

Response to Reviewer 1

We sincerely thank the reviewer for their time, and constructive feedback on our manuscript. We have carefully addressed all suggestions and implemented the corresponding changes, which have substantially identified areas for improvement of the manuscript. We acknowledge the identification of several important conceptual, structural, and issues that require substantial revision. The reviewer's comments are listed in **black**, followed by our response in "blue", with updated manuscript in "*blue*".

MAJOR GENERAL COMMENTS

A major issue throughout the manuscript is the interchangeable use of the terms NH_3 "emissions", "concentrations", and "total column", which are not equivalent. This conceptual confusion seriously undermines the soundness of the data and the interpretation of the results. Additionally, the document contains internal inconsistencies that raise concerns about its scientific rigor, making it challenging to evaluate its conclusions.

We agree with the reviewer that the inconsistent use of these terms was a major weakness of the manuscript. In the revised version, we have corrected the terminology throughout the entire manuscript to ensure the consistency. The term "emission" and "concentration" is no longer used unless explicitly referring to values reported in external literature. The study is based only on the concatenated NH_3 total column density retrieved from IASI reported in (molecules cm^{-2}). Therefore, no direct inference on the surface concentration or emission fluxes is made from the satellite data. In the revised manuscript we have addressed the inconsistencies and strengthen the scientific rigor of the manuscript including:

- Harmonize terminology (total column) throughout the text that include figures, tables etc.
- Provide explicit and consistent definition of the geographical areas in Guatemala (departments).
- Ensure that figure information, section references, and methodological description are aligned.
- Result and interpretation are now in section 3 and 4.

The manuscript is written in a very repetitive style, where similar ideas are repeated both within paragraphs and across sections where they do not belong. Furthermore, the manuscript does not follow the standard structure typically found in scientific writing. These patterns remind me of other manuscripts written using extensive AI assistance. While I do not believe the use

of AI is necessarily a reason for rejection, the authors should clearly describe the extent to which AI was used for data retrieval, analysis, interpretation, and writing.

Overall, the manuscript would greatly benefit from a revision that addresses the issues outlined above. Some specific examples of these issues are detailed below.

We thank the reviewer for raising this point, the manuscript has been substantially restructured to follow the ACP structure and format. Where section 2 now strictly contains data source and methodological description, with all interpretative statement removed. Section 3 presents result only, without discussion or conclusion. And section 4 has been rewritten to focus on interpretation, implication and comparisons avoiding repetition of results. Regarding the AI was used solely for language refinement and clarity. All data retrieval, processing, analysis, interpretation and scientific conclusions were performed by the authors.

SPECIFIC MAJOR COMMENTS

Section 2.1 (Data Analysis). This section is an example of not following the common manuscript structure, as it is a summarized narrative of the methodology, mixed with results and conclusions. This type of section is not usually found. Furthermore, results and conclusions are not supposed to be included in a Methodology section.

We thank the reviewer for the constructive suggestion. In the revised manuscript we have rewritten Section 2 Data and methods. The section 2.1 has been replaced with a new Section of Study location, describing the study area and geographical context including the departments of Guatemala. The methodological content previously presented in Section 2.1 (Data analysis) has been relocated in Section 2.2 (IASI NH₃ satellite-based data observation), which now describes only the concatenated IASI NH₃ total column and data processing. All results and interpretative statements have been removed from Section 2 and are now presented in Sections 3, respectively.

Section 2.3 (ESRI Land Cover Class Map). “The... LUC dataset... derived from Sentinel-2 satellite imagery...” and “The LULC ... dataset, based on data from the European Space Agency’s Sentinel-2 mission”. The above sentences are repetitive and appear in the same paragraph: This is only one example of repetitive writing found throughout the manuscript; there are several more.

We thank the reviewer for point out this issue. The repetitive paragraphs have been removed throughout the manuscript, the section 2.3 where redundant information of ESRI LULC dataset and Sentinel 2 were consolidated into one concise description. Similar revision has been applied across other sections to improve clarity (L176–L183).

The ESRI Land Use Land Cover (LULC) 2020 dataset, released in June 2021, was developed using deep learning models trained on more than 5 billion manually labelled pixel samples derived from the European Space Agency’s Sentinel-2 satellite imagery with 10 m spatial resolution (Karra et al., 2021), enables land cover mapping at both national and local scales. According to (ESRI, 2021) these training samples were collected from 24,000 image tiles globally, each measuring 510×510 pixels, and reflect a wide range of land surface types. The LULC 2020 product is classified into nine classes: Water, Trees, Flooded vegetation, Crops, Built area, Bare ground, Snow/Ice, Clouds, and Rangeland (Karra et al., 2021). In this study, the analysis was restricted to classes related to Water, Trees, Flooded vegetation, Crops, Built area, and Rangeland.

Figure 1. Regions mentioned in the text, such as Petén and Quiché, should be indicated on the map to help readers follow the discussion more easily.”

We have modified the Figure 1 adding Guatemala’s departments on the map in the revised manuscript (L113).

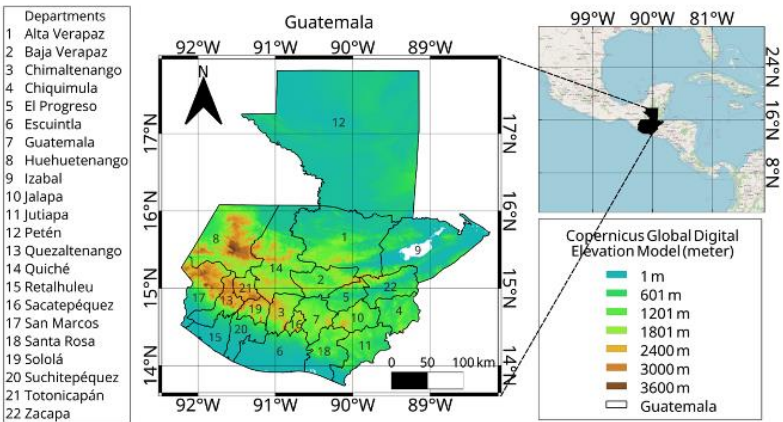


Figure 1: Departments of Guatemala and elevation (m) from Copernicus Global Digital Elevation Model.

L150 “Atmospheric total column measurements of NH3 were obtained...”. L184 “To identify spatial patterns in atmospheric NH3 emissions...”. Both NH3 observations (total column and emissions) are mentioned in section 2.4, but only the retrieval of the NH3 total column is described. Regarding NH3 emissions, either the authors are using this term as equivalent total column, or they are omitting how they obtained the total column. In the rest of the document, “total column”, “emissions”, and “concentration” are used interchangeably.

We thank the reviewer for this important comment. We agree that the terms: “total column”, “emission” and “concentration” were used previously interchangeable, this may have caused confusion. In the revised manuscript, we describe only the term of “total column” as it derived from IASI. For the section 2.2 IASI NH₃ satellite-based (L115–L150), all satellite based NH₃ observations are consistently described as NH₃ total column measurements derived from IASI. The term “emissions” has been completely removed, as no emission fluxes are derived in this study, and the term “concentration” is no longer used to describe satellite observations. In addition, Section 2.3 Cluster analysis of NH₃ (L150–L175) now clearly states that the k-means clustering is applied to NH₃ total column.

L216 “Correlation analyses between these variables and atmospheric NH₃ concentrations were performed to better understand the meteorological drivers influencing NH₃ variability across Guatemala.” The “Pearson correlation analysis” is also mentioned in L109; however, the manuscript presents no quantitative correlation analysis. There is only a qualitative comparison between the meteorological conditions and the NH₃ data described in the following sentence: L407 “... which points to a general inverse relationship where higher NH₃ concentrations tend to coincide with lower PBLH values, and vice versa.”

We thank the reviewer for pointing this out. We agree that the previous version of the manuscript didn’t explicit present the quantitative results of the Pearson correlation analysis. To address this, we have now included a quantitative value between NH₃ and meteorological variables, including fire counts. In the revised manuscript the correlation coefficient is reported in the discussion section (L427–443) and a correlation matrix in the supplementary material Fig. S5. Regarding the relationship between NH₃ and BLH is now supported by the reported correlation and correction related to height were made. Table S6 supports Summary statistics of annual and climatology monthly distribution of meteorological variables of boundary layer height (m), relative humidity (%), temperature (°C), and precipitation (mm) from ERA5 reanalysis. In addition, variables not direct discussed were removed from the correlation analysis (surface pressure (sp), Nitrate Dioxide (NO₂) and Sulphur Dioxide (SO₂)) to keep consistency on atmospheric NH₃ total column.

REVISED MANUSCRIPT (L346–L362)

3.4 Meteorology

Figure 7 illustrates the variability of meteorological variables derived from monthly scales over Guatemala from ERA5. Fig. 7 (a,c), exhibit the BLH and precipitation. The BLH shows fluctuations with the highest median recorded in 2019 (524 m), in contrast to the lowest median observed in 2017 (415 m) which also demonstrated the minimum value (305 m) (Table S6). The maximum vertical value was detected during 2020 (791 m) indicated a large data range. At the monthly scale, April shows the highest BLH (median 671 m) and lowest during October (median 348 m). Furthermore, the precipitation indicates that the annual distribution of monthly totals presents the highest median values recorded in 2020 (69 mm) and 2022 (55 mm), while the lowest median is observed in 2019 (34 mm) which also shows the minimum value (7.5 mm). The maximum monthly exceeds

130 mm (2017 and 2022). The monthly climatology presents peaks medians precipitation in the month of June (97 mm), and September (95 mm), while the lowest in February (13 mm).

