Author’s response to:
RC#1 from anonymous referee #1

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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

Specific comments

1. *Line 49. The upper-troposphere to lower-stratosphere self-lofting mechanism during the 2017 British Columbia fires was documented with both observations and model calculations by Torres et al (2020a).*

  * Thanks for pointing this out, we have added the respective reference (line 51 on page 2).

2. *Line 55. The authors seem unaware of available relevant literature. There have been publications suggesting the occurrence of self-lofting in the troposphere. See De Laat et al. (2012) and references therein.*

  * Thanks for pointing out the research conducted by De Laat et al. (2012). The study reports about fires in south-east Australia that occurred on 7 February 2009 (known as 'Black Saturday'), which burned over 450,000 ha and resulted in 173 human fatalities. Several studies have reported on the Black Saturday fires (Cruz et al., 2012; Dowdy et al., 2017; Fromm et al., 2021). These studies agree that pyrocumulonimbus clouds occurred on this day, resulting in the injection of

smoke into the lower stratosphere. We were indeed unaware of the study by De Laat et al. (2012), who ruled out pyroCb occurrence on 7 February 2009. De Laat et al. (2012) hypothesized that diabatic self-lofting was responsible for smoke transport from the free troposphere (below 10 km) into the lower stratosphere. However, Fromm et al. (2021) showed clear evidence that smoke was injected into the UTLS as it was observed the day after (8 September 2009 in Fig.18) from the nighttime CALIPSO overpass. Studies by (Cruz et al., 2012; Dowdy et al., 2017) also support that the Black Saturday event was a classic pyroCb direct-injection event. Given these contradictions, we chose not to cite De Laat et al. (2012). Nevertheless, as the second reviewer noted, a recent study by Huang et al. (2026) demonstrates that including self-lofting in model simulations can reproduce the observed smoke plume heights during the 2019 Australian wildfires. We have now revised our framing accordingly.

> **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.

3. *Line 58. Replace speculated with suggested.*

* We have replaced speculated with suggested.

4. *Lines 63-64. This can be achieved from sensors ‘ that measure the absorption of radiation by aerosols in quantitative terms such as single scattering albedo (SSA) and aerosol absorption optical depth (AAOD), and qualitatively such as the UV Aerosol Index, UVAI (Herman et al., 1997; Torres et al 1998)*

* Thank you for the clarification. We have revised the sentence to distinguish between quantitative and qualitative measures of aerosol absorption, as suggested.

> **Page 3, Line 63-64**:
>
> ~~Currently~~ . This is achieved through sensors that measure aerosol radiation absorption, either quantitatively (e.g., single scattering albedo, SSA; aerosol absorption optical depth, AAOD) or qualitatively (e.g., UV Aerosol Index, UVAI) (Herman et al., 1997; Torres et al., 1998)

5. *Line 65 – 70. The listing of UV-capable sensors should include relevant information such operating agency, resolution, retrieved aerosol-related parameters, and relevant references. Most listed sensors retrieve the same quantitative parameters, aerosol optical depth (AOD), single scattering albedo (SSA), and the qualitative UV aerosol index (UVAI). The TROPOMI and EPIC sensors also include Oxygen-A and Oxygen-B observing capability that allows the retrieval pf aerosol layer height, an important piece of information for the accurate retrieval of near-UV aerosol properties. It is suggested that the sensors be listed chronologically and mention their algorithms and retrieval products:*

