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Data Descriptor

Spatial Interpolation of Air Pollutant and Meteorological Variables in Central Amazonia

Renato Okabayashi Miyaji [1,*], Felipe Valencia de Almeida [1], Lucas de Oliveira Bauer [2], Victor Madureira Ferrari [1], Pedro Luiz Pizzigatti Corrêa [1], Luciana Varanda Rizzo [2] and Giri Prakash [3]

1 Polytechnic School, University of São Paulo, São Paulo 05508-070, Brazil; felipe.valencia.almeida@usp.br (F.V.d.A.); ferrari.victor99@usp.br (V.M.F.); pedro.correa@usp.br (P.L.P.C.)
2 Department of Environmental Sciences, Federal University of São Paulo, São Paulo 13635-900, Brazil; bauer@unifesp.br (L.d.O.B.); lrizzo@unifesp.br (L.V.R.)
3 Atmospheric Radiation Measurement Facility (ARM) Data Center, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA; palanisamyg@ornl.gov
* Correspondence: re.miyaji@usp.br

Abstract: The Amazon Rainforest is highlighted by the global community both for its extensive vegetation cover that constantly suffers the effects of anthropic action and for its substantial biodiversity. This dataset presents data of meteorological variables from the Amazon Rainforest region with a spatial resolution of 0.001° in latitude and longitude, resulting from an interpolation process. The original data were obtained from the GoAmazon 2014/5 project, in the Atmospheric Radiation Measurement (ARM) repository, and then processed through mathematical and statistical methods. The dataset presented here can be used in experiments in the field of Data Science, such as training models for predicting climate variables or modeling the distribution of species.

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Keywords: Amazon Rainforest; spatial interpolation; GOAmazon; aerosol

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1. Introduction

The Amazon Rainforest is one of the largest forests in the world, with an area that represents approximately 64% of the continental portion of Brazil. It hosts billions of trees of more than 15,000 different species that are vital to the maintenance of relevant atmospheric cycles worldwide [1]. Furthermore, the Amazon Basin shelters a substantial portion of the world's biodiversity. Since 1960, the city of Manaus, located in the central region of the Amazon Basin, has been growing rapidly, with its population increasing by 40% each decade [1]. In the past 20 years, the hydrological cycle in the region has changed significantly [2].

However, until recently, only a few studies have been conducted with the aim of collecting a large volume of data to understand the changes that happened in the region, due to the effects of anthropic action. Satellite data is also useful for environmental studies in remote areas like Amazonia. However, many atmospheric monitoring satellite products have insufficient spatial and temporal coverage and suffer from biases that must be compensated to retrieve data representative of surface conditions [3,4]. In this sense, this dataset was built to increase the availability of data regarding the distribution of meteorological variables and air pollutant concentration in the central region of the Amazon Basin, near the cities of Manaus and Manacapuru. This was accomplished through the application of spatial interpolation methods, aiming to map these variables throughout the study area.

With the release of this dataset, it is expected that further studies about the impacts of urban air pollutant emissions on the Amazon Rainforest can be conducted, such as machine learning experiments and training models to predict the concentration of pollutants.

2. Methods

2.1. GoAmazon 2014/5

To improve the knowledge about the fundamental cycles that occur in the Amazon Basin region, which have an impact on the world climate [2], the Green Ocean Amazon (GoAmazon 2014/5) experiment was carried out in the region during 2014 and 2015. The project was funded by the Atmospheric Radiation Measurement (ARM) from the Department of Energy (DoE) of the United States of America and Brazilian institutions, such as the University of Sao Paulo (*Universidade de São Paulo*—USP), the State University of Amazonas (*Universidade do Estado do Amazonas*—UEA) and the National Institute of Space Research (*Instituto Nacional de Pesquisas Espaciais*—INPE).

From 1 January 2014 to 31 December 2015, the experiment collected atmospheric data through nine ground research sites, distributed throughout the Amazon Basin, and two aircraft that conducted low-altitude flights covering the region between the cities of Manaus and Manacapuru, see in. The data acquisition was divided between two Intensive Operation Periods (IOPs), the first (IOP1) during the wet season and the second (IOP2) during the dry one.

The collected data were made available openly and free of charge in the ARM repository [5], see in the Appendix A. The data necessary for building this dataset were obtained from there. The [6–8] datasets contained data collected by the DoE's G-1 aircraft (a low-altitude G-129 Gulfstream I), which operated in both IOPs with the purpose of characterizing the atmospheric boundary layer in the region of interest [2]. The G-1 aircraft flew 35 times in 2014, 16 of these flights were during the wet season (IOP1) between 1 February to 31 March 2014 and 19 during the dry season (IOP2) between 15 August to 15 October 2014. Each of the flight paths is shown in Figure 1. Most of the flights were performed between late morning and early afternoon (11:00 AM to 1:00 PM, local time). Data were collected at altitudes Above Ground Level (AGL) ranging mainly from 700 m to 2000 m.

