Response to comments #2

We would like to thank the referee #2 for their constructive and useful comments. This document contains the authors' responses to comments from reviewer #2. Each comment is discussed separately with the following typesetting:

*Reviewer's comment

Author's response

Changes in the manuscript.

*General comments: This paper presents the comparative assessment of the GRASP (Generalized Retrieval of Atmosphere and Surface Properties) algorithm aerosol optical properties using combined sunphotometer and lidar measurements with other ground-based lidar products and airborne-based in-situ measurement during ChArMEx-ADRIMED 2013 campaign. The second section of the paper is the explanation of Granada site and instrumentation of ground-based remote sensing (sunphotometer and lidar) and airborne in-situ measurements during the campaign. The list of equipment, retrieved/measured optical properties with algorithm characteristics, and its uncertainties are presented with references. The third section is the explanation of GRASP and LIRIC inversion algorithms. Although both algorithms use the information of combined lidar and sun-sky photometer measurements, the detailed processes are different and described in this section. The main advantage of GRASP is the simultaneous inversion using 180◦ backscattering information of lidar and direct-sun and almucantar measurement of sky radiance by sun-sky radiometer. The fourth section contains the comparison results of GRASP and other measurements according to different optical properties: column-integrated properties such as size distribution, effective radii of course and fine modes, volume concentration, refractive indices, and single scattering albedo, and vertically-resolved properties such as volume concentration, extinction and backscatter coefficient profiles, single scattering albedo, and scattering Ångström Exponent. Most aerosol optical properties of GRASP show similar results with other measurements, but also provide different information such as coarse mode shift to higher radii compared to AERONET-only or more information such as profiles of SSA and scattering Ångström Exponent compared to LIRIC.

The paper presents an abundant comparison results of GRASP with other measurement during the campaign, and the results are clear. The scope is well-addressed also, thus I recommend it for publication after the responses for some points listed hereafter.

Specific comments/questions:

*In section 2.1, the distribution of observation sites or geological map could help to understand geographical conditions although the located information is described in manuscript because the authors explain apparent errors as the different location of measurement sites at some compared aerosol optical properties.

We agree with the referee and we have added a map illustrating the Granada and Cerro Poyos stations.

We add in the manuscript (section 2.1, page 3, line 21): Figure 1 shows a map illustrating the distance between Granada and Cerro Poyos stations.

We add in the manuscript (section 2.3, page 5, line 2): Figure 1 shows the spiral trajectory of F31 flight that is similar to that of F30, covering in both cases the same atmospheric column.

