Title: "Short-Lived Halogen Sources and Chemistry in the Community Earth System Model v2 (CESM2-SLH)"
Tracking #: 2024-01975
Authors: Fernandez et al.

Within this response letter, we use the following text format: Reviewer comments appear in regular black font, while our responses are in blue font. The original manuscript text is shown with double quotes and in *"italic-blue format"*, while the changes introduced in the revised draft are in ***"bold-italic blue"***. Please note that the line numbering used here (e.g., **L528-533**) points at the track-changed version of the revised draft.

Reviewer Comments:

Reviewer #2:

General Comments:

Overall quality of the preprint

R2-C1.0: This preprint is clearly targeted towards the Community Earth System Model (CESM) community and presents the implementation of short-lived halogen (SLH) sources and very short-lived (VSL) halocarbons into CESM version 2.2.0. The authors demonstrate substantial expertise in this subject area.

GENERAL ANSWER: We thank the reviewer for the recognition in the field and for the very useful and constructive suggestions that helped to improve the quality of our work.

Given the large number of individual comments, and to avoid excessive repetition, in this section we present a short and general answer to the main comments, and provide in next section below detailed and specific responses to each of the independent questions/comments.

The manuscript is organized as follows:

- Section 2 (2.1–2.4) provides a detailed account of historical developments related to SLH sources and VSL halocarbons, combined with model implementation details and scientific background.
- Section 2.5 describes shared community model configurations and setups for SLH and VSL experiments.
- Section 3 presents results from CESM-SLH experiments, comparing them to previous CESM1 work and observational benchmarks. These include global distributions, vertical species partitioning, and atmospheric burdens.
- A short summary concludes the manuscript.

R2-C1.1: This topic and the results presented are highly relevant to the SLH/VSL research community. However, the current presentation limits accessibility and clarity. Specifically, the manuscript is:

- insufficiently structured,
- repetitive, with numerous filler words and phrases (e.g. "we highlight/note that", "Here, we note/should be noted")
- grammatically inconsistent (e.g., plural nouns combined with singular verbs),

- using lab-specific jargon or unexplained community terms, and
- affected by persistent typesetting issues, particularly with citations (e.g., parentheses instead of in-text citation).

GENERAL ANSWER: We thank the reviewer for highlighting the relevance of or developments and results, and appreciate the very careful reading and constructive comments provided. As detailed below, we have re-structured the manuscript (including a dedicated Discussion section and a completely new Appendix), removed the numerous filler phrases, checked for grammar consistency, avoid using jargon style and formatted the whole text and references following GMD guidelines.

Equations, tables, and figures:

- Several tables and headings do not follow the journal's formatting standards
- Formulae are incorrectly typeset (see some examples in Section 3).
- Figures are sometimes low-resolution, with frame artifacts and inconsistent labeling
- Colormaps draw disproportionate attention to light blue and yellow regions.
- Empty figure panels are included.
- Exponential expressions are written as E-02 instead of 10^{-2}.

R2-C1.2: Although submitted to *GMD*, the manuscript does not yet meet expectations for a clear and comprehensive model description. For instance, the term compset is never explained for readers outside the CESM community.

GENERAL ANSWER: We appreciate the careful reading and detailed comments to follow the journal guidelines. The revised manuscript has now been checked for format consistency, particularly for table heading and figure captions. We provide high-quality figures, all of which has been re-generated using colorblind-friendly pallets with sequential scales. All equations, physical and chemical variables, range of values and exponential expressions have been re-formatted. We appreciate the reviewer suggestion to explain the term *"compset"* for readers outside the CESM community. Therefore, we have removed it usage from the abstract and introduction, and only defined it within the Model Description section as follows:

L515-518: *"The implementation of SLH sources and chemistry described in this work* ***was*** *performed* ***over the base*** *FCnudged and FCHIST* ***atmospheric chemistry*** *compsets (https://docs.cesm.ucar.edu/models/cesm2/config/2.2/compsets.html)* ***In CESM terminology, compset is an acronym for 'component setup' and refers to specific model configuration of the Earth System Model, specifying which components are used and how they are coupled (Danabasoglu et al., 2020).***"

Suggested Improvements

R2-C1.3: To enhance clarity and accessibility, the following structural changes are recommended:

- Split and reorganize Sections 2 and 3.
- Following common conventions, Section 4 should be titled "Summary and Conclusions."
- Introduce an additional section dedicated to discussion, consolidating currently fragmented discussion points.

GENERAL ANSWER: We thank the reviewer for his/her constructive suggestions. Therefore, we implemented several structural changes to improve the manuscript clarity and accessibility. In particular, we split and reorganize original Section 2 into two independent sections (new Sections 2 and 3), the results are now shown in Section 4, we included a new Section 5 dedicated to Discussions and entitled the final Section 6 as "Summary and Conclusions". See also the detailed response to **R2-C1.4** below.

More detailed structural advise:

- The new *Section 2* (Model description) should begin with a concise, general overview of *CESM2* and its relevant components. For example, explain:
    - CESM structure (refer to Supplement Chart S1),
    - definition of specified dynamics (SD),
    - what a compset is,
    - differences between compsets (e.g., SD vs. free-running).
- Only after this overview should CESM2 be contrasted with CESM1.
- Follow with an overview of CESM2-SLH developments and available compsets (currently Section 2.5). Detailed implementation should then be presented in the next section 3.
- Section 2.1 (historical developments), while interesting, is unnecessary for this manuscript and could be removed, as this is not intended as a review paper.
- The new *Section 3* (Model implementation of SLH and VSL) should combine Sections 2.2–2.4, focusing on implemented schemes, mechanisms, and chemistry.
- Consider including Figure S1 here, as it illustrates key differences in sea salt properties between CESM1 and CESM2.
- Avoid historical context and developments in this section. It is enough to briefly introduce the Ordoñez inventory.
- Move "user guide" like paragraphs into an Appendix section (User guide) or rephrase them for a more general audience.
- The new *Section 4* (Results) could be subdivided into:
    - 4.1 Validation (currently Sections 3.2.2 and 3.3.1),
    - 4.2 Comparison to CESM1 results,
    - 4.3 Sensitivity studies with CESM2-SLH and additional single-experiment studies.
- First describe sensitivity experiments and summarize them in tabular form (in parts Tab. 6).
- Consolidate all discussion into a dedicated *Section 5* (Discussion).
- Rename the final section as *Section 6* (Summary and Conclusions).

R2-C1.4: Implementing these changes will significantly improve readability, accessibility, and compliance with journal standards.

GENERAL ANSWER: While we accepted the reviewer suggestion to split the original Section 2 of the manuscript (Model Description), the intention of this manuscript is not to present an overview of CESM2 (which is comprehensively described in Danabasoglu et al. (2020)), but instead, to only point at the specific developments and configurations that are of importance to SLH. Therefore, the new structure of the manuscript includes first a detailed description of independent SLH and VSL developments (***"2. Implementation of SLH chemistry in CESM"***) followed by an overview of the new model configurations available in the current release (***"3. CESM2-SLH compsets and experiments"***). Here, we have split original Table 6 into two different tables: one describing the new compsets available and another one summarizing

the main experiments performed in this work. Note that we only turn-on "track-changes" in the revised version for the subsection titles, but not the whole block of paragraphs that were moved up/down.

We have also rearranged Section 4 (Results) to focus on the distribution and evolution of SLH for the main model configurations (Section 4.2), including as the first subsection the evaluation of SLH abundance in comparison with observations (4.2.1); followed by the influence of SLH over the main atmospheric components (Section 4.3), also initialized by the model validation (4.3.1). In doing so, we split and reorganized all "technical" blocks into the Appendix, while the comprehensive analysis and intercomparison between the different experiments and previous studies is all condensed in the new Section 5 (Discussion).

Finally, we refrain from moving Figure S1 from the supplement to Section 2 because the implementation of sea-salt aerosol (SSA) in CESM2 is not related to the SLH developments and have been performed by other groups. Similarly, we rather keep the original Section 2.1 (Historical Developments) with a double porpoise: *i)* to highlight that individual sources, sinks and chemistry for each of the independent halogen families were implemented and validated in the model throughout a long-lasting period and following a coordinated work among several groups; and ii) to provide for the non-expert in SLH chemistry, particularly those outside the CESM community, with a comprehensive review of the relevance of considering SLH chemistry in chemistry-climate studies. Note original Fig. S1 has now been shifted to Fig. S2.

R2-C1.5: The title may be expanded along the lines of "– implementations and benchmark results"

ANSWER: We appreciate the reviewer suggestion but prefer to keep the original title of the paper.

Specific comments:

Individual scientific questions/issues

GENERAL ANSWER: We thank the reviewer for the detailed analysis and for rising constructive questions and suggestions, whose implementation had substantially improve the manuscript quality. Below we provide individual answers to all individual issues belonging to **Section 2**. To avoid repetition, in some occasions we have grouped a few independent comments into a single response and/or point at the responses to the related technical comments included below in **Section 3**.

Section 2

R2-C2.1: L259–263: *"Despite [...]"* It seems there is no variable in Eq. (1) that connects emissions to the long- or shortwave incoming solar irradiance of the atmospheric basemodel which would vary with atmospheric state, season, time of the day, and orbit. Or is this hidden behind our "diurnal emission profiles"? From the text, it is not clear how these "profiles" are implemented.

R2-C2.2: L261–263: *"Emissions follow either [...]"* What does this mean? Can the user choose between the two?

ANSWER: Eq. (1) was used to generate monthly-mean VSLS emission files, computing each individual halocarbon flux strength at all latitudes and longitudes offline. Once those emission files are ready, they are read during CESM2-SLH execution, and a temporal profile is applied online to represent the hourly variability. Most species follow the Gaussian profile, with exception of one VSL iodocarbon, that present a top-hat shape. The implementation of all these developments has been described in the Ordóñez et al. (2012) inventory, although the hourly profile is not shown in the original reference. Therefore, we have included an additional figure to the Supplementary Material and rephrased the referred sentence as follows:

L231-235: *"**Once the monthly-mean prescribed fields are read,** hourly dependent **profiles are applied** to the flux strength of all halocarbons **to represent the** photosynthetic dependence on radiation intensity. **Therefore, VSLS** emissions follow a Gaussian diurnal profile **with** peak emissions at local solar noon (Ordóñez et al., 2012)**, with exception of CH_2I_2 that follows a top-hat shape with a uniform distribution during the day and no-null emissions at night (see Fig. S1).**"*

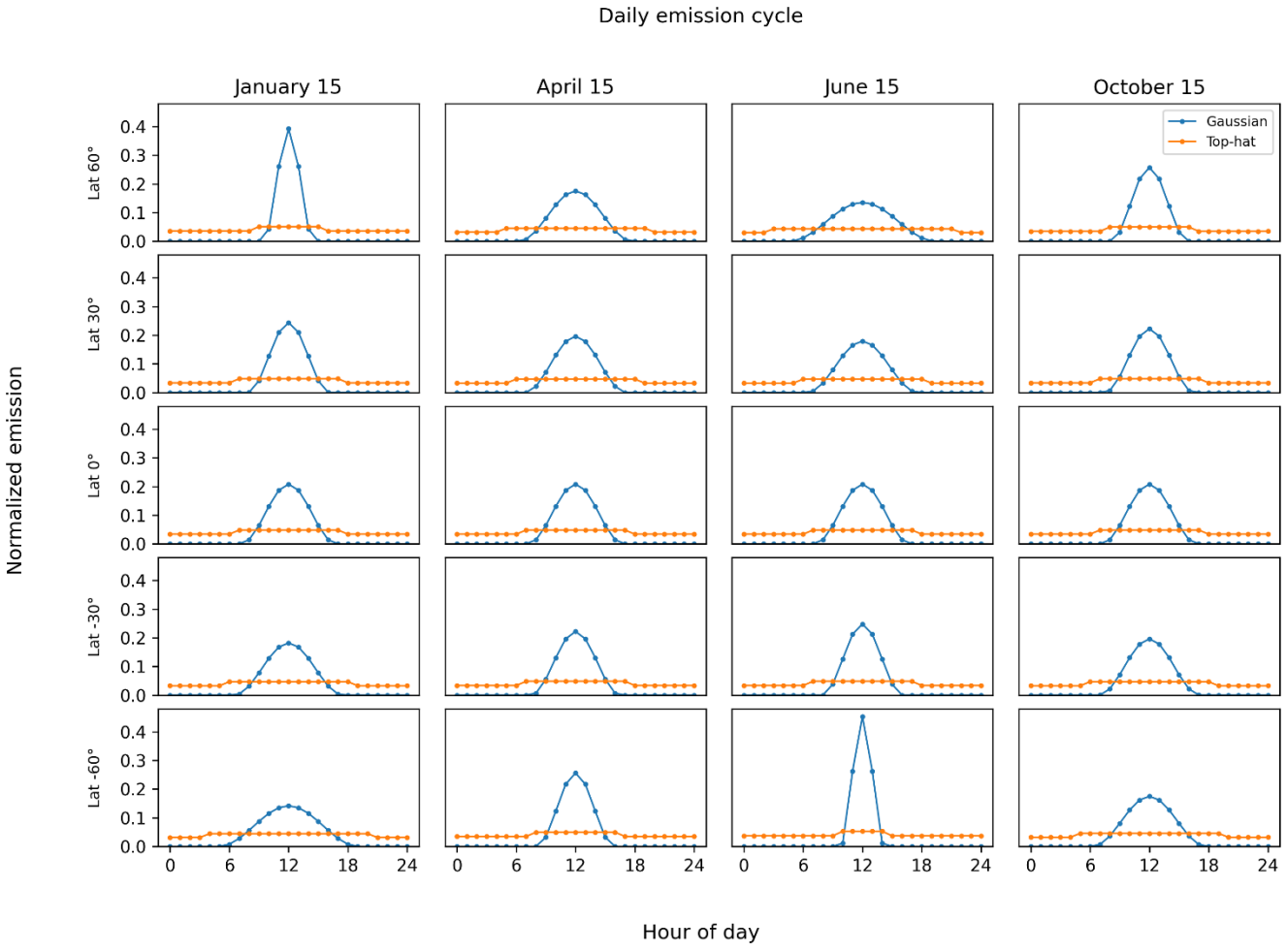

Figure S1: Hourly diurnal variation applied to all oceanic VSL halocarbon emissions considered in the in Ordóñez et al. (2012) inventory. Either the Gaussian or the top-hat temporal profiles are multiplied by the monthly offline emission strength interpolated to each day of the year, and considers the natural daily solar cycle at each specific latitude and longitude.

R2-C2.3: L263–264: *"Given that no long-term trend has been established [...]"* Has a trend been observed or not? Please include a recent reference (post 2007 and/or 2023) that could support your statement.

ANSWER: We have modified the sentence and provide a citation as follows:

L235-236: *"Given that no **global** long-term trend has been **observed or** established* (Tinel et al., 2023; WMO, 2022)*, the emission strength of oceanic halocarbons is assumed to follow a constant climatology."*

R2-C2.4: L264–268: This paragraph is an example of "user guide" like paragraphs. As indicated above, please collect this and similar paragraphs in a dedicated Appendix section. I will not point out each of them individually.

R2-C2.6: L311: "*routine [...]* iodine_emissions.F90 [...]" Here you refer to a Fortran (module) file as routine. Please be more precise and distinguish between subroutine and module file. What is the actual name of the subroutine? Please also refer my rephrasing suggestion in Section 3.

