Global Climate Connection

Atmosphere, Ocean and Amazon

Key Messages

- The Amazon faces increasing climate pressure, with projections indicating a continuous rise in temperatures over the coming decades.

- Atmospheric and oceanic circulation systems that regulate the global climate exert a direct influence on the Amazon's hydrological regime.

- Oceans absorb more than 90% of the planet's excess heat and regulate regional humidity and temperature. The warming of the Atlantic and the weakening of the Atlantic Meridional Overturning Circulation (AMOC) compromise moisture transport to the Amazon, affecting its hydrological regime.

- As a result, there is a growing risk of imbalance in the so-called Flying Rivers — moisture highways in the atmosphere, that sustain the rainfall regime and the ecological stability of the Amazon rainforest.

- Integrating scientific knowledge into public policies is essential to strengthen the Amazon's resilience, guiding effective adaptation and mitigation actions in the face of mounting climate challenges.

POLICY BRIEF No. 2

ACTO Amazon Cooperation Treaty Organization

ARO AMAZON REGIONAL OBSERVATORY

Climate Connections in the Amazon

Interactions between ocean and atmosphere are fundamental for the Amazon rainfall regime. Changes in these connections affect moisture transport to the region and increase the risk of droughts and climate instability. Global Climate Models, widely used by the Intergovernmental Panel on Climate Change (IPCC), help understand these dynamics and project future scenarios, guiding adaptation and mitigation actions. These models are based on Shared Socioeconomic Pathways (SSPs), where the pessimistic high-emission scenario (SSP-585) could lead to global warming above 4 °C by 2100. This scenario, used as a reference in risk analyses, indicates higher vulnerability of the Atlantic Meridional Overturning Circulation (AMOC) to pronounced weakening, interfering with key elements for the Amazon, such as the ocean.

THE ROLE OF THE OCEAN IN THE AMAZON CLIMATE

The ocean is the main regulator of the global climate. It absorbs more than 90% of the extra heat caused by greenhouse gas emissions[1]. This warming has been particularly intense in the tropical Atlantic, where sea surface temperature has been rising. As the ocean warms, evaporation and air humidity increase, shifting the zone where winds from both hemispheres converge to form clouds and heavy rainfall: the Intertropical Convergence Zone (ITCZ), which alters the precipitation patterns in the Amazon.

Between 2023 and 2024, sea surface temperature reached record levels, especially in the North Atlantic[2], which registered 0.42 °C above the previous record, according to the National Oceanic and Atmospheric Administration (NOAA). Projections indicate that this trend will continue. In pessimistic scenarios, the Atlantic temperature could rise by more than 2 °C in the 2050 agenda, increasing heat storage in the ocean's surface layers (Fig. 1).

Research shows that the warming of the tropical North Atlantic plays a central role in the reduction of precipitation in the Amazon, particularly during the dry season, which may have decreased by up to 30% in recent decades[3]. This warming modifies oceanic and atmospheric circulation patterns, which directly interfere with the region's rainfall dynamics.

In addition, this warming accelerates polar ice melt and increases freshwater input into the North Atlantic, reducing its salinity. This weakens the Atlantic Meridional Overturning Circulation (AMOC), a system essential for redistributing heat and maintaining global and regional climate stability[4], such as in the Amazon, the largest tropical forest in the world, which plays a critical role in regulating the global climate system.[5] (Fig. 2)

