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Dr. Schwarz

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Submission of revised manuscript

Dear Dr. Schwarz,

16 June 2017

thank you for the time you spent on assessing the manuscript '*Seasonal provenance changes of present-day Saharan dust collected on- and offshore Mauritania*' by C. Friese et al.. We received two very good (anonymous) reviews with detailed constructive comments which helped to improve the interpretation as well as structure and clarity of the manuscript. Therefore, we would also like to thank the reviewers for the time they spent on evaluating the manuscript and for elaborating their comments.

We received a number of similar comments from both reviewers. One dealt with the number of trajectories plotted in order to derive the likely source areas of the individual dust samples. Both reviewers recommended to show additional back trajectory heights because the shown back trajectory at 10 m may be prone to errors and the back trajectory at 4500 m may be higher than the SAL. We chose these back trajectory heights based on the studies of Skonieczny et al. (2013) and Stuu et al. (2005) who used these heights to represent the SAL and the trade-winds respectively. To improve the identification of likely dust sources, we additionally plotted back trajectories at a height of 100 m and 3000 m. This especially improved the determination of the sources of dust transported at low-level.

The reviewers asked for an explanation of ‘the sorting’ of a grain- size distribution and a definition of ‘well-sorted’. The sorting is a word used by sedimentologists to characterize the grain-size distribution: well-sorted refers to similar sizes and thus a low standard deviation of the grain-size distribution. To improve the clarity of the manuscript, we added this explanation to the text.

Moreover, both reviewers suggested to exclude the comparison between the atmospheric dust fluxes at the continental site and the dust deposition fluxes at the oceanic sites. This of course makes sense because atmospheric dust fluxes are higher by 2 – orders of magnitude compared to depositional fluxes and therefore it is difficult to execute a quantitative comparison. Following the reviewers’ suggestion, we removed the comparison which further improved the content of the manuscript.

Please find each of the reviewers’ individual comments and our revisions based on the reviewers’ comments in the attached supplements as well as in the revised manuscript. The reviewer’s comments are given with black normal text and our reply to the comments are given with black italic text. We used different colours for the revisions in the manuscript in response to the respective reviewer (referee #1 = red, referee #2 = blue).

Thanks again for your time and we look forward to hearing from you.

On behalf of all co-authors,
yours sincerely,

A handwritten signature in black ink, appearing to read 'C. Friese', written in a cursive style.

Dr. Carmen Friese

References

Skonieczny, C., Bory, A., Bout-Roumazeilles, V., Abouchami, W., Galer, S. J. G., Crosta, X., Diallo, A., and Ndiaye, T.: A three-year time series of mineral dust deposits on the West African margin: Sedimentological and geochemical signatures and implications for interpretation of marine paleo-dust records, *Earth and Planetary Science Letters*, 364, 145-156, <http://dx.doi.org/10.1016/j.epsl.2012.12.039>, 2013.

Stuut, J.-B. W., Zabel, M., Ratmeyer, V., Helmke, P., Schefuß, E., Lavik, G., and Schneider, R. R.: Provenance of present-day eolian dust collected off NW Africa, *Journal of Geophysical Research*, 110, 10.1029/2004JD005161, 2005.

Comment of Referee #1:

The work is an extensive analysis of different dust samples, sampled both on land and in the ocean. Samples were analyzed concerning different properties as grain size distributions and mineral composition, aiming at assigning source regions to the samples. Samples on land seem to be more influenced by local sources than oceanic samples, and it is indicated that long range transport decreases the average grain size of the deposited dust. This is all interesting and important information. However, being not a mineralogist, some passages were difficult to follow, and the overall structuring should be improved as well (see below). Also, occasionally statements seem to be too far-fetched. So in total, my judgement is that the manuscript can become fit for publication in ACP, but only after major revisions.

General comments:

Comment of Referee #1:

Several times in the manuscript, the impression is given that dust settling from the SAL starts to appear at the time when the air mass crosses the shore line, i.e., that SAL is a dust source above the Atlantic, only. This might just be formulated misunderstandingly, but in any case, dust will always settle from the SAL – it is just that on land, where nearby dust sources are present, they might be overwhelming. You have to go through the text and change the respective passages accordingly.

Reply to comment:

This is a good point. Dust already settles on land from the SAL and we formulated this unclearly. We agree, that the passages in which this happened need to be revised. Therefore, we changed all the sentences in which such a misunderstanding could lead to a false view on the dust transport.

Changes made in manuscript:

We modified the following sentences (page and line numbers refer to the revised manuscript):

Page 1, lines 19-20:

‘In continental dust source areas dust is also transported in the SAL, however the predominant dust input occurs from nearby dust sources with the low-level trade winds.’

Page 5, lines 150-153:

‘Low-level N trade winds blow and transport dust in coastal Mauritania year-round (National Geospatial-Intelligence Agency, 2006). Saharan dust is transported on- and offshore within the ‘Saharan air layer’ (SAL) at

an altitude of about 3 km (Prospero and Carlson, 1970; Carlson and Prospero, 1972; Prospero and Carlson, 1972; Diaz et al., 1976).’

Comment of Referee #1:

Your tables 1 and 2 are helpful, already, but I would have wished for an additional overview, showing which of the different locations contributed data for which kind of analysis. Also, all sites should be introduced together. E.g., Buoy Carmen is treated differently from CB and CBi, appearing for the first time in line 161, but not being shown in Fig. 1 and Fig. 2. Fig. 4 then shows the location of Iwik, CBi and Carmen and also of two new locations, but not the location of CB. This is all confusing, and a table could help to clarify that e.g., one place was only used for its information on meteorology, another one only for size distribution, etc. .

Reply to comment:

We agree that the structure of the manuscript would greatly improve when showing all sites together and when inserting a table showing which analysis has been done at each site. Therefore, we modified figure 1 by inserting all study sites together. Further, we inserted a new table 1 which gives an overview of the study sites with information on the respective location, samples, analyses and data.

Changes made in manuscript:

We inserted the following sentences:

Page 3, line 73:

‘and with the scientific dust-collecting buoy ‘Carmen’

Page 3, lines 82-88:

‘In Fig. 1 the location of the study sites and the North African dust sources are displayed. The dust-collecting buoy ‘Carmen’ (~21°15’ N, ~20°56’ W) and the sediment trap mooring site CB (~21°16’ N, ~20°48’ W) are virtually at the same position ~200 nautical miles offshore Cape Blanc. Sediment-trap station CBi (~20°45’ N, ~18°42’ W) is located ~ 80 nautical miles offshore Cape Blanc. The continental dust collector Iwik (~19°53’ N, ~16° 18’ W) and the meteorological station Arkeiss (~20° 7’ N, ~16° 15’ W) are located in a major potential dust source area (**PSA 2**) in the Parc National de Banc d'Arguin (PNBA) near Iwik and near Arkeiss in Mauritania. A further meteorological station is positioned in the **PSA 2** in Nouadhibou (~20° 55’ N, ~17° 1’ W) in the Western Sahara.’

We shifted the following sentence to:

Page 5, lines 118-119:

‘The local soils surrounding the dust collector site Iwik are composed of sandy deposits often rich in fossil shells and partly cemented by lime (Einsele et al., 1974).’

We modified Fig. 1:

Page 4, lines 97-100:

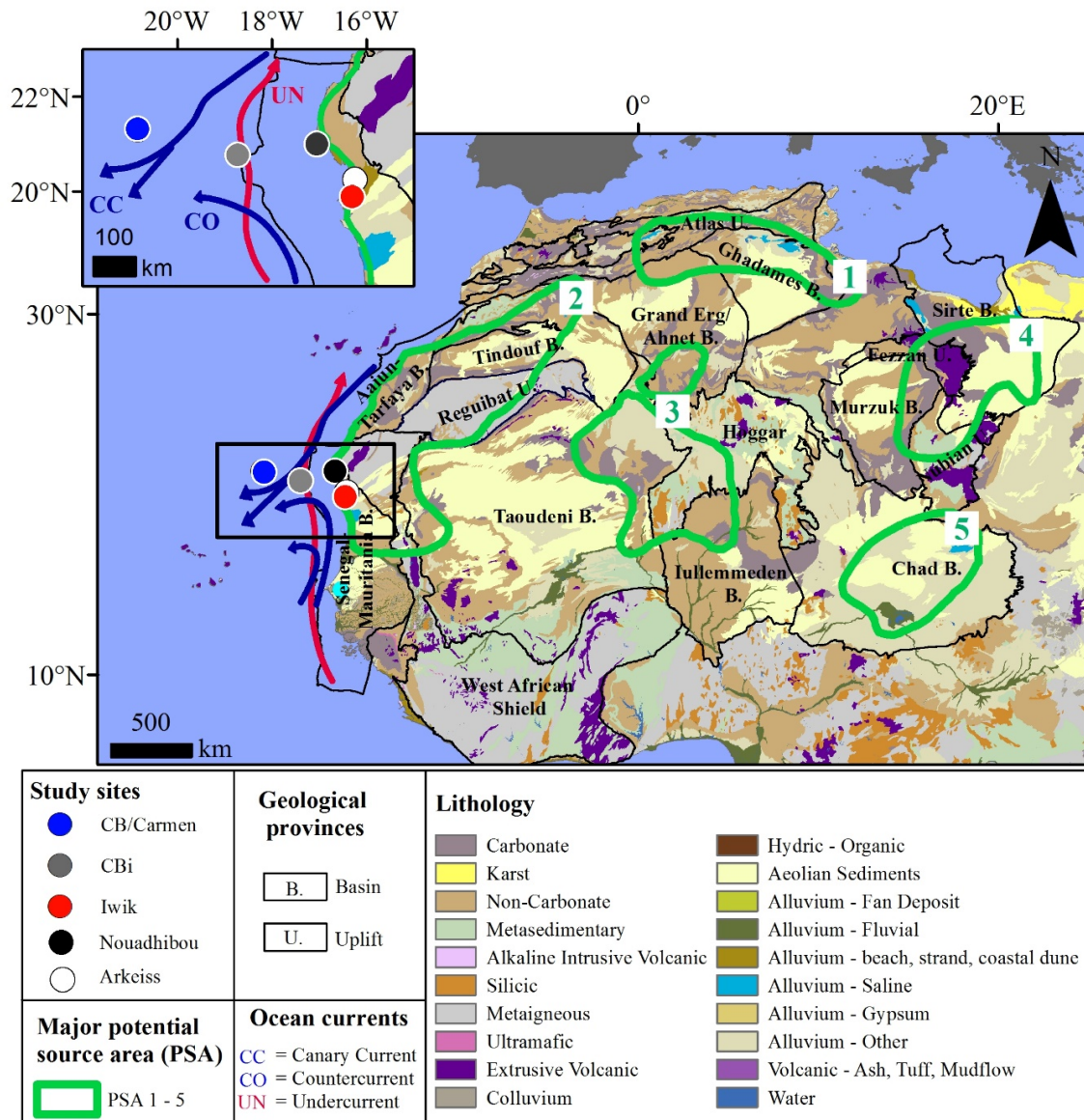


Figure 1: Map of the study sites under investigation: the scientific buoy Carmen as well as the sediment trap moorings CB and CBi offshore Cape Blanc, the MWAC dust collector onshore near Iwik and the ground stations near Nouadhibou and Arkeiss (shapefile of the surface lithology and the geological provinces: downloaded from the USGS website <http://rmgsc.cr.usgs.gov/ecosystems/africa.shtml#SL> and <http://certmapper.cr.usgs.gov/geoportal/catalog/main/home.page>, major potential dust source areas: redrawn from Scheuvens et al. (2013), ocean currents: redrawn from Mittelstaedt (1991)).

We inserted the following sentences and table:

Page 7, lines 190-199:

‘In Table 1 an overview of the material and methods employed for each study site is presented. Bulk sediment samples were obtained at the sites CB and CBI and dust samples at the sites Carmen and Iwik. All samples were analyzed for particle size and dust flux with the exception of the site Carmen, of which only dust particle size was analyzed. Only the sites CBI and Iwik were analyzed for mineral assemblages and only the samples of the site Iwik were used for microscopic investigation. Meteorological sensors were available for the stations Carmen, Iwik and Arkeiss, while for the site Nouadhibou meteorological data was downloaded online. TRMM precipitation data was downloaded online for all sites except for the site Nouadhibou.

Table 1: Overview of the material and methods employed at each study site. ‘

Study site	Lat./lon.	Samples	Analysis	Meteorological sensor and data	Downloaded meteorological data
Carmen	~21°15' N, ~20°56' W	1 MWAC sample	particle size	Vaisala WXT520: wind direction + speed, precipitation	TRMM 3B42: precipitation
CB	~21°16' N, ~20°48' W	38 sediment trap samples	lithogenic fluxes, particle size	-	TRMM 3B42: precipitation
CBI	~20°45' N, ~18°42' W	38 sediment trap samples	lithogenic fluxes, particle size, mineral assemblages	-	TRMM 3B42: precipitation, HYSPLIT back trajectories
Iwik	~19°53' N, ~16° 18' W	24 MWAC samples	microscopy, dust fluxes, particle size, mineral assemblages	Davis 6250 Vantage Vue: wind direction + speed	TRMM 3B42: precipitation, HYSPLIT back trajectories
Nouadhibou	20° 55' N, 17° 1' W	-	-	-	Wind direction + speed
Arkeiss	~20° 7' N, ~16° 15' W	-	-	Davis 6250 Vantage Vue: precipitation	TRMM 3B42: precipitation

Comment of Referee #1:

Similarly, it is not clear to me what is gained by showing wind directions in Nouadhibou if information from that location is then dismissed due to local effects, unless you want to make it clearer that ground based sampling on

land will not reflect long range transported dust (due to local sources and local winds) – but in this case, this needs to be discussed somewhat stronger. Consequently: if there are these local effects on land, will Iwik not be influenced similarly? This should be discussed, too.

Reply to comment:

We agree that the results on the meteorological data at station Nouadhibou should be mentioned in the discussion. The site served as an example for how local effects may influence the observed wind patterns. At site Iwik the synoptic change in the predominant trade wind direction can be clearly observed, while at other sites like Nouadhibou local effects bias an observation of synoptic wind patterns. This should also be kept in mind when choosing a site for paleoenvironmental reconstructions using sediment core records.

Changes made in manuscript:

We inserted the following sentences:

Page 35, lines 768-771:

‘The variability of the mineralogical composition of dust sampled at site Iwik could be related to the synoptic scale change in the surface trade wind direction. However, meteorological data from nearby sites like e.g., Nouadhibou demonstrate that local effects like the topography exert a strong influence on observed wind directions at ground level. (Fig. 2).’

Comment of Referee #1:

For your determination of possible dust sources, you use trajectories in heights of 10m and 4500m. You chose 10m based on your even lower sampling heights. But still, trajectories in heights as low as 100m or below are always very prone to errors, and 4500m is so height that it might be above the heights of the SAL. Please at least mention that and explain why you chose to calculate the trajectories at these heights, nevertheless.

Alternatively, choose additional different heights (e.g., 100m and 2000m or so) – you could check, if they are similar to those you used. Adding them could add credibility to your work.

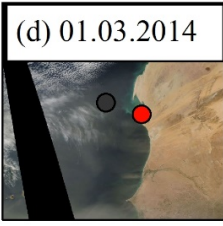
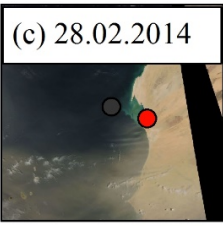
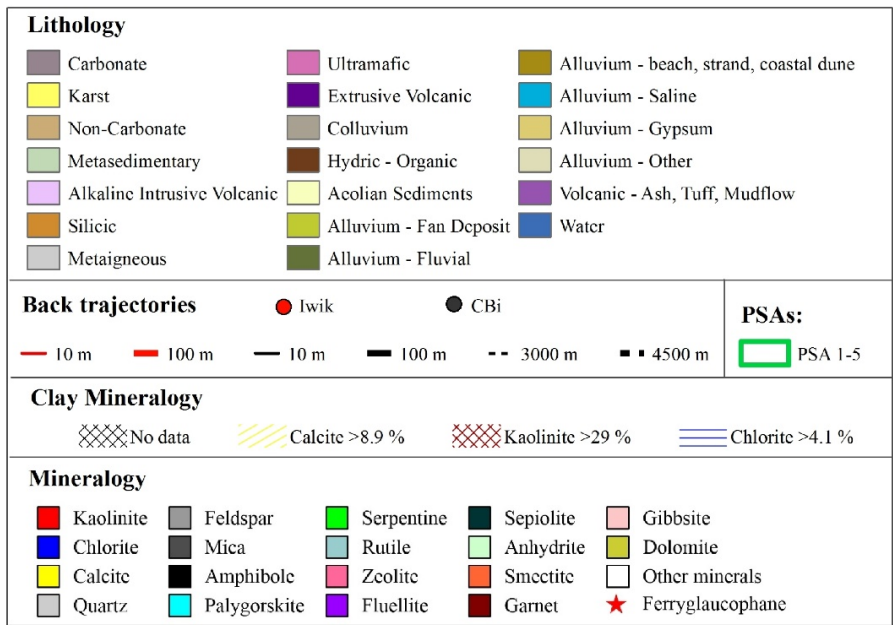
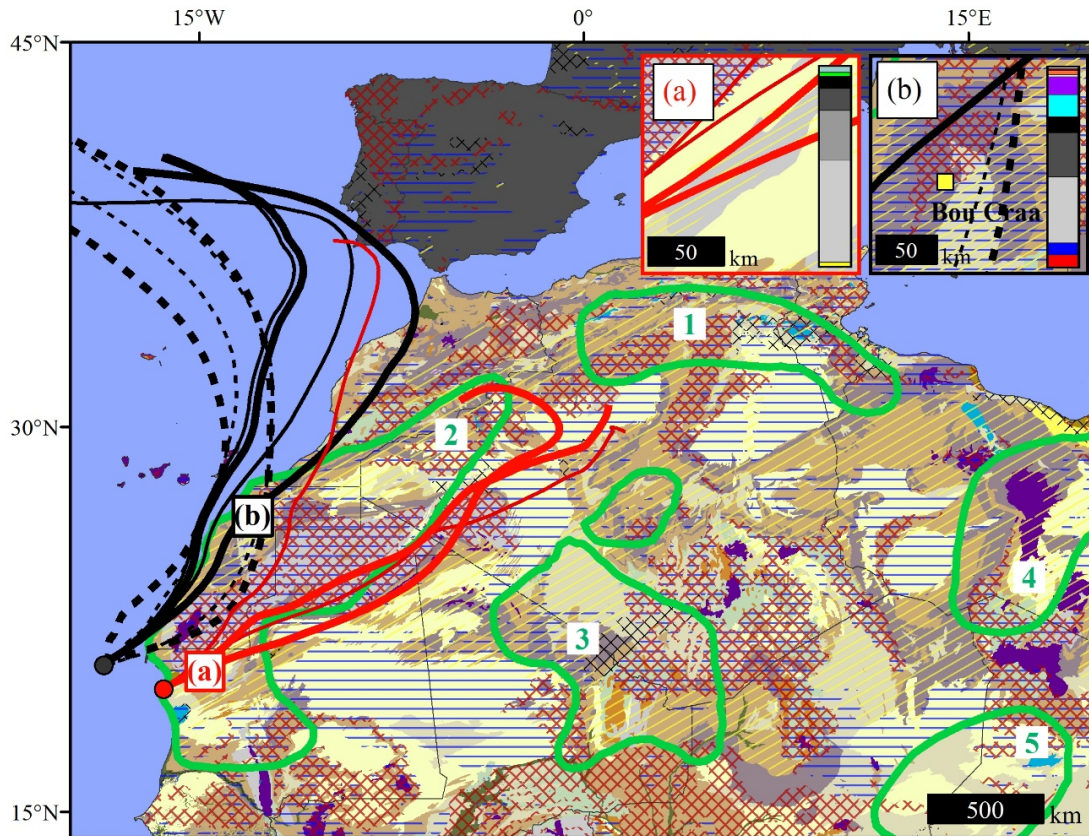
Reply to comment:

We chose the altitudes at which back trajectories were calculated on the basis of previous studies to which we compare our data. For example, Skonieczny et al., 2013 use 4500m to study the SAL. Following the reviewer’s suggestion, we now also included additional back trajectories at additional altitudes, which made the observed patterns much clearer. Back-trajectories of the heights 100 m and 3000 m were added to figures 9-12. This improved the detection of the likely dust source areas and the results and interpretation were adjusted.

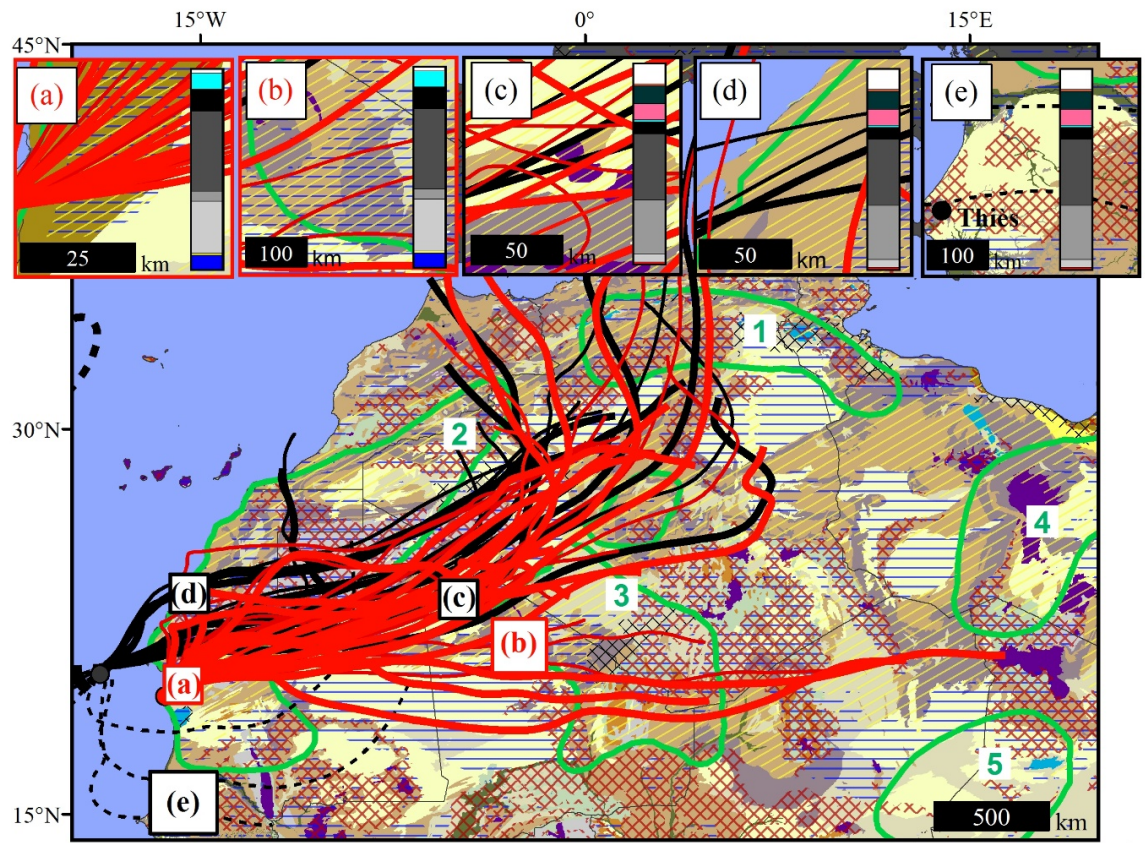
Changes made in manuscript:

We modified Fig. 9-12:

Page 24, line 563:



Page 26, line 585:

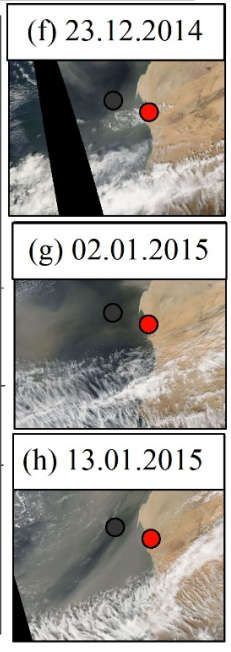


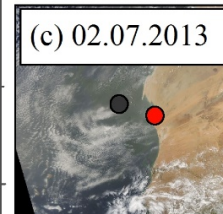
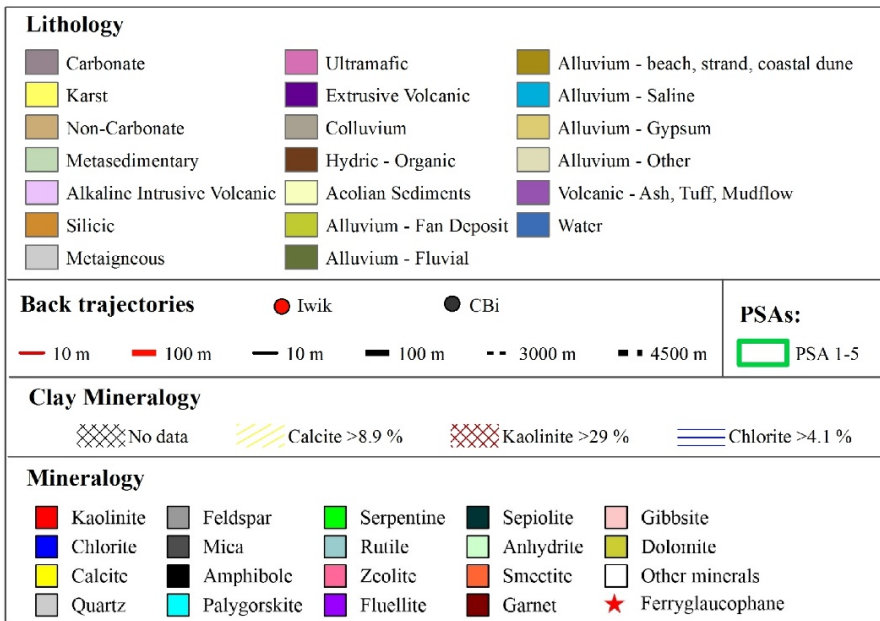
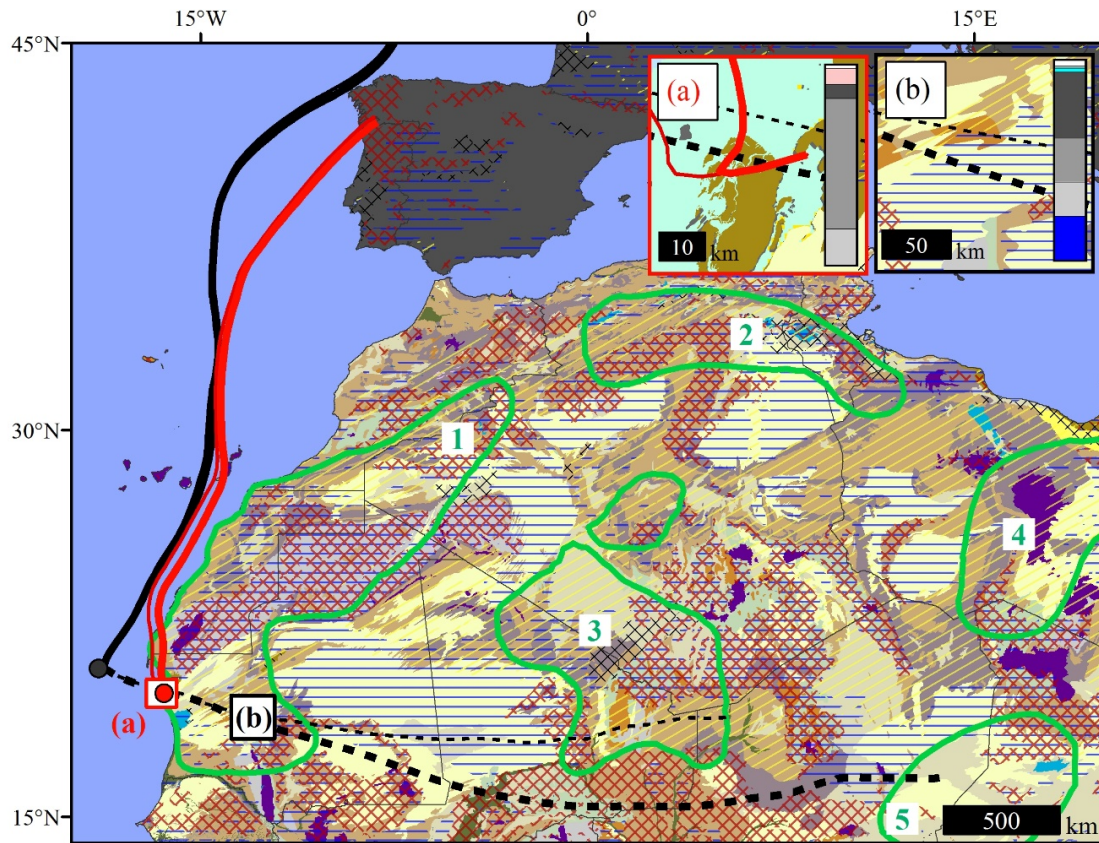
Lithology		
Carbonate	Ultramafic	Alluvium - beach, strand, coastal dune
Karst	Extrusive Volcanic	Alluvium - Saline
Non-Carbonate	Colluvium	Alluvium - Gypsum
Metasedimentary	Hydric - Organic	Alluvium - Other
Alkaline Intrusive Volcanic	Aeolian Sediments	Volcanic - Ash, Tuff, Mudflow
Silicic	Alluvium - Fan Deposit	Water
Metaigneous	Alluvium - Fluvial	

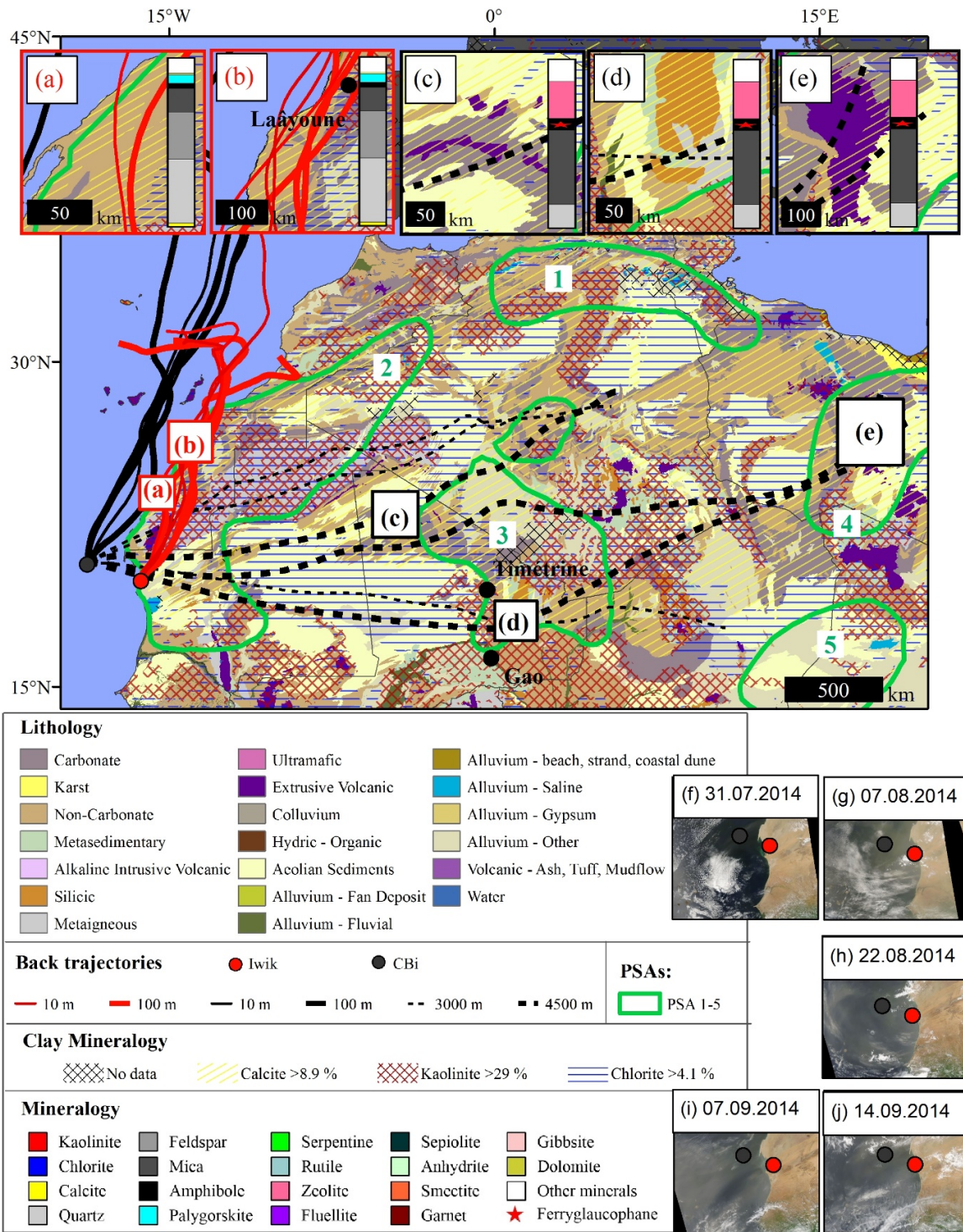
Back trajectories		PSAs:
● Iwik	● CBi	□ PSA 1-5
— 10 m	— 100 m	
— 10 m	— 100 m	
--- 3000 m	--- 4500 m	

Clay Mineralogy			
⊞ No data	▨ Calcite >8.9 %	⊞ Kaolinite >29 %	▨ Chlorite >4.1 %

Mineralogy				
■ Kaolinite	■ Feldspar	■ Serpentine	■ Sepiolite	■ Gibbsite
■ Chlorite	■ Mica	■ Rutile	■ Anhydrite	■ Dolomite
■ Calcite	■ Amphibole	■ Zeolite	■ Smectite	■ Other minerals
■ Quartz	■ Palygorskite	■ Fluellite	■ Garnet	★ Ferryglaucophane







We modified the following sentence to:

Page 14, lines 373-377:

‘Four-day back trajectories at altitudes of 10 (following Stuu et al. (2005)), 100, 3000, 4500 (following Skonieczny et al. (2013)) and 5500m were calculated ending at the dust collector site Iwik (19°52’ N, 16°17’ W) and at the proximal marine trap site CBi (20°46’, 18°44’ W) using the Hybrid Single Particle Langrangian

Integrated Trajectory (HYSPLIT) model (Stein et al., 2015) and the reanalysis dataset (2.5° spatial resolution) on the NOAA website at <http://ready.arl.noaa.gov>. ‘

We modified the following sentences:

Page 22, lines 546-548:

‘Four heights, 10, 100, 3000 and 4500 m were chosen to cover both low- (trades) and high-level (SAL) dust transport.’

