Response to Referee 1

We would like to thank the referee for her/his helpful comments and remarks. We expect that the revised version will address all comments.

Motivated by the comment number 7 by referee 2, in this revised version we have revisited our post-processing algorithm of the MISR level 2 data. We no longer assume that the extinction efficiency is independent from the size of the aerosol and instead we compute the extinction efficiencies using the refractive index reported in the MISR products and a well-established Mie code. This improves the quality of the fine mode AOD derived from the MISR observations, but it decreases the fine mode AOD by approximately 15 %. The total AOD remains unchanged. We have recomputed the MISR analysis with this new dataset and we have included these new estimates in the revised version of the manuscript. The results for the MISR analysis only change marginally and the conclusions of the study remain the same.

We reproduce comments from the referee in "script" font followed by our answer. A document listing the revisions to the manuscript is also provided.

`GENERAL COMMENTS:`

`This paper uses a state-of-the-art data assimilation system to investigate the influence of used satellite input into a dust emission inversion scheme. Inversion is still a relatively young field and it is therefore important to further develop existing systems and to test sensitivities. I therefore welcome this contribution to ACP. Overall the work is of high scientific quality and I have no issues with the content. However, to make this work more accessible for readers interested in dust emission, but not expert in inversion techniques, the authors should make more effort to improve the presentation, particularly the explanation of the methods. Moreover, the English is not always of highest standards; particularly the number of grammar errors (e.g. simple subject-verb disagreements) and punctuation errors is annoyingly large.`

We thank the referee for all his/her comments and for the English corrections. We have included, at the beginning of Section 2, an overview of the data assimilation system.

`MAJOR COMMENTS: 1) Introduction: To my taste it contains too much technical detail. Some of this could be moved to Section 2.`

We appreciate the referee's comment, however we argue that the introduction does not contain too many technical details. The technical appearance is due to the relatively long list of satellites and instruments (and their acronyms) used to estimate AOD. Also according to the referee, Section 2 is already quite long.

`2) Section 2: With 4.5 pages, this is quite long for a Methods section of a relatively short paper. It is quite technical and a little hard to read. It would be good if the authors could spend a little more time trying to streamline this section and make it as didactic as possible, in order to make it more accessible for readers not so familiar with inversion techniques. I would start out with something like a road map, such that the reader knows what to expect. Then I would describe the model, then the obs, then the observation operator and finally the actual data assimilation. The way it is now is not logical in my eyes. Many readers will not know what the "control vector" is and` introducing so early is a little hard to digest. Also the beginning of section 2.4 is hard to understand and the numbers given there all seem a little arbitrary.

We have included a new paragraph at the beginning of Section 2, which provides a roadmap to the four subsections of Section 2. The paragraph reads:

"Mineral dust emissions are estimated using the source inversion system described in this Section. Formally, the combination of the a priori information, the AOD observations and the modelling system is done through the minimization of the following cost function:

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}^b)^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^b) + \frac{1}{2}(\mathbf{y}-H(\mathbf{x}))^T\mathbf{R}^{-1}(\mathbf{y}-H(\mathbf{x})) \quad , \tag{1}$$

where the variable $\mathbf{x}$ is called the control vector and is related to the aerosol emissions (Sect. 2.2); $\mathbf{x}^b$ is the prior control vector, $\mathbf{y}$ are the assimilated observations (Sect. 2.3); H is the observation operator (Sect. 2.1); $\mathbf{B}$ is the covariance matrix of the background errors (Sect. 2.4); and $\mathbf{R}$ is the covariance matrix of the observation errors (Sect. 2.4).

The solution of the minimization problem is called the analysis (denoted by $\mathbf{x}^a$). In this work the *analysis AOD* is the observation operator evaluated for the analysis, that is, $H(\mathbf{x}^a)$. The components of the inversion system (the elements of Eq. (1)) and the configuration of the data assimilation system are now described."

Regarding the numbers given at the beginning of Sect. 2.4, we have included the following:

"The covariance matrix of the background errors ($\mathbf{B}$) and the covariance matrix of the observational errors ($\mathbf{R}$) have to be prescribed in the data assimilation system. The $\mathbf{B}$ matrix is defined similarly to EBCH16; the diagonal terms of the $\mathbf{B}$ matrix are defined using the error estimates presented in the work of Huneeus et al. (2013). These are mostly based on the range of emissions found in the literature, except for anthropogenic and fossil fuel emissions, which are based on the estimates of uncertainties found in the literature. The standard deviation of the control vector errors (i.e., the square root of the diagonal terms of $\mathbf{B}$) is 1.3 for biomass ..."