Fig. 7(b,e) presents the air temperature and relative humidity. The warmest median temperature during the year 2023 (22.8°C), whereas the maximum temperature was detected during 2020 (27.9°C). The coldest temperature was recorded during 2018 with 20.2°C. Additional, the warmest month is May (median 26.4°C) and the coldest is January (21.9°C). Relative humidity showed the highest median observed during 2016 (81%), while the lowest median year was 2019 (76%), the minimum year detected was 2020 with 63%, this also showed the largest vertical values. The years 2017 and 2022 exhibit the maximum values with 87%. The month medians indicate the lowest in April (mean 71%) and the highest in October (mean 84%).

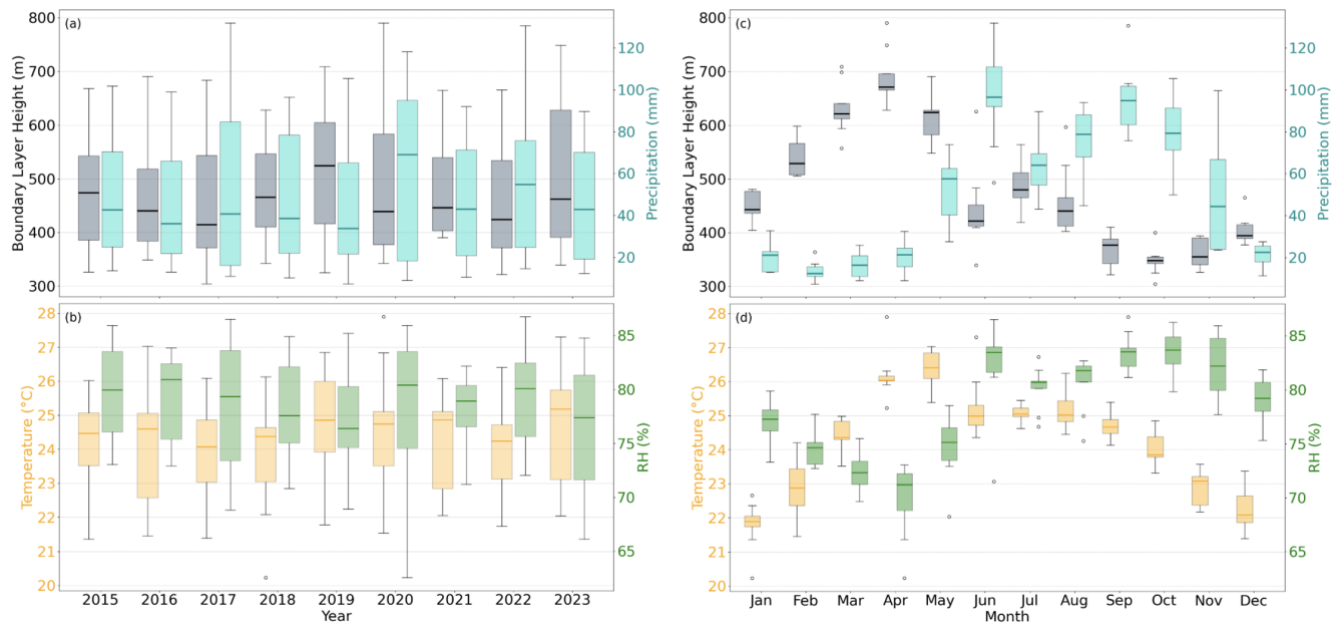


Figure 7: Boxplot distribution of meteorological variables over Guatemala (2015–2023) from ERA5 reanalysis, (a, c) show boundary layer height (m) (gray) and precipitation (mm) (turquoise), (b, d) relative humidity (%) (green) and temperature (°C) (yellow).

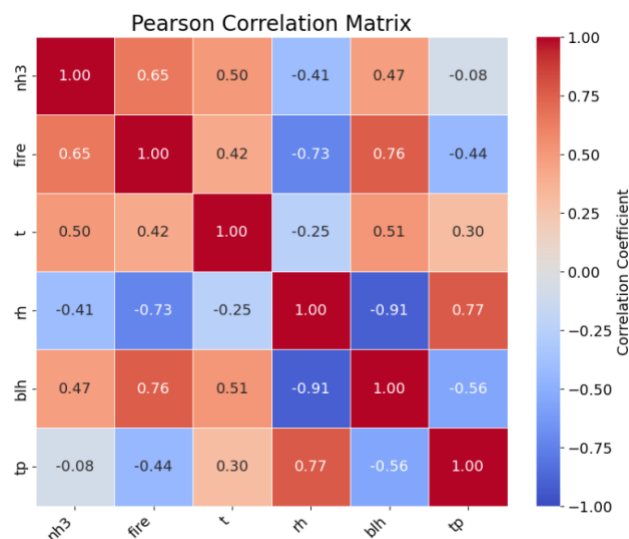


Figure S5: Pearson correlation matrix of NH₃ and different variables: fires, temperature (t, °C), relative humidity (rh, %), boundary layer height (blh, m), total precipitation (tp, mm).

The following paragraph is internally inconsistent (L273 - L280): “The concatenated data from IASI A/B/C data of spatial distribution of annual mean of NH₃ emissions...” “A consistent spatial pattern of elevated NH₃ concentrations was observed...”

Thanks very much for your suggestion, in the revised manuscript (L241–L247) we have made the corrections.

REVISED MANUSCRIPT (L241–L247)

The spatial distribution of NH₃, exhibited a consistent area-wide pattern characterized by elevated values in specific areas. Persistent hotspots are observed in the northern (Petén), north-central (Quiché, Alta Verapaz, and Izabal), and along the southern coastal department of Escuintla. Conversely, lower annual mean NH₃ dominate in the central midlands, including the departments of Totonicapán, Sololá, Chimaltenango, Sacatepéquez, Guatemala, Jalapa, and Jutiapa. Interannual variability in hotspot intensity is evident, with particularly values over Petén, Alta Verapaz and Quiché in 2016 and more widespread increases across Petén, Quiché, Alta Verapaz, Izabal and Escuintla in 2020. Notably, even in years with lower annual means such as 2018, increased NH₃ total column were still evident in Petén, Alta Verapaz, Izabal and Escuintla.

L273 “The concatenated data from IASI A/B/C data of spatial distribution of annual mean of NH₃ emissions across Guatemala from 2015 to 2023 exhibited a consistent pattern of elevated emissions in the northern and southern regions. A consistent spatial pattern of elevated NH₃ concentrations was observed, with discernible hotspots in the northern, north-central, and southern regions of the country. Conversely, the central midlands and highlands consistently displayed lower emission rates

throughout the period." Please define terms such as “northern and southern regions”, “north-central and southern regions“, and “north-central and southern regions“; otherwise, it is difficult to corroborate the description in the text. For example, I do not see the “consistently elevated NH₃ concentrations in the northern regions” that is mentioned. Also, “NH₃ concentrations” are mentioned, but Figure 2 declares to show only “NH₃ emissions”. In addition, the methodology section never mentions how the concentrations are determined. It seems, then, that both terms are being incorrectly used interchangeably.

Thanks very much for your suggestion, in the revised manuscript we have removed all the references of emission and concentration, now consistently refer to NH₃ total column. Spatial description regions to improve geographic clarity have been explicitly defined with the departments name (annually and monthly climatology). Additionally, in the revised manuscript we included in the methodology section that we worked only with the concatenation NH₃ total column.

REVISED MANUSCRIPT (L235-L247)

Fig. 2 shows the annual variability of NH₃ total column over Guatemala from the period 2015 to 2023. The respective boxplots show the distribution of monthly NH₃ values within each year. The medians reveal a NH₃ with a minimum of 2.90×10^{15} molecules cm⁻² in 2021 and a maximum of 2.33×10^{16} molecules cm⁻² in 2020 (Table S1). While the median values show an increase of NH₃ notable during 2020 (4.66×10^{15} molecules cm⁻²) and 2023 (4.33×10^{15} molecules cm⁻²). Consistently, the standard deviation varied considerably between years, reaching a peak in 2020 of 5.83×10^{15} molecules cm⁻².

The spatial distribution of NH₃, exhibited a consistent area-wide pattern characterized by elevated values in specific areas. Persistent hotspots are observed in the northern (Petén), north-central (Quiché, Alta Verapaz, and Izabal), and along the southern coastal department of Escuintla. Conversely, lower annual mean NH₃ dominate in the central midlands, including the departments of Totonicapán, Sololá, Chimaltenango, Sacatepéquez, Guatemala, Jalapa, and Jutiapa. Interannual variability in hotspot intensity is evident, with particularly values over Petén, Alta Verapaz and Quiché in 2016 and more widespread increases across Petén, Quiché, Alta Verapaz, Izabal and Escuintla in 2020. Notably, even in years with lower annual means such as 2018, increased NH₃ total column were still evident in Petén, Alta Verapaz, Izabal and Escuintla.