Page 22, lines 551-552:

‘The back-trajectories at 5500 m can be found in the supplements. ‘

Page 23, lines 561-562:

‘Thus, the source area of the samples was most likely the chlorite and kaolinite rich sediments located near the Bou Craa phosphate mine in the Western Sahara (Fig. 9b).’

Page 25, lines 581-584:

‘A further source area might be the southern shoreline of the Western Sahara in which chlorite depleted sediments are situated (Fig. 10d). The presence of the mineral kaolinite in this marine winter sample may be explained by a kaolinite-rich source area lying in the southern Senegal-Mauritania Basin (Fig. 10e).’

Comment of Referee #1:

When you discuss the dust sources, the basic assumption seems to be that there is always one source with one mixture of minerals. But couldn't dust be emitted from areas with differing mineral composition in one dust storm (in fact, even the regions you selected as “major potential source regions” are not homogenous concerning the mineral compositions). My understanding of mineralogy might be too limited, here, but for me the attribution to the characteristics of the sampled dusts to the source regions seemed to include a lot of guessing.

Reply to comment:

Of course, your argument is correct. Individual dust outbreaks may result from multiple dust source areas and the source areas are not homogenous with respect to the mineralogical composition. However, in order to be able to distinguish between the different PSA's we chose typical minerals that are characteristic for the different PSA's as defined by Scheuven et al., 2013.

Comment of Referee #1:

Again, tables could help, showing minerals that are present in the different “major potential source regions”, and at the same time showing the minerals found in the different samples. This would certainly have helped me to follow your conclusions. Also, statistically, the number of dust sample cases that could be evaluated and the number of particles analyzed all are rather low. It is, no doubt, a lot of effort to do all this, but the resulting data should not be overrated. In this context, certainly the last sentence in the “summary and conclusion” (line 843) (and some other sentences as well) is formulated too strongly.

Reply to comment:

Yes, indeed it is not easy to follow how the characteristic minerals of the individual samples were assigned to the PSA's and source rocks and deposits. Therefore, we included a table displaying information on the sampling interval and characteristic minerals of each sample. We further inserted information on the bulk mineralogical composition of the chosen PSA according to Scheuven et al., 2013 and information on the characteristic source rocks and deposits of the chosen source areas. When looking at the table, it should be clearer now how the source areas were chosen based on the characteristic minerals of the samples.

We further agree that the last sentence in the summary and conclusion is formulated too strongly based on the fact that the number of samples is rather low. Therefore, we removed the sentence.

Changes made in manuscript:

We inserted a table:

Page 34, lines 760-764:

‘In Table 7 an overview of the chosen dust source areas for the site Iwik and CBI is given together with the characteristic minerals of the samples that may be used as a tracer for the source area. In the following subsections the identification of the source areas and mineralogical tracers is described in detail.

Table 7: Overview of the chosen source areas and the tracer minerals of the individual samples together with the given characteristics of the source areas according to literature. ‘

Sampling interval	Characteristic minerals of sample	Chosen dust source area	Bulk mineralogical composition of chosen PSA ⁽¹⁶⁾	Characteristic source rocks and deposits of chosen source area
Iwik				
15.02.-15.03.14	*Rut, Serp, Cc	PSA 2: Reguibat Shield	C/K = 0.0–1.0 *Pal: 1-30 wt%	Metamorphic and granitic rocks ⁽¹⁾ Serpentinities ⁽²⁾
15.12.14-18.01.15	*Cc, Chl, Pal (8 wt. %)	PSA 2: Senegal-Mauritania Basin	C/K = 0.0–1.0 *Pal: 1-30 wt%	Chalky horizons ⁽³⁾
		PSA 3: Eastern Taoudeni Basin	C/K = 0.2–0.9 *Pal: 1-5 wt%	Carbonate sequences ⁽⁴⁾
24.06.-15.07.13	*Gib	PSA 2: Tidra Island	C/K = 0.0–1.0 *Pal: 1-30 wt%	Gibbsite maximum offshore Cape Blanc ⁽⁵⁾
15.08.-15.09.14	*Cc, Dol, Pal (5 wt. %)	PSA 2: Aaiun-Tarfaya Basin	C/K = 0.0–1.0 *Pal: 1-30 wt%	Limestone deposits ⁽⁶⁾ Outcrops near Laâyoune with dolomites ⁽⁶⁾
CBi				
26.02.-18.03.14	*Chl, Kao (C/K = 1), Pal (11 wt. %), Flu, Anh, Sme, Ga	PSA 2: Aaiun-Tarfaya Basin near Boucraa	C/K = 0.0–1.0 *Pal: 1-30 wt%	Phosphate deposits ⁽⁷⁾
16.12.14-04.01.15	*Kao (C/K = 0), Pal (1 wt. %), Zeo, Se, Sme	dike swarms and sills of northern Taoudeni Basin	-	Basalts with glass ⁽⁹⁾
		PSA 2: Aaiun-Tarfaya Basin	C/K = 0.0–1.0 *Pal: 1-30 wt%	Palygorskite-sepiolite mafic clays ⁽⁷⁾
		Southern Senegal-Mauritania Basin	-	Lateritic soil ⁽⁸⁾ Horizontal layers of palygorskite and sepiolite ⁽⁸⁾
25.06.-16.07.13	*Chl, Pal (2 wt. %), Rut	PSA 2: Mauritanides	C/K = 0.0–1.0 *Pal: 1-30 wt%	Strongly metamorphosed rocks ⁽¹⁰⁾ Greenschist facies ⁽¹¹⁾
01.08.-21.08.14	*Fe-Amf, Zeo	dike swarms and sills of northern Taoudeni Basin	-	Basalts with glass ⁽⁹⁾
		PSA 4: Fezzan uplift	C/K = 0.0–2.6 *Pal: 0 wt%	Zeolite in basaltic rocks ^(12,13)
		PSA 3: Pharusian belt	C/K = 0.2–0.9 *Pal: 1-5 wt%	Blueschists ⁽¹⁴⁾ Glaucofane bearing eclogites ⁽¹⁵⁾
* Amf = amphibole, Pal = palygorskite, Chl = chlorite, Cc = calcite, Dol = dolomite, Gib = gibbsite, Zeo = zeolite, Kao = kaolinite, Sme = smectite, Se = sepiolite, Rut = rutile, Serp = serpentine, Ga = garnet, Anh = anhydrite, Flu = fluellite				
⁽¹⁾ Schofield et al. (2006) and references therein ⁽²⁾ Schlüter (2008) ⁽³⁾ Wissmann (1982) ⁽⁴⁾ Bertrand-Sarfati et al. (1991) ⁽⁵⁾ Biscaye (1964) ⁽⁶⁾ Bosse and Gwosdz (1996) ⁽⁷⁾ Moreno et al. (2006) ⁽⁸⁾ García-Romero et al. (2007) ⁽⁹⁾ Verati et al. (2005) ⁽¹⁰⁾ Villeneuve (2005), ⁽¹¹⁾ Dallmeyer and Lécorché (2012) ⁽¹²⁾ Abdel-Karim et al. (2013) ⁽¹³⁾ Cvetković et al. (2010) ⁽¹⁴⁾ Caby (2014), ⁽¹⁵⁾ Caby et al., 2008) ⁽¹⁶⁾ Scheuven et al. (2013)				

We removed the last sentence in the summary and conclusions:

‘Finally, we have shown how the mineralogical composition of the samples can be used for provenancing of dust particles found in both on-land and marine dust archives.’

Specific comments:

Comment of Referee #1:

Line 67-69: Is this statement taken from one of the papers cited in the text close by? Which one? And in general: How far offshore can regional / local dust emissions be found? (Or, in other words, how large is the “footprint” of a dust source when it does not emit the dust to large heights?)

Reply to comment:

This is a good point. This sentence was formulated unclearly. It was related to the findings of the cited papers in the sentences before so we modified the sentence. Unfortunately, the exact distance to which regional/local dust emissions can be found offshore is not known. We hope to resolve this question in the future by comparing dust that is collected with three boys offshore.

Changes made in manuscript:

We modified the following sentence:

Page 2, lines 66-68:

‘The results of the above mentioned studies imply that dust collected on land is predominantly of local provenance, while the sources of dust sampled offshore NW Africa are of regional and long-distance provenance.’

Comment of Referee #1:

Line 82: Do you mean your Fig. 1 or the Fig. 1 from Scheuven et al.? Clarify.

Reply to comment:

This was related to the Fig. 1 of this manuscript.

Changes made in manuscript:

We modified the sentence to:

Page 3, lines 82 - 90:

‘In Fig. 1 the location of the study sites and the North African dust sources are displayed. The buoy ‘Carmen’ (~21°15’ N, ~20°56’ W) and the sediment trap mooring sites CB (~21°16’ N, ~20°48’ W) and CBi (~20°45’ N,

~18°42' W) are located ~ 200 and ~ 80 nautical miles offshore Cape Blanc in the north-eastern (NE) equatorial Atlantic Ocean. The continental dust collector Iwik (~19°53' N, ~16° 18' W) and the meteorological station Arkeiss (~20° 7' N, ~16° 15' W) are located in a major potential dust source area (**PSA 2**) in the Parc National de Banc d'Arguin (PNBA) near Iwik and near Arkeiss in Mauritania. A further meteorological station is positioned in the **PSA 2** in Nouadhibou (~20° 55' N, ~17° 1' W) in the Western Sahara.

The major PSA of northern African dust are summarized in a review by Scheuvens et al. (2013).'

Comment of Referee #1:

Line 383: Arkeiss and Iwik are not oceanic, are they? Rephrase.

Reply to comment:

Yes, you are absolutely right. We removed the word 'oceanic'.

Changes made in manuscript:

We modified the sentence to:

[Page 15, lines 399-401:](#)

'Moreover, the TRMM satellite product indicated larger rainfall frequencies during the summer season compared to the winter season regarding the stations Carmen, CBi, Iwik and Arkeiss.'

Comment of Referee #1:

Line 432 - 436: This discussion about dust fluxes is confusing, and I suggest to completely remove it, also because (see next comment):

Reply to comment:

Good point. We decided to remove the detailed comparison in the dust fluxes between the continental and oceanic sites as the sampling height and the sampling method complicates the comparison. We only mention the progressive downwind decrease in the dust fluxes from site Iwik to CBi and CB.

Changes made in manuscript:

We removed the following sentences:

'The dust fluxes were about 1000 times smaller at the oceanic sites compared to the continental site. A stronger decrease in the fluxes was observed from site Iwik to CB during summer compared to winter. The variation in

the seasonal average dust fluxes were well comparable between the continental and oceanic site CBI. A seasonal trend in the dust fluxes could not be observed for the ocean sites CBI and CB. However, a seasonal trend was observed for site Iwik when taking into account the spring and fall samples.’

Comment of Referee #1:

Line 438: Not surprisingly, the sampling heights has influences the results. This prohibits a direct comparison of mass concentrations and such parameters between the different sampling types (on mast and in traps in the water), while comparing shapes of size distributions and dust compositions might be possible. This should be discussed in the text somewhere. It is mentioned at line 607 again, but also not discussed. Based on this, a comparison of fluxes between the stations makes no sense.

Reply to comment:

Yes, good argumentation. The comparison between the fluxes is complicated as described in the answer to the previous comment. Therefore, we excluded the discussion on the dust fluxes. No trend in the modal particle size was observed with sampling height. Therefore, the particle size distributions were most likely not greatly influenced by the sampling height and a comparison between the size distributions of the sampling sites should be possible.

Changes made in manuscript:

We modified the following sentence:

Page 18, lines 452-453:

‘The dust fluxes generally decreased with collection height in the mast between 90 and 290 cm (not shown).’

We removed the following sentences:

‘The stronger decrease in the dust fluxes from site Iwik to CB during summer compared to winter (Table 4) may be explained in the following. During summer, dust was additionally transported with the trades to the site Iwik, (Fig. 9-12) leading to anomalously higher dust deposition at site Iwik compared to the oceanic sites. Further, the washout of dust during offshore transport may have depleted the atmospheric dust cloud resulting in strongly decreased dust deposition fluxes at site CB compared to site CBI during summer.’

We inserted and modified the following sentences in the discussion:

Page 31, lines 655-661:

‘The average horizontal fluxes at site Iwik were ~ 1000 times larger with ~ 100000 mgm⁻²d⁻¹ (Table 5) due to the different sampling technique. The MWAC samplers do not measure deposition fluxes but foremost dust concentrations. Only 1% or less drops out of a moving dust cloud within five minutes, hence, the horizontal dust flux is at least ~100 times higher than the dust deposition flux (Goossens, 2008). The fact that the dust fluxes decreased with height (not shown) further complicated a comparison between the sites due to the different sampling heights of the dust collectors (2.90 m at Iwik, versus traps in the water). Therefore, the fluxes between the site Iwik and the offshore sediment trap moorings cannot be compared.

Comment of Referee #1:

Line 450: The bi-modal distribution of Iwik 13-14 is shown in Fig. 6c, right? Add this information to the text.

Reply to comment:

One of this bimodal distribution is shown in Fig. 6c. The two other bimodal distributions were measured for a spring and a summer sample and are therefore not included in Fig. 6.

Changes made in manuscript:

We modified the following sentences:

Page 19, lines 464-466:

‘The three bimodal distributions of the Iwik 13-14 time series were characterized by an additional fine mode peaking at ~16 μm besides the more pronounced and variable coarse mode peaking at ~42 to 55 μm. The three Iwik dust samples characterized by a fine grain-size peak were collected during spring, summer (Fig. 6c) and fall.’

Comment of Referee #1:

Fig. 6: There is a change in sequence between the two captions, which I found disturbing.

I’d prefer to always list - CBi - CB - Iwik. Also: maybe put the black data on top of red one, in the plot, otherwise they are hard to see, or make a mix, so that at least some of the black ones are visible a bit better.

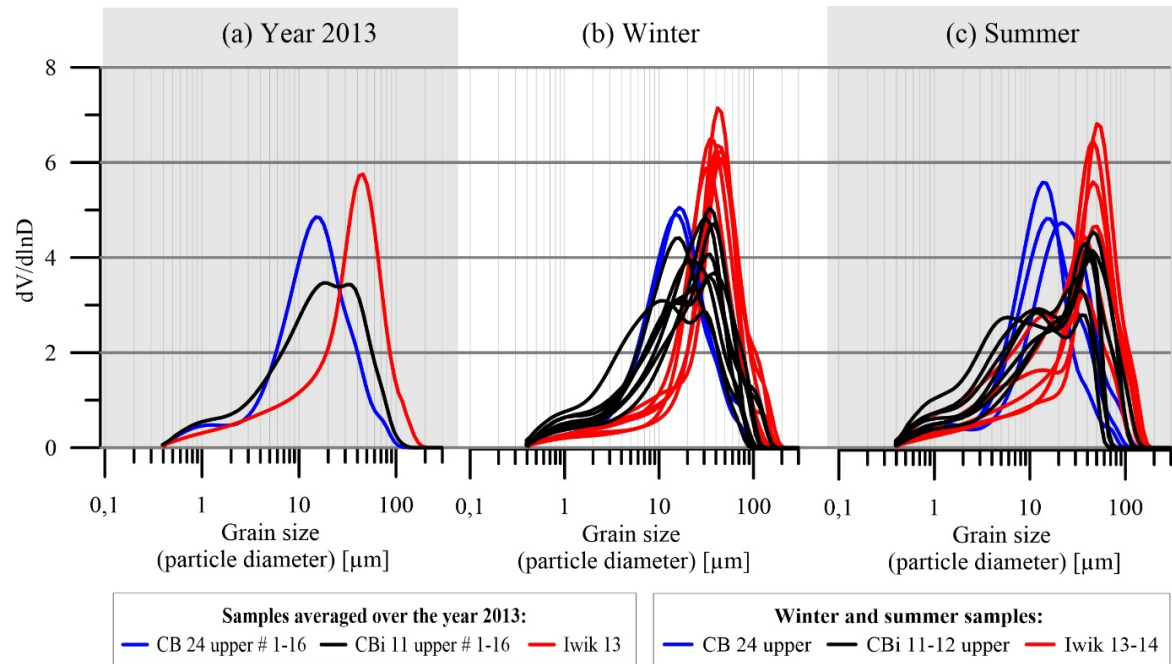
Reply to comment:

The comment helped to improve the figure. We put the black data on top of the red one in the plot to improve the visibility. Also, you are right, the order of sites in the legend was not consistent. However, we suggest to present the site CB first – as it is the most distant one – and the site Iwik last – as this is the most proximal sampling site. Or in other words: we displayed the sites in the legend now from West to East.

Changes made in manuscript:

We modified figure 6:

Page 19, line 480:



Comment of Referee #1:

Line 452: Explain what you mean by “the sorting”.

Reply to comment:

The sorting is expressed by the standard deviation of the grain-size distribution: the larger the standard deviation the weaker the sorting. We added this explanation to the text.

Changes made in manuscript:

We inserted the following sentence:

Page 19, lines 468-469:

‘The standard deviation of a grain-size distributions is a measure of the sorting of the dust sample: the larger the standard deviation the weaker the sorting.’

Comment of Referee #1:

Figure 7 a) and b): Why was a different wind speed chosen in a) (> 5 m/s) and b) (> 6.5 m/s)? Also: there is a frame around Fig. 7 (on 3 of the 4 sides) that has to be removed for the final version.

Reply to comment:

The explanation on why we chose these values is missing in the text. Only the threshold wind speed of the wind events for which the correlation was best was shown in the graph. This optimum threshold wind speed was different between the correlation to the dust fluxes and the correlation to the modal particle size. We added this information to the revised manuscript.

Changes made in manuscript:

We inserted the following sentences:

Page 20, lines 488-489:

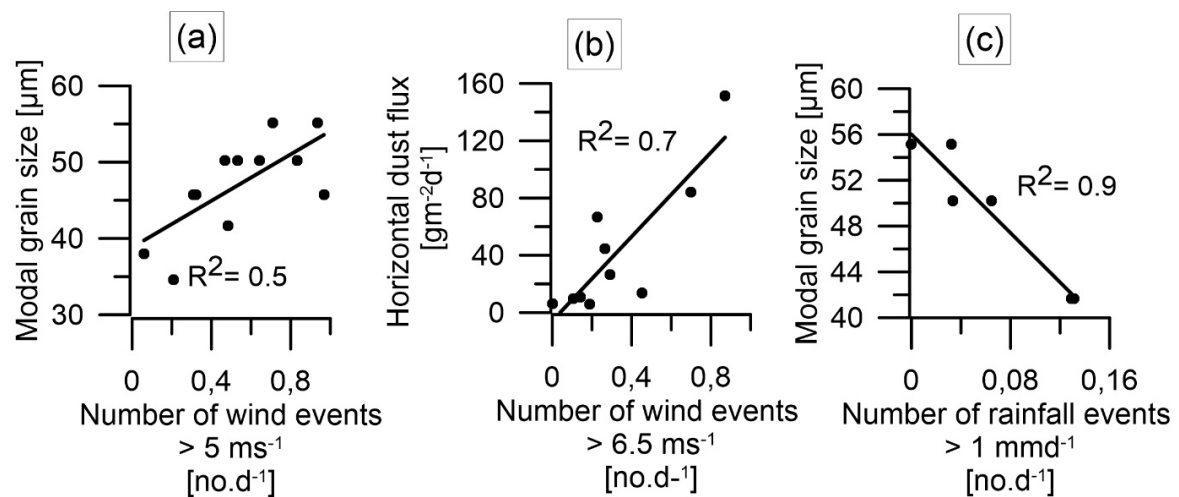
‘The correlation was only evident when using a threshold for wind events of 3.5 to 5.5 ms⁻¹ and was best for a threshold of 5 ms⁻¹.’

Page 20, lines 494-495:

‘The correlation was only evident when using a threshold for wind events of 6.5 to 7 ms⁻¹ and was best for a threshold of 6.5 ms⁻¹.’

We modified fig. 7:

Page 20, line 502:



Comment of Referee #1:

Line 527: Why are there 2 back trajectories, only? Were they only made for the time of the dust event? Then why 2 and not only 1? This has to be clearly explained (this also is valid for Fig. 10, 11, and 12, where different numbers or trajectories are shown.)

Reply to comment:

A backward trajectory was drawn only for the day with a dust storm event. So in figure 9 of the old version of the manuscript two days with a dust storm event were identified during the sampling interval of each site resulting in two back trajectories per height at each site. We inserted this information to the text.

Changes made in manuscript:

We inserted the following sentences:

Page 22, lines 547-548:

‘A back trajectory was drawn for the day when a dust storm event occurred as depicted on the satellite images.’

Page 23, lines 553-556:

‘During the sampling interval of each site at least two days with dust storms occurred (Fig. 9c,d). Therefore, two back trajectories were drawn for each height for the site CBi and CB respectively. The high-level back trajectories ending at site CBi pass either through the major **PSA 2** or point offshore.’

Page 24-25, lines 568-571:

‘During the sampling interval of the site Iwik at least three dust storms occurred and at the site CBi at least two dust storms occurred (Fig. 10f-h). Each dust storm lasted for several days for which we could model as many as 15 back trajectories for the site Iwik and 8 for the site CBi for each height. The large number of back trajectories complicated the determination of the likely source areas.’

Page 26-27, lines 590-592:

‘Only one dust storm event was observed during the sampling interval at both sites which lasted for one day (Fig. 11c) resulting in only one back trajectory per site and per height.’

Page 28, lines 603-607:

‘At least five separate dust events could be identified (Fig. 12f-j) out of which three occurred during the sampling interval of the site Iwik and two during the sampling interval of the site CBi. One of these dust storms occurring during the sampling interval of site CBi lasted for two days (07-08.08.2014), while all other dust storms lasted for only one day. As a result, three back trajectories could be drawn for each site and each height.’

Comment of Referee #1:

Line 538: Just out of curiosity: does sea spray (i.e., the Cl in it) engrave the analysis of chloride?

Reply to comment:

No, because the CBi samples were pre-treated with distilled water before analysis resulting in the washout of Cl-ions.

Comment of Referee #1:

Figure 9: The line for the 4500m back-trajectory for CBi is in the caption, but not in the plot. But it could be interesting to see it in here, as the dust transported from further away at higher altitudes might also contribute. This comment is valid also for Fig. 10.

Reply to comment:

This was a very good comment which helped to determine the likely source areas of the sampled dust. We added the back trajectories at 3000 and 4500 m to Fig. 9 and 10. With the new Fig. 10 we could find a new source area in Senegal which may have supplied the characteristic minerals kaolinite and sepiolite present in the sample.

Changes made in manuscript:

[Page 25, lines 582-584:](#)

‘The presence of the mineral kaolinite in this marine winter sample may be explained by a kaolinite-rich source area lying in the southern Senegal-Mauritania Basin (Fig. 10e).’

Comment of Referee #1:

Line 551: Replace “due to the” by “as there are”.

Reply to comment:

We revised the sentence.

Changes made in manuscript:

We modified the sentence to:

Page 25, lines 576-578:

‘Chlorite may have been supplied to Iwik from a source area nearby the Senegal-Mauritania Basin (Fig. 10a) or as far as the eastern Taoudeni Basin (Fig. 10b) as there are anomalously high chlorite content of the soils in these areas.’

Comment of Referee #1:

Line 596 ff: Was this for PM10 or total particulate mass? What exactly do you mean by “annual average dust concentrations”? The average per dust storm, or really the all-time average of dust, or something else? Please explain. Also: It is not clear to me how the monitoring of less dust events in Morocco due to the shorter sampling time can affect an average value, unless this average is "per year".

Reply to comment:

The annual average dust concentrations were calculated for total particulate mass using all dust samples. We modified the sentence to explain this. We also noticed that the sentence on the monitoring of dust events was not adequate also because the average value was calculated by excluding haze-periods and dust-storms at the sampling site. Therefore, the statement was removed and we modified the paragraph.

Changes made in manuscript:

We removed the sentence:

‘However, in Morocco dust was collected at a larger height of 4 m and the sampling time is much shorter leading to the monitoring of less dust events.’

We modified the sentences to:

Page 31, lines 640-644:

‘An annual average dust concentration (total suspended particles) of $\sim 214 \mu\text{g m}^{-3}$ and $275 \mu\text{g m}^{-3}$ was estimated for all dust samples of the year 2013 and 2014 respectively regarding the site Iwik (Table 4). These estimates were larger than what has been measured for background dust concentrations (total suspended particles) in Morocco which were in the order of $100 \mu\text{g m}^{-3}$ during spring 2006 (Kandler et al., 2009). However, in Morocco dust was collected at a larger height of 4 m and haze-periods and dust-storms were excluded from the average value.’

Comment of Referee #1:

Line 606-607: If the difference is due to different sampling techniques, does it make sense to do such a comparison as you present it here?

Reply to comment:

You are right. A comparison of the dust fluxes between the onshore and offshore sites is not feasible because of the different sampling techniques. Therefore, we excluded the comparison of the fluxes between site Iwik and the oceanic sites CB and CBi in the discussion.

Changes made in manuscript:

We modified and shifted the following paragraphs to:

Page 31, lines 651 – 661:

The observed general decrease in the dust flux from the sites CBi and CB can be explained via the increase in the distance to the source area. Decreased dust deposition fluxes offshore NW Africa with increasing distance from the African coast were also observed by Bory and Newton (2000) analysing the lithogenic fluxes in marine sediment traps.

The average horizontal fluxes at site Iwik were ~ 1000 times larger with ~ 100000 mgm⁻²d⁻¹ (Table 5) due to the different sampling technique. The MWAC samplers do not measure deposition fluxes but foremost dust concentrations. Only 1% or less drops out of a moving dust cloud within five minutes, hence, the horizontal dust flux is at least ~100 times higher than the dust deposition flux (Goossens, 2008). The fact that the dust fluxes decreased with height (not shown) further complicated a comparison between the sites due to the different sampling heights of the dust collectors (2.90 m at Iwik, versus traps in the water). Therefore, the fluxes between the site Iwik and the offshore sediment trap moorings cannot be compared.

Comment of Referee #1:

Line 608: In which time span does 1% drop out of a moving dust cloud? Per day, per year, ever (certainly not), : :? :

Reply to comment:

In a time span of five minutes. We changed the sentence accordingly.

Changes made in manuscript:

We modified the sentence to:

Page 31, lines 657-658:

‘Only 1% or less drops out of a moving dust cloud within five minutes, hence, the horizontal dust flux is at least ~100 times higher than the dust deposition flux (Goossens, 2008).’

Comment of Referee #1:

Line 613-614: Replace “in the following” by “as follows”.

Reply to comment:

We excluded the sentence according to the comments on the fluxes above.

