Response to Referee #2

We thank to Referee #2 for his/her positive review and helpful comments. Following, are the authors answer.

Specific questions and comments:

- In the abstract, a mention to the sensitivity analysis with an estimation of the inherent system uncertainty would be useful.

We have included the following sentence in the abstract: "The sensitivity study proved that the ZEN-LUT method is appropriate to infer AOD from ZSR measurements with an AOD standard uncertainty up to 0.06 for AOD_{500nm}≈0.5, and up to 0.15 for AOD_{500nm} ≈1.0, considering instrumental errors of 5%.".

- Page 5, line 4: how do you interpolate the radiance in the PPL for retrieving the ZSR? Do you use only two or more angles? Linear or non-linear approach?

The ZSR has been retrieved by linear interpolation between two adjacent points. A cubic spline interpolation has been also tested, obtaining very similar results.

- Page 5, line 12: please add some details about the cloud cover algorithm, if they are not included in the previous reference.

Since the cloud detection was performed visually we have rewritten the paragraph as follows: "Cloud cover detection was performed by visual inspection analyzing each individual hemispheric image…"

- Dusting of the sensor windows could be an error source, mainly when the window is horizontal and unprotected under strong dust episodes. How this issue has been addressed in the three sites?

In this study, only one ZEN-R41 prototype has been evaluated at Izaña station, where strict maintenance protocol is carried out by the observers, with frequent diurnal checks, so the cleanness of the window is assured. For those places with limited access, we propose an additional external blower to remove dust from the external window, as mentioned in page 5 line 27.

We have focused on the ZEN-R41 performance, ensuring a maximum cleaning, in order to assess the feasibility of the instrument and the methodology used. Operationally, it is true that it will be necessary to have the external blower and assess its effectiveness. This will be addressed in a future paper in which an assessment of the measurements obtained with a ZEN-R41 at Tamanrasset will be shown.

- Page 6, line 13: The calibration of the instrument, has been performed for only one radiance level?

Yes, the integrating sphere employed in this work is calibrated only for one radiance level so the radiometer cannot be calibrated for other radiance levels. However, the results of the radiometric comparison between CE318 and ZEN-R41 shown in section 3.1, indicate that both instruments perform quite similar ZSR measurements (within the uncertainty of the calibration technique) with a high coefficient of determination (R^2=0.99) and therefore a non-linearity problem of the ZEN-R41 detectors can be discarded. As a result we expect a very similar ZEN-R41 response if it was calibrated using a sphere calibrated at other radiance levels.

- Page 6, line 20: how the ZEN FOV has been taken into account when building up the LUT? This could be more important when the SZA is lower, as the variation of the radiation field within the instrument FOV is larger.

In order to simplify calculations, we have not taken the instrument FOV into account. Previous works, Shiobara et al., 1991 and B. Torres PhD theses, 2012, demonstrated that the consideration of a finite FOV (6^o or lower) in the radiance measurement is almost negligible for scattering angles larger than 15^o, being considerable for small scattering angles, as the referee already indicated. Shiobara et al. 1991, performed a test of the influence of different FOV values (from 0.25^o to 6^o) on the phase function. They found relative errors below 1% in the phase function for scattering angles larger than 10^o and a FOV of 6^o, while for scattering angles lower than 2^o and a 6^o FOV, the relative error are higher than -10%. A similar analysis can found in B. Torres 2012 PhD theses, where the influence of two finite FOV sizes, 1.2^o and 2.4^o, on the measured radiance at several spectral bands (centered at 440, 670, 870 and 1020 nm) were tested. This author found negligible influence for scattering angles larger than 15^o and a 2.4^o FOV size, while larger than 2% for scattering angles lower than 3^o. Considering these two previous works, we can say that the influence of the ZEN-R41 finite FOV (≈3^o) on the measured ZSR for SZA larger than 20^o, which is the range used in this work, is negligible.

- Page 11, line 6: in Tamanrasset site it is not possible to screen the clouds in the zenith because there is no sky camera available. Therefore, the authors apply the TT method to the AOD series. This is a valid solution. However, later it is said that the higher differences found in Tamanrasset could be due to the absence of a robust cloud screening method. Why not using the PPL information to improve the results for Tamanrasset data? I suggest using the information derived from the interpolation of radiance at the zenith (that's one more reason to use more than two points for the interpolation, as suggested before) as an auxiliary tool for rejecting ZSR data affected by clouds. Otherwise, could deposited dust be another reason for a higher deviation at this site?