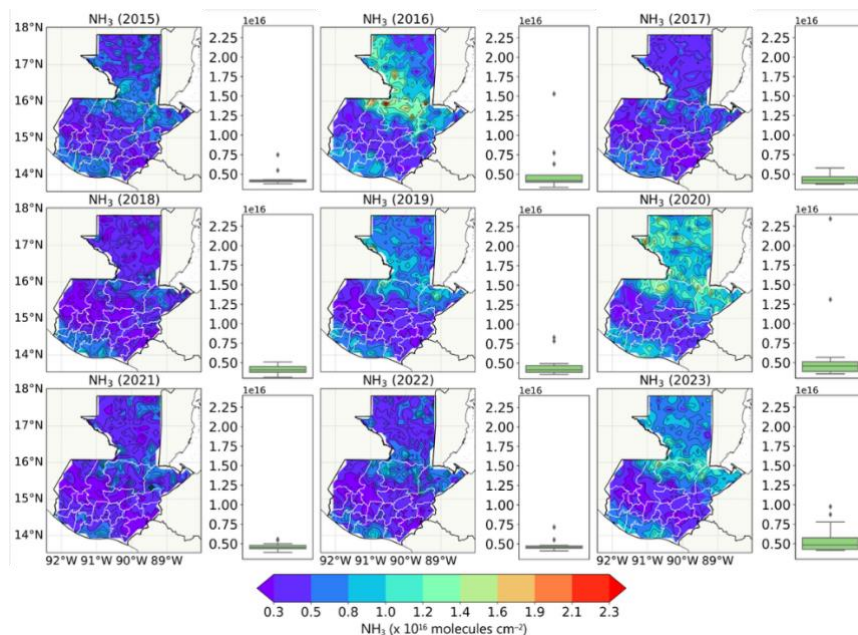


Figure 2: Annual means area-wide and boxplot of NH_3 emission total columns ($\times 10^{16}$ molecules cm^{-2}) over Guatemala (2015–2023) from concatenated IASI A, B and C.

Figure 5. What are the boxplots showing? FRP or fire counts? Units in the vertical axis are missing.

We thank the reviewer for pointing this out. Figure 5 shows the annual distribution of monthly fire counts. The boxplot shows the area-wide monthly fire counts for each year. The vertical axis is fire count (number of detections) and not FRP, which was used only as a filtering criterion. In the revised manuscript for fires (L309-L344), the y axis has been labelled as monthly fire counts by year. We also included in Figure 6, that present the monthly climatology of detected fires, and the boxplot exhibits the area-wide of number of detected fires for each month across all years. This is supported by Table S4 and S5 summarize the statistics of detected fires.

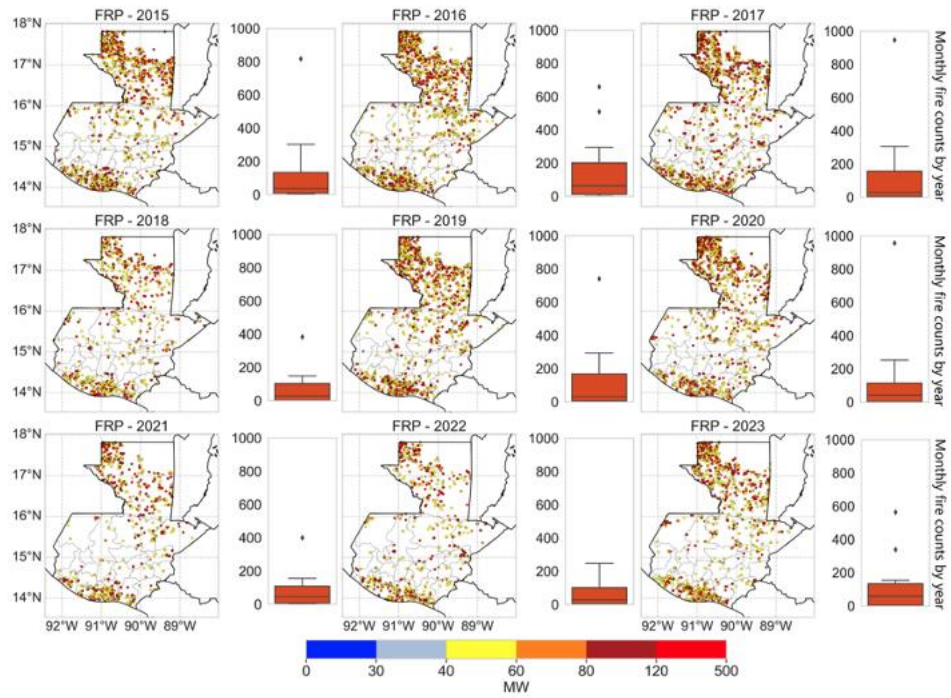


Figure 5: Annual distribution of monthly fire counts over Guatemala (2015–2023), MODIS fire detection filtered by nominal confidence level $\geq 70\%$ and FRP ≥ 40 MW, the Boxplots represent the area-wide monthly fire count for each year.

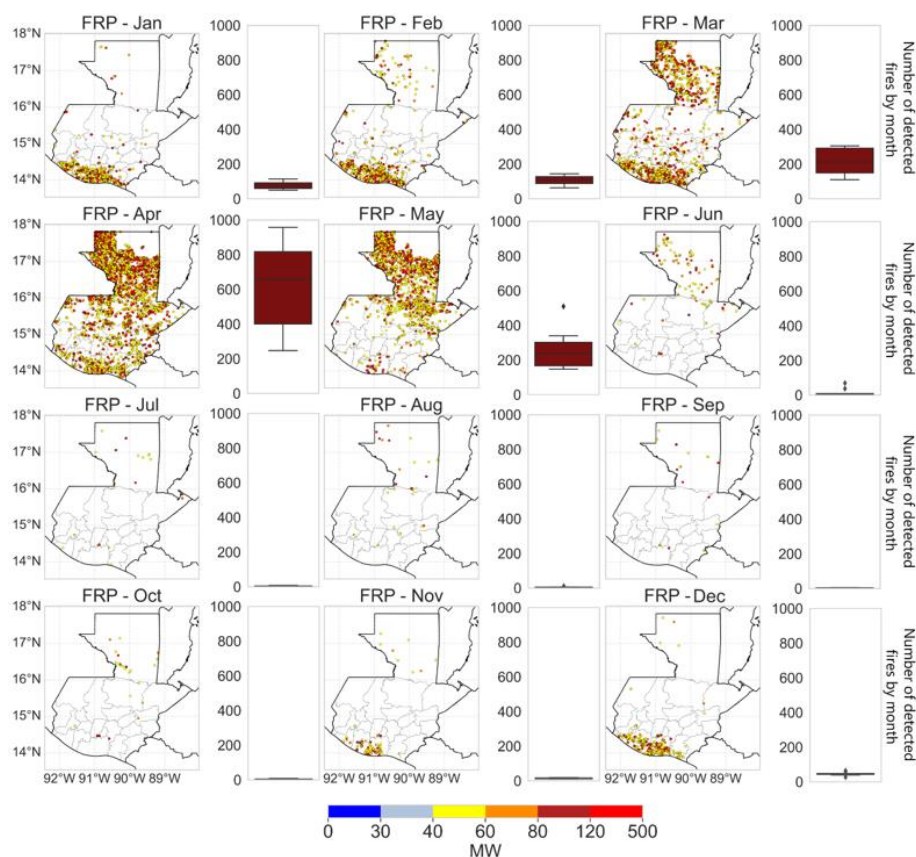


Figure 6: Monthly climatology of detected fires over Guatemala (2015–2023), MODIS fire detection filtered by nominal confidence level $\geq 70\%$ and FRP ≥ 40 MW, the boxplots represent the area-wide distribution of number of detected fires across all.

L419 “a monthly means detected by IASI A (2.32×10^{16} molecules/cm²), B (2.48×10^{16} molecules/cm²) and C (2.43×10^{16} molecules/cm²). “Why are the three values shown? Everywhere else in the manuscript, only one value (I guess it is the average of the three) is shown.

We thank the reviewer for this comment. The individual values are originally reported for completeness, however, this information was inconsistent with the rest of the manuscript, and this might lead to confusion, where analyses are from the concatenated IASI A/B/C rather than by averaging the three sensors. In the revised manuscript, the text has been corrected, and the monthly were calculated from the merge dataset.

REVISED MANUSCRIPT (L369-L375)

NH₃ anomalies were observed in Guatemala in April 2020, marking the highest recorded monthly mean (Fig. S3). This peak is particularly remarkable as it occurred shortly after the implementation of COVID-19 lockdown measures (March 2020).

The monthly mean spatial distribution of concatenated NH_3 in April 2020 (2.3×10^{16} molecules cm^{-2}), indicates distinct hotspots concentrated in the northern (Petén), north-central (Quiché) and southern (Escuintla) areas. The highest values were observed in the department of Petén, reaching up to (6.4×10^{16} molecules cm^{-2}) (Fig. 8). The corresponding environmental conditions, including wind vectors meter per second (m s^{-1}), with a strong easterly wind ($\sim 3 \text{ m s}^{-1}$) dominated the northern region, facilitating long-range transport of NH_3 , while central Guatemala experienced moderate to stagnant wind conditions.

Figure 9. Units on the color scale are inconsistent: ppmv (unit of concentration) is not equivalent to molecules/cm2 (units of total column).

We thank the reviewer for point this out. We agree that the units represent different quantities and should not be interchangeable. In the old version the vertical profiles from CAMS we expressed in ppmv, while IASI total column in molecules cm^{-2} that are not dimensionally equivalent. In the revised manuscript CAMS vertical profiles are now consistent and reported in mass mixing ratio (kg kg^{-1}). Also, both Fig. 9(a) zonal mean and Fig. 9(b) vertical and latitudinal profile uses to illustrate the NH_3 structure in (kg kg^{-1}), rather than for quantitative comparison with IASI total column. The colour scale and associated units have been corrected (L381-L396).