Changes made in manuscript:

We removed the paragraph:

‘The stronger decrease in the dust fluxes from site Iwik to CB during summer compared to winter (Table 4) may be explained in the following. During summer, dust was additionally transported with the trades to the site Iwik, (Fig. 9-12) leading to anomalously higher dust deposition at site Iwik compared to the oceanic sites. Further, the washout of dust during offshore transport may have depleted the atmospheric dust cloud resulting in strongly decreased dust deposition fluxes at site CB compared to site CBi during summer.’

Comment of Referee #1:

Line 638: You could stress stronger that a bi-modal size distribution (as observed e.g., at Iwik in Fig. 6c) be indicative for nearby sources. Different size modes typically indicate different sources!

Reply to comment:

Yes, of course bimodal distributions are indicative for different sources. Since this has not been stated clearly enough, we further stressed this in the manuscript. Bimodal distributions may further be indicative of precipitation in the study area due to the deposition of fine particles from higher altitude. This is discussed in the text in chapter 4.1.2.

Changes made in manuscript:

We inserted the following sentence:

Page 32, lines 683-684:

‘Bimodal grain-size distributions typically indicate the sampling of different dust sources (Stuut et al. (2009) and references therein).’

Comment of Referee #1:

Line 641: Not only the wind speed, but also the heights into which dust was emitted, will influence how far it can be transported.

Reply to comment:

Absolutely right. We modified this in the manuscript.

Changes made in manuscript:

We modified the following sentence:

Page 32, lines 687-689:

‘Therefore, it may be possible that wind velocities were high enough during the sampling interval to inject dust to higher altitude and transport it from more distant sources (Fig. 12b) to the sampling site resulting in the small peak in the grain-size distributions.’

Comment of Referee #1:

Line 648: I have a hard time imagining how precipitation droplets (with typically high fall velocities) enter your sampler in noticeable amounts. Or do you suggest here that precipitation is formed, falls, evaporates during its fall and leaves these dust particles behind at lower altitudes which can then be sampled? If this is so, mention it. This is only partly true as there were clearly remnants of water in the bottles. So, both are true!

Reply to comment:

Yes, thanks, it could be a good explanation that precipitation evaporates during its fall leaving the dust particles behind at lower altitude. So we added this to the text. However, we also observed that there were clearly remnants of water in the bottles. So also wet deposition into the bottles may have occurred!

Changes made in manuscript:

We inserted the sentence:

Page 32, lines 698-700:

‘The rain droplets may have evaporated during their fall releasing the dust particles at lower altitudes which can then be sampled with the MWAC sampler. However, we also observed some remnants of water in the bottles and therefore wet deposition into the bottles may have also occurred.’

Comment of Referee #1:

Line 692: Prior to this line, you explain that quartz seems to be present “everywhere” in North Africa. If this is the case, a high quartz content cannot be used to assume that it is mainly locally derived dust.

Reply to comment:

Good point. We removed the sentence.

Changes made in manuscript:

We removed the sentences:

‘Moreover, the continental sampling site is surrounded by sand dunes which are rich in quartz minerals (Schlüter, 2008;Lancaster, 2013). A high quartz content may therefore point to predominantly locally derived dust.’

Comment of Referee #1:

Line 736: This argument can only be correct if only this one nearby source does not have the mineral palygorskite in it, while it would be present in ALL other sources. Also: not finding palygorskite might simply be an issue of low sampling statistics – can you exclude this? So overall: Can this text in the manuscript really be stated like this? This is also connected to what you state in line 709, so check this location for consistency, too.

Reply to comment:

We revised the sentences in the manuscript in which this was stated incorrectly. Palygorskite may have been derived from several local sources in which it was not present in the soils instead of a single localized source.

Changes made in manuscript:

We modified the sentence:

Page 35, lines 779-780:

‘Therefore, we argue that the sampled dust was most likely derived from a localized source of **PSA 2**.’

Page 35, lines 793:

‘This may point to several externally mixed sources of **PSA 2** during transport.’

Page 36, lines 807-808:

‘Again, the absence of the mineral palygorskite is noteworthy which may point to the sampling of a localized dust source.’

Page 36, lines 820-821:

‘Hence, dust may have been supplied from several dust sources of **PSA 2** which were mixed during transport.’

Comment of Referee #1:

Line 784 ff: How fast do dust particles sink in the water – can they travel 500km and still be collected at the sampling site CBi? Or, in other words, how large is the catchment area of a trap? You mention 40km * 40 km above in the text yourself for the upper trap? Therefore, it seems that the here described time delay cannot be used as an explanation.

Reply to comment:

We argued that certain clay minerals may have been transported with the undercurrent to the sampling site. When not incorporated into marine aggregates clay minerals can easily be transported over long distances within nepheloid layers (ca. 500 km) because of their small size.

Comment of Referee #1:

Line 833-835: For continental sampling, rather than using the word “trade wind”, the word “nearby sources” would be more appropriate. Also, the discrimination between dust particles transported in the SAL or by the trade winds is awkward. The trade winds transport the SAL, while the SAL is the source of particles that deposit from air masses that are moved by the trade winds. In this sense, “trade wind” and “SAL” both contribute together and should not be separated. The formulation needs rewording. Also check the whole text to remove respective inconsistencies.

Reply to comment:

We agree that the sentence should be reformulated.

Changes made in manuscript:

We modified the sentence:

Page 39, lines 909-911:

- ‘dust deposited on the continent was predominantly transported from near-by local sources (Mauritania, Western Sahara and Mali), while dust deposited in the marine traps was transported from proximal (Mauritania, Western Sahara and Mali) and distal sources (Algeria and Libya)’

Comment of Referee #1:

Line 836-837: This result was only presented in bypassing (line 731 – or am I missing something), and I was quite surprised to see this as one of the main findings. On the other hand, changing grain sizes with distance to sources are not mentioned at all. I suggest to really reconsider which of your results are worth mentioning here, as for some readers, abstract and summary might be all they will ever look at.

Reply to comment:

Yes, you are right, this was not one of the major findings so we removed it from the summary and conclusions. The downwind decrease in particle size is mentioned in the discussion on page 32, lines 676-682 and pages 33-34 lines 752-756.

Changes made in manuscript:

We removed the sentence:

- ‘the percentage of mica relative to the quartz content increased in the deposited dust with increasing transport distance, most likely due to the platy shape of these minerals, which reduces settling’

Comment of Referee #1:

Line 842 ff: The wind at the sampling location might differ from the wind in the source region, if the latter is far away, and the sizes of dust particles present in the source region will influence the grain sizes that can be deposited as well. There might still be a connection between wind speed and transported grain size, but it should be discussed in a broader sense, including (or at least mentioning) the points I raise in the previous sentence.

Reply to comment:

We included these considerations in the summary and outlook of the revised manuscript.

Changes made in manuscript:

We inserted the sentence:

Page 39, lines 919-922:

‘It should be kept in mind, however, that the wind in the sampling location might differ from the wind in the source region if the source region is further away. Moreover, the sizes of dust particles present in the source region will influence the grain sizes of deposited dust.’

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Anonymous Referee #2

Received and published: 31 March 2017

In the manuscript, "Seasonal provenance changes of present-day Saharan dust collected on- and offshore Mauritania" the authors present data from sediment traps at multiple depths off the coast of Mauritania and surface collection sites close to the coast. They attempt to determine location and seasonality in potential source regions for different case studies based on the mineralogy of the samples and back trajectory analysis.

Comment of Referee #2:

The description of the methodology and measurements is comprehensive and well thought out. I cannot speak to the specifics of the measurement methodology but have added minor comments and clarification requests below. Unfortunately, the broader context and the scientific developments are lacking in the paper. The measurements are clearly valuable and should be published. The analysis of collected samples and the potential source regions is thorough in a qualitative sense. However, the useful scientific conclusions are not clear. This is indicated by the abstract that reads more like an introduction, the long, subjective discussion, and the relatively sparse summary and conclusions. For example, the last paragraph of the manuscript states that sediment records from land and ocean are likely to sample different source regions, based on the measurements showing more local sources over land. This could be an interesting point, but without further analysis (firmer understanding of the sources, dependence on the particular measurement site) the conclusion that sources are more likely to be local on land than at an ocean site further downwind seems common sense. I'm also not convinced that the atmospheric and sediment trap data should be presented side by side based on the difference in collection methodology and catchment. I think the authors need to consider how to better frame the important measurements presented in this manuscript, by presenting the data in a way that is easier to compare with other dust deposition and concentration measurements and a more thorough back trajectory analysis that answers the questions laid out in the introduction.

Comment of Referee #2:

The choice of questions (lines 76-79) is a little strange. For example, (1) why would one not expect there to be seasonality in the deposition when we know that there is seasonality in winds leading to dust emission and transport? (2) This is an interesting question, but how dependent is this on the specific locations chosen? (3) This is very similar to question (1). (4) This is a good question but is only tackled in a qualitative way in the manuscript. I think laying out the questions to be answered is a good format; however, they currently seem like an afterthought and they should be returned to explicitly in the summary/conclusions.

Reply to comment:

Yes, it is correct that the questions were not formulated and addressed adequately in the old version of the manuscript. Therefore, we modified the research questions. Further, we answered them more precisely in the

discussion, summary and conclusions part of the revised manuscript. Especially the newly developed table 6 which was demanded by reviewer 1 should help to answer the revised research question 2-3.

Changes made in manuscript:

We modified the research questions (page and line numbers refer to the revised manuscript):

Page 3, lines 76-79:

- 1) What is the seasonal variability in particle size of mineral dust deposited on land? How does the variability relate to meteorological parameters (wind speed, precipitation)?
- 2) What are the source regions of dust trapped on land versus dust trapped in the ocean?
- 3) Can we identify characteristic minerals that constitute a tracer for certain source areas?

We inserted the sentences:

Page 32, lines 701-703:

‘During summer, frequent rainfall resulted in a decrease of the particle sizes of deposited Saharan dust at the site Iwik (Fig. 7c). This observation may also be explained by the deposition of finer dust particles from higher altitude of the SAL due to precipitation.’

Page 32, lines 706-711:

‘Both at the onshore sampling site Iwik and at the offshore sampling site CBI a clear seasonal trend in the particle sizes of deposited dust could be observed with generally coarser modal particle sizes during summer (Fig. 6b,c). Generally coarser summer modal particle sizes of deposited dust at site CBI were observed before for a three year time series during 2003 to 2006 and related to moist convective dust storm events (Frieese et al., 2016). The generally coarser particle sizes during summer at the site Iwik may be explained by the trade wind speed as a positive correlation between the modal grain sizes and surface wind velocities was observed (Fig. 7a).’

Page 33 lines 717-719:

‘To sum up, the seasonal variability in the particle size of deposited dust at the site Iwik was mainly driven by the surface wind speed due to the predominant sampling of nearby dust sources year-round.’

Page 39, lines 906-913:

- A clear seasonal variability in the particle size of mineral dust deposited on land could be observed with generally coarser modal grain sizes during summer compared to winter. The modal particle sizes could be related to the trade wind speed.

- dust deposited on the continent was predominantly transported from near-by local sources (Mauritania, Western Sahara and Mali), while dust deposited in the marine traps was transported from proximal (Mauritania, Western Sahara and Mali) and distal sources (Senegal and Libya).
- Some rare characteristic minerals (e.g. ferryglaucophane, rutile, serpentine) could be related to local outcrops in NW Africa.

We inserted a new table:

Page 34, lines 760-764:

‘In Table 7 an overview of the chosen dust source areas for the site Iwik and CBI is given together with the characteristic minerals of the samples that may be used as a tracer for the source area. In the following subsections the identification of the source areas and mineralogical tracers is described in detail.

Table 7: Overview of the chosen source areas and the tracer minerals of the individual samples together with the given characteristics of the source areas according to literature. ‘

Sampling interval	Characteristic minerals of sample	Chosen dust source area	Bulk mineralogical composition of chosen PSA ⁽¹⁶⁾	Characteristic source rocks and deposits of chosen source area
Iwik				
15.02.-15.03.14	*Rut, Serp, Cc	PSA 2: Reguibat Shield	C/K = 0.0–1.0 *Pal: 1-30 wt%	Metamorphic and granitic rocks ⁽¹⁾ Serpentinities ⁽²⁾
15.12.14-18.01.15	*Cc, Chl, Pal (8 wt. %)	PSA 2: Senegal-Mauritania Basin	C/K = 0.0–1.0 *Pal: 1-30 wt%	Chalky horizons ⁽³⁾
		PSA 3: Eastern Taoudeni Basin	C/K = 0.2–0.9 *Pal: 1-5 wt%	Carbonate sequences ⁽⁴⁾
24.06.-15.07.13	*Gib	PSA 2: Tidra Island	C/K = 0.0–1.0 *Pal: 1-30 wt%	Gibbsite maximum offshore Cape Blanc ⁽⁵⁾
15.08.-15.09.14	*Cc, Dol, Pal (5 wt. %)	PSA 2: Aaiun-Tarfaya Basin	C/K = 0.0–1.0 *Pal: 1-30 wt%	Limestone deposits ⁽⁶⁾ Outcrops near Laâyoune with dolomites ⁽⁶⁾
CBI				
26.02.-18.03.14	*Chl, Kao (C/K = 1), Pal (11 wt. %), Flu, Anh, Sme, Ga	PSA 2: Aaiun-Tarfaya Basin near Boucraa	C/K = 0.0–1.0 *Pal: 1-30 wt%	Phosphate deposits ⁽⁷⁾
16.12.14-04.01.15	*Kao (C/K = 0), Pal (1 wt. %), Zeo, Se, Sme	dike swarms and sills of northern Taoudeni Basin	-	Basalts with glass ⁽⁹⁾
		PSA 2: Aaiun-Tarfaya Basin	C/K = 0.0–1.0 *Pal: 1-30 wt%	Palygorskite-sepiolite mafic clays ⁽¹⁰⁾
		Southern Senegal-Mauritania Basin	-	Lateritic soil ⁽⁸⁾ Horizontal layers of palygorskite and sepiolite ⁽⁸⁾
25.06.-16.07.13	*Chl, Pal (2 wt. %), Rut	PSA 2: Mauritanides	C/K = 0.0–1.0 *Pal: 1-30 wt%	Strongly metamorphosed rocks ⁽¹⁰⁾ Greenschist facies ⁽¹¹⁾
01.08.-21.08.14	*Fe-Amf, Zeo	dike swarms and sills of northern Taoudeni Basin	-	Basalts with glass ⁽⁹⁾
		PSA 4: Fezzan uplift	C/K = 0.0–2.6 *Pal: 0 wt%	Zeolite in basaltic rocks ^(12,13)
		PSA 3: Pharusian belt	C/K = 0.2–0.9 *Pal: 1-5 wt%	Blueschists ⁽¹⁴⁾ Glaucophane bearing eclogites ⁽¹⁵⁾
* Amf = amphibole, Pal = palygorskite, Chl = chlorite, Cc = calcite, Dol = dolomite, Gib = gibbsite, Zeo = zeolite, Kao = kaolinite, Sme = smectite, Se = sepiolite, Rut = rutile, Serp = serpentine, Ga = garnet, Anh = anhydrite, Flu = fluellite				
⁽¹⁾ Schofield et al. (2006) and references therein ⁽²⁾ Schlüter (2008) ⁽³⁾ Wissmann (1982) ⁽⁴⁾ Bertrand-Sarfati et al. (1991) ⁽⁵⁾ Biscaye (1964) ⁽⁶⁾ Bosse and Gwosdz (1996) ⁽⁷⁾ Moreno et al. (2006) ⁽⁸⁾ García-Romero et al. (2007) ⁽⁹⁾ Verati et al. (2005) ⁽¹⁰⁾ Villeneuve (2005), ⁽¹¹⁾ Dallmeyer and Lécorché (2012) ⁽¹²⁾ Abdel-Karim et al. (2013) ⁽¹³⁾ Cvetković et al. (2010) ⁽¹⁴⁾ Caby (2014), ⁽¹⁵⁾ Caby et al., 2008) ⁽¹⁶⁾ Scheuven et al. (2013)				

Comment of Referee #2:

While the back trajectory analysis is interesting, it is rudimentary. The choices of back trajectory heights appear to be arbitrary, I did not find a reason for the choice of 4500 m and 10 m is understandable, but those trajectories will be highly uncertain. A larger ensemble of back trajectories from different altitudes and start points would better quantify the likelihood of dust sources and also help represent the uncertainties in back trajectories that pass so close to the surface.

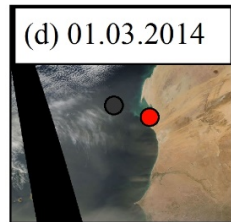
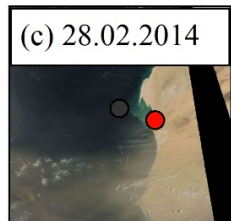
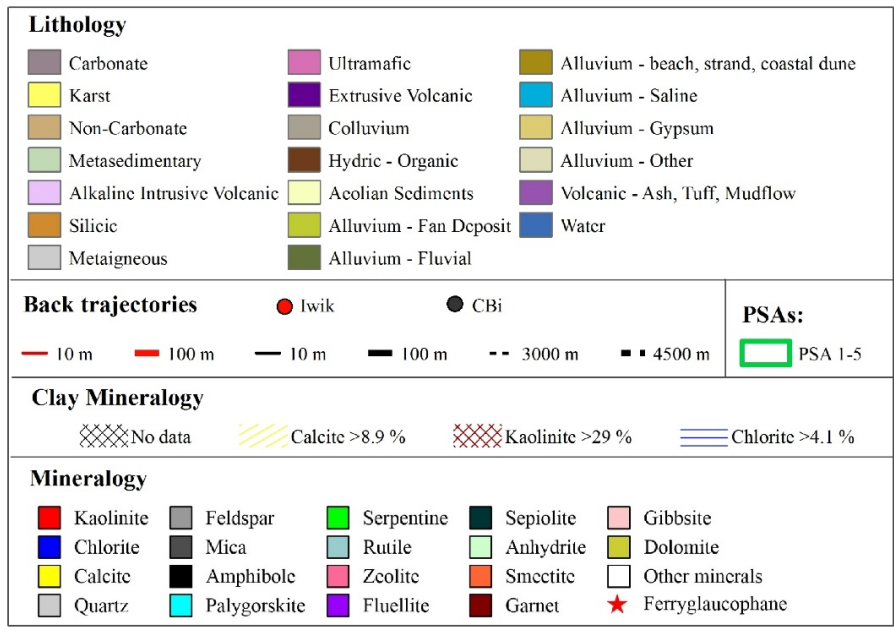
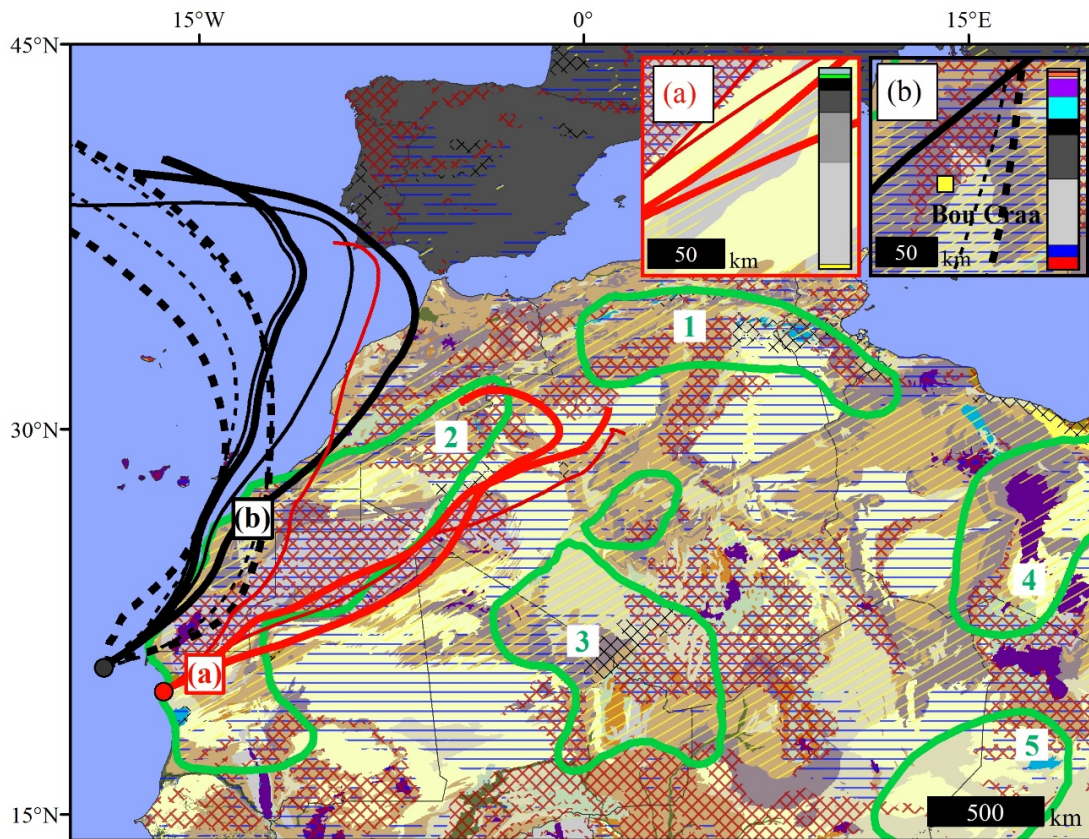
Reply to comment:

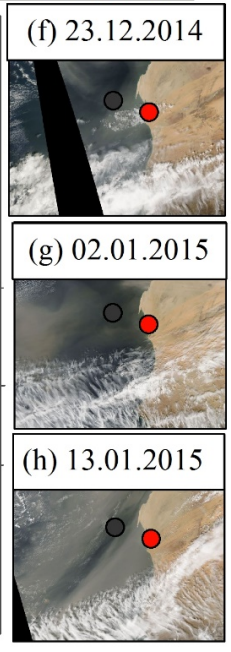
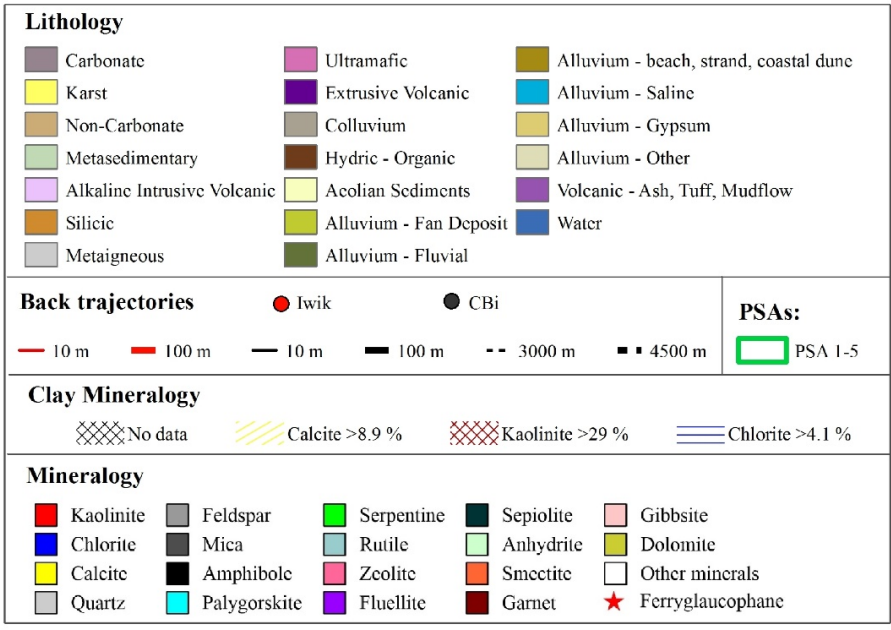
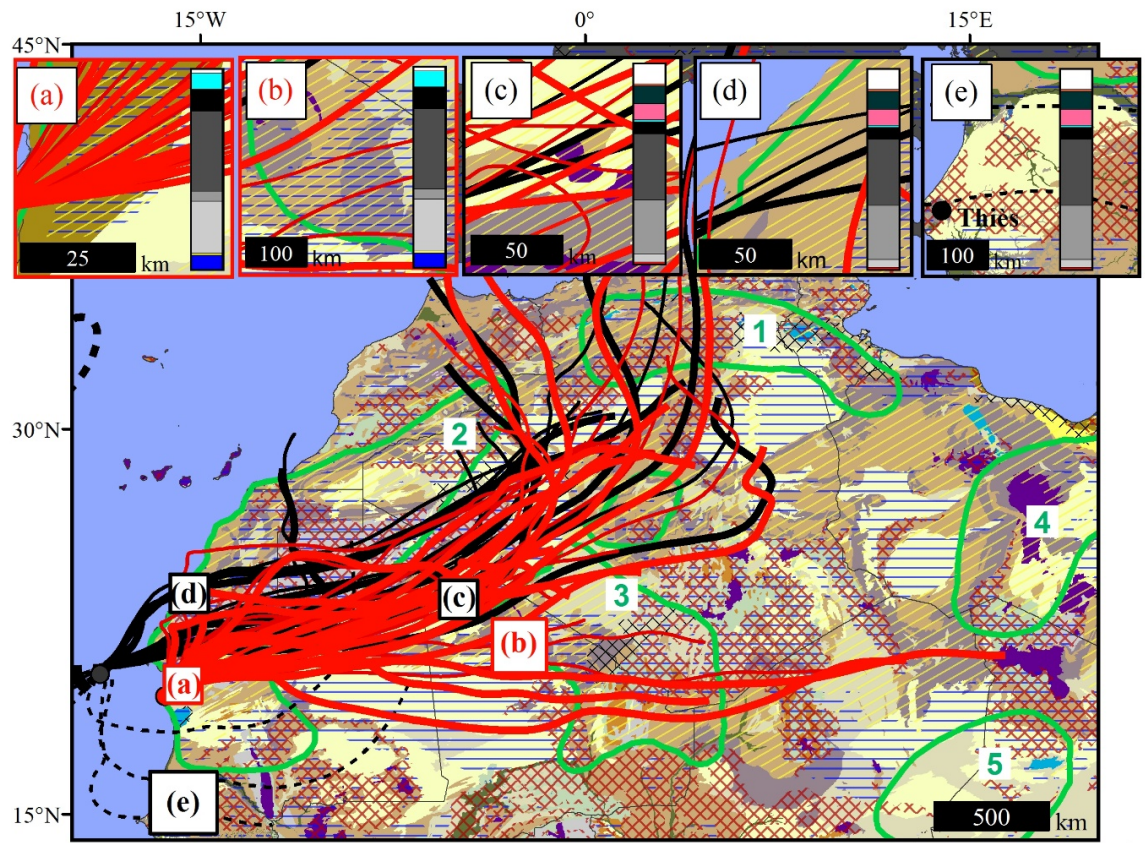
This comment was raised by reviewer #1 as well. We have chosen the altitudes for back trajectories on the basis of previous studies to which we compared our data. For example, Skonieczny et al. (2013) used 4500m to study the SAL. Following the reviewer's suggestion, we now also included additional back trajectories, which made the observed patterns much clearer. Back-trajectories of the heights 100 m and 3000 m were added to figures 9-12. This improved the detection of the likely dust source areas and the results and interpretations were adjusted accordingly.

