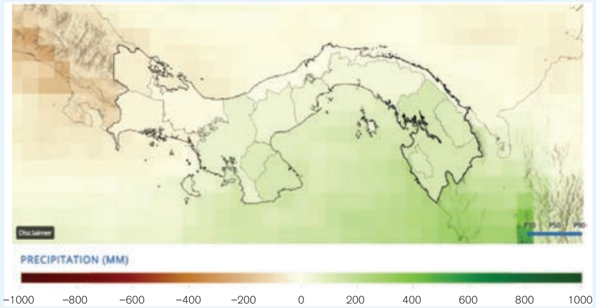
Projected precipitation patterns under SSP3-7.0 demonstrate little long-term change when aggregated at the national level but exhibit divergent regional and seasonal shifts in intensity by midcentury. At the national level, annual precipitation totals increase by a median of 45.09 mm with wide uncertainty (–307.60 mm, 298.70 mm) from the 1995–2014 reference period to 2040–2059 under SSP3-7.0. Western provinces over this timeframe are projected to experience the greatest decline in annual precipitation, Pacific-facing provinces are projected to experience the greatest increases in annual precipitation moving southward, while Caribbean-facing provinces are not projected to change much in yearly volume. **Figures 7a–b** capture the regionally distinct projected anomalies for 2020–2039 and 2040–2059 compared to the reference period.

FIGURE 7A. Projected Annual Precipitation Anomalies for Panama, 2020–2039 (Ref. Period 1995–2014) Under SSP3-7.0



Note marginal increases for all provinces.

FIGURE 7B. Projected Annual Precipitation Anomalies for Panama, 2040–2059 (Ref. Period 1995–2014) Under SSP3-7.0

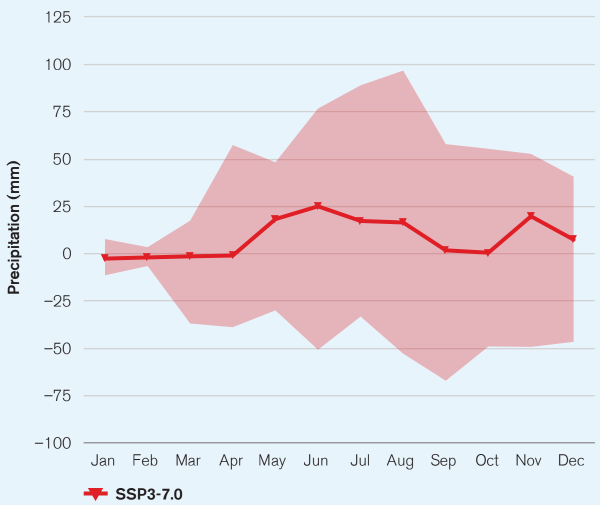


In contrast, positive precipitation anomalies occur along the southern Pacific provinces while negative precipitation anomalies occur in the western provinces. Precipitation anomalies decrease from 2020–2039 to 2040–2059 along the northern Caribbean provinces, amounting to virtually no annual change from the reference period by midcentury.

SSP3-7.0 predicts that western provinces will experience annual decreases in precipitation by midcentury (**see Figure 7b**), however annual precipitation anomalies do not decrease from the historical reference until after the 2020–2039 period (**see Figure 7a**). The greatest annual precipitation decrease of –53.25 mm (–458.64 mm, 230.01 mm) occurs in Bocas del Toro, with the largest monthly declines (median anomalies < –10 mm) during the peak months of the province's fall rainy season. As illustrated in **Figure 8b**, the only positive precipitation anomalies (medians >10 mm) occur during May and June at the beginning of the wet season. Precipitation decreases in the mountainous western provinces' rain shadow may indicate a strengthening of the Caribbean low-level jet.[23] By comparison, Pacific-facing provinces are expected to experience the greatest annual precipitation increases. The largest projected increase of 120.10 mm (–219.30 mm, 387.36 mm) annually is projected for Darién by midcentury, followed by 118.21 mm (–306.14 mm, 369.15 mm) for Los Santos and 103.79 mm (–232.31 mm, 367.15 mm) for Emberá. The largest seasonal precipitation increase in these provinces occurs during summer months and as **Figure 8a** illustrates for Los Santos, median monthly increases > 15 mm are

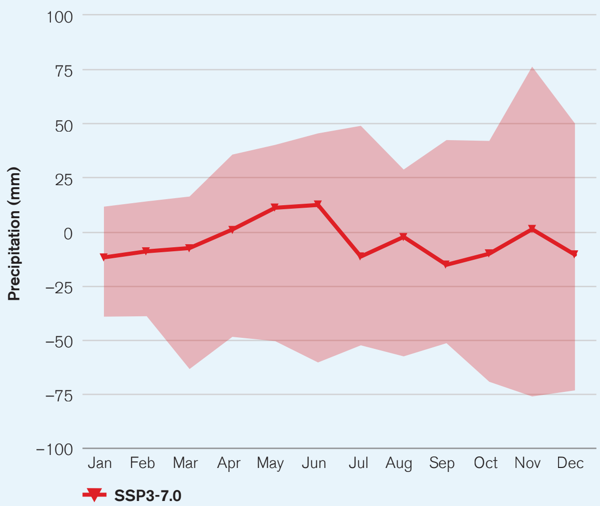
[23] Magaña, V., and Caetano, E. (2005). Temporal evolution of summer convective activity over the Americas warm pools. Geophysical Research Letters, 32(2), L02803. DOI: https://doi.org/10.1029/2004GL021033

FIGURE 8A. Los Santos' (Central Pacific) Projected Precipitation Anomaly for 2040–2059 (Ref. Period 1995–2014) Under SSP3-7.0



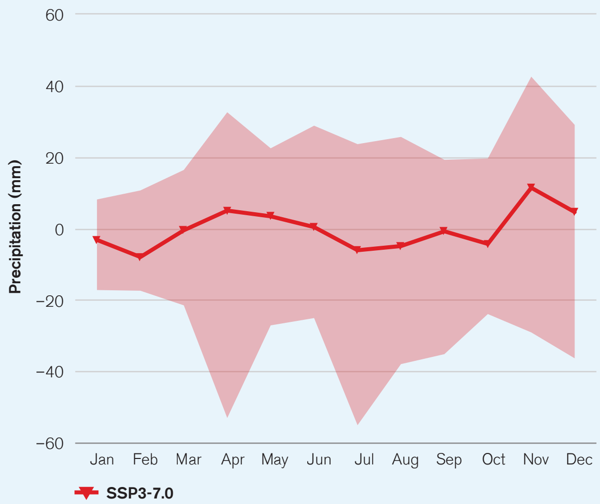
Area shaded red indicates 10th–90th percentiles. Note largest increases occur between May and August and during the month of November. See text for interpretation.

FIGURE 8B. Bocas del Toro's (Western Caribbean) Projected Precipitation Anomaly for 2040–2059 (Ref. Period 1995–2014) Under SSP3-7.0



Note the narrower scale of anomalies on the y-axis and precipitation decreases year-round except for May and June. See text for interpretation.