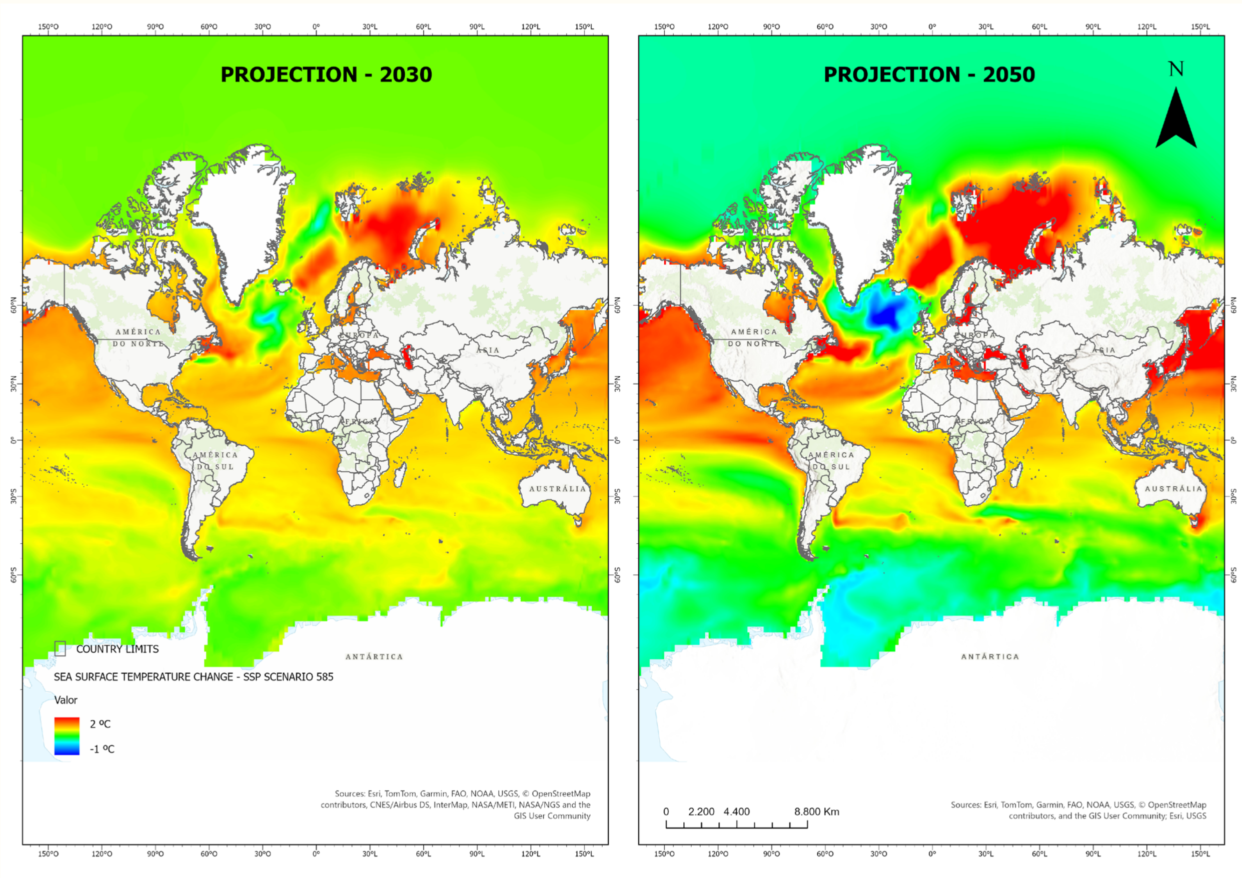


Figure 1. Multimodel ensemble mean (MME) of Sea Surface Temperature (∆SST) change (°C) for projections in 2030 and 2050 referent of the period 1970-2000 in the SSP-585 scenario. Source: Author.

HOW DOES THE AMOC INFLUENCE AMAZONIAN RAINFALL?

The AMOC directly impacts Amazon rainfall, as it regulates the Atlantic temperature gradient and the position of the ITCZ. When the AMOC weakens, less heat is transported to the Northern Hemisphere, which comparatively warms the South Atlantic and shifts the ITCZ southward. The result is a change in rainfall intensity and seasonality, increasing the frequency and severity of Amazon droughts.

These droughts are already a reality. The region has faced extreme events in 2005, 2010, 2015, 2016, and 2023, many of which were associated with anoumalous warming of the Atlantic and Pacific Oceans.[6,7,8] In 2024, the global average temperature exceeded 1.5 °C[9], and projections indicate more heat and prolonged droughts in the coming years, placing the Amazon in a critical condition.

