Response to the Anonymous Referee #2 comments for the manuscript "Retrieval of aerosol properties from zenith sky radiance measurements" By Sara Herrero-Anta et al. in AMT

First of all, we would like to thank the time and effort of the referee for their detailed review of the manuscript. Reviewer comments (RC) are in black font and author comments (AC) are in red.

Author's answer to Anonymous Referee #2

RC: This paper describes the retrieval of aerosol properties using zenith sky radiances (ZSR) measured with the ZEN-R52 radiometer. Although a ZEN-LUT methodology was previously published for this purpose, this paper presents a new alternative for aerosol properties retrieval based on the GRASP inversion strategy (ZEN-GRASP). This new strategy has the advantage of not being dependent on the study location, allowing it to be applied to any instrument worldwide without the need for compiling a specific lookup table (LUT). Another advantage is that the ZEN-GRASP is capable of retrieving extensive aerosol properties, including volume concentration (VCT, VCC and VCF). Considering that this paper introduces new insights to expand aerosol characterization with a robust instrument capable of operating in remote regions, it can play an important role in reducing the current lack of ground-based information in key areas for aerosol modelling or assimilation.
The authors provide a detailed explanation of the inversion strategy in this work, along with a sensitivity analysis to ensure the method's suitability.
I consider that this manuscript aligns well with the scope of AMT, and the presented results are relevant. However, there are some general and specific comments that this referee believes should be taken into account, particularly to enhance the readability of the paper.

General comments:
RC1. This referee strongly recommends that the authors revise the English language used in the paper. There are certain parts of the text that are difficult to understand.
AC: Following the referee comment, the English of the manuscript has been reviewed and improved in the new version of the manuscript.

RC2. Section 3 and 4 (Calibration and Sensitivity Analysis) constitute a significant portion of the document. They comprise 5 pages compared to the 2 pages dedicated to listing the results. I must acknowledge that while these sections contain useful information for presenting the results, they tend to distract the reader from the study's main objective. Additionally, in my opinion, section 3.5, which includes the comparison with the Cimel instrument in terms of radiance, should be included in the results section. This would considerably streamline Section 3.
AC: This work presents three well established targets: calibration of the instrument, to study the capability of the inversion strategy, and to apply the method to a real measurement database. For that, we decided to divide them in three sections. As referee says, all the three sections present results, then we consider that a section called "Results" has not sense. Then, the Section 5 has been renamed as "GRASP-ZEN application to

ZEN-R52 database" instead of "Results". With this change, we think that has not sense to add Section 3.5 to Section 5, since the comparison of sky radiances in the "ZEN-R52 vs. CE318 photometer comparison" does not fit with "GRASP-ZEN application to ZEN-R52 database".

RC3. In line with the last comment, the lack of information regarding the periods considered for calibration (Section 3) and the application of calibration for obtaining AOD and VC products (Section 5) makes it challenging to follow the authors' temporal sequence in presenting the results. Is this the reason why the validation in radiance is included in Section 3 instead of Section 5? Are you using different period for calibration (training) and application of the calibration (validation)? Please provide clarification on this matter.

AC: The total period of ZEN measurements in this work is used for the calibration and also for the retrieval of aerosol properties. It has been added at the beginning of Sections 3 and 5 adding: *"April 2019 to September 2021"*

This is possible because different information is used for each part, so it should not affect; calibration is based on almucantar/hybrid retrievals while Section 5 is mainly based on AOD data (sun measurements instead of sky radiances).

Specific comments:
RC: Line 20: AERONET has been named as Aerosol Robotic Network or AErosol RObotic NETwork, please homogenize.
AC: It has been homogenized to Aerosol Robotic Network.

RC: Line 25: pre-calculated.
AC: Done

RC: Line 38: no significant.
AC: Done

RC: Line 39: Could you please check the reference Cissé et al. (2022). The DOI does not work and I can not find a reference about aerosols in this text.
AC: The referee was totally right. It has been corrected, the correct reference is: Forster et al., 2021:
Forster, P., T. Storelvmo, K. Armour, W. Collins, J.-L. Dufresne, D. Frame, D.J. Lunt, T. Mauritsen, M.D. Palmer, M. Watanabe, M. Wild, and H. Zhang, 2021: The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 923–1054. https://doi.org/10.1017/9781009157896.009

RC: Line 47: … processing and data(?) distribution.
AC: Done

RC: Line 48: manufactured by Cimel Electronique SAS.

