Reviewer 1

In this manuscript, Yoon et al. present analysis of isoprene column satellite data in three different tropical regions: Amazonia, the Maritime Continent, and equatorial Africa. The authors propose three distinct chemical/environmental regimes that are responsible for the observed variability in isoprene concentrations, with Amazonia and the Maritime Continent representing the extremes of emissions- and chemistry-controlled, respectively, while equatorial Africa represents a mixed regime, where emissions and chemistry dominate the isoprene column variability to differing extents.

The presented analysis is interesting, well presented, and appears to be methodologically sound. Though no strong conclusions around the drivers of isoprene column variability in the Maritime continent are made by the authors, the drivers in the other two regions seem convincing. In all, the presented framework is a useful lens through which to interpret the potentially counter-intuitive observations that isoprene concentrations may not correlate well with optimal conditions for isoprene emissions, or with formaldehyde anomalies, in certain locations.

We thank the reviewer for their kind comments on the manuscript.

I recommend the article for publication in ACP after the following comments and corrections are addressed.

Comments

Line 81-84: The claims in this paragraph are not clearly supported by Figures 1c and 1d. While the description of the isoprene anomaly for Amazonia is reasonably accurate, the Maritime Continent anomaly regularly drops below 0 during 2019-2020, including at the same time as Amazonia towards the final quarter of 2019. In any case, this does not impact the analysis as the authors do not discuss these 2019-2020 trends further, meaning that this section could probably be removed.

We appreciate this point from the reviewer and acknowledge that the isoprene anomalies over the Maritime Continent do sometimes drop to 0 during 2020. We include this detail to highlight the differences between the global anomalies analyzed in Yoon et al., GRL (2025) and the regional anomalies investigated in this paper. 2020 serves as a point of comparison for the regional anti-correlation in 2015.

We have adjusted the manuscript as follows to emphasize the broad trends in isoprene anomalies rather than the month-to-month variability:

Line 97: In 2020, both Amazonia and Maritime Continent had **broadly** positive isoprene anomalies **for most of the year** until October 2020, when Amazonia dropped below its climatology while isoprene over the Maritime Continent stayed elevated. These responses resulted in some of the highest global isoprene anomalies over the 8-year period

Section 3: The authors do not discuss biomass burning at all in section 3, but then later reference it as a potential contributor later in the paper. I would suggest at least introducing the concept as a potential hypothesis at this point and potentially move some of the analysis regarding the Maritime Continent presented in Section 4 into this section.

We thank the reviewer for noting the lack of discussion for biomass burning in the Maritime Continent section, which can make the later mention of biomass burning in Section 5 (Discussion) feel abrupt. In response, we have made the following changes to Section 3:

1) We have moved the following paragraph from Section 5 (Discussion) to the beginning of Section 3, and adjusted the wording to reaffirm the role of biomass burning on [OH]:

Line 161: In addition to isoprene emissions, variability in local [OH] (e.g. from NOx sources) can affect isoprene columns. Shutter et al. (2024) found that biomass burning NOx modulated OH and isoprene columns over New Guinea. However, the impact of biomass burning is episodic: in New Guinea, it was largely relegated to January–May 2016, thus not covering the entire ENSO period (Shutter et al., 2024). Therefore, due to its episodic nature, biomass burning is unlikely to explain all of the isoprene variability observed over the Maritime Continent, although it is still an important driver of isoprene columns over the region.

To explain the continuous positive correlation between isoprene and precipitation over the entire 8-year record, we focus on the following four hypotheses:

…

We detail each potential hypothesis for this relationship and ultimately suggest that soil NO_x, **biomass burning NO_x,** and/or a combination of lightning and convection are the most likely causes for this unexpected relationship.

2) In Section 5, we have modified the wording to better include biomass burning:

Line 371: For the Maritime Continent, we described three hypotheses for the observed isoprene-precipitation relationship**, which are in addition to established, episodic contributions from biomass burning NO_x:** (1) soil NOx in oil palm plantations modulating [OH]; (2) satellite artifacts due to increased cloud cover or water vapor; and (3) convection and lightning affecting isoprene retrievals and chemistry.