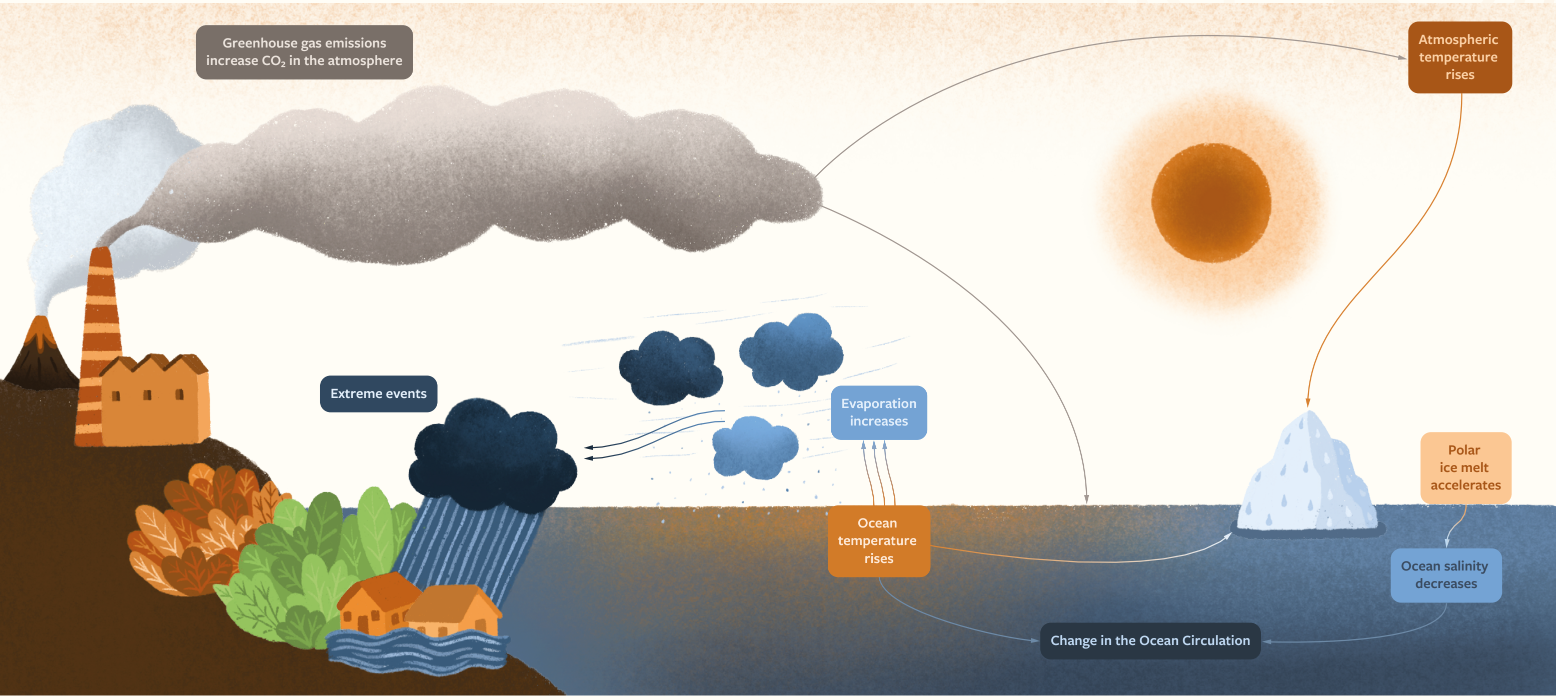


Figure 2. Ocean–atmosphere interaction under the effect of climate change in the Atlantic Ocean.

Climate Projections In The Amazon

Climate models and observational data indicate that changes in land and sea surface temperatures are already affecting the region's rainfall regime, increasing the frequency and intensity of droughts and extreme rainfall events.[10,11] The continuation of these pressures may lead to irreversible ecological transitions, tipping points, with the replacement of moist forest by less complex seasonal vegetation such as savannas, resulting in biodiversity loss, reduced carbon storage capacity, and cascading impacts on continental climate[12,13].

Understanding climate change in the Amazon basin depends on integrating local observations, regional reanalyses, and global and regional climate models capable of representing the complex interaction among forests, the atmosphere, and the oceans. These models enable impact simulations, risk assessments, and the design of mitigation and adaptation strategies.

PRECIPITATION CHANGES: WARNING SIGNAL

Climate projections point to reduced rainfall in the Amazon, with critical areas already projected to 2030 agenda and a tendency toward intensification by 2050 (Fig. 3). This pattern increases the risk of extreme droughts and seasonal floods, compromising: a) biodiversity; b) agriculture and river transport; c) water availability; d) moisture flows sustaining the Flying Rivers.

These interconnected impacts could push the forest past a tipping point, losing its regeneration capacity and triggering ecological collapse. The Amazon would cease to be a carbon sink, further aggravating global warming and highlighting the interdependence between Amazon stability and the global climate.

FLYING RIVERS: MOISTURE CORRIDORS AT RISK

The so-called Flying Rivers are flows of water vapor generated by Amazonian forest evapotranspiration and transported by low-altitude winds to central and southern regions of South America. These flows are essential to regulate rainfall across the continent.

However, climate changes, such as rising temperatures and prolonged droughts, combined with forest degradation, reduce moisture recharge, and compromise the formation and stability of these atmospheric corridors. Studies indicate that deforestation may reduce regional precipitation by 10 to 20%, further aggravating the progressive loss of Flying Rivers.[14]

The fragility of these systems highlights that the Amazon does not respond only to local pressures, but is deeply connected to global climate dynamics. The loss of Flying Rivers would have severe impacts on water security, agricultural production, and energy generation, although these costs are still difficult to estimate.