AC: Done

RC: Line 50: (or lunar**,** if available).
AC: Done

RC: Line 51: I will include a full stop here: This is achieved by applying…
AC: Done

RC: Line 52-54: As a reader, I would appreciate shorter and more direct sentences, like, for example, this one: AERONET also employs an inversion algorithm to retrieve more intricate aerosol properties, such as aerosol size distribution and refractive indices. This algorithm takes into account sky radiances at different angles and wavelengths, along with the AOD values, as input.
AC: This sentence has been changed following the referee suggestion.

RC: Lines 59-65: This sentence appears to be written in a confusing manner. I propose something like: In this regard, several authors have utilized GRASP to retrieve aerosol properties using various measurements as input, including: satellites…
AC: This sentence has been rephrased as:

L61-62: "*In this regard, some authors have utilized GRASP to retrieve aerosol properties using as input, among others, data from:*"

RC: Line 66: manufactured by …
AC: Done

RC: Line 69-70: dedicated to the retrieval of water vapour).
AC: Done

RC: Line 70-72: I suggest to re-write this sentence as follows: One advantage of this instrument is that it does not have moving parts and, in general, it is cheaper than more complex photometers. This affordability enables the installation of multiple instruments, thereby achieving a higher spatial coverage.
AC: This sentence has been rephrased as:

L72-74: "*One advantage of this instrument is that it does not have moving parts and is cheaper than more complex photometers. This affordability enables the installation of multiple instruments, thereby achieving a higher spatial coverage*".

RC: Line 80: The following paper?
AC: "following" has been changed by "current".

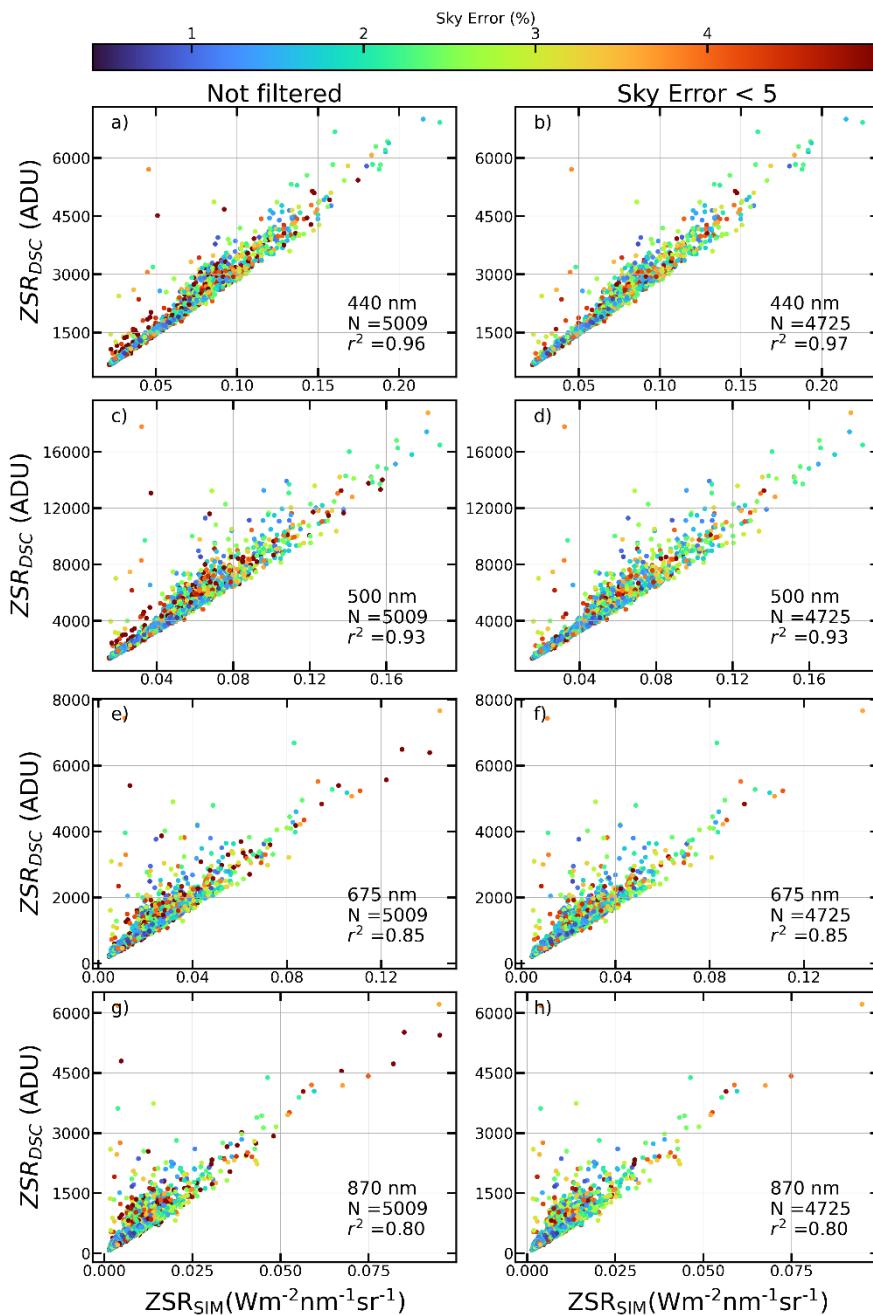
RC: Line 81: study location?
AC: "as well as the study location" has been changed by "as well as a description of the site".

