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ATMOSPHERIC CONCENTRATIONS OF GREENHOUSE GASES IN WILDFIRES AT THE AMAZON BIOME WITH GOSAT

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2023

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Thesis presented to the School of Agricultural and Veterinarian Sciences –Unesp, Jaboticabal Campus, as partial fulfillment of the requirements for the degree of Doctor in Science in Agronomy (Plant Production).

2023

M332a

Maria, Luciano de Souza
Atmospheric concentrations of greenhouse gases in wildfires at the amazon biome with GOSAT / Luciano de Souza Maria. -- Jaboticabal, 2023
105 p.

Tese (doutorado) - Universidade Estadual Paulista (Unesp), Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal
Orientadora: Newton La Scala Junior
Coorientadora: Carlos Antonio da Silva Junior

1. Climate change. 2. Fire foci number. 3. Atmospheric concentrations of gases. 4. Remote sensing. 5. Arc of Deforestation. I. Título.

Sistema de geração automática de fichas catalográficas da Unesp. Biblioteca da Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal. Dados fornecidos pelo autor(a).

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Câmpus de Jaboticabal

CERTIFICADO DE APROVAÇÃO

TÍTULO DA TESE: ATMOSPHERIC CONCENTRATIONS OF GREENHOUSE GASES IN WILDFIRES AT THE AMAZON BIOME WITH GOSAT

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Aprovado como parte das exigências para obtenção do Título de Doutor em Agronomia (Produção Vegetal), área: Agronomia (Ciência do Solo) pela Comissão Examinadora:

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“Each season of life is an edition, which corrects the one before and which will also be corrected itself until the definitive edition, (…)” Machado de Assis, *Memórias Póstumas de Brás Cubas. São Paulo: Ateliê Editorial, 2001, p.120.*

DEDICATION

To my wife ***Maria Inês Lidoino de Souza*** *and daughter* ***Rayssa Camila Lidoino Maria****, for their great affection, understanding, encouragement, and support in this journey. To all my friends for the shared moments.*

ACKNOWLEDGMENTS

First, my wife and daughter, Inês and Rayssa, for the unconditional support and for not giving up on my goals, thank you very much for your dedication and for all the love.

For my mother Ana Prata, who taught me to never give up the fight for knowledge and with her unconditional love inspired me to be a better person.

To my siblings Anésio, Adriano, Andréia, Cristiane, Rodrigo, and Angelo who always inspire me to seek the light of learning in an honest and dignified way, thank you for all the strength.

My advisor, Newton La Scala Júnior, I thank for the friendship and for being largely responsible for structuring and solidifying knowledge, and for all his patience and support in completing this new stage of my life.

To my co-advisor, Carlos Antonio da Silva Junior, for the technical knowledge and support in granting the GAAF infrastructure.

To Professor Alan Rodrigo Panosso, for the dedication and support in the statistical analysis, in addition to the personal teachings and passion for teaching in a humane and very fair way, my immense gratitude.

To my friend Fernando Rossi, always very present and supportive in the most difficult moments, thank you for your friendship.

To my friends Marcelo Odorizzi, Luis da Costa, Adriano Maltezo, and Thiago among so many others who contributed in being on the same journey and same purpose as me, thank you very much.

To Professor Paulo Alexandre, for having granted a teaching internship in his discipline and for the teachings on didactics and tips on how to improve the art of teaching.

The employee Adriana from the Exact Sciences department, for her attention and support, even remotely, thank you very much.

Finally, I would like to thank the São Paulo State University (Unesp), School of Agricultural and Veterinarian Sciences, Jaboticabal Campus, an institution made up of great people who helped me with professional and personal training.

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

ATMOSPHERIC CONCENTRATIONS OF GREENHOUSE GASES CORRELATED WITH WILDFIRES IN THE AMAZON BIOME WITH GOSAT

ABSTRACT - Understanding the spatio-temporal distribution of greenhouse gases (GHG) in the Amazon biome, as well as the occurrences of fire foci is relevant in the climate change scenario. Therefore, the main objective of the study was to evaluate increase or decrease in atmospheric concentrations of gases (CO_2, CH_4, and CO), as well as the spatio-temporal distribution and possible correlations between gases and fires and other orbital data from the Earth's surface in the time series from 2009 to 2019 for the Amazon biome. For this, we used data from the concentrations in the column-averaged of CO_2 (XCO_2), CH_4 (XCH_4) and carbon monoxide (XCO) based on OCO-2, GOSAT and MERRA satellites. Furthermore, we used the observations of the chlorophyll fluorescence induced by the sun (SIF) by the GOSAT satellite to understand the photosynthetic capacity of the vegetation, in addition to Moderate Resolution Imaging Spectroradiometer (MODIS) products, for example: Enhanced Vegetation Index (EVI), Fire Radiative Power (FRP) and fire foci number. For rainfall information, we used by the Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) and the soil moisture (SM), was obtained by the Soil Moisture Active Passive (SMAP) satellite. Through th trend analysis by the Mann Kendall test, we can observe a monotonic growth trend of XCO, XCO_2 and FRP at the end of the rainy period, as well as the temporal concentrations of gases and other orbital products, in addition to their strong correlation with changes in land use and extreme weather events between 2015 and 2020, for the Amazon biome. With the geostatistical interpolation techniques and methods, it is possible to better understand the spatio-temporal concentrations of CH_4 and its correlation with fire foci number, as well as its strong correlation with soil moisture, especially in the dry period in the Amazon region in the time series (2009-2019). Therefore, gases (CO_2, CH_4 and CO) and their correlations with fire foci number and with biophysical variables can be very important to guide new directions on the effect of anthropic actions and climatic change in the Amazon ecosystem.