GLOBAL WARMING AND LOCAL IMPACTS

Global climate models project a continuous rise in temperature throughout the 21st century, with stronger warming in the Northern Hemisphere compared to the South (Fig. 4). This asymmetric pattern reflects the historical inequality in greenhouse gas emissions, concentrated mostly in Global North countries, while tropical regions such as the Amazon, which have contributed far less to this problem, face disproportionate impacts from global warming.

Rising temperatures and changing precipitation patterns exacerbate the forest's ecological and socio-environmental vulnerability, highlighting an asymmetry between responsibility and exposure to climate risks. Projections indicate warming of up to 2.5 °C in the Amazon by 2050 for high emissions (Fig.4). This scenario threatens sensitive ecosystems, affecting the region's socio-environmental resilience and amplifying impacts on biodiversity, the hydrological cycle, and forest-dependent populations.

In the face of this climate inequality, the Amazon Cooperation Treaty Organization (ACTO) strengthens cooperation among Amazonian countries, integrating scientific data and information through the Amazon Regional Observatory (ARO), in order to improve regional adaptation and mitigation mechanisms.

THERMAL REGULATION BY ATMOSPHERIC AND OCEANIC CIRCULATIONS

The stability of the global climate system and of sensitive ecosystems such as the Amazon depends on thermal regulation promoted by atmospheric and oceanic circulations, which redistribute excess heat from the tropics toward higher latitudes.

In the atmosphere, latitudinal and longitudinal circulation flows redistribute heat and humidity across the tropics, directly influencing the position of the Intertropical Convergence Zone (ITCZ), an atmospheric instability belt that regulates the occurrence and intensity of rainfall in the Amazon. The ITCZ is a band near the equator where winds from both hemispheres converge, causing warm, humid air to rise and generate clouds and rainfall. This band shifts throughout the year, following the warmest regions of the Earth's surface and oceans.

In the ocean, heat is transported by surface currents driven by winds and by thermohaline circulation, caused mainly by the density differences due to variations in temperature and salinity of deep water, connecting ocean basins over thousands of kilometers. One of the main systems involved in this process is the Atlantic Meridional Overturning Circulation (AMOC), a large-scale current that acts as a "conveyor belt" of heat between the Southern and Northern Hemispheres.

The AMOC transports warm waters to the North Atlantic, where they cool, become denser, sink, and flow back southward. The AMOC influences interhemispheric thermal gradients and, consequently, the position of the ITCZ, which is crucial for the planet's thermal balance and directly influences the climate of several regions, including the Amazon.

The moisture that feeds the Amazon supply and influences the Flying Rivers comes primarily from the tropical Atlantic and is transported by easterly winds. The interaction between the ocean and the atmosphere modulates the transport of this moisture over the Amazon basin.