FIGURE 8C. Kuna Yala (Eastern Caribbean) Projected Precipitation Anomaly for 2040–2059 (Ref. Period 1995–2014) Under SSP3-7.0

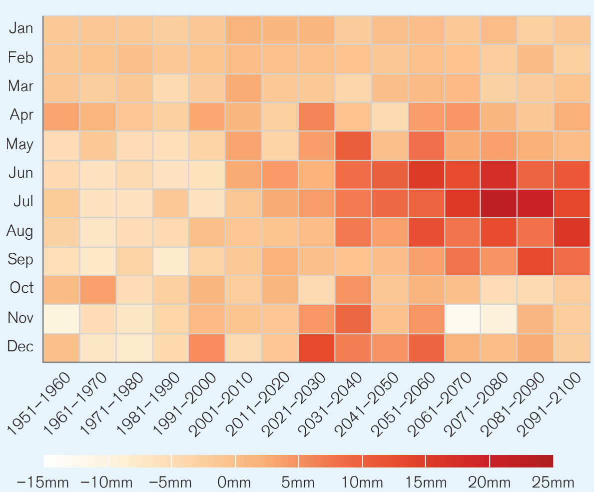


Note the narrower scale of anomalies on the y-axis and the largest percentage increase in November. See text for interpretation.

projected from May to August with monthly peaks in June as well as November (the beginning and end of the wet season, respectively). The Caribbean-facing provinces of the isthmus also differ, experiencing little change in annual precipitation by midcentury but a positive monthly precipitation anomaly at the end of the wet season. As an example, Kuna Yala (**see Figure 8c**) is projected to receive a precipitation increase of only 14.83 mm (–171.75 mm, 117.27 mm) annually by midcentury with a median anomaly >10 mm during the wettest month of November. Both scenarios SSP1-2.6 and SSP2-4.5 predict wetter and more homogeneous trends than SSP3-7.0 by midcentury (see Annex for more detail).

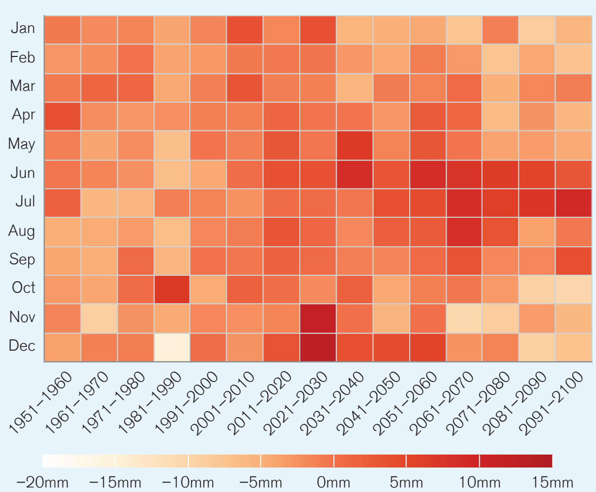
Panama's future precipitation intensities, measured by average largest 5-day cumulative anomalies, vary by province and month but increase nationally by a median of 11.98 mm (–81.77 mm, +81.00 mm) by midcentury and roughly correspond to trends in projected precipitation volume. Precipitation intensities increase 39.12 mm (–35.60 mm, 93.76 mm) in Los Santos (central Pacific, **see Figure 9a**) by midcentury, the most annually under SSP3-7.0. But while its precipitation intensity distinctly increases only during summer months by midcentury, other provinces such as Darién (east) have an additional peak in November at the end of the rainy season. These trends may reflect the potential southward shift of the future ITCZ.[24] Intensities decrease in the western provinces from 2020–2039 to 2040–2059. Chiriquí's intensity decreases the most annually, from an anomaly of 38.77 mm (–172.24 mm, 127.80 mm) over the 2020–2039 period to a slightly positive anomaly of 2.01 mm (–137.66 mm, 92.56 mm) over the 2040–2059 period. However, Ngäbe Buglé features the largest monthly decrease of –23.34 mm (–135.06 mm, 117.63 mm) during December, the beginning of the dry season. As **Figure 9b** illustrates, a trend of decreasing

FIGURE 9A. Los Santos' (Central Pacific) Projected Average Largest 5-Day Cumulative Precipitation Anomaly (Ref. Period 1995–2014) Under SSP3-7.0



Note by 2040–2059 (x-axis), a peak increase in intensity occurs during the summer wet season.

FIGURE 9B. Ngäbe Buglé's (Western Caribbean) Projected Average Largest 5-Day Cumulative Precipitation Anomaly (Ref. Period 1995–2014) Under SSP3-7.0



Note by 2040–2059 (x-axis), the same increase in intensity occurs during the summer months, but a general decrease in intensity occurs during other months toward the end of the century.

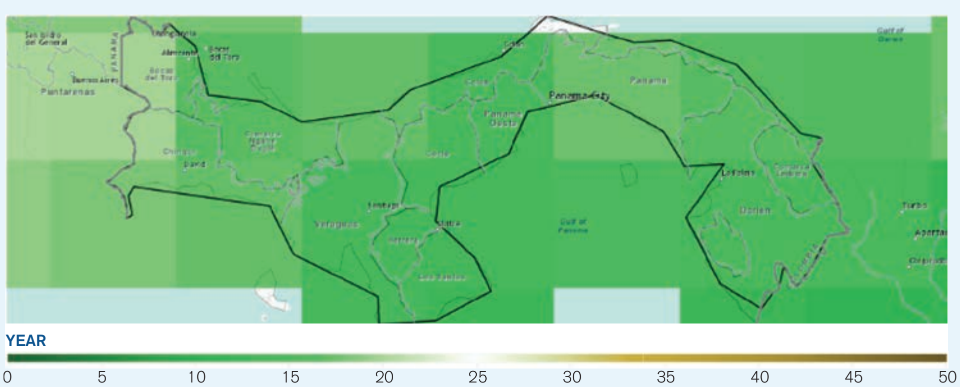
[24] Valencia, J., and Mejía, J. F. (2022). Projected Changes of Day-to-Day Precipitation and Choco Low-Level Jet Relationships over the Far Eastern Tropical Pacific and Western Colombia from Two CMIP6 GCM Models. Atmosphere, 13(11), 1776. DOI: https://doi.org/10.3390/atmos13111776

precipitation intensity during winter dry months as well as fall and spring months begins by midcentury and offsets the anomalous increases in intensity during summer months toward the end of the century. In addition, while maximum consecutive wet days increase by roughly a month from the reference period in Herrera (central Pacific), Panamá (central and eastern Pacific), and Kuna Yala (eastern Caribbean) by midcentury under SSP3-7.0, they do not substantively increase in westernmost Caribbean and central provinces.[25] Therefore, the propensity for drought events in these regions persists due to precipitation declines and interannual ENSO cycles of extreme precipitation, both of which are discussed further in the section on climate-related hazards.

Extreme Precipitation Events

By midcentury, Panama is likely to more frequently experience extreme precipitation event occurrence. For the projected period of 2035–2064, the largest 1-day precipitation amounts associated with 100-year historical return periods will be nearly two times more likely or more to occur in provinces along the central and eastern Pacific coast (**see Figure 10b**). The greatest change in future return periods is projected for Darién (50.47 years), followed by Los Santos (50.84 years) and Herrera (50.90 years). The least change is projected for Bocas del Toro and Chiriquí in the west (64.76 years, 64.61 years, respectively). However, the rate of change is lower for 25-year and 50-year events, and around 1.5 times more likely for 10-year events nationwide except for the westernmost provinces. While the projected future return periods for 25-year events shift for the same regions (14.25 years for Darién, 14.32 years for Los Santos, and 14.38 years for Herrera), the future return periods for Bocas del Toro and Chiriquí in the west change the least (19.68 years and 17.99 years, respectively) by midcentury (**see Figure 10a**). SSP1-2.6 and SSP2-4.5 do not forecast extreme event frequencies at significantly different rates than SSP3-7.0 for 2035–2064. More frequently occurring extreme precipitation events underscore future health risks related to flood impacts, agricultural yields, disease ranges, and critical infrastructure, including for water, sanitation, and hygiene.