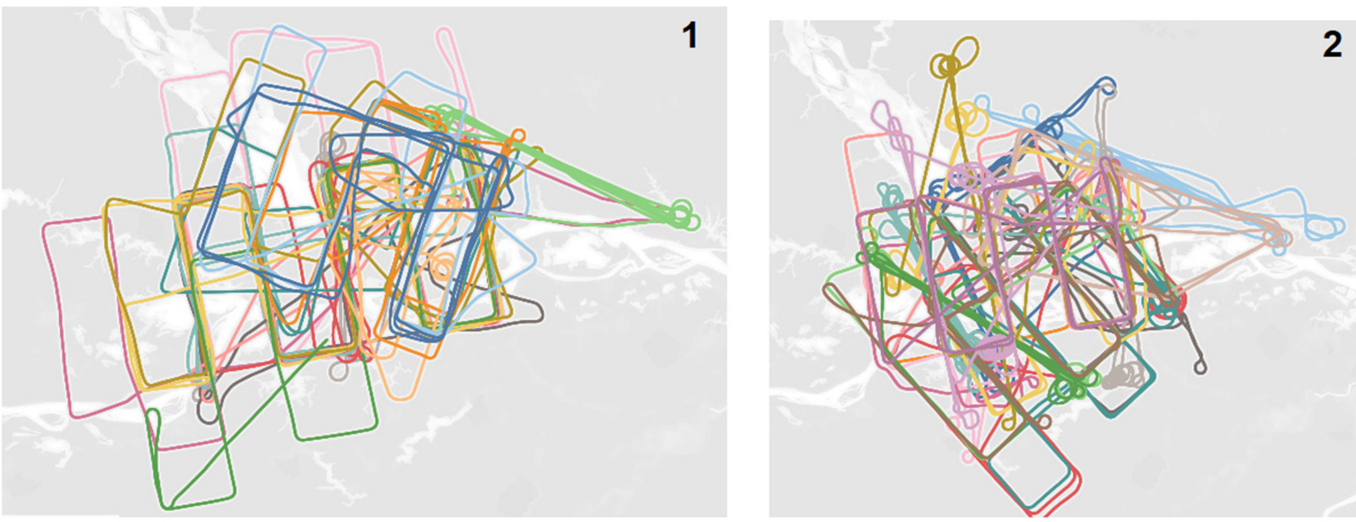

Figure 1. Flight paths realized by the G-1 aircraft. Each color represents a different fight. (**1**) wet season (**2**) dry season.

2.2. Spatial Interpolation

The data from the GoAmazon 2014/15 project were collected from the ARM repository [5]. From there, it was possible to obtain separated files and datasets, but all regarding the same flights of the G-1 aircraft. Each dataset contained only the variables that could be useful for a specific type of analysis.

In the [8] dataset, it was possible to obtain a dataset for each of the flights with measurements of the concentration of pollutants, such as methane (CH4), along the entire flight tracks of the G-1 aircraft. The [6,7] datasets contained data about other atmospheric variables, for instance, the numerical concentration of particles (N), temperature, among others. Through the join operation on the composite primary key of the datasets (latitude, longitude and date—variables that were present in all of the collected datasets), it was possible to build an integrated dataset with more than 50 variables measured during all flights of the G-1 aircraft, which were subsequently filtered.

With the integrated dataset, resulting from the join operation, it was necessary to process the data so the spatial interpolation methods could be applied to it. Initially, the dataset was filtered, selecting the available atmospheric variables and its composite primary keys: latitude, longitude, altitude, date, temperature, concentration of carbon monoxide (CO), ozone (O3), nitrogen oxides (NOx), methane (CH4), acetonitrile, isoprene and the numerical concentration of particles (N). Then, it was divided by IOP to which the data belongs (wet and dry seasons).

For the dataset of each season, the data was separated for each flight of the G-1 aircraft. For each variable in each flight, the following data manipulation steps were performed: the dataset was filtered by its altitude, considering only the points measured below 1500 m. Thus, the data points considered for the interpolation were homogeneous and inside the planetary boundary layer (PBL). The PBL is the lowest atmospheric layer and is influenced by phenomena such as friction, turbulence and pollutants emissions [9]. It also means an uniform values distribution of meteorological variables within the PBL, not occurring significant changes in values with altitude due a continuous vertical mixing process governed by the sun radiation availability, except in cases of thermals inversion's occurrence or another meteorological phenomena, which can lead to different values of meteorological variables within PBL [10]. In the Amazon Rainforest region, its average thickness is 1100 m and 1650 m in forest and grazing areas, respectively [11].