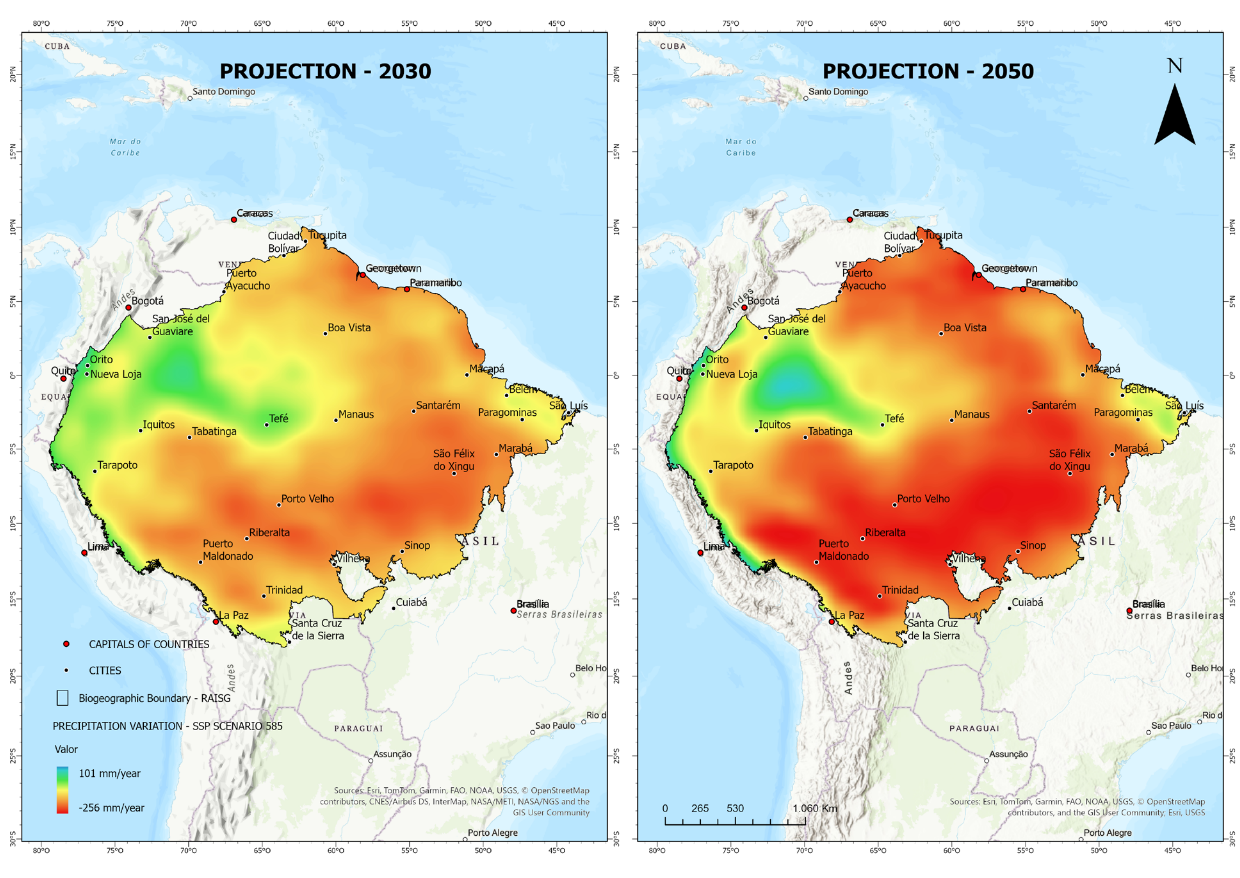


Figure 3. CMIP6 multimodel ensemble mean (MME mean) of precipitation (mm/year) projected change in 2030 and 2050, referring to the period 1970-2000 for the SSP-585 scenario in Amazon. Source: Author.