Line 165: As the authors note in Lines 21-22 of the introduction, the response of [OH] to changes in [NOx] can be complex and non-linear. The authors should justify why they expect decreased NOx emissions to result in decreased OH in this chemical environment specifically.

We acknowledge that the relationship between [OH] and [NOx] can be nonlinear depending on the local chemical regime. In response, we have added the following sentence to the manuscript:

Line 187: This decreased soil NOx would result in less OH **due to the low-NOx chemical regime typically observed in the tropics outside of urban areas**, and would subsequently increase isoprene columns.

Figure 7: For panels (a), (b), and (c), it would be useful to see the entire temperature and GFED4 time series compared against the ISOP column anomalies, even if this is only as additional supplementary figures.

We have added the following figure into the supplement:

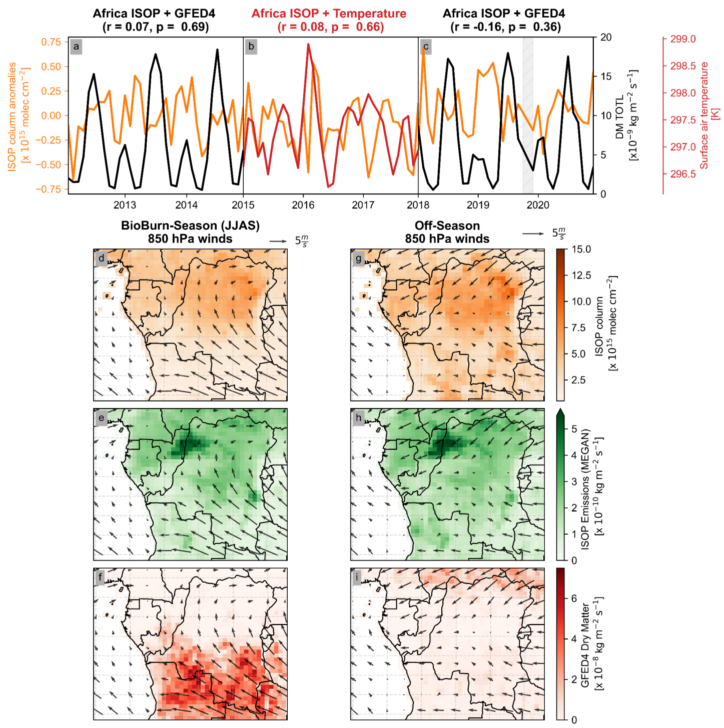

Figure S9: **Non-anomalized values in Africa**. Figure 7 in the manuscript but with GFED4 dry matter and surface air temperature from MERRA-2 plotted in (a, c) and (b), respectively.

And added a mention in the paper in Figure 7's caption:

Caption: In both seasons, the 850 hPa winds would advect smoke and thus NOx toward the areas with the highest isoprene columns and emissions. **An analogous plot with the non-anomalized GFED4 dry matter and surface air temperature can be found as Fig. S19.**

Line 309: It would be interesting for the authors to consider the potential impact of isoprene oxidation by the nitrate radical (NO3) on this analysis, as well as the direct ozonolysis of isoprene. Though both of these processes are predominantly night-time processes, a depletion of isoprene in the night-time could persist into the day-time and reduce background concentrations. This is particularly true given the reduced photolysis that may be provided by a biomass burning smoke plume.

Line 318: As with the reference to the change in [OH] in the maritime continent, the authors should explicitly state why they expect increases in NOx to increase [OH], considering the variability in HOx partitioning mentioned at this line.

Great point, we have added the following paragraph to Section 4.

Line 354: Importantly, although high NOx emissions in NOx-saturated regimes (e.g. in some flaming wildfire plumes) can decrease [OH] through increased HNO_3 and $RONO_2$ formation, these increases in NOx emissions generally co-occur with increases in HOx production from species like HONO (Jin et al., 2021). HONO in particular is an important source of OH in early-stage (<3 hour) plumes (Fredrickson et al., 2023; Peng et al., 2020). Furthermore, enhanced NO_3 and O_3 downwind of wildfires can provide alternative pathways for isoprene oxidation, which can become important in thick plumes with reduced photolysis or at nighttime (Millet et al., 2016). This positive correlation between biomass burning NOx and isoprene loss via OH or other oxidants is consistent with our GEOS-Chem simulations, which is further described in Section 6.