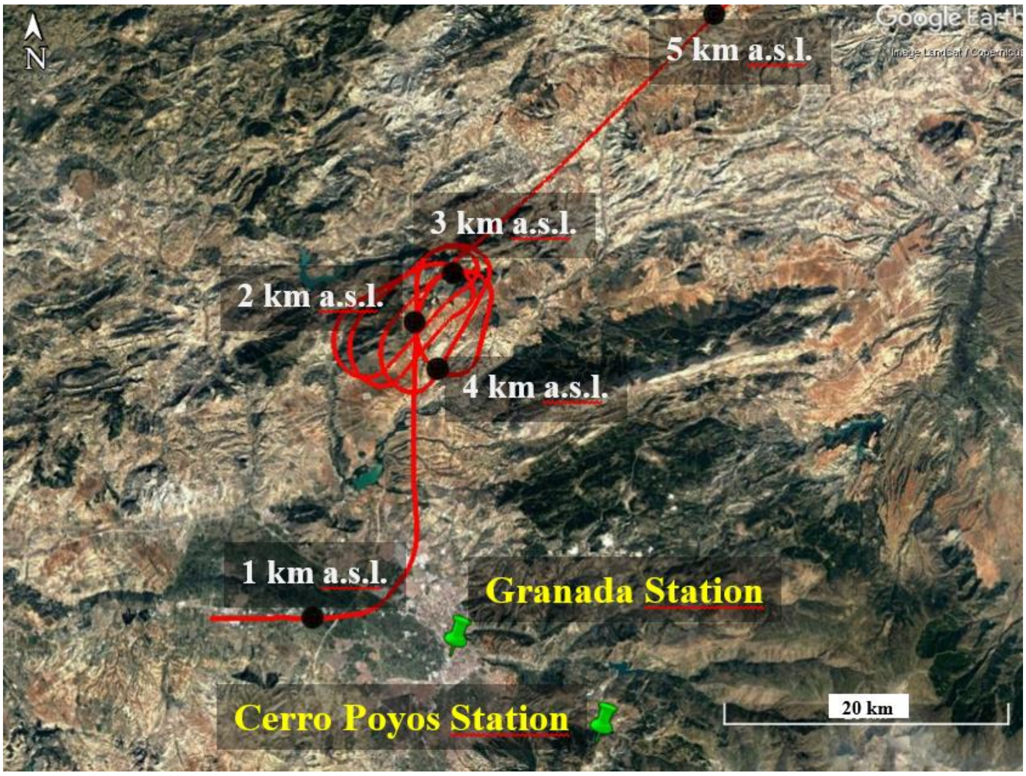

Figure 1. Map illustrating the Granada and Cerro Poyos stations. The red line indicates the trajectory and the black points the altitude of the aircraft on 17th June

*In section 2.2 (page 4 line 16), recent AERONET data version is changed from 2 to 3. Although the version of inversion data is still version 2, please notate the data version (i.e. version 2).

We added the AERONET data version used in this paper (version 2).

We changed (section 2.2, page 4, line 17): “In this work, the AERONET Version 2 Level 2.0 data obtained at Granada and Cerro Poyos during ChArMEx-ADRIMED 2013 are used.”

* In section 3, please describe the input and output information of lidar and sunphotometer for LIRIC and GRASP specifically (i.e. which wavelength of sky-radiance of sunphotometer, lidar measurement as input, and which column-integrated/vertical aerosol optical properties as output).

We add a new table with input/output information used/retrieved by GRASP and LIRIC.

We add the following sentence (section 3, page 5, line 21): “The input information needed by GRASP and LIRIC algorithms and the aerosol properties retrieved and used in this work are shown in Table 2”.

Table 2. Input and output information used for LIRIC and GRASP retrievals.

	LIRIC		GRASP	
INPUT	SUN-PHOTOMETER* • AOD • VC • RRI and IRI • % Sphericity	LIDAR Elastic backscattered signal: • 355, 532 and 1064 nm • 532-cross polarized signal	SUN-PHOTOMETER • AOT or AOD • Total scattered radiances At 440, 670, 870 and 1020 nm	LIDAR Elastic backscattered signal: • 355, 532 and 1064 nm
OUTPUT	• VC profile for fine and coarse mode		Columnar (fine and coarse) • SD • RRI and IRI • VC • r_{eff} • SSA • LR • % Sphericity (total)	Vertical (fine and coarse) • VC • α and β • SSA

*AERONET product

*In section 3 (page 5 line 31), Which information of the photometer is provided for lidar retrievals? Please describe “otherwise” (the assumption in lidar measurements) more specifically.

The sun-photometer provides the aerosol optical depth and the combination of direct sun and sky radiances provides column-integrated aerosol microphysical properties. Sun-photometer measurements, collocated with backscatter lidar, are used to estimate extinction-to-backscatter ratio, typically known as lidar ratio (LR). If there are no collocated sun photometer, the LR assumption are based on climatological values.

We changed (section 3, page 5, line 35): “… and the photometer data provides the information (e.g. amount and type) required for lidar retrievals that otherwise would be assumed from climatological data (Bovchaliuk et al., 2016)”

*In section 4 (figure 1), what is the definition of the lidar range corrected signal? Is it calculated as P*r2, where P is the lidar data (received power) and r is the range?

Yes, the referee is right.

We add the following sentence (section 4, page 6, line 9): The RCS is calculated as P*r2, where P is the lidar signal (corrected from background and dark current) and r is the altitude.

*In section 4.1 (page 7 line 11 and 27): the authors mentioned that the wavelength of RRI and IRI from airborne measurement is 500 nm. However, it is not on the 500 nm in the Figure 3. Please clarify it.

We made a mistake in the text but not in figure 3. The wavelength of RRI and IRI from airborne measurements is 530 nm and not 500 nm. We have changed it in section 4.1.

*In section 4.1, which height is represented from the airborne measurement? Would it be possible reason of difference because lidar profile shows different concentration in 17 June?

We think that the referee refers to section 4.2 indeed, where we use airborne data. Height is above sea level (a.s.l.) which is the same than for lidar data.

We believe that the differences in particle volume concentrations between GRASP and airborne data below 2km a.s.l on 17th June are explained because the flight was not exactly over Granada city as shown in Fig. 1 and in the firsts kilometers of the atmosphere could be more differences in the horizontal.

We add (section 4.2, page 9, line 4): On 17th June for Granada retrieval, the differences between both algorithms and airborne data below 2 km a.s.l. could be explained because the flight was not exactly over Granada city as shown in Fig. 1 and in the first two kilometers of the atmosphere differences are expected because of the influence of the city.