ANSWER: Following **R1** and **R2** comments, we have reduced the main text length and included a new Appendix with technical details and user-defined configurations. Regarding *iodine_emissions.F90* file, the reviewer has correctly identified it is a Fortran module. The corresponding subroutine is called *iodine_emissions_set (#)*. Note the whole block has now been moved to the Appendix. See also the related responses to **R2.C4.13-15** below.

Please refer to the revised manuscript for the complete Appendix.

R2-C2.5: L286–287: *Based on these works, [...]* With respect to the preceding sentence, it is unclear whether this imposed trend is part of the inventories or an alternation in present work. If latter is the case this imposed trend needs more explanation and references. If former is the case this sentence may be dropped as it doesn't provide much additional information.

ANSWER: Thanks for the suggestion, but we rather keep the sentence pointing at the trend of chlorinated VSLS emissions with the intention to highlight the different behavior with respect to oceanic VSL bromocarbons (cyclical climatology). To avoid being interpreted as a novel alternation of our work, we have rephrased the referred sentence as follows (see response to **R2.C4.9-12** below as the complete paragraph has been changed):

L247-250: *"**For anthropogenic VSL sources of chlorocarbons, we follow the Hossaini et al. (2019) and Claxton et al. (2020) emission inventories, which include time-dependent emission of two major contributors to the organic chlorine load (CH_2Cl_2 and C_2Cl_4.) as well as surface LBCs for two other compounds ($CHCl_3$ and $C_2H_4Cl_2$).** Based on these works, an increasing trend from 2000 to 2020 **is applied to** the **CESM2-SLH** emission **and LBC** files for the recent past **(see Appendix)**."*

R2-C2.7: L325–326: *"Note that the fitting [...]*. This sentence is not well written and should be rephrased along the lines: → 'Equation (2a,b) are only valid for wind speeds $\omega \geq 3$ m s^{-1} (Inamdar et al., 2020). Below this threshold, anonymously high iodine fluxes are predicted

R2-C2.8: L326–328: *"Therefore, a wind speed mask imposing [...] periods."* This paragraph is not entirely clear from an implementation point of view in the code. Rephrase: → To avoid this overprediction, $\omega = 3$ m s^{-1} is assumed for all grid cells where $\omega < 3$ m s^{-1}.

ANSWER: We understand the reviewer meant anomalously instead of anonymously. We have modified the manuscript as follows:

L277-279: *"**Equations (2a,b) are only valid for wind speeds $w \geq 3$ m s^{-1}. Below this threshold, anomalously high iodine fluxes are obtained. To avoid this overprediction, $w = 3$ m s^{-1} is assumed for all grid cells where $w < 3$ m s^{-1}. Not imposing this wind speed mask** result in an overestimation of iodine fluxes from the ocean during calm periods (Inamdar et al., 2020)."*

R2-C2.9: L350: *"[...] above a pressure threshold [...]"* Does this mean below or above 300 hPa?

ANSWER: To avoid confusion, we have replaced the text by *"**below** a pressure threshold **(P < 300 hPa)**."*

R2-C2.10: L367–373: *"Given, the large changes [...] (see Section 3.2.2)."* Be more explicit. How large are the uncertainties and how much have you adjusted the reaction rates compared to the most recent JPL catalog?

ANSWER: We apologize for the unspecific description of the changes in accommodation coefficients required to replicate previous estimation of the SSA-dehalogenation flux. We have now modified to explicitly mention the scaling factors implemented in the latest version of CESM2-SLH as follows:

L311-317: *"Given the large **increase** in SSA abundance and **vertical** distribution between CESM1 and CESM2 (see Fig. **S2), particularly over the boundary layer where the latter show up to 10 times larger values than the former,** the accommodation coefficients (γ_{ox}) **for halogenated reservoirs compiled in Table 4 of the Supplementary Material of Ordóñez et al. (2012) was reduced by a factor of 3 for chlorine and iodine and by a factor of 8 for bromine (see Table 1). This scaling factors are within the reported uncertainty and variability of γ^{ox} for the different halogen families and aerosol compositions (Burkholder et al., 2020) and allowed to reproduce previously estimated SSA-dehalogenation fluxes and burdens (see Section 4.2).**"*

R2-C2.11: L379–382: *"Careful consideration [...] budget and burden."* This content of this paragraph is of more general nature and should be formulated that way. → 'The representation of aerosols in general circulation models, their resulting distribution, abundance, and properties play a key role for prediction of SLH production via SSA dehalogenation in the troposphere'.

R2-C2.12: L384–385: *"[...] the vertical extent of sea-salt in the free-troposphere was largely reduced [...]"* Be more explicit. What does this mean? How was this achieved?

R2-C2.13: L478–482: *"CESM-SLH uses the Modal Aerosol Model with 4 Modes [...]"* This has been implicitly mentioned earlier in that section. Either include this, when you first mention the aerosol model difference between CAM4-chem and CAM6, or in the general CESM model description section as proposed.

ANSWER: We have implemented all of them in the revised version and rephrased the complete paragraph as follows (see also the related response to **R2-C6.23** and **R2-C6.32-33** below):

L534-545: ***"The representation of aerosols in general circulation models, including CESM, plays a key role for predicting halogen production via SSA-dehalogenation, which in turn impacts on** the SLH tropospheric budget and burden. **The major difference between CESM1 (CAM4-Chem) and CESM2 (CAM6-Chem) is that the former uses a continuous bulk representation of aerosols with four size bins, whereas the latter uses a modal representation with three bins (Danabasoglu et al., 2020). Another relevant difference is that MAM4 is the default dust scheme in CESM2 (Liu et al., 2016). Consequently**, the vertical extent of **SSA** in the free-troposphere was largely reduced to improve the model **overestimation obtained in previous studies** (Lamarque et al., 2012; Tilmes et al., 2023). Therefore, **to allow adjusting** the online efficiency of the SSA-dehalogenation flux and avoid unrealistic changes in the atmospheric burden **of tropospheric halogens due to parallel SSA developments**, the released CESM2-SLH configuration now*

*includes a group of SLH scaling factors (&slh_nl,) within the user-defined namelist (user_nl_cam). These tuneable scaling factors allow individual users to adjust the SSA-dehalogenation source in the different model resolutions and configurations in order to assure a consistent halogen atmospheric loading that are consistent with those shown in this work (see **Appendix for further details**).”*

In order to define MAM4 on its first mention, we have updated the closing paragraph of current Section 2.2.2 as follows:

L393-401: *“Oxidation of DMS to produce sulphur dioxide (SO_2) by BrO, Cl and IO are also included in the updated SLH chemical scheme. **These** improvements in sulphur chemistry representation **in CESM2 with respect to CESM1**, including tropospheric sulphate formation and washout, are a major source of uncertainty for radiative forcing estimations (Ge et al., 2022) and are currently under development. Therefore**, the current CESM2-SLH mechanism has been developed starting from** the benchmark sulphur scheme implemented in TS1.2 (Emmons et al., 2020). **Similarly, the Modal Aerosol Model with 4 modes (MAM4)** scheme **is the default aerosol option in CESM2,** which **includes updates in** the formation and growth of sulphate, black carbon and organic matter, secondary organic aerosols, sea salt, and dust (Liu et al., 2016). **Although no direct SLH changes to the** MAM4 scheme **were implemented, we note that indirect** perturbations of reactive halogens on OH abundance can influence the **global** aerosol burden (Saiz-Lopez et al., 2023).”*

R2-C2.14: L528–530: *”Regarding stratospheric heterogeneous [...]”* This sentence seems to refer to the stratospheric heterogeneous chemistry in the context of Polar Stratospheric Clouds (PSCs) that had been previously implemented in mo_strato_rates.F90. But it is unclear what ”complemented [...] mapping” means. The expression ”historical implementation” here seems inadequate. This sentence should be rephrased.

R2-C2.15: L536–539: *”In doing so, [...].”* This sentence is unclear and should be rephrased. Do you mean that you used reaction yields measured for chlorine and bromine species for the respective iodine species instead of the actually observed iodine yields rates? What is the reason for this?

ANSWER: We have rephrased the whole paragraph describing stratospheric heterogeneous reactions as follows (see also the related response to **R2-C6.35** below):

L445-455: *“**Implementation of** stratospheric heterogeneous **reactions of inorganic halogen reservoirs arising from the photodecomposition of long-lived halogens in WACCM** are important for **representing** the ozone layer (Marsh et al., 2013). This includes **temperature and water-vapour dependent** re-activation reactions **of chlorinated and brominated reservoirs** occurring over stratospheric sulphate (SAD_{sulfc}), ice-crystals (SAD_{ice}) and nitric acid trihydrate (SAD_{NAT}) surfaces (Kinnison et al., 2007), **including recent updates of individual stratospheric** accommodation coefficients (γ^{strat}; Solomon et al., 2015). Based on Cuevas et al. (2022), **in CESM2-SLH** we extended **WACCM developments by mapping** equivalent heterogeneous reactions in the stratosphere for the minor halogenated reservoirs (mainly HOCl and HOBr), as well as the previously neglected iodine species (see Table 3). **Here,** we assumed identical accommodation coefficients and reaction yields for **iodine than those used for the equivalent chlorinated and brominated reservoirs. This assumption represents a lower-limit of iodine impacts, as previous studies suggest that the reactive efficiencies of iodine species are larger than those for bromine and chlorine** (Koenig et al., 2020; Solomon et al., 1994).”*

R2-C2.16: L604–608: Putting on my code developer hat... Considering that the VSL/SLH developments in CESM1 were not directly transferable to CESM2, how sustainable are your developments based on CESM2? First, forking implies that the development may never be merged back into the CESM repository and is in jeopardy to end up on a stale branch (again). Second, taking a look at your github repository shows that the last pull request from the upstream repository has been more than one year ago. Third, since submitting this

preprint you have added changes to the branches on your CESM2 and CAMS forks without (as far as I can tell) tagging the versions you have based this preprint on. Therefore, it would not be possible to reproduce your results, although your repository is publicly available (which is actually great!).

ANSWER: First, we apologize for the erroneous usage of the terms fork and tag in the original manuscript. We have now corrected and used them appropriately. Most importantly, we have now created two CESM2-SLH tags: one reverted to the exact commit used to perform all simulations described in the manuscript (*cesm2.2-asdbranch_slh-gmdd* and *cam_cesm2_2_rel_09_slh-gmdd*), and another one where we have updated all SLH default namelists variables in the building scripts of CESM with the final user-defined values described in this work (*cesm2.2-asdbranch_slh_tag* and *cam_cesm2_2_rel_09_slh_tag*). To avoid confusion for new users, and given that FORTRAN changes were not implemented between tagged versions, we only point at the latest one in the revised manuscript.

Second, we appreciate the reviewer comment and understand his/her concerns about the importance of making sure the described SLH developments do not end up on a stale branch. This was indeed the case when performing the initial pull-request of our SLH commits to NCAR. We were suggested to shift all developments into the latest CAM6_dev branch as this would assure SLH developments to be maintained and updated in future versions of CESM. Here we note that once the final CAM6_dev version is frozen, it will become the core CAM7 atmospheric component of CESM v3. Therefore, we have now ported all SLH developments of CESM2-SLH into CAM6_dev, whose pull request had already been approved by NCAR and made available in the official GitHub repository (tag *cam6_4_153*).

Based on the above, we have rephrased the referred sentence, as well as the Code and Data Availability section as follows:

L528-533: *"**CESM2-SLH porting** was performed on top of version 2.2.0 of CESM2 (Danabasoglu et al., 2020), particularly over branch cesm2.2-asdbranch, which includes CAM6 tagged version cam_cesm2_2_rel_09**. Based on these versions, we forked and created the new CESM2-SLH and CAM6-SLH branches** called cesm2.2-asdbranch_slh and cam_cesm2_2_rel_09_slh, respectively, which incorporate SLH updates within the main FORTRAN routines as well as modifications **to building scripts** (e.g., cime and cime_config) and default namelist variables (see **Appendix**). These **open-access community developments allow to download, clone and build all SLH compsets available (see Code and Data Availability below; Fernandez et al., 2025)**."*

L1551-1561: *"The Community Earth System Model (CESM) code is maintained by the NSF National Center for Atmospheric Research (NCAR). The benchmark version of CESM2 **(Danabasoglu et al., 2020)** is distributed via GitHub (https://github.com/ESCOMP/CESM) and available at the NCAR's official site (https://www.cesm.ucar.edu/models/cesm2). The **final tag of the** CESM2-SLH branch used in this work **(cesm2.2-asdbranch_slh_tag)** can be **cloned** from GitHub **(https://github.com/RafaPedroFernandez/CESM/tree/cesm2.2-asdbranch_slh_tag)**, which **was originally forked** from the **latest** CESM2 **tag available in the NCAR** repository (https://github.com/ESCOMP/CESM/tree/cesm2.2-asdbranch). All SLH code and data supporting this work, including the complete set of building scripts, Fortran routines, individual namelist templates **and input files for SLH and NOH compsets,** as well as the annual mean output used to generate all Figures and Tables, can be obtained from Mendeley Datasets at https://doi.org/10.17632/f87hvrv25v.1 (Fernandez et al., 2025). **All SLH developments described here have also been ported into the latest CAM6 development branch maintained at NCAR (https://github.com/ESCOMP/CAM/tree/cam6_4_153) and will be available in the next release of CESM v3."***

R2-C2.17: L625–631: ”[...] factors are maintained identical to the default FCHIST and FCnudged parent’s configuration [...]” It remains unclear how the two compsets differ (without going through additional resources). I suggest elaborating on the difference between the two in the beginning of the results section

R2-C2.18: L643–645: *”Finally, a fully-coupled [...] setups, both of them at [...] resolution [...] were mapped to their corresponding WACCAM compsets.”* This sentence is grammatically not correct, hard to understand, and needs rephrasing. What do you mean by ”mapped”? Do you mean that you have created also compsets for WACCAM based on your BWHIST_slh and FWnudged_slh compsets that use CAM6?

ANSWER: To avoid any confusion about the new SLH configurations available, we have removed the term “parent’s” and rephrased the opening and closing sentences of the paragraph referred in both comments as follows:

L548-565: *“Two main CESM2-SLH* ***configurations*** *have been developed based* ***on the available CAM6 base atmospheric chemistry compsets: FCHIST_slh and FCnudged_slh (see Table 6), where the former resolves atmospheric dynamics internally (free-running) and the latter is forced by prescribed meteorological fields (new nudging approach for specified dynamics). Both*** *configurations* ***employ*** *the coarse f19_f19_mg17* ***horizontal resolution*** *(1.9° latitude × 2.5° longitude, hereafter 2°×2°) and 32 vertical levels* ***(low-top)*** *from the surface to approximately 40 km (~4 hPa)” ...* ***“In addition to the low-top configurations, whole atmosphere (high-top)*** *fully-coupled BWHIST_slh* ***(f19_g16) and*** *FWnudged_slh* ***(f19_f19_mg17) compsets were developed,*** *both* ***considering the coarse*** *2°×2° resolution and 70 vertical levels* ***as their corresponding base atmospheric*** *WACCM compsets. Table 6 summarizes the names and* ***specifications*** *of the main CESM2-SLH compsets.”*

R2-C2.19: L664 and following: *”stabilization”* Expression is unusual. Usually, this is referred to as ’equilibrium’.