Minor Comments

Line 19: [OH] should be defined as OH Concentration.

We have modified the manuscript as follows:

Line 19: Of recent interest is the impact of **OH concentrations ([OH])** on methane oxidation, which determines the methane lifetime and thus its global warming potential

Line 89: ENSO acronym should be defined.

We have defined the ENSO acronym as follows:

Line 56: Of special interest when investigating isoprene variability is the relationship between the El Niño-Southern Oscillation (ENSO) and isoprene emissions and columns.

Reviewer 2

The authors use novel retrievals of isoprene from the space-based CrIS instrument to evaluate drivers of isoprene abundances in three regions of the tropics. They deduce that Amazonia is emissions controlled, the Maritime continent is chemistry controlled, and equatorial Africa is a mix of both. The manuscript is reasonably well written, though a little meandering in the discussion of the results and in need of a dedicated methods section with a consolidated discussion of the CrIS isoprene dataset used.

We thank the reviewer for their thorough comments on the manuscript.

General and specific comments for the authors to address before publication in ACP are detailed below.

General Comments:

Given the prominence of ENSO in the abstract and results, the introduction should include a paragraph detailing how ENSO affects isoprene in the tropics.

We have added the following sentences to the Introduction to provide background for the ENSO-isoprene relationship:

Line 55: However, few studies have used these retrievals to analyze global isoprene variability and compare isoprene emissions and chemistry across different tropical regimes. **Of special interest when investigating isoprene variability is the relationship between the El Niño-Southern Oscillation (ENSO) and isoprene emissions and columns. Previous studies have shown increased global isoprene emissions during El Niño and lower emissions during La Nina largely due to changes in temperature and radiation, with the potential for strong El Niño to increase isoprene emissions for years after the event (Vella et al., 2023; Li et al., 2026).**

Methods detailed are peppered throughout the manuscript (specifically for CrIS isoprene and treatment of these data) or relegated to an appendix section. Given the journal format, these can be more conveniently consolidated to a Methods section, thus enhancing the reproducibility and traceability of the study. This dedicated section should include details of the CrIS instrument used, the retrieval method, priors used in the retrieval, data screening, and any quantitative assessment of the retrieved product so that the reader has context for the core data used throughout the study.

We appreciate this comment from the reviewer. After iterating on the structure multiple times, we have settled on this particular framing because many of the methods are only used in a specific section (e.g. the radiative transfer model or the GEOS-Chem simulations). Because of the variety of methodologies used throughout the study, we felt it was most appropriate to introduce the different methods as they are introduced in the Results/Discussion and to have more comprehensive descriptions of the methods in the Appendix.

That said, we absolutely agree with the reviewer that we should have a more detailed description of the CrIS retrievals in the Methods, so in response, we have moved the CrIS description into its own subsection and elaborated on the CrIS methods.

Line 67: CrIS is an infrared Fourier-transform spectrometer with spectral resolution of 0.625 cm^{-1} in the longwave band (650-1095 cm^{-1}) aboard the Suomi NPP satellite in sun-synchronous orbit with an equator overpass time of approximately 1:30 PM local time. This spectral range encompasses the bands where isoprene absorption is the strongest (v_{28} and v_{27}) with minimal interference from other species (Brauer et al., 2014). At nadir, CrIS has a footprint 14 km in diameter. The footprints are cloud-masked based on the difference between MERRA-2 surface temperatures and the 900 cm^{-1} brightness temperature. The choice of the cloud mask threshold provides less than 5% uncertainty to the overall retrieval (Wells et al., 2022).