Then, the maximum and minimum values of latitude and longitude covered by the aircraft in each of the seasons were determined. With these parameters and the discretization defined by the maximum interval between two consecutive measurements (0.001° in latitude and longitude), a mesh could be created, in which the spatial interpolation methods could be applied.

Three different methods were compared: a piecewise linear interpolation, an interpolation through splines and through the nearest neighbor algorithm. These were chosen because of their good performance in the literature for similar objectives [12,13]. The linear method applies a piecewise linear interpolation over the simplexes of the mesh, obtained through the Delaunay triangulation. Similarly, the splines method applies the interpolation through a spline polynomial function. The nearest neighbor algorithm searches the closest known points in the mesh and assigns the mean value of the set of neighbors to it [14].

For each variable, the interpolated data of each flight were summarized for each season through the average. A datapoint was considered only if its value was different from "Not a Number" (NaN) in more than half of the flights in that season. The steps of the data manipulation methodology are described in Figure 2.

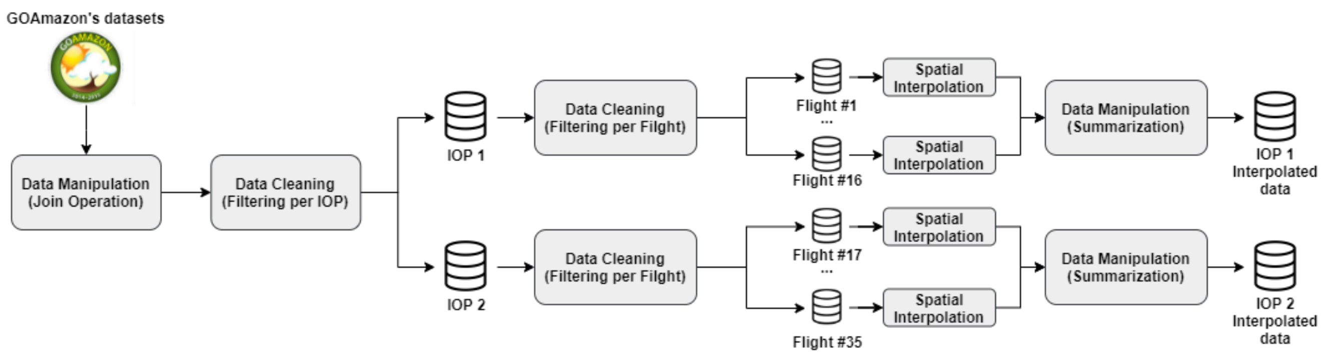

Figure 2. Data Manipulation Methodology.

2.3. Statistical Analysis

To determine the best spatial interpolation method, a cross-validation through the k-fold technique with k = 3 was performed. The dataset of each flight was randomly split into three parts. Two of these were used to apply the spatial interpolation methodology, while the other was used to validate the results, computing error metrics, such as the mean absolute error (MAE), the root mean square error (RMSE) and the mean absolute percentage error (MAPE). The comparison between the methods is presented in Table 1 for the carbon monoxide (CO) concentration in ppm. In Table 2, the MAPE for all variables is presented.

Table 1. Comparison of methods: MAE and RMSE for CO (ppm).

	MAE	RMSE
Linear	0.0108	0.0214
Splines	0.0141	0.0316
Nearest Neighbor	0.0117	0.0233

Table 2. Comparison of methods: MAPE for all variables.

	MAPE
Linear	7.80%
Splines	9.95%
Nearest Neighbor	8.44%

For the concentration of carbon monoxide, the linear method presented the lowest error metrics (both MAE and RMSE). The nearest neighbor method had a similar performance with slightly higher MAE and RMSE—8.33% and 8.88% higher, respectively. Spatial interpolation through splines showed the worst performance compared to all other methods. Considering all variables, the same behavior was observed for MAPE: the piecewise linear spatial interpolation had the best performance and, therefore, was chosen to be applied.

3. Data Description

3.1. Dataset Description

The weather in the Amazon Rainforest is characterized by two seasons: wet and dry. Biomass burning activities are enhanced in the dry season, impacting the chemical composition of trace atmospheric constituents [15]. The dataset consists of 422,649 rows containing interpolated data of eight different atmospheric variables: temperature, concentration of carbon monoxide (CO) in parts-per-million (ppm), ozone (O3) in parts-per-billion (ppb), nitrogen oxides (NOx) in ppb, methane (CH4) in ppm, acetonitrile (CH3CN) in ppb, isoprene (C5H8) in ppb and the numerical concentration of particles (N) measured with Condensation Particle Counter (CPC). Of these, 226,174 are of the dry season and 196,475 of the wet season. The composite primary key of the dataset consists of the geographical coordinates of latitude and longitude and the season. The original data used for interpolation were collected by the G-1 aircraft during the GoAmazon 2014/15 project. Table 3 provides summarized information about the dataset.

