Long-term Greenhouse Gas Observation at ATTO

The Amazon Tall Tower Observatory (ATTO) provides high-precision observations of greenhouse gases (GHGs) in an intact tropical rain forest, filling a crucial gap in global observing networks.

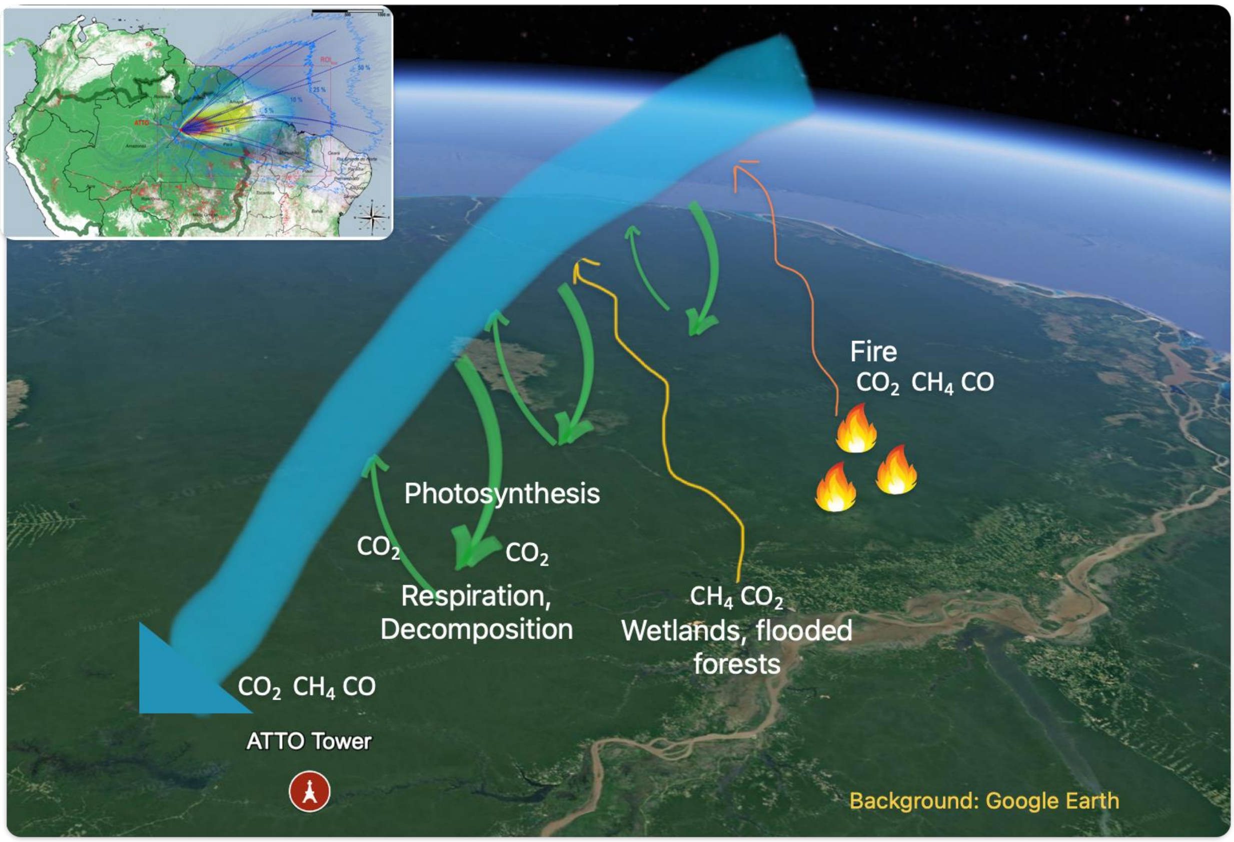


Figure 1. As oceanic air sweeps over forests, the concentrations of CO_2, CH_4, and CO are modified by interactions with the land surface, with vegetation mostly affecting CO_2; smoke from fires releasing CO and CO_2 and wetlands emitting CO_2 and CH_4.

