

Reviewer comments and questions are shown in bold; responses are in plain text.

**In “Spatially separate production of hydrogen oxides and nitric oxide in lightning”, Jenkins et al. report the generation of OH from lightning (LOH) based on laboratory studies and FOAM box model simulations. The authors suggest that OH can persist in the atmosphere as it is generated in the corona sheath, which is spatially separated from the lightning core, where large amounts of NO titrate OH immediately. They further propose that large amounts of HONO are generated in lightning strokes from the reaction of NO with OH.**

**This research is highly important given the limited knowledge of lightning and particularly the role of OH and suits the scope of ACP. However, I have several important questions which need to be addressed before I can recommend this manuscript for publication. While the introduction is well written and can be followed easily, the methods and results parts need some restructuring and additional information, as it is sometimes difficult to follow the reasoning. The authors often refer to their previous studies - I recommend adding a paragraph on these results as they are important for this manuscript, but not all readers might be familiar with them. Further, a schematic of the experimental set up could help to understand the laboratory methods better. I additionally wonder if the authors could carry out experiments under upper tropospheric conditions, where temperature, pressure and water vapor concentrations are different than those pursued by the authors, but lightning is most relevant. How relevant are the experiments to the actual conditions of lightning in the atmosphere (mostly in the UT)? Please find my specific comments and questions in the following.**

**Specific comments:**

**Line 33 & 46: 100s and 10s could be mistaken for 100 and 10 seconds. Maybe this could be spelled out.**

‘100s’ has been changed to ‘hundreds’ and ‘10s’ has been changed to ‘tens’ in the manuscript.

**Lines 53 ff: “UV radiation can also make extreme OH...” As far as I understood the authors earlier, the UV radiation is created from the corona. However, here it sounds like corona and UV radiation represent to different mechanism for creating LOH / LHOx. Could you please clarify this?**

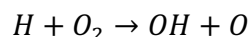
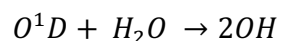
In the previous paragraph, we do say that both the corona and UV radiation extend around the hot core, but we do not say anywhere that the corona creates the UV

radiation, so we are unsure what we stated that caused this misunderstanding. Both the hot core and corona generate UV radiation, which can extend out beyond either the hot core or corona sheath.

We have added the following sentence at Line 45: "This UV radiation is generated by both the hot core and the corona sheath."

### **And what would be the mechanism of HO<sub>x</sub> formation from corona?**

Aside from the UV radiation, there are several different reactions that generate HO<sub>x</sub> in corona discharges. The table in Bruggeman and Schram (2010) (referenced in the manuscript) shows these pathways, most of which are initiated by an electron impacting a molecule or atom. Some examples include:



The following sentence has been added at Line 53: "These pathways include an electron dissociating a water molecule ( $\text{electron} + \text{H}_2\text{O} \rightarrow \text{OH} + \text{H}$ ) or an excited state oxygen atom dissociating a water molecule ( $\text{O}^1\text{D} + \text{H}_2\text{O} \rightarrow 2\text{OH}$ ), among several others."

### **How much HO<sub>x</sub> is formed in the corona versus from UV radiation?**

We investigated how HO<sub>x</sub> is formed in corona discharges in Jenkins et al., 2022. This previous study only looked at corona discharges, not sparks. Non-UV pathways for making HO<sub>x</sub> in corona discharges are initiated by electrons from the corona discharge colliding with molecules or atoms. The number and energy of these electrons is different in positive and negative corona, so if these non-UV pathways were dominant, our HO<sub>x</sub> production should have had a polarity dependence (much like O<sub>3</sub> production in corona discharges does). But our observations showed no difference in HO<sub>x</sub> production between positive and negative polarity corona discharge. Based on this information, along with the relatively equal amounts of OH and HO<sub>2</sub> produced, we concluded that most of the HO<sub>x</sub> was being made by the 185 nm UV radiation emitted by the corona.

We are currently collecting UV data from spark discharges, so we are in the process of performing a similar analysis for spark discharges. At this point, we cannot rule out that a reaction sequence such as  $electron + H_2O \rightarrow OH + H$  followed by  $H + O_2 + M \rightarrow HO_2 + M$  could be a more important contributor to HO<sub>x</sub> production in sparks/lightning compared to pure corona discharge, as sparks/lightning are not a single polarity but alternate between positive and negative. So we do not know how important UV versus non-UV pathways are for HO<sub>x</sub> production in sparks (yet).

**Line 61: “spatially separation LHOx and LNO production is possible” Is there a word missing? Or “spatially separate”?**

No words are missing; it is just a typo. “spatially separation” has been corrected to “spatially separate”.