ANSWER: Chemical species in the atmosphere, particularly SLH concentrations, do not reach chemical equilibrium. In any case, we can talk of a steady state. We have rephrased the sentence and included in the Appendix as follows:

L1586-1587: *“The initial condition (ncdata) data has been replaced to ensure* ***background*** *SLH species and atmospheric compounds* ***are stabilized****.”*

Section 3

R2-C3.1: L766–769: *”[...] their photodecomposition constitutes the critical first step in releasing inorganic chlorine and bromine [...]”* This is a repetition of scientific background presented in Section 2. Here, and elsewhere in this section, you should focus on the results and not on repeating scientific background.

ANSWER: The original sentence was oriented to connect the distinct influence of unreactive VSL halocarbons with that of reactive halogen species for the non-expert. We have now accepted the reviewer suggestion and removed the referred sentence as well as many others equivalent connections throughout Section 4 (Results). In some occasions, we have shifted down and rephrased as part of the SLH discussion in the new Section 5.

A detailed response to the suggestion of including a dedicated Discussion section is provided above (**R2-C1.3**) while individual answers to specific blocks that have been moved to the new Section 5 are detailed below (**R2-C3.8**, **R2-C3.9, R2-C3.12** and **R2-C3.14**).

R2-C3.2: L898: *"[...] in agreement with previous estimates [...]"* You may cite the numbers from the reference.

ANSWER: Thanks for the suggestion, but we do not further need it as we removed the final half-sentence to shorten the manuscript length.

R2-C3.3: L900–901: *"model surface"* What "surface" does this refer to? Is it the actual land/water surface or the lowermost model level above the surface?

ANSWER: Thanks. We have rephrase the sentence to explicit mention Lower Boundary Conditions:

L784-786: *"Here, it should be noted that the additional contribution from other anthropogenic VSL chlorocarbons ($CHCl_3$ and $C_2H_4Cl_2$) are also included **as LBCs** instead of considering offline emissions, reaching a total of ~48 pptv at the **lowest** model **level above the** surface."*

R2-C3.4: L904–907: *"This is explained by the large non-linear response of the [...]"* Can you further elaborate on this? Where do the non-linearities in Eq. (3) come from? I understand that there are non-linearities in the involved atmospheric feedback processes, e.g. radiation-temperature-photolysis.

ANSWER: The reviewer is correct that Eq. (3) alone cannot explain the non-linearity of the SSA-dehalogenation. Here, we do not point at radiation-temperature atmospheric feedbacks, but instead to the fact that every time a non-stoichiometric heterogeneous reaction occurs, the system contains more and more Br and Cl in the gas phase, which in the next cycle, will uptake once again bromide and chloride from the SSA. To make this clear, we have modified the referred sentence as follows:

L789-792: *"This is explained by the non-linear **release of Cl_2, Br_2 and BrCl through the non-stoichiometric heterogeneous reactions described in Table 1, which in turn depend on** the parameterized fields of SAD_{SSA} (Fig. **S2**) **and the partitioning shift between different** inorganic halogen reservoirs (Fig. **10**)."*

R2-C3.5: L952: *"[...] the IO_x burden change [...] remains close to 10%."* It is not clear, to what these 10% refer to. In Table 8 no "burden change" is found, rather the tropospheric burdens in Gg are displayed. The percentage difference between the two SLH experiments and the given burden of 3.2 Gg IO_x amounts to 9.4% and 12.5%, respectively. Please clarify and rephrase accordingly.

ANSWER: We were not pointing at the burden change for a specific experiment, but to the spread of burden values between different experiments. To clarify the modeled changes in IO_x and I_y abundance between experiments, we have modified the complete paragraph as follows (see also the response to **R2-C7.20** below):

L831-839: *"In contrast to bromine and chlorine, surface I_y abundance in **CC-SLH [2×2-ndg]** is ~40% higher compared to **CESM1-SLH [SL23]** (2.3 pptv I_y), which is mainly due to the different IO_x/I_y and OH/HO_2 ratios between **the different nudging approaches among** CESM versions (see Fig. 2i,k). **However, free-running experiments (CC-SLH [2×2-hst] and CESM1-SLH [QL22]) show equivalent surface abundances, particularly for the 2015–2020 period. The** larger OH abundance and lower HO_2/OH ratio in CESM2-SLH compared to CESM1 increases the contribution of HOI to the total I_y loading, and therefore, there is a major shift on the partitioning from reactive to reservoir species*

for iodine (see Table 8). Therefore, the reactive IO_x ***tropospheric burden in CESM2*** *(3.5-3.6 Gg I)* ***is only ~10% larger than the 3.2 Gg I estimated value found in*** *Saiz-Lopez et al. (2023).* ***Most notably, the spread in global I_y abundance between free-running and nudging CESM2 compsets is smaller than the spread in CESM1.****"*

R2-C3.6: L1023–1038: Given the varying height of the tropopause between 90°N - 90°S (≈400 - 90 hPa) and that the ratio between ocean to land is roughly 2 to 3, I don't quite understand this paragraph. First, a global average over pressure/height lumps together polar stratospheric and topical tropospheric air. Therefore, you absolutely cannot draw any conclusion with respect to the UTLS region. Second, you refer to the Marine Boundary Layer (MBL) but average globally including also grid cells over land, I suppose. Therefore, it seems impossible to draw conclusions with respect to the MBL. You would need to convert your data into vertical coordinates relative to the tropopause height and use a land-sea-mask to include ocean grid cells only to be able to draw robust conclusions.

R2-C3.7: L1051–1082: The concerns raised above also apply to these paragraphs and analyses.

ANSWER: The reviewer has a point that given to the latitudinal variation of the tropopause within the UTLS, as well as to the different representation of the boundary layer over the ocean (MBL) and continental domains (PBL), it is hard to draw robust (i.e., quantitative) conclusions. However, we respectfully disagree with R2 that it is not possible to draw any conclusion based on original Figure 6 (current Figure 9). Indeed, the computation of the global mean average was made on porpoise to summarize, in a single figure, the general behavior of organic and inorganic chlorine, bromine and iodine from the Earth's surface to the stratosphere. As conceived, we believe current Fig. 9 summarizes the main similarities and differences between halogen families.

We appreciate the careful reading and have rephrased the opening paragraph to avoid pointing at the UTLS and MBL explicitly. In addition, the revised manuscript now includes explicit clarification of the different regions and domains that are considered when computing the global mean,

L994-997: *"****We note that these global and annual mean averages lumped together continental and oceanic domains within the boundary layer, as well as tropospheric and stratospheric parcels due to the latitudinal variation of the tropopause (see dashed horizontal lines in Fig. 9). However, three*** *main differences* ***characterizing*** *the vertical distribution for each halogen family* ***are distinguished****."*

and remove on the forthcoming paragraphs any reference to the UTLS and MBL, as for example:

L1033-1039: *"As summarized in Table 8, SSA-dehalogenation is the dominant source of bromine and the second largest source for chlorine. However, Figure 7c highlights that these sources are primarily confined to the* ***lower troposphere****. For chlorine, the contribution of the acid-displacement HCl release dominates,* ***increasing surface Cl_y*** *particularly in the NH mid-latitudes and coastal locations* ***(Fig. 11d)****.* ***The*** *photochemical degradation of both VSL_{Cl} and VSL_{Br} dominates the release of Br and Cl atoms throughout the* ***free troposphere****, although the biogenic ocean flux is the sole source of bromine, while for the case of chlorine the contribution from anthropogenic VSL_{Cl} is at least two orders of magnitude larger than the natural oceanic source."*

Please refer to the related responses to **R2-C2.9** above as well as to **R2-C3.11** and **R2-C6.8** below.

R2-C3.8: L1132–1139: *"Please note that due to [...]"* This paragraph belongs to a discussion section.

ANSWER: The original sentence was oriented to provide insights about the similarities and differences of SGI and PGI for chlorine w.r.t. bromine, and to support our results with the available literature. We agree with the reviewer that the referred sentence better fit in a dedicated Discussion section. Please also refer to the responses to **R2-C1.3** and **R2-C3.1** above.

R2-C3.9: L1116–1165: *"Here we recall [...]"* Beside this odd expression, this paragraph belongs into a discussion section.

ANSWER: The original sentence was oriented to provide insights about the uncertainties and implications associated with the low model bias for SGI_{Cl} w.r.t. the dominant role played by CFCs and HCFCs. We agree with the reviewer that the referred sentence better fit in a dedicated Discussion section. Please also refer to the responses to **R2-C1.3** and **R2-C3.1** above, as well as **R2-C3.10, R2-C3.14** and **R2-C7.36-37** below.

R2-C3.10: L1165–1167: *"[...] should not represent a significant bias in our model implications on other atmospheric components."* Quite unclear. Do you mean that atmospheric (stratospheric) chemistry would not be affected (or only to a small degree) by the underestimation of SGI_I?

ANSWER: We are explicitly pointing at the minor contribution of SGI_{Cl} to total stratospheric chlorine. Based on the reviewer suggestion of including a dedicated Discussion section (**R2-C1.3** and **R2-C3.1**), we have moved the sentence to the new Section 5 and rephrased it as follows (see also the response to **R2-C7.36-37** below):

L1425-1427: ***"Given that chlorine influence on stratospheric ozone is dominated by long-lived CFCs and HCFCs, the current*** *model underestimation of* SGI_{Cl} ***does not introduce*** *a significant bias* ***in the total stratospheric chlorine budget and, consequently, does not substantially affect chlorine-driven ozone destruction."***

R2-C3.11: L1177–1182: *"[...] over the boundary layer (i.e., mean modelled value from the surface up to ~ 850 hPa)."* This should be rephrased, as the boundary layer is highly variable. → 'average over model levels $P \geq 850$ hPa and the time period $2015 - 2020$'

ANSWER: The reviewer is correct, thanks for the suggestion. We have rephrased the sentence as follows (see also response to **R2-C7.21** regarding pointing at individual figure's panels below):

L1058-1060: ***"****Figure 11 shows the spatial distribution of carbon-bonded VSLs (****Fig. 11a-c****), total inorganic halogens (****Fig. 11d-f****) and the most relevant reactive fraction (****Fig. 11g-i****) of each halogen family* ***averaged over model levels with P ≥ 850 hPa and for the time period 2015–2020."***

R2-C3.12: L1278–1284: *"Given [...] in the troposphere [...]."* This paragraph could be placed in a discussion section.

ANSWER: The original sentence was oriented to provide insights about the equivalent although not exactly identical absolute and percentage changes in ozone abundance in CESM2-SLH compared to CESM1. We agree with the reviewer that the referred sentence better fit in a dedicated Discussion section. Please also refer to the responses to **R2-C1.3** and **R2-C3.1** above.

R2-C3.13: L1434–1438: *"the old nudging over model levels [...] most recent nudging approach [...] the chemical influence of SLH on tropospheric and stratospheric transport are of equivalent magnitude."* The

first part is basically a repetition from the model description section. Albeit, the formulations differ. Please rephrase in more general terms. Regarding the second part, you have previously discussed in this preprint, that dynamics are important for the amount of VSL and SLH in the troposphere and stratosphere and therefore for the ozone depletion potential and ozone abundance. Please clarify, how the model results presented in this section could indicate an impact of SLH chemistry on atmospheric transport, especially in a SD or nudged setup where dynamics are prescribed.

ANSWER: We agree with the reviewer that the first part of the sentence is a repetition of the model description section. Regarding the second part, we believe that including a comprehensive analysis and discussion of the role played by STE on the transport of VSLS and SLH in this section would excessively enlarge an already long paper. Therefore, we decided to leave this detailed discussion for future studies and rephrased the sentence as follows (see also the related response to **R2-C2.18** above):

L1278-1280: ***"Differences between model versions are attributed to*** *dynamical changes in the representation of air subsidence and downward ozone transport across the tropopause between the old* ***and new*** *nudging* ***approaches*** *(Davis et al., 2022)* ***and will be evaluated in future studies.***"

R2-C3.14: L1517–1550: Large parts of this paragraph are written as if they were meant for a user guide which should clearly not be the purpose of a scientific paper. Please rephrase with a more general modeling community audience in mind

ANSWER: We agree with R2 that some parts of the referred block belong to the new Appendix. However, we believe that the final couple of sentences belongs to the new Discussion section. Therefore, we have substantially reduced the length of the original Section 3.4 almost by half and adapted the reaming text to other sections of the manuscript. We added the following sentence to the revised manuscript (see also response to **R2-C1.4, R2-C2.6** and **R2-C3.1** above):

L1358-1359: ***"A brief description of the main routines and user-defined namelist required to setup and modify different model experiments within CESM2-SLH is included in the Appendix.***"

Section 4

R2-C4.1: For your Summary and conclusions section, it would also be important to mention the necessary scaling of emissions depending on compset and model resolution. Potentially, the scaling factors for the nudged case will depend on the nudging datasets (e.g. ERA5, MERRA, CRUJRA, ...) as well. As part of this section, but also in the model development section, you should clearly state, how these scaling factors should be derived

ANSWER: We thank the reviewer for the suggestion, which is an important consideration for studies using other configurations. However, we believe the suggested clarification belongs to the new subsection 5.3 within ***"Discussion"*** instead of the final Section 6 (***"Summary and Conclusions"***). Therefore, we added the following sentence to the revised manuscript:

L1489-1494: ***". For the particular case of the FCnudged_SLH and FWnudged_SLH compsets, the scaling factors compiled in the Appendix for VSL emissions, SSA-dehalogenation and washout following FRA were adjusted***

considering the default meteorological MERRA2 dataset (Rienecker et al., 2011). However, we note that all &slh_nl values are affected by changes in the dynamical transport, and must be fine-tuned in case other meteorological fields are imposed, as for example those from the fifth generation ECMWF (European Centre for Medium-Range Weather Forecasts) reanalysis (ERA5, 2023). See the Appendix and the CESM2-SLH Mendeley repository for further details.*"***

Finally, we note that the description of the SLH scaling factors (including the original Table 7) as well as the basic guidance about how to adjust and/or extend them is now condensed in the new Appendix.

Technical corrections

GENERAL ANSWER: Thanks a lot for the very detailed evaluation. Below we provide direct answers to all technical corrections. In some cases, we have grouped consecutive comments into a single response. Note that "format/style" modifications have not been highlighted in the track-changes version of the manuscript.

Section 1

R2-C5.1: L82: "X, Y = Cl, Br, I" Maybe write this as mathematical expression? → X, Y ∈ {Cl, Br, I}.

ANSWER: No, thanks. We rather use the same style as in previous publications.

R2-C5.2: L99–118: Reactants in chemical formulae are supposed to be set upright, e.g. using \chem in LATEX.→ https://www.geoscientific-model-development.net/submission.html#math

ANSWER: Thanks. We now use "normal/upright" format for all chemical species. Note we have not used LATEX but the "MS Word template" instead.

Section 2

R2-C6.1: L151: "(e.g., (Saiz-Lopez et al., 2023)" Missing ')'. → e.g. using LATEXcommand citep[e.g.][]<sl23>, where <sl23> is the reference label ⇒ (e.g., Saiz-Lopez et al., 2023).

R2-C6.2: L239 (and many others): "[...] described in the original work of (Ordoñez et al., 2012)." When citing a reference in-text, in-text citation should be used, e.g. in LATEX\citet{} ⇒ Ordoñez et al. (2012).

ANSWER: Thanks. All references and citations (including in-text citation) now follow GMD style. Note we have not used LATEX but the "MS Word template" instead.