Table 3. Dataset information.

Type of Data	**CSV file**
Data Volume	72.8 MB
Subject area	Atmospheric Science
Atmospheric Variables	Temperature, CO, O3, NOx CH4, acetonitrile, isoprene and N
Data Acquisition	G-1 aircraft (altitude of flight: 700 m to 2000 m)
Area Coverage	Latitude: −3.632° to −2.813° Longitude: −60.831° to −59.937°
Spatial Resolution	Latitude: 0.001° Longitude: 0.001°
Date	Wet season: 01 February 2014–31 March 2014 Dry season: 15 August 2014–15 October 2014 Time of flight: 11:00 AM to 1:00 PM, local time

3.2. Study Area

The data covers an area of approximately 6900 km^2 in the central region of the Amazon Basin between the cities of Manaus and Manacapuru, as shown in Figure 3. The "Mother of Gods", Manaus is located in the Amazon River, which is a result of the confluence between the Black River and the Solimões River. The metropolis with a population of more than 2 million people [16] is considered an ideal laboratory to gain a better understanding of the consequences of anthropic activities on the climate, air quality and terrestrial ecosystems in a tropical forest [17], since it is isolated, being surrounded by the Amazon Rainforest. The city of Manacapuru is located 80 km downwind of Manaus.

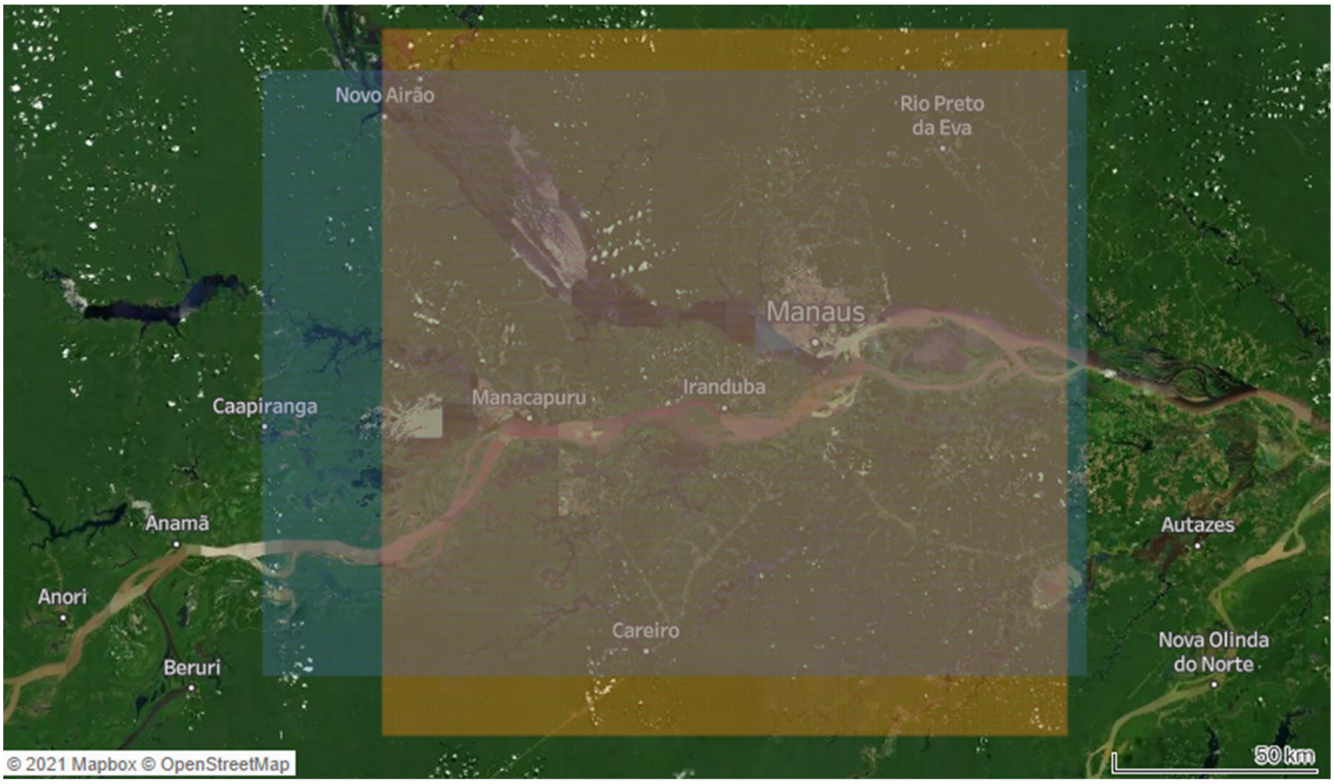

Figure 3. Study Area. Blue area—wet season | Orange area—dry season.

