Validating CAMS CH4 in Amazon Forest and examining its link to primary vegetation cover fraction

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Introduction

The Amazon Rainforest is a major natural source of methane, contributing about 8% of global emissions, primarily from natural processes in flooded areas and secondarily from human activities like wildfires and cattle ranching [1]. Monitoring this significant greenhouse gas is crucial, and remote sensing techniques are essential due to the Amazon's vast area and persistent cloud cover. The Copernicus Atmospheric Monitoring System (CAMS) provides valuable methane concentration data through products like the CAMS global inversion-optimized greenhouse gas fluxes and concentrations (2° x 3° resolution) and the CAMS global greenhouse gas reanalysis (EGG4) (0.75° x 0.75° resolution) [2,3]. Amongst many options provided by CAMS, which one could be the most accurate for the analysis in Amazon Forest? To answer this question, the present work validated the cited CAMS products against surface measurements from the Amazon Tall Tower Observatory (ATTO), which offers a continuous methane time series from 2012 to 2021 [4].

Materials and Methods

ATTO data at 79 meters altitude, collected between 12-14h (local time) during peak solar radiation and stable boundary layer conditions, were utilized. Accordingly, CAMS product measurements were taken at 14h (local time).

Where the CAMS products analyzed can be found:

- CH4 CAMS concentration **(modeling)**: https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-greenhouse-gas-inversion?tab=form
- CH4 CAMS mean column **(modeling)**: https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-greenhouse-gas-inversion?tab=form
- CH4 CAMS **reanalysis**: https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-ghg-reanalysis-egg4?tab=overview

Statistical metrics, including mean bias, RMSE, and Pearson correlation, were used to compare CAMS product measurements with ATTO observations. The results indicated that the reanalysis product corresponded well with ATTO measurements. Among the modeling products, the concentration product exhibited the lowest mean bias and highest precision, making it suitable for application in various Amazon regions.

Four regions in the Amazon were defined to investigate the cover type from MapBiomas cover maps and other meteorological metrics such as maximum and minimum precipitation from the Meteorology National Institute (INMET), the length of the dry season, and the mean CH4 concentration obtained from the CAMS product with the best performance.

Statistical analysis performed between CH4 CAMS products and ATTO CH4 measurements:

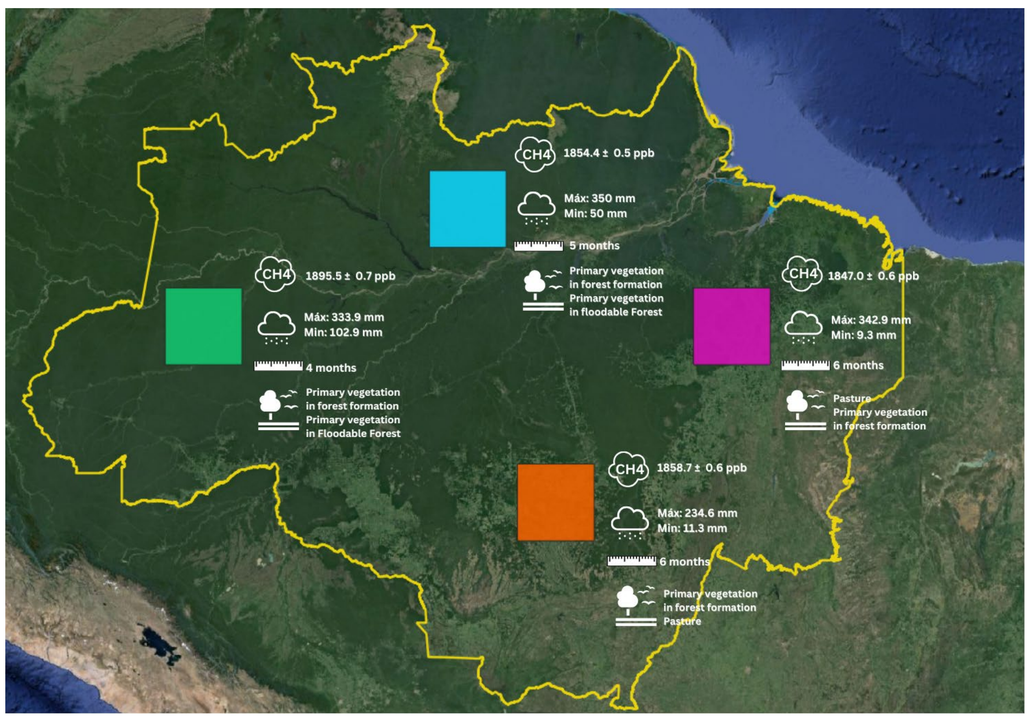
- $$r = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \overline{X})^2 \sum_{i=1}^{n}(Y_i - \overline{Y})^2}}$$
- $$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i|$$
- $$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

Results from the validation with ATTO measurements:

CAMS products	Mean bias (ppb)	RMSE (ppb)	Pearson corr. coef.
Model (concentration)	9.1 ± 0.8	29.2 ±	0.6
Model (mean column)	-42.6 ± 0.6	47.4 ± 0.5	0.6
Reanalysis (EGG4)	-768.6 ± 1.0	770.0 ±	0.1

The CAMS 'concentration' product from modeling had the best performance.