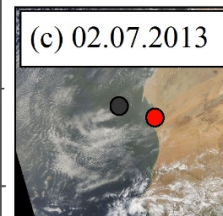
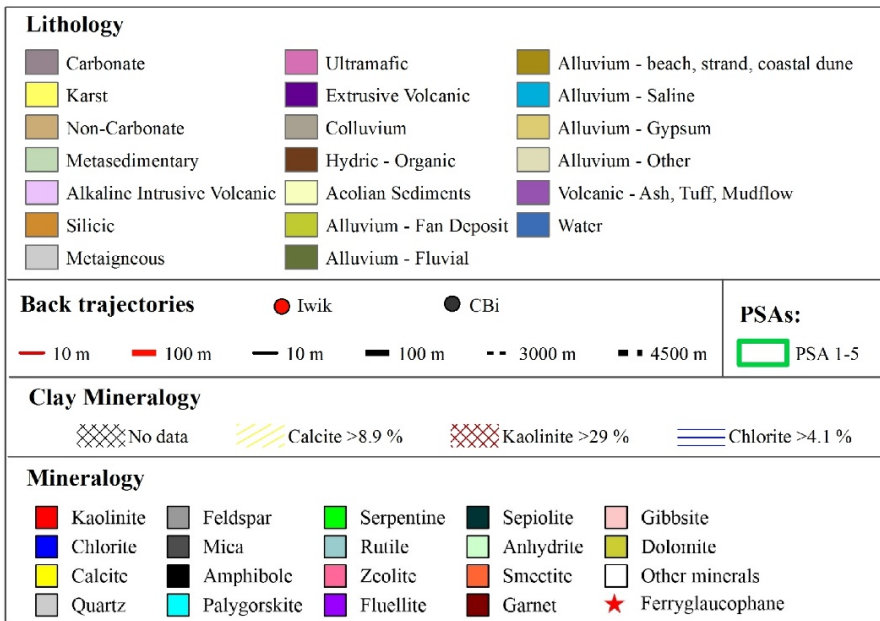
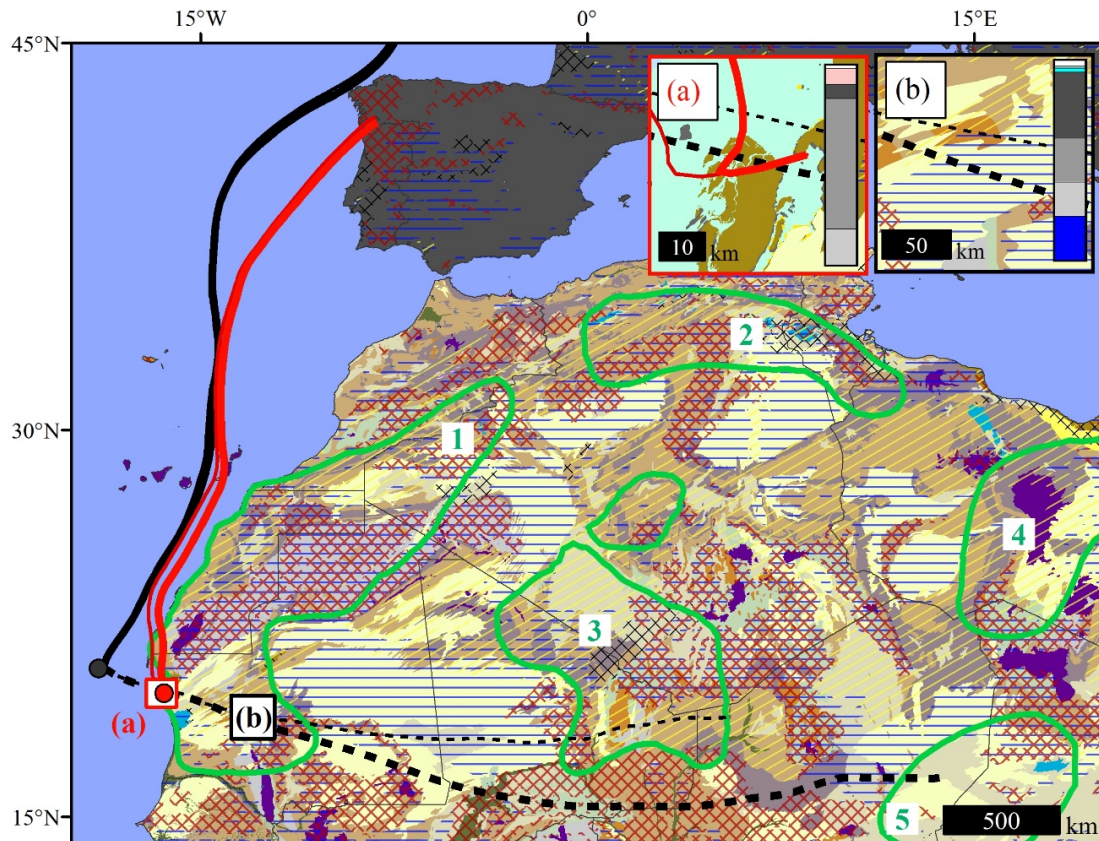
Changes made in manuscript:

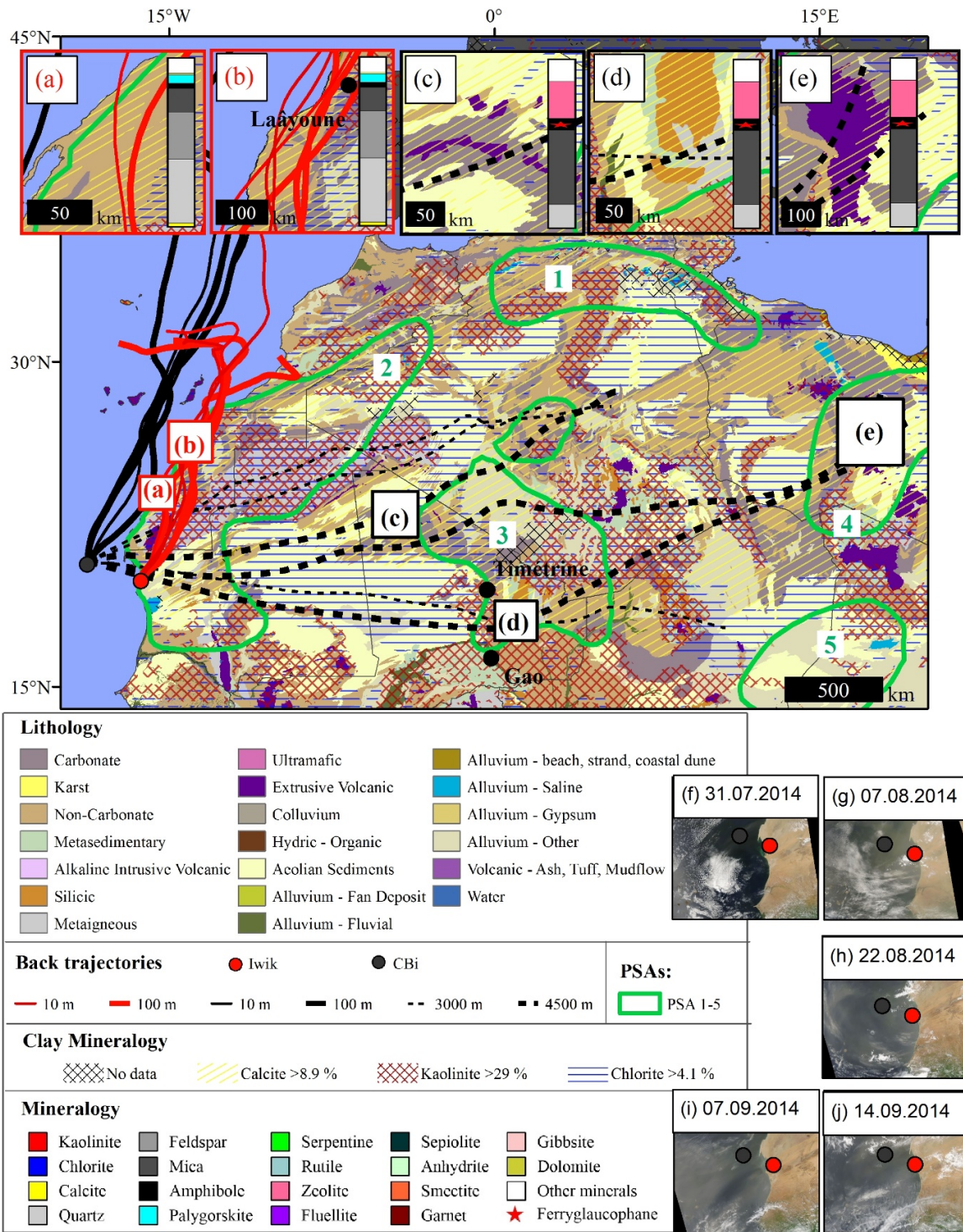
We modified fig. 9-12:

Page 24, line 563:









We modified the following sentence to:

Page 14, lines 373-377:

‘Four-day back trajectories at altitudes of 10 (following Stuu et al. (2005)), 100, 3000, 4500 (following Skonieczny et al. (2013)) and 5500m were calculated ending at the dust collector site Iwik (19°52’ N, 16°17’ W) and at the proximal marine trap site CBi (20°46’, 18°44’ W) using the Hybrid Single Particle Langrangian

Integrated Trajectory (HYSPLIT) model (Stein et al., 2015) and the reanalysis dataset (2.5° spatial resolution) on the NOAA website at <http://ready.arl.noaa.gov>.

We modified the following sentences:

Page 22, lines 546-547:

‘Four heights, 10, 100, 3000 and 4500 m were chosen to cover both low- (trades) and high-level (SAL) dust transport.’

Page 22, lines 551-552:

‘The back-trajectories at 5500 m can be found in the supplements.’

Page 23, lines 561-562:

‘Thus, the source area of the samples was most likely the chlorite and kaolinite rich sediments located near the Bou Craa phosphate mine in the Western Sahara (Fig. 9b).’

Page 25, lines 581-584:

‘A further source area might be the southern shoreline of the Western Sahara in which chlorite depleted sediments are situated (Fig. 10d). The presence of the mineral kaolinite in this marine winter sample may be explained by a kaolinite-rich source area lying in the southern Senegal-Mauritania Basin (Fig. 10e).’

Comment of Referee #2:

Further, including surface wind reanalyses (and other meteorology) in a comprehensive analysis of the mineralogy measurements and back trajectories, a more rigorous statistical analysis of likely source regions could be undertaken. A statistical approach would also provide a framework to analyze future measurements, rather than the case-by-case methodology shown. This would also help reduce the speculative nature of the discussion of sources in Section 4.2.

Reply to comment:

Very good point. We followed your advice and executed an analysis of surface wind reanalysis data (20th century reanalysis V2c dataset). This analysis proved anomalously high surface wind velocities for the respective dust storm events and chosen dust source areas. Therefore, the analysis supported the derivation of the source regions based on mineralogy.

Changes made in manuscript:

We inserted the following sentences:

Page 13, lines 362-364:

‘Maps of six hourly mean surface wind vectors and speed (20th century reanalysis V2c dataset) were provided by the NOAA/OAR/ESRL PSD, (Boulder, Colorado, USA) and downloaded from their website (<http://www.esrl.noaa.gov/psd/>). ‘

We inserted the following paragraph and figure:

Page 29-30, lines 621-632:

‘In Fig. 13a-d the mean wind vectors and speed are presented for chosen dust storm events. The individual dust source areas that were identified using the back trajectory of the day with the dust storm as shown in Fig. 9-12 are further displayed in Fig. 13a-d. As can be clearly seen in the subfigures, the mean wind velocities were anomalously large in the chosen dust source areas which enabled dust emission. During winter, six hourly mean wind velocities were larger than 7 ms^{-1} in the chosen dust source areas (Fig. 13a-b). During summer 2013, six hourly mean wind velocities were larger than 6 ms^{-1} in the chosen dust source area (Fig. 13c). During summer 2014 extremely high mean wind velocities were encountered near the study sites and in the dust source area enabling dust emission and transport from a more distant source to the site Iwik (Fig 13d).

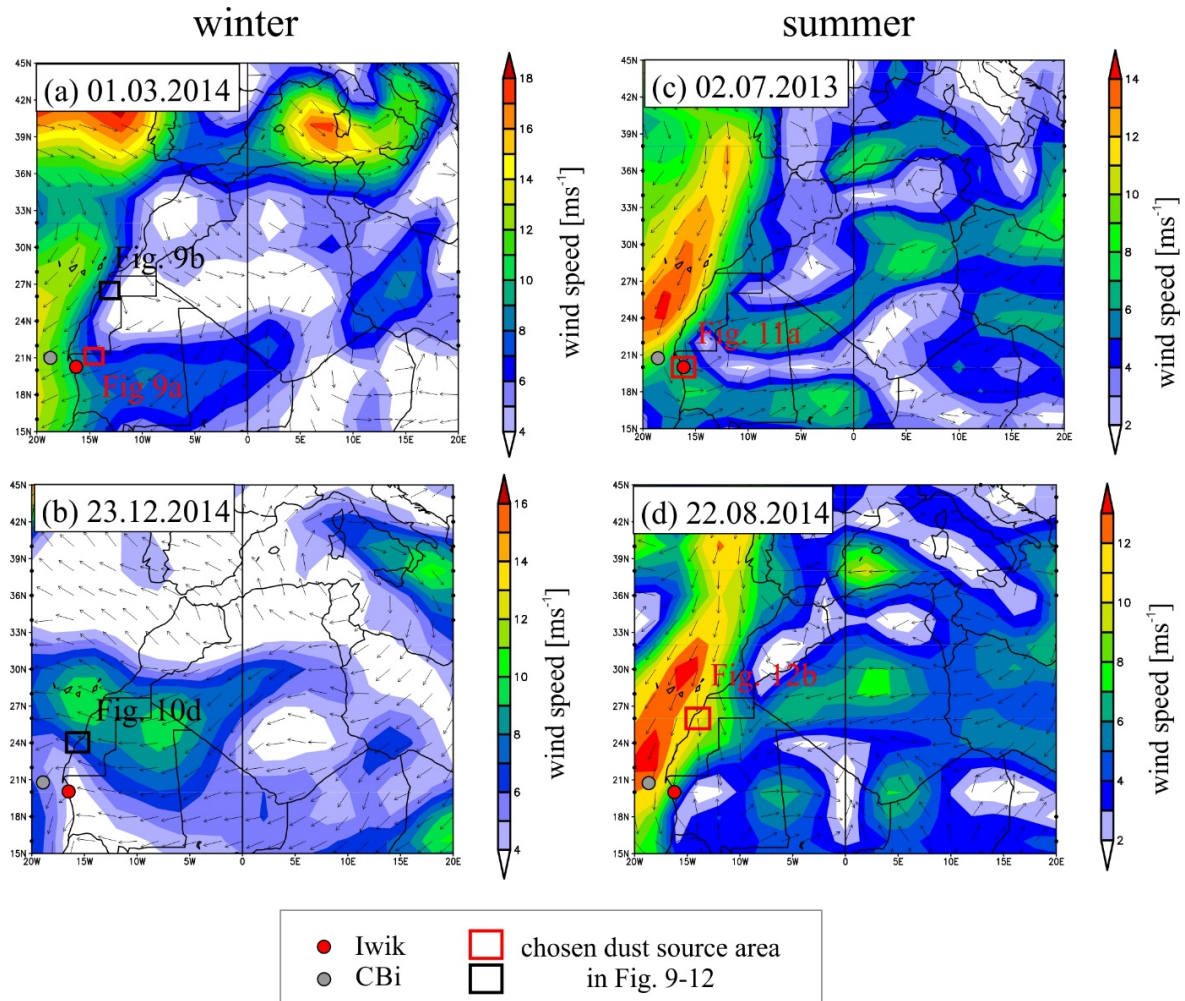


Figure 13: Six hourly composite mean wind vectors and speed at 1000 mb for selected days including a dust storm event during winter (a) – (b) and summer (c) – (d). The dust source area that was identified for the individual dust storm event using the back trajectory of the day with the dust storm is further displayed.’

We inserted the sentence:

Page 32, lines 689-691:

‘This interpretation is further supported by the reanalysis wind vector maps showing anomalously high wind velocities between the site Iwik and the proposed distant source area enabling dust emission and transport of dust particles from the more distant source to the site Iwik (Fig. 13d).’

Comment of Referee #2:

Are the distributions really unimodal in Figure 6, as stated on line 620? I can see the finer mode and sometimes a third mode in there.

Reply to comment:

You are right. Some distributions have a finer mode. However, most of the distributions are unimodal. This may have been formulated unclearly in the old version of the manuscript. Therefore, we modified the sentence.

Changes made in manuscript:

We modified the sentence to:

Page 31, lines 664-665:

‘The measured grain-size distributions for dust trapped at 2.90 m on land at site Iwik and for dust settling in the ocean were predominantly unimodal (Fig. 6).’

Comment of Referee #2:

Coming from an atmospheric modeling perspective, the mode between 1-10 μ m is of great interest and it is a shame that this is not discussed more. From an atmospheric perspective, the value of this work could be increased by presenting more information on the finer dust particles. Models are always in need of aerosol size distribution measurements for evaluation of dust emission, transport and deposition.

Reply to comment:

We also agree that we should describe the modes of the offshore dust samples more in detail as we have described the fine mode of the Iwik samples. Therefore, we added a more detailed description in the result section. The reason for the fine mode which we observe in the CBi samples may be mainly due to different transport distances and source areas as has been already stated in the discussion part of the old manuscript on page 32, lines 699 -701.

Changes made in manuscript:

We inserted the sentences:

Page 19, lines 467-468:

‘The eight bimodal grain size distributions of the CBi 11-12 time series were characterized by a variable coarse mode at \sim 25 to 35 μ m and a variable fine mode at \sim 6 to 16 μ m.’

Comment of Referee #2:

It would also be useful to have the size distributions presented as $dM/d\ln D$ or $dV/d\ln D$ to allow for comparison with model simulations and other measurements.

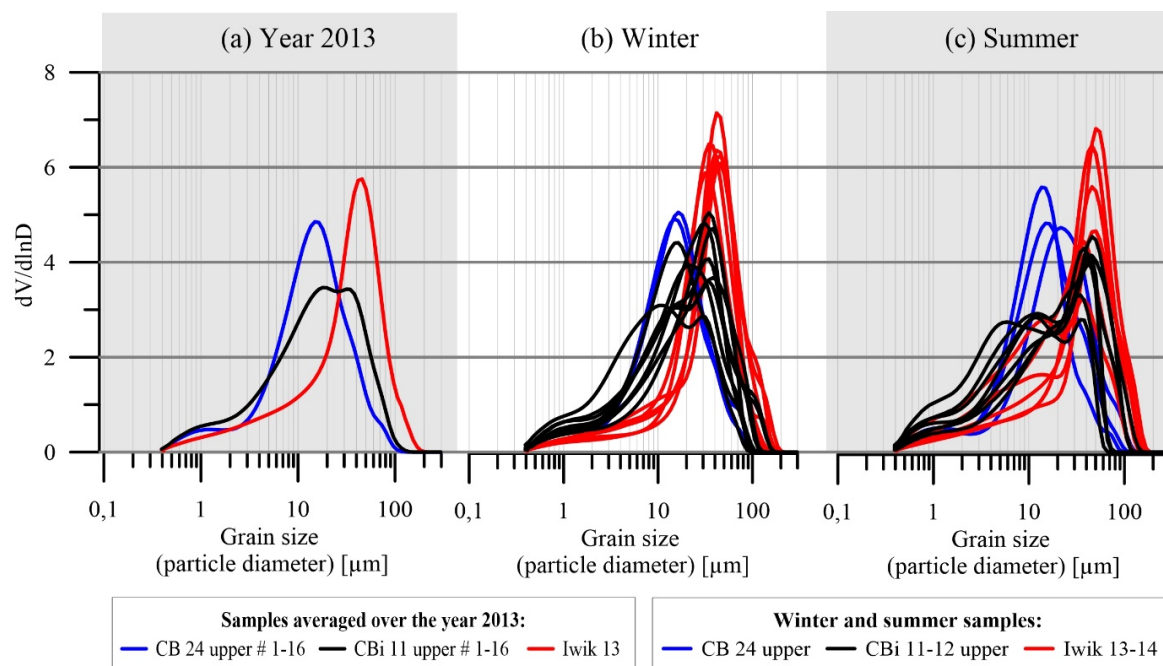
Reply to comment:

Good point as many modellers read and publish in the journal ACP. Therefore, we followed your suggestion and revised the figure 6.

Changes made in manuscript:

We modified figure 6:

[Page 19, lines 480:](#)



Comment of Referee #2:

To summarize, I think:

- The measurements and presentation of the results are of great value

- Determining dust sources could benefit greatly from an analysis of surface winds from meteorological reanalyses to accompany the back trajectories.

- The summary and conclusions seems like an afterthought in the current presentation.

Consider expanding this to crystallize the findings of the research better.

- The questions to be answered that are set out in the introduction are vague. It is useful to set out the motivational questions for the manuscript in this way, but I think more time should be put into the questions to be addressed and then ensuring that you return to these points in the discussion/summary/conclusions.

Reply to comment:

Since this comment summarizes the above mentioned comments, we have already answered them above.

Minor Comments

Comment of Referee #2:

line 14-15, 34 "Environmental parameters" is non-descriptive. Please revise. Line 34 could be deleted.

Reply to comment:

We revised the sentences to clarify what we mean by environmental parameters. Further, we also agree that line 34 could be deleted.

Changes made in manuscript:

We modified the sentences:

Page 1, lines 13-16:

‘Saharan dust has a crucial influence on the earth climate system and its emission, transport, and deposition are intimately related to e.g. wind speed, precipitation, temperature and vegetation cover. The alteration in the physical and chemical properties of Saharan dust due to environmental changes is often used to reconstruct the climate of the past.’

Comment of Referee #2:

line 95 "In the following," - add comma

Reply to comment:

We revised this sentence.

Changes made in manuscript:

Page 4, lines 107:

‘In the following, the lithology of the geological provinces that underlay the major PSA’s is outlined (Fig. 1). ‘

Comment of Referee #2:

line 131 - Haboobs are normally defined as the dust storm from evaporatively driven cold pool outflow from convective events, not low-level jets

Reply to comment:

This was formulated unclearly. Of course, haboobs are not low-level jets. The sentence included an enumeration of dust emission mechanism. To prevent confusion, we excluded the ‘so called’ from the sentence.

Changes made in manuscript:

We revised the sentence to:

Page 5, lines 144-145:

‘Dust emission is driven by low level jets, ‘haboobs’, African easterly waves (AEWs) and high surface winds associated with the Saharan heat low (Knippertz and Todd, 2012).’

Comment of Referee #2:

line 161-163 - this paragraph seems disconnected from the rest of the section

Reply to comment:

This comment is similar to the comment of reviewer # 1 who asked for a paragraph and figure in which all study sites are introduced together. Therefore, we shifted this paragraph to the introductory sentences of the other study sites and modified it accordingly.

Changes made in manuscript:

We shifted and modified the sentences to

page 3, lines 82-88:

‘In Fig. 1 the location of the study sites and the North African dust sources are displayed. The dust-collecting buoy ‘Carmen’ (~21°15’ N, ~20°56’ W) and the sediment trap mooring site CB (~21°16’ N, ~20°48’ W) are virtually at the same position ~200 nautical miles offshore Cape Blanc. Sediment-trap station CBI (~20°45’ N, ~18°42’ W) is located ~ 80 nautical miles offshore Cape Blanc. The continental dust collector Iwik (~19°53’ N, ~16° 18’ W) and the meteorological station Arkeiss (~20° 7’ N, ~16° 15’ W) are located in a major potential dust source area (**PSA 2**) in the Parc National de Banc d'Arguin (PNBA) near Iwik and near Arkeiss in Mauritania. A further meteorological station is positioned in the **PSA 2** in Nouadhibou (~20° 55’ N, ~17° 1’ W) in the Western Sahara. ‘

Comment of Referee #2:

line 222 and 235 repeat

Reply to comment:

We merged the two sentences.

Changes made in manuscript:

We removed the sentence:

‘The masts were aligned to the ambient wind direction via a wind vane (Fig. 2).’

We modified the sentence:

Page 10, lines 256-257:

‘The masts of the buoy Carmen and of the Iwik dust sampler were aligned to the ambient wind direction via a wind vane (Fig. 2).’

Comment of Referee #2:

line 247 - why is 2xCorg removed from the total mass? Is this a general scaling from organic carbon to organic mass?

Reply to comment:

Yes. About 50-60 % of marine organic matter is constituted by organic carbon. Therefore, we estimated the organic matter by multiplying organic carbon by a factor of two.

Comment of Referee #2:

line 350 - I think the long url links should go in the data availability section rather than in the text. Write out the usage but simply reference the data section rather than talking about downloading files in the manuscript.

Reply to comment:

Good point as this will improve the readability of the manuscript. We modified the section '2.8 Mapping with ArcMap' by removing the long url links.

Changes made in manuscript:

The following sentences were modified to:

Page 14, lines 378-382:

'An ArcGIS layer file of the African surface lithology (new_af_lithology_w_glbcvr_waterbdy_90m_dd84_final.lyr) was downloaded from the U.S. Geological survey (USGS) website (<http://rmgsc.cr.usgs.gov>).

An ArcGIS shape file of the African soils (DSMW.shp) was downloaded from the website of the food and agriculture organization of the United Nations (FAO) (<http://www.fao.org>).'

Comment of Referee #2:

line 357-358 - this repeats the previous sentence, condense.

Reply to comment:

We condensed the two sentences into one sentence.

Changes made in manuscript:

The sentence was modified to:

Page 14, lines 382-384:

‘The mean percentage of calcite (8.9 %), chlorite (4.1 %) and kaolinite (29%) in the clay fraction of Saharan soils in general and for each soil type is given by Journet et al. (2014).’

Comment of Referee #2:

line 377 - "ground station" could be misinterpreted as on land, consider "surface station"

Reply to comment:

We changed the word ‘ground station’ into ‘surface station’ all through the revised manuscript.

Changes made in manuscript:

Page 4, lines 98-100:

Figure 1: Map of the study sites under investigation: the scientific buoy Carmen as well as the sediment trap moorings CB and CBI offshore Cape Blanc, the MWAC dust collector onshore near Iwik and the surface stations near Nouadhibou and Arkeiss

Page 15, lines 395-396:

‘Regarding the surface stations Carmen and Arkeiss, a threshold of $>0.2 \text{ mmd}^{-1}$ was used in order to exclude events which may be related to anomalously high moisture instead of rainfall.’

Page 15, lines 405-407:

‘However, the spatial and seasonal trends observed by the TRMM data were not supported by the sensor on buoy Carmen and by the surface station in Arkeiss.’

Page 15, lines 408-410:

‘Further, disagreements between the surface stations and the TRMM stations maybe caused by the local signal recorded by the respective rain sensor.’

Page 16, line 416:

‘The wind direction and speed for the surface stations Carmen, Nouadhibou and Iwik are displayed in Fig. 4c.’

Comment of Referee #2:

line 461 - define "well sorted"

Reply to comment:

The same comment raised by reviewer # 1. 'Well sorted' refers to the standard deviation of the particle size distribution: the smaller the standard deviation the better the sorting. We added this information to the text.

Changes made in manuscript:

We inserted the sentence:

Page 19, lines 468-469:

'The standard deviation of a grain-size distributions is a measure of the sorting of the dust sample: the larger the standard deviation the weaker the sorting.'

Comment of Referee #2:

Figure 6 - These are not really unimodal, as referred in the text (line 620)

Reply to comment:

Most of them are unimodal, while some are bimodal. That was formulated unclearly. So we modified the sentence on line 620 of the old version of the manuscript.

Changes made in manuscript:

We modified the following sentence:

Page 31, lines 664 – 665:

'The measured grain-size distributions for dust trapped at 2.90 m on land at site Iwik and for dust settling in the ocean were predominantly unimodal (Fig. 6).'

Comment of Referee #2:

line 602 - which year?

Reply to comment:

That was for the year 2013.

Changes made in manuscript:

The sentence was modified to:

Page 31, lines 647:

‘At the distal oceanic site CB, the annual average dust deposition flux was $\sim 45 \text{ mgm}^{-2}\text{d}^{-1}$ (2013) (Table 4).’

Comment of Referee #2:

line 608 - is horizontal flux a useful metric to compare with ocean deposition?

Reply to comment:

We also realized that it is not possible to compare the dust fluxes measured at site Iwik with the dust fluxes of the sites CBi and CB due to the different sampling techniques and sampling heights. Therefore, we modified the paragraph on the dust fluxes.

Changes made in manuscript:

We modified the following paragraph:

Page 31, lines 655 – 661:

‘The average horizontal fluxes at site Iwik were ~ 1000 times larger with $\sim 100000 \text{ mgm}^{-2}\text{d}^{-1}$ (Table 5) due to the different sampling technique. The MWAC samplers do not measure deposition fluxes but foremost dust concentrations. Only 1% or less drops out of a moving dust cloud within five minutes, hence, the horizontal dust flux is at least ~ 100 times higher than the dust deposition flux (Goossens, 2008). The fact that the dust fluxes decreased with height (not shown) further complicated a comparison between the sites due to the different sampling heights of the dust collectors (2.90 m at Iwik, versus traps in the water). Therefore, the fluxes between the site Iwik and the offshore sediment trap moorings cannot be compared.’

Comment of Referee #2:

A minor issue, but there are formatting errors with brackets on the references throughout that need fixing.

Reply to comment:

We modified the references which were characterized by formatting errors.

Changes made in manuscript:

Page 2, lines 42-44:

‘For instance, the particle size of mineral dust in ocean sediment records varies according to the paleo-frequency of dust-storm and rainfall events (e.g. Friese et al. (2016)).’

Page 2, lines 50-56:

‘The source regions of Saharan dust have been studied frequently by analysing the mineralogical composition of dust collected at continental sites (e.g. Skonieczny et al. (2013); Skonieczny et al. (2011); Schütz and Sebert (1987); Kandler et al. (2009); Khiri et al. (2004)), during aircraft flights (e.g. Formenti et al. (2008)), on research ships (Chester et al., 1971; Chester et al., 1972; Stuut et al., 2005; Aston et al., 1973; Chester and Johnson, 1971b; Chester and Johnson, 1971a) and with gravity cores offshore NW Africa (Biscaye, 1964; Biscaye, 1965; Lange, 1982; Rateev et al., 1969; Griffin et al., 1968; Diester-Haass and Chamley, 1978; Meyer et al., 2013).’

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1 Seasonal provenance changes of present-day Saharan dust 2 collected on- and offshore Mauritania

3
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12 **Abstract.**

13 Saharan dust has a crucial influence on the earth climate system and its emission, transport, and deposition are
14 intimately related to e.g. wind speed, precipitation, temperature and vegetation cover. The alteration in the physical
15 and chemical properties of Saharan dust due to environmental changes is often used to reconstruct the climate of
16 the past. However, to better interpret possible climate changes the dust source regions need to be known. By
17 analysing the mineralogical composition of transported or deposited dust, potential dust source areas can be
18 inferred. Summer dust transport offshore Northwest Africa occurs predominantly in the Saharan air layer (SAL).
19 In continental dust source areas dust is also transported in the SAL, however the predominant dust input occurs
20 from nearby dust sources with the low-level trade winds. Hence, the source regions and related mineralogical
21 tracers differ with season and sampling location. To test this, dust collected in traps onshore and in oceanic
22 sediment traps offshore Mauritania during 2013 to 2015 was analysed. Meteorological data, particle-size
23 distributions, back-trajectory and mineralogical analyses were compared to derive the dust provenance and
24 dispersal. For the onshore dust samples, the source regions varied according to the seasonal changes in trade-wind
25 direction. Gibbsite and dolomite indicated a Western Saharan and local source during summer, while chlorite,
26 serpentine and rutile indicated a source in Mauritania and Mali during winter. In contrast, for the samples that were
27 collected offshore, dust sources varied according to the seasonal change in the dust transporting air layer. In
28 summer, dust was transported in the SAL from Mauritania, Mali and Libya as indicated by ferrylglaucophane and
29 zeolite. In winter, dust was transported with the Trades from Western Sahara as indicated by e.g. fluellite.

31 **Keywords**

32 Saharan dust, MWAC, sediment trap, mineralogy, particle size, major potential source area, provenance

33 1. Introduction

34 Mineral dust influences global climate through many feedback mechanisms and is in turn influenced by variations
35 in environmental parameters. The emission, transport and deposition of mineral dust reacts sensitively to
36 parameters of climate change like rainfall, wind, temperature and vegetation cover (Knippertz and Stuut, 2014).
37 In turn, the emission, transport and deposition of mineral dust has an impact on the atmospheric energy balance
38 (Haywood and Boucher, 2000), precipitation distribution and amplitude (Yoshioka et al., 2007), sea surface
39 temperatures (Lau and Kim, 2007) as well as the oceanic carbon pump (Martin et al., 1991; Martin, 1990; Jickells
40 et al., 2005; Iversen et al., 2010; Iversen and Robert, 2015; Ploug et al., 2008a). The sensitivity of mineral dust to
41 environmental parameters is used to reconstruct the climate of the past (Rea, 1994; Tjallingii et al., 2008; Mulitza
42 et al., 2010; Diester-Haass and Chamley, 1978; Holz et al., 2007; Stein, 1985). For instance, the particle size of
43 mineral dust in ocean sediment records varies according to the paleo-frequency of dust-storm and rainfall events
44 (e.g. Friese et al. (2016)). Further, the mineralogical composition of mineral dust in sediment core records can be
45 used as a qualitative proxy for paleo-dust source activity (Scheuven et al., 2013).