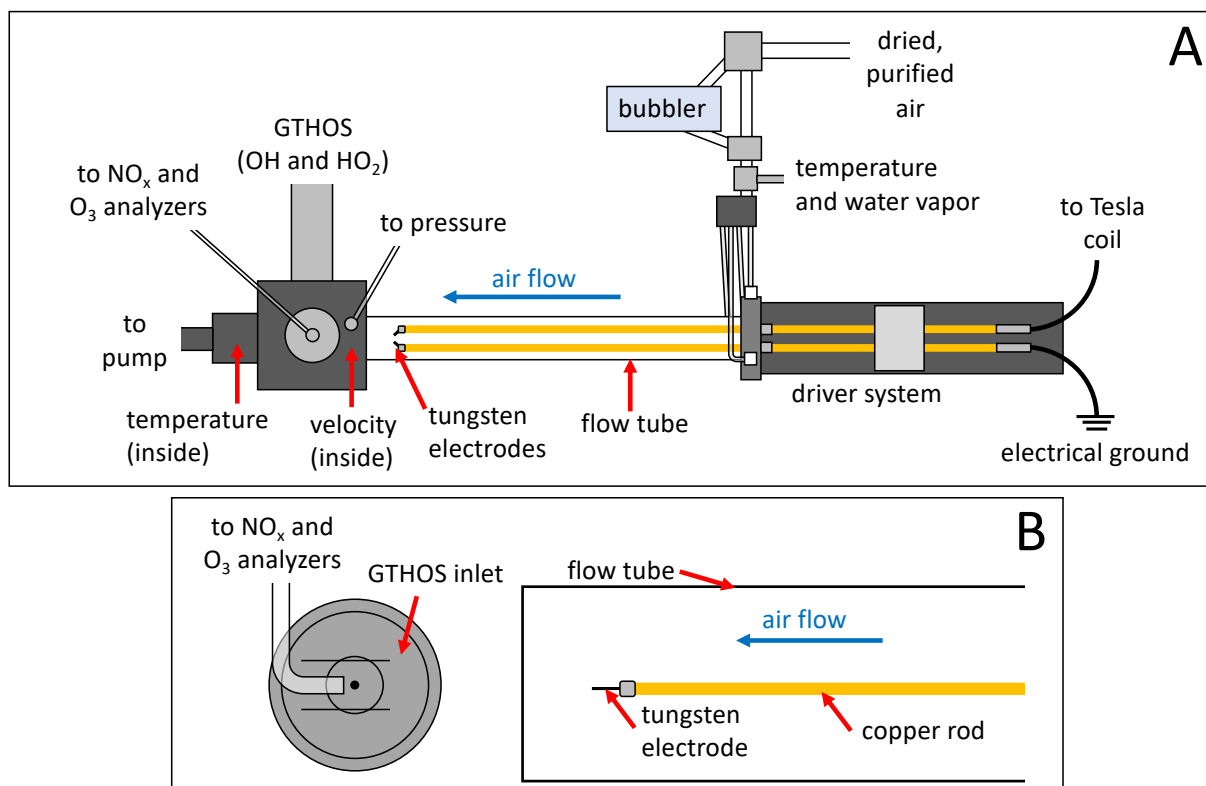
**Line 64: A previous reviewer of this manuscript or of another paper? If it refers to a different study, I recommend removing “as suggested by a previous reviewer” and replacing it by a reference to the study it follows up on.**

We were referring to a reviewer of our first paper on the subject of LHO<sub>x</sub>, Jenkins et al., 2021. The phrase has now been removed.

**Lines 73 ff.: It could be helpful for the understanding to add a schematic of the experimental set up, including the location of the sampling and the positions of the discharge generation.**

A diagram of the laboratory setup has been added as Figure S1 to the supplement, which shows the position of the inlet relative to the sparks in subdiagram (B). The following sentence has been added to text at Line 91: “A diagram of the laboratory setup is shown in Figure S1.”

The distance between each discharge position and inlet are shown in the new Figures S2 and S3 that were added in response to Reviewer 1’s questions, so are not included in the diagram in Figure S1. The distances are 5.5, 10.5, 18, 25.5, and 33 cm.



**Figure S1.** (A) Top-down diagram of the laboratory experimental setup showing the key components. (B) Side-view showing a close-up of the GTHOS inlet and Teflon line leading to the NO<sub>x</sub> and O<sub>3</sub> analyzers, which sample from the same volume as GTHOS in a 1-cm diameter tube placed over the GTHOS inlet (shown as two horizontal lines), along with the relative positions of the flow tube, copper rod, and tungsten electrode. Neither (A) nor (B) is shown to scale.

**Line 76: Is the flow tube “wide enough” to capture the center of the spark and the corona individually?**

Doing this kind of sampling is not possible for us presently, regardless of the flow tube width. The core and corona start mixing very quickly, so we would need to sample the air right where the spark occurs if we wanted to sample the center and corona individually. However, we cannot sample closer than ~5.5 cm from the sparks because otherwise the sparks could strike the instrument inlets and cause electrical interference in the signals or damage the instruments.