R2-C6.3: L239: *"[...] has been extensively described in the original work of [...]"* This expression is odd. → 'has been described in'.

ANSWER: Thanks. Done.

R2-C6.4: L248: *"20°-50°"* em-dash should be used according to journal house-style. Please check similar expressions! → *20° − 50°*

ANSWER: Corrected here and elsewhere.

R2-C6.5: L252: Formula not set correctly. Please refer to the journal house-style, e.g. non-counting indices should be typeset upright. →https://www.geoscientific-model-development.net/submission.html#math

ANSWER: Done.

R2-C6.6: L256: *"Note that, differing from previous [...]"* As indicated above, historical context is unnecessary and can be omitted.

ANSWER: The context is not historical, we aimed to highlight the advantages of the Ordoñez inventory in comparison to other approaches. To avoid confusion, we have rephrased the sentence as follows:

L228-231: *"**In comparison to other VSLS approaches considering** only only latitudinal bands* (Butler et al., 2007; Jones et al., 2010; Warwick et al., 2006b, a)*, the Ordóñez et al. (2012) inventory introduces a tropical geographically-heterogeneous and seasonally dependent variability, which allows for an improved spatio-temporal representation of VSL halocarbon distribution in the global troposphere."*

R2-C6.7: L259–263: *"Despite [...]"* This sentence is hard to understand like most of your sentences that start with "despite". Try to rephrase this and similar sentences! → 'The emission flux is predefined and read from file to which we referred to as offline emissions. The FORTRAN routine mo_srf_emissions.F90' was modified to compute a time-dependent halocarbon emission in hourly resolution accounting for the radiation dependency of photosynthesis. Emissions follow either [...]'

ANSWER: We have carefully checked all sentences staring with *Despite* and apply changes accordingly. We have rephrased the referred sentence as follows (see complete answer to **R2-C2.1**):

L231-233: *"**Once the monthly-mean prescribed fields are read,** hourly dependent **profiles are applied** to the flux strength of all halocarbons **to represent the** photosynthetic dependence on radiation intensity."*

R2-C6.8: L269–281: *"Finally, [...]."* Please refrain from giving historical context, rather concentrate on the important content! This paragraph should be rewritten along the lines: → 'Due to improvements in MBL dynamics and resulting different oxidative capacity, the Oro˜nez emission inventory for brominated and chlorinated species has to be rescaled by a factor of 1.15 (15%) to achieve the observed stratospheric halogen loading.'

ANSWER: The context is not historical, we aimed to highlight the advantages of the Ordoñez inventory in comparison to other approaches. To avoid confusion, we have rephrased the sentence as follows:

L237-**244: *"Due to** improvements in the representation of large-scale ascent and transport across the **boundary layer in CESM2** (Simpson et al., 2020) **as well as** in the emission strength and **speciation** of air pollutants **altering the** oxidative capacity of the troposphere (Emmons et al., 2020) the original Ordóñez et al. (2012) **inventory for chlorinated and brominates species was** increased by a constant factor of 1.15 (i.e., 15%) **to reproduce the stratospheric halogen loading obtained** in previous CESM1 **studies** (Fernandez et al., 2014, 2021). The rationale for increasing the offline emission fluxes is that the reduction of transport across the **boundary layer** and the increase near-surface OH abundance **in CESM2-SLH** results in more efficient conversion from SGs to PGs at lower model levels. **Given** the much shorter **photochemical** lifetime **of iodine species, no scaling was applied to** VSL iodocarbons."*

R2-C6.9: L284–286: *"For the particular case of chlorine, [...]"* In-text citation style instead of parenthesis needed. Rephrasing of this sentence is recommended as it is hard to understand. → 'For anthropogenic SLH sources of chlorine, we follow the Hossaini et al. (2019) and Claxton et al. (2020) emission inventories. These inventories include time-dependent emission of two major contributors to the organic chlorine load, CH_2Cl_2 and C_2Cl_4.'

R2-C6.10: L289–291: *"Given that the dominant VSL chlorine sources [...]"* This sentence is difficult to understand. Rephrase along the lines: → 'Beside significant emissions of $CHCl_3$ from natural sources, chlorinated VSL are dominated by anthropogenic emissions that display a pronounced hemispheric asymmetry.'

R2-C6.11: L293: *"[...] globally scaled [...] globally."* Doubling. Remove one "globally"

R2-C6.12: L297–298: *"[...] but not yet implemented [...]"* You may remove the part of the sentence as it is not important whether it has not been implemented in any CESM version.

ANSWER: Thanks for the suggestions. We have substantially modified and shorten the text as follows:

L247-257: ***"For anthropogenic VSL sources of chlorocarbons, we follow the Hossaini et al. (2019) and Claxton et al. (2020) emission inventories, which include time-dependent emission of two major contributors to the organic chlorine load (CH_2Cl_2 and C_2Cl_4.) as well as surface LBCs for two other compounds ($CHCl_3$ and $C_2H_4Cl_2$).*** *Based on these works, an increasing trend from 2000 to 2020* ***is applied to*** *the emission* ***and LBC*** *files for the recent past.* ***Beside a fraction of $CHCl_3$ emissions arise from natural sources (with minor contributions from the other compounds), chlorinated VSL are dominated by anthropogenic emissions that display a pronounced hemispheric asymmetry*** *(WMO, 2022).* ***Therefore,*** *hereafter we assume all of these offline emissions to have only an anthropogenic origin. Consistent with the scaling factor applied to the Ordóñez et al. (2012) inventory, both VSL chlorocarbon surface emissions and LBCs were globally scaled by* ***the same*** *constant factor* ***(****1.15* ***or*** *15% enhancement). It should be noted that additional anthropogenic halocarbon sources, as those arising from the waste treatment of power-plants as well as* ***seaweed aquaculture are not considered*** (Carpenter et al., 2000; Jia et al., 2023; Leedham et al., 2013)***."***

R2-C6.13: L298–301: *"To include [...]" This would be part of the proposed "user guide"* Appendix section.

R2-C6.14: L308: *"[...] variables HOI and I_2 [...]"* HOI and I_2 are not "variables" but 'trace gases'. Please phrase accordingly.

R2-C6.15: L307–310: *"To include [...] and replaced by the online computation."* This would also be part of the "user guide"

ANSWER: We have moved most of the referred text to the new Appendix (see complete response to **R2-C1.4** and **R2-C2.6** above), and rephrased the remaining sentence as follows:

L263-269: ***"Following Prados-Roman et al. (2015b), the parameterized expressions for HOI and I_2 fluxes from MacDonald et al. (2014) are computed online*** *by Eq. (2a) and (2b), respectively, ..."*

R2-C6.16: L315–317: Formulae not set correctly, e.g. $\boldsymbol{F_{I2}} \rightarrow \boldsymbol{F_{I_2}}$; $ln(\omega) \rightarrow \ln(\omega)$; $1.75 \times 10^9 \rightarrow 1.75 \cdot 10^9$; →https://www.geoscientific-model-development.net/submission.html#math

ANSWER: Done.

R2-C6.17: L310–313: *"The implementation of this source [...]. The online emission fluxes [...]."*. Rephrase. → 'Following Prados-Roman et al. (2015)b; MacDonald et al. (2014) the online emission fluxes of [...] are included in the Fortran module file iodine emissions.F90 and computed in subroutine ??? with Eq. [...].'

ANSWER: These technical descriptions have now been moved to the Appendix as follows:

L1619-1622: ***"Online oceanic sources for inorganic iodine are included by*** *adding variables HOI and* I_2 ***to the*** *standard srf_emiss_specifier used for* ***offline VSLS*** *halocarbons, although the imposed offline* ***iodine*** *file represents just a place-holder as the input values are forced to zero after being read within mo_srf_emissions.F90 routine and replaced by the online computation* ***performed in iodine_emissions.F90."***

R2-C6.18: L326,327: m/s → m s^{-1}

R2-C6.19: L328–329: *"Finally, we highlight [...] with ozone abundance [...]"* This sentence seems to be grammatically not correct and is one example for the extensive use of filler phrases mentioned above. *"Finally, we highlight"* should be removed and the sentence (and other sentences of similar kind, too) rephrased. → 'The first order dependency on ozone abundance of F_{HOI} and F_{I2} has important [...].'

ANSWER: Done.

R2-C6.20: L338: *"[...] following Eq. (3)"* Might be removed as the referred equation is following right after.

ANSWER: Done.

R2-C6.21: L345: *"[...] (R is the universal [...])."* Rephrase and resolve the brackets. → '[...], with R the universal [...].'

R2-C6.22: L346: *3 (three)* Not clear. According to house standard this should read 'three'.

ANSWER: Done, thanks.

R2-C6.23: L382–385: *"This is indeed the case, [...]"* This sentence should be rephrased and split to make it clearer. → 'The major difference for aerosols between CESM1 (CAM4-chem) and CESM2 (CAM6) is the change from a continuous bulk representation with four size bins to a modal representation with three bins.'

ANSWER: Thanks, we have split the sentence and rephrased the whole text as follows (see complete response to **R2-C2.11-13** above):

L535-540: ***"The major difference between CESM1 (CAM4-Chem) and CESM2 (CAM6-Chem) is that the former uses a continuous bulk representation of aerosols with four size bins, whereas the latter uses a modal representation with three bins (Danabasoglu et al., 2020). Another relevant difference is that MAM4 is the default dust scheme in CESM2 (Liu et al., 2016). Consequently****, the vertical extent of* ***SSA*** *in the free-troposphere was largely reduced to improve the model* ***overestimation obtained in previous studies*** *(Lamarque et al., 2012; Tilmes et al., 2023).****"***

R2-C6.24: L397: Wrong arrow. '→'

ANSWER: Replaced here and elsewhere.

R2-C6.25: L400–403: *"The CESM-SLH implementation [...]"* This sentence should be split after *"Eq. (3)"*. The second part is difficult to understand and should be rephrased along the lines: → 'The emission of chlorine from the bulk sea salt aerosols is driven by the heterogeneous reaction of oxidized nitrogen species that do not contain halogens.'

ANSWER: We have clarified the sentence as follows:

L334-336: *"The implementation of both chlorine sources follows the FRA-approach described above for oxidized halogen reservoirs (Eq. 3), although in this case* ***the uptake of*** *oxidized nitrogen species* ***drives the SSA-dehalogenation."***

R2-C6.26: L412–413: *"[...] (e.g. [...]"*. Missing parenthesis. It might be better to connect the half-sentence by comma. → '[...], e.g., [...].'

ANSWER: Done.

R2-C6.27: L427–432: The 'checksum' of reaction types seems to be unnecessary. You may consider constructing a matrix/table of the following form:

Family	ph	odd	org	sh	het	ss	strat	total
Chlorine	11	6	20	2	7	11	10	62
Bromine	10	9	8	1	6	6	13	53
Iodine	17	39	2	1	10	6	18	93
Total	31	46	24	4	17	16	25	163

ANSWER: We thanks the reviewer for the suggestion. Following the arrangement of other tables, we have reshaped and included the new Table A2 in the Appendix. The revised text reads as follows:

Table A2: Total number of additional gas-phase and heterogeneous-phase halogen reactions included in CESM2-SLH chem_mech.in.

Halogen Family ***Type of Reaction***	***Chlorine***	***Bromine***	***Iodine***	***Total*** [&]
Photolysis	***11***	***10***	***17***	***31***
Odd-Halogen	***6***	***9***	***39***	***46***
Organic Halogen	***20***	***8***	***2***	***24***
Sulfur Halogen	***2***	***1***	***1***	***4***
Het-recycling (Tropo)	***7***	***6***	***10***	***17***
SSA-Recycling	***11***	***6***	***6***	***16***
Het-recyciling (Strat)	***10***	***13***	***18***	***25***
Total	***67***	***53***	***93***	***163***

[&] Some reactions involve inter-halogen interactions (e.g., ClO + BrO) and are double-counted within each halogen family. Therefore, the total reaction sum by halogen families is not additive. The complete list of halogen reactions is provided in main Tables 1 to 5 and Supplementary Tables S1 to S3.

L1637-1642: *"Overall, the final SLH chemical mechanism implemented in CAM-Chem introduces* ***12, 9 and 19*** *additional* ***chlorine, bromine and iodine*** *species that participate in* ***67, 53 and 93*** *new reactions. These new reactions are categorized as: photolysis, odd-halogen reactions, organic-halogen reactions, sulfur-halogen reactions,*

heterogeneous recycling on tropospheric aerosols, sea-salt recycling, and stratospheric mapped ***reactions (see Table A2), where*** *some of the reactions involve inter-halogen interactions (e.g., ClO + BrO), and therefore are double-counted within each family.* ***The inclusion of SLH chemistry in CESM2 results in an increment of the computational cost of ~18-22%."***

R2-C6.28: L442–443: *"JPL [...] IUPAC"* Acronyms have not been previously defined.

R2-C6.30: L453: *"JPL 19-5 handbook"* inconsistent with L442.

ANSWER: Done.

R2-C6.29: L452–456: *"[...], some laboratory measurements show [...]. [...] recommends neglecting the photochemical breakdown [...]. Within CESM-SLH [...] forcing to zero [...] was required [...]."* These sentences are unclear and overcomplicated. Refrain from using a term like *"forcing to zero"*. You are basically trying to say: → 'We are following the JPL recommendation, although some laboratory measurements suggest [...].'

R2-C6.31: L456–457: *"Not doing so [...]."* This sentence is somewhat redundant. References are missing. The sentence could be removed or should be rephrased if kept: → 'Including photolysis rates above [...] resulted in a complete decomposition of C_2Cl_4 down to the surface which is not in line with observations.'

ANSWER: Thanks for the suggestions. We have clarified the whole sentence as follows:

L373-376: *"In addition,* ***we follow the JPL 19-5 recommendation (Burkholder et al., 2020) of neglecting the C_2Cl_4 absorption cross-section beyond $\lambda > 270$ nm (Keller-Rudek et al., 2013), as*** *not doing so resulted in a complete* ***photodecomposition in the lower troposphere which is not in line with observations (Roozitalab et al., 2024)."***

R2-C6.32: L475–477: *"Here, we highlight [...]" Rephrase and avoid phrases like "Here, we highlight"*. Furthermore, it is not clear which CESM version this sentence refers to.

R2-C6.33: L477–478: *"Therefore [...]."* Missing comma after *"Therefore"*. Overall, this sentence seems to be in disorder grammatically. Please rephrase.

ANSWER: We have clarified the whole sentence as detailed in **R2-C2.13**:

R2-C6.34: L491: $rate_{ICE}$: Variable typesetting not in accordance to house style. → $rate_{ice}$

ANSWER: Following the house style, we now use upright lower-capital letters for the subindex, but maintained the italic format for the reaction-rate ($rate_{ice}$), as it represent a varying magnitude as the flux (F_{I2}).

R2-C6.35: L491–493: *"[...] assumed to be uptake [...]"* This sentence is grammatically incorrect. Please correct.

ANSWER: We have clarified the text as follows (see also the related response to **R2-C2.14-15** above):

L447-449: *"This includes* ***temperature and water-vapour dependent*** *re-activation reactions* ***of chlorinated and brominated reservoirs*** *occurring over stratospheric sulphate (SAD_{sulfc}), ice-crystals (SAD_{ice}) and nitric acid trihydrate (SAD_{NAT}) surfaces (Kinnison et al., 2007),* ***including recent updates of individual stratospheric*** *accommodation coefficients (γ^{strat}; Solomon et al., 2015)."*

R2-C6.36: L533: *"[...] a logical condition of humidity [...]"* This phrase is unclear. What does this mean? Please rephrase and make clearer.