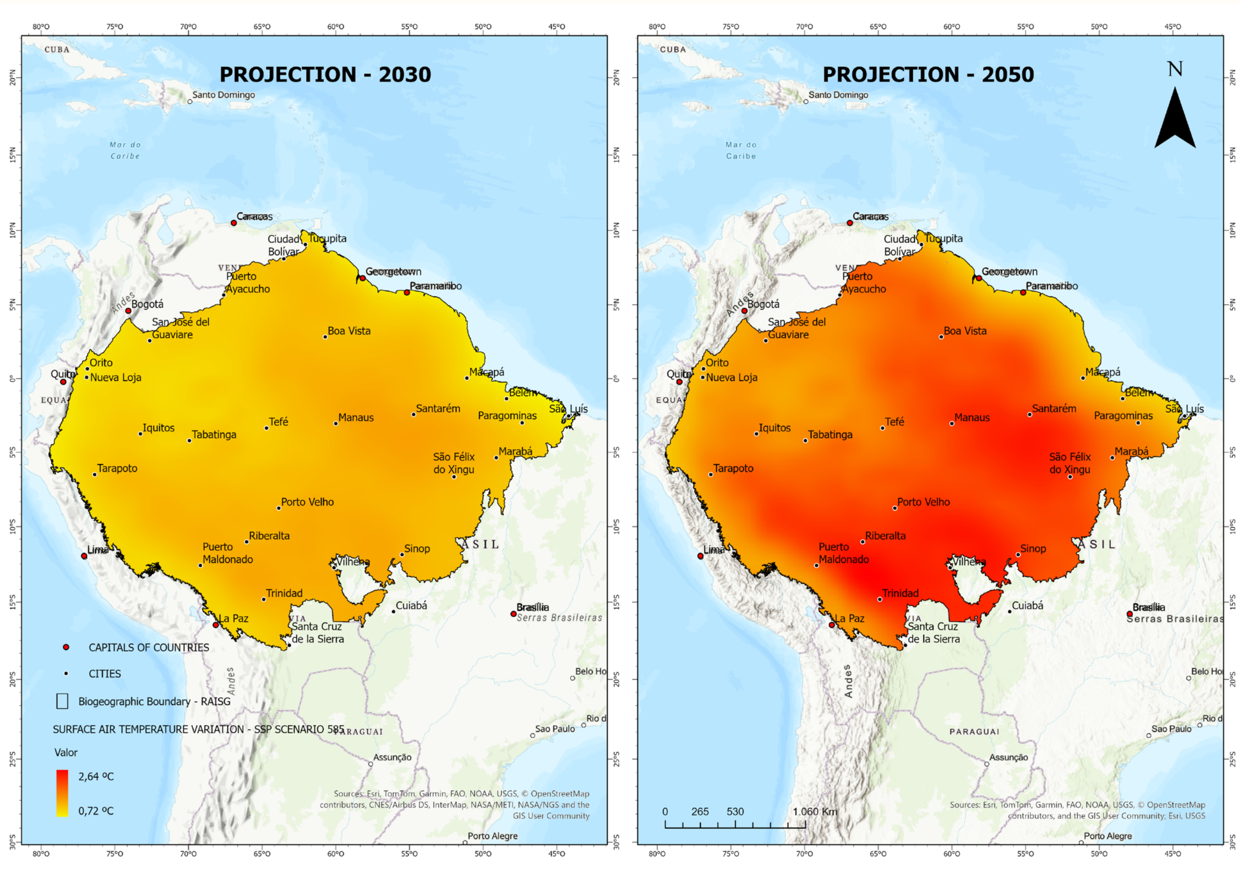
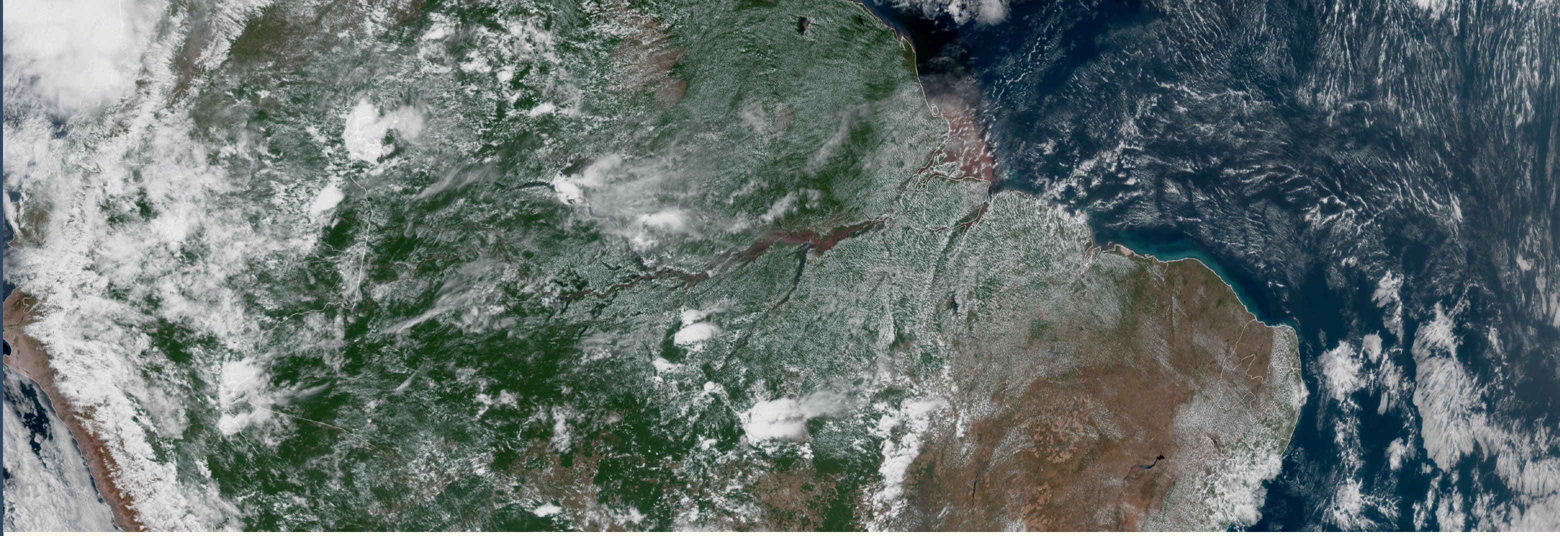


Figure 4. CMIP6 multimodel ensemble mean (MME mean) of Surface Air Temperature (°C) projected change for 2030 and 2050, referent to 1970-2000 period for the SSP-585 scenario in the Amazon. Source: Author.



Recommendations

INTENSIFY SCIENTIFIC AND INSTITUTIONAL COOPERATION
Strengthen integrated climate monitoring networks in the Amazon, focusing on the AMOC, a critical element of global climate stability and a key modulator of Amazon rainfall.