Furthermore, we have integrated the aspect regarding the vertical and latitudinal profiles from CAMS mass mixing ratio (kg kg^{-1}), in the methodology section (L141-L148).

REVISED MANUSCRIPT (Methodology, L141-L148)

“Additionally, NH_3 vertical profiles data were obtained from the ECMWF, Atmospheric Composition Reanalysis 4 (EAC4), produced by the Copernicus Atmosphere Monitoring Service (CAMS). This global reanalysis provides NH_3 with mass fraction in the air, provided as a mass mixing ratio (kg kg^{-1}), the model is defined by 60 hybrid sigma-pressure levels. It provides a detailed representation of the atmospheric structure, particularly near the surface (~ 0 – 100 m) where most emissions occur (Inness et al., 2019). These reanalysis datasets incorporate satellite observations and model simulations to provide globally consistent, spatially and temporally resolved atmospheric composition data (Flemming et al., 2017; Inness et al., 2019). In this study, the CAMS analysis of vertical structure and latitudinal distribution of NH_3 during a specific period of interest, rather than for a quantitative comparison with satellite of total column densities.”

REVISED MANUSCRIPT (Result, L381-L396)

The vertical and latitudinal distribution of atmospheric NH_3 over Guatemala was analysed using zonal means and area averaged vertical profiles in mass mixing ratios (kg kg^{-1}). Figure 9a shows a zonal mean cross-section of NH_3 kg throughout the atmosphere (vertical axis, model level 60 to 44) along the latitudes of Guatemala as a zonal mean during April 2020. It highlights a greater abundance of NH_3 in both the northern and southern areas. Furthermore, the NH_3 vary with both latitude

and altitude, the highest NH_3 are observed at lower model levels primarily confined near the surface (below approximately level 56). The highest NH_3 values are found between 14°N and 15°N latitude.

Fig. 9b further illustrates the area-average vertical profiles of NH_3 for April (blue line), spring (March – May, green line) and the annual mean 2020 (black dashed line). The vertical profile of NH_3 shows the April 2020 mean (blue line) with $\sim 1.0 \times 10^{-9} \text{ kg kg}^{-1}$, the spring mean (March–May 2020, green line) of $\sim 0.9 \times 10^{-9} \text{ kg kg}^{-1}$ and the annual mean for 2020 (black dashed line) with $\sim 0.5 \times 10^{-9} \text{ kg kg}^{-1}$ respectively.

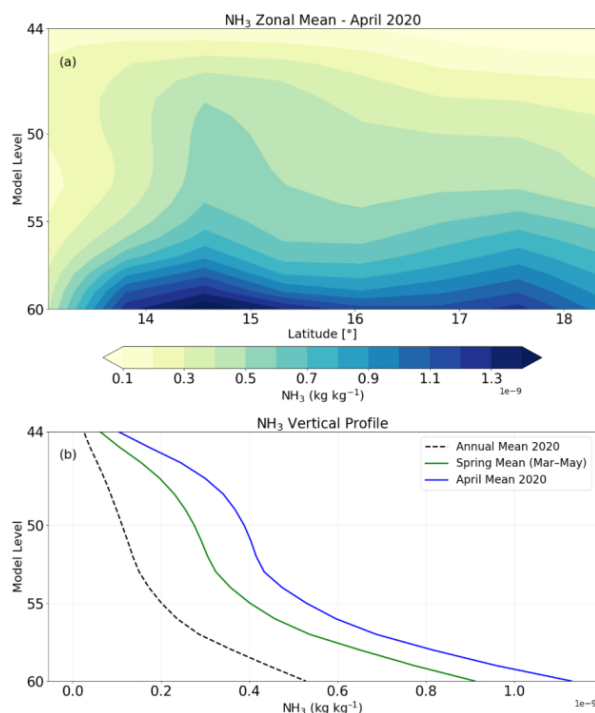


Figure 9: (a) zonal mean of NH_3 mass mix ratio (kg kg^{-1}) ~~total column ($\times 10^{16}$ molecules cm^{-2})~~ across latitudinal bands (model level 60 to 44) for April 2020 and (b) vertical profile of NH_3 mass mix ratio (kg kg^{-1}) for April (blue line), spring (March – May, green line) and annual mean 2020 (black dashed line) over Guatemala from global reanalysis CAMS.

L466: “April 2020 recorded the highest number of active fires across Guatemala throughout the entire study period (957), representing...” The reported number of fires in April 2020 (957) does not match Figure 10a, which shows only 85, approximately.

We thank the reviewer for this comment. In the revised manuscript the fire text has been made consistent throughout the document and supplementary material. Previously the value reported was approximately 85 fires, that corresponds to the monthly mean number of detected fires for April 2020, this value now has been removed from the manuscript to avoid

confusion. The Figure 10 shows the spatial distribution FRP filtered. The total number of detected fires for that month is 957, which is consistent with the value reported in L466 (Old Version), this further supported by the supplementary materials, Table S4 where it presents the maximum monthly fire count for 2020, Table S5 for the month of April show the same value, and Figure S6, present the time series of total number of detected fires per month where the highest number of fires is 957.

REVISED MANUSCRIPT (L438-L408)

Fire activity in spring 2020 showed an anomalous peak compared to the long-term pattern (Fig. 10). As mentioned above, March to May indicate a general increase phase in fire activities in Guatemala. April 2020 recorded the highest monthly total number of detected fires across Guatemala throughout the entire study period (957). The spatial distribution of FRP distribution illustrates widespread, affecting specifically in the northwestern (Petén) accounting for 674 detected fires (Table S7, Fig.S7), central-north (Quiché, Alta Verapaz, Izabal), and southern areas (Escuintla, Santa Rosa, and Jutiapa). The corresponding burned areas patterns further confirm the extension of the fire’s activities during the month, with the most extensive land burned occurred in the department of Petén.

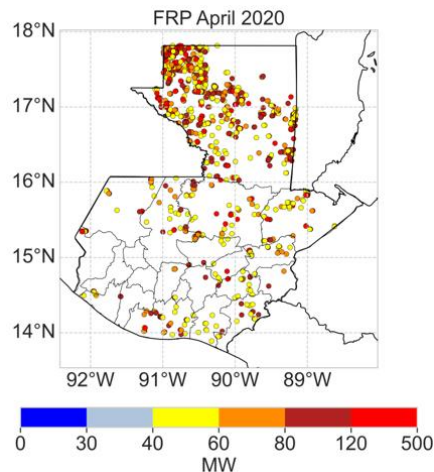


Figure 10: April 2020 shows the spatial distribution of area-wide of fires detected over the study period over Guatemala (2015–2023), using MODIS fire detection filtered by nominal confidence level $\geq 70\%$ and FRP ≥ 40 MW.

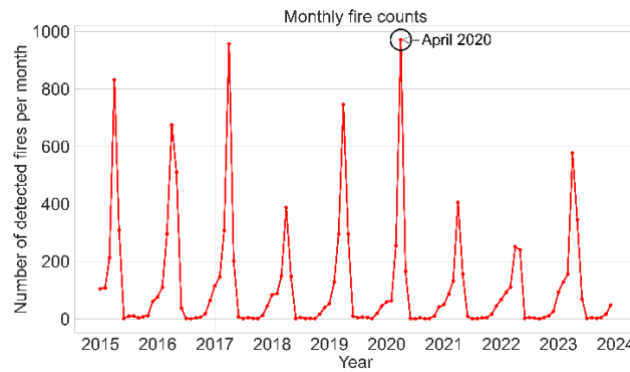


Figure S6: Total number of detected fires by month from MODIS filtered by a nominal confidence level $\geq 70\%$ and fire radiative power ≥ 40 MW over Guatemala (2015–2023), with April demonstrated the highest number of fires during the study period.

L474: The term “climatological peak” is illogical, as April 2020 represents an exceptional event.

We thank the reviewer for this comment. The term "climatological peak" has been removed and replaced in a text that explicitly refers to the highest fire activity in April 2020, without implying a climatological maximum (L399–L405).

L475:” This case study demonstrates that April 2020 was... an expanded spatial footprint compared to other years.” There is no data demonstrating how April 2020 compares to other years.

We thank the reviewer for this comment. We agree that the previous text implied a comparative of April 2020 with other years. In the revised manuscript, we have removed the statement that mentioned “expanded spatial footprint compared to other years” and now focus exclusively on the case study of April 2020 based on the observed information (L399–L405). The timeseries filtered of total number of detected fires by month from MODIS, and it was moved to the supplementary material (Fig. S6).

Figure 11. All the discussion in this section is about April of 2020 as a case study, so why is April combined with May data in this figure?

We thank the reviewer to mention this inconsistency. In the revised manuscript we moved the previous Fig. 11 to the supplementary materials Fig. S7. To show the Burned (red) areas only during the month of April 2020. For the result and discussion section regarding the fire activity during April 2020, the previous months of March and May have been removed to avoid confusion to ensure consistency and mainly focus solely on the case study (L399–L405).

Section 4 (Discussion) The Discussion section mainly repeats the Results and provides no additional interpretation or new insights. A substantially shorter version of this section could be included as the summary required by ACP in the Conclusions section.

We thank the reviewer for this comment. In the revised manuscript we have restructured to focus the interpretation, and broader implication to improve clarity, reduce redundancy and strength the interpretation of the results. While the conclusions section now presents a concise summary of the main findings, (Result L410–497), (Conclusion L498–516).

OTHER COMMENTS

L23. The statement “Continuous satellite monitoring is essential to ... support strategies to reduce biomass burning” seems unrealistic and is not supported by the analysis shown in the manuscript.