ANSWER: We have clarified the text as follows:

L410-420: *"For heterogeneous reactions occurring over ice-crystals, we **use the FRA approach to** compute the reaction rate constant **($rate_{ice}$) considering** the total number of gas-phase **species that suffer uptake on** the aerosol surface, resulting in the following expressions for uni-molecular and bimolecular reactions **(see Table 2)."***

R2-C6.37: L540: *"FC"* is not defined and should be explained

ANSWER: We now explicitly point at FCnudged_slh and FCHIST_slh compsets.

R2-C6.38: L575: *"Henry law coefficient"* inconsistent naming. Called "constants" in L576.

ANSWER: We have now modified the text to use always "constants" following Sander (2015).

R2-C6.39: L630: *"maintained"* → 'kept'.

ANSWER: *"are identical to **those used in**".*

R2-C6.40: L634–635: *Despite none of them have been used in this work, we note [...]* Odd expression. The quoted part of the sentence may be removed.

R2-C6.41: L639: *"[...] many [...] depends [...]"* → 'depend'.

R2-C6.42: L640–642: *"Similarly, we highlight that [...] significantly impact on [...]"* Filler-phrase and grammar. You may remove the filler-phrase. The preposition "on" doesn't belong to "impact" and should be removed.

R2-C6.43: L642–643: *"[...] shifting [...]"* The expression might not to be correct. → 'changing'

ANSWER: Thanks for the suggestions. We have split the referred sentence between new Sections 3.1 (***"Model compsets and Resolutions"***) and 5.1 (***"Discussion"***) and clarified all of the above as follows:

L558-562: *"**We** note that additional emission and LBC files for other configurations using different SSP scenarios are available **in the published CESM2-SLH repository** and can be changed **through** user-defined namelist options (see below). In addition, equivalent model configurations using a finer resolution f09_f09_mg17 grid (0.9° latitude × 1.25° longitude, hereafter 1°×1°) have also been tested and adjusted to reproduce results **obtained** with the 2°×2° grids."*

L1477-1484: *". **Despite a high-spatial resolution being available (see Table 7)**, we recommend new users to select the coarse resolution setup as many of the online photochemical sources and recycling reactions described in Section **2 depend** on highly variable resolution-dependent atmospheric fields, such as SAD_{SSA} and SAD_{ice}**, which typically show larger variability with increasing resolution (see Tables S4 and S5)**. Similarly**, we found that resolution-dependent scaling factors for** lightning-NOx production **typically used in** CESM2 (Emmons et al., 2020; Wild et al., 2020) **result in** significant **alterations of** the chemical partitioning and washout efficiency of SLH. Therefore, caution should be taken when **moving** from a coarse to a fine resolution, as the resulting halogen abundances can significantly vary between them."*

R2-C6.44: L705: *"rationale"* This expression may not be correct in this context. → 'reason'

ANSWER: Done.

R2-C6.45: L719: *"(the so called AANE sensitivity in (Saiz-Lopez et al., 2023)"* Missing parentheses and formatting of the citation. Acronym AANE is not resolved. The insertion should be elaborated on and written out.

ANSWER: We have clarified the Anthropogenically Amplified Natural Emissions (ANNE) concept as follows:

L612-617: *"**This inventory is mostly relevant for air quality studies focused on urban and/or continental regions (Chang et al., 2024; Fu et al., 2024), without contribution to the free troposphere and stratospheric halogen loading. Indeed**, Saiz-Lopez et al. (2023) found that the SLH influence on global atmospheric composition **and radiative balance** is dominated by natural SLH emissions**, which have been anthropogenically amplified since pre-industrial periods due to the efficient coupling of halogenated species with background air pollutants, e.g.** the so called AANE sensitivity in Saiz-Lopez et al. (2023)."*

Section 3

R2-C7.1: L738–740: *"Results presented [...] are based on [...] sensitivities [...]*. Sentence contains lab-slang. "sensitivities" → 'sensitivity studies' or 'sensitivity experiments'. Please change all occurrence accordingly!

ANSWER: Following reviewer comments **R2-C1.4** and **R2-C9.6**, we have now include a whole new section describing the CESM2-SLH release, where we split original Table 6 into two separate tables: Updated Table 6 which includes the new SLH compsets and configurations, and the new Table 7, that summarizes the full set of experiments performed. To make this clear, the manuscript structure has been modified to include the following subsections ***"3.1 Model Compsets and Resolutions"*** and ***"3.2 Model Experiments and Sensitivity Simulations".*** We have revised the manuscript to make sure to unify the usage of the terms *"experiment"* (for SLH) and *"sensitivity"* (for NOH) throughout the text, while using the general term and *"simulations"* when referring to either of them. We have defined all terms in Section 3.2 as follows:

L570-576: ***"The complete set of model experiments performed in this work is presented in Table 7. Each experiment's name is composed by a prefix describing the model used and the inclusion of short-lived halogens (e.g., CC-SLH for CAM6-Chem with SLH turned on) and a suffix indicating the model resolution and meteorology option (e.g., [2×2-ndg] for coarse resolution and nudging approach). Although all model configurations have been validated, initial results presented in Section 4 are based on low-top and coarse CC-SLH [2×2-ndg] and/or CC-SLH [2×2-hst]. We note that for each of the six SLH experiments shown in Table 7, an additional model sensitivity was performed neglecting the sources and chemistry of short-lived halogens (e.g., the corresponding CC-NOH [2×2-ndg] experiment, see Appendix)."***

R2-C7.2: L747–748: *"Finally [...] model inter-comparison between the different CESM2-SLH resolutions and configurations.* Usually the term "model inter-comparison" is reserved for the Coupled Model Intercomparison Project (CMIP) and derivatives – organized comparisons between different models in the Earth System and Climate modeling community with a clear modeling protocol. "model intercomparison" → 'comparison' or 'sensitivity experiments' or 'sensitivity studies'.

R2-C7.3: L754: *"Therefore, we highlight that [...]"* As mentioned previously, these filler-phrases should be removed throughout the text to improve readability.

ANSWER: We made sure not to use "model inter-comparison" here and elsewhere to avoid misleading interpretations. We also removed filler-phrases to improve readability.

R2-C7.4: L780–782: *"Here, we highlight [...]"* This sentence should be split after "iodine".

R2-C7.5: L782: *"on-line"* → 'online'

ANSWER: We have completely rephrased and split the sentence and made sure to correct "online" and "offline" here and elsewhere:

L662-667: *"**This online inorganic halogen flux shows** an increasing emission trend between 1980 and 2020 (Fig. 1) **for the three halogen families, although the main drivers of the parameterized expressions are significantly different for chlorine and bromine with respect to iodine (see Section 2.1.3)**. Indeed,* (Prados-Roman et al., 2015a) *suggested that this **online** ocean–atmosphere coupling represents a negative geochemical feedback loop by which current ocean emissions of iodine (HOI + I_2) would be 2-3 times higher than in pre-industrial times, **constituting** a natural buffer for ozone pollution in the global marine environment."*

R2-C7.6: L809: *"allow"* → 'allow for'

R2-C7.7: L809–810: *"to provide [...] to show"* Correcting the above, these infinitive forms become unnecessary.

R2-C7.8: L816: *"[...] presents a larger increment than in CESM1 [...]"* This sentence is unclear. Do you mean → 'Iodine volume mixing ratios continue to increase after year 2000 in the CESM2 experiments, while they flatten out in the CESM1 results' ? This could be construction of your CESM1 experiments, e.g. recycling of SSTs and SICs after the end of the hindcast period...

ANSWER: We have corrected the whole text as follows:

L699-707: *"**These** CESM1 configurations were selected as they **allow for a better qualitative visualization and quantitative comparison of** the absolute abundances of each halogen family and their reactive to inorganic halogen ratios (XO_x/X_y, with XO_x = X + XO and X = Cl, Br and I)**, as well as** the main atmospheric components driving the trends **during the hindcast period.**"... "**Indeed, the increasing trend in surface ozone abundance during the 1980–2020 period in CESM2-SLH compared to the more flatten trend observed in CESM1 (Fig. 2f) results in an increasing trend in iodine volume mixing ratios in the former, while I_y abundances in the latter remained approximately constant, particularly after year 2000 (Fig. 2c).**"*

R2-C7.9: L864–868: *"Here we note that [...]"* Remove filler-phrase and split the sentence before "highlighting"

R2-C7.10: L870–873: *"In addition, [...] in any case [...] in any case"* Repetitive expression. At least on "in any case" should be removed.

R2-C7.11: L870–873: *"[...] in the lower edge [...]"* grammatically not correct. → 'at the lower margin'

ANSWER: We have corrected the whole text as follows:

L750-758: *"Second, the spread **of the global mean tropospheric halogen burden** between the different CESM2-SLH **experiments** is smaller than that obtained with CESM1 in previous studies. Indeed, for the case of bromine, the tropospheric Br_y burden for both **CC-SLH [2×2-ndg] and CC-SLH [2×2-hst]** are equivalent to those obtained for **CESM1-SLH [QL22],** although they lie in between **CESM1-SLH [SL23] and CESM1-SLH [JB23] (Fig. 3e). This range of** tropospheric Br_y **burdens arise due to changes in the seasonal and latitudinal sea-salt aerosol masks used when the CESM1 polar module is enabled** (Fernandez et al., 2014, 2021), highlighting the large sensitivity of the SSA-dehalogenation source to the modelled changes in SSA abundance and distribution (see Fig. **S2**). **The tropospheric Cl_y burden for both CESM2-SLH nudged and free-running configurations are equivalent to those obtained for CESM1-SLH [JB23] and lower than for CESM1-SLH [QL22] and CESM1-SLH [SL23] (Fig. 3d).**"*

R2-C7.12: L874: *"timeline simulation"* This expression is odd. Do you mean 'transient simulation' or 'hindcast' ?

ANSWER: Done.

R2-C7.13: L877–880: *"The larger tropospheric [...]"* This sentence is grammatically not sound and should be rephrased. How is present-day conditions defined? → 'The larger present-day tropospheric I_y burden in *FCHIST_slh* and *FCnudged_slh* ([...]) compared to estimates by Saiz-Lopez et al. (2023) and Barrera et al. (2023) ([...]) are due to substantial changes [...]'

ANSWER: Present-day was already *"defined as the mean 2015−2020 period"* in the original manuscript (see **L642**). Note we corrected to use en-dashes (−) instead of hyphens (-) for concatenating period ranges here and elsewhere. We have rephrased the referred sentence as follows:

L762-764: *"The larger **present-day** tropospheric I_y burden between current **CESM2-SLH experiments** (17.2-17.7 Tg I) **compared to to CESM1-SLH [SL23] and CESM1-SLH [JB23]** (14–14.5 Tg I) are explained by the significant changes in reactive (IO_x) vs. reservoir iodine partitioning (IO_x/I_y) between CESM1 and CESM2."*

R2-C7.14: L885–886: *"Table 8 [...]"* This is a rather unusual way to start a section. You should rather start with a sentence of introduction.

R2-C7.15: L887–888: *"Equivalent results highlighting [...]"* This sentence is unclear and should be rephrased or, as it references a later section, it may be removed

ANSWER: We have modified the opening paragraph of the section as follows (see response to comment **R2-C9.8** below related to the shift in the numbering of tables in the revised manuscript):

L770-774: *"**Annual mean** tropospheric **halogen** abundances**, LBCs, sources** and sinks during present-day **(2015–2020) are summarized in Table 8.** These global-mean reference values **for the CC-SLH [2×2-ndg] and CC-SLH [2×2-hst] experiments** should be taken as **a** guideline for any other CESM2-SLH configuration. **The** main similarities and differences **between the recommended setup** with respect to the remaining CESM2-SLH **compsets and/or resolutions available (Tables 6 and 7) are described in Section 4.4.**"*

R2-C7.16: L890–893: *"Here, we recall [...]"* Odd style AND repetition. Should be removed.

ANSWER: Done.

R2-C7.17: L893–896: *"Thus, VSL iodine mean global emissions are the same between [...]"* This half-sentence is grammatically not sound and difficult to understand. It should be rephrased. → 'Global mean iodine emissions are (by definition) the same in CESM1 and CESM2, while [...]'

ANSWER: We have modified the opening paragraph of the section as follows:

L776-780: *"**Due** to changes in transport and **background** OH abundance between CESM1 and CESM2 (see Figure 2), we increased the flux strength of the original VSL inventory (Ordóñez et al., 2012) by 15% for all VSL bromo- and chloro-**carbon (e.g., CH_2Br_2 and CH_2BrCl)** but retained the magnitudes of iodo-carbon species, including **CH_2ICl and CH_2IBr. As a result,** Cl and Br emissions are ~14% and 6% larger in CESM2 compared to CESM1**. As a result, chlorinated (VSL_{Cl})** and **brominated (VSL_{Br}) halocarbon** emissions are**, respectively**, ~6% and 14% larger in CESM2 compared to CESM1"*

R2-C7.18: L902: *"online sources"* → 'online emissions'

R2-C7.19: L919: *"[...] inspection of Table 8 shows [...]"* This expression is odd. → 'We show in Table 8 [...]' or 'In Table 8 it is shown [...]'

ANSWER: Done both.

R2-C7.20: L950: *"[...] remains similar compared to [...]"* This is another odd expression and should be rephrased. Please also include some numbers from the cited publication. → 'remains comparable with'

ANSWER: Thanks for the suggestion. We have modified the referred sentence as follows: (see also the response to **R2-C3.5** above):

L836-838: *"Therefore, the reactive IO_x **tropospheric burden in CESM2** (3.5-3.6 Gg I) **is only ~10% than the 3.2 Gg I estimated value found in** Saiz-Lopez et al. (2023)."*

R2-C7.21: L955: *"Fig. 3 bottom row"* Here and elsewhere, please reference the subplots with their respective subcaptions.

ANSWER: We have changed all sentences in the text where pointing at rows or columns of Figures, and replaced by the corresponding panel letters (e.g., Fig. 3a-c for the referred comment). However, we keep pointing at rows and/or columns within some figures' captions and table's footnotes to ease the reading.

R2-C7.22: L958: Wrong arrow in the in-line formula. → '→'

R2-C7.23: L968: *"Here it is evident [...]"* Yet another filler-phrase that can be safely removed.

R2-C7.24: L984: *"[...] the difference between both configurations [...]"* "Configurations" is not the right term. As indicated above, you should clearly distinguish between setups/configurations/compsets and model experiments → 'experiments'.

R2-C7.25: L986–987: *"[...] from organic SGs to inorganic halogen (PGs) [...]"* The brackets around PGs seem to be misplaced.

ANSWER: Done all. See the response to **R2-C1.4** and **R2-C7.1** above for a detailed answer about the experiments.

R2-C7.26: L989–990: *"[...] (see for example Table A-1 in the Annex of (WMO, 2022) and elsewhere) [...]"*. In-text citation needed. You should refrain from using "elsewhere", either you would cite other sources or not. The sentence is too complicated and should be split here, removing the parentheses.

ANSWER: We have modified the sentence as follows:

L964-966: *"Given the typically longer photochemical lifetimes of long-lived chlorinated compounds compared to brominated halons (see Table A-1 in the Annex of WMO (2022)), **the latter presents** a steeper **vertical** gradient in the lower stratosphere and an almost complete conversion to inorganic bromine in the upper stratosphere (Fig. **9b**)."*

R2-C7.27: L1004–1005: *"[...] which is driven by [...] (see Fig. 7)."* Either the order of figures is wrong here and you are actually referring to Figure 6 or the order of the text does not match the figure order.