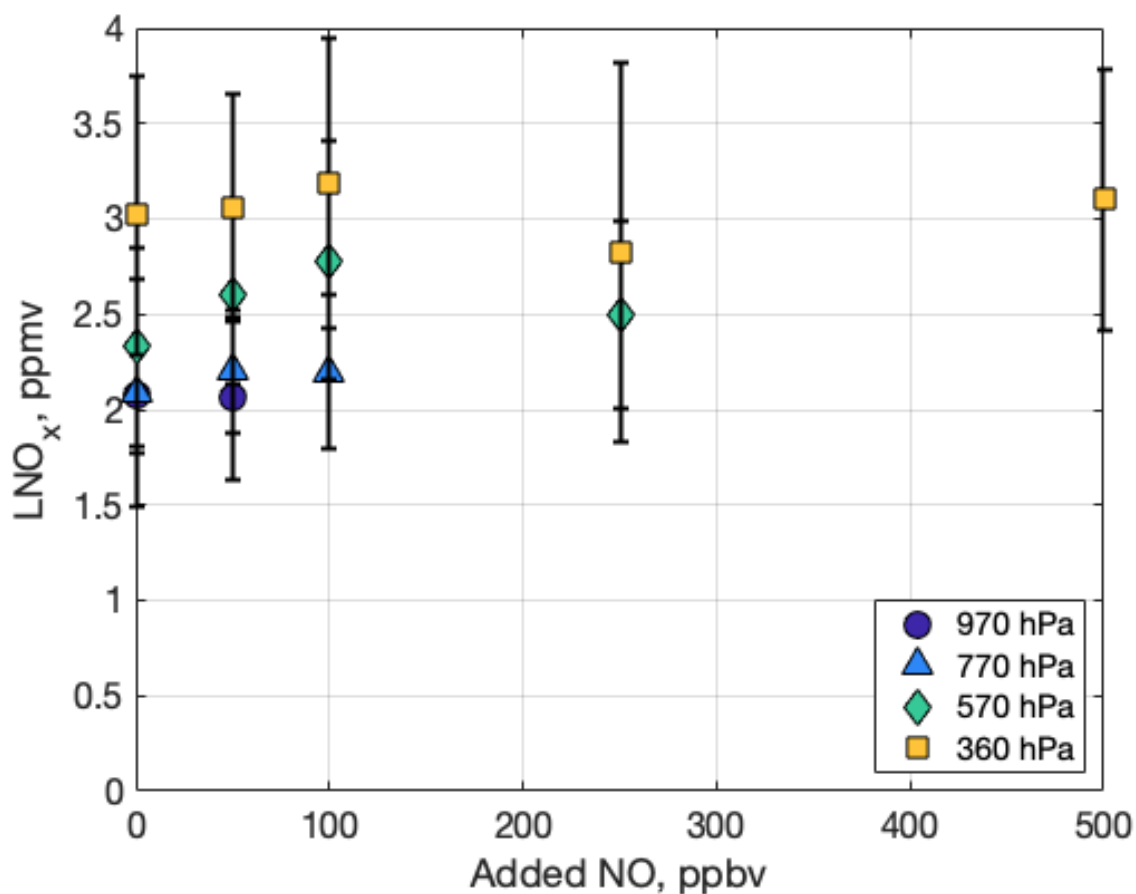
The other issue is that the instruments need rather large flows relative to the size of the sparks. The sparks are 0.7 cm long, but the GTHOS sampling flow rate alone is ~4 standard liter per minute (slpm) or greater, and the NO<sub>x</sub> and O<sub>3</sub> sampling flow rates are each ~1 slpm. So the size of the sparks would also need to be scaled up to only sample

the center or corona (which would also likely create more electrical interference issues).

**Line 96: What's the mixing ratio of NO in the flow tube generated from the spark?**

The generated LNO<sub>x</sub> varied from ~2-3 ppmv per spark. A new figure and caption, shown below, has been added to the supplement as Figure S6 and shows the average LNO<sub>x</sub> generated in each of the laboratory experiments.

The following line has also been added to the main text: "The average LNO<sub>x</sub> generated in the laboratory experiments is shown in Figure S6."



**Figure S6.** Average LNO<sub>x</sub> generated per spark in the laboratory experiments at different pressures and added NO amounts. Error bars are the standard deviations from multiple (19-20) measurements.

**Line 99: Have you tried to carry out an experiment under upper tropospheric conditions, i.e. lower temperature (e.g. 220K) and lower pressures (e.g. 200hPa),**

**where lightning is most frequent? If that's not possible with your set-up I recommend discussing the implications of different conditions. Reaction (R2) seems to be highly dependent on temperature and pressure**

They were not NO addition experiments like in this study, but yes, we did experiments at temperatures as low as ~260K and pressures down to ~250 hPa in a previous study (Jenkins and Brune, 2023). These values are the lowest we can do with the current laboratory setup. We found that decreasing temperature can decrease the LHO<sub>x</sub> production (the exact decrease is dependent on water vapor), but lower pressure does not significantly affect the LHO<sub>x</sub> production. LNO<sub>x</sub> production increases slightly with lower pressure (less than a factor of 2 from 970 hPa to 250 hPa) and is independent of temperature.

For this study, we are more interested in the HO<sub>x</sub> decays rather than the absolute HO<sub>x</sub> or NO<sub>x</sub> production. The reactions OH + NO + M → HONO + M and HO<sub>2</sub> + NO → OH + NO<sub>2</sub> are by far the most dominant reactions at all the pressures we tested, accounting for 50% or more of the OH losses and 80% or more of the HO<sub>2</sub> losses, respectively. For the 3% NO + 3% HONO runs, OH + HONO → H<sub>2</sub>O + N<sub>2</sub>O was the second largest OH loss and OH + HO<sub>2</sub> → H<sub>2</sub>O + O<sub>2</sub> was the second largest HO<sub>2</sub> loss. The rate of all these reactions increases ~30% as the temperature decreases from 290 K to 220 K, except for OH + NO + M, which increases ~110%. OH + NO + M is also the only reaction with a rate coefficient dependent on pressure, so some of the rate increase from the temperature drop will be offset by the decrease in pressure in the upper troposphere. However, modelling tests show that OH + NO + M would still be expected to be the dominant OH loss reaction at 200 hPa and 220 K, followed by OH + HONO. Similarly, HO<sub>2</sub> + NO remains as the dominant HO<sub>2</sub> loss followed by OH + HO<sub>2</sub>. Based on this information, we would not expect any significant changes to the HO<sub>x</sub>-NO<sub>x</sub> chemistry at lower pressures and temperatures.