We thank the reviewer for this comment. We don’t evaluate the mitigation strategies. Therefore, in the revised manuscript the sentence was deleted to avoid overstated policy implications (L23).

L87 and L141 (maybe more lines). “Environmental Systems Research Institute (ESRI)” The ESRI acronym was defined on line 87, so it does not need to be defined again on line 141. In fact, once the acronym is defined, the full name should not be used again. There are several other cases similar to this in which the acronyms are not used correctly (i.e. next comment).

In the revised manuscript “Environmental Systems Research Institute (ESRI)” is defined only once at its first occurrence, and all subsequent references use the acronym ESRI.

L249 “Moderate Resolution Imaging Spectroradiometer (MODIS)” The acronym MODIS is defined in L249, but it is used several times before this line.

In the revised manuscript the “Moderate Resolution Imaging Spectroradiometer (MODIS) it is now defined at its first mention and subsequent reference using the acronym.

L261 “The respective boxplots reveal a generally stable NH₃ concentration throughout the study period.” L269 “... indicating substantial variability and peak emissions.” Both sentences in the same paragraph are contradictory.

L278 - L281. The information was already stated in the previous paragraph.

We thank the reviewer to highlighting this inconsistency. In the revised manuscript we separated the background months from the extreme variability months (Old version L261). In addition to this, the redundant statement regarding spatial patterns (Old version L278-L281) has been removed to avoid repetition (L234-L247).

REVISED MANUSCRIPT (L235-L249)

Fig. 2 shows the annual variability of NH_3 total column over Guatemala from the period 2015 to 2023. The respective boxplots show the distribution of monthly NH_3 values within each year. The medians reveal a NH_3 with a minimum of 2.90×10^{15} molecules cm^{-2} in 2021 and a maximum of 2.33×10^{16} molecules cm^{-2} in 2020 (Table S1). While the median values show an increase of NH_3 notable during 2020 (4.66×10^{15} molecules cm^{-2}) and 2023 (4.33×10^{15} molecules cm^{-2}). Consistently, the standard deviation varied considerably between years, reaching a peak in 2020 of 5.83×10^{15} molecules cm^{-2} .

The spatial distribution of NH_3 , exhibited a consistent area-wide pattern characterized by elevated values in specific areas. Persistent hotspots are observed in the northern (Petén), north-central (Quiché, Alta Verapaz, and Izabal), and along the southern coastal department of Escuintla. Conversely, lower annual mean NH_3 dominate in the central midlands, including the departments of Totonicapán, Sololá, Chimaltenango, Sacatepéquez, Guatemala, Jalapa, and Jutiapa. Interannual variability in hotspot intensity is evident, with particularly values over Petén, Alta Verapaz and Quiché in 2016 and more widespread increases across Petén, Quiché, Alta Verapaz, Izabal and Escuintla in 2020. Notably, even in years with lower annual means such as 2018, increased NH_3 total column were still evident in Petén, Alta Verapaz, Izabal and Escuintla.

Response to Reviewer 2

We sincerely thank the reviewer for their time, and constructive feedback on our manuscript. We have carefully addressed all suggestions and implemented the corresponding changes, which have substantially identified areas for improvement of the manuscript. We acknowledge the identification of several important conceptual, structural, and issues that require substantial revision. The reviewer's comments are listed in **black**, followed by our response in "blue", with updated manuscript in "*blue*".

General comments:

This paper presents the first study on the seasonal and interannual trends of NH₃ over Guatemala using IASI A, B, and C total columns. By combining satellite observations with land use and fire data, the authors conclude that the NH₃ trends over Guatemala between 2015 and 2023 were mainly driven by agricultural emissions and episodic fire events.

A number of studies have used IASI observations to look at NH₃ trends and variabilities at country and regional scales, but most focused on major agricultural regions such as North America, Europe, and Asia, where elevated NH₃ plumes are easily detectable from space because the column concentrations are one to two orders of magnitude higher than the instrument's detection limit. This study adds value to the existing body of literature because NH₃ concentrations in Guatemala are generally near the detection limit of IASI, shedding light on the technical limitations of satellite measurements. This is a potentially interesting point that remains under-explored in the current paper.

The paper also needs some reorganization. For example, in the first paragraph of Methodology, the authors are already discussing results. This section should start with a description of the datasets and mathematical/statistical methods used, which are currently placed later in the section. My other concerns and questions can be found below.

Major comments:

L41-49: This paragraph heavily focuses on vehicle emissions as an underestimated source of NH₃, so I was expecting to see some analysis on vehicle emissions, but there were none except one sentence mentioning that traffic activity decreased in April 2020. If you are not going to delve into traffic emissions, I recommend shortening this paragraph to one sentence just saying that vehicle emissions remain an underestimated source in NH₃ emission inventories and merging it with the previous paragraph.

We agree that the previous paragraph mentioned vehicle emissions without providing any analysis. In the revised manuscript, we have shortened and merge with the previous paragraph. Vehicles emission now mentioned only briefly as underestimated no agricultural source.

REVISED MANUSCRIPT (L31-L39)

NH₃ is also a key component in atmospheric chemistry and in the coupling of nitrogen and carbon cycles within ecosystems, with broad consequences regarding climate regulation, agricultural sustainability, air quality and public health. NH₃ emissions originate from both natural and anthropogenic activities, with the latter contributing the majority of the global NH₃ burden. The agricultural sector remains the principal source, accounting for over 81% of total anthropogenic emissions globally (Van Damme et al., 2021; Wyer et al., 2022), while additional anthropogenic contributions stem from residential combustion, vehicular exhaust, industrial production, and wastewater treatment systems (Abeed et al., 2022; Dragosits et al., 2002; Sutton et al., 2007). Although agriculture particularly using fertilizers and manure remains the dominant source of atmospheric NH₃. Nonagricultural sources such as vehicular and industrial emission may be also contribute and are significantly underestimated (Chen et al., 2024; Chen and Wang, 2025; Farren et al., 2020; Gu et al., 2023; Zhou et al., 2017). Empirical evidence indicates that diesel vehicles equipped with selective catalytic reduction (SCR) systems can emit NH₃ as an unintended byproduct (Sun et al., 2017; Wen et al., 2023). Vehicular NH₃ emissions are known to contribute to the rapid formation of fine particulate matter, particularly during air pollution episodes, underscoring the predominant role of fossil fuel combustion as a non-agricultural NH₃ source in urban environments (Farren et al., 2020, 2021; Pan et al., 2016). Additionally, various industrial activities including steel production (Chen and Wang, 2025), power generation, and fertilizer manufacturing also release substantial amounts of NH₃ into the atmosphere (Van Damme et al., 2018; Gu et al., 2023).

L98: The authors seem to use the words “emission” and “concentration” interchangeably throughout the paper, including here where it says the authors will first detail the spatiotemporal variability of NH₃ emissions. Another example is Figures 2 and 3, which captions both say “NH₃ emissions (molecules/cm²)”, but these are the units of column concentrations (or more precisely, total columns), not emissions. “Emission” and “concentration” have different scientific meanings and should not be mixed, as deriving emissions from column concentrations requires more than satellite observations and typically involves a modeling approach.

We thank the reviewer for pointing out this inconsistency. In the revised manuscript, we have removed all the references of emission and concentration, now consistently refer only to NH₃ total column (molecules cm⁻²), this includes text, figures, tables, and supplementary document, unless explicitly referring to values reported in external literature.

L172: This detection limit ($4\text{--}6 \times 10^{15}$ molecules/cm²) was for an earlier version of IASI product. Is there an updated number for version 4? As mentioned earlier, this becomes relevant because the reported annual mean NH₃ concentrations over

Guatemala ($4.12\text{--}6.67 \times 10^{15}$ molecules/cm²) are very close to the detection limit of IASI. Can we realistically draw conclusions on the interannual trends when the mean concentrations are so low? Would other satellite instruments that have higher sensitivities to surface NH₃ be better options?

We Thank the reviewer for this comment, and we acknowledge the concern regarding the detection limit. The detection limit ($4\text{--}6 \times 10^{15}$ molecules/cm²) referenced for previous studies and retrieval version. The current version is v4.0.1R (2024/10/25 – current). For our study (2015–2023) we used ANNI-NH₃ v4.0.0R ULB-LATMOS L3 gridded average (spatial and temporal) (available version 2023/07/03 – 2024/10/25) that reduces random error and improve the effective sensitivity. Version 4 incorporates retrieval improvements, updated spectroscopy, enhanced uncertainty characterization, and improved column values that are about 15–20% larger due the upgraded Hyperspectral Range Index (HRI) (Clarisse et al., 2023).

The detection capability cannot be described by a single threshold, because the retrieval sensitivity depends on several factors including thermal contrast, cloud fraction, and surface condition (Clarisse et al., 2023; Van Damme et al., 2017). Thus, to avoid potential confusion, the detection limit of IASI cited in the old version has been removed from the manuscript. The robustness of the results is supported by a relative high data volume with an average of 1,395 pixels per month, with the standard error annual means remains lower (1.65×10^{14} molecules cm⁻² to 1.68×10^{15} molecules cm⁻²) (Table S9, S10). Additionally, Guatemala is situated in a tropical region where the thermal contrast is generally favorable for thermal contrast (latitude 13.5°–17.8° N). Contrary to relatively colder areas, such higher latitudes are linked to limited thermal contrast, which limits the sensitivity of nadir sounders to surface concentrations (Clarisse et al., 2009; Franco et al., 2018).