- *Ozone Monitoring Instrument (OMI, 2007 – present) on low Earth orbit (LEO) Aura satellite, 13x24 km pixel size. Two aerosol algorithms: OMAERO developed by KNMI (Torres et al., 2007) and OMAERUV developed by NASA (Torres et al., 2007, 2013). Since about 2007 OMI observations have been affected by the row anomaly (Torres et al, 2018).*
- *The Ozone Mapping and Profiler Suite Nadir Mapper (OMPS-NM) on the Suomi National Polar-orbiting Partnership (SNPP) satellite, deployed in 2011, reports the UVAI parameter at 50 km resolution (Kramarova et al., 2014)*
- *Earth Polychromatic Imaging Camera (EPIC) on the National Oceanic and Atmospheric Administration's Deep Space Climate Observatory (DSCOVR) platform at the Lagrangian 1 point. The EPICAERUV algorithm retrieves, near UV AOD and SSA (Ahn et al., 2021) as well as Oxygen-B based aerosol layer height (ALH) at 18x18 km (Xu et al., 2019, , Torres et al., 2025)*
- *Tropospheric Monitoring Instrument (TROPOMI) on European Space Agency (ESA) Sentinel-5 Precursor (S5P) satellite. NASA's TROPOMAER aerosol algorithm [Torres et al., 2020b] derives aerosol properties at 5.5X3.5 km resolution. It reports UVAI ,AOD, and SSA retrieved from near-UV observations as well as ALH from Oxygen-B band observations.*

* Thanks for pointing this out and mention the relevant literature. We have restructured the paragraph including the relevant informations.

Page 3, Line 65 – 70:

Several operational UV-capable sensors ~~are KNMI's OMI sensor ...~~ currently retrieve near-UV aerosol properties. For instance, the Ozone Monitoring Instrument (OMI) aboard the low Earth orbit (LEO) Aura satellite (2004–present) offers a pixel size of 13 × 24 km and supports two aerosol algorithms: OMAERO (KNMI) and OMAERUV (NASA) (Torres et al., 2007, 2013). Since ∼2007, OMI observations have been degraded by the row anomaly, reducing effective coverage (Torres et al., 2018) The Ozone Mapping and ~~Profiler Suite (OMPS~~Profiler Suite Nadir Mapper (OMPS-NM) on the ~~Suomi National Polar-orbiting Partnership (SNPP) ...~~ Suomi-NPP ~~OMPS. Additionally, an~~ satellite (launched 2011) provides observations at 50 km resolution, with data available from January 2012 to present (Kramarova et al., 2014) The Earth Polychromatic Imaging Camera (EPIC) aboard NOAA's DSCOVR spacecraft at the L1 point retrieves near-UV AOD and SSA (Ahn et al., 2021) as well as O_2-B–based aerosol layer height ~~product exists for TROPOMI. However, TROPOMI data is only available from~~ (ALH) at 18 × 18 km resolution since June 2015 (Xu et al., 2019; Xu et al., 2025) Since 2018~~onwards, and the detection of high-altitude smoke plumes by the aerosol layer height algorithm is limited to altitudes of below 13~~, the Tropospheric Monitoring Instrument (TROPOMI) on ESA's Sentinel-5 Precursor satellite has provided global products of aerosol properties at a high spatial resolution of of 5.5 × 3.5 km ~~. An update to include detection for higher altitudes is not foreseen for the near future (Lambert et al., 2024)~~. Data from the OMPS sensor is available since January (improved from 7 km×3.5 km since August 2019), including UVAI, AOD, SSA, and ALH.

6. *Lines 70-71. The statement on EPIC observations '...polar coverage cannot be reached and thinned aerosol layers are not detectable over more than two weeks' is incorrect and unsupported by the listed Torres et al.,2020a reference. EPIC measurements from the Lagrangian 1 point attain full coverage of both polar regions most of the year except for a few weeks during their respective winter seasons. Also, the statement that 'thinned aerosol layers are not detectable over more than two weeks' (also not supported by the cited reference) does not sound like a major limitation of a nadir-looking space sensor. As a matter of fact, any nadir- looking satellite-borne sensor will have difficulties detecting thinned aerosol layers after two weeks. The two statements above are inaccurate and misleading . They should be either removed or properly backed up with specific references.*

* Thanks for the clarification, we removed the two statements.