RC: Line 106: almost always?
AC: Replaced by only "always".

RC: Line 119: The authors are using level 1.5 data. Is not the level 2.0 available in the period 2019-2021 at your site?

AC: When level 2.0 is available in AERONET, level 1.5 is directly updated to 2.0, but if it is not, it remains at 1.5. The difference between 1.5 and 2.0 is only the application of the last calibration in the latter, which occurs once a year, so usually last year of measurements are only available at level 1.5 as it occurred by the time of the study with year 2021, but the rest of the years correspond to 2.0. This 1.5 level is also quality assured.

RC: Line 121: Why the 10% limit? Is there a reference?

AC: Actually it is 5%, it has been changed it. As a preliminar option it was selected the limit 10%. After that, a visual analysis as the ones done for SZA or ZEN variability in Section 3.2 was carried out for the sky error. We could see most points had a good correlation except with some points with sky error > 5% (red points), so we stablished the final limit at 5%. This part has not been included for the simplification of the section.

RC: Line 131: Each filter is placed over…
AC: Done

RC: Lines 208-209: The authors stated here that "This methodology is a field campaign" with no need of laboratory measurements. I do not understand the point of referring it as a field campaign. Furthermore, temperature characterization also needs the use of a thermal chamber in the laboratory…
AC: As mentioned in the paragraph, it can be calculated from field measurements using the temperature information provided by the ZEN, using night-time measurements or even a full-day measurements using a dark piece to cover the instrument. The paragraph has been rewritten as next to clarify these issues:

L214-217: "*A methodology for the ZEN-R52 calibration is proposed in this Section. This methodology can be developed using only field measurements, so it would not require laboratory measurements. It is based on four steps: dark signal correction, quality data filtering, temperature correction, and a final comparison against simulated values to convert the output signal from ADU into radiance units ($Wm^{-2}nm^{-1}sr^{-1}$)*".

RC: Section 3.1: "…but it could be calculated from the night-time measurements (dark sky) when a thermal chamber is no available." Is it recommended by looking at the important T dependence of some ZEN filters not including DC correction (T dependent) and T correction on the ZEN systems?
AC: It is recommended to include both corrections.