46 Every year, about 2000Mt dust are emitted from source areas around the world, of which 75% are deposited on
47 land and 25% into the oceans (Shao et al., 2011). The Saharan Desert is the world's largest source of mineral
48 aerosols with an annual dust transport of ~180 Mt westwards towards the North Atlantic (Yu et al., 2015). About
49 140Mt is actually deposited into the North Atlantic Ocean (Yu et al., 2015). Therefore, Saharan mineral dust
50 constitutes an essential component of the global climate system. The source regions of Saharan dust have been
51 studied frequently by analysing the mineralogical composition of dust collected at continental sites (e.g.
52 Skonieczny et al. (2013); Skonieczny et al. (2011); Schütz and Seibert (1987); Kandler et al. (2009); Khiri et al.
53 (2004)), during aircraft flights (e.g. Formenti et al. (2008)), on research ships (Chester et al., 1971; Chester et al.,
54 1972; Stuut et al., 2005; Aston et al., 1973; Chester and Johnson, 1971b; Chester and Johnson, 1971a) and with
55 gravity cores offshore NW Africa (Biscaye, 1964; Biscaye, 1965; Lange, 1982; Rateev et al., 1969; Griffin et al.,
56 1968; Diester-Haass and Chamley, 1978; Meyer et al., 2013). Continental dust studies in northern Morocco revealed
57 that dust is produced predominantly locally (Khiri et al., 2004; Kandler et al., 2009). For instance, a high percentage
58 of quartz and feldspar and a low amount of micas in the dust samples was interpreted to represent mostly local
59 dust sources and the availability of calcite sources from proximal coastal dunes in Morocco (Khiri et al., 2004).
60 Further, also in Morocco, dust was sampled in Tinfou at a height of 4 m during the SAMUM 2006 field campaign.
61 These samples were analysed for their physical and chemical properties. The particle size correlated to local
62 surface wind speed suggesting the contribution of local dust (Kandler et al., 2009). In contrast, in coastal Senegal
63 dust is sourced by the Sahel during winter as shown by low illite/kaolinite (I/K) ratios and lower palygorskite
64 contents as opposed to the summer samples which were suggested to be originating from the Sahara (Skonieczny
65 et al., 2013). Further, the I/K ratio in dust sampled on the Cape Verde Islands showed that dust was derived from
66 strongly varying sources: north-western Sahara, central and southern Sahara and the Sahel (Caquineau et al.,
67 2002). The results of the above mentioned studies imply that dust collected on land is predominantly of local
68 provenance, while the sources of dust sampled offshore NW Africa are of regional and long-distance provenance.
69 As a result, a large seasonal difference can be expected in the composition of the marine climate archives, related
70 to the different dominating transport mechanisms of dust in summer and winter (Friese et al., 2016).

71 To test this, we compared the mineralogical composition, the fluxes, and the particle size of Saharan dust sampled
72 from 2013-2015 in Iwik (Mauritania) in on-land dust traps with Saharan dust sampled from 2013-2015 offshore

73 Cape Blanc (Mauritania) in sub-marine sediment traps **and with the scientific dust-collecting buoy 'Carmen'**. By
74 comparing the data with meteorological data, back trajectories, the African lithology and satellite images we aim
75 to address the following questions:

- 76 1) What is the seasonal variability in particle size of mineral dust deposited on land? How does the variability
77 relate to meteorological parameters (wind speed, precipitation)?
- 78 2) What are the source regions of dust trapped on land versus dust trapped in the ocean?
- 79 3) Can we identify characteristic minerals that constitute a tracer for certain source areas?

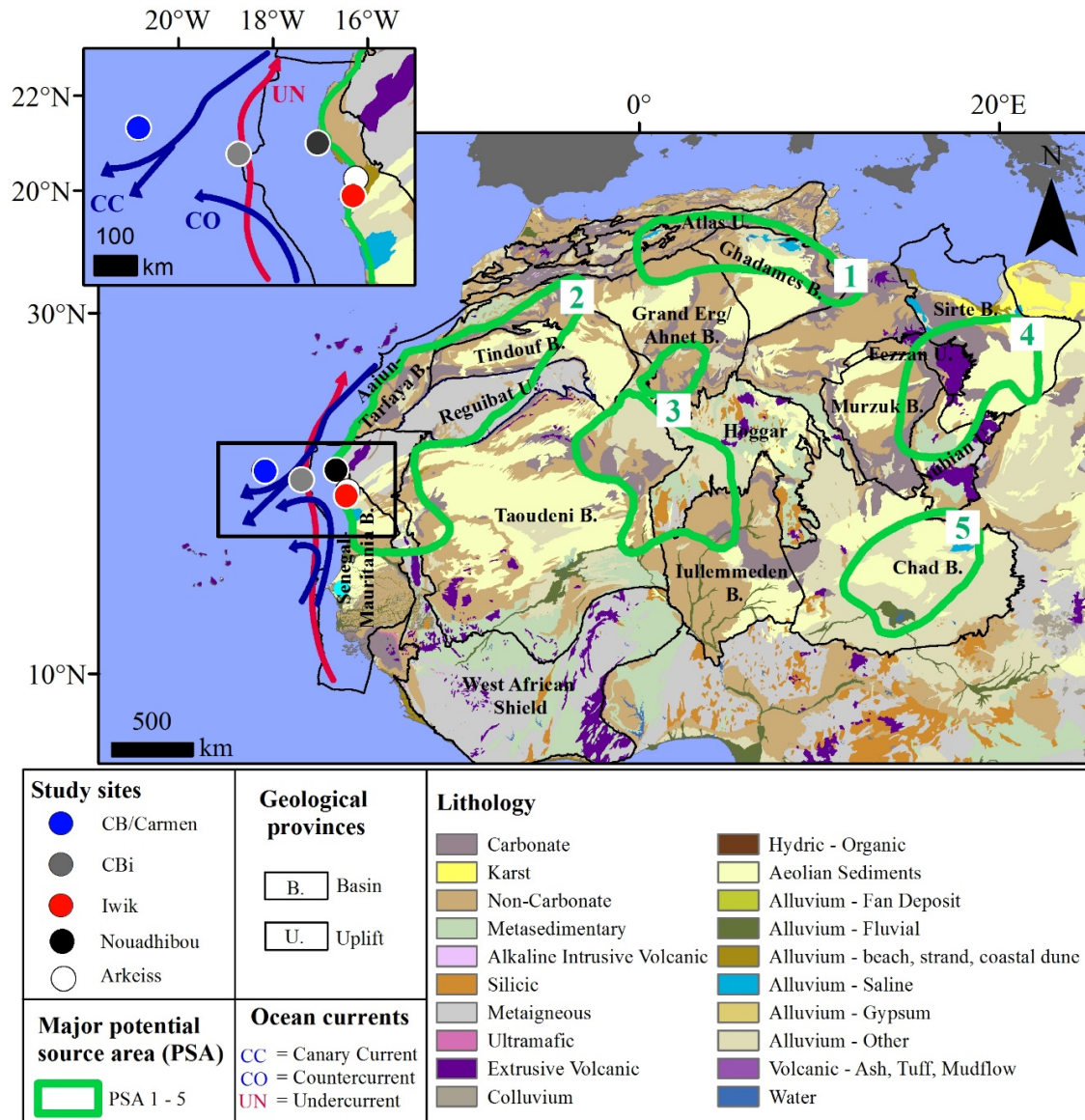
80 **1.1 Study sites and North African dust sources**

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82 In Fig. 1 the location of the study sites and the North African dust sources are displayed. The dust-collecting buoy
83 'Carmen' (~21°15' N, ~20°56' W) and the sediment trap mooring site CB (~21°16' N, ~20°48' W) are virtually
84 at the same position ~200 nautical miles offshore Cape Blanc. Sediment-trap station CBi (~20°45' N, ~18°42' W)
85 is located ~ 80 nautical miles offshore Cape Blanc. The continental dust collector Iwik (~19°53' N, ~16° 18' W)
86 and the meteorological station Arkeiss (~20° 7' N, ~16° 15' W) are located in a major potential dust source area
87 (**PSA 2**) in the Parc National de Banc d'Arguin (PNBA) near Iwik and near Arkeiss in Mauritania. A further
88 meteorological station is positioned in the **PSA 2** in Nouadhibou (~20° 55' N, ~17° 1' W) in the Western Sahara.

89

90 The major PSA of northern African dust are summarized in a review by Scheuven et al. (2013). Predominant dust
91 transport towards western Africa and offshore the Atlantic Ocean occurs from the foothills of the Atlas mountains,
92 Western Sahara and Western Mauritania (**PSA 2**), southern Algeria and northern Mali (**PSA 3**) and Western Chad
93 including the Bodélé depression (**PSA 5**) (Scheuven et al., 2013). In contrast, dust sourced from Tunisia and
94 northern Algeria (**PSA 1**) is transported predominantly to the western Mediterranean and Western Europe (Stuut
95 et al., 2009). Central Libya (**PSA 4**) is the most important region for dust transport to the eastern Mediterranean
96 (Scheuven et al., 2013).



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98 **Figure 1: Map of the study sites under investigation: the scientific buoy Carmen as well as the sediment trap moorings**
 99 **CB and CBi offshore Cape Blanc, the MWAC dust collector onshore near Iwik and the surface stations near**
 100 **Nouadhibou and Arkeiss (shapefile of the surface lithology and the geological provinces: downloaded from the USGS**
 101 **website <http://rmgsc.cr.usgs.gov/ecosystems/africa.shtml#SL> and**
 102 **<http://certmapper.cr.usgs.gov/geoportal/catalog/main/home.page>, major potential dust source areas: redrawn from**
 103 **Scheuvs et al. (2013), ocean currents: redrawn from Mittelstaedt (1991)).**

104

105 1.2 Geological characterisation of dust-producing areas

106

107 In the following, the lithology of the geological provinces that underlay the major PSA's is outlined (Fig. 1).

108 The PSA 1 is underlain by the eastern Atlas chain and the northern Grand erg/Ahnet and Ghadames Basins. The
 109 outcrops in the Atlas uplift are composed of e.g. limestones, sandstones and evaporites (Piqué, 2001). The thick
 110 strata overlying the northern Ahnet and Ghadames Basin consist of e.g. sandstones and mudstones (Selley, 1997c).

111 The **PSA 2** is underlain by the Reguibat Shield, the Mauritanides and the Senegal-Mauritania, Aaiun-Tarfaya,
112 Tindouf and Taoudeni Basins. The western part of the Reguibat Shield is dominated by granitic rocks, while the
113 eastern part is dominated by metamorphic and granitic rocks (Schofield et al. (2006) and references therein). West
114 of the Reguibat Shield, the Mauritanides consist of a metamorphic belt and ophiolite (Villeneuve, 2005). West of
115 the Taoudeni Basin, the Mauritanides are characterized by granites, quartzites and strongly metamorphosed rocks
116 (Villeneuve, 2005). While the Aaiun-Tarfaya Basin features outcrops with dolomites and limestones, the Senegal-
117 Mauritania Basin is characterized by very few carbonate deposits (Bosse and Gwosdz, 1996). The Tindouf Basin
118 is characterized by mainly sandy deposits (Selley, 1997a, c). **The local soils surrounding the dust collector site**
119 **Iwik are composed of sandy deposits often rich in fossil shells and partly cemented by lime (Einsele et al., 1974).**
120

121 The **PSA 3** is underlain by the western Hoggar and parts of the Ahnet, Taoudeni and Iullemeden Basins. The
122 Pharusian belt located in the western Hoggar is characterized by Eburnean granulites, gneiss, graywackes and
123 magmatic rocks (Boullier, 1991). In the southern Ahnet Basin sandstone strata crop out. On the eastern edge of
124 the Taoudeni Basin outcropping sediments are characterized by conglomerates, sandstones and limestones
125 (Bertrand-Sarfati et al., 1991). The outcrops of the Iullemeden Basin are composed of e.g. sandstones,
126 carbonaceous shale, laterites and massive clays (Kogbe, 1973).
127

128 The **PSA 4** is underlain by parts of the Fezzan and Nubian uplifts and the Sirte and Murzuk Basins. The eastern
129 Fezzan uplift consists of ocean island basalts (Cvetković et al., 2010; Abdel-Karim et al., 2013), while sediments
130 outcropping in the northern Nubian uplift are composed of e.g. sandstones, limestones and gypsiferous horizons
131 (El Makkrouf, 1988). The southern Sirte Basin is covered by sands, gravel and sand seas (Selley, 1997b). Outcrops
132 of the eastern Murzuk Basin are composed of marine limestones and alluvial sandstones (Selley, 1997c, a).

133 The **PSA 5** is underlain by the Chad Basin. During the Holocene, the Chad Basin was filled with fine-grained
134 particles from the drainage of the Tibesti mountains to the north (Prospero et al., 2002). Hence, the sediments that
135 outcrop in the central Chad Basin are characterized by fluvial and alluvial sediments such as laminated diatomites,
136 pelites and coastal sandridges (Schuster et al., 2009).

137 **1.3 Atmospheric setting**

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139 Saharan dust emission, transport and deposition are related to seasonal variations in atmospheric circulation
140 (Knippertz and Todd, 2012). The intertropical convergence zone (ITCZ) shifts meridionally from ~12 °N during
141 boreal winter to ~21 °N during boreal summer resulting in a seasonal change in rainfall and winds over the African
142 continent (Nicholson, 2009).

143 During summer, continental rainfall is most intense and the rain belt is positioned near ~10°N with smaller amounts
144 of rainfall near ~21°N. **Dust emission is driven by low level jets, ‘haboobs’, African easterly waves (AEWs) and**
145 **high surface winds associated with the Saharan heat low (Knippertz and Todd, 2012). Low-level N trade winds**
146 **blow and transport dust in coastal Mauritania year-round (National Geospatial-Intelligence Agency, 2006).**
147 **Saharan dust is transported on- and offshore within the ‘Saharan air layer’ (SAL) at an altitude of about 3 km (Diaz**
148 **et al., 1976; Carlson and Prospero, 1972; Prospero and Carlson, 1972; Prospero and Carlson, 1970).**

149 During winter, dust emission is driven by the break-down of nocturnal low-level jets after sunrise, increased surges
150 in Harmattan winds and microscale dust devils and dust plumes (Knippertz and Todd, 2012; Koch and Renno,
151 2005). Dust is transported within the NE and E trade winds to coastal Mauritania (Dobson, 1781) and also offshore
152 to the sediment-trap mooring sites (Stuut et al., 2005).

153 **1.4 Oceanic setting** 154

155 The surface-water circulation offshore Cape Blanc is influenced by the southward-flowing Canary Current (CC)
156 and the poleward-flowing coastal counter current or Mauritania Current (Fig. 1). Underneath, the undercurrent is
157 flowing poleward in water depths down to 1000 m (Fig. 1). The undercurrent flows along the continental slope
158 and transports water masses originating from ~5-10 °N to latitudes up to 26 °N. The poleward flowing South
159 Atlantic Central Water (SACW) and the southward flowing North Atlantic Central Water (NACW) are situated
160 below the counter current and meet offshore Cape Blanc (Mittelstaedt, 1991). The study area is positioned in a
161 zone of permanent annual upwelling of sub-surface water masses (Cropper et al., 2014). The NACW and SACW
162 may be upwelled and mixed laterally off Cape Blanc (Meunier et al., 2012). The permanent annual upwelling of
163 nutrient-rich subsurface waters results in high phytoplankton concentrations offshore Cape Blanc (Van Camp et
164 al., 1991). As a result, the surface waters are rich in organic detritus, usually referred to as ‘marine snow’, and
165 faecal pellets which are produced by marine zooplankton (Iversen et al., 2010).

166
167 Individual Saharan dust particles which settle at the ocean surface hardly settle to the deep sea. Instead, fine dust
168 particles can be transferred from the ocean surface to the deep sea by being incorporated into marine snow
169 aggregates and faecal pellets (Ternon et al., 2010). The aggregate formation and ballasting of marine snow
170 aggregates and faecal pellets with marine carbonate and opal as well as with Saharan dust particles results in
171 anomalously high sinking velocities (Iversen and Robert, 2015; Fischer and Karakas, 2009; Iversen and Ploug,
172 2010; Iversen et al., 2010; Ploug et al., 2008b). Dust-loaded particles that sink into the deeper water column are
173 assumed to have a mean settling speed of ~ 240 m d⁻¹ at site CB (Fischer and Karakas, 2009).

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2. Material and Methods

In Table 1 an overview of the material and methods employed for each study site is presented. Bulk sediment samples were obtained at the sites CB and CBi and dust samples at the sites Carmen and Iwik. All samples were analyzed for particle size and dust flux with the exception of the site Carmen, of which only dust particle size was analyzed. Only the sites CBi and Iwik were analyzed for mineral assemblages and only the samples of the site Iwik were used for microscopic investigation. Meteorological sensors were available for the stations Carmen, Iwik and Arkeiss, while for the site Nouadhibou meteorological data was downloaded online. TRMM precipitation data was downloaded online for all sites except for the site Nouadhibou.

Table 1: Overview of the material and methods employed at each study site.

Study site	Lat./Lon.	Samples	Analysis	Meteorological sensor and data	Downloaded meteorological data
Carmen	~21°15' N, ~20°56' W	1 MWAC sample	particle size	Vaisala WXT520: wind direction + speed, precipitation	TRMM 3B42: precipitation
CB	~21°16' N, ~20°48' W	38 sediment trap samples	lithogenic fluxes, particle size	-	TRMM 3B42: precipitation
CBi	~20°45' N, ~18°42' W	38 sediment trap samples	lithogenic fluxes, particle size, mineral assemblages	-	TRMM 3B42: precipitation, HYSPLIT back trajectories
Iwik	~19°53' N, ~16° 18' W	24 MWAC samples	microscopy, dust fluxes, particle size, mineral assemblages	Davis 6250 Vantage Vue: wind direction + speed	TRMM 3B42: precipitation, HYSPLIT back trajectories
Nouadhibou	20° 55' N, 17° 1' W	-	-	-	Wind direction + speed
Arkeiss	~20° 7' N, ~16° 15' W	-	-	Davis 6250 Vantage Vue: precipitation	TRMM 3B42: precipitation

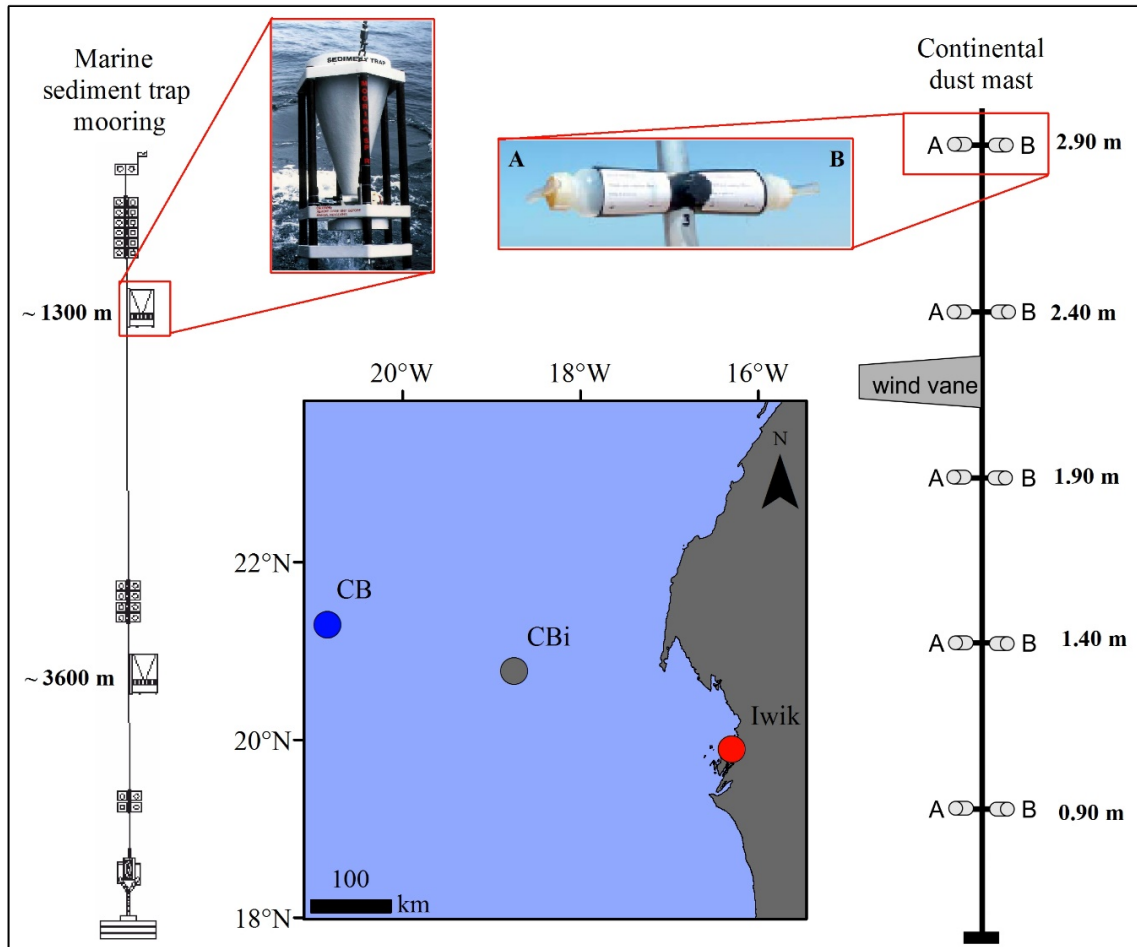
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2.1 Sediment traps

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Saharan dust was collected in the ocean using marine sediment traps of the type Kiel (model SMT-234/243) which are conical with an opening of 0.5 m² (Fig. 2). The principle of particle collection is much the same as described by Van der Does et al. (2016b) and Korte et al. (2017). At the top of the opening a honeycomb grid is installed to prevent large swimmers (>1 cm) from entering the trap. The sediment traps were equipped with twenty sample cups which rotated according to a pre-programmed sampling interval (Fischer and Wefer, 1991). The sampling interval was chosen depending on the timing of the ship expeditions.



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Figure 2: The marine sediment trap moorings CB and CBi offshore Cape Blanc and the dust masts near Iwik, Mauritania. On the left, a sketch of the sediment trap mooring (sketch of CB 24 copied from Fischer et al. (2013)) together with a photograph of the trap (downloaded from www.kum-kiel.de) is displayed. On the right, a sketch of the dust mast together with a photograph of the MWAC sampling bottles is depicted.

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The sampling intervals were synchronized between the two sites. The intervals ranged from 9.5 days to 21.5 days (Table 2). Deployment and recovery of the sediment-trap samples was performed during the Research Vessel Poseidon expeditions POS445 (Fischer et al., 2013), POS464 (Fischer et al., 2014) and POS481 (Fischer et al., 2015) (Table 2). The working steps related to the trap deployment and treatment are described in Fischer and Wefer (1991). In order to prevent outflow of water from the cups during sampling, each sampling cup was filled with 20 ml of filtered (<0.2 μm) seawater with a salinity of 40 ‰. To produce seawater with a salinity of 40 ‰, 100 g NaCl suprapur was added to 1 l of filtered seawater. Microbial and zooplankton activity was inhibited inside the trap samples by adding 1 ml of a saturated solution of the biocide HgCl_2 per 100 ml of seawater. After recovery, swimmers <1 cm were removed from the samples by sieving each sample through a 1 mm mesh. A McLane rotary liquid splitter was used to split the <1 mm fraction of each sample into five equal aliquots.

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The samples of two sediment-trap deployments during 2013–2015 of the sediment trap mooring stations CB and CBi were chosen for grain-size analyses (Table 2). The upper traps sampled at an average water depth of ~ 1300 m and the lower trap sampled at a water depth of ~3600 m (Table 2). Dust which settles at the ocean surface is advected by ocean currents during settling in the water column. As a result, particles that settle in an area of ~ 40

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228 x 40 km² in the ocean surface above the traps may be collected in a water depth of ~ 1300 m (Friese et al., 2016).
 229 Two winter and two summer samples were chosen for X-ray Diffraction (XRD) measurements (Table 3).

230 **Table 2: Specifications of the sediment trap samples collected during 2013-2015 chosen for flux and grain-size analysis.**

Trap series	Trap type	Sampling period	Cruise deployment	Cruise recovery	Position	Trap depth [m]	Water depth [m]	No. of samples	Sampling intervals
CBi 11 upper (GeoB 18006-2)	SMT 243	29.01.2013 – 25.03.2014	Pos445	Pos464	20°46.4' N 18°44.4' W	1406	2800	18	17x21d, 1x20d
CBi 12 upper (GeoB 19402-01)	SMT 234 NE	14.02.2014 - 23.02.2015	Pos464	Pos481	20°46.4' N 18°44.5' W	1356	2750	20	1x12.5 d, 19x19.5
CB 24 upper (GeoB 18001-1)	SMT 234 NE	24.01.2013 - 05.02.2014	Pos445	Pos464	21°16.9' N 20°50.6' W	1214	4160	18	1x26 d, 16x21 d, 1x15 d
CB 25 lower (GeoB 19401-1)	SMT 234 NE	07.02.2014 – 21.02.2015	Pos464	Pos481	21°17.8' N 20°47.8' W	3622	4160	20	19x19.5 d, 1x9.5 d

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232 **Table 3: Sediment trap and MWAC samples chosen for mineralogical investigation.**

Sample	Sampling period	Mast	Bottle	Elevation/water depth [m]	Sampling interval
CBi 11 upper # 8	25.06.-16.07.13	-	-	1406	21d
CBi 12 upper # 2	26.02.-18.03.14	-	-	1356	20d
CBi 12 upper # 10	01.08.-21.08.14	-	-	1356	20d
CBi 12 upper # 17	16.12.-04.01.15	-	-	1356	19d
Iwik 13-7-2-3B	24.06.-15.07.13	2	B	1.90	21d
Iwik 14-8-2-5B	15.08.-15.09.14	2	B	2.90	31d
Iwik 14-12-1-4A	15.12.14-18.01.15	1	A	2.40	34d
Iwik 14-2-2-5B	15.02.-15.03.14	2	B	2.90	28d

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234 **2.2 Modified Wilson and Cooke (MWAC) samplers**

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236 Saharan dust was collected on land near Iwik, Mauritania, with a passive dust sampler consisting of two masts (1
 237 and 2) with two sets of five air sampling bottles each (A and B, Fig. 2). The dust sampling bottles are referred to
 238 as modified Wilson and Cooke (MWAC) samplers (Mendez et al., 2011; Wilson and Cooke, 1980) and consist of
 239 a closed Polyethylene bottle through which the wind can pass via two glass tubes of 8 mm openings. Thus, a big
 240 difference between the traps and the MWAC collectors is the much smaller collection area of the MWAC collectors
 241 with 44 mm². The MWAC dust sampler was chosen because it is one of the most common (Zobeck et al., 2003)
 242 and most efficient dust samplers (Goossens and Offer, 2000). The sampling bottles were mounted horizontally at
 243 five different heights.

244 The samples collected in 2013-2015 were chosen for subsequent flux and grain-size analyses (Table 4). Saltating
 245 dust particles may be collected in the lower sampling bottles at 90 cm. However, the aim was to analyse dust
 246 transported in suspension to enable a better comparison between the continental and marine sites. Therefore, the
 247 highest sampling bottles attached to the mast at 2.90 m height were used for microscope, flux and grain-size
 248 analysis (Table 4). One series of bottles (series B2) of mast 2 were analysed with the microscope. The other three
 249 replicate samples (bottles A1 and B1 of mast 1, bottles A2 of mast 2) were analysed for flux and grain-size analysis.
 250 Out of the three replicate samples, the sample with the highest mass was chosen for the interpretation of the flux
 251 and grain-size data because this bottle was assumed to have sampled most efficiently. Three samples mounted at
 252 a height of 2.40 m of mast 2 were chosen to test the effect of the chemical pre-treatments that we do to isolate the
 253 terrigenous fraction from marine sediments on the resulting grain-size distributions (Fig. 2). Two winter and two
 254 summer samples that contained enough material were chosen for XRD measurements (Table 3).

255 Furthermore, dust was sampled with a MWAC dust sampler mounted on the mast of buoy Carmen, at about 2 m
 256 above the sea surface (Stuut et al., 2015). The masts of the buoy Carmen and of the Iwik dust sampler were aligned
 257 to the ambient wind direction via a wind vane (Fig. 2). This MWAC dust sample was also analysed for grain-size
 258 distribution.

259 **Table 4: Specifications of the MWAC samples collected during 2013-2015 chosen for flux and grain-size analysis.**

Dust collector series	Trap type	Sampling period	Position	Height [m]	No. of samples	Sampling intervals
Iwik 13	MWAC	27.01.2013 – 20.01.2014	19°53.1' N 16° 17.6' W	2.90	11	19 d, 28 d, 32 d, 29 d, 40 d, 21 d, 31 d, 61 d, 31 d, 31 d, 35 d
Iwik 14	MWAC	20.01.2014 - 18.01.2015	19°53.1' N 16° 17.6' W	2.90	13	26 d, 28 d, 31 d, 30 d, 31 d, 30 d, 31 d, 31 d, 30 d, 32 d, 29 d, 34 d
CB-MWAC	MWAC	23.08.2014 – 16.11.2015	21°15.8' N 20°56.1' W	2.00	1	450 d

260

261 2.3 Microscopy

262

263 The MWAC samples chosen for microscopic investigation were analysed with a Leica M165 C microscope.
 264 Microscope pictures were taken using a Leica DFC420 camera attached to the microscope. The software Leica
 265 application suite 3.8 was used for taking the pictures.

266

267 2.4 Dust and lithogenic fluxes

268

269 1/5 splits of the sediment trap samples were analysed for dust fluxes and the bulk components following the method
 270 presented in Fischer and Wefer (1991). The lithogenic flux [$\text{mgm}^{-2}\text{d}^{-1}$] was estimated according to Eq. (1):

$$271 \quad \text{lithogenic material} = \text{dust} = \text{total mass} - \text{carbonate} - \text{opal} - 2 \times \text{Corg} \quad (1)$$

272 Organic carbon was measured after the removal of carbonate with 2N HCl using a CHN-Analyser (HERAEUS).

273 Total carbon was estimated by combustion without pre-treatment. Carbonate was determined according to Eq. (2):

274
$$\text{carbonate} = \text{total carbon} - \text{organic carbon} \quad (2)$$

275 Biogenic opal was determined with a sequential leaching technique (Müller and Schneider, 1993).

276 The MWAC samples chosen for dust flux analyses were weighed on a Mettler-Toledo AT261 Delta Range balance
 277 with a precision of 0.0001 g. Mean atmospheric dust concentrations were estimated as Eq. (3):

278
$$DL = \frac{MAR}{(v \cdot A)} * \frac{1}{\eta} \quad (3)$$

279 Where DL is the mean dust concentration [μgm^{-3}], MAR is the mass accumulation rate [μgs^{-1}], v is the mean wind
 280 speed per sampling month [ms^{-1}], A is the cross-sectional area of the inlet tube of the MWAC sampler [m^2] and η
 281 is the estimated sampling efficiency of MWAC bottles. A sampling efficiency of 90 % was assumed based on an
 282 efficiency study of Goossens and Offer (2000). Mean horizontal dust fluxes were calculated according to Eq. (4):

283
$$F_h = \frac{MAR}{A} * \frac{1}{\eta} \quad (4)$$

284 where F_h is the horizontal dust flux [$\text{mgm}^{-2}\text{d}^{-1}$], MAR is the mass accumulation rate [mgd^{-1}], A is the cross-
 285 sectional area of the inlet tube of the MWAC sampler [m^2] and η is the estimated sampling efficiency of MWAC
 286 bottles.