7. *Line 72-76 A TROPOMI aerosol algorithm is discussed by the authors without providing any references. It is not clear if they refer to the NASA TROPOMAER product (Torres et al., 2020, discussed above in this review). Please discuss the connection between the mentioned TROPOMI- KNMI aerosol product (add a reference) and the aerosol layer height product associated with the listed Lambert et al. (2024) reference.*

* Thanks for this helpful comment. We admit that we were unaware that multiple TROPOMI aerosol retrieval products exist. In the revised manuscript, we have therefore added a general statement acknowledging that several retrieval products are available, without going into specific details about the individual algorithms or their differences.

8. *Lines 77. The authors refer to an OMPS sensor on the Suomi NPP satellite. The OMPS (Ozone Mapping and Profiler Suite) acronym does not refer to a sensor. OMPS consists of two instrument modules: a combined ozone Nadir Mapper (NM) and ozone Nadir Profiler (NP), and a separate Limb Profiler (LP), for a total of three sensors (Kramarova et al., 2014). In addition to total column ozone, OMPS-NM observations are used to calculate the UVAI parameter. Limb Profiler (LP) observations of scattered solar radiation in the 290–1000 nm spectral range are used to retrieve high vertical resolution (1.8 km) ozone and aerosol profiles. OMPS-LP provides daily global measurements of the vertical distribution of spectral aerosol extinction from cloud top up to 40 km (Loughman et al., 2018).*

* We have changed OMPS to OMPS-NM for clarity. As the paragraph has changed due to the previous comment, this is now more clear.

9. *Lines 78-80 The statement 'A comparison between OMPS and EPIC shows…' is ambiguous as it does not indicate which parameter, and from which of the sensors of the OMPS suite, is compared to which EPIC retrieved parameter.*

* We have omitted the statement as we used only the OMPS-NM observations and not the OMPS-LP observations that were referred to in Torres et al. (2020).

Page 3, Line 78-80:

~~until present, with higher resolution compared to OMI, but lower compared to TROPOMI and EPIC. A comparison between OMPS and EPIC shows that OMPS outperformes EPIC when detecting stratospheric smoke: OMPS can detect it up to 10 months after the initial injection (Torres et al., 2020)~~.

10. *Line 83 Clarify to what OMPS sensor the sentence '…with global smoke layer information derived from UVAI measurements from OMPS' is referring to.*

* We clarify now that OMPS-NM is used to derive global smoke layer information.

11. *Line 85 There are two MODIS sensors. Specify which MODIS sensor this statement refers to. Also define and/or provide a reference for the Suomi NPP Data Exploitation Level 2 product or database.*

* Thanks for pointing out the missing information regarding the references to the data products. We have added them to the respective paragraph.

Page 3, Line 85:

Additionally active fire data from ~~MODIS and Suomi NPP Data Exploitation Level-2 is~~ Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on board the Aqua and Terra platform or from the Visible Infrared Imaging Radiometer Suite (VIIRS) instruments aboard the Suomi National Polar-orbiting Partnership (Suomi-NPP) can be used for smoke identification close to fire sources. ~~The results~~ In this study we used the latest collection of MODIS active fire products (MCD14ML) (Giglio et al., 2016) and the VIIRS 375 m active fire product VNP14IMGML (Schroeder et al., 2014), both of which can be downloaded from the Fire Information for Resource Management System (FIRMS) website.

12. *Line 86. How are absorbing aerosol layers above clouds dealt with? See related comment on line 187.*

   * We do not account for effects on UVAI from aerosol layers present above clouds. We have added a respective sentence acknowledging this in the introduction. See also response to comment 14.

13. *Line 153-154 The statement '. . . .nominal at-launch spatial resolution of about 50km × 50km with an imagery resolution of the final data output of 2km' makes no sense. Please correct and provide a reference.*

   * We agree and removed the part of the sentence mentioning "imagery resolution of the final data output 2km".