The interpolated distributions of the eight atmospheric variables in each of the seasons (wet and dry) are presented in Figures 4 and 5.

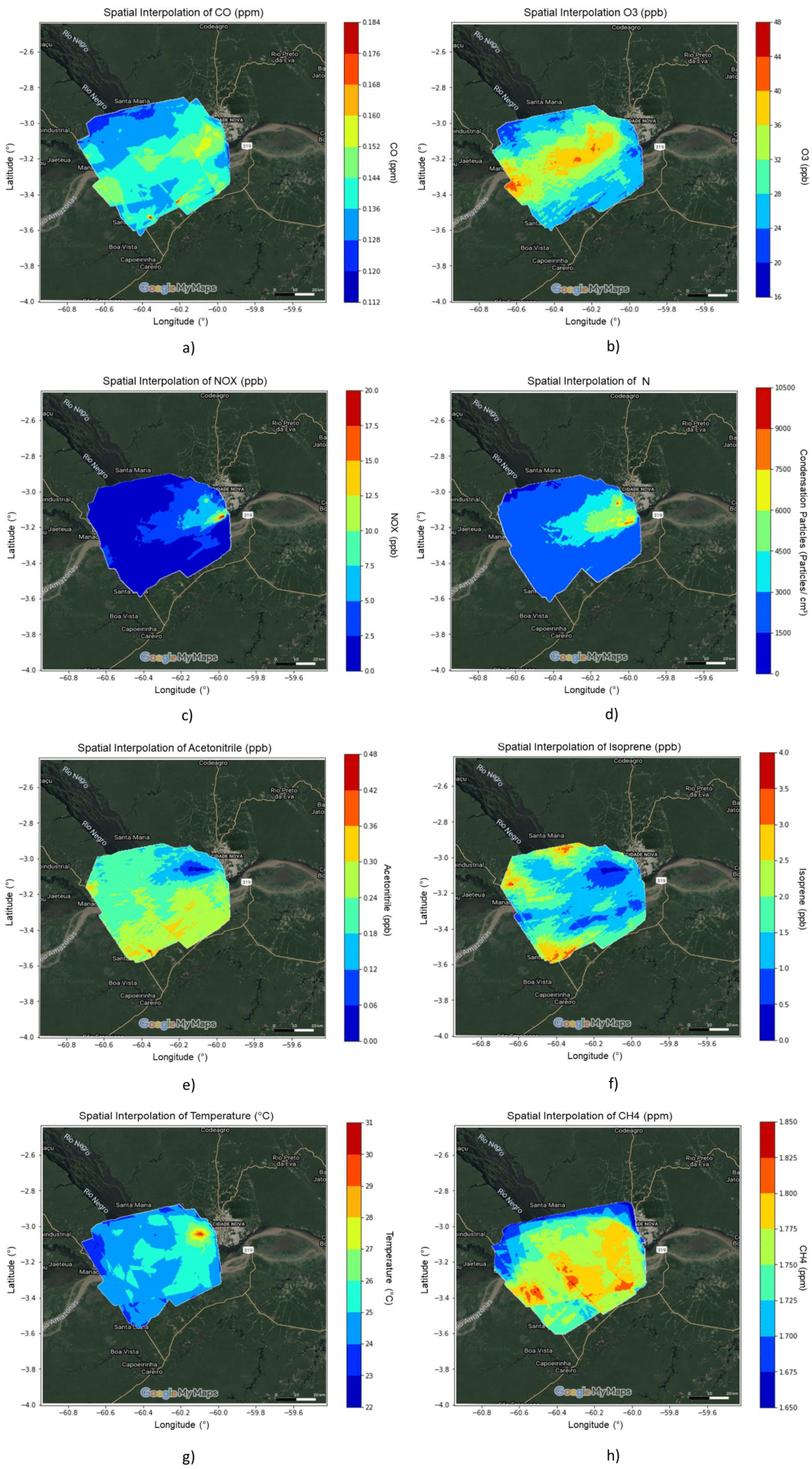

Figure 4. Interpolated distributions during the dry season of (**a**) CO (ppm), (**b**) O_3 (ppb), (**c**) NOx (ppb), (**d**) N (Particles/cm^3), (**e**) Acetonitrile (ppb), (**f**) Isoprene (ppb), (**g**) Temperature (°C) and (**h**) CH4 (ppm).