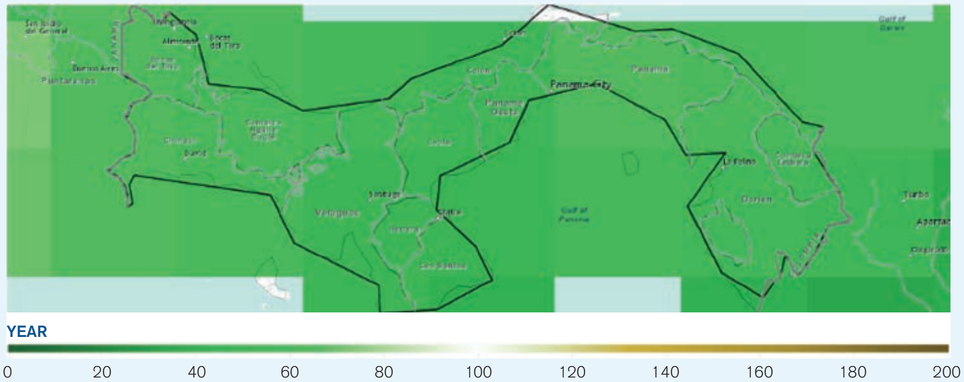
FIGURE 10A. Future Return Period of Largest 1-Day Precipitation, 25-Year Event Under SSP3-7.0 (2035–2064, Center 2050)



Note the greatest change in future return periods projected for provinces along the central and eastern Pacific coast.

[25] The maximum number of consecutive wet days annually projected under the SSP3-7.0 scenario uses 1.00° × 1.00° (100 km × 100 km) data resolution, under which the estimated number of days for Panamá Province also include Panamá Oeste Province.

FIGURE 10B. Future Return Period of Largest 1-Day Precipitation, 100-Year Event Under SSP3-7.0 (2035–2064, Center 2050)



Note the greatest change in future return periods for the same provinces.

CLIMATE-RELATED NATURAL HAZARDS

Between 1982 and 2008, Panama experienced 32 events billed as natural disasters with total economic damages estimated at US$86 million.[26] Since 1998, episodes of flooding often associated with the La Niña phase of ENSO comprised the majority of such events, affecting tens of thousands of people and causing millions of dollars in damage. In urban areas, heavy rainfall threatens critical infrastructure, economic activity, and human health. In rural areas, both excess rainfall and precipitation deficits affect agriculture, livestock production, and food security, with El Niño-related droughts exacerbating high water stress at the end of the growing season.[27] Since Panama heavily relies on water resources for hydropower generation, changes in rainfall patterns would reduce water availability and therefore the energy supply during dry seasons. The frequency of intense floods and droughts associated with ENSO will likely become more common in the future. In coastal areas, rising seas, coupled with increased storm surges pose localized flood threats to critical infrastructure, biodiversity, and tourism particularly along the Caribbean coast. In addition to these hazards, seismic risks – including landslides – affect the entire country. Past and future impacts associated with each of Panama's notable hazards are discussed below.

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[26] Global Facility for Disaster Risk Reduction (2011). Panama Climate Risk and Adaptation Country Profile. URL: https://climateknowledgeportal.worldbank.org/sites/default/files/201810/wb_gfdrr_climate_change_country_profile_for_PAN.pdf

[27] Ruane, A. C., Cecil, L. D., Horton, R. M., Gordón, R., McCollum, R., Brown, D., Killough, B., Goldberg, R., Greeley, A. P., and Rosenzweig, C. (2013). Climate change impact uncertainties for maize in Panama: Farm information, climate projections, and yield sensitivities. Agricultural and Forest Meteorology, 170, 132145. DOI: https://doi.org/10.1016/j.agrformet.2011.10.015

Sea Level Rise and Sea Surface Temperature

Panama's observed sea surface temperatures reflect varying rates of change between and within its Pacific and Atlantic coasts that correlate with interannual and decadal climate patterns. Sea surface temperature anomalies in the East Pacific are one of the primary drivers of interannual and decadal climate variability in Panama. Average monthly observed (2002–2016) sea surface temperatures remain relatively constant along the Gulf of Chiriquí in southwest Panama at 28°C year-round, whereas along the Gulf of Panama in southern and southeastern Panama, northeast trade winds during the winter dry season drive upwelling and cooler average minima in February and March of 24°C.[28] On Panama's Caribbean coast, seasonally observed (1982–2016) mean sea surface temperatures are 27°C during winter and spring months and 28°C during summer and fall months.[29] On average, El Niño produces warmer sea surface temperatures and drier conditions, while La Niña produces cooler sea surface temperatures and wetter conditions. However, a trend of warmer sea surface temperatures in the East Pacific Ocean reduces thermal differences between land and sea and ultimately reduces the northward extent of ITCZ precipitation on Panama's Pacific coast.[30] The increase in coral bleaching events attest to warmer sea surface temperatures, especially along the Gulf of Chiriquí where temperatures increased faster and with greater variability over the last century.[31]

Sea level rise and coastal inundation will increasingly threaten Panama's coastal zones. Panama's coastal areas house roughly half of the country's population, with a coastline extending 1,290 km along the Caribbean Sea and 1,700 km along the Pacific Ocean.[32] On the Caribbean side (Cristóbal, Colón) under SSP3-7.0 with a historical baseline of 1995–2014, sea level rise is projected to increase 0.27 m (0.20 m, 0.35 m) by 2050 and 0.78 m (0.61 m, 1.04 m) by 2100.[33] Sea level rise occurs at a relatively slower pace on the Pacific coast. For example, at Puerto Armuelles (Chiriquí), sea level increases 0.22 m (0.18 m, 0.29 m) from the reference period by 2050 and 0.72 m (0.55 m, 0.98 m) by 2100.[34] The national government expects that sea level rise will trigger a variety of regionally specific effects across Panama,[35] though to date government and scholarly research studies have not fully quantified the estimated cost of such impacts. In the western Pacific (Pacífico Occidental), coastal flooding and beach erosion will particularly affect Puerto Armuelles (Chiriquí). In Panamá Oeste along the central Pacific coast (Arco Seco), saltwater intrusion poses a significant threat to water resources. Along the Caribbean coast, the higher rate of sea level rise threatens mangrove, wetland, and estuary ecosystems, spurring losses in the economically important tourism sector for areas such as Bocas del Toro (western Caribbean or Caribe Occidental). Denser

[28] Randall, C. J., Toth, L. T., Leichter, J. J., Maté, J. L., and Aronson, R. B. (2020). Upwelling buffers climate change impacts on coral reefs of the eastern tropical Pacific. Ecology, 101(2), e02918. DOI: https://doi.org/10.1002/ecy.2918

