



By backtracking air parcels arriving at the ATTO towers and measuring gases at multiple heights, we can quantify the contribution of each process to the observed GHG signals.

The location and heights of the ATTO towers allow observation of long-range atmospheric signals that integrate the influence of largely undisturbed forest areas extending tens to hundreds of kilometers upwind.

Relevance of ATTO GHG observations

The location of ATTO is important for global networks: by combining ATTO GHG concentrations with information on atmospheric transport and upwind ocean background stations, we can quantify the net influence of Amazon ecosystems on the atmosphere (Figure 2).

Integrating ATTO GHG observations into global observing networks, such as the World Meteorological Organization Global Atmospheric Watch, requires highly precise measurements. Intercomparability of ATTO measurements is ensured by following established global standards and procedures. Beyond the EU and North America, few monitoring stations are located in regions with large land-based carbon sources and sinks.

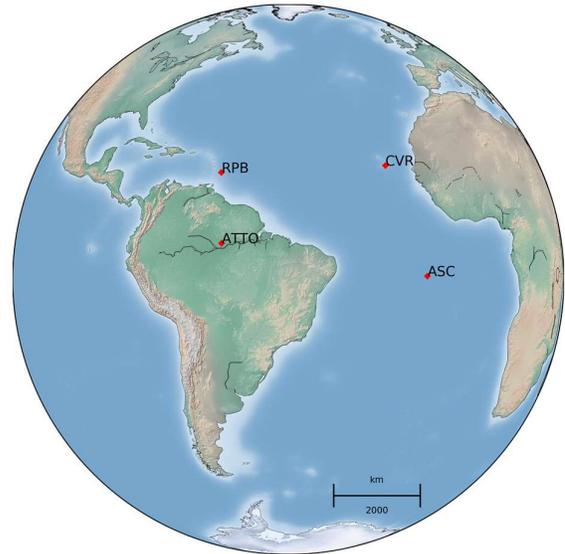


Figure 2. Location of the ATTO field site and three key background stations: Barbados (RPB), Cape Verde (CVR), and Ascension Island (ASC). Comparing ATTO measurements with those from background stations allows us to evaluate how Amazon ecosystems modify atmospheric GHG levels as air moves from the ocean across largely undisturbed forest toward the ATTO site.

Data from ATTO have helped quantify the role of the Amazon forest as a net carbon sink, highlighted wetlands as a key source of methane, and clarified the contribution of fires to regional carbon emissions.

ATTO thus fills a critical gap in the global observing network, providing essential data from the world's largest tropical forest.

12 years of ATTO observation: Key findings

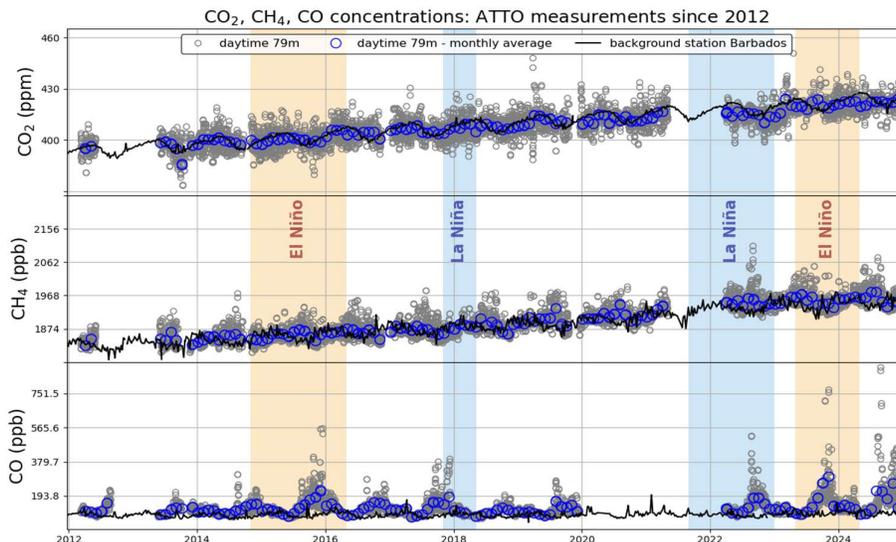


Figure 3. Concentrations of CO₂, CH₄, and CO measured at 79 m at ATTO, compared with the upwind background station Barbados (Fig. 2) ^{7,8,9}. Data gaps indicate periods of instrument malfunction or breakage, with the longest gap occurring during the pandemic, when travel restrictions and shipping delays hindered instrument repairs.

Carbon dioxide (CO₂) – Forests as carbon sinks

In recent decades, intact Amazon forests have functioned as an important global sink for carbon dioxide emitted from burning fossil fuels. At ATTO, atmospheric CO₂ concentrations are typically lower than those at the upwind ocean background stations (Figure 3, upper panel), indicating net CO₂ uptake by the land. CO₂ concentrations at ATTO rise by about 2.5 ppm from one year to the next, consistent with other sites around the globe.

By combining ATTO data with regional measurements, researchers have improved global carbon models—capturing processes often overlooked in simulations—and shown that the Amazon forest is still a small net carbon sink.