Reaction R2 does have temperature and pressure dependences, but it is still a fast reaction for any temperature/pressure found in the troposphere. The latest JPL\* evaluation lists the rate coefficient for R2 at 298 K and 1 atm (near surface conditions) as  $1.15 \times 10^{-12} \text{ cm}^{-3} \text{ molecule}^{-1} \text{ s}^{-1}$ . Using the low-pressure limit equation in the JPL with a pressure of 200 hPa and temperature of 220K, the rate coefficient becomes  $6.0 \times 10^{-13} \text{ cm}^{-3} \text{ molecule}^{-1} \text{ s}^{-1}$ , a decrease of about ~50%. If you add in the uncertainties to these values (at least ±20% at 298 K), then that 50% difference becomes even less significant. Thus, despite appearances, R2 is really not very dependent on temperature or pressure for the ranges found in the troposphere.

We have added the following paragraph to the Conclusion in the main text, at Line 298: "While we did not test the full range of possible tropospheric pressures and

temperatures in this study, we still expect that these results apply for the lower pressures and lower temperatures found in the upper troposphere where most lightning occurs. Regardless of where it occurs in the troposphere, a lightning flash is composed of a hot core surrounded by a corona sheath and UV radiation, so HO<sub>x</sub> and NO<sub>x</sub> production is also expected to be spatially separate in the upper troposphere. Our previous study showed that the initial LNO<sub>x</sub> mixing ratio is independent of temperature and only slightly dependent on pressure, with less than a factor-of-2 difference in production between 970 hPa and 250 hPa, while the initial LHO<sub>x</sub> mixing ratio is independent of pressure and decreases with decreasing temperature, depending on the available water vapor (Jenkins and Brune, 2023). Therefore, we expect roughly the same LNO<sub>x</sub> production in the upper troposphere as was observed in the experiments here, with likely ~200-300 pptv of LHO<sub>x</sub> produced. The modelling results showed that for all the pressures tested in this study, the reaction  $OH + NO + M \rightarrow HONO + M$  accounts for over half of the OH loss, while the reaction  $HO_2 + NO \rightarrow OH + NO_2$  accounts for 80% of the HO<sub>2</sub> loss. The rates of these two reactions increases with decreasing temperature, although the rate of  $OH + NO + M$  is also pressure dependent. However, further modelling tests using the lowered LHO<sub>x</sub> production with the same LNO<sub>x</sub> as was measured at 360 hPa demonstrate even at 200 hPa and 220 K, the reactions  $OH + NO + M$  and  $HO_2 + NO$  still accounts for more than 50% of the OH loss and 80% of the HO<sub>2</sub> loss, respectively. Thus, based on this information, we also expect the same subsequent HO<sub>x</sub>-NO<sub>x</sub> chemistry to occur in the upper troposphere as shown for the pressures and temperatures here."

We have also made the following addition to the first paragraph of the Conclusions at Line 288: "It took 3% NO and 3% HONO to resolve the measured-modelled discrepancy in these laboratory experiments, where the sparks occurred in a flow tube with laminar flow and a fast air velocity. In the atmosphere, the percentage of NO or HONO reacting with LHO<sub>x</sub> could be lower or higher than 3%, depending on the turbulence and air velocity where the lightning flash occurs, and likely varies from one lightning flash to the next. But the overall conclusion, that the HO<sub>x</sub> generated outside the hot channel only partially interacts with the hot channel products, will still be true in the atmosphere.

Additionally, these results indicate only..."

\*J. B. Burkholder, S. P. Sander, J. Abbatt, J. R. Barker, C. Cappa, J. D. Crouse, T. S. Dibble, R. E. Huie, C. E. Kolb, M. J. Kurylo, V. L. Orkin, C. J. Percival, D. M. Wilmouth, and P. H. Wine "Chemical Kinetics and Photochemical Data for Use in Atmospheric Studies, Evaluation No. 19," JPL Publication 19-5, Jet Propulsion Laboratory, Pasadena, 2019 <http://jpldataeval.jpl.nasa.gov>.

**Line 108: Could your detection limit (20ppbv?) for O<sub>3</sub> be too low to capture it?**

Yes, it is entirely possible some O<sub>3</sub> is formed that is below our detection limit. However, we do not have an O<sub>3</sub> analyzer with a lower detection limit that can also make measurements at different pressures and at a rate of 1 Hz or faster.

**If you generate short wave UV radiation from the sparks, O<sub>3</sub> should probably be formed both from O<sub>2</sub> and from NO<sub>2</sub>. The amount of O<sub>3</sub> generated would be dependent on the amount of NO added and can also react with OH and HO<sub>2</sub>. Is the timescale of these reactions not relevant to the decay of HO<sub>x</sub> or can you exclude the impact of O<sub>3</sub> via the model simulations?**