Preface

The Amazon Basin covers one-third of the South American continent and approximately 4% of the world's land area, yet its vegetation holds 10–20% of the land's biomass and accounts for about 12% of global photosynthesis. Despite its recognized importance in the global carbon cycle, the response of this region to current and future climate change remains highly uncertain. To address this, the Amazon Tall Tower Observatory (ATTO) was established through a partnership between Brazil and Germany to provide a platform for interdisciplinary research on the Amazon forest[1].

The ATTO field site is located in the central Amazon, about 150 km northeast and upwind of the city of Manaus (Figure 1). In 2012, high-precision continuous greenhouse gas (GHG) measurements began on an 80-meter tower, monitoring carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO) at different heights within and above the 35–40 m tall canopy. In 2022, continuous and flask-based GHG observations were extended to a new 325-meter tower, the so-called Tall Tower, extending observations of GHG higher above the canopy and adding nitrous oxide (N_2O) and isotopes[2,3].

Several processes influence GHG concentrations as air interacts with the forest, including daily CO_2 uptake through photosynthesis, release via respiration and decomposition, emissions from fires, and gases emitted from wetlands and rivers (Figure 1). These processes affect CO_2, CH_4, and CO in different ways.

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.

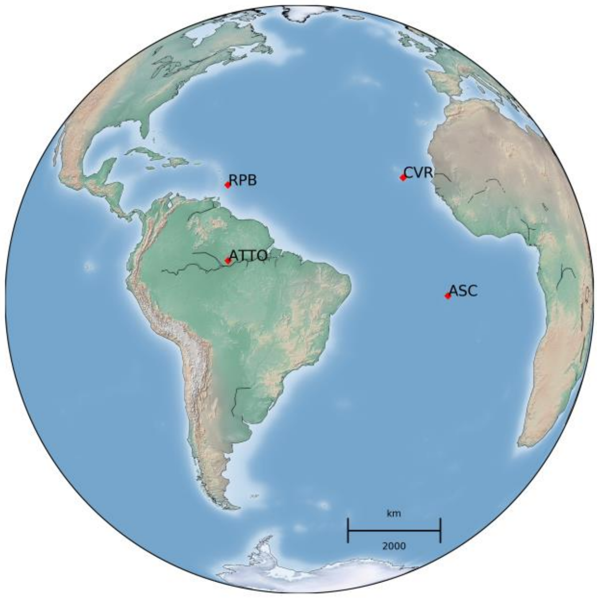


Figure 2. Location of the ATTO field site and three key background stations: Barbados (RPB), Cape Verde (CVR), and Ascension Island (ASC). Comparing ATTO measurements with those from background stations allows us to evaluate how Amazon ecosystems modify atmospheric GHG levels as air moves from the ocean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