Regarding to draw conclusions on the interannual trends when the mean concentrations are so low? To assess if the interannual variability can be robustly enough to be interpreted, we compared the magnitude of the variability with the relative uncertainty, as we mentioned above then we computed a correlation analysis of concatenated NH₃ columns and monthly observation density (Fig. S9). The minor correlation $R^2 = 0.028$ and $p = 0.082$, suggest that the variability in total columns is large enough and independent of how often the sensors observe the area of Guatemala. Specifically for the year 2020 (1.97 obs. grid cell month per month) where was the highest mean total column of NH₃, this value is 17% relative lower respecting the previous year for the observation density, likely due to increase on cloud cover, however it reminded sufficiently to obtain the maximum of NH₃.

Regarding the use of other satellite sensors to detect higher sensitive to surface NH₃, IASI provides different sensors with a consistency and stable spatio-temporal resolution, that is suitable for interannual variability. For this reason, we focused on IASI for homogeneity across Guatemala.

Table S9: Annual summary of statistics of the of the concatenated NH₃ total column density, and IASI metrics over Guatemala (2015–2023). The table include annual mean (molecules cm⁻²), standard error of the mean (SEM) (molecules cm⁻²), relative uncertainty (%), total pixel counts, and mean monthly observations per 0.25 grid cell.

Year	Annual Mean (molec cm ⁻²)	Standard Error Error (molec cm ⁻²)	Relative Uncertainty (%)	Total Pixel (annual sum)	Obs. Grid Cell Month ⁻¹
2015	4.64×10^{15}	4.58×10^{14}	9.85	15696	2.16
2016	6.27×10^{15}	1.52×10^{15}	24.26	15931	2.19
2017	4.43×10^{15}	2.78×10^{14}	6.27	17142	2.36
2018	4.08×10^{15}	2.25×10^{14}	5.52	18286	2.52
2019	5.12×10^{15}	7.38×10^{14}	14.43	19255	2.65
2020	6.68×10^{15}	1.68×10^{15}	25.19	14305	1.97
2021	3.99×10^{15}	1.65×10^{14}	4.14	15162	2.09
2022	4.41×10^{15}	2.94×10^{14}	6.68	13432	1.85
2023	5.48×10^{15}	8.09×10^{14}	14.76	16485	2.27

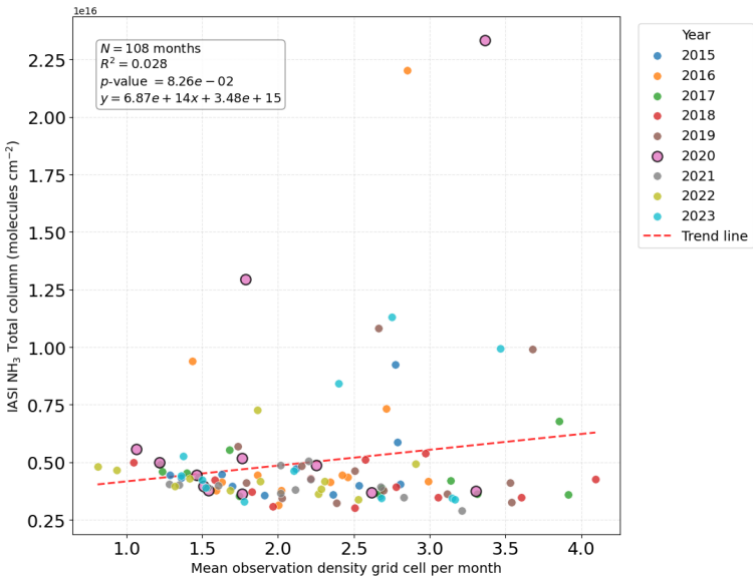


Figure S9: Correlation analysis of the concatenated monthly NH₃ total column and observation per grid cell per month over Guatemala (2015–2023), each point represents the monthly average with a specific colour by year. The weak correlation (R²=0.028 and p<0.001) suggest the annual variability of NH₃ that is large independent of sample frequency. The 2020 (black edge circle) demonstrate highest column (April, top-right) despite the moderate observation sample density.

Figure 2: How much do the measurements vary between the three IASI instruments? Can you show some statistics of NH₃ columns by instrument? Without knowing this, this figure feels like comparing apples to oranges because not all years are covered by the same IASI instruments.

It would also be interesting to see if the number of IASI pixels are significantly different 1) between the years, and 2) between the low concentration grids and high concentration grids. This helps to understand whether the low concentrations are affected by sampling bias. Can you also describe how the IASI algorithm handles spatial averaging/weighting in the L3 data?

We thank the reviewer for this comment. To ensure continuity across IASI instruments, we conducted a comparison using IASI-B (January 2015–December 2023) as the reference sensor because covers the long-term period analysis compared with A (January 2015–December 2020), and C (January 2020–December 2023). During overlapping observation periods, the sensors exhibited strong agreement. The comparison between IASI-A and IASI-B, based on 72 overlapping months, yielded a coefficient of determination (R^2) of 0.93. In comparison, IASI-C and IASI-B, with 48 overlapping months, demonstrated a stronger relationship with $R^2 = 0.98$. Linear regression slopes were 0.96 (IASI-A and IASI-B), and 0.99 (IASI-C and IASI-B), neither was statistically different from 1 ($p > 0.05$), indicating strong agreement between the instruments. A paired t-test revealed no statistically significant mean difference between IASI-A and IASI-B ($p = 0.18$), while IASI-C and IASI-B was statistically significant ($p < 0.01$). However, the magnitude of this difference was small, with mean biases of -1.46×10^{14} molecules cm^{-2} for IASI-A versus IASI-B and 2.45×10^{14} molecules cm^{-2} for IASI-C versus IASI-B. These values are minor compared to the long term mean total column over Guatemala (5.01×10^{15} molecules cm^{-2}) and with the standard error (1.65×10^{14} molecules cm^{-2} to 1.68×10^{15} molecules cm^{-2}), (Table S9). The corresponding to relative differences of approximately 2–5% of the mean column are smaller than the observed annual and climatology variability, therefore the concatenated dataset is suitable for our study with long term column analysis over Guatemala.

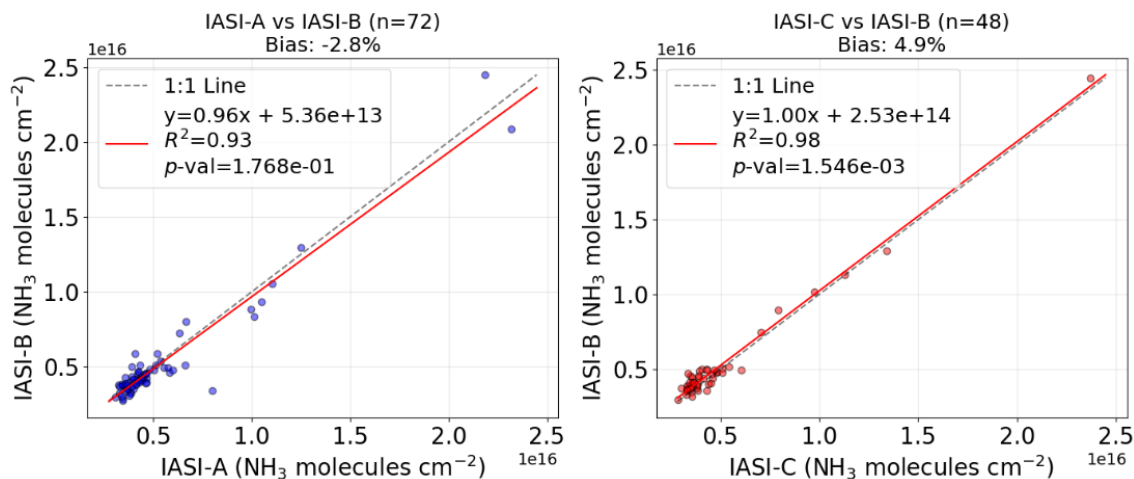


Figure S8: Scatter plots monthly mean comparison of IASI A/B/C sensors. (Left), IASI A-B for 73 overlapping months. (Right), IASI C-B for 48 overlapping months.

For the observation sampling bias, the annual mean sampling density remained robust through the study period (1.85–2.65 obs. grid cell month per month). Specifically for the year 2020 (1.97 obs. grid cell month per month) where was the highest mean total column of NH_3 , this value is 17% relative lower respecting the previous year for the observation density, likely due to increase on cloud cover, however it reminded sufficiently to obtain the maximum of NH_3 .

Regarding the relationship between observation and total column, the Fig. S9, shows a linear regression between monthly total columns of NH_3 and observations density across the 108 months. It demonstrates no significant correlation $R_2=0.028$ and no significance with $p=0.082$.

The spatial area-wide mean observation grid cell ranged from 0.68–3.68 obs. grid cell month per month. The lowest observation occurs over high altitude terrain (~ 2700 m a.s.l.), located in the Sierra de las Minas, Alta Verapaz department (approx. 15.19°N , 89.69°W). In these areas, persistent cloud cover associated with the tropical cloud forest that is characterized by high annual precipitation ($600\text{--}2500$ mm yr^{-1}), elevated relative humidity (67%–95%), and lower surface temperatures (5° to 25°C) (Chaluleu, 2020; Holder, 2003, 2006). This extreme condition frequently limits infrared retrievals.

Finally, the L3 algorithm utilizes arithmetic averaging of $0.25^\circ \times 0.25^\circ$ grid cell presented in level 2 (L2) pixel centres falling within that cell. Thus, no extra spatial interpolation or distance based weighted were applied, to ensure that L3 dataset remains of its original IASI measurement. By concatenating IASI A, B and C, we used a total of 228 observations of sensor months over the 108 months of the study period increasing the signal to noise ratio and spatial representativeness.

