Response to Referee#4

The paper "CALIPSO Level 3 Stratospheric Aerosol Product: Version 1.00 Algorithm Description and Initial Assessment" presents and discusses the new science algorithm and data handling techniques that are developed to generate the CALIPSO version 1.00 level 3 stratospheric aerosol profile product. The study falls within the scope of AMT. The authors have done a thorough job, the manuscript is well-written/structured, the presentation clear, the language fluent, the quality of the figures high. The result support the conclusions.

Thanks very much for carefully reading the manuscript and for your useful suggestions.

Two major deficiencies are the implementation of a constant stratospheric aerosol lidar ratio (50 sr), regardless of an aerosol type classification, and the evaluation of the stratospheric aerosol product against SAGEIII extinction coefficient observations, a product which has not been validated (including issues of SAGEIII such as cloud contamination propagating in the comparison). However the stratospheric aerosol product and all the issues are properly and extensively discussed in the manuscript, thus I recommend publication in AMT, under minor revisions before it can proceed to be published.

For this first version of the product we have used a constant lidar ratio of 50 sr globally. In future versions we hope to incorporate a more informed lidar ratio distribution. As shown in Figure 14, by making use of the extinction retrievals from SAGE III and backscatter measurements from CALIPSO, an initial estimate of the stratospheric aerosol lidar comes out to be ~46±6 sr, quite close to the value we have adopted. Although not validated yet, the SAGE III extinction retrievals are still the gold standard for stratospheric aerosol data and so we have used them in our initial comparisons.

Minor comments:

1) P1L17-18: "gridded level 3 product is based on version 4.2 of the CALIOP level 1 and level 2 data products". According to this sentence CALIOP level 1 V4.2 is used. It is not clear whether the authors refer to Level 1B or Level 1.5 Profile Data. In the case of L1B, please provide a web link to the used data repository.

Added 1B in P1 and given the link to the data repository in section 2.1.

2) P1L27: "where the average difference between zonal mean extinction profiles is typically less than 25% between 20km and 30km". Please rephrase to provide also whether the sentence refers to overestimation or underestimation compared to SAGEIII.

We have added "(CALIPSO biased high)" within brackets.

3) P3L29-30: "This is a level 3 monthly averaged product gridded in latitude (5o), longitude (20o) and altitude (900m)". Although the justification of the 900m vertical resolution is sufficient, the authors should provide explanation on the reasons why the spatial resolution of 5ox20o deg2 grids was selected. How much the selected spatial (horizontal), vertical and temporal resolution affect the final dataset (in terms of backscatter and extinction coefficient profiles at 532nm)?

We have added the following in the text:

"Given the low SNR in the stratospheric backscatter measurements, it is necessary to average the data substantially, both spatially and temporally. Averaging the backscatter data over 5^o in latitude increases the SNR by a factor of 40 (compared to single shot profiles) and provides a reasonable depiction of stratospheric aerosol distribution. This is also consistent with the early results of Thomason et al. (2007), who used the early CALIPSO measurements together with data from the CALIPSO simulator (Powell, 2005) to show that averaging the data over 5° in latitude and about 1 km in the vertical resulted in fairly representative stratospheric distribution. Further, spatial distributions of stratospheric species tend to be zonally symmetric (e.g. Kremser et al., 2016). In order to capture the signature of any possible longitudinal variation, e.g., the Asian Tropopause Aerosol Layer (ATAL) which occurs over Asia every summer during the monsoon months, we have used a longitudinal grid of 20^{o}."

It is important to remember that we are trying to retrieve very low extinction coefficients (~10^{-4} - 10^{-5} km^{-1}) in the stratosphere using the backscatter measurements with low SNR at those altitudes. This cannot be achieved without a significant amount of averaging of the data spatially and temporally. It may be mentioned that the currently available Global Space-based Stratospheric Aerosol Climatology (GLOSSAC) product that uses CALIPSO data as well as OSIRIS data is zonally invariant and binned in 5 degree in latitude and produced on monthly basis, consistent with the needs of the climate modelling community.