Similar to the IASI ammonia retrievals described in Whitburn et al. (2016), the CrIS isoprene retrieval first calculates a hyperspectral range index (HRI) between 890-910 cm^{-1} for each CrIS footprint. The HRI, background spectrum, and covariance matrices are solved iteratively. The CrIS HRIs are then gridded and fed into a neural network trained on synthetic radiances simulated by the Earth Limb and Nadir Operational Retrieval (ELANOR) radiative transfer model, with the ELANOR inputs being temperature and water vapor profiles from GMAO, and GEOS-Chem isoprene profiles with Gaussian noise. To quantify isoprene columns from CrIS observations, the neural network uses thermal contrast, water vapor columns, surface pressures, and the viewing angle as inputs in addition to the HRI, and outputs daily isoprene columns from -60° to 60° latitude at 0.5° x 0.625° spatial resolution. The final retrievals show general agreement with ground-based isoprene measurements, as demonstrated with Fourier-transform infrared measurements taken from Porto Velho in Brazil (r = 0.47 using daily CrIS retrievals) (Wells et al., 2022). We remove October and November 2019 from our analysis due to potentially anomalous striping, as described in Yoon et al (2025b). More information on the isoprene retrievals and their evaluation can be found in Fu et al. (2019), Wells et al. (2020), and Wells et al. (2022). Although Fu et al. (2019) uses optimal estimation to retrieve isoprene columns, as compared to the artificial neural network used in Wells et al. (2020, 2022), both methods show strong agreement and similar spatial distributions over Amazonia (r > 0.9) (Wells et al., 2022).

For filters, is there any screening for contamination from biomass burning isoprene and what proportion of data is removed with the cloud masking? The latter is important for assessing whether there is potential for representation error in a region that is often cloudy.

Biomass burning is not a significant source of isoprene except in areas with low biogenic emissions (e.g. the mid-latitudes in the winter, where combustion-produced isoprene can become significant) (Zhang et al., 10.1093/nsr/nwae474; Andreae, 10.5194/acp-19-8523-2019), and we expect spatial separation between biomass burning regions and major isoprene source regions. Therefore, it is unlikely that isoprene from biomass burning affects our conclusions in the tropics. We also note that biomass burning plumes are generally transparent in the thermal infrared, as many of the particles are << 10 um. In tropical forests, the median carbonaceous particle size from biomass burning is ~100-150 nm in diameter (Reddington et al., 10.5194/acp-16-11083-2016). Therefore, smoke plumes should not be removed by the 900 cm^{-1} cloud mask.

As for the number of datapoints removed by the cloud masking, we have added the following figure to the supplement. In general, at least 20–60% of the grid points within the three tropical regions have non-cloudy scenes each day.