[29] Rodriguez-Vera, G., Romero-Centeno, R., Castro, C. L., and Castro, V. M. (2019). Coupled interannual variability of wind and sea surface temperature in the Caribbean Sea and the Gulf of Mexico. Journal of Climate, 32(14), 4263–4280. DOI: https://doi.org/10.1175/JCLI-D-18-0573.1

[30] Valencia, J., and Mejía, J. F. (2022). Projected Changes of Day-to-Day Precipitation and Choco Low-Level Jet Relationships over the Far Eastern Tropical Pacific and Western Colombia from Two CMIP6 GCM Models. Atmosphere, 13(11), 1776. DOI: https://doi.org/10.3390/atmos13111776

[31] Claar, D. C., Szostek, L., McDevitt-Irwin, J. M., Schanze, J. J., and Baum, J. K. (2018). Global patterns and impacts of El Niño events on coral reefs: A meta-analysis. PLoS One, 13(2), e0190957. DOI: https://doi.org/10.1371/journal.pone.0190957; Randall, C. J., Toth, L. T., Leichter, J. J., Maté, J. L., and Aronson, R. B. (2020). Upwelling buffers climate change impacts on coral reefs of the eastern tropical Pacific. Ecology, 101(2), e02918. DOI: https://doi.org/10.1002/ecy.2918

[32] Ministry of Environment (2023). Fourth National Climate Change Communication. URL: https://unfccc.int/sites/default/files/resource/53792416_Panama-NC4-1-4CNCC_2023_PANAMA_H.pdf

[33] NASA (2023). Sea Level Projection Tool. URL: https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool; note the figures inside parentheses represent 17th and 83rd percentiles, respectively.

[34] NASA (2023). Sea Level Projection Tool. URL: https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool

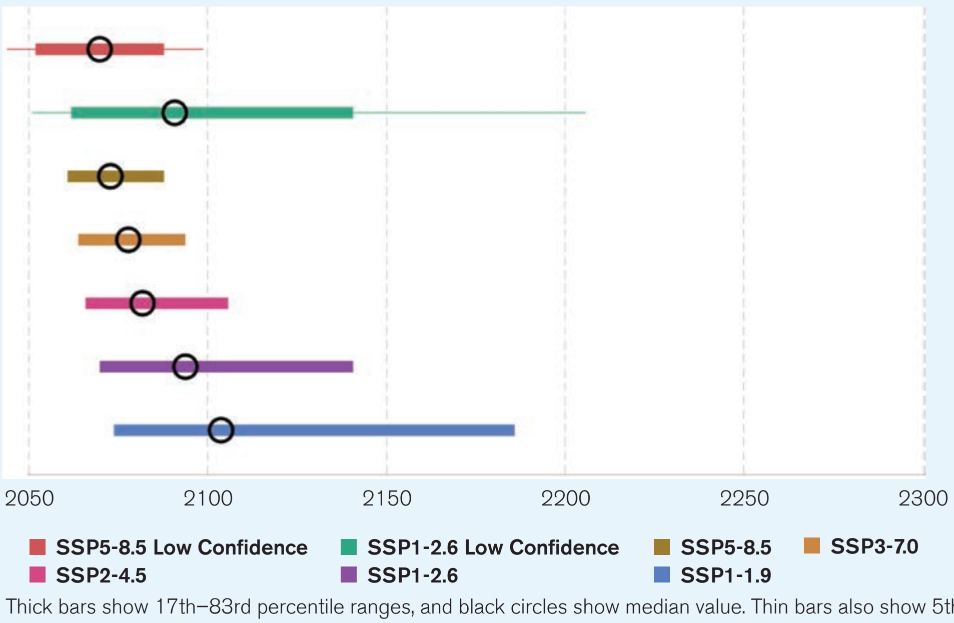
[35] Ministry of Environment (2018). Third National Climate Change Communication. URL: https://unfccc.int/sites/default/files/resource/Tercera%20Comunicacion%20Nacional%20Panama.pdf

concentrations of settlements and economic assets along the Panama Canal in support of the country's international trade, especially port and sewage infrastructure in the province of Colón, remain notably exposed to future coastal impacts. However, the national government identifies indigenous communities in Kuna Yala along the eastern Caribbean (Caribe Oriental) as disproportionately vulnerable to the effects of sea level rise, since many live on roughly 300 low-lying coral islands where increasingly dangerous storm surges threaten local fisheries, small- and medium-scale agriculture, and permanent habitation before the end of the century.

Sea level rise along Panama's coastlines exhibit discernible differences between the Caribbean and the Pacific regions under different climate scenarios.[36] Under SSP3-7.0, sea level rise is projected to increase 0.50 meters above the historical baseline along the Caribbean coast of Cristóbal (Colón) after 2070 (**see Figure 11a**). This rate of change does not differ much under SSP2-4.5, but under SSP1-2.6 sea level rise does not reach this threshold until nearly 2100 and with higher relative uncertainty. Compared to SSP3-7.0 which rises 0.78 m (0.61 m, 1.04 m) by 2100, SSP2-4.5 rises 0.66 m (0.49 m, 0.90 m) while SSP1-2.6 rises 0.52 m (0.38 m, 0.73 m) over the same timeframe.

On the Pacific coast, Puerto Armuelles (Chiriquí, **see Figure 11b**) is projected to experience a slower rate of sea level rise, reaching the threshold of 0.50 meters above the historical baseline after 2080 (median) under SSP3-7.0. Under SSP2-4.5, sea level rise does not reach the 0.50 m threshold until around 2090 (median) and under SSP1-2.6, sea level rise does not reach this threshold until approximately 2100 (median). However, scenarios SSP2-4.5 and

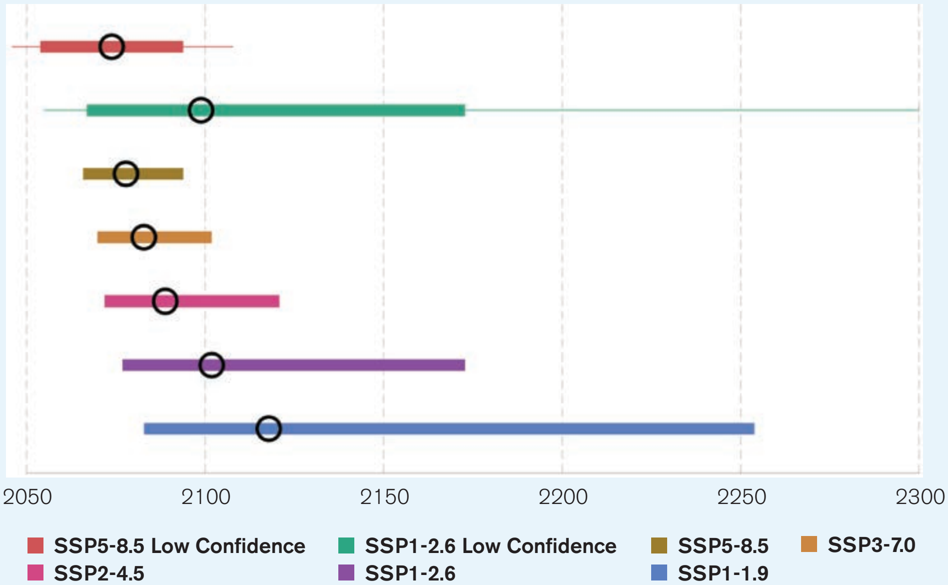
FIGURE 11A. Projected Timing of 0.5-Meter Sea Level Rise Along Cristóbal's (Colón's) Coast Under Various Scenarios (Ref. Period 1995–2014)[37]



Thick bars show 17th–83rd percentile ranges, and black circles show median value. Thin bars also show 5th–95th percentile ranges for SSP1-2.6 Low Confidence and SSP5-8.5 Low Confidence scenarios.