Methane (CH₄) – Wetland GHG sources

Methane (CH₄) is the most important greenhouse gas after CO₂, with tropical wetlands representing

its largest natural source. Increases in these wetland emissions have been suggested as a factor in the atmospheric rise of CH₄ since 2010.

At ATTO, CH₄ concentrations rise by about 10 ppb per year (Figure 3, middle panel), consistent with the global average. CH₄ concentrations at ATTO are highly variable, reflecting the passage of air masses in contact with surface methane sources. The main source is likely nearby wetlands, including seasonally flooded forests and valleys, making the region a net CH₄ source. Ongoing local studies aim to better understand these complex methane processes and why they vary (Figure 4).

New CH₄ observations, combined with isotope analyses, will improve estimates of Amazon methane sources and sinks—critical for predicting future CH₄ patterns and assessing the region’s role in the global methane budget.

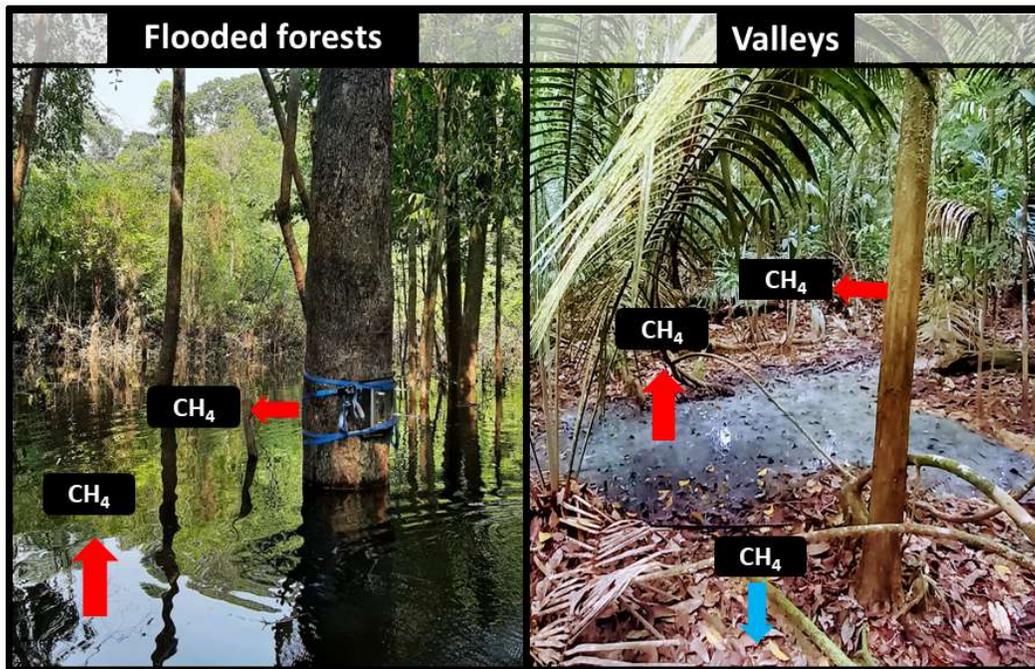


Figure 4. Each compartment of the ecosystem (e.g., soil, trees, water) has its own processes, which collectively contribute to the ecosystem’s CH₄ dynamics

Carbon Monoxide (CO) – Distinguishing fire

Carbon monoxide (CO) is an “indirect” greenhouse gas, influencing atmospheric methane and tropospheric ozone. While intact forests emit small, steady amounts of CO⁵, ATTO observations show that concentrations are largely driven by regional fires, with pronounced dry-season peaks and record

levels during the 2023–2024 drought (Fig. 3, lower panel). Combined with emission ratios, CO measurements help distinguish CO₂ originating from fires from CO₂ absorbed by forests.

Ongoing studies combining continuous tower CO observations with isotopic analyses will improve understanding of fire contributions to the regional

carbon budget and help identify the sources of smoke affecting the Manaus region.

Recommendations

High-quality monitoring of greenhouse gas concentrations is essential for policies to regulate GHGs, as the atmosphere integrates all sources and sinks and provides a valuable “top-down” constraint on models that estimate surface–atmosphere fluxes.

Governments seeking to measure and verify the impact of their emission policies need to invest in maintaining and expanding this network of high-quality observations.

Continuous observations at ATTO have proven valuable for improving constraints on seasonal carbon dynamics and for assessing how extreme hot droughts can reduce or even reverse the Amazon

forest’s net carbon sink.

Continuation of ATTO GHG observations is therefore crucial to ensure reliable regional and global climate model projections in the future.

During the first ten years, ATTO observations have captured weather extremes associated with El Niño and La Niña events. Beyond documenting short-term effects of events like droughts, ATTO GHG measurements offer an unprecedented opportunity to observe and explain their long-term impacts.

Given the IPCC’s projections of more frequent and severe climate extremes, it is essential to improve our understanding of their long-term impacts on the Amazon and its inhabitants. This requires supporting further research on how the region both influences and is affected by climate change and extreme weather.

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