We believe the justification for the adopted grid lies in capturing the various stratospheric perturbations in the retrieved products, to the extent possible. As shown in the manuscript, seasonal and regional perturbations like the Asian Tropopause Aerosol Layer (ATAL) as well as the pyroCb events and volcanic signatures are well captured in the product, vindicating the spatial and temporal resolution adopted for the product.

4) P5L26: "Note that the range of altitudes to be covered in the stratosphere at various latitudes is from 8.2 km to 36 km, the latter being the lower limit of the calibration region". Please mention the applied methodology of decoupling stratospheric and tropospheric layers, since the altitude of 8.2 km frequently lies below Tropopause? Does it rely on MERRA-2 by GMAO?

We have added the following:

"The altitude resolution of the CALIOP level 1 profiles varies with altitude from 60 m between 8.3 km and 20.2 km to 180 m between 20.2 km and 30.1 km and finally to 300 m between 30.1 km and 40.0 km. In order to achieve a uniform altitude resolution, the vertical grid resolution was set to 900 m. Note that the tropopause can occur below 8.3 km at high latitudes, but the vertical resolution of level 1 profiles changes again below this altitude and the lower limit was kept at 8.3 km as a trade-off between computational complexity and the stratospheric information content, while the upper limit was set at 36 km, which is the lower limit of the calibration region. The tropopause heights were taken from the Modern-Era Retrospective analysis for Research and Applications 2 (MERRA-2) reanalyses as in all V4 products (Gelaro et al., 2017)."

5) P8L8-9: "Further, all L1B profiles within the South Atlantic Anomaly (SAA) region are also removed": Why do the authors remove CALIOP observations over the SAA region. Based on Kar et al., 2017 (CALIPSO lidar calibration at 532âĂ L'nm: version 4 nighttime algorithm), the new nighttime CALIOP calibration technique compensates for the higher NSR values, resulting in reliable calibration

coefficients even over the SAA region. The authors it is suggested to include the justification in the manuscript.

While the version 4 calibrations were done over SAA region also, the stratospheric profiles over this area may still be noisy. Therefore, for this first version of the product, we decided to remove all data over the SAA region. In fact this issue has been discussed in detail in the second paragraph on this page.

6) P8L25: ". . . leading to generally lower CAD scores (Liu et al., 252019).". Since CAD ranges between -100 and 100, it is not clear whether the authors refer to more aerosol reliable retrievals (CAD -> -100) or to absolute values of CAD score, therefore, CAD values closer to zero.

We have revised the text as "generally lower absolute values of CAD scores".

7) P9L4-7: Although the authors provide the Vaughan et al., 2009 reference, some information on the noise filter should also be included in the manuscript, even if briefly.

We have modified the text adding some information on the noise filters as:

"Essentially a range dependent threshold array of attenuated scattering ratios is constructed, which incorporates noise from two types of sources. The first category is the range invariant noise and includes detector dark noise and noise from the solar background light. The second category is the range dependent noise from single shot measurements and is calculated from the molecular models. Using this range dependent threshold, outliers are removed (for details see Vaughan et al., 2009, section 2c). After removing the outliers, the 5 km profile is assigned to the appropriate spatial grid."

8) Figure 4: Based on the manuscript, Figure 4b and 4c refer to the aerosol mode, however it is not clear neither in the caption nor in the manuscript whether they refer to the background or the aerosol mode. In addition, high stratospheric values are observed at 0o latitude, between 25 and 30 km height. Where do the authors attribute the observed values?