[36] NASA (2023). Sea Level Projection Tool. URL: https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool
[37] NASA (2023). Sea Level Projection Tool. URL: https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool

FIGURE 11B. Projected Timing of 0.5-Meter Sea Level Rise Along Puerto Armuelles' (Chiriquí's) Coast Under Various Scenarios (Ref. Period 1995–2014)[38]



Thick bars show 17th–83rd percentile ranges, and black circles show median value. Thin bars also show 5th–95th percentile ranges for SSP1-2.6 Low Confidence and SSP5-8.5 Low Confidence scenarios. Note the generally similar ranges of uncertainties but later thresholds for all scenarios compared to Cristóbal (Figure 11a).

SSP1-2.6 possess higher ranges of uncertainty, similar to Cristóbal. Sea level in Puerto Armuelles increases 0.72 m (0.55 m, 0.98 m) by 2100 under SSP3-7.0, but 0.58 m (0.42 m, 0.83 m) under SSP2-4.5 and 0.48 m (0.33 m, 0.69 m) under SSP1-2.6 over the same timeframe. The difference between rates of sea level rise along Panama's Caribbean and Pacific coasts can be attributed largely to differences in ocean currents, temperature, and salinity. Balboa (Panamá), located on the Pacific side of the Panama Canal, is projected to experience sea level rise only slightly higher than Puerto Armuelles on the southwest Pacific coast under each scenario.

Flood and Drought Risk

Incidents of both flooding and drought in Panama will likely occur with greater intensity and frequency in the future and are strongly influenced by ENSO. Between 1920 and 2017, the highest number of recorded floods occurred in the Panama Canal region (Panamá Oeste, Colón) and coastal areas of Bocas del Toro (western Caribbean), Chiriquí (western Pacific), and Los Santos (central Pacific).[39] In recent years (2016–2021), more

[38] NASA (2023). Sea Level Projection Tool. URL: https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool
[39] Ministry of Environment (2018). Third National Climate Change Communication. URL: https://unfccc.int/sites/default/files/resource/Tercera%20Comunicacion%20Nacional%20Panama.pdf

than 100 flood events occurred in Panamá (eastern Pacific) and Chiriquí (western Pacific).[40] While Panama lies outside the zone of typical tropical cyclone paths, a recent increase in direct hurricane impacts led to extensive flooding and landslides especially in the western provinces, most notably during Hurricane Otto in 2016 and Hurricane Iota in 2020.[41] The national government identifies the highest flood exposure in the western highlands (Bocas del Toro, Ngäbe Buglé) and eastern highlands (Panamá, Darién), and the highest exposure to drought (maximum consecutive dry days and land degradation) in the Arco Seco region, particularly Los Santos and Coclé.[42] However, overall climate vulnerability (including adaptive capacity) remains highest in Ngäbe Buglé, Panamá, Kuna Yala, and Darién, as illustrated in **Figure 12**. According to WBG's Global Facility for Disaster Risk Reduction (GFDRR), watersheds on the eastern part of the isthmus (including Panamá and Darién) maintain a high risk of riverine flooding with potentially damaging and life-threatening flooding expected to occur at least once in the next 10 years, while the Panama Canal watershed possesses a medium-level risk of urban flooding.[43] Among the most impactful events, the "La Purísima" storm at the end of the rainy season in December 2010 – which produced the largest 3-day runoff amounts on record, designating it as a 150-year to 300-year storm event – resulted in hundreds of landslides, compromised drinking water supply for Panama City and Colón, and generated severe infrastructure failures, including a historic temporary closure of the Panama Canal.[44] Abnormal climatic conditions associated with El Niño phases can produce high temperatures and severe droughts in Panama, damaging agricultural output and threatening operations at the hydroelectric power projects which generate most domestic energy supplies. Rainfall reductions during the El Niño events of 1982–1983 and 1997–1998 severely impacted river flows while precipitation deficits associated with the 2015–2016 El Niño limited the passage of traffic along the Panama Canal.[45] Such conditions lead to an increasingly high risk of conditions supporting wildfires nationwide.

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[40] Ministry of Economy and Finance (2023). Inventario de las Incidencias de los Desastres en la República de Panamá al 2022. URL: https://www.mef.gob.pa/wp-content/uploads/2023/06/Inventario-de-los-Desastres-2023.pdf

[41] International Federation of Red Cross and Red Crescent Societies (2020). Panama: Hurricane Eta. URL: https://reliefweb.int/report/panama/panama-hurricane-eta-dref-operation-n-mdrpa013; International Federation of Red Cross and Red Crescent Societies (2017). Panama: Floods. URL: https://reliefweb.int/report/panama/panama-floods-dref-final-report-n-mdrpa012

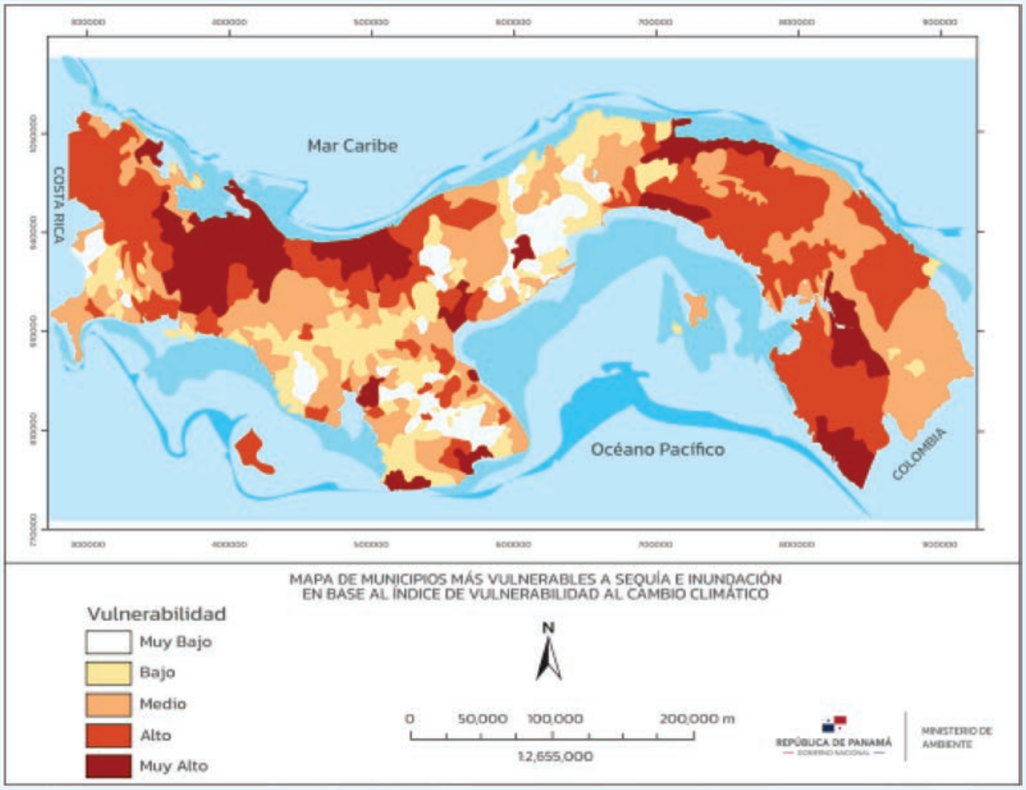
[42] Ministry of Environment (2023). Fourth National Climate Change Communication. URL: https://unfccc.int/sites/default/files/resource/53792416_Panama-NC4-1-4CNCC_2023_PANAMA_H.pdf