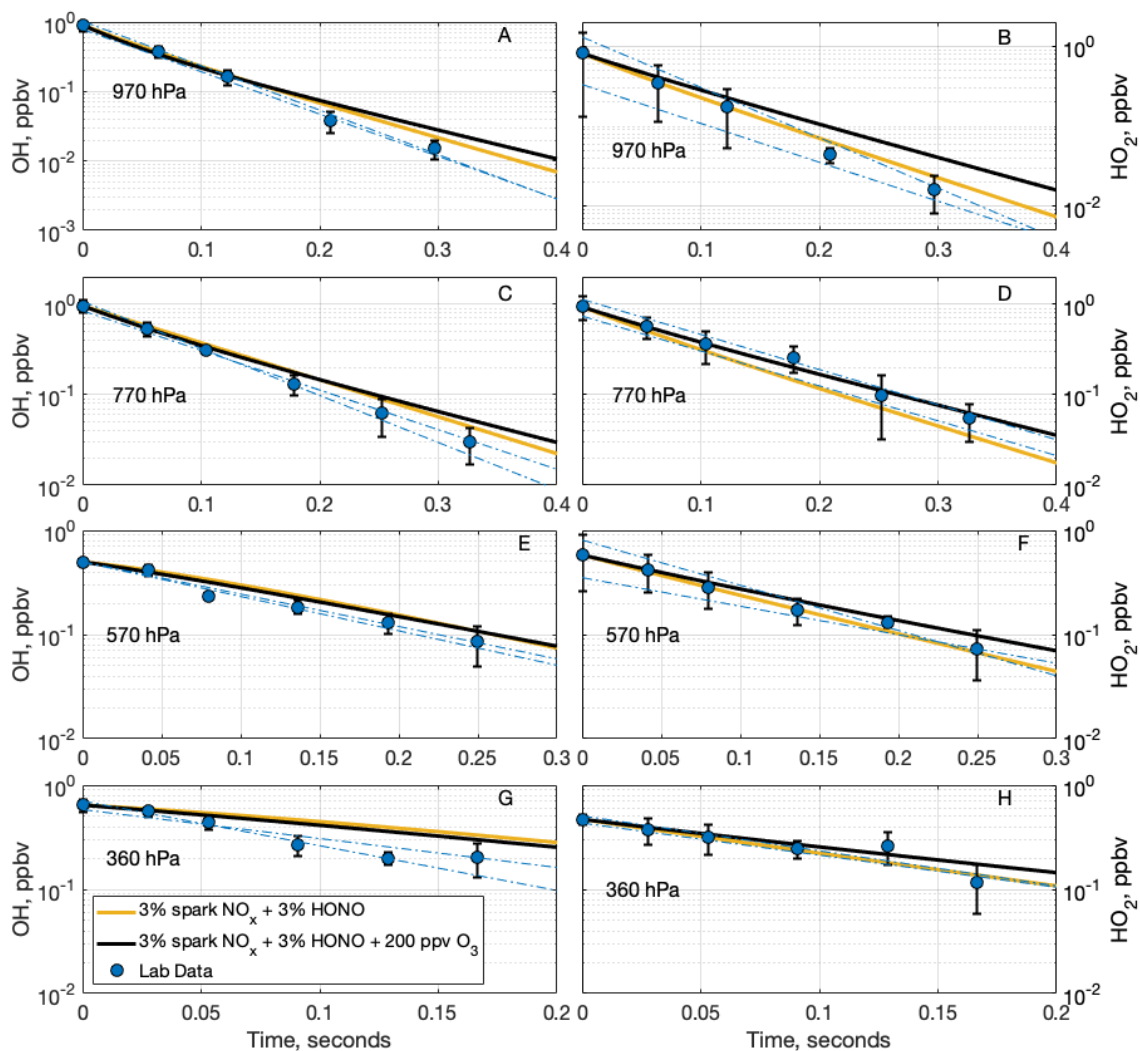
Even if O<sub>3</sub> is formed, the reactions of O<sub>3</sub> with OH and HO<sub>2</sub> are not very fast relative to the timescales we are considering here. From the most recent JPL evaluation:

$$k_{OH+O_3} = 7.3 \times 10^{-14} \text{ cm}^3 \text{ molecules}^{-1} \text{ s}^{-1}$$

$$k_{HO_2+O_3} = 1.9 \times 10^{-15} \text{ cm}^3 \text{ molecules}^{-1} \text{ s}^{-1}$$

If we run a version of the 3% NO + 3% HONO model runs that also includes 200 ppbv of O<sub>3</sub> (an amount we surely would have detected), we can see the effect of O<sub>3</sub> on the OH and HO<sub>2</sub> decays is not very substantial, especially for OH:





Based on this information, we feel justified in neglecting any O<sub>3</sub> possibly generated below our detection limit.

A new sentence has been added at Line 142: "Model tests confirmed that even if up to 20 ppbv of O<sub>3</sub> (our limit of detection) had been generated in the laboratory experiments, it would not have significantly affected the HO<sub>x</sub> decays, so O<sub>3</sub> was not included in any of the model runs shown here."

**Lines 114 f.: Could the losses for HO<sub>x</sub> and NO be different, e.g. through wall effects?**

Wall loss rates for OH and HO<sub>2</sub> are about 0.9 s<sup>-1</sup> and 0 s<sup>-1</sup>, respectively (from Line 142), and there is not enough time for NO and NO<sub>2</sub> to have any wall interactions. It is

possible that there are differences between the HO<sub>x</sub> and NO<sub>x</sub> losses, but given that we cannot measure the HO<sub>x</sub> diffusion directly, assuming HO<sub>x</sub> and NO<sub>x</sub> diffuse similarly because of their similar diffusion coefficients is the best we can do.

**Line 119: Did you also change the location of the sampling or are you referring to the different locations of the discharge generation?**

The location of the sampling was fixed; this line refers to the different locations for the discharge. We have rewritten the end of the sentence from "...flow tube positions" to "...discharge positions in the flow tube" for clarity.

**Line 137: Do these cases also include 0ppbv of added NO, only considering spark NO<sub>x</sub>?**

Yes. These cases are the dotted green lines shown in subplots A and B on Figures 2, S7, S8, and S9.

**Line 149: Which reactions do you expect to occur? NO + HO<sub>2</sub> → NO<sub>2</sub> + OH, NO + OH → HONO, NO<sub>2</sub> + OH → HNO<sub>3</sub>? Which one is dominant?**

OH + NO → HONO and HO<sub>2</sub> + NO → OH + NO<sub>2</sub> are by far the most dominant reactions at all pressures, according to the modelling. The next most important reaction for HO<sub>2</sub> is OH + HO<sub>2</sub> → H<sub>2</sub>O + O<sub>2</sub> and for OH is OH + HONO → H<sub>2</sub>O + NO<sub>2</sub> (for the model runs that include 3% NO + 3% HONO). OH + NO<sub>2</sub> is at most the fourth most important OH loss, but is usually ranked even lower, while HO<sub>2</sub> + NO<sub>2</sub> is the third or fourth most important HO<sub>2</sub> loss.