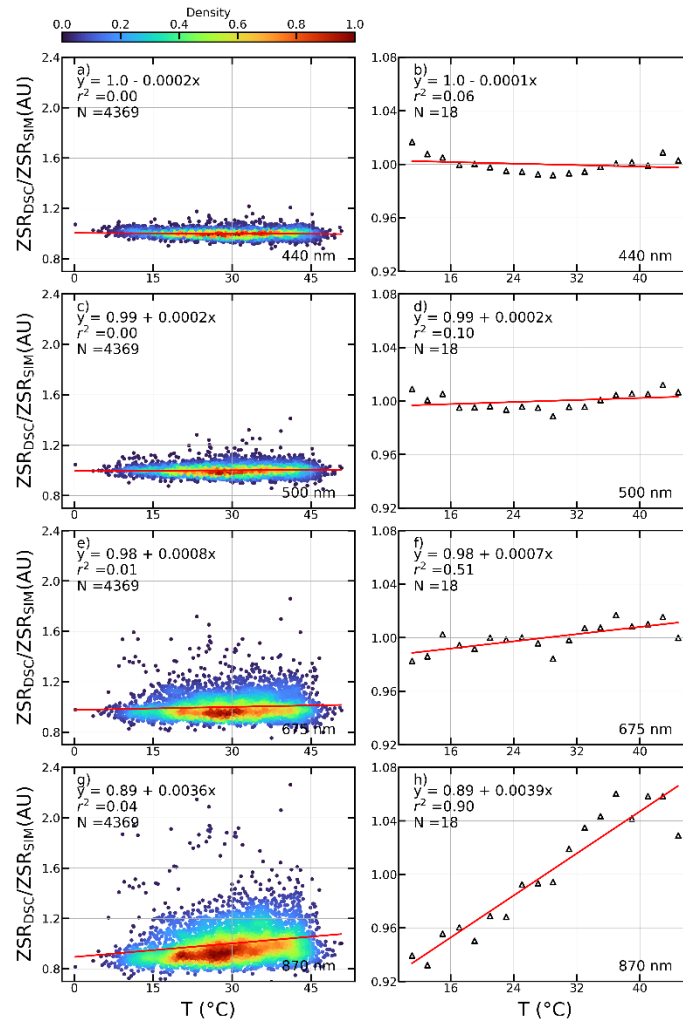
RC: Line 233: The colour of the points…
AC: Done

RC: Section 3.3: I do not understand how the temperature correction has been done. The authors have the information of real ZSR measurements and simulated values when the ZEN system is inside the thermal chamber? Could you please clarify?
AC: The thermal chamber is only used for the dark signal evaluation in section 3.1. For the temperature correction the ZSR_{DSC}/ZSR_{SIM} ratio normalized to the mean value is plotted against the temperature in Figure 3. It is explained in the new manuscript:

L269-270: "*In order to check the dependence with temperature of each channel the ratio ZSR_{DSC}/ZSR_{SIM} normalized by the mean ratio has been plotted against the temperature in Figure 3.*"

Where ZSR_{DSC} are the ZSR raw signal from the zen with dark signal corrected (DSC) and ZSR_{SIM} are the ZSR simulated by GRASP. As mentioned, we also are excluding those points which do not satisfy the quality control filtering calculated in section 3.2:

L307-309: "*From now on ZSR_{ZEN} will stand for the calibrated zenith sky radiances measured by the ZEN-R52 satisfying the stablished quality controls ($30° < SZA < 80°$; ZEN variability < 4%).*"

RC: The different scales of the plots in Figure 3 prevents us for discerning the trends described in the paper.
AC: This figure has been updated as referee suggests. It is shown next:

RC: Line 263: When the authors state the presence of a trend with temperature, is "trend" the correct wording? I suggest to talk about temperature dependence.
AC: It has been changed by the next:

L270-272: "*In the left panels (a, c, e and g) of Figure 3 all data points are represented together with the linear fit, showing a negligible dependence on temperature for 440 and 500 nm*"

RC: Line 269: Please remove indent.
AC: Done

RC: Line 272: Please remove "λ-wavelength". It is redundant.
AC: Done

RC: Line 275: "Definitive comparison". Why this comparison has been labelled as definitive? As mentioned in the general comments, I consider that including here the time period will help the reader to clear the time sequence.
AC: The sentence including the "definitive comparison" has been simplified, removing the term 'definitive', with:

L287-288: "*The calibration factors can be directly obtained by comparing the dark and temperature corrected ZSR from the ZEN-R52 against the values simulated by GRASP*"

As mentioned above the whole dataset is used all the time.

RC: Lines 287-290: Could the authors clarify why systematic errors are expecting in case of sphere calibration is used (provided the same E0 for normalization is used)?
AC: This section has been updated since it looks to be not so clear. Due to the normalization used by GRASP, if radiance data is being used to GRASP it needs to be normalized, therefore including a systematic error due to this normalization. But if the measurements are obtained from GRASP, we are not including are using the same normalization or not normalization at all if we already use the normalized radiances from GRASP.