The authors agree with the referee that the PPL information can be used to check cloud contaminated data. However, for the authors it is not evident using the interpolation to perform cloud screening. On the other hand, we propose to check the smoothness of the PPL curves to detect clouds as commented in Holben et al. (1998). To do this, we have checked for the second derivative of the PPL Radiances with respect to the scattering angle (we do not use all scattering angles available in the PPL scenario, just from 2^o to 90^o). For clear skies the second derivative of the PPL curve will be positive for the considered scattering angles, but when clouds are present this value might become negative for some scattering angles. Then, if negative values are found, at least for one scattering angle, the PPL curve is not used to obtain the ZSR. The threshold value for this smoothness criterion is not exactly 0 but -1E-7, as determined empirically for the 3 spectral bands.

In table 1, the statistics results for Tamanrasset station after applying the PPL smoothness and the Thompson Tau cloud screening methods, are shown. As it can be seen from the statistics, the PPL Smoothness criterion seems to be more restrictive than Thompson Tau method, since 321 and 385 data points are selected as cloud-free, respectively, and the comparisons with AERONET AOD data are improved, showing higher R^2 and lower RMSE. So, it can be concluded that the PPL smoothness criterion shows a better cloud contaminated data rejection. However, further independent evaluations are needed.

The authors concur with the referee that deposited dust on the CE318's lenses might be responsible of part of the AOD differences observed in the comparisons between the ZEN-LUT method and AERONET. To illustrate such statement, the AOD results (cloud screened) and the AOD differences between both methods for a period of time of 12 days in June (from 9th to 20th of June), when AOD absolute differences higher than 0.1 were found, are shown in figure 1. In this figure it can be seen a good agreement between both methodologies for the period between 9th and 12th of June, with low absolute AOD differences, but higher discrepancies after 13th of June, when an abrupt change can be observed. It can be also seen a diurnal cycle in AERONET AOD data for the period of time between 13th and 18th of June. The authors suspect that the observed concave shape of the diurnal AOD shown by AERONET in that period of time is fictitious and it is produced by dirt on the lenses. Dirty lenses produce a reduction on the measured direct sun light, leading to a magnification in the retrieved AOD which increases as the SZA decreases. On the other side, the dirtiness over lenses causes also a decrease of the measured sky radiance which results in a reduction of the retrieved AOD by ZEN-LUT method. Then, as the effect produced by dirty lenses on the retrieved AOD is opposite in both methods, the AOD differences are higher than they should be with clean lenses.

The cloud detection algorithm has been changed in the final version taking into account this comment. We have used the PPL Smoothness criterion to screen clouds in Tamanrasset.

Method	**Wavelength (nm)**	**R^2**	**RMSE**	**MB**	**N**
PPL Smoothness	870	0.98	0.030	-0.031	321
	675	0.98	0.030	-0.022	321
	440	0.97	0.032	-0.023	321
Thompson Tau	870	0.95	0.034	-0.023	385
	675	0.95	0.033	-0.012	385
	440	0.94	0.035	-0.009	385

Table 1. Statistic results for Tamanrasset using two different cloud screening methods: PPL smoothness and the modified Thompson Tau method.