ANSWER: The order of the figures is correct. We are pointing at the green lines showing the SSA dehalogenation sources of chlorine and bromine presented in original Figure 7a,c (current Figure 10a,c). We've updated the text to avoid confusion.

R2-C7.28: L1010: *"throughout tropical injection"* → 'through the tropical tropopause region'

ANSWER: Thanks for the suggestion. Done.

R2-C7.29: L1086–1089: *"In doing so, [...]"* This is a repetition of model description and development and does not belong here.

R2-C7.30: L1089–1090: *"For this exercise, [...]"* This expression is odd in the context of scientific paper. Furthermore, you should give references to the indicated "standardized evaluations against observations and international assessments" and describe them briefly.

R2-C7.31: L1086–1090: Given the comments above, you could also remove the whole paragraph and only keep the first sentence.

ANSWER: We completely changed the validation section and therefore removed the complete paragraph.

R2-C7.32: L1099: *"configurations"* Do you mean 'model experiments' ?

ANSWER: Yes. We have rephrased the whole sentence. See related response to **R2-C7.1** above.

R2-C7.33: L1105: *"[...] the more extreme contributions [...]"* Unclear expression. What do you mean by "extreme contributions"?

ANSWER: We removed the referred half-sentence to avoid confusion.

R2-C7.34: L1120: *"[...] modelled range indicate the variability between compsets."* Grammatically not correct. "indicate" → 'indicates'. Furthermore, you may need to rephrase this sentence as it is not quite clear. → 'The results show that the modelled SG to PG partitioning and total abundance of VSL in the stratosphere

depend on the chosen compset.' You may discuss the reason (difference between the compsets) in a dedicated discussion section.

ANSWER: We have split the sentence in two, and rephrased the second half-sentence as follows:

L863-865: *"Notably,* ***all experiments simulate SGs vertical profiles*** *that are within the accepted range reported in the last Ozone Assessment Report (WMO, 2022) throughout the tropical troposphere* ***regardless of the compset and resolution considered.****"*

R2-C7.35: L1130: *"Differing [...]"* → 'Unlike'

ANSWER: Done.

R2-C7.36: L1165: "Having said this, we acknowledge [...]" This expression is misplaced in the context of a scientific paper.

R2-C7.37: L1169: *"online sources"* This seems to be lab-slang. → 'online emissions' or 'emission computed during runtime of the model'.

ANSWER: Based on the reviewer suggestion of including a dedicated Discussion section (**R2-C1.3** and **R2-C3.1**), we have moved the sentence to the new Section 5 and rephrased it to avoid using lab-slang as follows (see also response to **R2-C3.10** above):

L1409-1410: *"****In particular,*** *VSL_{Cl} photodegradation represents only a minor contribution to atomic Cl* ***release in the troposphere****, which is largely dominated by the* ***online*** *acid-displacement* ***emissions****."*

R2-C7.38: L1183–1204: This whole paragraph should be revised. Many sentences are grammatically incorrect or use odd expressions: "Several distinct features are observed", "This species presents", "Indeed, despite maximum Br_y peaks in the NH are up to".

ANSWER: We have completely re-structured the whole paragraph, without using an explicit bullet for each halogen family and avoiding the use of odd expressions. The revised paragraph reads as follows:

L1062-1079: ***"Driven by the prevalence of anthropogenic sources in the NH, VSL_{Cl} exhibits a pronounced South-North latitudinal gradient between ~60 and ~260 pptv (Fig. 11a), with peak values exceeding 500 pptv over China. In contrast, VSL_{Br} shows a more homogeneous spatial distribution with maximum abundances observed over the equatorial regions due to the dominant source from the tropical oceans (Ordóñez et al., 2012). Minimum, maximum and mean global VSL_{Br} mixing ratios reach 2.9 pptv, 12.9 pptv and 6.8 pptv, respectively. The global mean VSL_I is ~1.0–1.2 pptv (see Table 8). Inorganic chlorine also maximizes over the NH, particularly over coastal locations where the mixing of halogen-rich SSA and HNO_3/N_2O_5 plumes results in an enhanced chlorine source. The highest Cl atom concentrations occur over the coastal regions of Europe, US and East Asia, with maximum values smaller than 0.4×10^{-3} pptv and a global mean average of 4×10^{-5} pptv. These distributions are consistent with maximum and mean Cl_y levels of ~640 pptv and ~47 pptv, respectively (Fig. 11d). Similarly, modelled Br_y also maximizes over coastal regions co-located with high SSA abundance (Fig. S2). However, the inter-hemispheric bromine enhancement is less pronounced than for chlorine because SSA-debromination is not controlled by HNO_3 and N_2O_5, but instead by shifts in Br_y partitioning between $BrONO_2$, $BrNO_2$ and HOBr (see Table 1). Maximum Br_y peaks in the NH are up to 2 times larger than in the SH. However, the corresponding maximum BrO abundances does not present such inter-hemispheric asymmetry (Fig. 11h), highlighting the strong dependence of reactive bromine partitioning on the background atmospheric composition of NO_x and HO_x. For iodine, global I_y distributions is primarily controlled by***

oceanic HOI/I_2 emissions that peak within the tropics. The mean modelled I_y and I+IO surface abundances reach ~1.25 pptv and ~0.15 pptv, respectively, with corresponding volume mixing ratios spanning between (0.05 – 21) pptv for I_y and (0.008 – 0.90) pptv for I+IO. Notably, the global mean IO_x/I_y ratio is ~0.12, whereas in regions with the highest I_y, abundances it remains below ~0.04."

R2-C7.39: L1276: *"significant"*. If significance is not strictly proven the term should not be used. → 'strong' or 'substantial'

ANSWER: Done.

R2-C7.40: L1293: *"Regardless of the compset [...]"* This phrase is not correct and should be removed, because the results for the CESM1 experiments do not fall within the given bounds of −(2.7 − 3.9)%

ANSWER: The referred values point at CESM2-SLH results. To avoid confusion, we have rephrased the text as follows:

L1144-1146: *"**CESM2-SLH reductions** range between −2.7% and −3.9% at the surface and approximately −6% integrated in the troposphere for OH, while for NO_2 differences remain below −1% at the surface and ranging between −7.2% and −8.6% in the troposphere."*

R2-C7.41: L1301: *"[...] is encouraged for future studies."* Odd expression. Rephrase. → 'should be subject to future studies.'

ANSWER: Done.

R2-C7.42: L1303–1304: *"[...] (top) [...] (middle) [...] (bottom row)."* Please reference the subfigures by their labels. → '(a–c) [...] (d–f) [...] (g–i)'

ANSWER: We removed the referred sentence. Note that we now point at the specific subfigures labels throughout the text. ""

R2-C7.43: L1306–1308: *"[...], although due to the high [...]."* "although" can be removed.

ANSWER: Done.

R2-C7.44: L1327: *"[...] is similar to the analogous pattern [...]."* It is not clear what "analogous" refers to in this context. It can be removed.

R2-C7.45: L1333: *"Indeed, and despite [...]"* Filler-phrase. Can be removed.

ANSWER: Done both.

R2-C7.46: L1348: *"60N-60S"*. Wrong formatted geographic range. → '60° N − 60° S'

ANSWER: Corrected here and elsewhere. See complete answer to **R2-C1.2** above.

R2-C7.47: L1353–1354: *"[...], where the model [...] fails to capture their seasonal cycle."* "their" probably shall refer to "stations 11 and 12". The stations do not have a "seasonal cycle", but the ozone observed at the stations does. "their" → 'the'

R2-C7.48: L1356: *"[...] impact in the [...]"* Grammatically not sound. → 'impacts the'

R2-C7.49: L1357–1358: *"[...] predicted by a [...] pixel size in the model."* Odd expression. A pixel size cannot predict anything. → 'predicted by the model in a [...] resolution.'

R2-C7.50: L1358–1360: *"[...] demonstrate that the inclusion of SLH chemistry in the model helps to close the gap with observations"* Preposition "with" is not grammatically correct. → 'on' or 'between model and observations'

ANSWER: Thanks for the suggestions. We have rephrased the complete sentence as follows:

L1202-1208: *"However, discrepancies emerge at some stations like 11 and 12, where the model successfully reproduces the observed ozone magnitude but fails to capture **the** seasonal cycle. This divergence likely stems from incomplete representation of ozone sources and sinks in this pristine region. Finally, the coarse resolution of the model is **well-known factor affecting** the comparison with in-situ observations, as the local ozone values in some observational sites do not necessarily represent the mean background levels predicted **over** a 1.9° × 2.5° pixel size. Nevertheless, Fig. 14 clearly shows that the inclusion of SLH chemistry in CESM2 helps to close the gap **between the model and** observations."*

R2-C7.51: L1399: *"setup"* Please clearly distinguish between 'model experiments' (in this section) and 'model configurations' in the model description section. Consistently use either 'configuration' or 'compset' or 'setup'. It is not clear if those are the same.

ANSWER: Done. See the response to **R2-C1.4** and **R2-C7.1** above for a detailed answer about the experiments.

R2-C7.52: L1421: *"Globally, of the total halogen [...]"* This sentence is grammatically not correct and difficult to understand. Please rephrase.

ANSWER: To avoid confusion, we now point at the total halogen loss followed by the percentage contribution of iodine, bromine and chlorine. We have rephrased the complete sentence as follows:

L1265-1267: *"Globally, **the** halogen driven tropospheric **photochemical** ozone destruction **reaches 659.4** Tg yr^{-1} for **CC-SLH [2×2-ndg]** and 662 Tg yr^{-1} for **CC-SLH [2×2-hst]**, **dominated by** IO_x-induced **$OddOx_{Loss}$ (accounting for 76–79%) and** with minor contributions for bromine **(16-18%)** and chlorine **(5%)."***

R2-C7.53: L1513: *"on-line"* Inconsistency. → 'online'.

R2-C7.54: L1568: *"1 × 1"* → 1° × 1°

R2-C7.55: L1570: *"This is associated with to the [...]"* → Remove "to".

ANSWER: Done all of the above.

Section 4

R2-C8.1: This section accumulates many of the repeated issues with expressions and lab-slang. Please rephrase in accordance to all suggestions made. I refrain from giving a detailed account.

ANSWER: We have now checked the whole manuscript and rephrased to avoid repetition and using lab-slang. In particular, note that the revised manuscript now include a dedicated Section 5 for Discussions and that the original Section 4 has been re-numbered to Section 6. Please see also the general response to main comment **R2-C1.1-4** above and refer to the revised manuscript for the implemented changes.

Tables and Figures

Tables

R2-C9.1: Table 1

- Chemical reactions are not correctly set, e.g. $BrONO_2$ -> $0.65 * Br_2 + 0.35 * BrCl$

$\Rightarrow BrONO_2 \rightarrow 0.65 \cdot Br_2 + 0.35 \cdot BrCl$

- Exponential expressions are not correctly set.
- Empty lines and subheadlines should be removed. The information contained in the subhead-lines should be part of the table caption. → 'Table 1: [...]. Reactions het_ss_0...8 include heterogenated-reservoir species and het_ss_9...12 oxidized nitrogen-compounds.'

R2-C9.2: Table 2: same as Table 1.

R2-C9.3: Table 3: same as Table 1. What does "mapped to X" mean?

R2-C9.4: Table 4: same as Table 1. There us a lot of unnecessary whitespace in one column. This could be optimized.

R2-C9.5: Table 5: same as Table 4.

ANSWER: Done. Empty lines and blank spaces have been removed, while we kept a few essential subheadings to facilitate manipulation and formatting with the journal's graphical editors. To avoid an excessive length of the table caption, most information originally provided in subheading has been moved to table footnotes whenever needed. We have also corrected column titles and text format. These changes have been applied to all tables in the main text and supplementary material.

R2-C9.6: Table 6: Mixes the overview over available compsets with performed model experiments. It should be split. The part containing a summary of the available SLH-compsets should remain here. A Table summarizing ALL model experiments (also CESM1) should be place in the next section (Model experiments and results). You should clearly distinguish between compsets and model experiments. It is rather unfortunate

that model experiments at different horizontal resolutions are listed under the same name. This ambiguity has to be resolved. Each experiment should have a unique identifier. ”Suggested” and ”available” do not make sense in the table. The recommendation should be part of the table caption.

ANSWER: We thanks the reviewer for this very important suggestion, that allowed us to clearly distinguish among the different model configurations used for each independent experiment. Based on his/her suggestions, as well as on the main comment **R2-C1.4** oriented to reorganize the manuscript and also on **R2-C7.1** pointing at the importance of unify and/or discern between the usage of setup, configuration, simulation and sensitivity, we introduced a whole new section entitled ***“3.2 Model Experiments and Sensitivity Simulations”***, were we include the new Table 7 and describe the whole set of experiments performed in this work.

The revised manuscript also clarifies that all CESM1 results shown in this work refer to previously published results and reads as follows:

L569-578: ***“3.2 Model Experiments and Sensitivity Simulations***

The complete set of model experiments performed in this work is presented in Table 7. Each experiment’s name is composed by a prefix denoting the model used and the inclusion of short-lived halogens (e.g., CC-SLH for CAM6-Chem with SLH turned on) and a suffix indicating the model resolution and meteorology option (e.g., [2×2-ndg] for coarse resolution and nudging approach). Although all model configurations have been validated, initial results presented in Section 4 are mostly based on low-top and coarse CC-SLH [2×2-ndg] and/or CC-SLH [2×2-hst] experiments. We note that for each of the six SLH experiments listed in Table 7, an additional sensitivity was conducted neglecting the sources and chemistry of short-lived halogens (e.g., the corresponding CC-NOH [2×2-ndg] experiment, see Appendix). For most analysis comparing CC-SLH and CC-NOH distributions, we used the FCnudged_slh compset as this ensures that dynamical transport is consistently represented across experiments, which is crucial for isolating and quantifying chemical changes.

Table 7: CESM2-SLH experiments performed in this work.

Experiment name	*SLH compset*	*Resolution (lat × lon)*	*Period of time*
CC-SLH [2×2-ndg]	*FCnudged_slh*	*(1.9º × 2.5º)*	*1980 - 2020*
CC-SLH [2×2-hst]	*FCHIST_slh*	*(1.9º × 2.5º)*	*1950 - 2020*
CC-SLH [1×1-ndg]	*FCnudged_slh*	*(0.9º × 1.25º)*	*2000-2005*
CC-SLH [1×1-hst]	*FCHIST_slh*	*(0.9º × 1.25º)*	*2000-2005*
FW-SLH [2×2-ndg]	*FWnudged_slh*	*(1.9º × 2.5º)*	*2000-2005*
BW-SLH [2×2-cpl]	*BWHIST_slh*	*(1.9º × 2.5º)*	*2000-2005*

In addition to the CESM2-SLH experiments presented above, and with the intention to validate current model performance compared with previous CESM1 studies, we also analysed model output from the main simulations originally published by Li et al. (2022) and Saiz-Lopez et al. (2023), as well as in Barrera et al. (2023) and Bossolasco et al., (2025). For consistency, these experiments are referred to, respectively, CESM1-SLH [QL22], CESM1-SLH

[SL23], CESM1-SLH [JB23] and CESM1-SLH [AB25]. Although these CESM1 configurations are not strictly identical, the experiments were conducted considering analogous spatial resolution and nudging options to those employed here in CESM2-SLH. They are therefore considered as the benchmark simulations for quantitative and qualitative intercomparison between CESM model versions. Further details of the main similarities and differences between SLH results performed with CESM1 and CESM2 are described below."