CLIMATE INDICATORS IN NATIONAL ADAPTATION PLANS (NAPS)
Integrate oceanic and atmospheric variables, such as tropical Atlantic warming, into NAPs to anticipate hydrometeorological risks.

DEVELOP AND IMPLEMENT ADAPTATION AND MITIGATION MECHANISMS
Based on updated scientific data, considering forest ecological dynamics, territorial climate vulnerability, and the socio-economic needs of Amazonian populations.

ENSURE THE PROTECTION OF INDIGENOUS PEOPLES IN ISOLATION AND INITIAL CONTACT (PIACI)
Strengthen safeguard instruments for intangible cultural heritage and value Amazonian ecosystems, terrestrial and aquatic, as fundamental for biodiversity, water security, and climate resilience.

STRENGTHEN INTERNATIONAL CO-RESPONSIBILITY IN PROTECTING THE AMAZON
Recognize Amazonian vulnerability: although it is an important carbon sink, the Amazon disproportionately suffers the impacts of climate change due to its high tropical sensitivity and the structural asymmetry of global emissions concentrated in the Northern Hemisphere.

ENSURE FAIR INTERNATIONAL COOPERATION TO STRENGTHEN REGIONAL RESILIENCE AND REDUCE SOCIO-ENVIRONMENTAL RISKS
Aligned with the UNFCCC and the Paris Agreement, this process must be supported by climate finance, just energy transition, technology transfer, and international technical cooperation, especially from countries with the greatest historical responsibility for greenhouse gas emissions, in line with the principle of common but differentiated responsibilities.

ENABLE THE TROPICAL FORESTS FOREVER FUND (TFFF)
As an instrument for mitigation and adaptation, mobilizing long-term international financing for Amazon conservation and climate resilience strengthening, in line with the Paris Agreement.

STRENGTHEN REGIONAL COORDINATION
ACTO, as a strategic integration mechanism among the eight Amazonian countries, needs to advance in defining and implementing the Financial Mechanism, and promote joint public policies and technical-scientific exchange through the ARO, consolidating strategic climate and environmental data and information to support regional decision-making.

Amazonian Trajectories And The Atlantic Meridional Overturning Circulation (AMOC)

Global warming simultaneously weakens the Atlantic Meridional Overturning Circulation (AMOC) and reduces rainfall in the Amazon, placing both systems at risk of abrupt transition. However, an AMOC collapse could, paradoxically, mitigate precipitation loss in the region, offering a possible stabilizing effect on the forest, albeit with serious implications for global climate.[15,16] Nevertheless, AMOC weakening could also intensify aridity in the far northern Amazon, influencing rainfall patterns and extreme events, potentially exceeding the direct impacts of global warming and tending to exacerbate drought in the northern part of the region.[17] These already complex effects may be further aggravated by anthropogenic pressure on ecosystems, including deforestation and increased fire incidence, amplifying risks to the region's socio-environmental resilience.[18]

This pattern of atmospheric moisture redistribution exposes the Amazon rainforest to an increasing aridification risk, with critical ecological, hydrological, and socioeconomic implications.

If the AMOC enters abrupt decline, the impacts will be global, with drastic changes in tropical rainfall[19]. In the Amazon, this would mean greater hydrological imbalances and increasing aridification risk, compromising biodiversity, flying rivers, and the region's socio-environmental security.