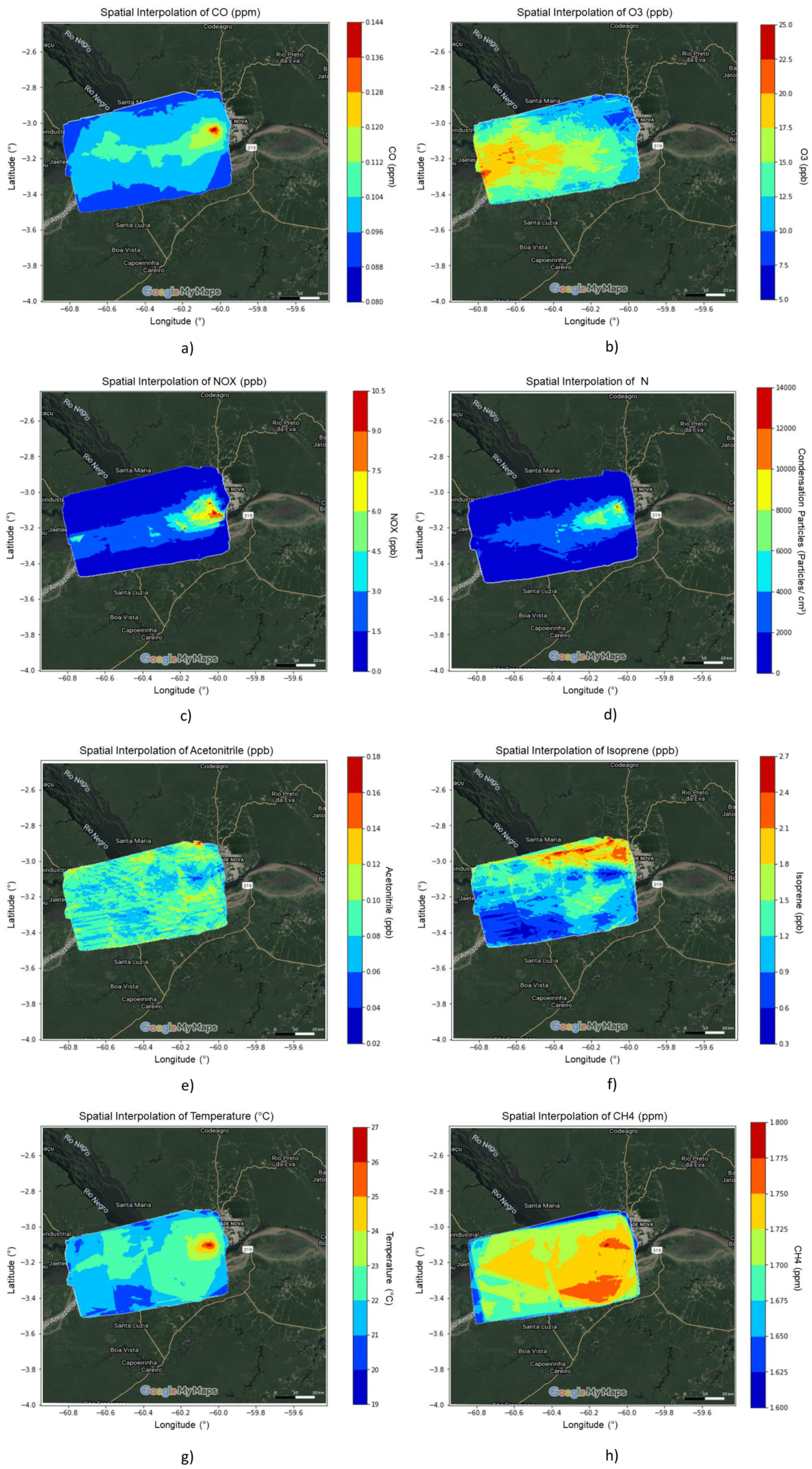

Figure 5. Interpolated distribute ons during the wet season of (**a**) CO (ppm), (**b**) O_3 (ppb), (**c**) NOx (ppb), (**d**) N (Particles/cm^3), (**e**) Acetonitrile (ppb), (**f**) Isoprene (ppb), (**g**) Temperature (°C) and (**h**) CH_4 (ppm).

3.3. Environmental Variables

The environmental variables CO, O_3, NOx and CH_4 are examples of trace gases, constituting less than 1 percent of the atmosphere but are important to the radiative balance and atmospheric chemistry, along with aerosols [18]. O_3 and CH_4 are also greenhouse gases (GHG) that contribute to global warming [9].

CO is mainly emitted by anthropogenic activities into the atmosphere [18] by incomplete combustion of carbon-containing fuels and is also formed in the atmosphere by photochemical reactions [19]. Furthermore, the CO can be removed by processes as surface deposition as soil uptakes and reactions with hydroxyl radicals (OH) with a lifetime of 30–90 days in the atmosphere [18].