*In section 4.1 (page 7 line 32) which wavelength for SSA of “0.80-0.90”?

Thanks to the referee comments we notice that there was a misspelling in the current version of the manuscript.

We changed this sentence in the text (section 4.1, page 8, line 14): “The retrieved SSA values are in the range between 0.85-0.98 (355-1064 nm wavelength range) and are in the ranges…”

*In section 4.2 (page 8 line 30), please briefly describe difference in the method of “Klett” and “GRASP” in terms of lidar ratio (LR).

The Klett uses the assumption of constant LR for the entire column. LR ratio were computed fitting the integral of the extinction to the measured aerosol optical depth. However, GRASP retrieves the LR (fine and coarse) directly from the sun-photometer and lidar measurements. The text has been modified in the methodology section to clarify these points.

We add (section 4.2, page 9, line 12): The LR used in Klett method is assumed constant for the entire profile and was computed by fitting the integral of the different extinction profiles to the measured aerosol optical depth. However, GRASP uses both sun/sky radiances and the backscatter lidar data to provide LR values, both in column-integrated and vertical profiles.

*In section 4.2, (page 8 line 39), could you explain why the discrepancies b/w two B-coeffi products are getting larger in longer wavelength although the error range of GRASP B-coeffi profile is smaller in longer wavelength in Granada on 16th June and Cerro Poyos on 17th June?

Only two study cases are presented here, so we cannot assume that discrepancies are larger for longer wavelengths or that the error range is smaller for a certain wavelength. An additional study, with a synthetic database provided by global models and an analysis with more cases, would be needed to get to significant conclusions in this respect. In the cases presented here, the discrepancies between the backscatter coefficient retrieved by Klett and GRASP were within the uncertainties for our system (~30%).

*In section 4.3 (page 9 line 12), could you show the error range of SSA profiles from GRASP? It could be useful information to understand this SSA profiles because the AODs of all cases are less than 0.3 and SSA error could be large.

GRASP developers are currently doing in depth studies of errors in SSA, and therefore, we are not able to provide them. That was commented in section 3.

*In section 5 (page 10 line 20), I agree for the combination of lidar and sun-photometer data in GRASP algorithm can provide improved and more complete data compared to AERONET retrieval. The refractive indices of GRASP show better agreement with in-situ measurement compared to those of AERONET. However, the column integrated size distribution and SSA doesn’t show any in-situ measurement results together. Could you quantify the improvement in GRASP compared to AERONET measurement?

We cannot compare the column-integrated size distribution between GRASP, AERONET and in-situ measurements because the latter are not available. For to quantify the improvement of GRASP compared to AERONET would be

necessary study more cases with more in-situ measurements at different wavelengths. However, we add the column-integrated SSA value measured in-situ in Figure 5.

We modified the text (section 4.1, page 8, line 8): Moreover, the SSA value at 530 nm calculated by Denjean et al. (2016) for dust layer using airborne measurements during the campaign was 0.95 ±0.04. SSA retrieved by GRASP at 532 nm are close to the airborne value. Better agreement with this value is found for the retrievals from Granada on 16th June and at Cerro Poyos on 17th June. The differences from Granada on 17th June could be due the in-situ value was calculated for the dust layer whereas that GRASP and AERONET use sun-photometer data, which measures the total atmospheric column. Furthermore, in the case of Granada station, these measures could be influenced by injections of local pollution.