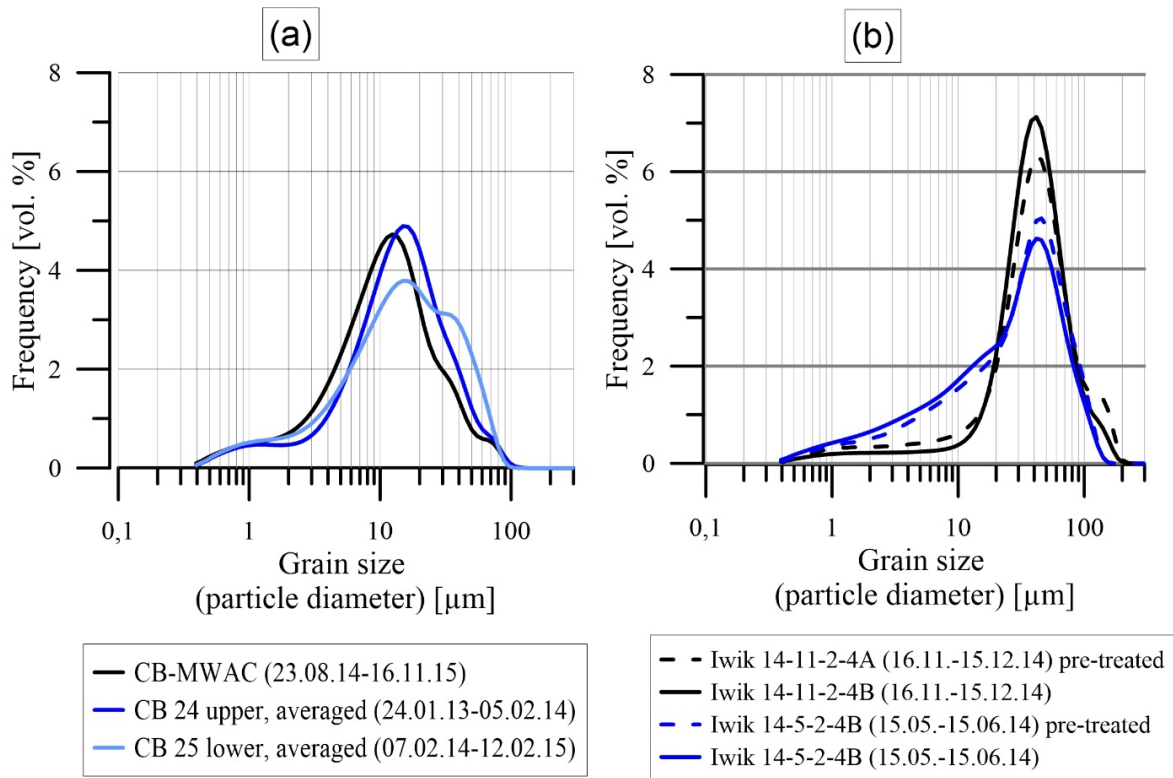
287 **2.5 Particle size**

288

289 A 1/25 split of the marine sediment trap samples was analysed for particle size of the terrigenous fraction. The
 290 samples were pre-treated before measurement in order to isolate this fraction (see also Filipsson et al. (2011); Friese
 291 et al. (2016), Meyer et al. (2013) and Stuu (2001) for methodology) with the following steps: (1) removal of
 292 organic matter: Addition of 10 ml of H_2O_2 (35%) to the sediment sample and subsequent boiling until the reaction
 293 stops, (2) removal of calcium carbonate: Addition of 10 ml HCl (10%) to the sediment sample and subsequent
 294 boiling for exactly 1 minute and (3) removal of biogenic silica: Adding 6 g of NaOH pellets to the sediment sample
 295 and subsequent boiling for 10 minutes. Before particle-size analysis, 10 drops of $\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$ were added to
 296 each sample to assure the full disaggregation of the particles. The pre-treatment of the MWAC samples differed
 297 from the pre-treatment of the sediment trap samples as, obviously, these samples did not contain any biogenic
 298 material originating from marine plankton. Further, the disaggregation of particles needed to be kept at minimum
 299 to allow for the study of dust transport processes, the so-called ‘minimally dispersed’ aeolian fraction (McTainsh
 300 et al., 1997). Therefore, the MWAC samples were solely pre-treated with three drops of $\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$ before
 301 analysis. The marine sediment-trap samples as well as the MWAC samples were analysed with the laser particle
 302 sizer Beckmann Coulter LS13320 at NIOZ using a Micro Liquid Module (MLM). This instrument allows quick,
 303 accurate, and precise data acquisition of large size intervals (Bloemsmma et al., 2012). An analytical error of ± 1.26
 304 μm ($\pm 4.00\%$) was considered for the measurements (Friese et al., 2016).

305 To investigate the comparability of the MWAC samples with the oceanic sediment-trap samples, the particle-size
 306 distribution of the MWAC sample attached to buoy Carmen was compared to the averaged particle-size
 307 distributions of the upper and lower trap series at site CB (Fig. 3a). The grain-size distribution of the MWAC
 308 sample was comparable to both sediment trap time series even though the sampling time period was different. To
 309 ensure that the pre-treatment steps of the traps did not influence the terrigenous fraction itself, tests were made in
 310 which the on-land MWAC samples were exposed to the same pre-treatment steps as the marine samples (Fig. 3b).

311 One spring sample has been measured with and without a chemical pre-treatment. Two fall dust samples were
 312 obtained from the same height and mast and sampling interval, however from different bottles (A and B) and were
 313 measured with and without pre-treatment. The figure indicates that a pre-treatment of the Iwik dust samples did
 314 not alter the particle distributions of the samples significantly. Further, the particle-size distribution of dust sampled
 315 with different bottles is comparable.



316

317 **Figure 3: (a) Grain-size distributions for the station CB: Dust sampled with the MWAC sampler 2 m above sea level,**
 318 **with the upper sediment trap at 1214 mbsl and the lower trap at 3622 mbsl. (b) Grain-size distributions of samples of**
 319 **the Iwik 14 time series which have been pre-treated with HCl, H₂O₂ and NaOH (dotted lines) and without pre-**
 320 **treatment (lines).**

321 **2.6 Mineral assemblages**
 322

323 Two winter and two summer samples of the MWAC dust collector and the sediment-trap series CBi were chosen
 324 for XRD analysis (Table 3). X-Ray Diffraction pattern analyses were carried out in the laboratory of the research
 325 group Crystallography (University of Bremen, Central Laboratory for Crystallography and Applied Material
 326 Sciences, ZEKAM, Dept. of Geosciences).

327 Due to the small amount of material in the available dust samples (< 100 mg), the preparation for the measurement
 328 was done by pipetting a demi-water-sample mixture on glass slides. A thorough preparation commonly increases
 329 reproducibility of the results, however, the standard deviation given by Moore and Reynolds (1989) of ±5% can
 330 be considered as a general guideline for mineral groups with >20% clay fraction. In addition, the determination of
 331 well-crystallized minerals like quartz, calcite or aragonite can be done with better standard deviations (Tucker and
 332 Tucker, 1988; Vogt et al., 2002). The X-Ray Diffraction was measured on a Philips X'Pert Pro multipurpose
 333 diffractometer equipped with a Cu-tube (k. 1.541, 45 kV, 40 mA), a fixed divergence slit of 1/4°, a secondary Ni-

334 Filter and the X²Celerator detector system. The measurements were carried out as a continuous scan from 3 – 85°
335 2θ, with a calculated step size of 0.016° 2θ (calculated time per step was 100 seconds). Mineral identification was
336 accomplished using the Philips software X²Pert HighScore™, which, besides the mineral identification, can give
337 a semi-quantitative value for each identified mineral on the basis of Relative Intensity Ratio (R.I.R.)-values. The
338 R.I.R.-values are calculated as the ratio of the intensity of the most intense reflex of a specific mineral phase to the
339 intensity of the most intense reflex of pure corundum (I/I_c) referring to the “matrix-flushing method” after Chung
340 (1974). Unfortunately R.I.R. values are sparse for clay minerals and long chain organic materials hampered the
341 quantification of our samples.

342 **2.7 Meteorological data**

343

344 The obtained flux and size data were compared to near-by meteorological data (wind speed, wind direction and
345 precipitation).

346 Wind direction, wind speed and precipitation data with a 20 minute resolution were gathered for the sampling site
347 CB (21°17' N – 21°12' N, 20°56' W - 20°54' W) during the buoy Carmen deployments from November 2013 to
348 September 2015 with a Vaisala WXT520 meteorology sensor. The size of the dataset was reduced by calculating
349 four hour averages. Moreover, wind direction and wind-speed data with a resolution of five minutes to one hour
350 were gathered during sampling at site Iwik (19°53.1' N, 16° 17.6' W) from January 2013 to January 2015 with a
351 Davis 6250 Vantage Vue meteorology sensor. The size of the dataset was reduced by calculating one-hour
352 averages. Further hourly precipitation data were gathered from the station Arkeiss (20° 7' N, 16° 15' W) from
353 December 2013 to March 2015 with another Davis 6250 Vantage Vue meteorology sensor. Continental hourly
354 wind direction and wind-speed data was acquired for the Nouadhibou meteorological station (20° 55' N, 17° 1'
355 W) online from the Cedar Lake Ventures website (<https://weatherspark.com>).

356 Local daily precipitation data (TRMM 3B42 dataset, 0.25° spatial resolution) were derived from the Giovanni
357 online data system, developed and maintained by the NASA GES DISC (<http://gdata1.sci.gsfc.nasa.gov>). Daily
358 precipitation data were downloaded as area-averages around CBi (20° 58' N - 20° 34' N, 18° 56' W - 18° 32' W),
359 Iwik (19° 41' N - 20° 5' N, 16° 29' W - 16° 05' W), CB/Carmen (21° 05' N - 21° 29' N, 21° 02' W - 20° 38' W) and
360 Arkeiss (20° 19' N - 19° 55' N, 16° 28' W - 16° 04' W) according to the assumed catchment area of the upper trap
361 (~ 40 x 40 km²).

362 Maps of six hourly mean surface wind vectors and speed (20th century reanalysis V2c dataset) were provided by
363 the NOAA/OAR/ESRL PSD, (Boulder, Colorado, USA) and downloaded from their website
364 (<http://www.esrl.noaa.gov/psd/>).

365 **2.8 Mapping with ArcMap**

366

367 The mapping software ArcMap version 10.3.1 was used to analyze the source regions of the dust samples
368 investigated for mineralogical composition. A map was created with four-day back-trajectories for days with a
369 dust-storm event as depicted on satellite images. In addition, the African surface lithology was included in the map
370 and soils rich in the minerals calcite, kaolinite and chlorite were marked.

371 Satellite quasi-true colour RGB images (MODIS dataset) were retrieved from the NASA Worldview website
372 (<https://worldview.earthdata.nasa.gov>).

373 Four-day back trajectories at altitudes of 10 (following Stuu et al. (2005)), 100, 3000, 4500 (following Skonieczny
374 et al. (2013)) and 5500m were calculated ending at the dust collector site Iwik (19°52' N, 16°17' W) and at the
375 proximal marine trap site CBI (20°46', 18°44' W) using the Hybrid Single Particle Lagrangian Integrated
376 Trajectory (HYSPLIT) model (Stein et al., 2015) and the reanalysis dataset (2.5° spatial resolution) on the NOAA
377 website (<http://ready.arl.noaa.gov>).

378 An ArcGIS layer file of the African surface lithology
379 (new_af_lithology_w_glbcvr_waterbdy_90m_dd84_final.lyr) was downloaded from the U.S. Geological survey
380 (USGS) website (<http://rmgsc.cr.usgs.gov>).

381 An ArcGIS shape file of the African soils (DSMW.shp) was downloaded from the website of the food and
382 agriculture organization of the United Nations (FAO) (<http://www.fao.org>). The mean percentage of calcite (8.9
383 %), chlorite (4.1 %) and kaolinite (29%) in the clay fraction of Saharan soils in general and for each soil type is
384 given by Journet et al. (2014). Soils with larger percentages of calcite, chlorite or kaolinite in the clay fraction than
385 the average percentages were marked in the ArcGIS map.

386

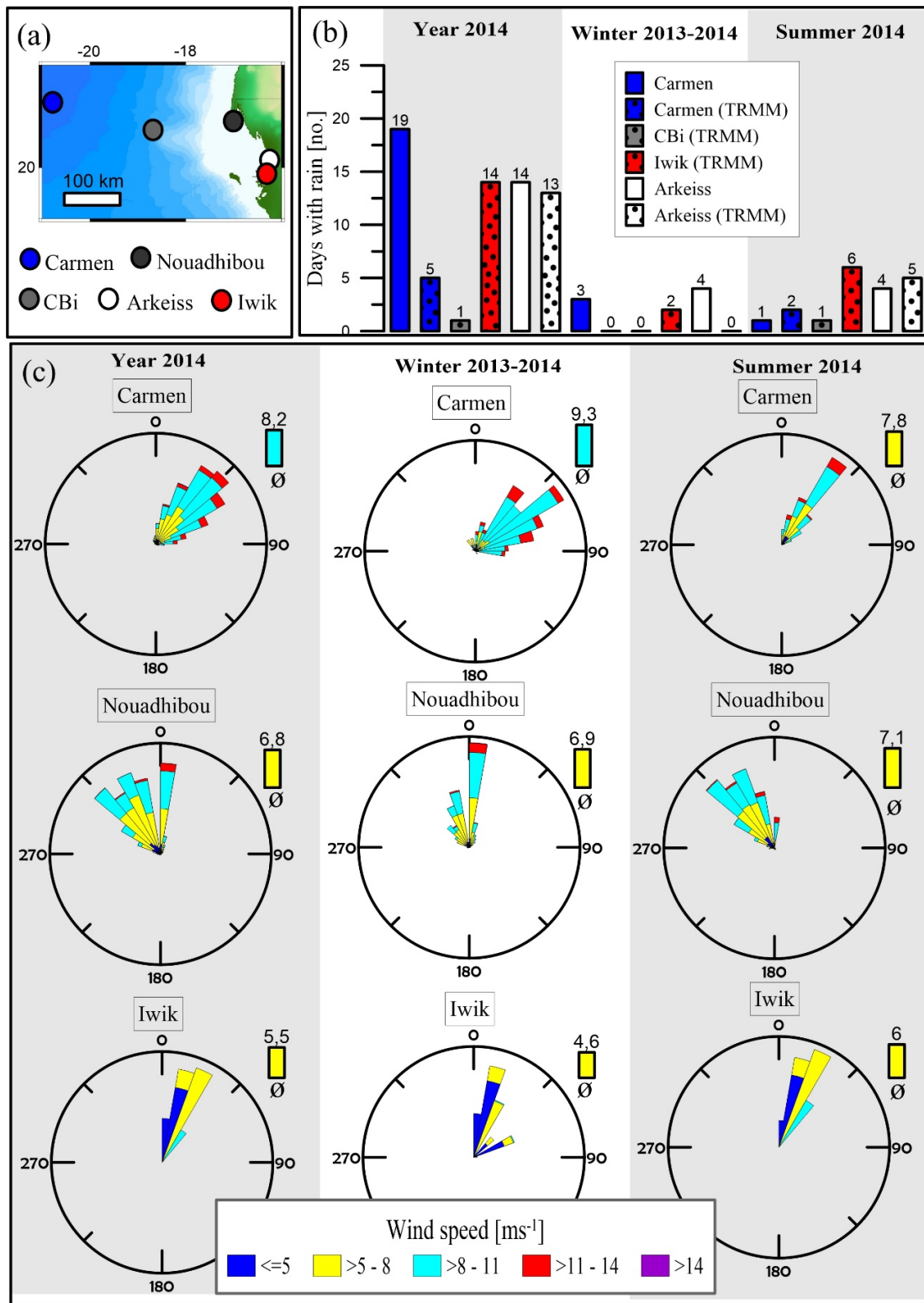
387

388 **3. Results**
389 **3.1 Meteorology**
390

391 In Fig. 4 the meteorological data of the sites Carmen (CB), CBi, Iwik, Arkeiss and Nouadhibou during 2013 to
392 2014 are presented (see Fig 4a for location of the sites). The rainfall frequency is given in Fig. 4b for each site.
393 The number of rainfall events were calculated regarding the TRMM stations for precipitation rates $>1 \text{ mmd}^{-1}$
394 because smaller precipitation amounts which were detected by the satellite may not actually reach the ground.
395 Regarding the surface stations Carmen and Arkeiss, a threshold of $>0.2 \text{ mmd}^{-1}$ was used in order to exclude events
396 which may be related to anomalously high moisture instead of rainfall.

397 According to the TRMM satellite product the annual precipitation frequency was larger on the shoreline (station
398 Arkeiss and Iwik) than offshore (station CBi and Carmen) (Fig. 4b). This may be explained by a decrease in
399 atmospheric water vapor content due to precipitation when the winds move westward. **Moreover, the TRMM**
400 **satellite product indicated larger rainfall frequencies during the summer season compared to the winter season**
401 **regarding the stations Carmen, CBi, Iwik and Arkeiss.** Larger summer rainfall frequencies can be explained by the
402 summer northward shift of the ITCZ to $\sim 21^\circ \text{ N}$ resulting in more frequent moist convection and rainfall in the
403 study area.

404 The annual rainfall frequency at the site Arkeiss and the summer rainfall frequencies at the sites Arkeiss and
405 Carmen compare quite well between the sensors and the TRMM observations. **However, the spatial and seasonal**
406 **trends observed by the TRMM data were not supported by the sensor on buoy Carmen and by the surface station**
407 **in Arkeiss.** The larger annual and winter rainfall frequency recorded with the sensor on buoy Carmen may be
408 related to water emission from the ocean surface during time periods with strong surface winds. **Further,**
409 **disagreements between the surface stations and the TRMM stations may be caused by the local signal recorded by**
410 **the respective rain sensor.** A larger number of rain sensors would most likely improve the comparability to the
411 TRMM data.



412

413 **Figure 4: Meteorological data: (a) map showing the sites Carmen (CB), CBi, Iwik, Nouadhibou and Arkeiss under**
 414 **investigation (b) precipitation at the sites Carmen (CB), CBi, Iwik and Arkeiss (c) wind direction and speed at the sites**
 415 **Carmen (CB), Nouadhibou and Iwik.**

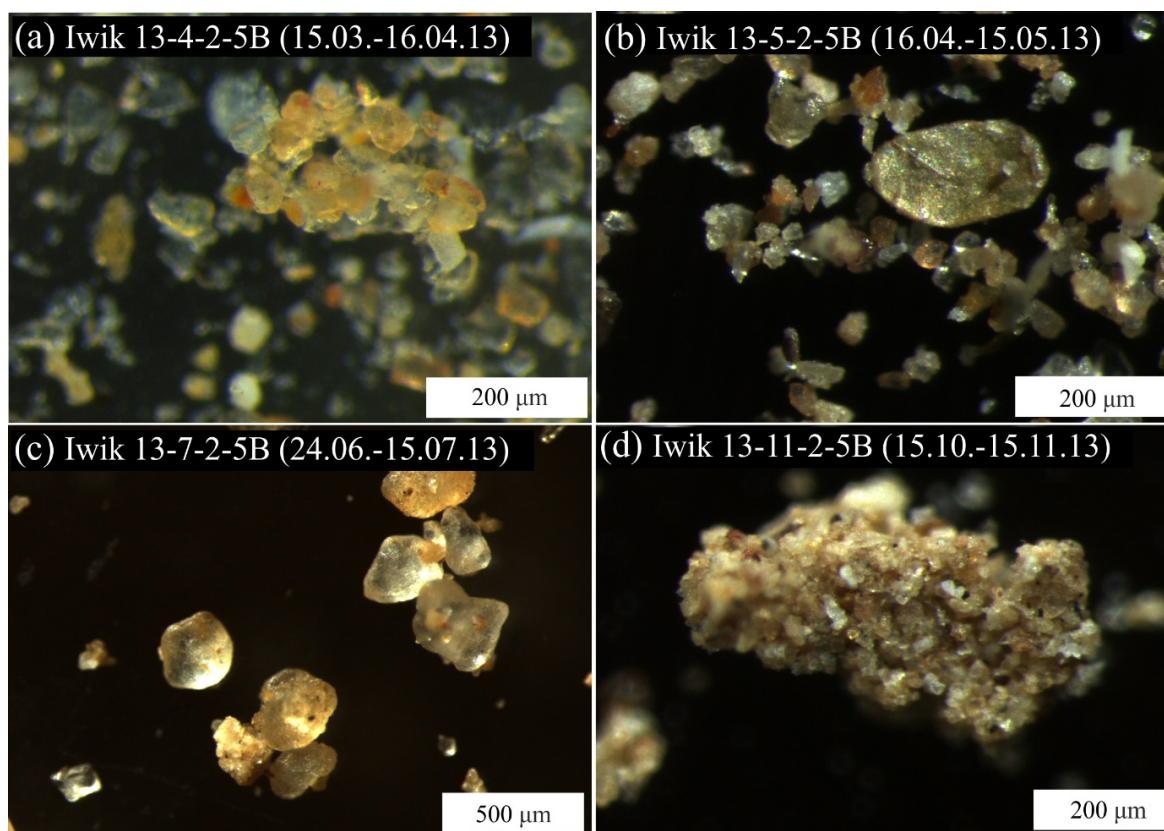
416 The wind direction and speed for the surface stations Carmen, Nouadhibou and Iwik are displayed in Fig. 4c. The
 417 annual average surface wind velocity was maximum offshore at buoy site Carmen (CB) with ~ 8 m/s. The buoy

418 recorded a larger average wind velocity during winter than during summer, which is consistent with this season
419 being dominated by the Trades. On the shoreline, the average wind velocity was slightly larger during summer
420 than during winter. The predominant annual wind direction was NE at site Carmen and Iwik, while predominant
421 NW winds were recorded for the site Nouadhibou. The wind direction changed from predominant NE during
422 winter to predominant NNE direction during summer at site Carmen. A similar, but less pronounced seasonal trend
423 can be observed for the continental site Iwik. In Nouadhibou, the predominant winter wind direction is NNW
424 switching to a predominant NW wind direction during summer. Obviously, with winds originating from the open
425 ocean, not a lot of dust is anticipated. Therefore, we interpret these wind directions as being very local and caused
426 by the shape of the peninsula of Cape Blanc.

427 3.2 Microscope findings of the dust samples from Iwik

428

429 In Fig. 5 the results of the microscopy investigation of the Iwik 2013 time series are presented. In general, the
430 majority of the particles consisted of angular and moderately spherical quartz grains with a diameter of $\sim 50 \mu\text{m}$
431 (Fig. 5a,b). A small percentage of large platy minerals with a diameter of $\sim 200 \mu\text{m}$ were found in all samples (Fig.
432 5b). Large quartz grains with a diameter of ~ 150 to $200 \mu\text{m}$ were detected in 45 % of the samples. An anomalously
433 high percentage of sub-angular and moderately spherical quartz grains with an average diameter of $\sim 200 \mu\text{m}$ was
434 observed in one summer sample (Fig. 5c). Aggregated grains occurred in all samples. However, the percentage
435 and size of the aggregates as well as the size of the aggregated grains differed from sample to sample. Usually, the
436 size of the aggregated grains was $\sim 50 \mu\text{m}$ (Fig. 5a). Two samples were characterized by aggregates composed of
437 particles with a smaller size of $\sim 20 \mu\text{m}$ (Fig. 5d).



438

439 **Figure 5: Microscopic photographs of selected dust samples from the Iwik 2013 time series. (a) Spring dust sample with**
 440 **a ~ 250 x 150 μm aggregate, (b) spring dust sample with a ~ 200 x 100 μm mica chip, (c) summer dust sample with ~**
 441 **200 x 200 μm quartz grains, (d) fall dust sample with a ~ 600 x 250 μm aggregate.**

442 **3.3 Dust fluxes and size on land and in the ocean**
 443

444 In Table 5 the average dust fluxes are given for the sampling sites Iwik, CBi and CB. The dust concentrations at
 445 site Iwik were determined based on the measured wind speed of the meteorological sensor attached to the sampling
 446 mast. For four samples no wind data were available due to a failure of the instrument. For these samples a wind
 447 velocity was assumed based on the seasonal averages calculated from the available wind data of the meteorology
 448 sensor in Iwik (Fig. 4c). The annual average horizontal dust fluxes at site Iwik were of the same order of magnitude
 449 during 2013 and 2014. The annual average dust fluxes decreased from the on-land site Iwik towards the proximal
 450 site CBi and the distal site CB. At the site Iwik the average dust concentration was maximum during spring plus
 451 winter 2013 and 2014 with $393 \mu\text{g m}^{-3}$ and $341 \mu\text{g m}^{-3}$, respectively, and minimum in fall 2013 and 2014 with 48
 452 and $68 \mu\text{g m}^{-3}$, respectively. **The dust fluxes generally decreased with collection height in the mast between 90 and**
 453 **290 cm (not shown).**

454 **Table 5: Seasonal and annual average dust fluxes and average modal grain size, mean/mode ratio and standard**
 455 **deviation of the grain-size distributions from Iwik 13-14, CBi 11-12 upper and CB 24 upper time-series.**

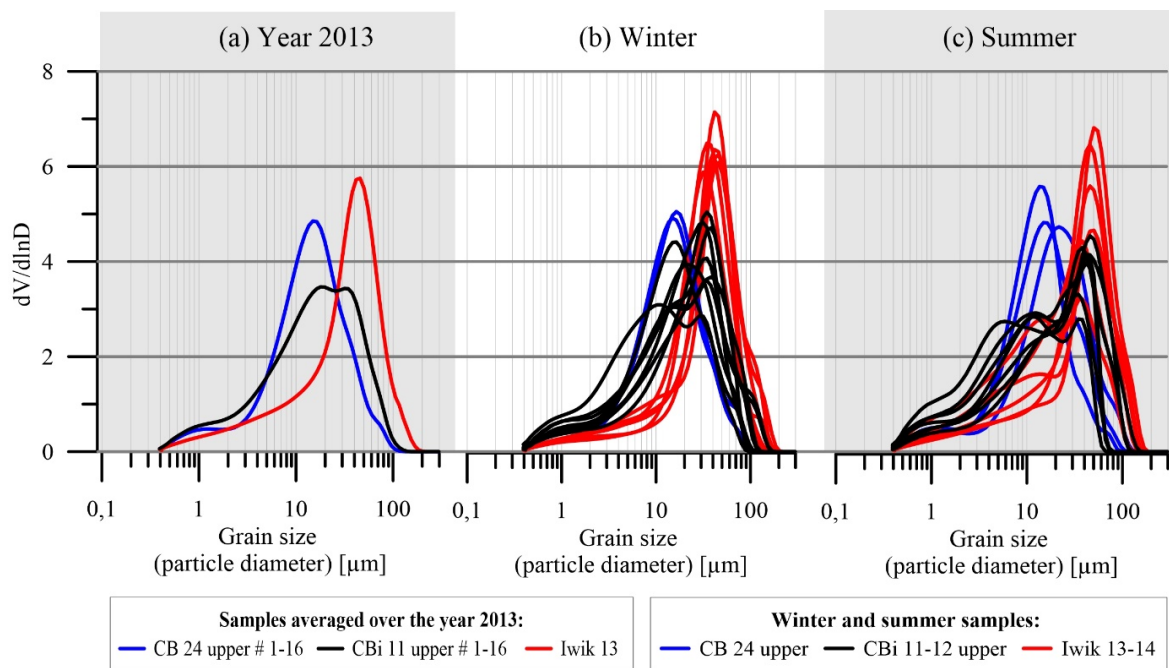
Series	Year	Winter	Summer	Annual
<i>Average dust fluxes [$\text{mg.m}^{-2}.\text{d}^{-1}$] (dust concentration [$\mu\text{g.m}^{-3}$])</i>				
Iwik 13	2013	10000 (30)	113000 (268)	95000 (214)
CBi 11 upper	2013	106	168	99
CB 24 upper	2013	53	44	45
Iwik14	2014	208000 (603)	55000 (127)	102000 (275)
CBi 11+12 upper	2014	98	20	47
<i>Average modal grain size [μm]</i>				
Iwik 13	2013	44	49	48
CBi 11 upper	2013	27	39	29
CB 24 upper	2013	16	17	16
Iwik 14	2014	45	49	48
CBi 11+12 upper	2014	34	44	33
<i>Average mean/mode ratio [μm]</i>				
Iwik 13	2013	0.7	0.6	0.6
CBi 11 upper	2013	0.5	0.3	0.5
CB 24 upper	2013	0.7	0.8	0.7
Iwik14	2014	0.6	0.4	0.6
CBi 11+12 upper	2014	0.5	0.3	0.5
<i>Average standard deviation [μm]</i>				
Iwik 13	2013	2.8	3.1	3.0
CBi 11 upper	2013	3.0	3.3	3.1
CB 24 upper	2013	2.7	2.6	2.6
Iwik 14	2014	2.8	3.5	3.1
CBi 11+12 upper	2014	3.1	3.3	3.0

456

457 The statistical values of the measured grain-size distributions for the stations CB, CBi and Iwik are given in Table
 458 5. In addition, the measured grain-size distributions for the time series of the stations CB, CBi and Iwik are
 459 displayed in Fig. 6. In Fig. 6a the average grain-size distribution for the samples of each of the three stations for
 460 the year 2013 are given. The maximum measured particle size decreased from ~223 μm on land at site Iwik to

461 ~169 μm at the proximal site CBi and ~140 μm at the distal site CB (Fig. 6a). In addition, the average modal grain
 462 size decreased from ~48 μm at site Iwik to 16 μm at site CB (Table 5). Bimodal grain-size distributions were
 463 encountered for 23 % of the CBi 11-12 samples, 13 % of the Iwik 13-14 samples, and none of the CB 24 samples.
 464 The three bimodal distributions of the Iwik 13-14 time series were characterized by an additional fine mode
 465 peaking at ~16 μm besides the more pronounced and variable coarse mode peaking at ~42 to 55 μm . The three
 466 Iwik dust samples characterized by a fine grain-size peak were collected during spring, summer (Fig. 6c) and fall.
 467 The eight bimodal grain size distributions of the CBi 11-12 time series were characterized by a variable coarse
 468 mode at ~25 to 35 μm and a variable fine mode at ~6 to 16 μm . The standard deviation of a grain-size distribution
 469 is a measure of the sorting of the dust sample: the larger the standard deviation the weaker the sorting. The sorting
 470 of the CB samples was better than the sorting of the Iwik and CBi time series as indicated by the average geometric
 471 standard deviations of 2.6 μm for CB and 3.1 μm for both Iwik and CBi (Table 5). The lowest average mean/mode
 472 ratio was recorded for the CBi time-series with ~0.5 due to the weak sorting of the samples (Table 5).