[43] GFDRR (2020). Panama. URL: https://thinkhazard.org/en/report/191-panama

[44] Stallard, R. F. (2023). Extreme Rainstorms and Landslides in the Panama Canal Watershed–Lessons Learned from the Storms of December, 2010. Soil Erosion Research Under a Changing Climate, January 8–13, 2023, Aguadilla, Puerto Rico, USA. American Society of Agricultural and Biological Engineers. DOI:10.13031/soil.23600

[45] Ministry of Environment (2023). Fourth National Climate Change Communication. URL: https://unfccc.int/sites/default/files/resource/53792416_Panama-NC4-1-4CNCC_2023_PANAMA_H.pdf

FIGURE 12. Map of Municipalities Most Vulnerable to Drought and Flood Based on Ministry of Environment's 2021 Climate Change Index[46]



Local vulnerabilities are ranked from very low (muy bajo) in white to medium (medio) in orange to very high (muy alto) in dark red. Note the areas of highest vulnerability in the westernmost and easternmost regions.

Earthquake, Volcano, and Landslide Hazards

Climate variability exacerbates high seismic risks across Panama, including the Panama City metropolitan region and rural areas. Panama is located along the Pacific Ring of Fire and sits atop the Panama Microplate at the intersection of four major tectonic plates: the Cocos, Nazca, Caribbean, and South American (**see Figures 13a–b**).[47] As pictured in **Figure 13a**, the oceanic Cocos Plate moves in a northeast direction and subducts beneath the lighter crust of both the Caribbean Plate along the Middle American Trench (which terminates off Costa Rica's Pacific shoreline) as well as the southwest boundary of the Panama Microplate. Circumscribing the western boundary of the Panama Microplate, from Costa Rica's western (Pacific) to eastern (Caribbean) coasts is a complex system of overland faulting and volcanism (the Central Costa Rica Block). Panama's three western

[46] Ministry of Environment (2023). Fourth National Climate Change Communication. URL: https://unfccc.int/sites/default/files/resource/53792416_Panama-NC4-1-4CNCC_2023_PANAMA_H.pdf

[47] Carvajal-Soto, L. A., Ito, T., Protti, M., and Kimura, H. (2020). Earthquake potential in Costa Rica using three scenarios for the Central Costa Rica deformed belt as western boundary of the Panama microplate. Journal of South American Earth Sciences, 97, 102375. DOI: https://doi.org/10.1016/j.jsames.2019.102375

provinces maintain a high volcanic hazard risk because Volcán Barú, which last erupted in the 15th century, is located in this region.[48] North of the Isthmus of Panama, the Panama Microplate subducts beneath the Caribbean Plate, while to the south, the Panama Microplate converges with the Nazca Plate along a weak seismic interface called the South Panama Fracture Zone. The Panama Fracture Zone, a series of north-south underwater ridges and trenches up to 3,300 meters deep, forms the eastern boundary of the Cocos Plate and western boundary of the Nazca Plate, which moves in an east-northeast direction toward the Colombian North Andes Block of the South American Plate.[49]

Seismic records (**see Figure 13b**) document the greatest frequency of earthquakes along the Panama Microplate's western boundary, including the Panama-Costa Rica border region and offshore area along the Panama Fracture Zone. A sizable number of earthquakes also occur along the microplate's eastern boundary along Panama's border with Colombia. Fewer earthquake epicenters occur north and south of the Isthmus of Panama associated with the North Panama Deformed Belt and the South Panama Fracture Zone, respectively, but those of the former tend to possess higher magnitudes. The Global Earthquake Model (GEM) Foundation identifies the greatest potential for seismic movement – peak ground acceleration > 0.55 g with a 10% probability of being exceeded in 50 years – in Darién along the Panama Microplate's boundary with the South American Plate (Colombian border), Chiriquí's Burica Peninsula near the Panama Microplate's junction with the underwater Panama Fracture Zone, and northeast of the Panama Canal (Colón and Panamá).[50] However, the highest annual average earthquake losses occur in Panamá, which includes the capital and southern Panama Canal (US$35 million), followed by Chiriquí (US$20 million) and the two other provinces comprising the capital region and canal – Panamá Oeste and Colón (~US$10 million). All provinces on the Pacific coast possess a high risk (>40% probability) of experiencing a potentially damaging tsunami in the next 50 years according to WBG's Global Facility for Disaster Risk Reduction (GFDRR), while eastern Colón and Kuna Yala on the Caribbean possess a medium risk (>10% probability in the next 50 years).[51] The largest and most devastating earthquake in the country's recent history struck Limón in eastern Costa Rica in 1991 with a magnitude of 7.7, which resulted in 79 fatalities in Panama's Bocas del Toro Province and widespread liquefaction and landslides that damaged buildings and infrastructure.[52] Another major event included the 6.6 magnitude Puerto Armuelles earthquake (Chiriquí) in 2003, which similarly resulted in severe liquefaction and landslides.[53] GFDRR estimates that if the 7.8 magnitude earthquake that hit northern Panama in 1882 struck today, it would cause US$810 million in losses.[54]

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[48] Smithsonian Institution (2023). Panama Volcanoes. National Museum of Natural History Global Volcanism Program. URL: https://volcano.si.edu/volcanolist_countries.cfm?country=Panama; Global Facility for Disaster Risk Reduction (2020). Panama. URL: https://thinkhazard.org/en/report/191-panama/TS

[49] Moore, G. F., and Sender, K. L. (1995). Fracture zone collision along the South Panama margin. Geologic and tectonic development of the Caribbean plate boundary in southern Central America. Geological Society of America Special Paper 295. DOI: https://doi.org/10.1130/SPE295-p201

[50] Global Earthquake Model Foundation (2019). Panama. URL: https://downloads.openquake.org/countryprofiles/PAN.pdf

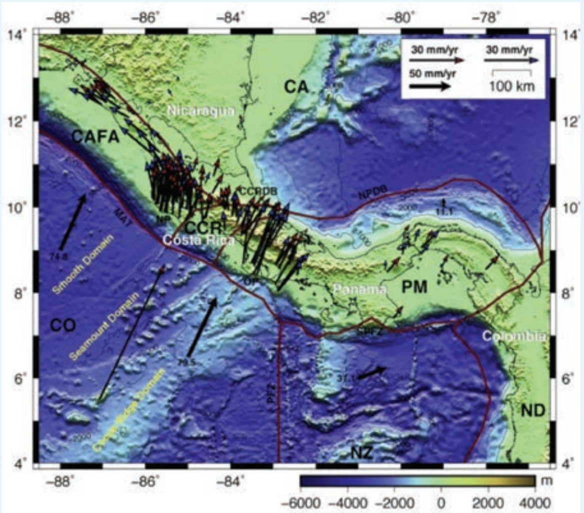
[51] Global Facility for Disaster Risk Reduction (2020). Panama. URL: https://thinkhazard.org/en/report/191-panama/TS

