Reply to reviewer 2 (Feng Xu).

Authors are grateful for the valuable comments that help to improve the paper. In the revised version of manuscript, we tried to address all the questions raised. The detailed responses and clarifications are given below.

Overall comments: The paper by Lopatin et al. employed the GRASP algorithm to investigate the benefits of combining multiple ground-based observations (namely sun-photometric, lidar and radiosonde observations) to constrain aerosol retrievals in terms of their vertical concentration distribution, refractive index, size distribution and spherical particle fraction. With the assumption of temporal continuity of aerosol properties, the synergetic retrieval mitigates the insufficient information content in lidar only night-time retrieval and brings up the retrieval accuracy. The full-length paper covers a large amount of valuable work on algorithm development, test and validation

Reply: We are thankful for overall positive evaluation of our paper.

The point-by-point responses:

Comment 1. Section 3.1.1 discusses the multi-temporal retrieval of combined COBALD, AERONET and MPL observations. Regarding the balloon-borne COBALD data, does the retrieval underlying Figs.1-3 use a series of COBALD temporal measurement during the night of Aug 05, 2015 ? If multiple COBALD measurements are inverted, then it will be helpful to add a time series plot showing the temporal evolution of certain retrieval aerosol quantity (e.g. fine aerosol concentration or other properties). Following the use of multiple COBALD measurement (if this is true), does the “Fine night” and “Coarse night" in Figs. 1-3 averages the retrievals of night measurements from 13:21UTC to 05:16UTC of next day ?

Reply: Only one COBALD profile per night (containing two simultaneous measurements at 455 and 940 nm) was used in the retrievals. The lidar profiles were averaged within ~30 min – the time that is needed for the balloon to reach the top of the profile (~8km). The following clarifications were put to the text:

- lines 610–614: “Thus, an observation set used in multi-temporal AERONET/COBALD/MPL retrievals consists of three diurnal sets including two (evening and morning) co-located observations of AERONET and MPL (see Table 2) and backscatter profiles provided by a single COBALD flight at night. All observations are considered to be instant and observing the aerosol properties averaged within a timeframe not exceeding 30 minutes.”

Comment 2. In some figures (e.g. Figs. 25-31), I saw terms “multi-pixel” in legend, but "multi- temporal” in figure caption. To clarify, did the balloon-borne COBALD measurement resolve both multiple pixel and multiple-temporal measurements so that smoothness constraints were imposed in both dimensions ?

Reply: The constraints were applied only on temporal dimension. Term multi-pixel representing both time and spatial measurement discretization, was replaced in the text to avoid the confusion. The following clarifications were added:

- lines 133-143: “This approach uses a priori knowledge of limited time or spatial variability of the parameters retrieved from coordinated but not fully co-incident and/or simultaneous observations. For example, it is used in processing of satellite observations where observations for a large group of different satellite pixels are inverted simultaneously. In this study, it is demonstrated below that this principle can be rather efficient for combining non-coincident but close in time observations, e.g. day- and night- ground-based measurements”.

- lines 564–567: “Therefore, a generalized multi-pixel approach realized in GRASP (Dubovik et al., 2011) that allows for applying constraints on variability of aerosol and surface parameters in three dimensions (latitude, longitude and time) is reduced to an application of only multi-temporal constraints in this study, as all provided observations are considered to be spatially co-located, and no spatial variability constraints were used in the retrievals.”
- lines 1003–1006: “It was shown that the multi-pixel approach developed within GRASP concept could be efficiently used for combining not fully co-incident but co-located and close in time observations of various origins, for e.g. day- and night measurements, by providing sufficient constraints on aerosol columnar properties

variability to provide additional benefits to the retrievals of the night-time observations that are usually lacking sensitivity to qualitatively retrieve these parameters."

Additionally, descriptions of the constrains applied to aerosol properties during the retrieval were put in Tables 1 and 7.

Comment 3. Table 2: it might be helpful to add another column providing the measurement uncertainties for MPL, COBALD and sun-photometer which are used in retrieval.

Reply: Measurement uncertainties were added into table 2.

Comment 4. In Section 3.1.1, demonstration of retrieval results were provided for refractive index, size distribution and vertical profiles of aerosol concentration. How about the spherical aerosol fraction ? Is it also retrieved retrieved and worthwhile to demonstrate ?

Reply: Spherical fraction is retrieved. However, the studied cases are dominated by desert dust, and do not demonstrate any significant change of this parameter overnight. The changes are below one percent. This is why the retrieved values of sphericity fraction were not illustrated in the figures. Instead, the retrieval results of sphericity fraction were additionally discussed in the text. For better consistency of presentation, the discussions of sphericity fraction retrieval were placed after a size distribution description for each retrieval date both in sections 3.1 and 3.2.

Comment 5. Section 3.2.1 and Section 3.2.2, do the stand-alone COBALD and LILAS retrieval involve the use of any multi-temporal/mullti-pixel constraints ? Please clarify.

Reply: None multi-temporal or multi-pixel constraints were used in stand-alone retrieval. Clarifications were added in the text:

- lines 1014–1017: "Here, unlike a multi-temporal approach described in Section 3.1, only single sets of measurements were inverted. In with these regards the retrieval; could be considered as single pixel, following the terminology used by Dubovik et al. (2011) and above in in Section 3.1"

Additionally, the description of all the constraints applied to retrieved properties were added to Table 1 and 7.

Comment 6. Figs. 25, 26, 27, 29, 30 and 31, it took me a while to confirm the meaning of "components" in the figure legends. For clarify, authors might mention it again in Fig. 25 caption that "components retrieval" here mean "stand-alone COBALD" (or "stand-alone COBALD" retrieval) with a) turning off temporal constraint and b) using pre-determined size distribution for all aerosol types (Table 5), while "multi-pixel retrieval" means a) using all types of instrumental data and b) imposing temporal constraint in retrieval.

Reply: Figure captions and legends were corrected to correspond with the terminology used in the article and to avoid the term "components".

Comment 7. As the authors pointed out, Fig. 29 indicates "some significant differences ... in the lower part of the extinction profiles at 455 nm below 500 m." Could this be due to the impact of measurement uncertainties, or neglecting the multiple scattering in the model, or others ? Is there any constraints imposed on the vertical variations of aerosol concentration or properties ? If so, maybe it's worthwhile to try relaxing the constraint and see if one can observe more consistency in the two types of retrievals.

Reply: The differences observed are coming from different vertical profile cropping, since multi-temporal retrieval requires all three evening/night/morning profiles to be cropped within same altitude range, COBALD data was cropped higher to correspond to MPL profiles provided in the evening and morning, in a stand-alone retrieval a much lower cropping could be applied. The following clarifications were put to the text:
- lines 1199–1200: "coming from a different altitude range of profiles used in both retrievals.".