473 In Fig. 6b-c the measured grain-size distributions for winter and summer samples are displayed. The averaged
 474 modal grain size for the summer samples was coarser grained compared to the winter samples of the respective
 475 grain-size time series (Table 5). The seasonality in modal grain size was largest for the CBi 11 upper trap series
 476 of the year 2013 with a difference of ~12 μm (Table 5). The average standard deviation was larger and the average
 477 mean/mode ratio was smaller in the summer samples compared to the winter samples regarding the sites Iwik and
 478 CBi (Table 5). In other words: the summer samples of sites CBi and Iwik were less well sorted (Fig. 6b and c).
 479 This seasonal trend was not observed in the CB 24 upper samples which were generally well sorted (Table 5).



480

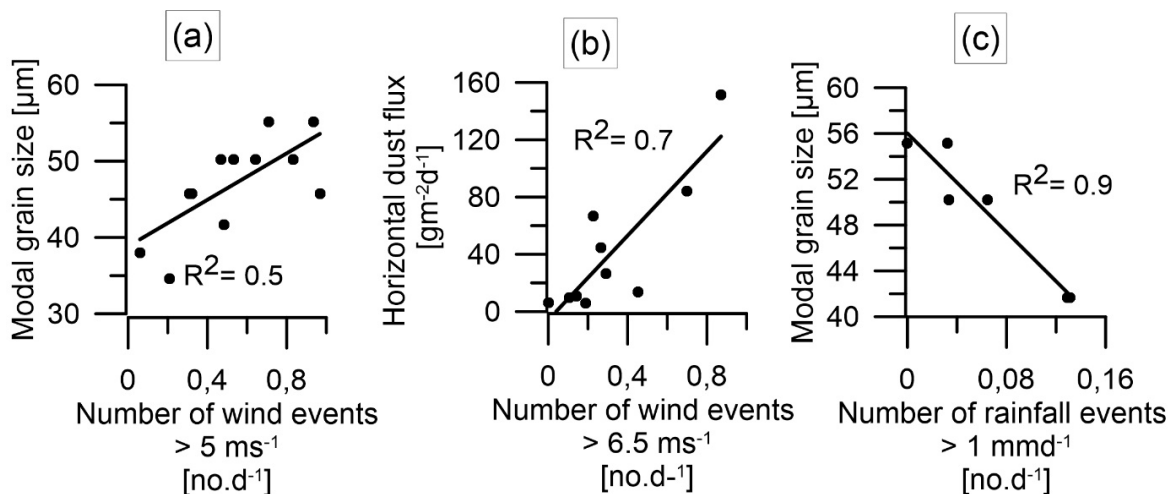
481 **Figure 6: Grain-size distributions of the stations Iwik, CBi and CB (a) averaged for the samples of the year 2013 (b)**
 482 **winter samples (c) summer samples.**

483 In Fig. 7a –c the results of the correlation between the characteristics of the dust sampled on land and the local
 484 meteorological data are presented. In Fig. 7a the particle sizes were correlated to the surface wind speed data (N =
 485 13 samples). A correlation above a coefficient of determination (R^2) of 0.3 was considered significant at the 95 %

486 confidence level for two-tailed probabilities. The modal particle size of the Iwik samples showed a positive linear
 487 correlation with the daily wind speed events with $R^2 = 0.5$, which is significant at the 99.31 % confidence level.
 488 **The correlation was only evident when using a threshold for wind events of 3.5 to 5.5 ms^{-1} and was best for a**
 489 **threshold of 5 ms^{-1} .** A better positive linear correlation was obtained when excluding the spring sample resulting
 490 in $R^2 = 0.7$ which is significant at the 99.96 % confidence level.

491 In Fig. 7b the dust fluxes were correlated to the surface wind-speed data ($N = 10$ samples). A correlation above R^2
 492 $= 0.4$ was considered significant at the 95 % confidence level for two-tailed probabilities. The horizontal dust flux
 493 of the Iwik samples correlated positively to the daily wind speed events during the sampling interval with $R^2 = 0.7$
 494 which is significant at the 99.75 % confidence level. **The correlation was only evident when using a threshold for**
 495 **wind events of 6.5 to 7 ms^{-1} and was best for a threshold of 6.5 ms^{-1} .** Moreover, a significant linear correlation
 496 with $R^2 = 0.6$ was observed at the 99.15 % confidence level between the dust fluxes and the mean wind strengths
 497 during the sampling intervals (not shown).

498 In Fig. 7c the particle size of the Iwik summer samples was correlated to the local TRMM precipitation data ($N= 6$
 499 samples). In this case a correlation above $R^2 = 0.7$ was considered significant at the 95 % confidence level for two-
 500 tailed probabilities. A good linear negative correlation with $R^2 = 0.9$ was observed which is significant at the 99.78
 501 % confidence level.



502
 503 **Figure 7: Correlation between the observed local surface wind speed at site Iwik and the measured (a) modal grain size**
 504 **and (b) flux. (c) Correlation between the observed local precipitation at site Iwik (TRMM data) and the modal grain**
 505 **size of the summer samples.**

506 3.4 Mineral assemblage of dust sampled on land and in the ocean

508 In Table 6 the mineralogical composition averaged over all eight samples, averaged over the four Iwik samples
 509 and the four CBI samples is given. All dust samples contained the minerals quartz and mica. Further minerals that
 510 occurred with significant quantities but which were not present in all dust samples were feldspar, amphibole,
 511 zeolite, chlorite and palygorskite. Calcite, dolomite, gibbsite, kaolinite, smectite, sepiolite, fluellite, anhydrite,
 512 rutile and serpentine occurred only in some samples resulting in a low average abundance $\leq 1\%$. However, we
 513 argue that these minerals can be used as dust source indicators because of (1) the characteristic distribution of
 514 gibbsite, kaolinite, smectite and sepiolite in North Africa according to different weathering regimes (Biscaye,

1964) and (2) the characteristic occurrence of fluellite, anhydrite, rutile and serpentine according to outcropping rock type (Deer et al., 1992). Further minerals that occur in low abundances ($\leq 3\%$) were summarized as ‘other minerals’ and will not be discussed in the manuscript. While the continental samples were dominated by quartz and feldspar, the marine samples were dominated by mica, followed by quartz and feldspar.

Table 6: Results of the mineralogical investigation: Mineral assemblage averaged over all samples (Total), the Iwik samples (Iwik) and the CBI samples (CBI).

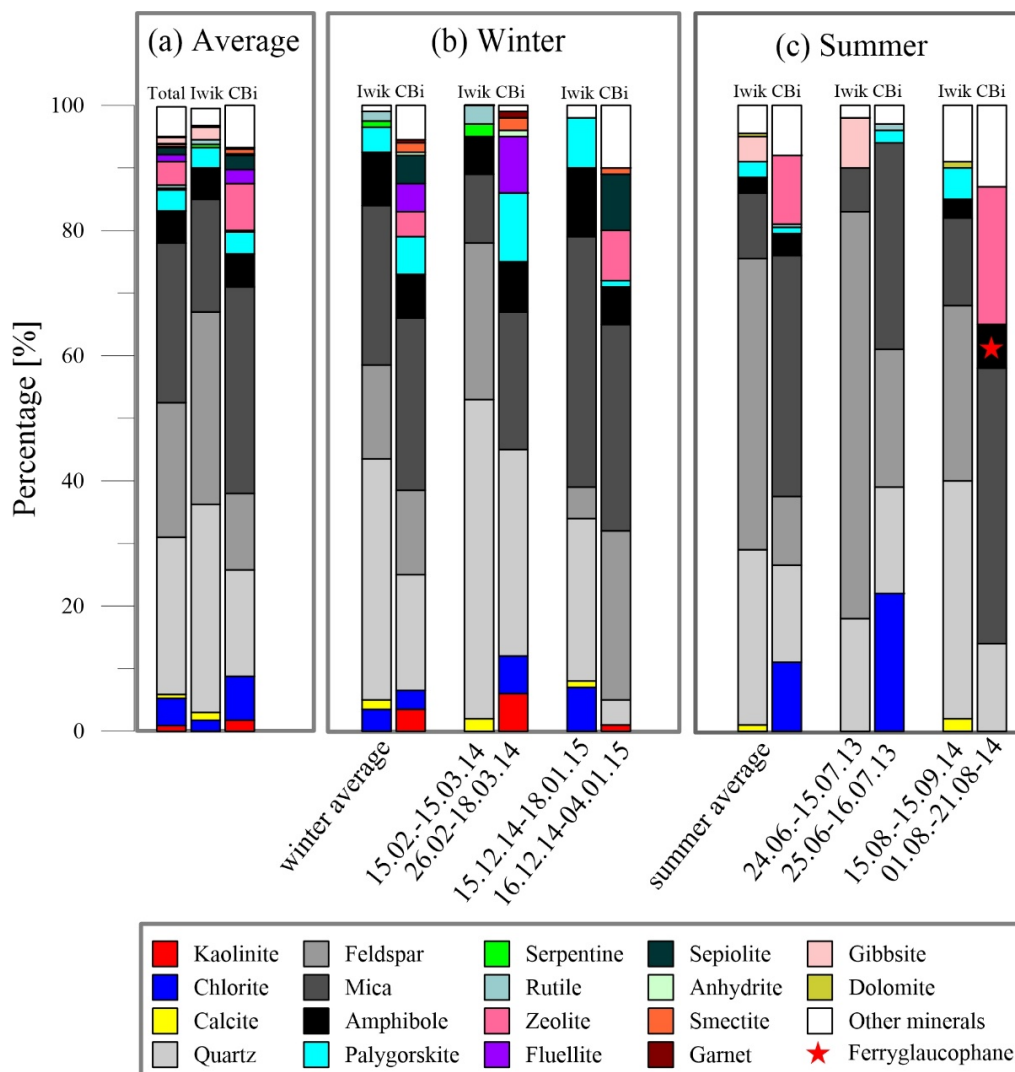
*	Qz [%]	Fsp [%]	Mi [%]	Amf [%]	Pal [%]	Chl [%]	Cc [%]	Dol [%]	Gib [%]	Zeo [%]	Kao [%]	Sme [%]	Se [%]	Rut [%]	Serp [%]	Ga [%]	Anh [%]	Flu [%]
Total	25.1	21.5	25.5	5.1	3.4	4.4	0.6	0.1	1.0	3.8	0.9	0.4	1.1	0.5	0.3	0.1	0.1	1.1
Iwik	33.3	30.8	18.0	5.0	3.3	1.8	1.3	0.3	2.0	0.0	0.0	0.0	0.0	0.8	0.5	0.0	0.0	0.0
CBI	17.0	12.3	33.0	5.3	3.5	7.0	0.0	0.0	0.0	7.5	1.8	0.8	2.3	0.3	0.0	0.3	0.3	2.3

*Qz = quartz, Fsp = feldspar, Mi = mica, Amf = amphibole, Pal = palygorskite, Chl = chlorite, Cc = calcite, Dol = dolomite, Gib = gibbsite, Zeo = zeolite, Kao = kaolinite, Sme = smectite, Se = sepiolite, Rut = rutile, Serp = serpentine, Ga = garnet, Anh = anhydrite, Flu = fluellite

521

In Fig. 8a-c the results of the mineralogical investigation of the eight chosen dust samples are presented. Figure 8a depicts again the average composition of the samples per sampling site (N=4). The minerals zeolite, anhydrite, garnet, sepiolite, fluellite, kaolinite and smectite were only found in the marine samples. Only the continental sample of 15.08.-15.09.14 contained traces of zeolite. While gibbsite, serpentine, calcite and dolomite were detected in the continental dust samples, these minerals were absent in all marine samples. The absence of calcite and gibbsite may have been caused by the pre-treatment of the marine sediment-trap samples with HCl. Although the concentration of the used acid is fairly low (10%) and the exposure time of the samples was exactly 1 minute, we cannot exclude that carbonate minerals were dissolved. Therefore, the absence of these minerals in the marine traps will not be discussed further.

In the following, the seasonality in the average mineralogical composition will be outlined for each site as given in Fig. 8b,c. At site Iwik, the winter dust samples were characterized by the occurrence of chlorite, serpentine and rutile, while the summer samples were characterized by the minerals gibbsite and dolomite. At site CBI, the winter dust samples were characterized by the occurrence of the minerals sepiolite, fluellite, kaolinite, smectite, garnet and anhydrite, while the summer samples were characterized by the mineral rutile. Only for the marine trap samples an annual average chlorite/kaolinite ratio (C/K = 4) could be derived owing to the occurrence of kaolinite.



537

538 **Figure 8: Mineralogical composition (a) averaged over all samples and for sites Iwik and CBI, (b) averaged for the**
 539 **winter samples at sites Iwik and CBI and for each individual winter sample and (c) averaged for the summer samples**
 540 **at sites Iwik and CBI and for each individual summer sample. The category 'other minerals' comprises the minerals**
 541 **todorokite, sodalite, konicklite, guyanaite, nitratnine, urea, bernalite, akermanite, mixed-layer clay and talc.**

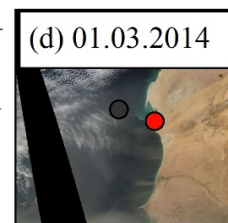
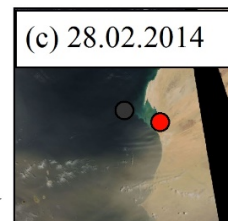
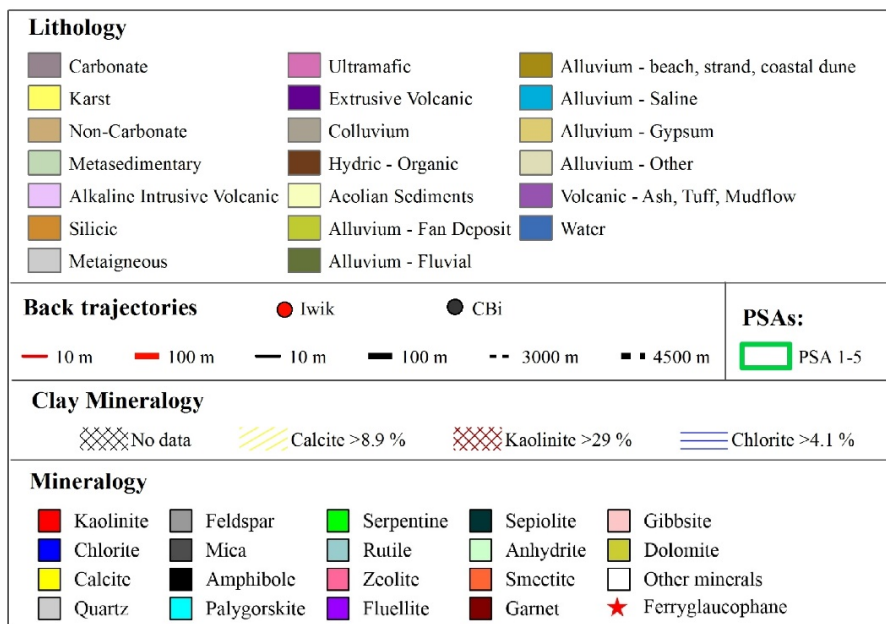
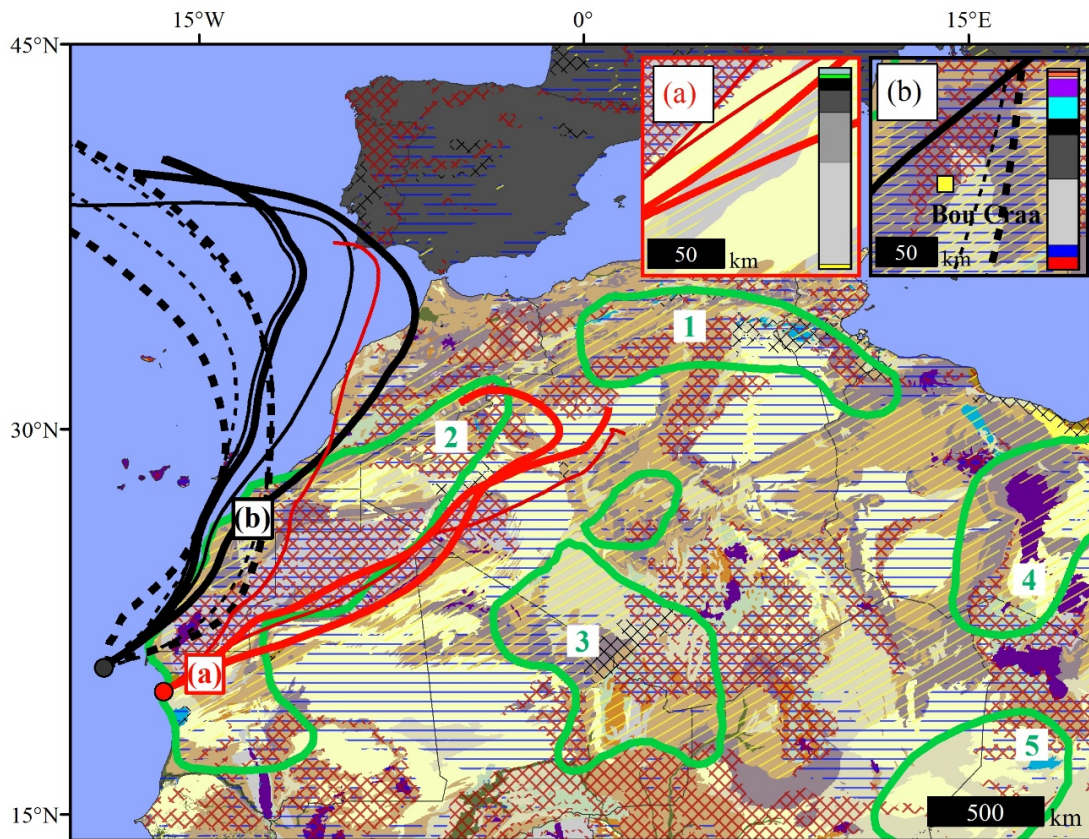
542

543 3.5 Identification of dust source regions

544

545 In Fig. 9-12 the results of the four day back-trajectory analysis are presented for each sample which has been
 546 analyzed for mineralogical composition. **Four heights, 10, 100, 3000 and 4500 m were chosen to cover both low-**
 547 **(trades) and high-level (SAL) dust transport. A back trajectory was drawn for the day when a dust storm event**
 548 **occurred as depicted on the satellite images.** Only the low-level back-trajectories were plotted for site Iwik because
 549 of the correlation of the measured dust characteristics to the low-level wind speed. Moreover, the MWAC samplers
 550 were designed to only sample dry deposition, whereas the marine sampling sites collect material settling through
 551 the water column, i.e., dust resulting from both dry- and wet deposition. **The back-trajectories at 5500 m can be**
 552 **found in the supplement.**

553 Figure 9 illustrates a typical late-winter situation. During the sampling interval of each site at least two days with
554 dust storms occurred (Fig. 9c,d). Therefore, two back trajectories were drawn for each height for the site CBi and
555 CB respectively. The high-level back trajectories ending at site CBi pass either through the major PSA 2 or point
556 offshore. Both the low-level back-trajectories ending at the continental trap site Iwik and at the oceanic trap site
557 CBi point to a dust source within the major PSA 2 (Scheuvens et al., 2013). Some calcite was present in the
558 continental dust sample, but no chlorite nor kaolinite was detected. Therefore, the dust source was most likely
559 located in the nearby southwestern Reguibat Shield where sediments are rich in calcite and quartz and depleted in
560 chlorite and kaolinite (Fig. 9a). Dust deposited in the marine traps during the time interval was characterized by
561 the occurrence of chlorite and kaolinite. Thus, the source area of the samples was most likely the chlorite and
562 kaolinite rich sediments located near the Bou Craa phosphate mine in the Western Sahara (Fig. 9b).

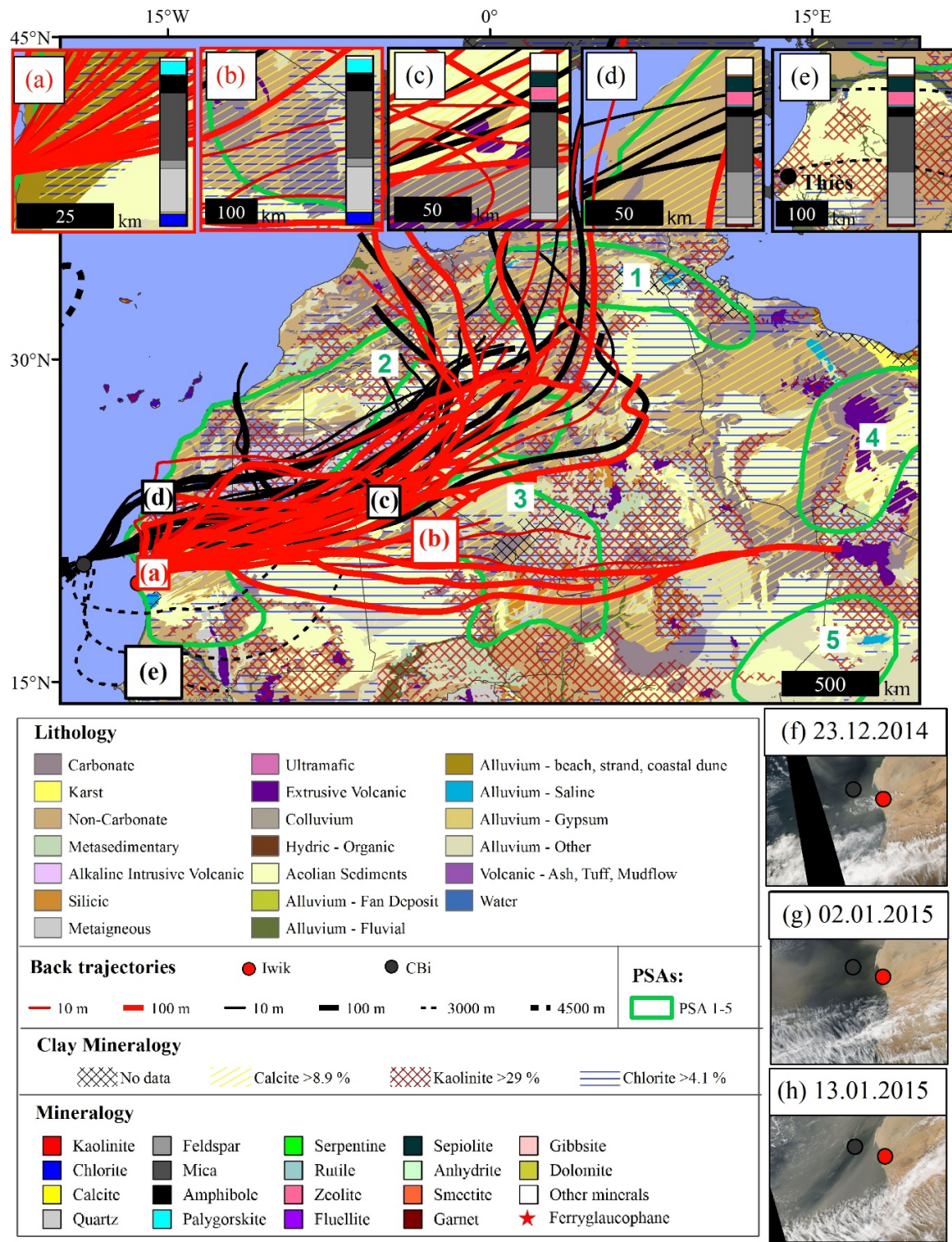


563

564 **Figure 9: Low-level (10 m) four-day back trajectories of dust events ending during the sampling interval 15.02.-15.03.14**
 565 **at site Iwik and during the sampling interval 26.02.-18.03.14 at site CBI. The potential dust source areas and the**
 566 **mineralogy of the samples are given in the subfigures a-b. The dust-storm events occurring during the sampling interval**
 567 **are indicated in subfigures c-d.**

568 Figure 10 represents a typical early-winter situation. During the sampling interval of the site Iwik at least three
 569 dust storms occurred and at the site CBI at least two dust storms occurred (Fig. 10f-h). Each dust storm lasted for
 570 several days for which we could model as many as 15 back trajectories for the site Iwik and 8 for the site CBI for

571 each height. The large number of back trajectories complicated the determination of the likely source areas. All
572 low-level back trajectories pass through the major **PSA 2** and some point to the **PSA 1** and **PSA 3** (Scheuvens et
573 al., 2013). One high-level back trajectory ending at site CBI passes through PSA 2 and two through Mauritania
574 and Senegal. However most of the high-level back trajectories ending at site CBI predominantly point offshore.
575 Dust sampled in the marine traps during this sampling interval did not contain any chlorite, while the dust trapped
576 at Iwik did. Chlorite may have been supplied to Iwik from a source area nearby the Senegal-Mauritania Basin (Fig.
577 10a) or as far as the eastern Taoudeni Basin (Fig. 10b) as there are anomalously high chlorite content of the soils
578 in these areas. The continental sample is further characterized by the occurrence of calcite and the absence of
579 kaolinite which fits to the soils of the chosen source areas (Fig. 10a,b). The marine sample was characterized by
580 the occurrence of zeolite and absence of chlorite. Therefore, zeolite may have been derived from the extrusive
581 volcanic rocks of the northern Taoudeni Basin (Fig. 10c). A further source area might be the southern shoreline of
582 the Western Sahara in which chlorite depleted sediments are situated (Fig. 10d). The presence of the mineral
583 kaolinite in this marine winter sample may be explained by a kaolinite-rich source area lying in the southern
584 Senegal-Mauritania Basin (Fig. 10e).

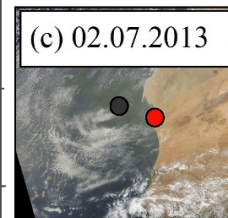
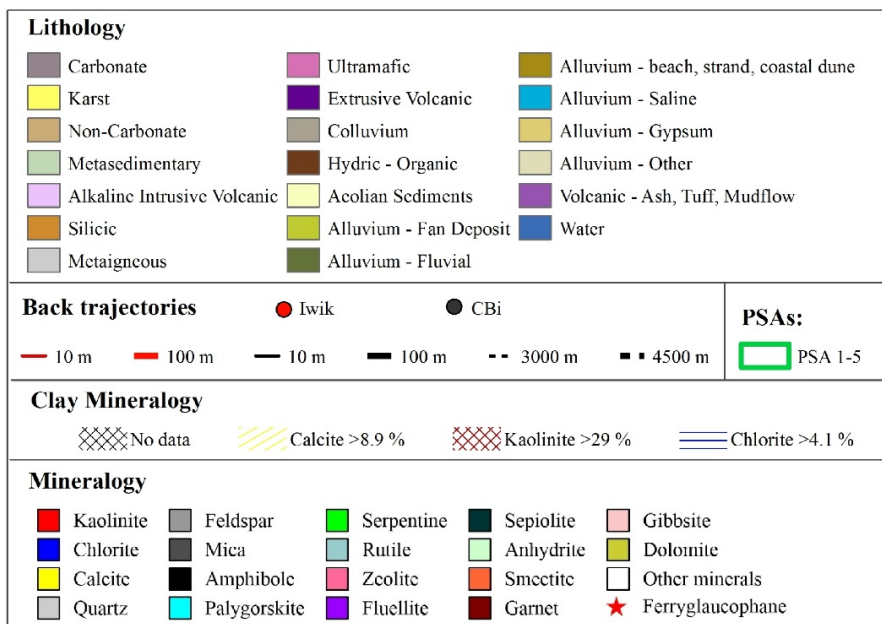
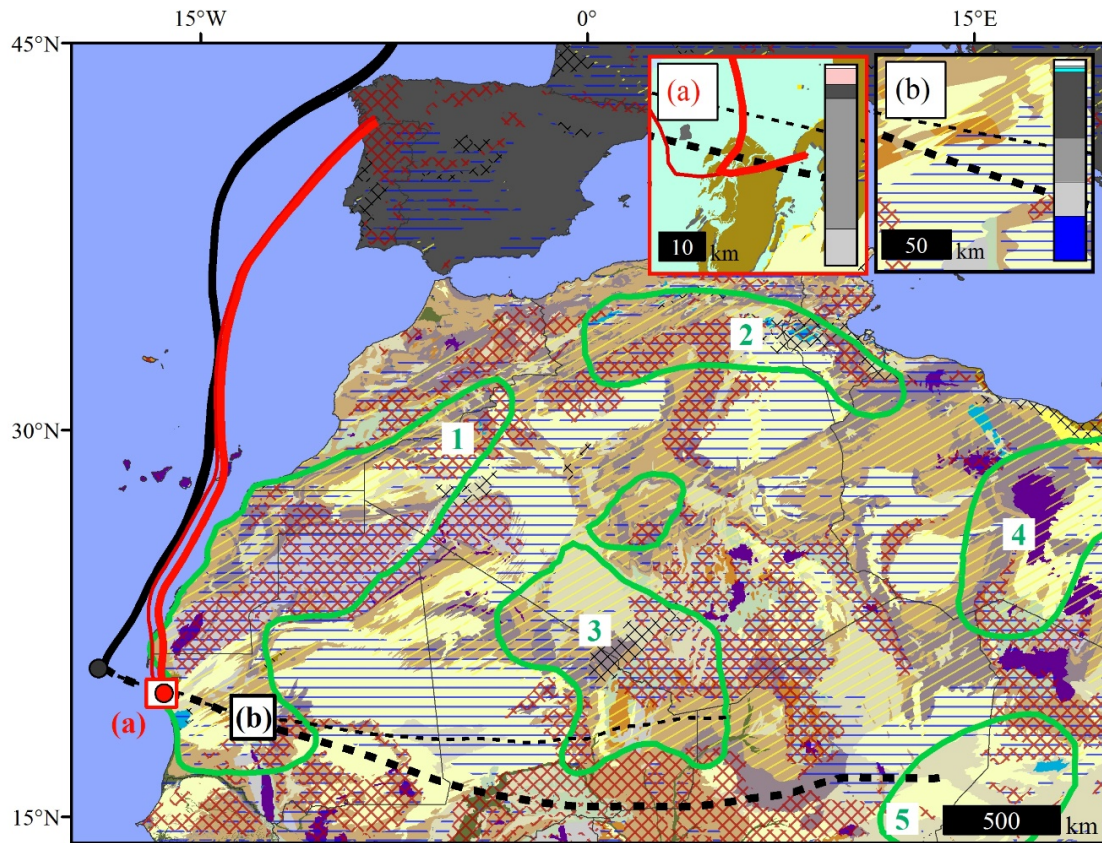


585

586 **Figure 10: Low-level (10 m) four-day back trajectories of dust events ending during the sampling interval 15.12.14-**
 587 **18.01.15 at site Iwik and during the sampling interval 16.12.14-04.01.15 at site CBi. The potential source areas and the**
 588 **mineralogy of the samples are given in the subfigures a-c. The dust storm events occurring during the sampling interval**
 589 **are indicated in subfigures e-g.**

590 In Fig. 11 a typical early-summer situation is presented. **Only one dust storm event was observed during the**
 591 **sampling interval at both sites which lasted for one day (Fig. 11c) resulting in only one back trajectory per site and**

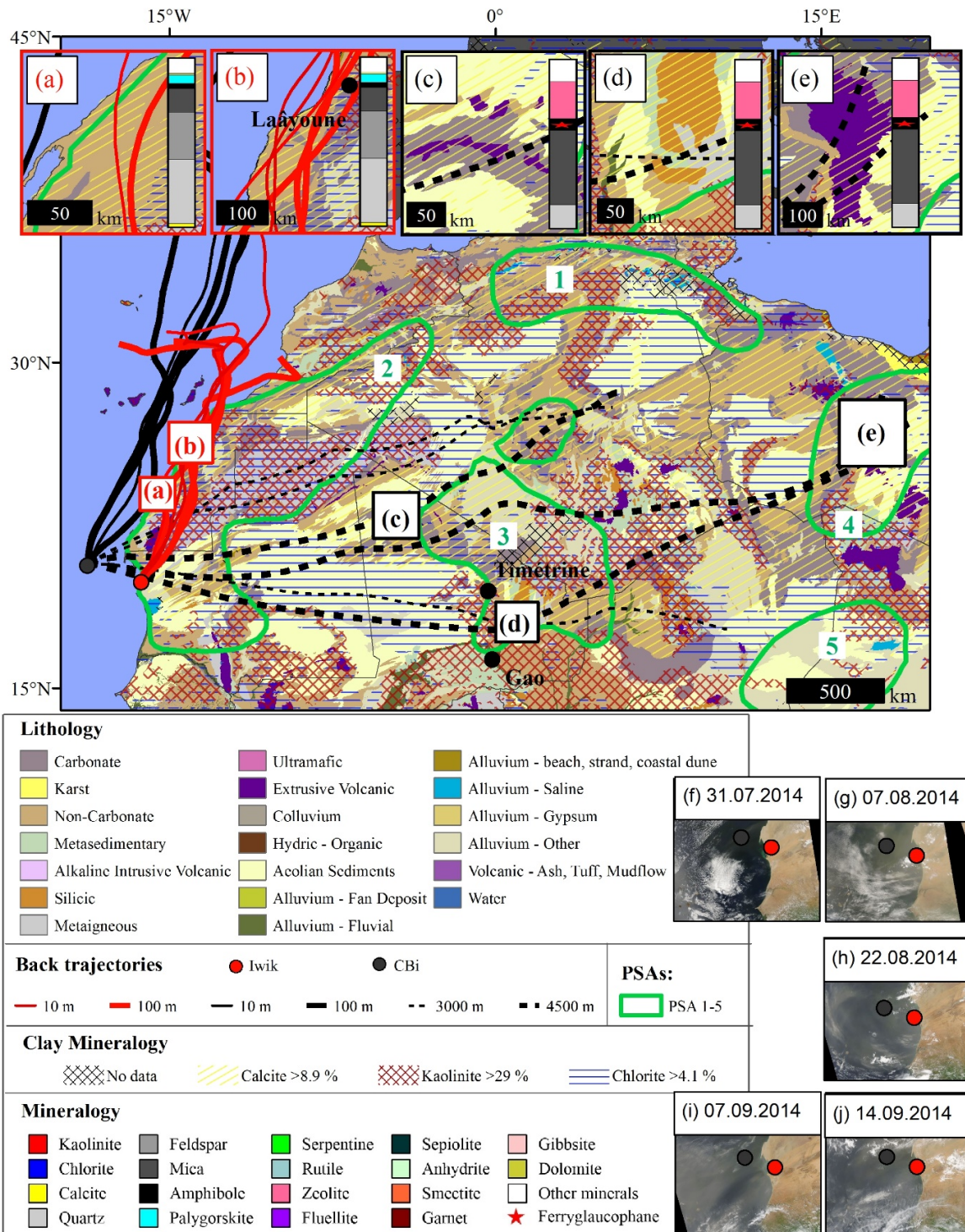
592 per height. The low-level back trajectory ending at site CBI runs offshore. The low-level back trajectory ending at
 593 site Iwik passes through the major PSA 2 and the high-level back trajectory passes through the major PSA 2, 3
 594 and 5 (Scheuvens et al., 2013). Dust sampled on land at site Iwik was characterized by the absence of chlorite,
 595 kaolinite and calcite which fits to the soils of northern Tidra Island (Fig. 11a) making it a really local phenomenon.
 596 In contrast, dust sampled offshore at site CBI was characterized by chlorite and by the absence of kaolinite which
 597 fits to the chlorite rich soils in the Mauritanides of Mauritania (Fig. 11b).