The tropospheric O_3 is a secondary pollutant whose production is governed by the sunlight and the emission of this precursors gases: NOx, non-methane Volatile Organic Compounds (VOCs), CH_4 and CO, and can be removed by dry deposition on vegetation surfaces. Tropospheric O_3 has impacts on plant physiological structures and the human respiratory system [20]. It has a lifetime of about 25 days [18].

NOx consists in the sum of nitrogen oxide (NO) and nitrogen dioxide (NO2) and are emitted by natural and anthropogenic sources: soils, lightning, stratosphere, ammonia (NH3) oxidation and fossil fuel combustion, biomass burning and aircraft with a rapid lifetime about 1 or 2 days near the surface and 2 weeks at upper troposphere. The products from NOx oxidation are the Reactive Odd Nitrogen (NOy) which plays a crucial function in chemistry atmosphere processes [18].

CH_4 is emitted by natural and anthropogenic sources as natural wetlands, freshwater, wild animals, wildfires, termites, hydrates and geological sources, but also by agriculture, ruminants, landfills and waste [21]. CH_4 is the hydrocarbon with the greatest abundance in the atmosphere removed by chemical reactions with OH in the troposphere [21].

C_5H_8 (isoprene) is the most abundant biogenic VOC in Amazonia, emitted by vegetation as a function of temperature, photosynthetic active radiation (PAR) and plant physiology. It plays an important role in the tropical atmosphere chemistry processes [18].

The CPC stands for Condensation Particle Counter and consist in an optical device that counts liquid and solid aerosol particles with diameter above 10 nm (CPC, TSI Inc., Model 3010). The CPC device provides measurements of particle number concentration (N) in units per cm^3 including all particles size ranges [22]. These particles are also known as aerosols, defined as a particle liquid or solid in suspension in the air with different sizes varying from tens of micrometers (μm) to a few nanometers (nm). The origin can be natural or from human activities, some examples of sources: vehicles emissions, dust resuspension, volcanic activity and oceans. At certain concentrations these aerosols can cause health and environmental effects such as aggravation of respiratory symptoms, lung and cardiovascular diseases, and damage to vegetation and deterioration of visibility, among other impacts [23].

CH_3CN (acetonitrile) is a chemical compound that can be used as tracer biomass burning [24]. However, in areas under urban pressure, the use of CH_3CN as tracer biomass burning can be disturbed by interferences from other sources of CH_3CN such as vehicle emissions [25].

In the present study, temperature is related to the air near the surface and plays a crucial role in Earth's life and can enhance or limit various ecological processes and land-atmosphere interactions.

3.4. Discussion

The spatial distribution of variables provided by this study represent the mean atmospheric conditions at surface during the wet and dry season in the study area, near the Manaus city. The spatial resolution provided by the interpolations are about 100 times greater than satellite measurements [3,4]. Future studies about the impact of air pollutants on the Amazonian flora and fauna can benefit from the high spatial resolution provided by the interpolations. The Manaus urban plume may systematically affect the areas depicted with relatively high concentrations of CO, NOx, O_3 and particles [26,27].

As other urban areas worldwide, the Manaus city emits CO, NOx and particles, constituting an urban plume that is clearly depicted in the interpolations (Figures 4 and 5). The concentration of CO, NOx and particles are greater near the source (Manaus), and gradually diminish as a result of dilution, chemical processing and dry deposition. CO is less reactive, so that its concentration decreases more slowly compared to NOx and particles. The interpolated spatial distribution and the concentration ranges of CO, NOx and particles are in accordance with previous studies in the area [1,17].

On the other hand, O3 interpolation showed higher concentrations far from Manaus (Figures 4b and 5b). That is explained by the fact that O_3 is not emitted directly from vehicles and industry, but it is produced in the atmosphere by photochemical reactions involving NOx and volatile organic compounds [20]. As the NOx rich plume moves away from Manaus, it gets mixed with air masses rich in biogenic volatile organic compounds emitted by the forest, providing appropriate conditions for O_3 formation in the atmosphere, and leading to a concentration increase far from the city, in agreement with previous studies [1,17]. O_3 concentration is higher in the dry season (Figure 4b) due to a combination of two factors: (i) regional biomass burning provides an additional source of NOx for O_3 production; (ii) the dry season is less cloudy compared to the wet season, providing greater solar radiation input for photochemical reactions [15]. Accordingly, acetonitrile, which is a tracer for biomass burning emissions, showed higher concentrations in the dry season and in the southern part of the study area, closer to the arc of deforestation.

Isoprene concentrations were greater in the dry season and in areas outside the urban plume (Figures 4d and 5d). Isoprene and other biogenic volatile organic compounds emitted by the forest are consumed within the plume, leading to the formation of secondary pollutants like O3 and organic aerosols [1,28]. Greater isoprene concentrations in the dry season corroborates the hypothesis of increased vegetation metabolism in the Central Amazonia during the dry season, associated with a higher input of solar radiation without water stress [29]. Finally, CH_4 concentration ranges are similar to previous observations in the Amazon Basin [30].