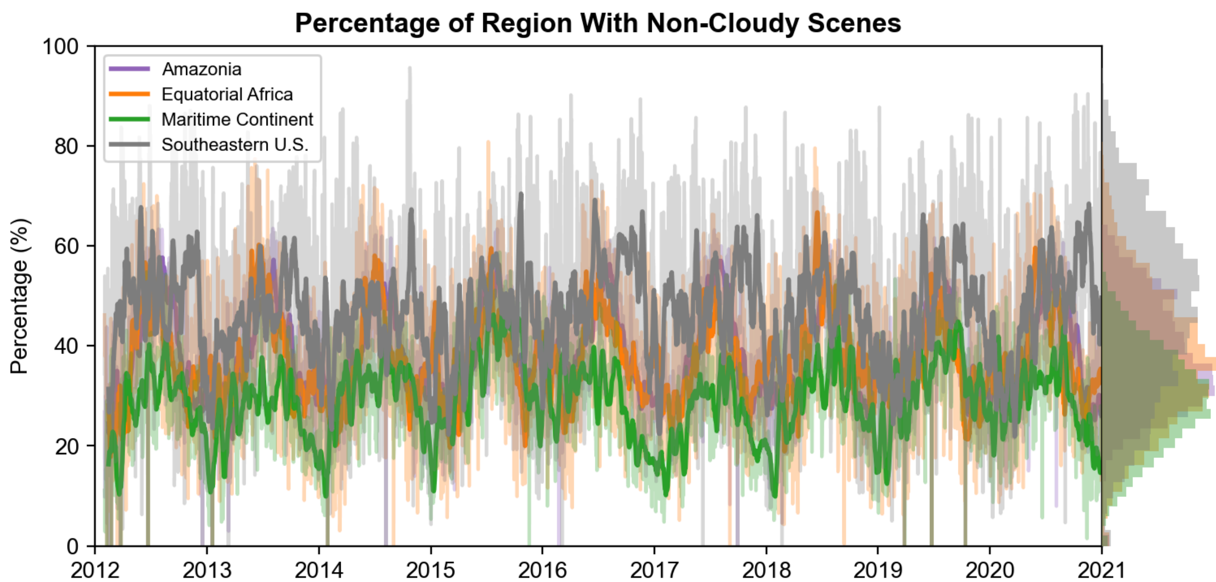

Figure S5: The percentage of the given region with non-cloudy scenes every day, with the 14-day centered rolling mean overlaid on top. All three tropical regions of interest are plotted, as well as the Southern United States (bounding box: [minimum longitude = -98.525391, minimum latitude = 24.607069, maximum longitude = -68.291016, maximum latitude = 40.446947]) for comparison. On the right are histograms showing the distributions of all four regions.

We have also added a reference to the supplemental figure in the Methods section:

Line 73: In general, 20-60% of the gridpoints within the tropical regions of interest contain non-cloudy scenes each day (Fig. S5).

Not discussed is the potential effect of vertical sensitivity of the instrument on the analysis. A major disadvantage of the retrieval method used is that it does not output averaging kernels, so it is not possible to assess the information content to determine whether the retrieved product is being informed mostly by the prior or the observations. The IASI NH3 product that first used the retrieval method applied to retrieve CrIS isoprene has developed an approach to calculate averaging kernels (Clarisse et al., 2023). The same might not be the case yet for CrIS isoprene. Some discussion is needed regarding the implications of the quality and information content of the CrIS data used and the potential impact on the study findings.

We thank the reviewer for noting the importance of the instrument's vertical sensitivity. In our discussion section, we note that a new isoprene retrieval is currently in development that would account for some of this vertical profile dependence using the P_{90}, and suggest that vertically-resolved modeling (e.g. large-eddy simulations) is necessary to fully address these hypotheses. We also mention the sensitivity studies conducted in Wells et al. (2022) about the vertical profiles in the Discussion. Furthermore, although the retrieval does not calculate averaging kernels, the simulated HRIs in the neural net's training set reflect the vertical sensitivity in the thermal infrared in an ensemble sense.

We realize that the lack of an averaging kernel may have been unclear in our first submission. We expanded on the text in Section 4 here:

Line 261: **Unlike traditional optimal-estimation satellite retrievals, the CrIS isoprene retrieval does not calculate an averaging kernel, resulting in uncertainty from the species' vertical distribution.** In the CrIS isoprene retrieval, Wells et al. (2022) calculated up to a 20% error associated with vertical profile uncertainty within the boundary layer, which was calculated by comparing a full-mixing scheme that instantaneously mixes isoprene from the surface throughout the entire boundary layer to GEOS-Chem's default non-local mixing scheme. We conducted an additional sensitivity test in vSmartMOM by changing the isoprene vertical profile to set an upper-bound on convection's impact on isoprene vertical profiles (Fig. 6c). Our results reveal an HRI increase when isoprene is lofted, which would result in a higher retrieved column if the effect were not considered. Wells et al. (2022) obtained similar results under dry conditions, but under humid conditions showed that the sign of the effect can depend on the relative vertical locations of isoprene and water.

It is not apparent that assessment of a representation error due to screening for clouds is suitably tested, as described in Section 3.2. The effect on the CrIS isoprene retrieval is tested, but not the effect on only considering scenes that are cloud masked. It would be worthwhile to evaluate whether any of the findings could potentially be affected by this cloud masking, especially in the tropics where clouds are abundant and dense and so may induce effects like relatively low temperatures and limited incoming radiation, impacting isoprene emissions.