**How important is recycling of OH through NO + HO<sub>2</sub>?**

This reaction is the only significant OH production pathway in the system (again, per the model runs). For the 0 ppbv of added NO cases this production pathway is always less than the total OH loss rate. For some of the cases with more than 0 ppbv of added NO, this recycling can be competitive with the total OH loss rate, at least initially.

**I recommend adding the reactions already in the introduction to explain the effects of NO<sub>x</sub> on HO<sub>x</sub>.**

We have added some discussion of the HO<sub>x</sub>-NO<sub>x</sub> chemistry and which reactions dominate in a paragraph in the Conclusion (see response to an earlier question). Our overall goal with these experiments as mentioned in the Introduction was to determine whether LHO<sub>x</sub> was reacting with the spark or added NO, which is a not a question that these reactions can answer. The reaction OH + NO + M is no different whether the NO

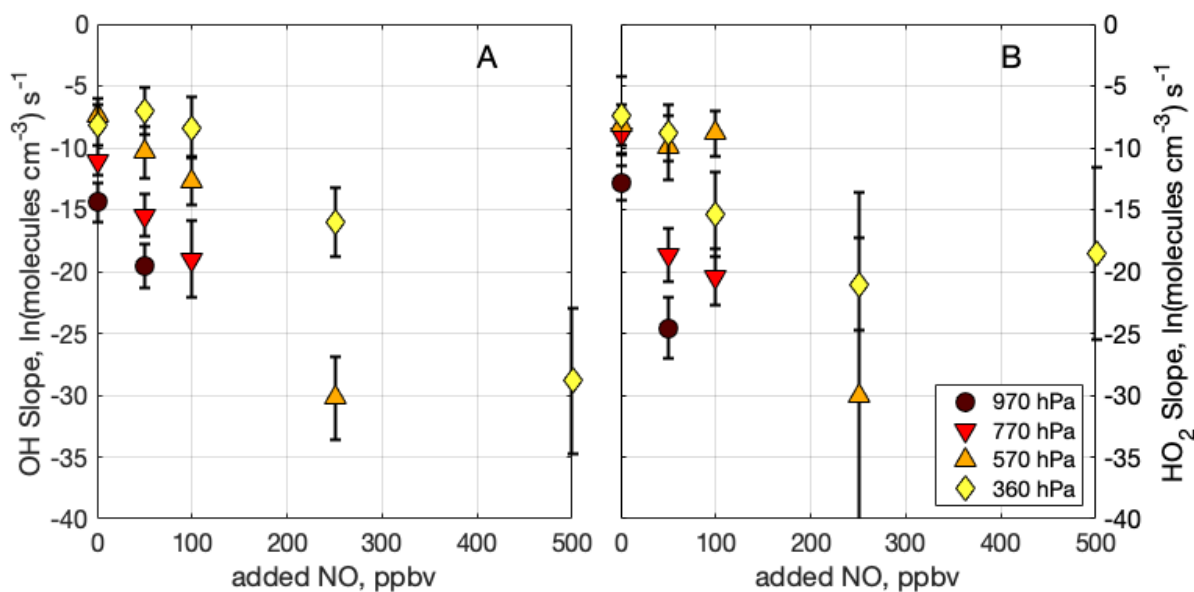
comes from the spark or is added to the background air. So we will leave out discussing these reactions in the Introduction, and let the discussion in the Conclusion cover the important points.

**Figure 1: Are the differences between 0ppbv and 50ppbv of added NO really significant for 970hPa?**

Yes. The slopes and uncertainties for the individual experiments with 0 ppbv and 50 ppbv of added NO at 970 hPa are shown below (units are  $\ln(\text{molecules cm}^{-3}) \text{ s}^{-1}$ ):

<i>OH slopes</i>	<u>Experiment 1</u>	<u>Experiment 2</u>
0 ppbv added NO	-15±1	-14.0±0.8
50 ppbv added NO	-21±1	-18±1
<i>HO<sub>2</sub> Slopes</i>		
0 ppbv added NO	-14±1	-11.2±0.9
50 ppbv added NO	-22±2	-27±1

We have added a plot showing the slopes and uncertainties for all the different NO addition experiments at all four pressures to the Supplement as Figure S5. The sentence at Line 146 has been modified as follows (modification underlined): “As an increasing amount of NO was added to the air flow in the laboratory experiments, the OH and HO<sub>2</sub> decays became progressively steeper, as shown Figure 1 (970 hPa and 360 hPa), Figure S4 (770 hPa and 570 hPa), and Figure S5 (average slopes for all experiments).”



**Figure S5.** Average slopes for the OH (A) and HO<sub>2</sub> (B) decays from the NO addition experiments at different pressures.

**Line 155: How many measurements are included in each data point?**

Each OH or HO<sub>2</sub> data point contains data from 1-2 experimental decays (Line 152), and within each experiment, 4 sparks were made at each position in the flow tube (newly added Line 101). Because the GTHOS laser is set off the OH absorption wavelength for one of these four sparks (see replies to Reviewer 1), this means each OH or HO<sub>2</sub> data point contains 3 or 6 measurements (for 1 or 2 decays, respectively).