R2-C9.7: Table 7: Empty rows should be removed. The subtitles "SSA-Sources" and "FRA-Sinks" should be moved into the Table caption.

ANSWER: Done. See related response to **R2-C9.1-5** above. Due to suggestion of moving the technical details to the Appendix (see response to **R2-C1.4** and **R2-C2.4-6** above), Table 7 has now been moved to Table A1.

R2-C9.8: Table 8: Table is oddly formatted. Horizontal lines appear broken and not all columns are labeled correctly, e.g. "species" seems to refer to 'species families'. The caption is not correct because the table displays different emission fluxes, volume mixing ratios, sinks, and atmospheric abundances. The rows "Abundance–Long-lived halogens" have no unit assigned. You may consider splitting the table into three or four parts which would make it also easier to reference in the text.

ANSWER: We implemented all format suggestions, corrected the table title, point at individual halogen families and included the missing units, However, we regret to split the table in parts as all sources, volume mixing ratios and burdens are of importance to properly evaluate the performance of different experiments. Therefore, we removed most of the horizontal broken lines but kept essential table subheadings to separate the different magnitudes. Please refer to the revised manuscript for the reformatted table.

R2-C9.9: Table 9: As mentioned earlier: "sensitivities" → 'sensitivity experiments'. Here and in other parts of the preprint, it remains unclear whether the CESM1 results refer to previously published results, which would need explicit citations, or new results based on old/repeated model experiments.

ANSWER: The revised text now refers to SLH and NOH experiments, and avoid using the term *compset* (see related response to **R2-C7.1** above). We have also clarified that all CESM1 results shown in this work refer to previously published results and modify the text as follows (see related response to **R2-C10.2** below).

L697-699: *"In order to compare the current CESM2-SLH inorganic halogen abundances with previous studies, Fig. 2 also shows the* ***results obtained in previous studies (i.e., CESM1-SLH [QL22] and CESM1-SLH [SL23] corresponding*** *to Li et al. (2022) and Saiz-Lopez et al. (2023), respectively)."*

R2-C9.10: Table 10: Wrong font. Empty lines should be removed. All tropospheric magnitudes [...] This text should be part of the table caption. What are "tropospheric magnitudes"? What is a "minimum lapse rate pressure"? Do you mean the pressure at which the lapse rate minimum is reached? A dot is missing at the end of the caption.

R2-C9.11: Table 11: A dot is missing at the end of the caption. The line below the table should be part of the caption. Wrong font.

ANSWER: We implemented all of the above format requirements in both tables, correcting font type and size and removing empty lines and blank-spaces. We also corrected definitions provided in the footnotes. To avoid an excessive length of the table caption, we rather keep the information as footnotes of each table.

R2-C9.12: Table 12: This looks like two pictures rather than a continued sideways table with a lot of artifacts (”continue next page”, ”page”, cut in half row ”Simulation ...”). Horizontal lines are broken.

ANSWER: We agree with the reviewer that original Table 12 was ugly formatted. We initially submitted inside a landscape page but we were requested to change it to portrait format during GMD quality check, and therefore it didn't fit into a single page. We have now carefully split the table in two and reformatted following the reviewer suggestions in **R2-C9.1-5** and **R2-C9.8**. Note that due to the major manuscript rearrangements applied to include the new Discussion Section 5, we decided to move original Table 12 to the Supplementary Material and split it in two separate tables (Tables S4 and S5).

Figures

R2-C10.1: Figure 1: *”NH = 20°N(S) - 90°N(S)”* Do not apply to the journal style guide (ranges and em-dash)

ANSWER: Thanks for the careful reading. We have now corrected the latitudinal and time-period ranges in all figures and captions. See also the response to **R2-C6.4** above.

R2-C10.2: Figure 2: As indicated above. The CESM1 experiments are not well characterized in this preprint and difficult to set in context. The arrangement of this figure is a bit unfortunate, putting VOC volume mixing radiations to a (random) spot in second row together with species ratios. It might be possible to split this figure into two (7:5 panels each).

ANSWER: We thanks the reviewer suggestion and have modified the arrangement of the figure to avoid including VOCs vmr in the second row where otherwise species ratios are presented. The new disposition of Figures panels, with the corresponding updated caption, is shown below:

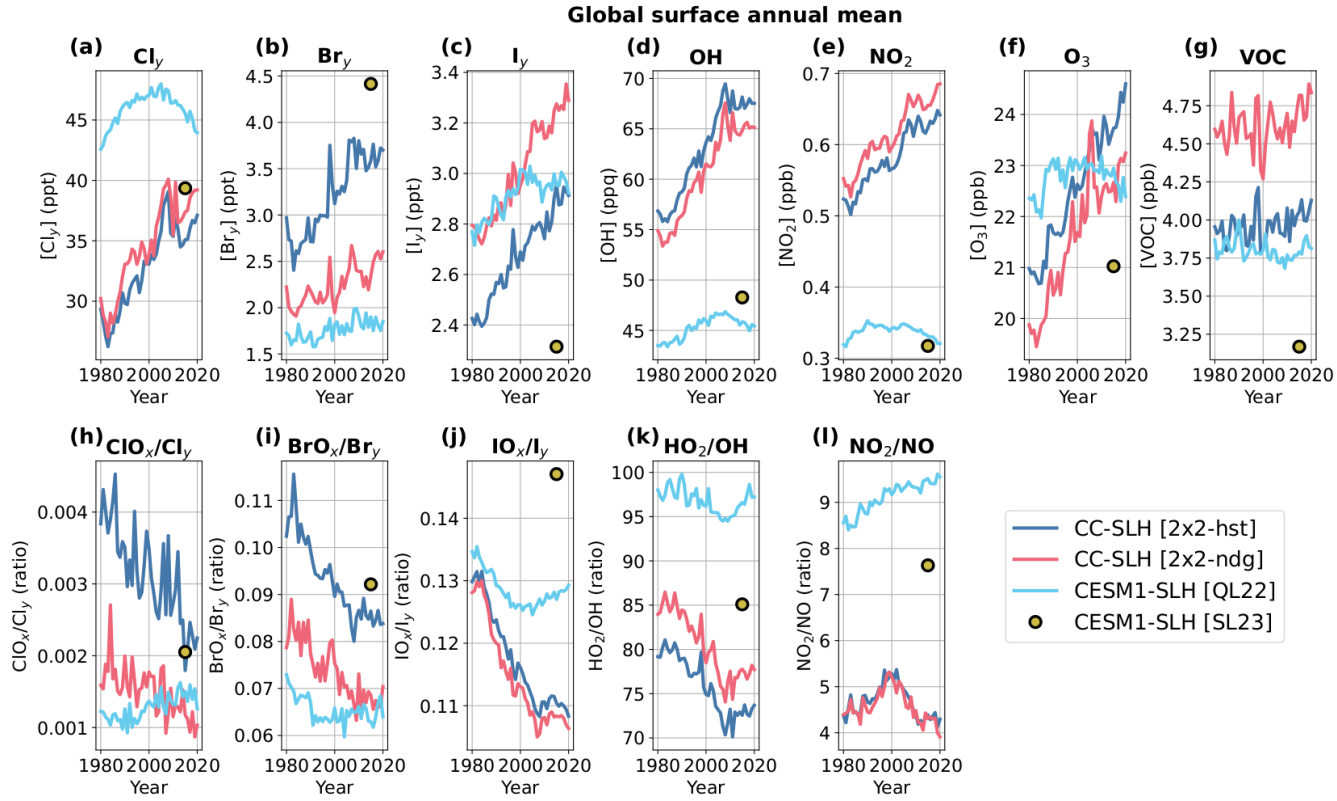

Figure 2: Historical evolution of global annual mean surface abundance and partitioning of main atmospheric components during 1980-2020. Top-row shows the total inorganic halogen surface abundance for a) Cl_y, b) Br_y and c) I_y, as well as the surface mixing ratio for d) OH, e) NO_2, f) O_3, and g) VOC (calculated as the sum of species: ISOP, MTERP, CH_3OH, C_2H_5OH, CH_2O, CH_3CHO, CH_3COOH, CH_3COCH_3, HCOOH, C_2H_2, C_2H_4, C_2H_6, C_3H_8, C_3H_6, BIGALK, BIGENE, MEK, TOLUENE, BENZENE, XYLENES). Bottom row shows the reactive (XOx) to reservoir (X_y) surface ratio (i.e., XO_x/X_y) for h) chlorine, i) bromine and j) iodine, as well as the k) HO_2/OH and l) NO_2/NO mean ratio at the model surface. Results for the nudged CC-SLH [2×2-ndg] (pink) and free-running CC-SLH [2×2-hst] (blue) experiments obtained with the CESM2-SLH release are compared with those obtained in previous CESM1 studies (see Section 3.3).

Finally, we have rephrased the text to clarify that the CESM1 results shown here belongs to previously published work (see related response to **R2-C9.9** above).

L697-699: *"In order to compare the current CESM2-SLH inorganic halogen abundances with previous studies, Fig. 2 also shows the **results obtained in previous studies (i.e., CESM1-SLH [QL22] and CESM1-SLH [SL23] corresponding** to Li et al. (2022) and Saiz-Lopez et al. (2023), respectively)."*

R2-C10.3: Figure 3: The caption is too long and should not repeat the figure legend. Time ranges are not in accordance to journal style. Yellow, open markers are difficult to see. Another color could improve this. *compset_non* was not defined previously. Do you mean 'compset_noh' ?

ANSWER: Thanks for the careful reading. We have now corrected the latitudinal and time-period ranges in all figures and captions. We have now reduced the caption length to avoid repetition with the legend, and also modified all markers are clearly visible. Based on the reviewer suggestion, all figures and tables now point at the independent experiments shown (see related responses to **R2-C7.1** and **R2-C9.5** above).

R2-C10.4: Figure 4:

- The resolution of this figure is rather low. It should be improved.
- Panel (d) and (f) are misaligned compared to panel (a) and (c).
- Panel (c) does not contain any data as stated in the figure caption (”empty panel c”) and should be removed.
- The colormap is not colorblind-friendly and draws the attention towards light blue and yellow. It should be replaced. See also https://www.geoscientific-model-development.net/submission.html#figurestables.
- The uppermost tick and every second tick on the pressure-axis are unlabeled. With respect to the space restrictions on the pressure-axis, ticks should be labeled where possible, else removed.
- Subcaptions (a-f) are placed inside the axis frame, which is in contrast to the previous figures. You may consider placing them outside.
- The brackets around units should be round like in the previous figures.
- The colorbar labels indicate that *white* refers to values below zero. From the arrangement of the figure, I guess, *white* is supposed to indicate *invalid* values in panel (c). Usually this would be marked with a ◁, e.g., extent=’left’ in python, matplotlib or *gray* color. Removing panel (c) will probably resolve this issue.
- The zonal mean tropopause (not ”mean model tropopause” as stated in the figure caption) displays a strange gap at around 30°S. You may consider plotting the zonal mean tropopause as a line not with markers.

R2-C10.5: Figure 5: In general, the same as Figure 4 applies. In addition:

- Panel (f) does not contain any data and should be removed.
- Panel (i) is identical to panel (c) as it is supposed to show the difference between (c) and (f). It should be removed.
- It might be better to use a sequential colormap for panels (g,h) that would highlight that the difference between the two experiments is shown here and that species concentrations in FCnudged_slh are always higher.
- In figure titles, FCnudged_NON is displayed. Did you mean FCnudged_noh?

ANSWER: Thanks for the careful reading and for the detailed suggestions. We have reproduced the original Figures 4 and 5 (as well as all equivalent figures) following the journal guidelines (i.e., using a color-blind sequential style, removing empty panels, moving sub-caption letters outside each plot frame, etc.). We also thanks for the suggestions regarding the tropopause definition. Note that all figures and tables now point at the independent experiments shown (see related responses to **R2-C7.1** and **R2-C9.5** above). Finally, note that due to the suggested reordering of sections in comment **R2-C1.4**, original Figures 4 and 5 have been shifted down to Figures 7 and 8.

R2-C10.6: Figure 6:

- Captions should not replace figure legends. You may include another legend entry displaying the assignment of each experiment to the open or filled markers.
- The subcaptions (a–c) are inconsistent with previously used placements and style.

- It is not clear, what a ”mean height of the global tropopause” is. Do you mean ’global mean tropopause height’ ?

R2-C10.8: Figure 8: Probably the most important figure of this manuscript. Although, it can also be improved.

- Observations are missing in the figure legend.
- ”vmr” → ’VMR’ or use $X_{Cl,Br,I}$. X is preferred by the measurement community.
- Volume mixing ratio (VMR) is not defined in the manuscript and referred to as ”mole fractions” in the figure caption which is inconsistent.
- The expression ”observed mean ± range mole fractions” is odd. Do you mean ’Average and range of halogen volume mixing ratios (VMR) compiled from observations in the tropical tropopause region’?
- ΔX_i is not mentioned in the legend. It is called PGs there. Hence, legend and caption are inconsistent.
- ”mean ± range (computed as the standard deviation [...]) is shown by [...] coloured shading [...]”. The ”coloured shading” is usually referred to as ’error bands’. Why do you call the standard deviation ”range”?
- The caption is too long, difficult to understand, and should not replace or repeat the main text.
- The figure caption could read: ’Vertical profiles of the tropical (20°N − 20°S) zonal mean, averaged over the time period 2015 − 2020 for experiments [...] compared to observations for (a) X_{Cl}, (b) X_{Br}, and (c) X_I.

ANSWER: Thanks for the careful reading and for the detailed suggestions. We have now reduced the caption length to avoid repetition with the legend, and moved sub-caption letters outside each plot frame. In addition, we have included additional markers in the legend to distinguish modeled and observational data. We have also rephrased the caption and made sure all acronyms and symbols are mentioned in the legend. Finally, we have corrected the definition of the tropopause to “global mean tropopause height) and explain what the shading represents.