MINOR COMMENTS: 1) Title: I would avoid an abbreviation in the title.

Done.

2) P1, L5: better have?

Done.

3) P1, L17-18: ... combine model and observational information in the best possible way. Their application ... .

Done.

4) P1, L18-19: In recent years, ... AOD has also been ...

Done.

5) P2, top: Add reference for Fe and P fertilisation!

Done.

6) P2, L5: Deposition into the ocean ...

Done.

7) P2, L7: new paragraph after "quality." Then "Among other uncertainties ..."

Done

8) P2, L14: emission uncertainties

Done.

9) P2, L23: comma before respectively

Done.

10) P2, L24: However, MODIS products are not free of problems ...

Done.

11) P2, L25: the MODIS aerosol product

We have changed the phrase to: "... the MODIS-DB aerosol product ... ".

12) P3, L24: referred to as SPLA

Done.

13) P3, L29: aerosol is

Done.

14) P3, L29: diameters less than ... has diameters

Done.

15) P3, L31: aerosol tracer

Done.

16) P4, L4: were performed ... ERA-Interim ... as explained

Done.

17) P4, L12: tests ... analysis to the grouping ...

Done.

18) P4, L16: The same sub-regions as in EBCH16, defined depending on the emission category, are used.

Done.

19) P4, L18: map

Done.

20) P4, L19: have been defined: 15 over northern Africa, 3 over ... the Middle East

Done.

21) P4, L26-29: Long and complicated sentence. Reword!

We have reformulated the sentence as follows:

“This results in a control vector of 4674 components (that is about 10 times larger than in EBCH16), with a **B** matrix of 4674 by 4674 elements (see Sect. 2.4). We have improved the data assimilation system presented in EBCH16 in order to deal with the larger control vector. To this effect we have carefully recoded some matrix multiplication and inversion routines, paying special attention to the computational memory management and minimizing numerical errors as much as possible. We have also applied the algorithm of Qi and Sun (2006) to ensure the semi-positiveness of some of the matrices involved in the inversion.”

`22) P4, L32: over the ocean`

Done.

`23) P5, L1: ... instrument, as they ...`

Done.

`24) P5, L15: ... coverage, although ... hence in the ...`

Done.

`25) P5, L29: of the MISR algorithm`

Done.

`26) P6, L10: onto the model grid`

Done.

`27) P6, L18: ... sample our region of interest only once per day.`

Done.

`28) P6, L19: ... PARASOL), and so its ...`

Done.

`29) P6, L23: standard deviation ... is ...`

Done.

`30) P6, L27: timescale gives`

Done.

`31) P6, L27: avoid repitition of words`

We have replaced the sentence by:

“In comparison with EBCH16, this shortened timescale gives more freedom to the inversion system. Along with the three day sub-periods, this timescale allows the system to have more control over the emissions, with the aim of improving the representation of individual dust events in the analysis.”

`32) P6, L33: was`

Done.

`33) Caption of F1: shown in the left column ... in the right column. Please note the ...`

Done.

34) P7, L4: (EE), which

Done.

35) Table 1: What is Ck?

C_k is the error reported in the AERUS-GEO product. It is computed in the AERUS-GEO retrieval algorithm. We have added the following to the Table caption:

"Errors for the SEVIRI dataset (C_k) are reported along with the AERUS-GEO AOD product and they are described in Carrer et al. ..."

36) P8, L8: errors, which

Done.

37) P8, L11: error, assuming

Done.

38) P8, L15: These help to detect ...

Done.

39) P8, L16: They assume that ...

Done.

40) P8, L18: is better to draw ...

We have replaced this sentence with the following:

"Additionally, a common configuration for all the inversions ensures a consistent methodological approach to compare the five data assimilation experiments."

41) P9, L2: more or less?? Reword!

We have deleted "more or less".

42) P9, L3: retrieval dataset

Done.

43) P9, L5: where available, that is: ...

Done.

44) P9, L14: refer back to methods section

Done.

45) P9, L16: super-coarse

Done.

46) Section 3.1: odd title

We have changed the title.

