Author's response to:
RC#2 from anonymous referee #2

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Dear Reviewer,

Thank you for carefully reading the manuscript and pointing out several issues where the description needs to be improved for understanding. The requested clarifications and references to ambiguities contribute to the improvement of the manuscript.

In order to separate the your comments and the author's response, we printed the comments in black and the response in blue. Excerpts of the manuscript with marked changes are pinned directly to the appropriate responses, with the indicated text location (e.g., line number) referring to the manuscript in preprint.

Sincerely, on behalf of all authors

Johanna Roschke

Changes to the Manuscript:

- Expanded the introduction paragraph on self-lofting for troppospheric smoke layers including recent findings of Huang et al. (2026).
- Expanded and corrected inaccurate statements on UV-sensitive satellite sensors (OMI, EPIC, TROPOMI, OMPS-NM)
- Added references to the MODIS and VIIRS "Active Fire products"
- Added a precise definition of a "cluster" for the CALIPSO smoke-classified region
- Added clarification to how classification thresholds were derived for the CALIPSO derived smoke idenfication
- We mention now earlier in Sec. 2.1, that the CALIOP-derived smoke boundaries are used to derive the UVAI–height relationship in Section 3.3.
- Updated the Haarig et al. (2025) reference from a 2025 preprint to the final 2026 journal publication: Haarig et al. (2026).
- Added a new paragraph discussing a potential positive bias in retrieved plume heights due to cloud contamination given OMPS-NM's coarse (50 km) resolution (Jethva and Torres, 2011; Torres et al., 2012; Jethva et al., 2018)
- Added a new paragraph justifying the `FRP_thresh`$=30\,\mathrm{MW}$ value based on detection reliability statistics rather than fire behavior (Roberts and Wooster, 2008; Laurent et al., 2019)
- Consistent fix: "Suomi NPP" to "Suomi-NPP" and "OMPS" to "OMPS-NM" throughout.
- Fixed small wording mistakes in several figure captions (Figs. 8, 10, 11).
- Legend variables in Fig. 11(c) were updated for consistency

General comments

1. *Page2Line55: I happen to come across of the Huang et al. (2026; https://doi.org/10.1029/2025GL120904), who in fact observed it.*

* Thanks for refering to the recent study by Huang et al. (2026). We changed the respective paragraph:

> **Page 2, Line 55:**:
>
> ~~To our knowledge, this~~ Using the Community Earth System Model (CESM),Huang et al. (2026) demonstrated that incorporating self-lofting ~~process has not been directly observed in the troposphere~~for tropospheric smoke plumes improved the agreement between modeled and observed smoke plume heights from the 2019–2020 Australian New Year (ANY) wildfires.

2. *Page3Lines85-86: It is not clear to me, not at least at this point, but do active fire data are part of Radenz et al. (2021)? If this is the case, this sentence could be omitted.*

* We confirm that active fire data are not part of Radenz et al. (2021). The authors only highlight the potential of incorporating wildfire smoke emission information into the retrieval, but do not implement it. Hence, the sentence is necessary and we have kept it unchanged.

3. *Page5Line115: Tackett et al. (2023) introduced the improved stratospheric typing algorithm; therefore I would suggest including also Kim et al. (2018; https://doi.org/10.5194/amt-11-6107-2018).*

* We have added Kim et al. (2018) as a reference.

> **Page 5, Line 115**:
>
> ---
>
> Subsequently, aerosol types are classified using predefined lidar ratios from the Lidar Level 2 Aerosol Profile (Version 4.51) product (NASA/LARC/SD/ASDC) as detailed in ~~Tackett et al. (2023)~~ Kim et al. (2018); Tackett et al. (2023)

4. *Page6Lines123-125: Why is it needed? How does it serve TRAILS? Is it valid only for the cases presented here, and can it be used to improve the classification in general?*

* We highlight the limitations of the CAD algorithm to justify our custom classification scheme, which enables the retrieval of CALIPSO smoke plume heights for comparison with OMPS UVAI (Fig. 6). As this relationship was derived manually by visually inspecting each CALIPSO overpass, its general applicability for improving smoke classification in the CAD product remains unknown and is beyond the scope of this study. We added a sentence to clarify the purpose of the improved classification and reference to the respective section.

> **Page 6, Line 123-125**:
>
> ---
>
> To resolve this for our analysis, we implemented a custom classification scheme that allows the accurate identification of plume altitude for our case studies. These smoke plume altitude boundaries are then used to derive an altitude relationship with Suomi-NPP OMPS UVAI (Fig.6, Eq.5).

5. *Page6Line128: Which denoising and filtering techniques?*

* The denoising and filtering techniques consist of median blur (5×5 kernel), signal thresholding (attenuated backscatter $<$ 0.00005), Gaussian blur (11×11 kernel), a second threshold (< 0.0003), percentile-based binarization (90^{th} percentile), and connected-component filtering (minimum area 500 pixels). The resulting plume detections were additionally checked manually for each CALIPSO overpass to ensure quality control. A detailed description of these steps is beyond the scope of the manuscript.