The reviewer brings up an important point about how the dense cloud cover over the tropics may result in representation bias over time. As shown in Fig. S5, approximately 20-60% of the tropical regions have non-cloudy retrievals every day. We have also made the following supplemental figure, which shows the correlation between the number of CrIS footprints within each gridbox (Ndata, in black) and the mean isoprene column anomaly (in color).

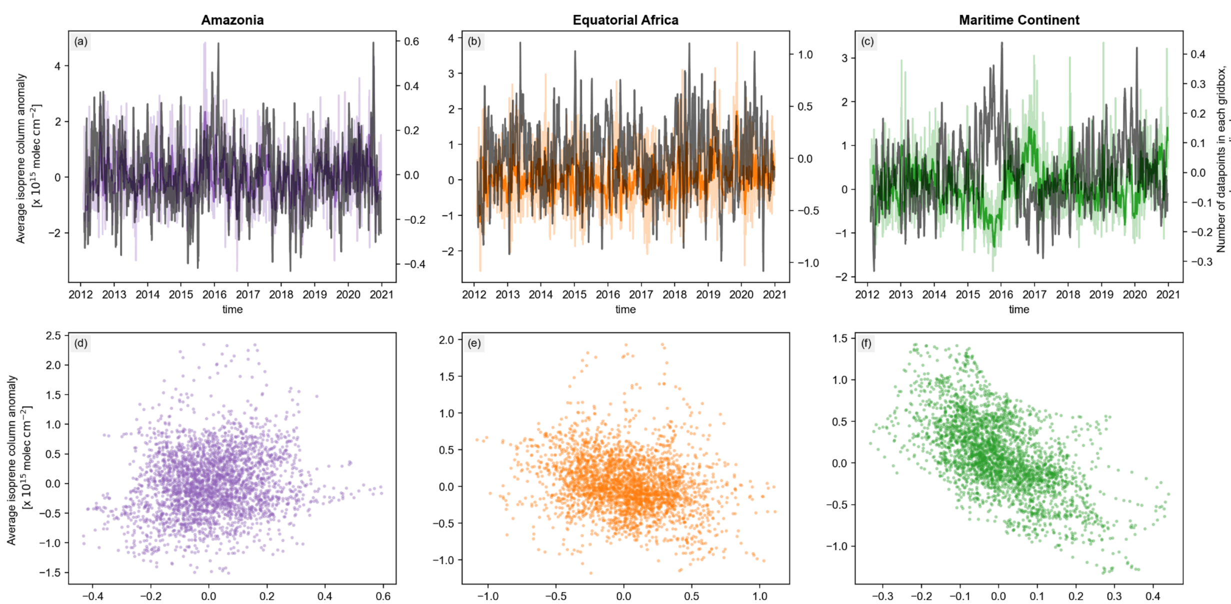

Figure S6: (a, b, c) The correlation between the average number of non-cloudy CrIS footprints within each 0.5° x 0.625° gridbox (in black, deseasonalized) and the spatially-averaged isoprene column anomaly (in color) for the three tropical regions. Both variables are smoothed using a 14-day centered rolling mean. (d, e, f) The same 14-day centered rolling means plotted against each other.

When looking at daily correlations between the deseasonalized data coverage and the average isoprene column anomaly, we observe a weak positive correlation in Amazonia, a weak negative correlation in equatorial Africa, and a stronger negative correlation in the Maritime Continent. Evidently, we do not see a consistent bias across regions between the number of datapoints and isoprene columns.

Focusing on the Maritime Continent, we also note that this negative correlation between the number of datapoints and the average isoprene column anomaly would translate to a positive correlation between cloud cover and average isoprene column anomalies (as higher cloud cover → lower Ndata). Higher cloud cover would decrease surface temperatures and incoming PAR, which would decrease isoprene columns via both isoprene emissions and the isoprene-OH feedback. This response would run counter to our observed relationship. For representation error to solely explain our observations with no impact from NO_x sources, it would have to be strong enough to counter both the isoprene emission response and isoprene-OH feedback.