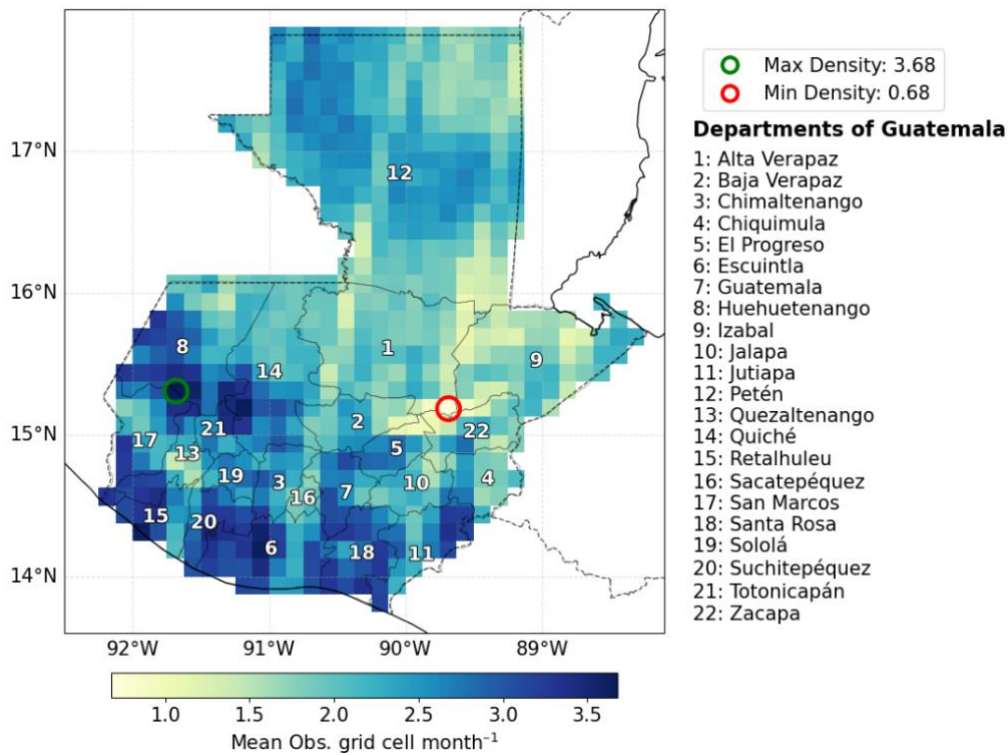


Figure S10: Spatial area-wide of means of observation grid cell month per month over Guatemala (2015–2023), representing the highest and lowest distribution detection, green circle showing the highest and with the red circle showing the lowest density obs. located in Sierra de las Minas, Alta Verapaz department (15.19°N, 89.69°W).

Table S10: Annual summary of statistics of the observation density grid cell per month and pixel per month over Guatemala (2015–2023)

Observation density grid cell per month					
Year	Annual Mean	Standard deviation	Min	Median	Max
2015	2.16	0.57	1.29	2.24	2.81
2016	2.19	0.52	1.44	2.18	2.99
2017	2.36	1.02	1.22	2.21	3.91
2018	2.52	0.86	1.04	2.54	4.09
2019	2.65	0.68	1.74	2.59	3.68
2020	1.97	0.76	1.07	1.76	3.37
2021	2.09	0.60	1.28	2.07	3.21
2022	1.85	0.64	0.81	1.87	2.91
2023	2.27	0.77	1.36	2.25	3.47
Pixel per month					
Year	Annual Mean	Standard deviation	Min	Median	Max

2015	1177	401	575	1137	1679
2016	1222	375	785	1155	1797
2017	1316	663	574	1205	2332
2018	1391	571	485	1421	2464
2019	1492	479	755	1423	2223
2020	1145	488	573	991	2037
2021	1140	389	598	1112	1868
2022	978	428	300	1036	1741
2023	1249	521	669	1297	2097

L407: “...which points to a general inverse relationship where higher NH₃ concentrations tend to coincide with lower PBLH values, and vice versa. This pattern suggests that a shallower boundary layer, which restricts the vertical dispersion, leads to an accumulation of NH₃ near the surface.” This explanation would hold true for surface NH₃ concentrations. However, IASI measures vertically integrated columns which are less sensitive to fluctuations in BLH. Figure 7 also does not quite reflect an inverse relationship between IASI and BLH. In fact, the Pearson correlation matrix in Figure S3 even shows NH₃ and BLH are moderately positively correlated.

We thank the reviewer for pointing this out. In the old version, the description related of the NH₃ and BHL was imprecise and could lead to confusion. In the revised manuscript, Fig. 7, we use a boxplot distribution of meteorological variable rather than combining them with NH₃ timeseries. Now the analysis focuses on the statistical variability of BLH, temperature, relative humidity, and precipitation. Additionally, the quantitative relationship of NH₃ and meteorological variables in the Pearson correlation is described in the discussion section. Also, the old version Fig. 7 timeseries has been moved to supplementary document (Fig. S4).

REVISED MANUSCRIPT (L346-L365)

Figure 7 illustrates the variability of meteorological variables derived from monthly scales over Guatemala from ERA5. Fig. 7 (a,c), exhibit the BLH and precipitation. The BLH shows fluctuations with the highest median recorded in 2019 (524 m), in contrast to the lowest median observed in 2017 (415 m) which also demonstrated the minimum value (305 m) (Table S6). The maximum vertical value was detected during 2020 (791 m) indicated a large data range. At the monthly scale, April shows the highest BLH (median 671 m) and lowest during October (median 348 m). Furthermore, the precipitation indicates that the annual distribution of monthly totals presents the highest median values recorded in 2020 (69 mm) and 2022 (55 mm), while the lowest median is observed in 2019 (34 mm) which also shows the minimum value (7.5 mm). The maximum monthly exceeds

130 mm (2017 and 2022). The monthly climatology presents peaks medians precipitation in the month of June (97 mm), and September (95 mm), while the lowest in February (13 mm).

Fig. 7(b,e) present the air temperature and relative humidity. The warmest median temperature during the year 2023 (22.8°C), whereas the maximum temperature was detected during 2020 (27.9°C). The coldest temperature was recorded during 2018 with 20.2°C. Additional, the warmest month is May (median 26.4°C) and the coldest is January (21.9°C). Relative humidity showed the highest median observed during 2016 (81%), while the lowest median year was 2019 (76%), the minimum year detected was 2020 with 63%, this also showed the largest vertical values. The years 2017 and 2022 exhibit the maximum values with 87%. The month medians indicate the lowest in April (mean 71%) and the highest in October (mean 84%).

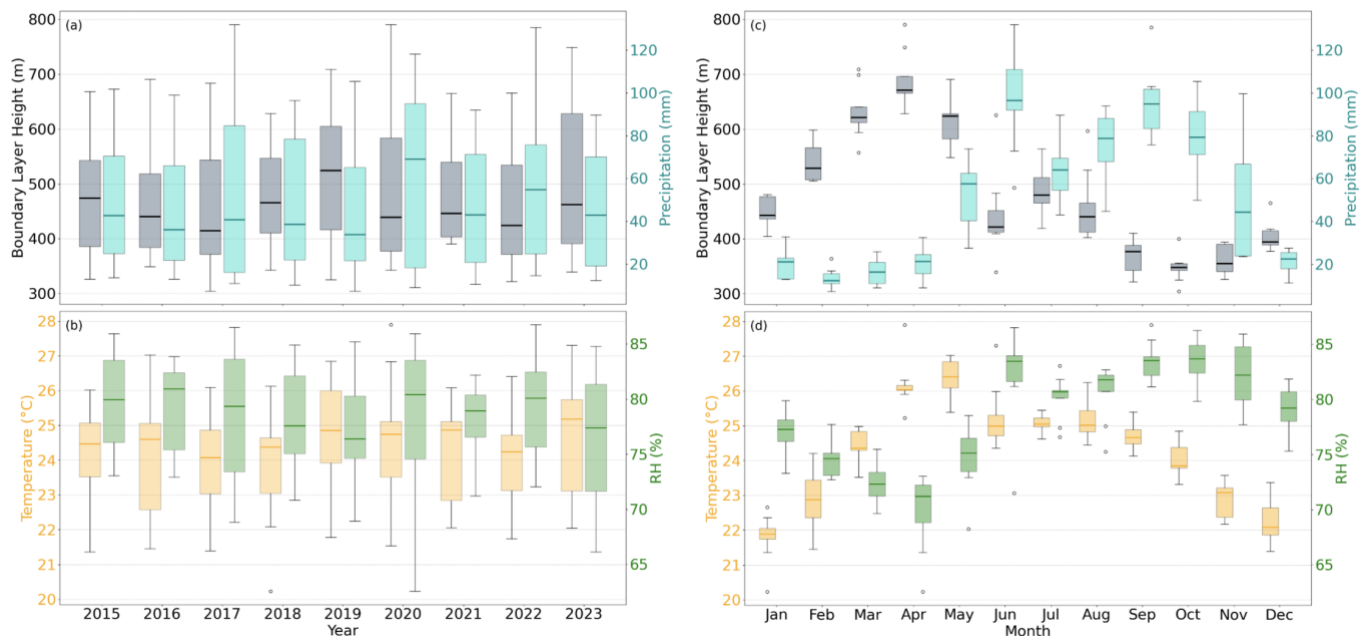


Figure 7: Boxplot distribution of meteorological variables over Guatemala (2015–2023) from ERA5 reanalysis, (a, c) show boundary layer height (m) (gray) and precipitation (mm) (turquoise), (b, d) relative humidity (%) (green) and temperature (°C) (yellow).