Keywords: Climate Change; Forest Degradation; Savanization; Severe Droughts

CONCENTRAÇÕES ATMOSFÉRICAS DE GASES DE EFEITO ESTUFA CORRELACIONADAS COM INCÊNDIOS FLORESTAIS NO BIOMA AMAZÔNIA COM GOSAT

RESUMO – Compreender a distribuição espaço-temporal dos gases de efeito estufa (GEE) no bioma Amazônia, bem como as ocorrências de focos de incêndio são relevantes no cenário de mudanças climáticas. Portanto, o principal objetivo do estudo foi avaliar o aumento ou diminuição das concentrações atmosféricas de gases (CO_2, CH_4 e CO), bem como a distribuição espaço-temporal e possíveis correlações entre gases e incêndios e outros dados orbitais da Terra superfície na série temporal de 2009 a 2019 para o bioma Amazônia. Para isso, utilizamos os dados das concentrações na coluna média de CO_2 (XCO_2), CH_4 (XCH_4) e monóxido de carbono (XCO) com base nos satélites OCO-2, GOSAT e MERRA. Além disso, utilizamos as observações da fluorescência da clorofila induzida pelo sol (SIF) pelo satélite GOSAT para entender a capacidade fotossintética da vegetação, além de produtos Moderate Resolution Imaging Spectroradiometer (MODIS), por exemplo: índice de vegetação aprimorado (EVI), Potência radiativa do fogo (FRP) e número de focos de incêndio. Para as informações pluviométricas, utilizamos o Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) e a umidade do solo (SM), obtida pelo satélite Soil Moisture Active Passive (SMAP). Pela análise de tendência pelo teste de Mann Kendall, podemos observar uma tendência monotônica de crescimento de XCO, XCO_2 e FRP ao final do período chuvoso, assim como as concentrações temporais de gases e outros produtos orbitais, além de sua forte correlação com mudanças no uso da terra e eventos climáticos extremos entre 2015 e 2020, para o bioma Amazônia. Com as técnicas e métodos de interpolação geoestatística, pode-se entender melhor as concentrações espaço-temporais de CH_4 e sua correlação com o número de focos de incêndio, bem como sua forte correlação com a umidade do solo, principalmente no período seco na região amazônica no período série (2009-2019). Portanto, os gases (CO_2, CH_4 e CO) e suas correlações com o número de focos de incêndio e com variáveis biofísicas podem ser muito importantes para orientar novos rumos sobre o efeito das ações antrópicas e mudanças climáticas no ecossistema amazônico.

Palavras-chave: Mudanças Climáticas; Degradação Florestal; Savanização; Secas Severas

CHAPTER 1 – WILDFIRE AND GREENHOUSE GAS CONCENTRATION IN THE AMAZON BIOME

1. Introduction

The occurrence of wildfires increased in several regions of the world, justified by the increase in global temperatures and the extension of drought periods, therefore, highlighting the consequences of climate change (Duane; Castellnou; Brotons, 2021). In addition, in several regions of the world, the inappropriate practice of using fire impacts and affects the regions between deforested and protected forest areas (Pivello et al., 2021). Thus, wildfires lead to economic losses (Campanharo et al., 2019), cause respiratory health problems (Campanharo et al., 2022; Schroeder et al., 2022; Smith et al., 2014), and increase emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and carbon monoxide (CO) (Brando et al., 2020b; Miettinen et al., 2016).

The Amazon is the Brazilian biome with the highest greenhouse gas (GHG) emissions from deforestation or forest degradation, with the land use change sector being the main source of GHG emissions in Brazil, with 1.09 Gt of CO_2 emission in 2021 (SEEG, 2022). This fact does not make the climate agreements signed by Brazil, such as the 26th United Nations Conference on Climate Change (COP 26), for example, unfeasible, but rather more difficult to meet (Da Silva Junior et al., 2022),. Thus, reducing deforestation and GHG emissions is a major challenge for Brazilian society (Deutsch; Fletcher, 2022).

The Amazon biome is highly representative and is considered to contain the largest continuous tropical forest on Earth (Heinrich et al., 2021). It has an immense biodiversity of plants and animals (Antonelli et al., 2018) and the largest carbon pool in the biosphere (Hubau et al., 2020). Therefore, understanding the dynamics of the concentration of GHG such as CO_2, CH_4, N_2O, and CO in the Amazon biome, as well as its correlation with the fire foci number, becomes very relevant in the current scenario due to the notoriety of the theme.