14. *Line 154. At 50km×50km resolution there is a large probability of cloud presence either at the same altitude as the aerosols or beneath the absorbing aerosol layers. The latter would result in an UVAI increase unrelated to either aerosol amount or aerosol layer height. Discuss how this UVAI increase is dealt with without explaining it as a spurious aerosol layer height effect. See comment on line 187.*

   * Thanks for pointing this out. We have added a discussion of this effect in Sect. 2.2 and Sect. 3.3 (see diff), explaining that a bright underlying cloud can enhance UVAI (Jethva and Torres, 2011; Torres et al., 2012; Jethva et al., 2018), and that this effect reduces UVAI's height sensitivity. We do not explicitly correct for this; instead we rely on the reception-height margins already built into TRAILS and note that the derived UVAI–height relationship is most reliable for optically thick, young smoke over low-reflectivity scenes.

Page 7, Line 154:

Model simulations show that the UVAI is further enhanced when the absorbing aerosol layer overlies a bright underlying scene. This occurs, for example, when liquid or ice clouds are located beneath or are embedded within the aerosol layer. The magnitude of the change in UVAI depends particularly on the cloud and aerosol optical depth and the aerosol single scattering albedo (Jethva and Torres, 2011; Jethva and Torres, 2012). Moreover, the sensitivity of the UVAI to aerosol layer height is reduced when underlying clouds are present (Torres et al., 2012).

Page 16, Line 370:

Additionally, the potential presence of underlying cloud contamination due to the coarse spatial resolution of OMPS-NM (50 km × 50 km) is likely another source of uncertainty. As our empirical relationship (Eq.5) does not explicitly account for this effect, cloud-contaminated pixels could bias the derived plume height upward. This potential positive height bias may partly offset the underestimation in plume height from optically thin or aged smoke plumes, which are expected to produce a weaker UVAI response for a given height (Torres et al., 2012; Torres et al., 2018). However, as aerosol optical depth decreases, the sensitivity to enhanced scene reflectance also decreases (Jethva et al., 2018). We do not attempt to disentangle or explicitly correct for either effect. Consequently, the retrieved plume-height relationship is expected to be especially reliable for optically thick, young tropospheric smoke plumes over low-reflective underlying scenes (e.g. cloud-free conditions). It should be noted that our objective is not to retrieve exact layer heights but rather to constrain the horizontal and vertical extent ~~in~~ within which smoke may occur.

15. *Line 159, 183, 361 (Fig.6) and 609: It is OMPS-NM*

 * We now always mention that we refer to the OMPS-NM instead of only OMPS.

16. *Line 173 Add Torres et al 2020b reference on ALH dependence of UVAI.*

 * We have added the respective reference.

17. *Line 175. Add the Ginoux and Torres (2003) reference on parameterization of UVAI based on model calculations.*

 * Thanks, we have added the Ginoux and Torres (2003) reference at the relevant location, where it supports the described dependence of UVAI on aerosol optical depth, layer height, and single scattering albedo.

Page 8, Line 175:

For AOD larger than 2, further increases in UVAI depend mainly on aerosol layer height (Ginoux and Torres, 2003; Torres et al., 2020).

18. *Line 187. Absorbing aerosol layers are often located above highly reflective water/ice clouds. A bright cloud background increases the UVAI value of an aerosol layer in relation to what should be under cloud-free conditions. This increase depends on both the aerosol and cloud optical depths (Jethva et al., 2018). How is that effect handled in the proposed UVAI to height adjudication?*

 * See comment 14.

19. *Line 190 Which MODIS sensor?*

* We mention now in the respective line, that active fires were identified by MODIS (Aqua and Terra combined) product.

> **Page 8, Line 190**:
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> Active fires detected by MODIS (Aqua and Terra combined) between 16-18 July 2014 ...

20. *Line 203 Provide a reference for Suomi NPP Data Exploitation Level2 document.*

* We now provide the correct references in the respective section and also in the Table 1.

> **Page 8, Line 203**:
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> We obtain daily ~~globally~~ global active fire data from ~~Suomi NPP Data Exploitation Level-2 active fire (NDEAF-L2~~the MODIS MCD14ML product (Aqua and Terra combined) (Giglio et al., 2016) and the VIIRS 375 m active fire product VNP14IMGML (Schroeder et al., 2014), both available via the Fire Information for Resource Management System (FIRMS).

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