We have added the following sentences to the radiative transfer section:

Line 242: To test the retrieval's sensitivity to clouds and water vapor, we (1) halved and doubled water vapor, and (2) added aerosols to mimic a low cloud that is not screened through the 900 cm^{-1} brightness temperature mask. Low clouds that unexpectedly pass the retrieval's cloud mask would mute the isoprene signal, which would lead to lower isoprene retrievals, in opposition to the observations (Fig. 6a). Additionally, water vapor is an input to the retrieval's artificial neural network and its fluctuations are therefore directly accounted for in the measurements; it also has lower absorption at wavenumbers where isoprene absorption is strongest (894 cm^{-1} (Fig. 6b). **Moreover, although cloud masking over tropical regions with dense cloud cover may result in representation bias by selecting for clear scenes, there is no consistent bias across regions between the number of non-cloudy datapoints and isoprene column anomalies (Fig. S6).** Thus, we conclude that clouds and/or water vapor are unlikely to cause this observed correlation between isoprene and precipitation over the Maritime Continent.

Past literature targeting these regions is not sufficiently sourced, in particular the literature using satellite observations of formaldehyde to derive isoprene emissions and evaluate temporal trends and environmental drivers in emissions. Though these focus on emissions and the current study on abundances, there are findings and insights related to emissions that could be supported by these past studies. For example, Barkley et al. (2013) for estimating isoprene emissions in South America, Marais et al. (2012) in support of extensive transport of biomass burning across Africa affecting NOx, Marais et al. (2014) in assessing relationships between isoprene emissions and environmental drivers, and Stavrakou et al. (2015) for all 3 regions.

We thank the reviewer for suggesting these citations, and we have added references to these papers in Section 3.

<u>Specific Comments:</u>

L2: Fix order to “hydroxyl radical (OH)”.
We have made the requested change to the abstract.

L47: “especially as anthropogenic NOx emissions decrease” maybe true for most of the northern hemisphere, but can such a statement be made for the tropics? See for example, positive trends in urban NOx from Vohra et al. (2022) and decline in burned area in the tropics from Andela et al. (2017) affecting biomass burning NOx.
We appreciate the reviewer for pointing out this discrepancy. The statement was meant to be a broad overview of why non-anthropogenic NO_x emissions matter, but we acknowledge that tropical cities show different trends in NO_x than cities in the Northern Hemisphere. Since tropical isoprene is largely emitted in low-NO_x, remote forests, we chose not to discuss anthropogenic NO_x emissions from tropical cities, but for clarity, we qualified the sentence as follows:

Line 46: Validating modeled non-anthropogenic NOx fluxes and assessing their impacts on regional chemistry warrants continued investigation, especially as anthropogenic NOx emissions **in the Northern Hemisphere** decrease and non-anthropogenic (e.g. soil) NOx fluxes become more important (Song et al. 2021, Christiansen et al., 2024).

L49: “novel isoprene retrievals” is overstated and without context. This is an established retrieval method already applied to IASI NH3 (Whitburn et al., 2016), so including a reference to this methodology would make it clearer that this is a standard retrieval method for IASI NH3 that is now being successfully applied to CrIS isoprene and/or adapted to suit CrIS isoprene if this is the case.
We have modified this sentence to cite the Whitburn paper and to remove “novel”:

Line 49: Using isoprene retrievals from the Cross-track Infrared Sounder (CrIS) instrument on the Suomi-NPP satellite **processed analogously to the IASI ammonia retrievals described in Whitburn et al. (2016),**

L61: What is the source of the “50%” value? Past bottom-up or top-down studies? Or your own simulation of MEGAN?
We have modified the sentence to make it clearer that the 50% is from the CrIS isoprene retrievals:

Line 85: Amazonia, the Maritime Continent, and equatorial Africa are regions of special interest, as these regions account for 50% of the global isoprene column burden **from the CrIS record (2012-2020)**.