Note that due to the suggested reordering of sections in comment **R2-C1.4**, we have now moved up the halogen validation to be the first subsection 4.2.1, and therefore, the original Figure 6 (global distribution) has been moved down to Figure 9, while original Figure 8 (tropical validation) has been shifted up to Figure 4. The revised figure and caption now reads as follows:

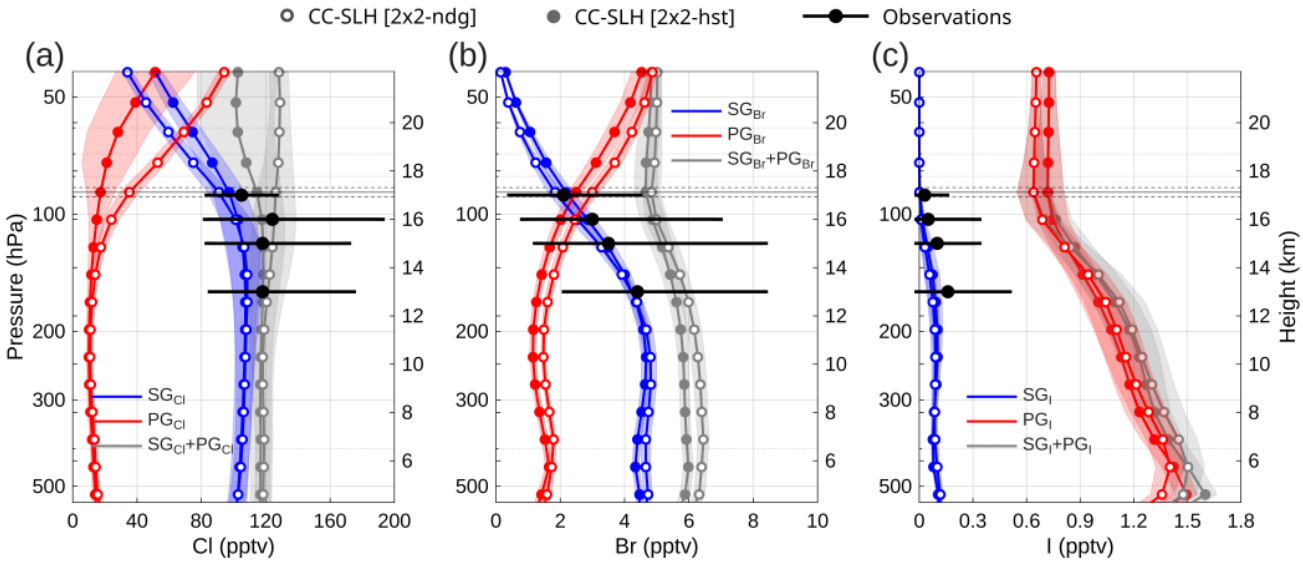

Figure 4: Tropical mean vertical profile of organic SLH source gases (SG_X) and product gases (PG_X) during present-day (2015–2020) for a) chlorine, b) bromine and c) iodine. The SGs profiles (blue lines) correspond to the nudged CC-SLH [2×2-ndg] (empty symbols) and the free-running CC-SLH [2×2-hst] (filled symbols) experiments, while PGs profiles (red lines) are obtained as the difference with respect to the corresponding CC-NOH sensitivity (see text for details). The total additional halogen abundance due to SLH (SG_X + PG_X) is shown in grey. The tropical (20°N – 20°S) mean and spread (i.e., ± the interannual standard deviation for the 2015–2020 period) are shown with solid lines and coloured shading, respectively. Average and range of observed VSL mixing rations in the tropical tropopause layer compiled in Table 1-5 of WMO (2022) are shown in black symbols and solid-thick horizontal lines at 13, 15, 16 and 17 km, respectively. The solid and dashed horizontal lines indicate the tropical mean tropopause height ± standard deviation.

R2-C10.7: Figure 7: The line colors used are difficult to distinguish. The legends are overlapping with the data. The x-axis labels of panels (a,c,e) are not correct, as they display a flux. The flux units are rather unusual. Usual flux units are kg s^{-1} or molec s^{-1} is used. You may fix the units. The information contained in this figure may be supplementary material

ANSWER: Thanks for the careful reading and for the detailed suggestions. Flux panels are now shown in volumetric source units (molec. cm^{-3} s^{-1}). We rather keep this figure in the main text and moved it to revised Figure 10.

R2-C10.9: Figure 9:

- The caption is too long and should be rephrased.
- Time axis label may be added.
- Units should be placed in round brackets.
- Shouldn't the tropopause height show a climate trend over this period?

ANSWER: Thanks for the careful reading and for the detailed suggestions. We have now reduced the caption length to avoid repetition with the legend, and corrected the temporal axis and units format. Note the solid and horizontal dashed lines do not represent the tropopause, but the mean and range of SGI values as estimated in the latest WMO (2022) report. Note that due to the suggested reordering of sections in comment **R2-C1.4**, we have now moved up the halogen validation to be the first subsection 4.2.1, and therefore, the original Figure 9 has been shifted up to Figure 5.

R2-C10.10: Figure 10:

- The colormap is not colorblind friendly and highlight the regions early named.
- The colorbars are not labeled.
- Subplot captions are placed inside the axis frames and hardly visible.
- Colorbar ticks in subplot (g) should be formatted in exponential form ($\times 10^{-4}$)

ANSWER: Thanks for the careful reading and for the detailed suggestions. We have reproduced the original Figure 10 (as well as all equivalent figures) following the journal guidelines (i.e., using a color-blind sequential style, including colorbar labels, moving sub-caption letters outside each plot frame, etc.). We also used the exponential format whenever is needed. Following reviewer **R1** suggestion, we added a new validation figure for inorganic halogens (Figure 6), and therefore in the revised manuscript original Figure 10 has been renumbered to Figure 11.

R2-C10.11: Figure 11: The hatches are almost invisible. You may choose different hues or shades of red and blue instead. ”Empty” is an odd expression for unhatched bars.

ANSWER: Thanks for the careful reading and for the detailed suggestions. To make sure all hatched and unhatched are clearly distinguished, we have modify the colors and format and shifted to a logarithmic scale highlighting the smaller values. Following reviewer **R1** suggestion, we added a new validation figure for inorganic halogens (Figure 6), and therefore in the revised manuscript original Figure 11 has been renumbered to Figure 12.

R2-C10.12: Figure 12: Some units are not placed in parentheses. Labels are hardly readable due to the low resolution picture. You may consider plotting the zonal mean tropopause height as line not with markers. The color range of subfigure (c,f) is saturated in large parts of the Northern Hemisphere. Upper and lower bounds should be adapted.

R2-C10.13: Figure 13: Same as Figure 12.

ANSWER: Thanks for the careful reading and for the detailed suggestions. We have adapted the ranges of the individual color-scales to avoid saturation and use a solid line for the tropopause. Following reviewer **R1** suggestion, we added a new validation figure for inorganic halogens (Figure 6), and therefore in the revised manuscript original Figures 11 and 12 have been renumbered to Figures 12 and 13, respectively.

R2-C10.14: Figure 14: Albeit the model experiments are only evaluated for one year (2015) a monthly mean should be accompanied by a standard deviation or standard error. It remains unclear what the error bars in the TOAR observations are. If the TOAR data represent climatologies (which years?), aka multi-annual means for each month, then these would represent the inter-annual variability. This should be clarified here and in the main text. Usually the annual averages displayed here would be separated from the monthly means by a vertical line. Is ”NON” in the legend the same as model experiment *FCnudged_noh*? Should it read ’NOH’ ?

ANSWER: Thanks for highlighting the importance of including the modeled standard deviation of monthly mean values. Following the reviewer suggestions, we repeated the CC-SLH [2×2-ndg] and CC-NOH [2×2-ndg] experiments for year 2015 and extracted the surface ozone abundance with hourly resolution, which

allowed to compare our modelling results with the same temporal resolution as the TOAR dataset. The revised validation figure now shows the mean ± range (computed as the standard deviation of hourly values) for modelled (shading) and observations (black bars). Most notably, the inclusion of SLH chemistry results in an overall reduction of ozone that reduces the model bias and in most locations is larger than the spread of modelled values between the CC-SLH and CC-NOH simulations. Note that all figures and tables now point at the independent experiments shown (see related responses to **R2-C7.1** and **R2-C9.5** above). The revised ozone validation figure and caption reads as follows:

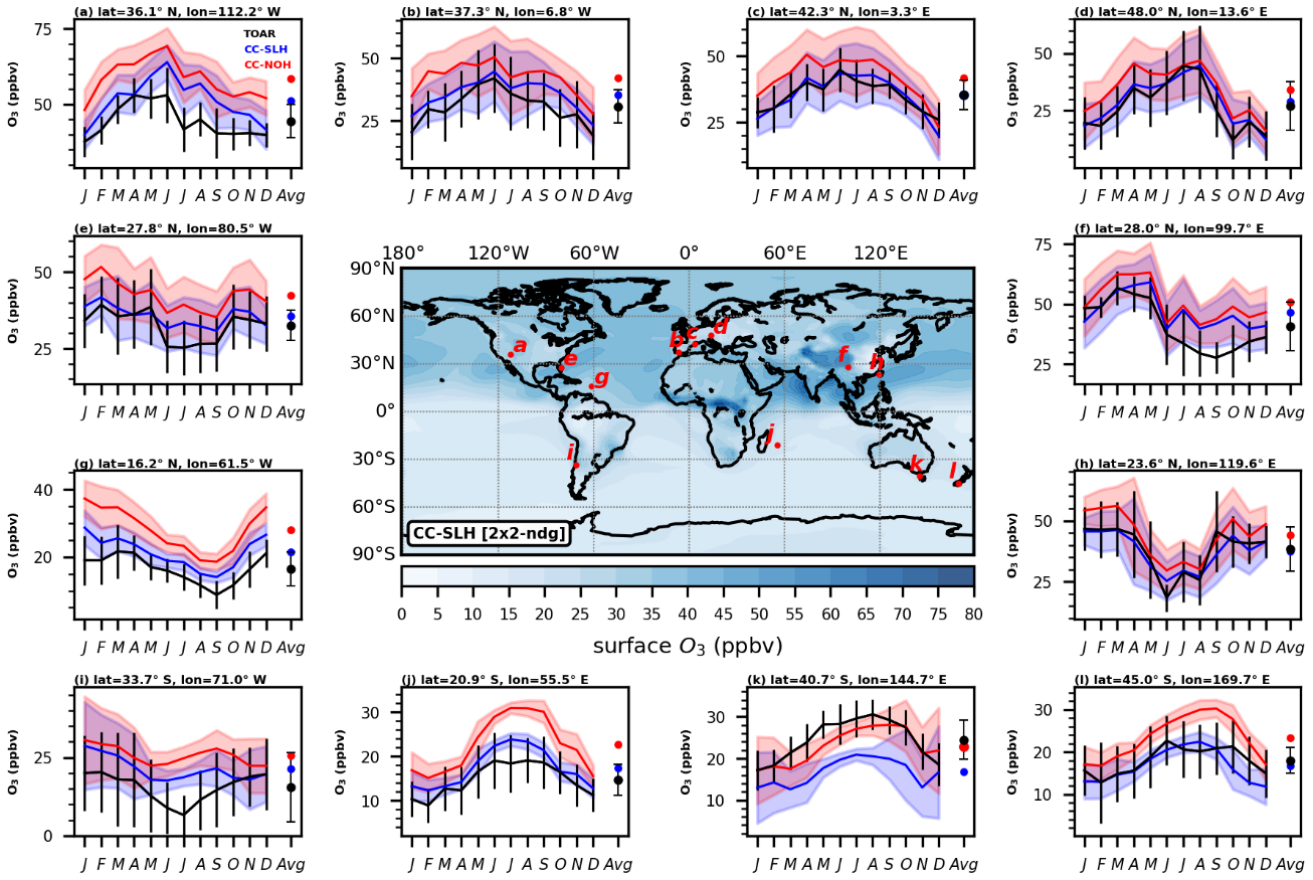

Figure 15: Comparison of CESM2-SLH nudged CC-SLH [2×2-ndg] and CC-NOH [2×2-ndg] simulations with TOAR-I observations. The center panel shows the geographical distribution of surface ozone for the CC-SLH [2×2-ndg] experiment, as well as the location of each of the observational sites shown in the side panels (red points). The side panels (a-l) show the monthly mean ± range seasonality (solid lines and shading) and the annual average (separate marker) of surface ozone for CC-SLH [2×2-ndg] (blue) and CC-NOH [2×2-ndg] (red) experiments. Black lines and error bars show surface observations reported in the first phase of Tropospheric Ozone Assessment Report (TOAR-I) (Schultz et al., 2017). Both model output and observations ranges have been computed as the standard deviation of hourly data for year 2015.

R2-C10.15: Figure 15: Axis labels and tick labels are too small. The colormap is drawing the attention to the yellow region and hence highlights features that might not be there. A different (sequential) colormap should be chosen. The range of the colormap is not the same for subfigures (a–c) and (d–f).

R2-C10.16: Figure 16: Yet another variant of units not placed on round brackets. Labels and tick labels are too small. Line colors are hardly visible or distinguishable. For subfigure (a–c), the same as for previous global averages applies – polar stratosphere and tropical troposphere are lumped together. Global averages should be made in vertical coordinate system relative to the tropopause.

ANSWER: Thanks for the careful reading and for the detailed suggestions. We have increase the size of all ticks and labels in all panels, corrected the format in *x*-axis magnitudes and units, and modified the color-palette to a sequential style. Please refer to the response to **R2-C3.6-7** above for a detailed response to the reviewers concerns about showing a global mean vertical profiles. Note we have now added horizontal solid and dashed lines representing the mean ± range of values for the tropopause, which clear show a much larger spread for the global mean (bottom-panels) than for the tropical average (top-panels). Following reviewer **R1** suggestion, we added a new validation figure for inorganic halogens (Figure 6), and therefore in the revised manuscript original Figures 15 and 16 have been renumbered to Figures 16 and 17, respectively.

R2-C10.17: Figure 17: "°lat → Latitude (°)"

ANSWER: Done. Note that this figure has been renumbered to Figure 18.

R2-C10.18: Figure 18: Same as for similar plots.

R2-C10.20: Figure 20: Same as for similar plots: colormap and missing colorbar labeling.

ANSWER: We have applied the same format changes as those described in the response to **R2-C10.4-5** and **R2-C10.10** above. Note that due to the major manuscript rearrangements applied to include the new Discussion Section 5, we decided to move original Figures 18 and 20 to the Supplementary Material Figures S7 and S9.

R2-C10.19: Figure 19: (a–c), same as for similar plots regarding the vertical coordinates and globally averaged tropopause and boundary layer.

ANSWER: Thanks for the careful reading and for the detailed suggestions. Please refer to the response to **R2-C3.6-7** above for a detailed response to the reviewers concerns about showing a global mean vertical profiles. Note we have now moved up/down the bottom/top panels to show global and tropical means in the same order as in the old Figure 16 (current Figure 17, see **R2-C10.16**). In addition, we now added horizontal solid and dashed lines representing the mean ± range of values for the tropopause, which clear show a much larger spread for the global mean (bottom-panels) than for the tropical average (top-panels).

REFERENCES:

1. Burkholder, J. B., Sander, S. P., Abbatt, J., Barker, J. R., Cappa, C., Crounse, J. D., Dibble, T. S., Huie, R. E., Kolb, C. E., and Kurylo, M. J. (2020). Chemical Kinetics and Photo-chemical Data for Use in Atmospheric Studies, Evaluation No. 19 (JPL Publication 19-5). Jet Propulsion Laboratory, https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://jpldataeval.jpl.nasa.gov/pdf/NASA-JPL%2520Evaluation%252019-5.pdf&ved=2ahUKEwisr4TPsLCRAxV-BdsEHXGNNWYQFnoECBAQAQ&usg=AOvVaw23Z7bVIzdNIUSCUh5CkFcG.

ANSWER: Thanks for the careful reading. We have corrected the year of JPL 19-5 Publication to 2020.

L1704-1707: *"Burkholder, J. B., Sander, S. P., Abbatt, J. P. D., Barker, J. R., Cappa, C., Crounse, J. D., Dibble, T. S., Huie, R. E., Kolb, C. E., Kurylo, M., Orkin, V., Percival, C., Wilmouth, D. and PH, W.: Chemical Kinetics and Photochemical Data for Use in Atmospheric Studies Evaluation Number 19 - Publication 19-5, JPL_NASA, 32(15–10), 170 [online] Available from: https://jpldataeval.jpl.nasa.gov/,* ***2020****."*