Figure 4 (now Figure 3 in the revised version) is showing the effects of the various filters. Figure 3a is the standard background mode where a depolarization filter is employed after removing all layers or features. Figure 3b is not really part of the product but is only meant to show the result, if we had employed a depolarization filter after retaining the aerosol layers in the stratosphere—clearly the Cordon plume is being missed here. Figure 3c is the standard "all aerosol" mode" where a color ratio filter is used after retaining the aerosol layers and shows that this filter captures both the volcanoes. We have modified the caption as:

"Zonally averaged height-latitude cross sections of attenuated scattering ratio for June 2011: a) after removing all detected layers and using a volume depolarization ratio filter (i.e., background aerosol only); b) including aerosol layers in the stratosphere detected by the level 2 algorithms with a 5% volume depolarization ratio filter applied; and c) including the level 2 aerosol layers but using an attenuated color ratio filter instead of the volume depolarization ratio filter. The white area in the northern high latitudes in summer indicates lack of nighttime data."

As regards the high values over the tropics we have added the following sentence:

"Note that the enhanced scattering ratios near 25-30 km represent the tropical reservoir of stratospheric aerosols (Trepte and Hitchman, 1992, Kremser et al., 2016)."

9) P12L5: "Note the high scattering ratio values in the Antarctic latitudes between 15 km and 25 km". The authors are kindly requested to provide a reference for this statement.

No reference is available for this statement---essentially this is what we are pointing out from CALIOP measurements.

10) P12L17-18: "The white grid cells over southeast Asia occur because the tropopause is higher than 16 km in this region". The authors are kindly requested to provide a reference for this statement, including the typical tropopause height over this region.

Note that this Figure has now been revised and we are now showing the sample number distribution at 17 km, where no data drop out can be seen from tropopause-related issues.

11) P12L21-22: "This is again likely due to small particles which are in the process forming PSCs". The authors are kindly requested to provide a reference for this statement.

This particular sentence has now been deleted and the sentence preceding this has been modified as:

"Also note the high number of samples over parts of Antarctica, partly due to oversampling from orbital configuration and related to small particles below the detectability of PSCs by the PSC mask algorithm."

12) P13L13: "For the CALIPSO stratospheric aerosol product, the particulate multiple scattering factor is taken as 1 for all species of stratospheric aerosols". The authors are kindly requested to provide a reference for this statement. Which is quantitative the effect of this assumption on the discussed stratospheric aerosol product?

We expect the single scattering assumption to hold in the stratosphere most of the time, except may be for the early part of the plume injection. This is also consistent with the retrievals in the version 4 level 2 aerosol retrievals

We have revised the relevant text as:

"For the CALIPSO stratospheric aerosol product, the particulate multiple scattering factor is taken as 1 for all species of stratospheric aerosols, consistent with the approach taken in the CALIPSO level 2 aerosol retrievals (Young et al., 2013; Young et al., 2016; Young et al., 2018)."

A quantitative discussion of this is examined in the comprehensive error analysis detailed in Young et al., (2013).

13) P13 - Stratospheric Aerosol Lidar Ratio of 50 sr is used. Although the authors explain in detail the selection of the specific lidar ratio value and evaluate against SAGEIII observations, it is expected that the uniform value used globally, regardless of the aerosol type, introduces large uncertainties. Which is the effect of this assumption to the stratospheric aerosol product? The authors mention that appropriate LR values for different aerosol subtypes will be introduced in future versions of the stratospheric product, however the assumption of constant LR value highly affects the reliability of the extinction coefficient profiles and should be mentioned in the abstract.

We believe we have adequately discussed the lidar ratio issue in the discussion section. In particular the lidar ratio obtained by using the extinction from SAGE III and backscatter from CALIOP gives a value quite close to the adopted lidar ratio in much of the stratosphere.

We have revised the relevant sentence in abstract as:

"Further, we show that the extinction profiles (retrieved using a constant lidar ratio of 50 sr) capture the major stratospheric perturbations in both hemispheres over the last decade resulting from volcanic eruptions, extreme smoke events, and signatures of stratospheric dynamics."

14) Figure 8: The authors should discuss on the high values of attenuated scattering ratios observed over the equator, including the proper references.

We have added the following:

"As in Figure 3, the feature with high attenuated scattering ratio near 25-30 km seen in all the four panels is the signature of the tropical reservoir of stratospheric aerosols, maintained by a complex interplay of transport from the troposphere and stratospheric dynamics as well as microphysical processes including the Brewer-Dobson circulation, the QBO, evaporation and sedimentation (Trepte and Hitchman, 1992, Kremser et al., 2016)."