47) P9, L23: in the southern Red Sea

Done.

48) P9, L24: downwind of the ... are hardly evident ...

Done.

49) P9, L25: Atlantic is more extended than in the rest

Done.

50) P9, L26: Atlantic Ocean are found close to the ...

Done.

51) P9, L26: yearly means for fine ....

Done.

52) P9, L27-28: remove brackets around lat-lon

Done.

53) P9, L31: To be able to roughly discriminate between the ...

Done.

54) P9, L33: in Fig. 2. In this figure ...

Done.

55) Fig. 2: caption too short, explain individual panels, ideally label them

We have expanded the caption in concordance with the caption of Fig. 1.

56) P10, L6: relatively

Done.

57) P10, L7-8: in the south). However, total ... Aqua in Fig. 2 is ... counterpart in ...

Done.

58) P11, L1: still hold

Done.

59) P11, L13: or in other words that the model ...

Done.

60) P11, L16: counterparts

Done.

61) P11, L19: AODs (explained above) we think that ... ; what makes you think so??

We have expanded our explanation as follows:

"We recall that the prior simulation is the same for all panels, and the difference in prior lies in the local time and gridboxes for which the model values are sampled. We have shown in Sect. 3.1 that, even for colocated retrievals, the geographical distribution of the AOD varies between the satellite products. We think that these differences contribute more to the differences between the histograms of Fig. 3 than the sampling differences. For example, the MODIS/Terra AOD of Fig. 1 is qualitatively similar to the MODIS/Terra AOD of Fig. 2, where only a subset of observations (which are coincident with MISR retrievals) is taken into account. On the contrary, it is easier to qualitatively observe the differences between the MISR and the MODIS/Terra panels of Fig. 2 (where both panels have the sample sampling)."

`62) P11, L21: have total AOD available over land is PARASOL.`

Done.

`63) P11, L24: eastern Atlantic`

Done.

`64) P11, L29-30: plural of analysis is analyses! This part does not read very well.`

We have corrected the paragraph accordingly.

`65) Fig. 4: better "analysed AOD"? In the latter, we included the ...`

We have rewritten the sentence:

"Simulated AOD at 550 nm for the prior and for the five analyses ..."

`66) P13: I'm not sure I understand why it results in LARGE AOD values over land?!?`

We have expanded the paragraph by the following:

"The SEVIRI analysis shows a larger transatlantic dust plume in MAM and JJA along with larger values of AOD over land. Observational uncertainties for SEVIRI are generally larger over land than over ocean. This allows the assimilation system to favour a better fit of the AOD over the ocean than over land. Over the transatlantic dust plume, the assimilated AOD is larger than the prior AOD. The analysis decreases this AOD difference by increasing the dust emissions in West Africa, and therefore the SEVIRI analysis shows larger AOD values over land."

`67) P14, L3: even though`

Done.

`68) P14, L 12 peaks in September`

Done.

`69) P14, L13: better "rule out" than "discard"`

Done.

`70) Fig. 5: Note that the three plots ...`

Done.

`71) P15, L2: can be inferred to some extent from ...`

Done.

72) P15, L4: of the overall analysed

Done.

73) P16, L15: move "well" to end of sentence

Done.

74) P16, L17: capability to report

Done.

75) P16, L19: (Appendix A); the MISR ...

Done.

76) P17, L4: some key model parameters ...; which ones do you have in mind??

We have realised that the model parameter optimization could be hard to accomplish, mostly because of the difficulties in defining the **B** matrix properly. Instead, we have opened a different perspective that now reads:

"... Another approach which we leave for future work would be to estimate the net aerosol fluxes, that is, including variables related to the aerosol removal processes in the control vector. It would be interesting to explore this approach, since bias in the aerosol removal processes could introduce bias in the emissions if only the emissions are optimised; but the implementation of this data assimilation could be be difficult to accomplish, due to the increase in the degrees of freedom in an ill-posed data assimilation problem."

References

Huneeus, N., Boucher, O., and Chevallier, F. (2013). Atmospheric inversion of SO_2 and primary aerosol emissions for the year 2010. *Atmospheric Chemistry and Physics*, 13(13):6555–6573.

Qi, H. and Sun, D. (2006). A quadratically convergent newton method for computing the nearest correlation matrix. *SIAM Journal on Matrix Analysis and Applications*, 28(2):360–385.