[52] Quesada-Román, A. (2021). Review of the geomorphological effects of the 1991 Limón earthquake. Revista Geológica de América Central, (65), 370–395. URL: https://revistas.ucr.ac.cr/index.php/geologica/article/view/46697; Bommer, J. J., and Rodríguez, C. E. (2002). Earthquake-induced landslides in Central America. Engineering Geology, 63(3–4), 189220. DOI: https://doi.org/10.1016/S0013-7952(01)00081-3

[53] Linkimer, L., and Schmidt, V. (2004). Sismos en la Península de Burica entre diciembre del 2003 y febrero del 2004. Instituto de Investigaciones en Ingeniería, Universidad de Costa Rica. URL: https://www.lis.ucr.ac.cr/_vista/documentos/04.pdf

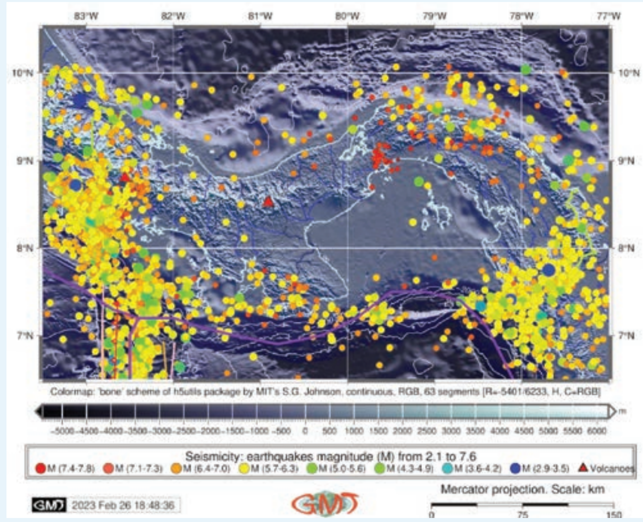
[54] Global Facility for Disaster Risk Reduction (2016). Panama Earthquake Risk Profile. URL: https://www.gfdrr.org/sites/default/files/Panama1.pdf

FIGURE 13A. Panama's Key Seismic Features[55]



Note the northeast motion of the Cocos Plate and its subduction beneath Costa Rica (the Caribbean Plate) and western Panama (the Panama Microplate). The boundaries of the Panama Microplate surrounding the Isthmus of Panama, amidst other plate boundaries, are highlighted red. Arrows indicate plate motion direction and velocity relative to the Caribbean Plate. Abbreviations signify the following: Cocos Plate (CO), Nazca Plate (NZ), Caribbean Plate (CA), Panama Microplate (PM), Central American Fore Arc (CAFA), Central Costa Rica Block (CCR), Central Costa Rica Deformed Belt (CCRDB), Middle American Trench (MAT), Nicoya Peninsula (NP, Costa Rica), Osa Peninsula (OP, Costa Rica), Panama Fracture Zone (PFZ), South Panama Fracture Zone (SPFZ), North Panama Deformed Belt (NPDB), and North Andes Block (ND, South American Plate).

FIGURE 13B. Recorded Earthquakes in Panama by Magnitude, 1970–2021[56]



Note the high frequency of earthquakes along western and eastern boundaries of the Panama Microplate, but the particularly intense earthquakes centered along the northern boundary.

Landslides and various types of mass movement can be influenced by an array of factors, ranging from seismic activity, geology, water saturation, and erosion, all of which have the potential to be exacerbated by climate change and human activities. GFDRR identifies the highest landslide hazard risks – often caused by heavy rains and flooding – in the mountains of the western provinces, Azuero Peninsula, and eastern provinces.[57] For example, in July 2021, heavy rainfall triggered nearly a dozen landslides in western Panama, affecting thousands.[58] However, risks also extend to Panama's central provinces, as flooding from and subsequent landslides generated by Hurricane Eta in 2020 and Hurricane Otto in 2016 demonstrated.[59] Projections for more extreme precipitation will heighten these risks.

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55 Carvajal-Soto, L. A., Ito, T., Protti, M., and Kimura, H. (2020). Earthquake potential in Costa Rica using three scenarios for the Central Costa Rica deformed belt as western boundary of the Panama microplate. Journal of South American Earth Sciences, 97, 102375. DOI: https://doi.org/10.1016/j.jsames.2019.102375

56 Lemenkova, P., and Debeir, O. (2023). Correlations between the Topography-Induced Gravity, Terrain Structure and the Seismicity in the Gulf of Panama. Environmental Research, Engineering and Management, 79(2), 64–76. DOI: https://doi.org/10.5755/j01.erem.79.2.33500

57 Global Facility for Disaster Risk Reduction (2020). Panama. URL: https://thinkhazard.org/en/report/191-panama/TS

58 International Federation of Red Cross and Red Crescent Societies (2022). Panama: Floods. URL: https://reliefweb.int/report/panama/panama-floods-dref-final-report-operation-n-mdrpa014

59 International Federation of Red Cross and Red Crescent Societies (2020). Panama: Hurricane Eta. URL: https://reliefweb.int/report/panama/panama-hurricane-eta-dref-operation-n-mdrpa013; International Federation of Red Cross and Red Crescent Societies (2017). Panama: Floods. URL: https://reliefweb.int/report/panama/panama-floods-dref-final-report-n-mdrpa012

KEY NATIONAL DOCUMENTS

- Fourth National Communication to the UNFCCC (2023) (Spanish)
- Second Biennial Update Report (2021) (Spanish)
- Updated Nationally Determined Contribution (2020) (Spanish)
- First Biennial Update Report (2018) (Spanish)
- Third National Communication to the UNFCCC (2018) (Spanish)
- First Nationally Determined Contribution (2016) (Spanish)
- Second National Communication to the UNFCCC (2011) (Spanish)
- First National Communication to the UNFCCC (2000) (Spanish)

ANNEX OF PROJECTED CLIMATE SCENARIOS

Compared to SSP3-7.0, which results in the greatest temperature shifts nationally across all key metrics by the end of the century (see Table 4), SSP1-2.6 and SSP2-4.5 demonstrate Panama's lower overall rates of change and severity of climate impacts as a result of carbon emission reductions. The differences between projected temperatures under the three scenarios are particularly pronounced (**see Figure 14a**). SSP1-2.6 has the lowest annual mean temperature increase – an anomaly close to 1°C by 2080–2099. Mean temperature rises by an anomaly of nearly 2°C by end-of-century under SSP2-4.5 and greater than 2.5°C by end-of-century under SSP3-7.0. The minimal increase in number of tropical nights (T-min >20°C and T-min >26°C) experienced nationally by the end of the century under SSP1-2.6 (<25 nights above the reference period annually) contrasts those of the other two scenarios. SSP2-4.5 projects an increase in number of tropical nights (T-min >26°C) of more than two months above the historical reference annually by the end of the century, while SSP3-7.0 projects the most dramatic increase of nearly five months annually for this metric over the same time period. Most of the change in tropical nights (T-min >20°C) is concentrated in the western provinces, as the already high year-round mean prevents further increases in this temperature range across much of the country. The shift in number of tropical nights with a higher threshold (T-min >26°C) disproportionately affect provinces in the central isthmus, especially under the highest emission scenario.