15) P18L1-5: "The persistence of the stratospheric perturbation for several months is consistent with the results of Vernier et al. (2016) who found the presence of ash in the lower stratosphere 3 months after the Kelud eruption from balloon observations". The observed features are qualitative consistent with the results of Verner et al. (2016). Is it possible to the authors to include a quantitative comparison?

It is not possible to do a comparative comparison, because we are using a monthly averaged product at 5^{o} latitude by 20 ^{o} longitude—for a proper profile by profile comparison we need to have proper collocations. In any case, this paper is primarily devoted to a description of the algorithm and data product. While we offer an initial assessment of data product quality by providing multiple comparisons to SAGE III measurements, this paper is not intended as a comprehensive validation of all possible results that could be retrieved from this product.

16) P20L3-5: "SAGE III performs solar and lunar occultation measurements as the ISS orbits the Earth and covers the entire global latitude (90oS to 90oN) and longitude range (180oW to 180oE)." ISS orbital characteristics are characterized by 51.6o inclination, therefore the authors it is suggested to check the global latitude coverage (90oS to 90oN).

We have modified this sentence to:

"SAGE III performs solar and lunar occultation measurements as the ISS orbits the Earth and covers a broad latitude band (60^{o}S to 60^{o}N) and longitude range (180^{o}W to 180^{o}E)."

17) P20L15-17: "The globally averaged value of the Angstrom exponent derived using all 15 months of data is about 1.56". Please mention between which wavelengths.

In the preceding sentence we had already mentioned that the Angstrom exponent was derived from 521 nm and 1022 nm. In any case we have added "(between 521 nm and 1022 nm)" once again.

18) P20L22: "σ(z) = 100×(σ(z)CALIPSO–σ(z)SAGE)/σ(z)SAGE". How are extreme cases treated? Which computational filters are applied? For instance, cases with σ(z)CALIPSO = 0 (σ(z) = -1), or cases with very low values of σ(z)SAGE are also included? In case of applied filters in the dataset used prior to the results, the authors should mention them in the manuscript.

As clearly mentioned in the text, we have used the extinction coefficients with fractional uncertainties less than 100% as retrieved from both SAGE III and CALIPSO. No other filters were used for these comparisons.

19) P22L14: "between CALIPSO and SAGE III extinction at all altitudes with CALIPSO having a high bias". Wherever the manuscript refers to statistical indicators, such as the "high bias" here, the authors should mention the corresponding computed values.

Done.

20) P23L8: "calculated using the average extinction coefficient profiles between 20 km and 30 km". The reason of selecting vertically the region between 20km and 30km and not the region from 20 km up to 34 km, hence including the stratospheric region of V3 calibration, is not clear nor justified in the manuscript, since it is proven in Kar et al. (2017) that this region is not aerosol free.

The retrieved profiles above 30 km are often quite noisy from both the instruments and were not used. Once again, retrieving aerosol extinction coefficients ~10^{-5} km^{-1} from these measurements is stretching the limits of the instruments' measurement capabilities while at the same time not adding anything significant to the stratospheric optical depth estimates. The purpose of this figure is to show the difference in the retrieved optical depths within the altitudes where much of the stratospheric aerosol generally resides.

21) P2314: "though the differences begin to rise substantially in the midlatitudes of both hemispheres". Please include explanation on the observed features, including the necessary references.

We don't completely understand the cause of these differences at this time. Further validation work using data from other instruments providing extinction retrievals might be of help in determining these.

References:

Thomason, L.W. et al., Atmos. Chem. Phys., 7, 5283-5290, https://doi.org/10.5194/acp-7-5283-2007, 2007.

Powell, K. A., Development of the CALIPSO lidar simulator, M. S. thesis, College of William and Mary, 228 pp. available at http://www-calipso.larc.nasa.gov/resources/publications.php