6. *Page6Line131: What do you mean by cluster? Is it a binary array: say 0 for cloud and 1 for aerosol? So, if I get it right, a cluster is a “pixel” and multiple clusters correspond to a layer.*

* Yes, the input is a binary array where 1 indicates smoke (based on our classification) and 0 indicates non-smoke (clouds, other aerosols, clear sky). A "cluster" is a contiguous region of smoke pixels identified by connected-component labeling (`measure.label` in scikit-image), with each distinct cluster assigned a unique integer. Multiple clusters may belong to the same smoke layer if the layer is fragmented. This definition has been clarified in the manuscript.

> **Page 6, Line 131**:
>
> Here, a "cluster" is defined as a contiguous region of pixels classified as smoke, identified via connected-component labeling. Each distinct cluster is assigned a unique integer label, while multiple clusters may belong to the same smoke layer if the layer is horizontally fragmented.

7. *Page6Lines138-139: This statement refers to the visual inspection of the smoke layer boundaries and whether the method enclosed correctly the plume, as in figures 1e and 1f. The thresholds of Table 2, where do they come from?*

* Yes, the statement refers to visual inspection of smoke layer boundaries as shown in Figures 1e and 1f. The thresholds in Table 2 were derived empirically by testing a range of values for $\delta_{532,\text{mean}}$ and $S_{532,\text{max}}$ across multiple CALIPSO overpasses and selecting the thresholds that best reproduced visually identified smoke plumes. This empirical approach is now clarified in the manuscript.

> **Page 6, Line 138-139**:
>
> The classification thresholds applied were ~~established through careful visual inspection of selected CALIPSO overpasses~~ derived empirically by testing a range of values for $\delta_{532,\text{mean}}$ and $S_{532,\text{max}}$ across multiple CALIPSO overpasses and selecting the values that best reproduced the smoke boundaries identified through visual inspection.

8. *Page8Section 2.3: Is it really needed? Isn't it part of Radenz et al. (2021)?*

* Section 2.3 is necessary and presents new material not included in Radenz et al. (2021). See answer to general comment 2.

9. *Page12Senction3.1: Figure 5 is not introduced at all. Please do so. Also, the choice for the default `UVAI_fresh` value is only given in the Appendix (lines 684-686), it would be worthwhile also to mention it as well in this section.*

* We have added the reference to Fig.5 and the value for `UVAI_fresh` in section 3.1.

Page 12-13, Line 277-281:

As shown in Fig ~~5~~4, the algorithm initializes at the air parcel position at step i = 80 (corresponding to the 10th day backward in the trajectory). For each air parcel, FLEXPART provides the particle position and tropopause height (z_tropo) at 3 h time steps. If the air parcel's altitude (~~z_p~~z_p) is located above the tropopause, potential stratospheric smoke influence is investigated ~~.~~ (see Fig.5). As an input, the daily maximum global UVAI field is used. Air parcels located above grid points where the UVAI exceeds the ~~UVAI_fresh threshold~~ threshold UVAI_fresh= 10

10. *Page13Figure5: The* UVAI_dust *default threshold does not appear in the caption.*

   * We have added the default UVAI_dust threshold to the caption of Fig.5.

Fig.5:

Overview of smoke and dust identification within TRAILS. Air parcels located within grid points where enhanced values of the UVAI are observed ~~,~~ are assumed to ~~been~~ be affected by smoke. For this, the classification involves comparing the air parcels altitude z_p with the location of the altitude of the tropopause and the theoretical plume height boundaries (h_min < z_p < h_max), estimated from the UVAI-plume height relationship. Different thresholds for dust (default UVAI_dust=5) and stratospheric smoke identification (UVAI_fresh, UVAI_aged) can be chosen. The maximum dust plume altitude can be defined by z_dust.

11. *Page14Line320: Please define* z_tropo*.*

   * z_tropo is the tropopause height taken from the FLEXPART mode output. We have added this convention to Section 3.1. Line 326

12. *Page17Line404: Maybe discussion on the choice.*

   * We have added an explanaition for the FRP_thresh=30 MW choice to the manuscript, explaining that it is based on MODIS detection reliability (following Laurent et al. (2019)) rather than on a fire-behaviour threshold, and clarifying how it relates to the sensor's detection limit and to the grid-cell averaging used in our method. The added text is shown in the diff below.