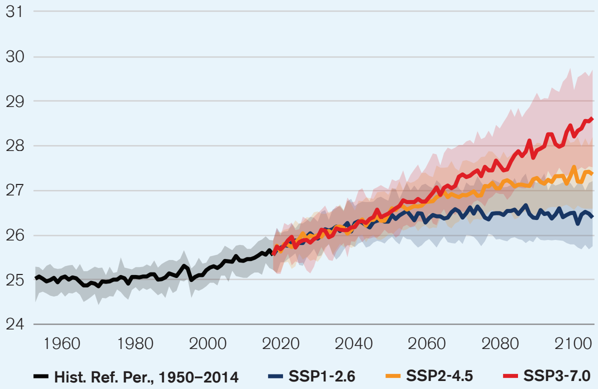
The projected precipitation patterns countrywide under the three scenarios produce noticeable differences by end of century, with the lowest potential annual increases according to the highest emission trajectory (**see Figure 14b**). As early as the 2020–2039 period, Panama is expected to experience a rise in annual precipitation of 123.67 mm (–133.98 mm, 256.03 mm) from the reference period under SSP1-2.6, which holds relatively constant through the end of the century. Under SSP2-4.5, by comparison, nationwide precipitation totals progressively increase from 64.24 mm (–116.63 mm, 242.88 mm) above the reference period for the 2020–2039 period to the highest anomaly of 162.98 mm (–136.37 mm, 417.60 mm) by the end of the century. However, the median precipitation anomalies under SSP3-7.0 trend quite different. From a 2020–2039 precipitation anomaly

TABLE 4. Key National-Level Projected Anomalies Through End-of-Century (Ref. Period 1995–2014) Under SSP1-2.6, SSP2-4.5, and SSP3-7.0 Scenarios

Metric	SSP1-2.6 Projection		
	2020–2039	2040–2059	2080–2099
Annual Mean Temperature	0.66°C (0.40°C, 1.00°C)	1.00°C (0.59°C, 1.50°C)	1.06°C (0.51°C, 1.74°C)
Tropical Nights (No. Nights T-min >20°C) Annually	9.49 (5.56, 14.40)	12.91 (7.85, 20.17)	13.33 (6.99, 22.86)
Tropical Nights (No. Nights T-min >26°C) Annually	10.59 (3.85, 24.02)	20.35 (6.29, 52.70)	24.68 (5.29, 70.53)
Annual Precipitation (mm)	**123.67** (–133.98, 256.03)	**145.34** (–151.98, 324.03)	**115.92** (–141.13, 334.23)
Average Largest 5-Day Cumulative Precipitation (mm) Annually	15.87 (–61.45, 73.41)	22.12 (–47.08, 88.03)	11.18 (–71.71, 91.82)
Metric	**SSP2-4.5 Projection**		
	2020–2039	**2040–2059**	**2080–2099**
Annual Mean Temperature	0.68°C (0.44°C, 0.99°C)	1.17°C (0.83°C, 1.69°C)	1.89°C (1.24°C, 2.62°C)
Tropical Nights (No. Nights T-min >20°C) Annually	9.53 (5.68, 14.53)	15.53 (10.39, 22.06)	22.24 (14.96, 30.55)
Tropical Nights (No. Nights T-min >26°C) Annually	10.32 (4.21, 25.73)	31.59 (12.48, 65.98)	**77.06** (30.30, 146.44)
Annual Precipitation (mm)	64.24 (–116.63, 242.88)	**142.34** (–129.32, 332.16)	**162.98** (–136.37, 417.60)
Average Largest 5-Day Cumulative Precipitation (mm) Annually	23.16 (–67.29, 92.28)	17.96 (–67.18, 75.39)	**29.56** (–53.47, 108.09)
Metric	**SSP3-7.0 Projection**		
	2020–2039	**2040–2059**	**2080–2099**
Annual Mean Temperature	0.65°C (0.42°C, 1.04°C)	1.26°C (0.91°C, 1.83°C)	**2.68°C** (2.01°C, 3.67°C)
Tropical Nights (No. Nights T-min >20°C) Annually	9.21 (5.32, 14.46)	16.29 (10.94, 23.47)	**29.03** (21.27, 37.53)
Tropical Nights (No. Nights T-min >26°C) Annually	9.44 (4.08, 29.69)	34.60 (15.01, 85.11)	**145.89** (83.88, 231.95)
Annual Precipitation (mm)	54.43 (–144.13, 259.08)	45.09 (–307.60, 298.70)	**2.52** (–859.10, 413.29)
Average Largest 5-Day Cumulative Precipitation (mm) Annually	18.99 (–94.81, 95.94)	11.98 (–81.77, 81.00)	3.16 (–105.75, 80.22)

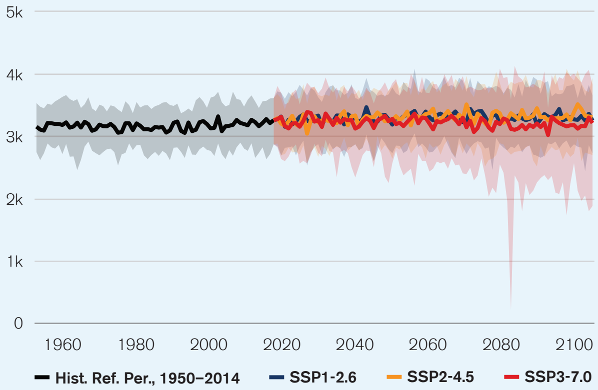
10th percentile and 90th percentile values are shown in parentheses. Key values or shifts over time are shaded orange and bolded. See text for interpretation.

FIGURE 14A. Projected Average Mean Temperature in Degrees Celsius Nationwide (Ref. Period 1995–2014) Under Various Scenarios



Shaded areas indicate ranges of 10th–90th percentiles. Note clearly higher increase of SSP3-7.0 starting midcentury.

FIGURE 14B. Projected Precipitation in Millimeters Nationwide (Ref. Period 1995–2014) Under Various Scenarios



Shaded areas indicate ranges of 10th–90th percentiles. Note the least median change and greatest uncertainty under SSP3-7.0 compared to SSP1-2.6 and SSP2-4.5 by the end of the century. Probability ranges for all scenarios extend above and below the historical reference period, indicating a potential likelihood for precipitation decreases or increases.

roughly equivalent to that of SSP2-4.5, SSP3-7.0 predicts no net precipitation change from the reference period nationally by the end of the century. Specifically, while annual precipitation in the western and Caribbean-facing provinces begins decreasing from the reference period by midcentury under SSP3-7.0, relatively homogeneous precipitation increases occur across the country according to the other two scenarios. Of all the trajectories, SSP3-7.0 displays the largest range of uncertainty (>1,000 m) and the greatest potential for experiencing negative anomalies by the end of the century. Nonetheless, it is important to note that the ranges of probability for the two wettest scenarios do not rule out potential precipitation decreases in the short or long term. Precipitation intensity, as measured by the average largest 5-day cumulative precipitation annually, increases the most from the reference period by the end of the century under SSP2-4.5 and the least under SSP3-7.0, whereby western and central provinces actually project annual decreases in intensity.

CLIMATE RISK COUNTRY PROFILE

PANAMA

WORLD BANK GROUP