4. User Notes

We believe that the data here presented could be used mainly in three different approaches. The first one consists of studying the influence of the Manaus plume over the area covered by the dataset during the dry and wet seasons. Compared to other data sources, such as satellite data, the spatial resolution of the presented dataset is higher [31] and therefore the quality of the analysis could be improved. Furthermore, the interpolated data together with data from different datasets, obtained from research centers or even satellite data, could also be analyzed. For example, a researcher could compare the same surface area from this dataset with a more recent one, obtained from a satellite image, with the purpose of comparing the temporal effects in the region.

Another possibility is to conduct machine learning experiments, training classifiers or applying regression models. For instance, species distribution modeling (SDM) uses models which can benefit from our data, being trained to predict the probability of a certain species can be found in that area based on the atmospheric variables concentration, as presented in Figure 6.

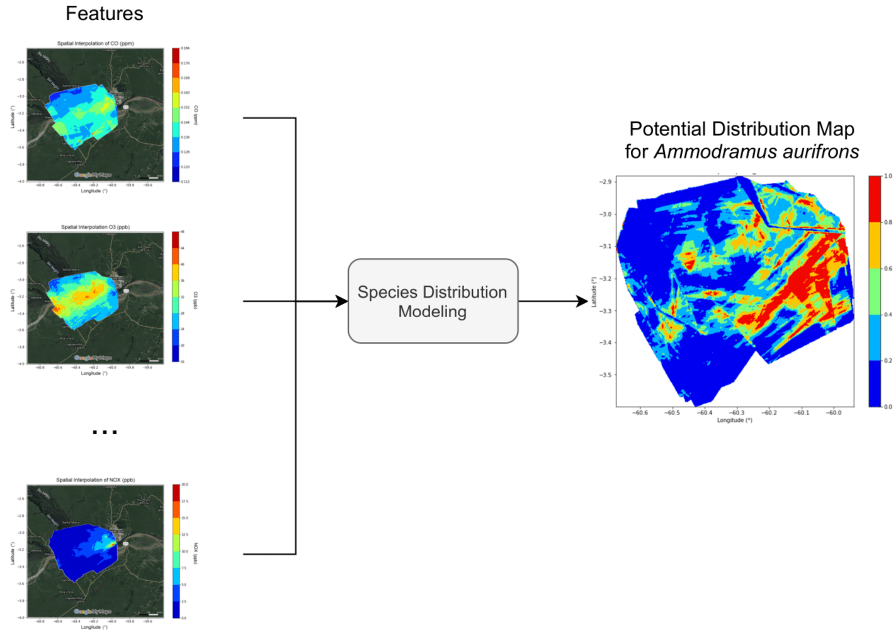

Figure 6. Example of species distribution modelling based on atmospheric variables.

5. Conclusions

This article described a dataset of air pollutant and meteorological variables that were mapped with a spatial resolution of 0.001° in an area of approximately 6900 km^2 in the central region of the Amazon Basin, between the cities of Manaus and Manacapuru. Original data were obtained from the ARM repository and were collected by an aircraft of the GoAmazon 2014/15 project that conducted 35 low-altitude flights in the region of interest. Three spatial interpolation techniques—linear, splines and nearest neighbor algorithm—were compared and the one with the lowest error metrics—RMSE, MAE and MAPE—was selected. The linear interpolation method presented 0.0214 of RMSE, 0.0108 of MAE and 7.80% of MAPE and was used to map 8 variables: temperature, concentration of carbon monoxide (CO), ozone (O_3), nitrogen oxides (NOx), methane (CH_4), acetonitrile, isoprene and the numerical concentration of particles (N).

Author Contributions: Experiment—R.O.M. Writing—Original Draft Preparation—R.O.M., F.V.d.A., L.d.O.B. and V.M.F.; Writing—Review & Editing—P.L.P.C., L.V.R. and G.P.; Visualization, R.O.M. and F.V.d.A. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Not applicable.

Data Availability Statement: Dataset is available on Zenodo (https://doi.org/10.5281/zenodo.5089039, accessed on 15 June 2021), with the licence CC-BY 4.0.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

The original datasets collected by the G-1 aircraft during the GoAmazon 2014/15 project are available in the ARM repository [5]. To access it, it is necessary to create a free account in the ARM portal. Several data products regarding the GoAmazon 2014/15 project are available in this repository, but only the datasets [6–8] were used for this paper. When a data product is selected, it is possible to download all data files that are available, which can be in different formats, such as .csv, .txt, .xlsx, etc. For this paper, the datasets were manipulated with Python.

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