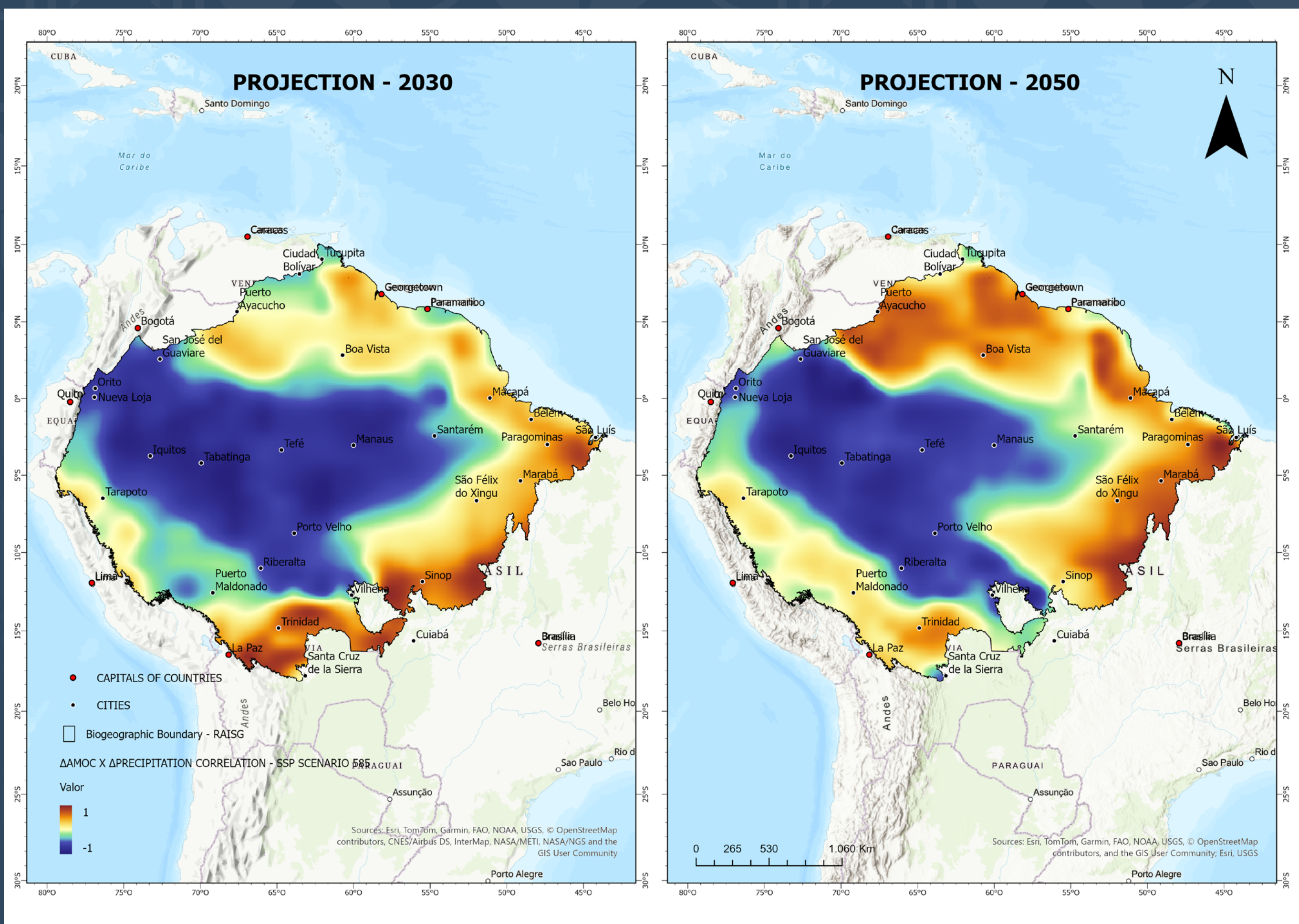


Figure 5. Correlation map of CMIP6 climate models: Between changes in the AMOC accumulated transport (Sv) (from 20 North to 20 South) and precipitation variation (mm/year) in the Amazon projected for 2030 and 2050, referring to the period 1970-2000 in the SSP-585 scenario. Source: Author.

Glossary

INTERTROPICAL CONVERGENCE ZONE

The Intertropical Convergence Zone (ITCZ) is a band near the Equator where humid air masses converge and rise, forming dense clouds and intense rainfall, playing a central role in precipitation distribution across tropical regions, such as the Amazon.

GLOBAL CLIMATE MODELS

The global climate models from the Coupled Model Intercomparison Project Phase 6 (CMIP6)[20] used here were: GFDL-ESM4, MPI-ESM1-2-LR, MIROC6, NorESM2-LM, and UKESM1-0-LL. Metadata: https://ora-otca.opendata.arcgis.com

SHARED SOCIOECONOMIC PATHWAYS (SSPS)

SSP trajectories are combined with different levels of radiative forcing (measured in W/m² through 2100), which combine emissions projections with different development scenarios, resulting in scenarios such as SSP-126, SSP-245, and SSP-585. The latter is widely used as a reference scenario for assessing extreme climate risks, as it represents a high-emissions future with prolonged dependence on fossil fuels.

CITATION SUGGESTION

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AMAZON REGIONAL OBSERVATORY (ARO)

ARO is ACTO's reference center that integrates data, tests innovations, and disseminates information to support member countries in cooperation and decision-making.

AMAZON COOPERATION TREATY ORGANIZATION (ACTO)

ACTO is an intergovernmental organization formed by eight Amazon countries: Bolivia, Brazil, Colombia, Ecuador, Guyana, Peru, Suriname, and Venezuela, which signed the Amazon Cooperation Treaty, making it the only socio-environmental bloc in Latin America.

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