L565: Sometimes I find it difficult to associate the argument with the results supporting it. For example, here it says the high number of fires in April 2020 was likely driven by prolonged dry conditions. This initially confused me because the following sentence says the year 2020 recorded the highest total precipitation. I had to look through the paper again to see that April 2020 indeed had one of the lowest monthly precipitations according to Figure 7, but this was never explicitly called out.

We thank the reviewer for this important comment regarding more clarity of fires and atmospheric conditions during April 2020, which might lead to confusion. While 2020 showed of the highest annual total precipitation (707 mm) (Table S6), the

dataset also shows relatively low minimum month precipitations (9 mm) following 2019 (7.5 mm), indicating the occurrence of the shortly dry period within that year. This year coincide with peak fire activity, highest temperature recorded (27.9° C) and highest BHL (791 m), created favourable conditions of fire increase and observed NH₃ peak (Fig. S4) (L446–465).

Finally, a lot of interesting results presented in Figure S3 were never discussed in the main text. In particular, it was mentioned in section 2.1 that the interrelationships between NH₃ and other air pollutants (NO₂ and SO₂) will be explored, but they were not. Also, what are the sources of the NO₂ and SO₂ data (satellite observations or surface measurements)?

We thank the reviewer for this comment. In the revised manuscript we wanted to keep the consistency of NH₃ and variables not direct discussed were removed from the analysis (surface pressure (sp), Nitrate Dioxide (NO₂) and Sulphur Dioxide (SO₂)). In the old version the NO₂ and SO₂ were retrieved from global reanalysis CAMS.

Minor comments:

L81: When you say “previous research has often overlooked the integrated role of multiple environmental drivers...” without giving examples, it is unclear to me which studies you are referring to, since you also mention there is a significant lack of studies on Central America. Can you add some references?

Thank you for the suggestion. In the revised manuscript, for the Introduction section, we have revised and clarified the paragraph, regarding the limited integration of multiple variables to assess the integrated analysis combining NH₃, fires, meteorology, and land cover.

REVISED MANUSCRIPT (L71-L77)

Despite the increasing availability of satellite-based datasets for monitoring atmospheric NH₃, there remains a significant lack of regional-scale studies in Central America, particularly in Guatemala, where land use dynamics and biomass burning are likely to play an important role in shaping substantially to atmospheric NH₃ patterns. Previous research has primarily examined individual drivers, such as meteorological circulation and fire season in Central America (Corona-Núñez and Campo, 2023; Liu et al., 2024), or continental scale assessment of NH₃ variability (Clarisse et al., 2009; Van Damme et al., 2021; Herrera et al., 2022; Luo et al., 2022; Zhu et al., 2015). However, integrated regional analysis that simultaneously consider concatenated NH₃, fire activity, land cover and meteorological variables remain limited.

L174: The authors may also want to double check the existing citations. For example, the 2012 paper cited here seems unrelated to IASI.

We thank the reviewer for the comment. In the revised manuscript we have made the corrections regarding the correct citation for IASI (L119).

L195: This equation does not look right. It is missing an equal sign, and the square root sign should extend further. Please double check this equation and also Equation (2).

We thank the reviewer for raising this point, in the revised manuscript we have made the corrections for equation (1) (L161) and (2) (L167).

L240: This should be Equation (3).

In the revised manuscript we have made the corrections and add the Equation (3) (L219).

L314: “3.2 Land cover classification driven a k-means clustering of NH₃ emissions” This subtitle needs some grammar editing.

We thank the reviewer for the comment. In the revised manuscript we changed the subtitle (3.2 Land cover classification driven by NH₃ cluster k-means) (~~Land cover classification driven a k-means clustering of NH₃ emissions~~), (L274).

L341: Here it says Cluster 1 covers the smallest area compared to Cluster 2 and Cluster 3. However, the paragraph above says Cluster 3 has the smallest territorial extent. I do not understand the difference.

We thank the reviewer for this comment. In the old version, the contradictory text was made regarding the extent area of cluster 1 and 3. In the revised manuscript we modified the area supported by Table 1, and cluster 1 present the smallest area extent (~28,254 km²), cluster 2 with larger area extent (~45,662 km²) and cluster 3 with intermediate (~34,640 km²), (L280-L297).

L355: Why does it suddenly say ammonium (NH₄⁺) here?

We thank the reviewer for this comment. In the revised manuscript we change to specify NH₃ and not ammonium (L309).

L453: ppmv does not need to be in uppercase. Also, instead of writing 1.55×10^{-3} ppmv, it is more natural to say 1.55 ppbv.

We thank the reviewer for the suggestion. In the old version NH₃ mixing ratios were expressed in ppmv and total column units. In the revised manuscript the sentence has been corrected to consistently report CAMS reanalysis in mass mixing ratios kg kg⁻¹. The ppmv notation has been removed and no conversion to column unit is applied in this section to ensure the dimensional

consistency. Therefore, we use to illustrate the NH_3 structure in (kg kg^{-1}), rather than for quantitative comparison with IASI total column (Results, L381-L396). Additionally, we explain in the methodology section the description regarding the vertical and latitudinal profiles from CAMS mass mixing ratios (Methodology, L140-L148).

REVISED MANUSCRIPT (Methodology, L140-L148)

Additionally, NH_3 vertical profiles data were obtained from the ECMWF, Atmospheric Composition Reanalysis 4 (EAC4), produced by CAMS. This reanalysis provides NH_3 with mass fraction in the air, provided as a mass mixing ratio (kg kg^{-1}), the model is defined by 60 hybrid sigma-pressure levels. It provides a detailed representation of the atmospheric structure, particularly near the surface (~0–100 m) where most emissions occur (Inness et al., 2019). These reanalysis datasets incorporate satellite observations and model simulations to provide globally consistent, spatially and temporally resolved atmospheric composition data (Flemming et al., 2017; Inness et al., 2019). In this study, the CAMS analysis of vertical structure and latitudinal distribution of NH_3 during a specific period of interest, rather than for a quantitative comparison with satellite of total column densities.

REVISED MANUSCRIPT (Results, L381-L396)

Figure 9a shows the vertical and latitudinal distribution of atmospheric NH_3 over Guatemala using zonal means and area averaged vertical profiles in mass mixing ratios (kg kg^{-1}). The zonal mean cross-section of NH_3 throughout the atmosphere (vertical axis, model level 60 to 44) along the latitudes of Guatemala as a zonal mean during April 2020. It highlights a greater abundance of NH_3 in both the northern and southern areas. Furthermore, the NH_3 vary with both latitude and altitude, the highest NH_3 are observed at lower model levels primarily confined near the surface (below approximately level 56). The highest NH_3 values are found between 14°N and 15°N latitude.

Fig. 9b further illustrates the area average vertical profiles of NH_3 for April (blue line), spring (March – May, green line) and the annual mean 2020 (black dashed line). The vertical profile of NH_3 shows the April 2020 mean (blue line) with $\sim 1.0 \times 10^{-9} \text{ kg kg}^{-1}$, the spring mean (March–May 2020, green line) of $\sim 0.9 \times 10^{-9} \text{ kg kg}^{-1}$ and the annual mean for 2020 (black dashed line) with $\sim 0.5 \times 10^{-9} \text{ kg kg}^{-1}$ respectively.

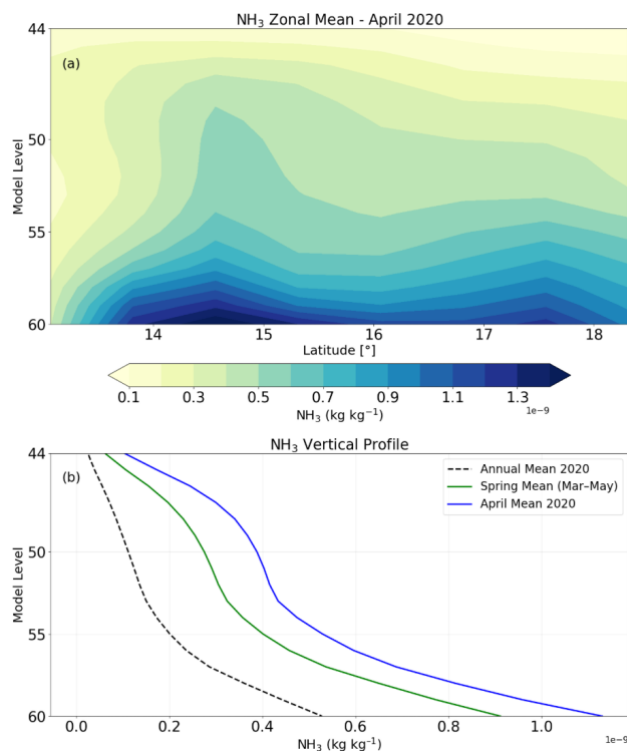


Figure 9: (a) zonal mean of NH₃ mass mix ratio (kg kg⁻¹) total column ($\times 10^{16}$ molecules cm⁻²) across latitudinal bands (model level 60 to 44) for April 2020 and (b) vertical profile of NH₃ mass mix ratio (kg kg⁻¹) for April (blue line), spring (March – May, green line) and annual mean 2020 (black dashed line) over Guatemala from global reanalysis CAMS.

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