Results from the cover analysis:

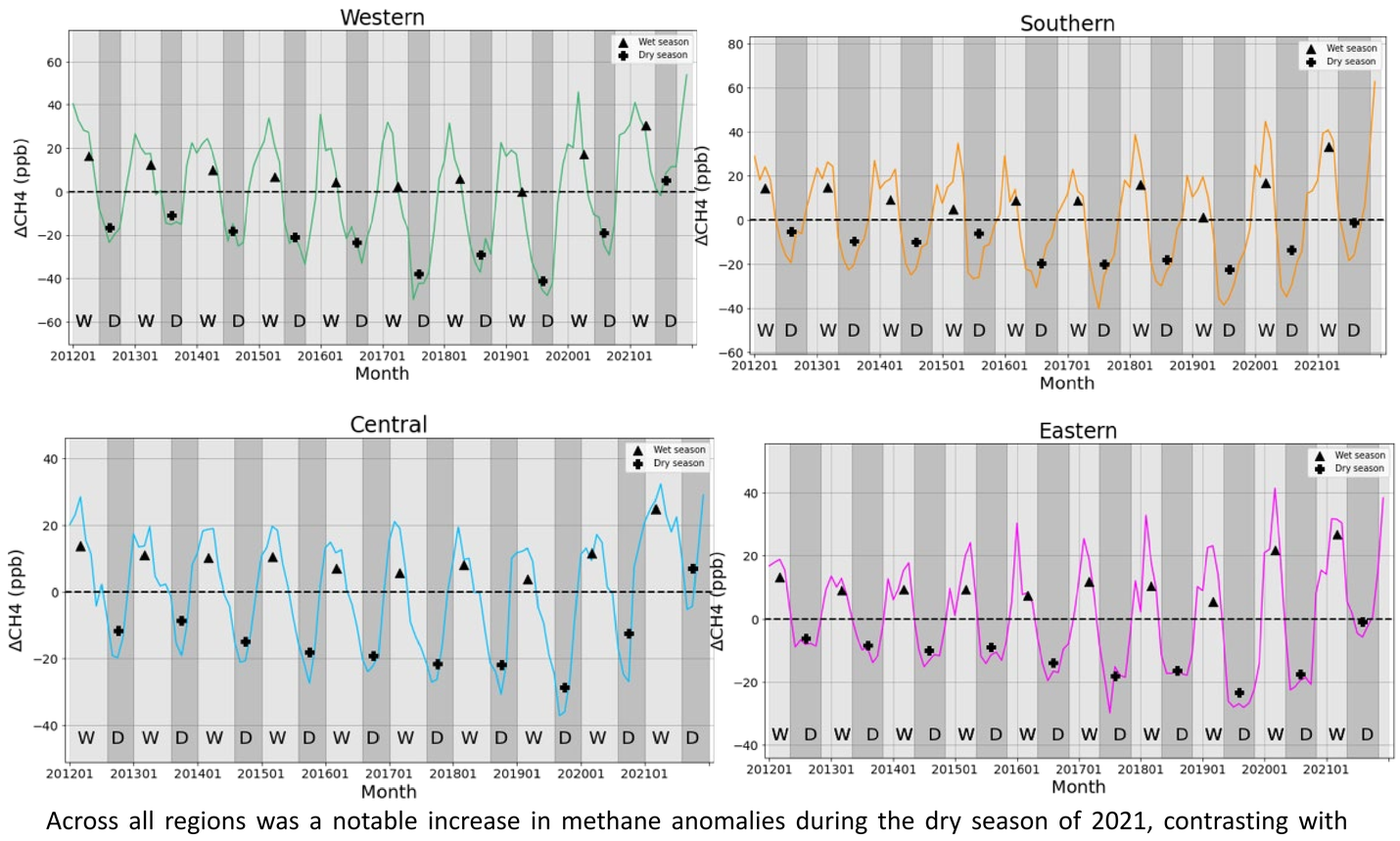


- Western Amazon: This region showed the highest methane concentration from 2012-2021. Its primary land covers include primary vegetation in forest formation (94%) and flooded forests (4%). This region experiences high precipitation and a short dry season, likely contributing to its high methane levels due to the presence of wetlands and favorable meteorological conditions.

- Southern Amazon: The second-highest methane concentration was observed here. Land covers include primary forest formation vegetation (42%) and pasture (28%). The region has a six-month dry season with low precipitation, possibly affecting soil methane absorption capacity. Its region of influence includes the Western region (as shown in [1]).

- Central Amazon: This region, with primary forest formation vegetation (96%) and some flooded areas (1%), showed significant methane concentrations. Its five-month dry season and high precipitation could influence methane levels.

- Eastern Amazon: This region had the lowest methane concentration. It includes pasture (52%) and primary forest formation vegetation (35%), with a six-month dry season and higher precipitation during the wet season than in the south. Its lack of influence from the western region might contribute to its lower average methane levels.



Across all regions was a notable increase in methane anomalies during the dry season of 2021, contrasting with negative anomalies in previous years. The average anomaly in 2021 was the highest in absolute values across all regions. In 2021 there was an intense flood in the Amazonas state.

Conclusions

Using satellites to monitor atmospheric methane concentrations is essential, especially in large areas with significant natural methane sources like the Amazon Basin. The Copernicus Atmosphere Service provides a variety of methane modeling and reanalysis products. This study aimed to determine the most suitable product for applications in the Amazon by comparing it with surface measurements taken at the ATTO site in Central Amazonia. The best-performing product was the CAMS concentration (modeling). Using this product to quantify the average CH4 concentration in the Amazon, we found that the highest concentration was in the western region (~1895 ppb) and the lowest in the eastern region (~1847 ppb) between 2012-2015. One objective was to analyze the relationship between CH4 concentration and land cover type. Primary forest formation vegetation was present in all analyzed areas and was the predominant cover, except in the east where pasture was dominant. Although primary forest vegetation is often converted to pasture, no relationship was found between its fraction and methane concentration. However, regions influenced by floodplain forests showed higher average methane concentrations.

References:

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