The Figures 1 and S4 captions have been modified as follows (modifications are underlined): "Laboratory decays of OH (A,B), HO<sub>2</sub> (C,D), and net HO<sub>x</sub> (E,F) at 970 hPa (A,C,E) and 360 hPa (B,D,F). The markers are the averaged data points containing 3 or 6 measurements from 1 or 2 laboratory experiments, respectively. The markers at time zero are the averaged extrapolated values from the decays. The lines on A, B, C, D are the linear fits to the individual decays. Error bars are the standard deviation from averaging the multiple laboratory measurements."

**Line 166 ff.: Do I understand correctly that in your experiment, HO<sub>x</sub> and NO<sub>x</sub> is both generated from the spark?**

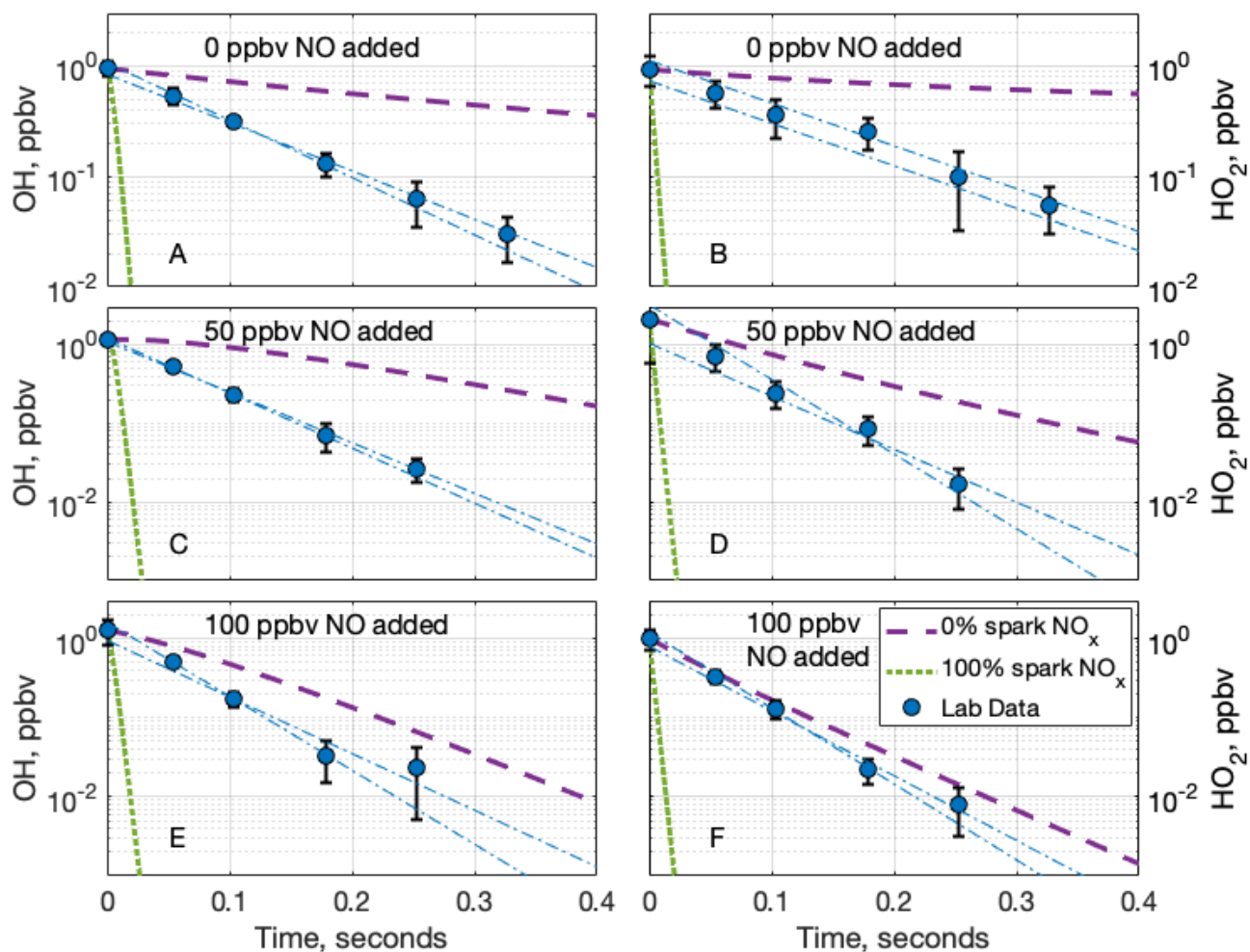
Yes, both HO<sub>x</sub> and NO<sub>x</sub> are generated in the sparks, but generating both is not unique to our experiments. Anytime a spark occurs in air with water vapor it will generate both HO<sub>x</sub> and NO<sub>x</sub>.

**So, for the 0% spark NO<sub>x</sub> case in your model, do you assume an initial HO<sub>x</sub> mixing ratio based on the experiments? Please clarify.**

Yes, except for the model run where we tested for HONO production, all the model runs use the same initial OH and HO<sub>2</sub> that was determined from the laboratory experiments, including the 0% spark NO<sub>x</sub> case, the 100% spark NO<sub>x</sub> case, and the cases using a small percentage of spark NO<sub>x</sub>. For example, on Figure 2, for each subplot, the 0% spark NO<sub>x</sub> model case, the 100% spark NO<sub>x</sub> model case, and the laboratory data all start with the same initial HO<sub>x</sub>. We explain the choice of initial HO<sub>x</sub> at Line 137 manuscript: "The initial OH and HO<sub>2</sub> determined from the extrapolation of the laboratory decays, scaled down 10-fold, were chosen as the initial OH and HO<sub>2</sub> (respectively) for the model runs." We have rewritten the next sentence to help clarify that the same initial HO<sub>x</sub> was used for all the runs using different NO<sub>x</sub>, from "For NO<sub>x</sub>, three cases were tested. " to "Using this same initial HO<sub>x</sub>, three cases using different amounts of initial NO<sub>x</sub> were tested."