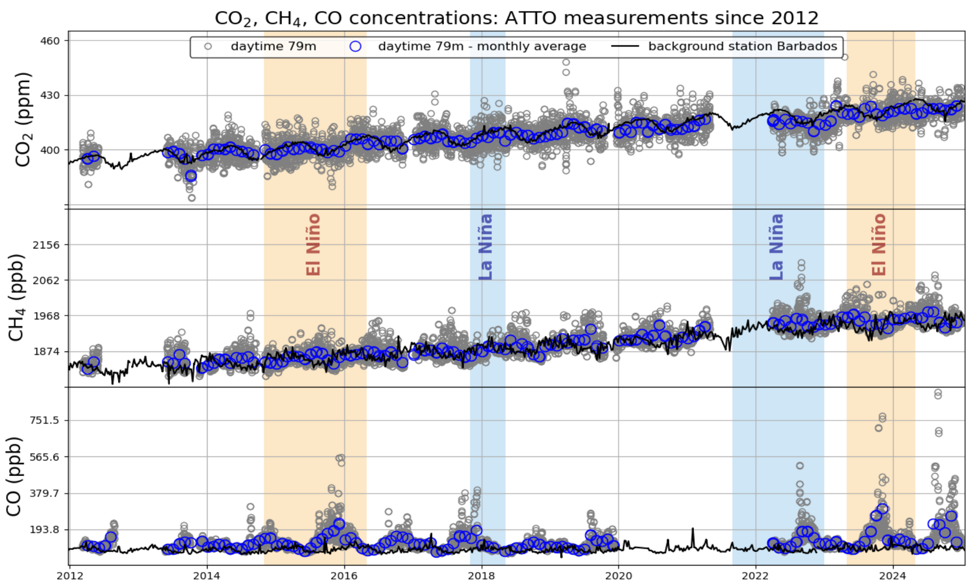


Figure 3. Concentrations of CO_2, CH_4, and CO measured at 79 m at ATTO, compared with the upwind background station Barbados (Fig. 2) [7,8,9]. Data gaps indicate periods of instrument malfunction or breakage, with the longest gap occurring during the pandemic, when travel restrictions and shipping delays hindered instrument repairs.

Carbon dioxide (CO_2) – 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 CO_2 concentrations are typically lower than those at the upwind ocean background stations (Figure 3, upper panel), indicating net CO_2 uptake by the land. CO_2 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 (CH_4) – Wetland GHG sources

Methane (CH_4) is the most important greenhouse gas after CO_2, with tropical wetlands representing its largest natural source. Increases in these wetland emissions have been suggested as a factor in the atmospheric rise of CH_4 since 2010.

At ATTO, CH_4 concentrations rise by about 10 ppb per year (Figure 3, middle panel), consistent with the global average. CH_4 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 CH_4 source. Ongoing local studies aim to better understand these complex methane processes and why they vary (Figure 4).

New CH_4 observations, combined with isotope analyses, will improve estimates of Amazon methane sources and sinks—critical for predicting future CH_4 patterns and assessing the region's role in the global methane budget.