L113: provide quantitative values to demonstrate how much smaller the range in temperatures is in the Maritime Continent and equatorial Africa.
We originally provided quantitative values for the Maritime Continent in sentence 105, but we have added values for Amazonia for comparison:

Line 119: For instance, the spatially-averaged temperature anomalies (10th-90th percentiles) over the Maritime Continent never exceed 1 K over the eight-year period, **compared to Amazonia's >2 K temperature anomalies in 2015.**

L187: Rather starting the sentence as "According to the measurements, …" would ensure it's not written as though the measurements were responsible for providing this insight.
We have updated the sentence as follows:

Line 209: **According to measurements taken** in Sabah, Malaysia on the island of Borneo, boundary-layer NO, NO2, and PAN concentrations over an oil palm plantation were nearly double the concentrations detected over rainforest (Hewitt et al., 2009), highlighting a potential soil NOx source.

L272-273: is "input" correct here? If so, is this coming from the prior? And would this hold value to the user because it serves an indication of the skill of the retrieval?
No, the value to the user is that it allows the user to adjust the retrieval to any external constraint on the vertical profile shape. One can then, for example, do satellite-model comparisons that are internally consistent. Essentially the retrieval is performed across a range of P90 values and you can interpolate between these to compute the satellite column that corresponds to any imposed P90 value (e.g., one predicted by the model you are comparing to)

L286: "end-of-the-year" is stated, but biomass burning peaks in Amazonia and The Maritime continent in September.
We have modified the sentence as follows:

Line 315: In Amazonia and the Maritime Continent, both soil and biomass burning NOx have a seasonal peak **in the second half of the year** that coincides with a peak in isoprene emissions, columns, and temperature.

L290-300: Need to be specific that this is the timing of the dry season south of the Equator, as Sub-Saharan Africa has 2 distinct dry seasons.
We thank the reviewer for catching this mistake, and we have updated the sentence:

Line 318: Although there is some spatial heterogeneity between NOx and isoprene sources, seasonally-averaged 850 hPa winds are in the correct orientation to carry air masses from regions with heavy biomass burning toward isoprene source regions throughout the year, **but especially during the dry season south of the equator** (June-September) (Fig. 7).

L308: What is the logic of "which is consistent with high NOx emission factors from these fires."? Comparison to another region might help clarify the point being made.
The wording of the sentence was confusing, and so we have reworded the sentence as follows:

Line 334: May–July is when GFED4-derived biomass burning emissions are highest in equatorial Africa and the surrounding savannahs, **which generally coincides seasonally with flaming fires with higher NOx emission factors compared to fires later in the year.**

Figure 9 caption: Move portion of caption interpreting the content of the figure to the manuscript text.
We have removed the sentences interpreting the figure from the caption to the main text:

Line 417: These modeled relationships between formaldehyde, isoprene, and NOx are consistent with observed daily L3 satellite retrievals from the Ozone Monitoring Instrument (OMI) (Chance et al., 2024) that were bilinearly interpolated to the CrIS 0.5° x 0.625° grid and resampled to monthly values. Outliers were removed using the 1.5 x IQR threshold. **Over Amazonia, isoprene and formaldehyde have a positive correlation ($p < 0.05$), which indicates that changes in isoprene are likely due to isoprene emissions. On the other hand, formaldehyde and isoprene from the Maritime Continent have a consistently negative correlation, indicating that another driver (e.g. NOx) is responsible for changes in isoprene. These correlations provide observational evidence for the "emissions-controlled" regime over Amazonia and the "chemistry-controlled" regime over the Maritime Continent throughout the entire 8-year CrIS record (Figure 9).**

References:

Andela et al. (2017), doi:10.1126/science.aal4108.
Barkley et al. (2013), doi:10.1002/jgrd.50552.
Clarisse et al. (2023), doi:10.5194/amt-16-5009-2023.
Marais et al. (2012), doi:10.5194/acp-12-6219-2012.
Marais et al. (2014), doi:10.5194/acp-14-7693-2014.
Stavrakou et al. (2015), doi:10.5194/acp-15-11861-2015.
Vohra et al. (2022), doi:10.1126/sciadv.abm4435.
Whitburn et al. (2016), doi:10.1002/2016JD024828.