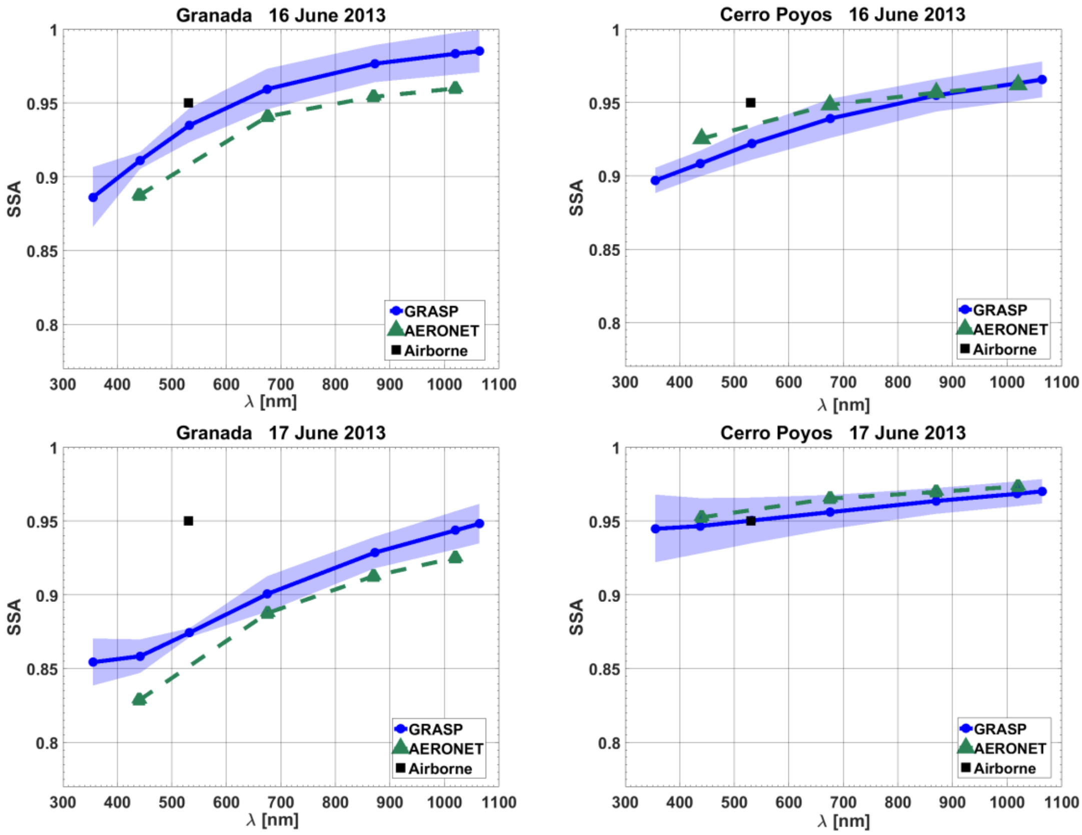

Figure 5. Single-scattering albedo retrieved by GRASP (blue) with its uncertainty (shaded area), AERONET (green) and airborne measurement for dust layer (black) on 16th (top) and 17th (bottom) June 2013 at Granada (left) and Cerro Poyos (right).

* In Section 5 (page 10 line 29-30), please explain which the improvements of GRASP are new and the method of a second sun-sky photometer in your plan. Is the three instruments combination as one lidar and two sun-photometers in GRASP?

GRASP exploits the synergy among lidar and sun-photometer data just providing enhanced column integrated retrievals over the standard AERONET approach and at the same time allows a profiling of some aerosol microphysical

properties. The use of a second sun-photometer located over the local atmospheric boundary layer can be very relevant for the study of the properties of aerosol layers with features really different than the atmospheric boundary layer aerosol. Thus, the use of the second photometer can be crucial for monitoring microphysics of long range transported particles in the free troposphere. In response to referee question: Yes, in the future, we could try to use of the combination of one lidar with two sun-sky photometers at different height.

We decided delete this sentence and we add the following conclusion:

We add (section 5, page 11, line 19): The analysis presented here is useful as a primary evaluation of the GRASP algorithm using sun-photometer and lidar signal to retrieve aerosol microphysical properties, both integrated along the vertical column and as vertical profiles. The use of a second sun-photometer located over the local atmospheric boundary layer can be very relevant for the study of the properties of aerosol layers with features really different than the atmospheric boundary layer aerosol. However, the presented analysis is representative of Saharan dust transport to south Europe and still it is necessary to use a more complete dataset that includes different aerosol loads and types. In future studies, we could try to use of the combination of one lidar with two sun-sky photometers at different height to try improve the retrievals in the cases with different aerosol layers. In addition, in order to validate the presented GRASP scheme, in the future it is planned to use global aerosol models (e.g. GEOS-5) following an approach similar to Whiteman et al., (2017).

Technical correction:

Please check whether the typos I found are correct.

*In section 2.1 (page 3 line 31) it local sources → its local sources

We have changed “it local sources” by “its local sources” as suggested.

*In section 2.2 (page 4 line 20), removing “)”.

We have removed “)” as suggested.

*In section 3 (page 5 line 29): lidar “an” sun-sky photometer measurements → lidar “and” sun-sky.

We have changed “lidar ‘an’ sun-sky photometer measurements” by “lidar ‘and’ sun-sky” as suggested.

*In section 3 (page 5 line 35), please write full name of “CRI” (is it “components of refractive indices”?)

CRI is Complex Refractive Indices. Due to that CRI is used only one time in the paper we decided changed it by “RRI, IRI” (real and imaginary refractive indices).

*In section 5 (page 10 line 29), vaity → variety

This word does not appear now.