In the same way, it is noted that the high amounts of plumes from the burning of the Amazon rainforest (Yuan et al., 2022) result in high concentrations of aerosol particles and can impact regional and global rainfall regimes (Tosca; Randerson; Zender, 2013). Through this approach, fires in the Amazon in 2019 impacted the region and there was the aerosol radiative forcing equivalent to +26 W m^{-2}, with an increase of 30% compared to 2018 (Yuan et al., 2022). On the other hand, the indirect effects are changes in the properties and life cycle of clouds, justified by the correlation between the aerosols and the formation of cloud condensation nuclei (Rosenfeld et al., 2014). As aerosols act as condensation nuclei (CCN), there is a direct effect in the alteration of the physics and formation of clouds, and consequently, an alteration in the precipitation patterns in the Amazon region (Artaxo et al., 2022; Machado et al., 2018).

Thus, regional climate projections in southern Amazon have a strong increase in fire foci use activities and have the potential to reach 6.0 Pg CO_2 emissions from forest fires in the 2050s, three times higher when compared to emissions in the 2000s (2.0 Pg CO_2) (Brando et al., 2020b). In this way, the transformation of the Amazon forest into a net source of carbon reduces its capacity as a carbon sink due to changes in temperature and reductions in rainfall regimes (Brando et al., 2020b; Gatti et al., 2014). This forest transition is exacerbated by the climate and releases high amounts of GHGs into the atmosphere, accentuating the Global Warming (GW) effect (Nobre et al., 2016).

That is why several studies indicate that change in land use and occupation is mainly associated with increasing rates of deforestation and the correlation with increased GHG emissions resulting from fires foci number (Amaral et al., 2019; Gatti et al., 2021; Lima et al., 2022; Silva et al., 2021; Touma et al., 2021). However, understanding the temporality and spatialization of these gases to the occurrence of fires, as well as their relationships with terrestrial biophysical variables (temperature, soil moisture, and precipitation) is limited due to the lack of measurements of concentrations across the entire Amazon region.

Within this context, in the last two decades, the launch of several satellites, such as Greenhouse gas Observing SATellite (GOSAT), satellite of the Japanese Space Agency (JAXA) (Kuze et al., 2009), Orbiting Carbon Observatory-2 mission (OCO-2) of the National Aeronautics and Space Administration (NASA) (Crisp et al., 2012; Frankenberg et al., 2015; O'Dell et al., 2012), and the Sentinel-5 satellite, of the European Space Agency (ESA) (Veefkind et al., 2012), among others, made it possible to monitor the atmospheric concentration of GHGs. The sensors used in these satellites characterize the average mole fraction of dry air in the XCO_2, XCH_4, and XCO columns, contributing to studies that seek to understand the sources and identify the drains of GHGs, such as wildfires (Guo et al., 2019, 2017; Li; Wang; Yung, 2019;

Mousavi; Falahatkar; Farajzadeh, 2017).

Thus, the hypothesis tested raised by the study is that there is a correlation between the atmospheric concentration of CO_2, CH_4, and CO with wildfires in the dry season to be observed via remote sensing with the GOSAT, MERRA and OCO-2 satellites, in the Amazon biome, with fire foci number being the main reason.

Therefore, the objective was to verify what the spatio-temporal trends of atmospheric concentrations of gases (CO_2, CH_4, and CO) and possible correlation with fire foci number and data of the biophysical variables (rainfall, temperature, moisture soil) and correlation the photosynthetic capacity of the vegetation (EVI and SIF) in the time series from 2009 to 2019 for the Amazon biome.

3.5. Conclusions

For the period evaluated in this study, XCH_4 showed an increase due to higher SMAP in wet period, as well as XCH_4 was higher LST, validated by positive correlation in temporal distribution of XCH_4 with SMAP and LST. The spatial distribution of XCH_4 was correlated with the XCO_2 Anomaly but only for the dry period. On the other hand, a spatial distribution pattern of XCH_4 was observed for the dry period, consistent with the spatial pattern of SMAP evidenced by the strong positive correlation between XCH_4 and SMAP. This confirmed the hypothesis that XCH_4 shows a positive relationship with SMAP, both for the dry and wet periods under the Amazon biome and corroborates the positive relationship between the variables. Nonetheless, no pattern was observed in the spatial distribution for XCH_4 for the wet season, with a moderately positive correlation between XCH_4 and SMAP. This shows that the issue of climate change and the change in land use and occupation significantly interfered as drivers of higher methane emissions in the Amazon biome. Regarding fire foci, there was a moderate correlation between the XCH_4 variable, especially for the wet season. This made it possible to validate hypothesis "i" and helped to foster new scientific studies on GHG emissions for the Amazon biome, especially considering the seasonality of dry and wet periods and the contribution of Fire foci number.

3.6. Acknowledgments

The study was funded by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES). I am grateful to the Geotecnologia Aplicada em Agricultura e Floresta (GAAF) and SojaMaps of the Universidade do Estado de Mato Grosso (UNEMAT) for infrastructure for the present study.

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