This paragraph has been rephrased as:
L296-303: *"The proposed calibration method uses the standard ASTM-E490 solar spectrum to transform the unitless output radiances from GRASP, as indicated in Equation 1. This fact can increase the relative differences between the two calibration methods, together with the lack of temperature correction in the second one. However, when using the calibration method developed in this study, the same normalization factor applied to the ZSR simulated by GRASP (ZSR_{SIM}) can be applied to the calibrated ZEN-R52 measurements when using them as input to GRASP for the inversion. This way it can be avoided the introduction of a systematic error due to the normalization required by GRASP inversion algorithm."*

RC: Section 3.5: Similar problem with the time period.
AC: In the new manuscript it is clearer that all the available dataset has been used with different purposes, including the time period *"April 2019 to September 2021"*.

RC: Line 296: Please correct the typo in "whole".
AC: Done

RC: Line 308: Please remove the final comma.
AC: Done

RC: Line 316: Can you add more information about the considered "wrong" values? Some statistics can help to understand why the values are wrong.
AC: "Wrong" meaning that these points (SZA<30º) do not correlate with the reference values. This sentence has been rephrased as:

L331-334: *"Hence, the ZSR_{ZEN} values do not correlate with reference values for SZA<30º when the sun is cloud-free, which confirms the suggested explanation that ZSR_{ZEN} measurements are contaminated by stray sun light under cloud-free conditions when the sun elevation is high (SZA<30º)"*

RC: Line 332: Please add a point missing.
AC: Done

RC: Line 340: Why this paragraph has a different indent?
AC: This paragraph has been homogenized with the others.

RC: Section 5: I can read here the number of data included in the analysis but not the period covered. Are the authors using here a different quality-controlled analysis than the one presented in the Section 3.2? I do not expect so, since this specific ZEN method includes the measurement errors. Maybe I have misunderstood the text, but I don't see the point of using different QC methodologies. Could you please clarify?

AC: In the new version of the manuscript it has been clarified the period (April 2019-september 2021). As suggested by the referee, the same QC is used here. To avoid confusion this paragraph has been rephrased as:

L504-505: *"This dataset has been obtained using ZSR_{ZEN} measurements which satisfy the filtering criteria determined in Section 3.2"*

RC: Line 526: Please include a comma after because.

AC: Done

RC: Line 532: VCT, VCC and VCF.

AC: Done

RC: Line 546: …a r2 of about …

AC: Done

RC: Lines 553-566: I understand that it can be challenging to leave unpublished results that may be considered scientifically interesting. However, it is important to assess whether doing so would come at the expense of reducing the comprehension of the text or making it less appealing to the reader.

AC: We acknowledge the comment, but we believe that including this paragraph provides relevant information on how to address the same problem we have faced using alternative strategies. Moreover, it briefly presents interesting results that, we consider, do not distract the readers from the main work.

RC: Line 584: A couple of tests?

AC: It has been changed by "Two different tests".

RC: Lines 615-616: It seems redundant with the information provided at the beginning of this paragraph.

AC: Removed

RC: Conclusions: I'm surprised it is not included in the conclusions the fact that this new strategy is not linked to the place of study as the former ZEN-LUT. It is actually one relevant improvement of the method…

AC: Referee is totally right. It is added in the conclusions:

L634-635: *"This methodology also represents a major advance over the former ZEN-LUT proposed by Almansa et al. (2020) for aerosol properties retrieval, since it is not linked to the place of study."*

RC: Do the authors have an estimation of the decaying period of the calibration proposed in this paper? Is it expected the instrument to be recalibrated against a Cimel instrument every a certain period of time?

AC: We have assumed that during the period of study the calibration has not decayed, since it is not a long dataset. However, a recalibration must be considered, especially if there is any maintenance or repair task.

It has been included in:
 L305-307: *"For this work, it has been assumed that during the period of study the calibration has not decayed, since it is not a long dataset. Nevertheless, a recalibration must be considered, especially if there is any maintenance or repair task."*

RC: Figure 4: The x-labels should be "ZSR_DSC_T"
AC: Done

RC: General things in the text: Please add a space before "nm" and correct the degree sign.
AC: Done