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Interactive comment on "Harmattan, Saharan heat low and West African Monsoon circulation: Modulations on the Saharan dust outflow towards the north Atlantic" *by* Kerstin Schepanski et al.

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The authors would like to thank the reviewer for the time spend on the manuscript, and for providing helpful and constructive comments and suggestions. We have considered carefully all comments made; please find our detailed reply (italic) below.

Anonymous Referee 1

This study aims at assessing the influence of the main components of the West African Monsoon on the Saharan dust outflow towards the north Atlantic. After a careful reading, I am afraid to request major revisions before to accept this study.

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Discussion paper

Therefore, despite some interesting results to study the mechanism associated with dust outburst, the second part (from section 6) of the study is not clear: the objectives are not well identified, the methodology is not well adapted and some conclusions are too speculative. For these reasons, I would recommend to deeply modify the second part that includes a clarification of the objectives to the improvement of the methods. The major and detailed comments are provided below.

Major comments

Why the climatology is restrained as the period 2006-2009?

The DSAF for June, July 2013, during which the SALTRACE field campaign took place, are compared to June, July 2006-2009 (4 years) as the DSAF analysis is available for just these years, and cannot be easily expanded. Nevertheless, while a certain year-to-year variability is evident in the DSAF analysis the individual years agree clearly in the locations of major dust source areas as well as dependence of the dust events on meteorological features, such that we find the use of a climatology from 4 years as a baseline to be acceptable for the purpose of this publication.

The figures 1 and 2 are done using June-July then in the second part JJAS is considered. This creates some confusions.

The satellite-based DSAF are shown for June, July only as the SALTRACE field campaign took place during these months. Based on the DSAF analysis, the model-based approach was developed. In order to draw a conclusion, which is representative for the entire season, the considered period was expanded to include June, July, and August (JJA). We did not consider September at all in the context of this study.

Once the dust outbursts for the year 2013 are analyzed, the second part (from section 6) is not clear to me. What is the objective? As I understand, the impacts of the seasonal cycle of the main components of the West African Monsoon are studied. But in West Africa, all these components are governed by a strong and similar (or at

least very close) seasonal cycle. For example, the NAFTI index is clearly related to the onset, established and retreat monsoon phases.

The focus of the present manuscript is on the variability of the atmospheric circulation over North Africa governed by the different circulation elements and their impact on North African dust export towards the tropical north Atlantic. These circulation elements or features are: (1) the Harmattan fow, (2) the Saharan heat low, and (3) the West African Monsoon. As stated in the introduction, the aim of this study is twofold. "First, it discusses the spatio-temporal distribution of active dust sources over North Africa regarding implicit information on the meteorological elements driving dust emission and their predominance during a typical summer season. To achieve this, the study makes use of satellite observations for identification of active dust source regions. Second, the study elaborates the atmospheric circulation with regard to its relevance for dust source activation and dust transport towards the tropical North Atlantic. For this, simulations from the dust-atmosphere model system COSMO-MUSCAT are analysed."

We think the review too much stresses the role of the West African Monsoon. However, as also shown by the outcomes from this study, the West African Mosnoon system is more complex. The strength of the Harmattan flow, the nature of the Saharan heat low, and the propagation of the Monsoon front are linked and in concert determine the atmospheric circulation over North Africa. The North African Dipole Intensity (NAFDI), which simply is a measure for the pressure gradient across North Africa, reflects the strength of the Harmattan flow and the westward displacement of dust-laden air within the Saharan Air Layer. Therefore, the NAFDI is used as an easy-to-understand proxy index for the Saharan dust export towards the North Atlantic Ocean.

In contrast, the monsoon onset (retreat) is a less appropriate indicator for describing the modulations on the Saharan dust export due to the lack of a concise definition. See Fitzgerald et al. (J.Clim., 2015): "The concept of West African monsoon onset is not a straightforward issue. While the monsoon system is clearly defined, picking a singular point at which onset occurs is reliant on understanding what onset means to

the end users."

Why only the NAFTI and the SHL are specifically analyses? The monsoon flow is mentioned (Fig. 10) but why there is no analyse of its impact as done for the others components?
The focus of this manuscript is on the atmospheric circulation modulating the North African dust export towards the tropical North Atlantic. The Harmattan circulation and the SHL are, due to their geographical position, prominent features of the atmospheric circulation stimulating or even determining North African dust emission and consequent dust transport. The direct impact of the strength of the monsoon circulation on the dust export towards the north Atlantic appears to be minor compared to the impact of the Harmattan flow. Nevertheless, the SHL as an element stimulated by both the Harmattan flow and the Monsoon flux, indirectly reflects the impact of the Monsoon circulation on the atmospheric circulation over North Africa ultimately modulating the dust export towards the north Atlantic.

The SHL is defined following a method proposed by Lavaysse et al. (2009), where the SHL moves depending the LLAT intensities. The intensity of the SHL is thus one part of its characteristics, and the location of the SHL may have strong impacts depending where it is located. What happen if the longitude or the latitude is chosen? To avoid the problem related to the transitions phases of the SHL in June and September, the mean LLAT over the Sahara could be used.
The role of the longitude on the position of the SHL identified via LLAT is presented in Fig. 8. The spatio-temporal evolution of the SHL was plotted in various ways including Hovemöller diagrams at different longitudes and latitudes. Eventually, we came to the conclusion that the in Fig. 8 shown Hovemöller diagram presenting the longitudinal propagation along 23°N is appropriate for illustrating variabilities in SHL strength and position modifying Saharan dust transport. As we focus on the variability in the SHL modulating North African dust transport, we prefer to use daily values for the SHL

position, strength, and extend over the multi-monthly mean.