Page 17, Line 404:

We set `FRP_thresh`=30 MW based on detection reliability, not fire behaviour. This threshold sits at the upper end of the peak in fire detection across all world regions (Laurent et al., 2019) and well above the sensor's detection limit (9–11 MW (Roberts and Wooster, 2008)). Consequently, reaching 30 MW on average across a grid cell requires a robust and spatially consistent fire signal. This is different from the FRP level at which fire size stops growing, which Laurent et al. (2019) show varies widely by region (roughly 10 to 280 MW). Since our goal is to filter out unreliable low-intensity detections rather than to match a specific fire regime, a single global value based on detection statistics fits better than a region-specific one.

13. *Page24Lines520-521: Would the presence of pyrocb activity explain the high depolarization ratio values?*

  * We thank the reviewer for this suggestion. Indeed, pyroCb-injected smoke can produce elevated depolarization ratios in the UTLS, as noted in our manuscript. However, in the present case, the trajectory analysis, with enhanced UVAI values above a desert region identified by MODIS land cover category "barren" all consistently point to a dust source rather than pyroCb activity. We therefore maintain our interpretation as already discussed in the text.

Technical comments

1. *Page1Line10: Close parenthesis or remove.*

  * Corrected. The parenthesis was closed in Line 10.

2. *Page1Line23: It should be "short for".*

  * Corrected. The phrase "or short pyroCb" has been changed to "or pyroCb for short" in line 23.

3. *Page3Line69: It should be "EPIC's".*

  * The respective paragraph has changed substationally. However, we made sure to correctly write "EPIC's" instead of "EPICs" within the paragraph.

4. *Page3Line79: Correct to "outperforms".*

  * This paragraph has changed and does not mention "outperformes" anymore.

5. *Page3Line 81: Change "studies" to "study".*

  * Corrected. Changed "studies" to "study" as suggested now in line 99 on page 4.

6. *Page6Lines118-119: Review "prohibiting an ambiguous classification". Prohibiting and ambiguous are contradictory.*

  * Corrected. Changed "prohibiting" to "preventing" (page 7, line 150)

7. *Page6Line130: Remove "via" and double parentheses.*

* We removed "via" and parentheses.

Page 6, Line 130:

~~(via (Van der Walt et al., 2014, scikit-image))~~ (Van der Walt et al., 2014, scikit-image)

8. *Page8Line175: I would probably remove "Observations conducted by".*

* Removed as suggested.

Page 8, Line 175:

~~Observations conducted by~~ Guan et al. (2010) demonstrated that the UVAI, as measured by OMI, increases with plume height for fresh tropospheric and stratospheric smoke plumes exhibiting UVAI >7.

9. *Page8Line186: Remove double parentheses.*

* Removed parentheses.

10. *Page8Line188: Consider changing "based on" with "with."*

* Corrected to "with".

11. *Page11Line261: Fix parentheses.*

* Added parentheses to the respective citation.

12. *Page11Line269: Something is wrong "Fig. 5 is explained".*

* Corrected to:

Page 11, Line 269:

The applied methodology to identify tropospheric smoke and to filter stratospheric smoke as well as dust is illustrated in Fig. 4 and Fig. 5~~is~~ , which are explained subsequently..

13. *Page12Line277: Change "5" to "4".*

* Corrected.

14. *Page12Line279 and Line292: Keep consistent nomenclature.*

* Corrected nomenclature for parcel altitude to: `z_p`.

15. *Page13Figure 5: Remove comma after "observed" and change "been" into "be".*

* Corrected. See general comment 10

16. *Page14Line300: Close the references in parentheses.*

   * Closed parentheses in Line 350, page 15 now.

17. *Page14Line318: Correct "parcle".*

   * Corrected to "parcel".

18. *Page16Line380-381. Correct the sentence*

   * Corrected.

Page 16, Line 380-381:
Consequently, if the altitude (~~z_p~~ z_p) of the air ~~parcle~~ parcel is located below the tropopause (see Fig.5), it is screened for dust ~~inlfuence~~influence.

19. *Page17Line393: "posit"?*

   * Changed to "argue" (page 19, line 450)

20. *Page20Figure8: Review parentheses*

   * Corrected figure description.

Page 20, Fig.8 :
30 May 2023 at 21:00 UTC ((a) and (d)), 31 May 2023 at 00:00 UTC ((b) and (e)), and ~~01~~ 1 June 2023 at 21:00 UTC ((c) and (f)): Smoke occurrence fraction (SOF) vs. MARTHA fluorescence backscatter (β_{F}) and capacity (G_{F}) ((a)~~–c~~–(c)), and compared to the Polly$^{\mathrm{XT}}$ particle backscatter coefficient at 1064 nm and volume linear depolarisation ratio at 532 nm ((d)~~–f~~–(f)).

21. *Page25Figure11: Change "d)" to "c)". Add "the" after "of which".*

   * Corrected in Fig.11 (page 27).

22. *Page26Line597: Add "of" after "lacking".*

   * added in line 713 on page 30.

23. *Page28Line631: Fix parentheses*

   * Fixed citation parentheses.

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