**Figure 2: Is the scaling of the y axis for panels C-F the same as for A-B? The minimum is not visible. And does the OH axis somehow relate to the HO2 axis? - The outline of the figure is a bit irritating (2 black outlines for the left and 3 for the right panels).**

We have updated Figure 2 to properly show the scaling on all the subplots. We have also changed the default outlining to completely go around all four sides on every subplot on this figure and all the other figures as well. The OH axis and HO<sub>2</sub> axis for the same NO addition experiment have the same scaling, so they are related that way.



**Figure 2:** Comparison of measured OH (A,C,E) and HO<sub>2</sub> (B,D,F) laboratory decays and two model decays at 770 hPa and (A,B) 0 ppbv of added NO, (C,D) 50 ppbv of added NO, and (E,F) 100 ppbv of added NO. The dashed purple lines are the model decay with only the added NO, and includes no NO<sub>x</sub> from the spark, and the dotted green lines are the model decay with the added NO and all of the spark NO<sub>x</sub>. The blue circles are the average laboratory measurements and average extrapolated value at time zero, while the dashed-dotted blue lines are the individual

extrapolated linear fits to the laboratory data. Error bars are the standard deviation from averaging multiple measurements.

**Line 186: Does this mean that the default model run only includes HO<sub>x</sub> from the spark?**

We think that by “default model runs” you mean the model runs that produce the purple dashed lines. They are initiated with the measured HO<sub>x</sub>, no LNO<sub>x</sub> from the spark, and the amount of NO added upstream in the flow tube that is indicated on Figures 2, S7, S8, and S9. So for the experiments with 0 ppbv of added NO, these model runs only include HO<sub>x</sub>, 20 ppbv of CO, and OH wall loss.

**Or NO<sub>x</sub> from the spark is increased by x% because the amount of LNO<sub>x</sub> is uncertain?**

No, we do not add more NO<sub>x</sub> on top of the spark NO<sub>x</sub> and added NO. The model runs that give the OH and HO<sub>2</sub> decays shown by the green dashed line are initiated by the measured HO<sub>x</sub>, the measured LNO<sub>x</sub> produced only by the sparks, and the amounts of added NO shown in the figure.

**Does this mean you were previously able to reproduce the HO<sub>x</sub> decay in the model without assuming spatial separation?**

No, we were never able to reproduce the HO<sub>x</sub> decays in a model without assuming that HO<sub>x</sub> was reacting with much less than 100% of the spark NO<sub>x</sub>.

In this line, we are referring to the modelling we did in a previous study, Jenkins et al., 2021, which was very similar to the modelling we are doing here (e.g. with the 3 different modelling cases containing 100%, 0%, and a small % of spark NO<sub>x</sub>). We also briefly talked about this study in the second paragraph of the Introduction. Much like how we needed to include ~3% of the spark NO<sub>x</sub> to help resolve the measure-modelled discrepancy in this study, in that previous study we used 0.5% of the spark NO<sub>x</sub> to reduce the discrepancy. The subsequent sentences explain why that 0.5% was not enough to resolve the discrepancy in this study.

We have rewritten this Line to clarify this information: “When we first observed this measured-modelled discrepancy in Jenkins et al., 2021, we were able to resolve the discrepancy for both OH and HO<sub>2</sub> by including just 0.5% of the spark NO<sub>x</sub> in a model run.”

**Lines 249 ff.: How about upper tropospheric pressures? Would we expect a lower agreement given that the pressure is even lower?**

Possibly but we would not read too much into this lower agreement at this point. In order to conduct experiments at lower pressures we increase the air velocity in the flow tube, leading to measurements made over shorter and shorter timeframes. This apparent disagreement may be therefore partly driven by the experimental setup. Additionally, as we explain in the subsequent paragraph there is a lot of chemistry happening very rapidly when the discharge first occurs, and we do not have a model that can reproduce any of those processes. It may be that because we are making our first measurement faster at 360 hPa than the other pressures, we are catching some of that initial spark chemistry that we cannot fully model. Thus, this disagreement between the model and laboratory may be due more to our own laboratory or model limitations than something that is physically meaningful in the atmosphere.

**Table 1: What are the units of these values?**

Units (all ppbv) have been added to the table.

**Line 258: Are you able to measure HONO and confirm the model results?**

Unfortunately, we do not have an instrument able to measure HONO. If we did, we absolutely would have conducted experiments with it hooked up to the laboratory setup to test the model results.

A few other minor corrections/clarifications were made in the text (modifications have been underlined):

Line 40: "At the center of a lightning flash is a ~1-2 cm diameter core (Rakov and Uman, 2006) with air temperatures exceeding 30,000K (Orville, 1968a)."

Line 93: "To capture the LHO<sub>x</sub> decay, the copper rods were moved by a driver system so discharges were generated in 5 different positions in the flow tube..."

Line 215: Incorrect name spelling in reference; "Brandbold" corrected to "Brandvold".

Line 294: "and it is likely that UV is also responsible..." has been changed to "...and UV may also be responsible..."

Second sentence of the Abstract: "...which could rapidly remove..." has been changed to "which would rapidly remove..."