Detailed comments

p5 l2 double brackets

This comment refers to the following text: "(June, July, August (JJA))". As there are two left parentheses used, we also use two right parentheses. No changes will be made to the revised version of the manuscript.

P6 l7 Chauvin et al. (2010)

Many thanks for spotting this. It's corrected in the revised version of the manuscript.

P6 l19 10% represents a spatial or temporal detection?

"The area of the SHL is refined to the 90th percentile of the LLAT values." This means that the area of the SHL is where the local LLAT value exceeds the 90th percentile. In other words: the local LLAT value is part of the upper 10% of the range of LLAT values.

P8 l15-l23 There is no dust coming from outside the domain (Arabian Peninsula)?

Correct, there is no dust transported into the domain. Dust originating from the Arabian Peninsula is not considered in this study here as no significant amount of dust originating from the Arabian Peninsula is expected to enter the model domain and contribute to the dust export towards the northern Atlantic. This argument is justified by the prevailing wind regimes over both North Africa and the Arabian Peninsula.

P10 l7 and Fig. 2 It could be interesting to compare these results with the climatology (as done for Fig. 1)

Many thanks for this suggestion, which is considered for the revised version of the manuscript. The fraction of dust source activations during the first respectively second half of the day for the 4-year period June, July 2006-2009 shows a similar distribution

than the June, July 2013 period: morning-time dust source activations dominate over the Sahara and Soudan zone (sub-Sahara), where the Harmattan regime and linked LLJ related winds foster dust emission. Dust source activations related to (moist) convection predominantly occur over regions dominated by the Monsoon circulation. Due to the interannual variability, in particular for the number of 12-00 UTC events, the mean distribution is smoother for the 4-year period than the 1-year period (June, July only).

p11 last paragraph of section 5 and Fig. 3: Scatter plots are more suitable for validation purposes. Bias, correlation and uncertainties are better represented.
We choose to present the comparison between sun-photometer AOD estimates and model simulated AOD as time series as this allows for expressing not only the match of the actual values but also for expressing the match in temporal evolution. This way, the model's ability to capture individual dust events with regard to strength (dustiness) and temporal evolution can be validated. This plot type much better serves the study's objective to analyse the temporal modulations of the Saharan dust export.

P11 l29 The low NAFTI index value is defined according to the climatology?
Low NAFDI index values are with regard to the range of values during JJA 2013. This will be clarified in the revised version of the manuscript: "The JJA 2013 summer season is characterised by for this period low NAFDI index values during the first three weeks."

Figures:
Fig 1: Add Bodele region in the map, please adjust the color scale
The Bodélé region is already shown. The colour scale is adapted to the range of values.

Fig 2: adjust the color scale. Also the change in % is not necessarily well adapted since it overestimates the region with low dust activation.

The colour scale is adapted to the range of values. We choose to express the change in DSAF as fraction (%) as this illustrates the relative magnitude and thus the predominance of the change with respect to the local level of occurrence.

Fig 3: Please change to scatter plots
We prefer to show the comparison between AERONET sun-photometer AOD and model simulated AODs as time series. This way, the ability of the model simulation to capture the temporal evolution of dust events is shown, which is a criterion for model evaluation here.

Fig 5: Again, I am not convinced by the scales used (in %). This increases the weight of the signal over region with low AOD. The difference is more adapted to me.
Please see our reply to your comment made above.

Fig 6: Very complicated to understand how this figure is realized. Why the Q25 and 75 of U or V are not simply used.
Obviously, there is a misunderstanding. This figure actually shows the 75th and 25th percentiles of the meridional (V) wind component. Northerly components are associated with the Harmattan, southerly with the monsoon flow. We refer to the figure caption. The figure shows the composite of meridional winds for the 75th (top (positive) NAFDI values) and 25th (lowest (negative) NAFDI values). We decided to select the winds for the NAFDI percentiles in order to present the "extreme" situations over the normal average condition.

Fig 7: This figure looks like a simple difference in between the established and the onset (or retreat) phases and do not bring innovative information
We disagree here. Again, the results are too much seen only from the aspect of the monsoon. The figure presents composites of the vertical distribution of the dust plumes during days with low NAFDI index values (25th percentile) and high NAFDI

index values (75th percentile). The NAFDI represents the strength of the Harmattan circulation, and thus the composites represent the dust distribution during two different atmospheric circulation regimes (cf. Fig. 4b, c). "Low NAFDI index values are associated with a SHL in its western position, generally low pressure over the Sahara, and a weak subtropical ridge over the Mediterranean basin. In contrast to this, high NAFDI index values reflect a pressure distribution characterised by a SHL in its eastern position, and a pronounced subtropical ridge over the Mediterranean basin with an enhanced pressure gradient towards the SHL."

Fig 9: Same problem with the scale in %
Please see our reply to your comment made above.

Fig 12: Why the intensity of the monsoon is not added?
In this study, of course, we also analysed the mass flux through 20°N averaged between 20°W and 20°E to evaluate the impact of the monsoon flux. The results, however, show that due to its intermittency, of the monsoon flux, which is orientated in meridional direction, the mass flux through 20°N averaged between 20°W and 20°E does not seem to be an appropriate measure to be related with the dust export towards the tropical north Atlantic, which is orientated in zonal direction. Therefore, we decided to not show the integrated monsoonal flux in Fig. 12. Nonetheless, we emphasise that the monsoon impact is implicitly included in LLAT and NAFDI.

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