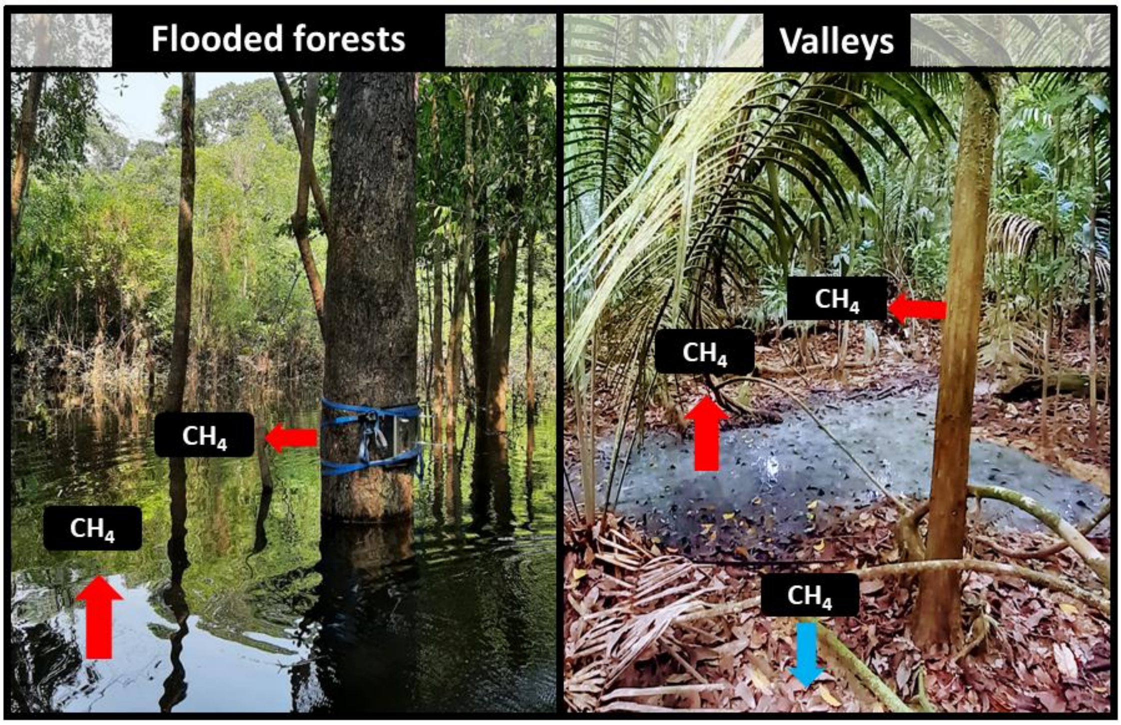


Figure 4. Each compartment of the ecosystem (e.g., soil, trees, water) has its own processes, which collectively contribute to the ecosystem's CH_4 dynamics

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 CO[5], 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 CO_2 originating from fires from CO_2 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.

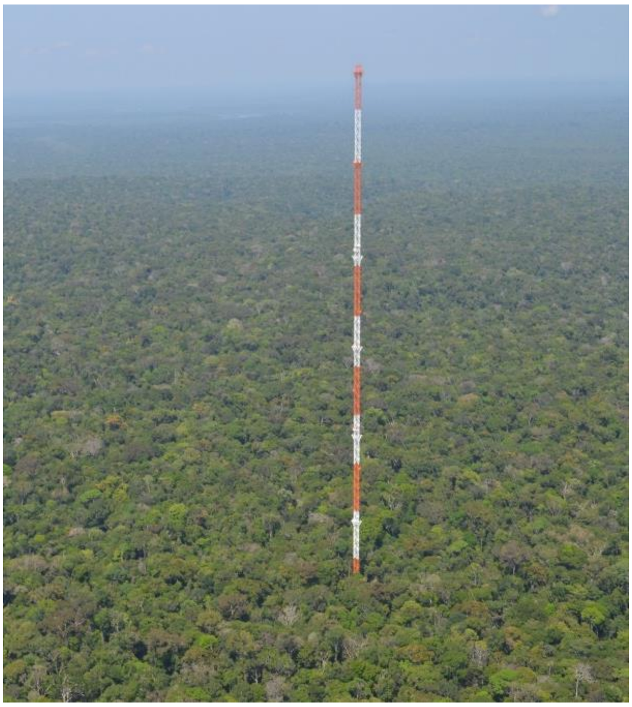
Continuation of ATTO GHG observations is therefore crucial to ensure reliable regional and global climate model projections in the future.

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.

References

1. Andreae, et al. (2015), The Amazon Tall Tower Observatory (ATTO): overview of pilot measurements on ecosystem ecology, meteorology, trace gases, and aerosols. Atmospheric Chemistry and Physics, doi:10.5194/acp-15-10723-2015
2. van Asperen et al (2023), Unique Tall Tower GHG Measurements in the Amazon Rainforest. EGUsphere, doi: 10.5194/egusphere-egu23-10522
3. Sierra et al. (2024), The flask monitoring program for high-precision atmospheric measurements of greenhouse gases, stable isotopes, and radiocarbon in the central Amazon region, Earth System Science Data, doi:10.5194/essd-2025-151
4. Botía et al (2020), Understanding nighttime methane signals at the Amazon Tall Tower Observatory (ATTO). Atmospheric Chemistry and Physics, doi:10.5194/acp-20-6583-2020
5. van Asperen et al (2024), The emission of CO from tropical rainforest soils. Biogeosciences, doi: 10.5194/bg-21-3183-2024
6. Lan et al. (2024), Atmospheric NOAA Carbon Dioxide Dry Air Mole Fractions. doi: 10.15138/wkgj-f215
7. Lan et al. (2024), Atmospheric NOAA Methane Dry Air Mole Fractions. doi:10.15138/VNCZ-M766
8. Petron et al. (2024), Atmospheric NOAA Carbon Monoxide Dry Air Mole Fractions. doi:10.15138/33bv-s284



Contact

Hella van Asperen
Max Planck Institute for Biogeochemistry,
Dept. Biogeochemical Processes
Hans-Knöll-Str. 10, 07745 Jena, Germany
hasperen@bgc-jena.mpg.de