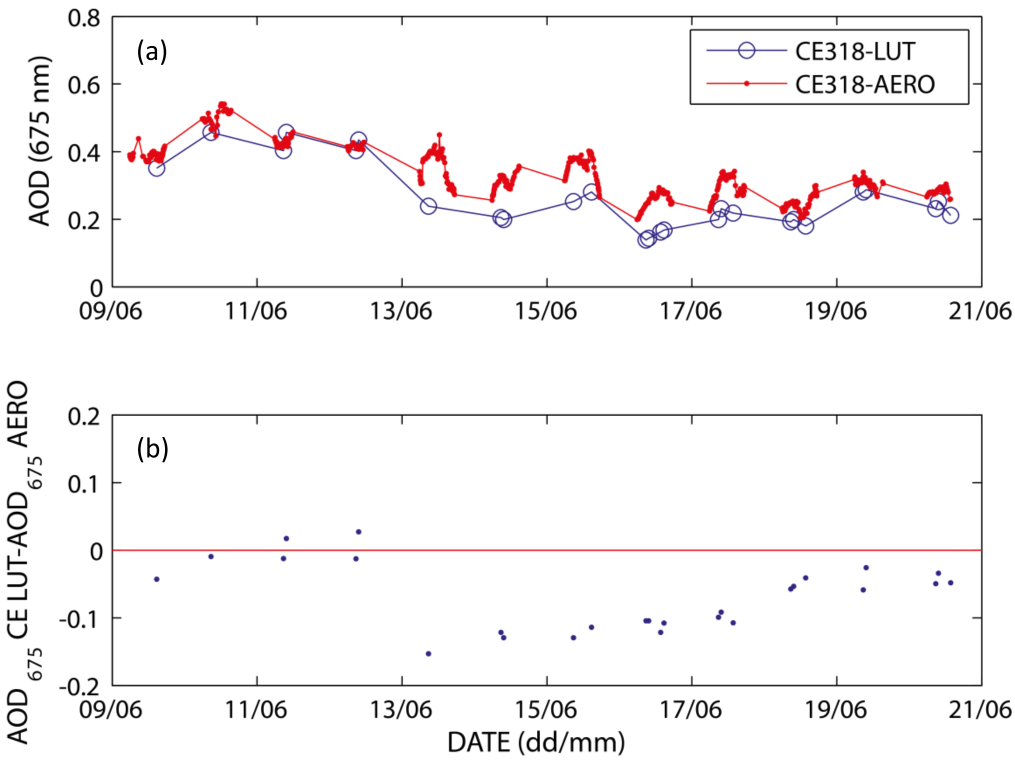

Figure 1. (a)Temporal evolution of the AOD at 675 nm for a period of time included between 2013/06/09 and 2013/06/21 (AERONET in red dots and ZEN-LUT in blue circles). (b) Temporal evolution of the AOD difference at 675 nm between AERONET and the ZEN-LUT technique for the same period of time.

Technical or minor comments:

- Page 2, lines 35: although the reviewer agrees that the tracking system from cimel increases the power consumption, solar panels are sufficient to feed the instrument, without a need to be connected to an electric grid.

The corresponding sentence has been removed since this is not an essential limitation.

- Page 3, lines 27-30. It looks like a very long sentence, consider to rewrite it in two different sentences.

We have rewritten the sentence as follows: "The Izaña… background conditions. It is a consequence of its location over a strong temperature inversion layer as a result of general subsidence processes and the presence of cool trade winds in lower levels."

- page 4, line 24: consider more recent references for the Dubovik code.

We have included the following references:

Dubovik, O., Holben, B., Lapyonok, T., Sinyuk, A., Mishchenko, M., Yang, P., and Slutsker, I.: Non-spherical aerosol retrieval method employing light scattering by spheroids, Geophysical Research Letter, 29, doi:{10.1029/2001GL014506}, 2002b.

Dubovik, O., Sinyuk, A., Lapyonok, T., Holben, B. N., Mishchenko, M., Yang, P., Eck, T., Volten, H., Munoz, O., Veihelmann, B., Van Der Zande, W. J., Leon, J., Sorokin, M., and Slutsker, I.: Application of spheroid models to account for aerosol particle nonsphericity in remote sensing of desert dust, Journal of Geophysical Research Atmospheres, 111, doi:{10.1029/2005JD006619}, 2006.

- page 4, line 29: to be accurate, the measurements are performed in the solar almucantar plane, where the almucantar zenith angle is equal to the solar zenith angle.

Same for PPL.

We consider this information is included in the text. In Page 4, line 30 we wrote: "In the ALM routine, the azimuth angle is varied while the zenith angle is kept constant (equals to the solar zenith angle)". Maybe we have not understood the question…

Same for PPL.

- Page 6, line 27: but still within the combined uncertainty from ZEN and Cimel

We have added this information.

- Page 10, line 11: this information could be shown in a Figure (as with the other cases)

We prefer to present the results for albedo effect in a table, considering the amount of figures included in this manuscript.

- Page 10, line 19: Figure 3 -> 4?

It was a typo. We are referring to Fig. 4.

- page 11, line 20: TamaNrasset

It is shown in figure 1. Corrected.

- Sometimes R2 is used in the text, R in the figures. Please use the same

We have replaced R by R2 in the figures 5, 6, 7 and 8.

REFERENCES

Holben, B. N., Eck, T. F., Slutsker, I., Tanré, D., Buis, J. P., Setzer, A., Vermote, E., Reagan, J. A., Kaufman, Y. J., Nakajima, T., Lavenu, F., Jankowiak, I. and Smirnov, A.: AERONET- A federated instrument network and data archive for aerosol characterization, Rem. Sens. Environ., 66, 1-16, 1998.

Shiobara, M., Tadahiro Hayasaka, T. Nakajima and M. Tanaka, 1991. Aerosol monitoring using a scanning spectral radiometer in Sendai, Japan. J. Meteorol. Soc. of Japan, 60: 57-70.

Torres, B.: Study on the influence of different error sources on sky radiance measurements and inversion-derived aerosol products in the frame of AERONET, Ph.D. thesis, Universidad de Valladolid, 2012.