598

599 **Figure 11: High- (4500 m) and low-level (10 m) four-day back trajectories of a dust event ending during the sampling**
600 **interval 24.06.-15.07.13 at site Iwik and during the sampling interval 25.06.-16.07.13 at site CBI. The potential source**
601 **areas and the mineralogy of the samples are given in the subfigures a-b. The dust storm event is indicated in subfigure**
602 **c.**

603 In Fig. 12 a typical late-summer situation is illustrated. **At least five separate dust events could be identified (Fig.**
604 **12f-j) out of which three occurred during the sampling interval of the site Iwik and two during the sampling interval**
605 **of the site CBI. One of these dust storms occurring during the sampling interval of site CBI lasted for two days**
606 **(07-08.08.2014), while all other dust storms lasted for only one day. As a result, three back trajectories could be**
607 **drawn for each site and each height.** The low-level back trajectories ending at site CBI run offshore. The low-level
608 back trajectories ending at site Iwik pass through the major **PSA 2**. The high-level back trajectories pass through
609 the major **PSA 2, 3 and 4** (Scheuven et al., 2013). Dust deposited in the continental traps was characterized by
610 the presence of calcite and the absence of chlorite and kaolinite. Therefore, the source area of the dust was most
611 likely in the Western Sahara where soils rich in calcite but poor in chlorite and kaolinite are located (Fig. 12a,b).
612 Dust sampled with the oceanic traps during this sampling interval was characterized by the absence of chlorite and
613 kaolinite and by the presence of a high percentage of zeolite (22 %) (Fig. 8c). Therefore, a possible source area
614 may have been extrusive volcanic rocks of the northern Taoudeni Basin (Fig. 12c) and the Fezzan uplift (Fig. 12e).
615 Ferryglaucophane may have been sourced by the Pharusian belt (Fig. 12d).



616

617

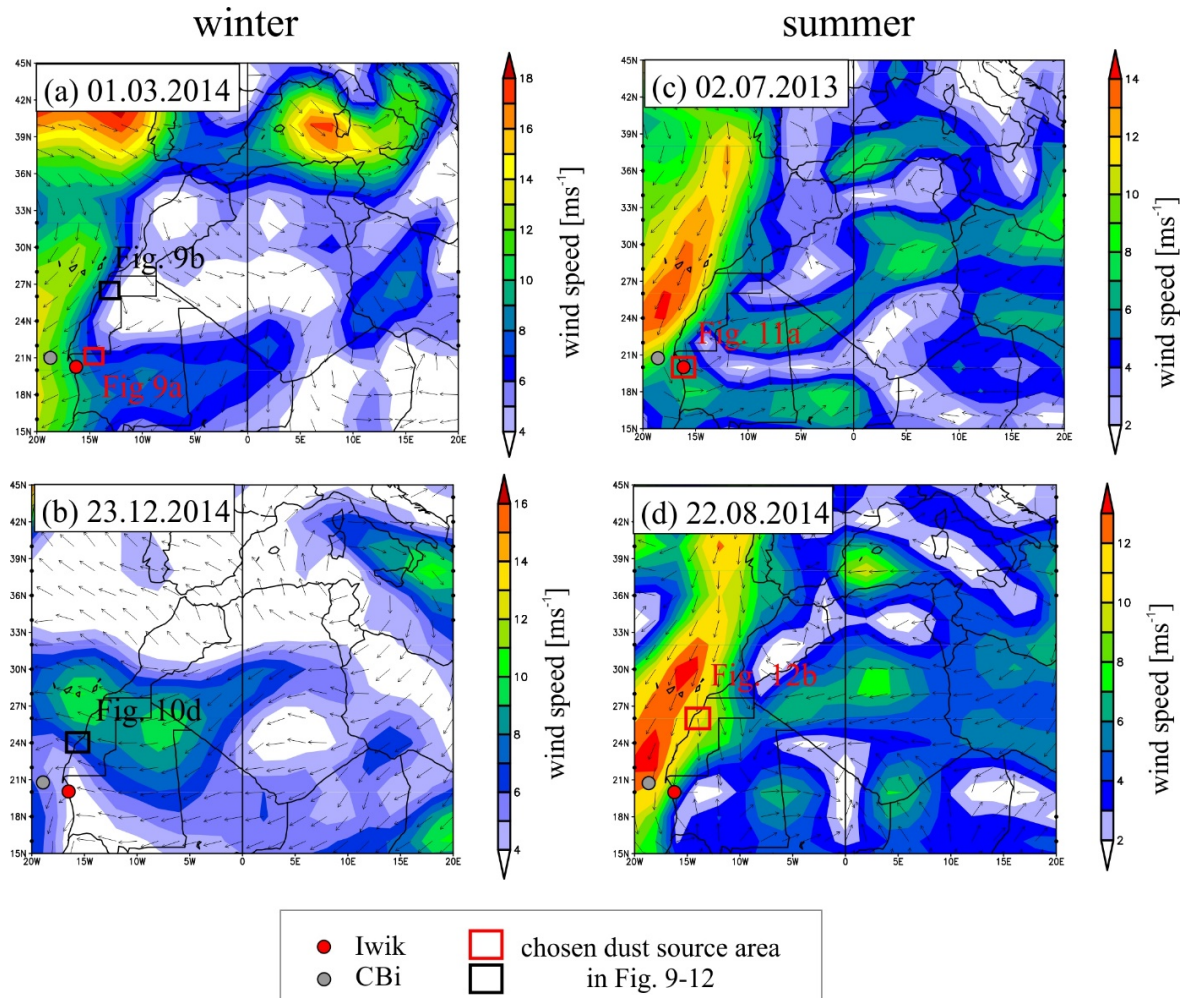
Figure 12: High- (4500 m) and low-level (10 m) four-day back trajectories of dust events ending during the sampling interval 15.08.-15.09.14 at site Iwik and during the sampling interval 01.08.-21.08.14 at site CBI. The potential source areas and the mineralogy of the samples are given in the subfigures a-c. The dust storm events are indicated in subfigures e-i.

621

In Fig. 13a-d the mean wind vectors and speed are presented for chosen dust storm events. The individual dust source areas that were identified using the back trajectory of the day with the dust storm as shown in Fig. 9-12 are further displayed in Fig. 13a-d. As can be clearly seen in the subfigures, the mean wind velocities were

623

624 anomalously large in the chosen dust source areas which enabled dust emission. During winter, six hourly mean
 625 wind velocities were larger than 7 ms^{-1} in the chosen dust source areas (Fig. 13a-b). During summer 2013, six
 626 hourly mean wind velocities were larger than 6 ms^{-1} in the chosen dust source area (Fig. 13c). During summer
 627 2014 extremely high mean wind velocities were encountered near the study sites and in the proposed dust source
 628 area (Fig 13d).



629

630 **Figure 13: Six hourly composite mean wind vectors and speed at 1000 mb for selected days including a dust storm event**
 631 **during winter (a) – (b) and summer (c) – (d). The dust source area that was identified for the individual dust storm**
 632 **event using the back trajectory of the day with the dust storm is further displayed.**

633

634 4. Discussion

635

636 4.1 Comparison of dust collected on land and in the ocean

637

638 4.1.1 Dust concentrations

639

640 An annual average dust concentration (total suspended particles) of $\sim 214 \mu\text{g m}^{-3}$ and $275 \mu\text{g m}^{-3}$ was estimated for
641 all dust samples of the year 2013 and 2014 respectively regarding the site Iwik (Table 5). These estimates were
642 larger than what has been measured for background dust concentrations (total suspended particles) in Morocco
643 which were in the order of $100 \mu\text{g m}^{-3}$ during spring 2006 (Kandler et al., 2009). However, in Morocco dust was
644 collected at a larger height of 4 m and haze-periods and dust-storms were excluded from the average value. The
645 horizontal dust fluxes at site Iwik correlated positively to wind speed (Fig. 7b) and decreased with collection height
646 (not shown). This underscores the proximity of this continental site to the dust emission source.

647 At the distal oceanic site CB, the annual average dust deposition flux was $\sim 45 \text{ mg m}^{-2} \text{ d}^{-1}$ (2013) (Table 5). The
648 dust flux was slightly larger than the average annual dust flux observed at site CB between 1988 and 2012 with \sim
649 $30 \text{ mg m}^{-2} \text{ d}^{-1}$ (Fischer et al., 2016). The slightly larger dust fluxes may have been caused by the anomalously high
650 frequency in dust storm events as observed on satellite images occurring during the studied time period (not
651 shown). The observed general decrease in the dust flux from the sites CBi and CB can be explained via the increase
652 in the distance to the source area. Decreased dust deposition fluxes offshore NW Africa with increasing distance
653 from the African coast were also observed by Bory and Newton (2000) analysing the lithogenic fluxes in marine
654 sediment traps.

655 The average horizontal fluxes at site Iwik were ~ 1000 times larger with $\sim 100000 \text{ mg m}^{-2} \text{ d}^{-1}$ (Table 5) due to the
656 different sampling technique. The MWAC samplers do not measure deposition fluxes but foremost dust
657 concentrations. Only 1% or less drops out of a moving dust cloud within five minutes, hence, the horizontal dust
658 flux is at least ~ 100 times higher than the dust deposition flux (Goossens, 2008). The fact that the dust fluxes
659 decreased with height (not shown) further complicated a comparison between the sites due to the different
660 sampling heights of the dust collectors (2.90 m at Iwik, versus traps in the water). Therefore, the fluxes between
661 the site Iwik and the offshore sediment trap moorings cannot be compared.

662 4.1.2 Dust transport

663

664 The measured grain-size distributions for dust trapped at 2.90 m on land at site Iwik and for dust settling in the
665 ocean were predominantly unimodal (Fig. 6). Unimodal grain-size distributions are typical for wind-blown
666 sediments (Pye, 1995). Unimodal grain-size distributions were also measured for dust deposited in a vertical dust
667 sampler in M'Bour (Skonieczny et al., 2011), dust sampled on ship vessels (Stuut et al., 2005) and in other
668 sediment trap samples offshore NW Africa (Ratmeyer et al., 1999b; Van der Does et al., 2016a; Friese et al., 2016).

669 The measured annual average modal grain size at site Iwik was $48 \mu\text{m}$ (Table 5). The obtained average annual
670 modal grain size was close to the coarse mode of $44 \mu\text{m}$ observed by Gillies et al. (1996) for dust trapped at a
671 height of 10 m during spring in Fakarbé (Mali) which is located about 700 km southeast of Iwik. Gillies et al.
672 (1996) conclude that the coarse mode in the dust samples points to locally-derived dust. Based on this observation,
673 we argue that also the dust trapped near Iwik was most likely generally of regional instead of long-distance

674 provenance. The distance to the main source area may be, however, not in the direct surrounding of the dust
675 collector since dust sampled with MWAC samplers in the vicinity of barchan dunes of the Bodélé depression at
676 2.4 m height is characterized by a larger modal particle size of $\sim 100 \mu\text{m}$ (Chappell et al., 2008). The annual
677 average modal and maximum particle size gradually decreased from the on-land site Iwik, to the proximal oceanic
678 site CBi and the distal oceanic site CB (Table 5, Fig. 6a). This decrease in particle size between the stations CB
679 and CBi was observed before and was attributed to the preferred gravitational settling of coarse particles during
680 dust transport (Friese et al., 2016). Moreover, many studies have confirmed a downwind fining of the terrigenous
681 fraction of surface sediments offshore NW Africa (Koopmann, 1981; Holz et al., 2004; Fütterer, 1980; Radczewski,
682 1939; Lange, 1975), and it is intuitively logical.

683 **Bimodal grain-size distributions typically indicate the sampling of different dust sources (Stuut et al. (2009) and**
684 **references therein).** The three samples of the Iwik time series that were characterized by an additional small peak
685 in the grain-size distribution around $\sim 16 \mu\text{m}$ were sampled during sampling intervals of anomalously high wind
686 velocity. The back-trajectories of one of these samples pointed towards a proximal and more distal dust source
687 (Fig. 12a,b). **Therefore, it may be possible that wind velocities were high enough during the sampling interval to**
688 **inject dust to higher altitude and transport it from more distant sources (Fig. 12b) to the sampling site resulting in**
689 **the small peak in the grain-size distributions.** This interpretation is further supported by the reanalysis wind vector
690 maps showing anomalously high wind velocities between the site Iwik and the proposed distant source area
691 enabling dust emission and transport of dust particles from the more distant source to the site Iwik (Fig. 13d).
692 On the other hand, microscopic examination prior to particle-size analyses of the Iwik samples revealed that the
693 samples included many aggregates (Fig. 5d). Hence, locally derived aggregates may have been sampled during
694 periods of high wind velocities. These aggregates may have been dispersed in the demineralized water during the
695 measurement of the laser resulting in the observed additional fine peak at $\sim 16 \mu\text{m}$. Further, precipitation was
696 encountered according to the TRMM data during the sampling interval of two of these three samples. Therefore,
697 a further explanation for the bimodal grain-size distributions may be the deposition of finer dust particles from
698 higher altitude of the SAL due to precipitation. **The rain droplets may have evaporated during their fall releasing**
699 **the dust particles at lower altitudes which can then be sampled with the MWAC sampler. However, we also**
700 **observed some remnants of water in the bottles and therefore wet deposition into the bottles may have also**
701 **occurred.** During summer, frequent rainfall resulted in a decrease of the modal particle size of deposited Saharan
702 dust at the site Iwik (Fig. 7c). This observation may also be explained by the deposition of finer dust particles from
703 higher altitude of the SAL due to precipitation. One winter and one summer sample of the oceanic samples that
704 were characterized by bimodal grain-size distributions have several proposed dust source areas each (Fig. 10, 12).
705 Thus, the sampling of long- as well as short-travelled dust may have resulted in a bimodal grain-size distribution.

706 Both at the onshore sampling site Iwik and at the offshore sampling site CBi a clear seasonal trend in the particle
707 sizes of deposited dust could be observed with generally coarser modal particle sizes during summer (Fig. 6b,c).
708 Generally coarser summer modal particle sizes of deposited dust at site CBi were observed before for a three year
709 time series during 2003 to 2006 and related to moist convective dust storm events (Friese et al., 2016). The
710 generally coarser particle sizes during summer at the site Iwik may be explained by the trade wind speed as a
711 positive correlation between the modal grain sizes and surface wind velocities was observed (Fig. 7a). This implied
712 that dust was predominantly transported with the trade winds from sources of a quite constant distance year-round.
713 During dust storm events particles with a diameter of 40 to 50 μm may be transported $\sim 100 \text{ km}$ (Tsoar and Pye,

714 1987). The proposed source areas all fall in this range except for the winter sample of 2014-2015 (Fig. 10). The
715 winter sample was characterized by an anomalously low modal grain size of 38 μm and particles of this size may
716 be transported more than 100 km during dust storm events (Tsoar and Pye, 1987). Moreover, Van der Does et al.
717 (2016a) observed how particles up to 100 μm were transported \sim 3500 km across the Atlantic Ocean. **To sum up,**
718 **the seasonal variability in the particle size of deposited dust at the site Iwik was mainly driven by the surface wind**
719 **speed due to the predominant sampling of nearby dust sources year-round.**

720 **4.1.3 Dust mineralogical composition**

721

722 In the dust sampled at Iwik the minerals quartz, feldspar, mica, amphibole, palygorskite, chlorite, calcite, dolomite,
723 gibbsite, rutile and serpentine were present (Fig. 8a). The observed occurrence of the minerals quartz, feldspar,
724 mica, chlorite and calcite has also been described for the bulk size fraction of soil samples and dust samples
725 collected in Mauritania (Schütz and Sebert, 1987). Palygorskite, mica and chlorite have also been detected by
726 Skonieczny et al. (2013) in the PM_{30} size fraction of a three-year time series of dust deposition at M'Bour, Senegal,
727 more than 500km south of Iwik, Mauritania. Smectite and kaolinite, which were absent in the Iwik samples, were
728 the dominant minerals of the dust sampled at M'Bour (Skonieczny et al., 2013). Smectite and kaolinite are
729 considered as indicative for wet tropical soils and their relative abundance in soils increases southwards along the
730 northwest African coast (Lange, 1982; Biscaye, 1964). We argue that the mineralogical differences between the
731 two sites are explained by the >500 km distance between Iwik and M'Bour and the fact that the latter station is
732 surrounded by tropical soils. Gibbsite, rutile and serpentine have not been reported in any continental dust study
733 so far and thus seem to be indicative for locally-derived dust (Fig. 9a, Fig. 11a).

734 The dust sampled at the proximal marine site CBI contained the minerals quartz, feldspar, mica, amphibole,
735 palygorskite, chlorite, zeolite, kaolinite, smectite, sepiolite, rutile, garnet, anhydrite and fluellite (Fig. 8a). The first
736 seven of these minerals were also found in the clay and/or silt and sand fraction of Saharan dust sampled during
737 ship cruises parallel to the coast about 70 km off Cape Blanc (Chester et al., 1971) and perpendicular to the coast
738 about 80 to 180 km off Cape Blanc (Chester and Johnson, 1971b). Analogous to the samples of this study, the
739 PM_{20} fraction of surface sediments of the piston cores RC05-57, RC05-60 and A180-44 also feature zeolites and
740 the surface sediments of core RCRC05-57 also traces of pyrophyllite (sepiolite belongs to the pyrophyllite group)
741 (Biscaye, 1964). Further, rutile was also present in the silt and sand fraction of Saharan dust sampled perpendicular
742 to the coast on the research vessel (Chester and Johnson, 1971b). Palygorskite was found in the clay fraction of
743 the surface sediment of sediment core GIK12329 ($19^{\circ} 22' \text{ N}$, $19^{\circ} 56' \text{ W}$) offshore Cape Blanc and is considered a
744 characteristic mineral of Saharan dust (Lange, 1975). The observed annual average C/K ratio ($C/K=4$) recorded
745 for the bulk size fraction of the trap samples was larger than the C/K ratio ($C/K=0.3-1$) recorded in the clay fraction
746 of surface sediment samples offshore Cape Blanc by Lange (1982). The disagreement may be due to the generally
747 larger percentage of kaolinite in the clay fraction compared to the silt fraction (Journet et al., 2014).

748

749 The dust samples of the site Iwik were further characterized by a dominance in quartz and feldspar (Fig. 8a). A
750 dominance in quartz has also been described for continental dust samples and soil samples collected in Mauritania
751 by Schütz and Sebert (1987). More than 20 papers published XRD data of northern African dust reporting quartz
752 as the main mineral in most dust samples (Scheuven et al., 2013). The observed increase in micas and decrease
753 in quartz and feldspar observed for the marine samples relative to the Iwik samples (Fig. 8a) can be explained via

754 the preferential gravitational settling of the larger dust minerals quartz and feldspar during transport (Delany et al.,
 755 1967;Glaccum and Prospero, 1980;Chester and Johnson, 1971b;Schütz and Sebert, 1987). A strong downwind
 756 decrease in quartz content in Saharan dust was also observed by Korte et al. (2016).

757

758 **4.2 Mineralogy as a provenancing tool**

759

760 In Table 7 an overview of the chosen dust source areas for the site Iwik and CBi is given together with the
 761 characteristic minerals of the samples that may be used as a tracer for the source area. In the following subsections
 762 the identification of the source areas and mineralogical tracers is described in detail.

763 **Table 7: Overview of the chosen source areas and the tracer minerals of the individual samples together with the given**
 764 **characteristics of the source areas according to literature.**

Sampling interval	Characteristic minerals of sample	Chosen dust source area	Bulk mineralogical composition of chosen PSA ⁽¹⁶⁾	Characteristic source rocks and deposits of chosen source area
Iwik				
15.02.-15.03.14	*Rut, Serp, Cc	PSA 2: Reguibat Shield	C/K = 0.0–1.0 *Pal: 1-30 wt%	Metamorphic and granitic rocks ⁽¹⁾ Serpentinities ⁽²⁾
15.12.14-18.01.15	*Cc, Chl, Pal (8 wt. %)	PSA 2: Senegal-Mauritania Basin	C/K = 0.0–1.0 *Pal: 1-30 wt%	Chalky horizons ⁽³⁾
		PSA 3: Eastern Taoudeni Basin	C/K = 0.2–0.9 *Pal: 1-5 wt%	Carbonate sequences ⁽⁴⁾
24.06.-15.07.13	*Gib	PSA 2: Tidra Island	C/K = 0.0–1.0 *Pal: 1-30 wt%	Gibbsite maximum offshore Cape Blanc ⁽⁵⁾
15.08.-15.09.14	*Cc, Dol, Pal (5 wt. %)	PSA 2: Aaiun-Tarfaya Basin	C/K = 0.0–1.0 *Pal: 1-30 wt%	Limestone deposits ⁽⁶⁾ Outcrops near Laâyoune with dolomites ⁽⁶⁾
CBi				
26.02.-18.03.14	*Chl, Kao (C/K = 1), Pal (11 wt. %), Flu, Anh, Sme, Ga	PSA 2: Aaiun-Tarfaya Basin near Boucraa	C/K = 0.0–1.0 *Pal: 1-30 wt%	Phosphate deposits ⁽⁷⁾
16.12.14-04.01.15	*Kao (C/K = 0), Pal (1 wt. %), Zeo, Se, Sme	dike swarms and sills of northern Taoudeni Basin	-	Basalts with glass ⁽⁹⁾
		PSA 2: Aaiun-Tarfaya Basin	C/K = 0.0–1.0 *Pal: 1-30 wt%	Palygorskite-sepiolite mafic clays ⁽⁷⁾
		Southern Senegal-Mauritania Basin	-	Lateritic soil ⁽⁸⁾ Horizontal layers of palygorskite and sepiolite ⁽⁸⁾
25.06.-16.07.13	*Chl, Pal (2 wt. %), Rut	PSA 2: Mauritanides	C/K = 0.0–1.0 *Pal: 1-30 wt%	Strongly metamorphosed rocks ⁽¹⁰⁾ Greenschist facies ⁽¹¹⁾
01.08.-21.08.14	*Fe-Amf, Zeo	dike swarms and sills of northern Taoudeni Basin	-	Basalts with glass ⁽⁹⁾
		PSA 4: Fezzan uplift	C/K = 0.0–2.6 *Pal: 0 wt%	Zeolite in basaltic rocks ^(12,13)
		PSA 3: Pharusian belt	C/K = 0.2–0.9 *Pal: 1-5 wt%	Blueschists ⁽¹⁴⁾ Glaucofane bearing eclogites ⁽¹⁵⁾
* Amf = amphibole, Pal = palygorskite, Chl = chlorite, Cc = calcite, Dol = dolomite, Gib = gibbsite, Zeo = zeolite, Kao = kaolinite, Sme = smectite, Se = sepiolite, Rut = rutile, Serp = serpentine, Ga = garnet, Anh = anhydrite, Flu = fluellite				
⁽¹⁾ Schofield et al. (2006) and references therein ⁽²⁾ Schlüter (2008) ⁽³⁾ Wissmann (1982) ⁽⁴⁾ Bertrand-Sarfati et al. (1991) ⁽⁵⁾ Biscaye (1964) ⁽⁶⁾ Bosse and Gwosdz (1996) ⁽⁷⁾ Moreno et al. (2006) ⁽⁸⁾ García-Romero et al. (2007) ⁽⁹⁾ Verati et al. (2005) ⁽¹⁰⁾ Villeneuve (2005), ⁽¹¹⁾ Dallmeyer and Lécorché (2012) ⁽¹²⁾ Abdel-Karim et al. (2013) ⁽¹³⁾ Cvetković et al. (2010) ⁽¹⁴⁾ Caby (2014), ⁽¹⁵⁾ Caby et al., (2008) ⁽¹⁶⁾ Scheuven et al. (2013)				

765

4.2.1 Dust collected on land

The variability of the mineralogical composition of dust sampled at site Iwik could be related to the synoptic scale change in the surface trade wind direction. However, meteorological data from nearby sites like e.g., Nouadhibou demonstrate that local effects like the topography exert a strong influence on observed wind directions at ground level. (Fig. 2). The back trajectories indicate that the dust sources for the dust collected in Iwik during winter were located NE and E of the sampling site (Fig. 9a, Fig. 10a,b), while those during summer were located W (within the PNBA) and NNE of the sampling site (Fig. 11a, Fig. 12a,b). This is in accordance with a change in the dominant local surface trade wind direction from NE in winter to NNE in summer (Fig. 2) and is also reflected in the clay-mineralogical composition of the samples.

Generally, there is not much variability in the clay-mineralogical composition of the Iwik samples. The back trajectories for the winter sample of 2014 indicate that the material was blown from the southwestern Reguibat Shield (**PSA 2**) (Fig. 9a). The lack of palygorskite in this sample does not fit to the proposed bulk palygorskite content (1-30 %) of **PSA 2** (Scheuvens et al., 2013) (Table 7). **Therefore, we argue that the sampled dust was most likely derived from a localized source of PSA 2.**

The sample included the characteristic minerals rutile and serpentine (Table 7) which are usually a result of metamorphic processes (Deer et al., 1992). Indeed, the western Reguibat Shield is composed of metamorphic and granitic rocks (Schofield et al. (2006) and references therein) and the rocks are intruded by serpentinites (Schlüter, 2008). The sample was further characterized by the highest quartz percentage among all samples (~ 50 %) (Fig. 8b). The sand dunes of the Azefal sand sea which cover part of the southwestern Reguibat Shield might have sourced these quartz grains (Fig. 9a). The sand dunes may have been fed by outcropping carbonate deposits at the northern rim of the Taoudeni Basin via the NE-trade winds leading to anomalously high percentages of calcite in the sand dunes (Fig. 9). Thus, the sand dunes may have also sourced the calcite present in the sample (Fig. 8b).

The winter sample of 2014-2015 was suggested to be sourced from sediments of the northern Senegal-Mauritania Basin (**PSA 2**) (Fig. 10a) and the eastern rim of the Taoudeni Basin (**PSA 3**) (Fig 10b). The palygorskite content of the sample (8 %) fits to the proposed bulk palygorskite content of **PSA 2** (Scheuvens et al., 2013) (Table 7). **This may point to several externally mixed sources of PSA 2 during transport.**

The sample was further characterized by calcite and chlorite (Table 7). The sediments in the northern Senegal-Mauritania Basin (Fig. 10a) comprise Quaternary chalky horizons (Wissmann, 1982) which may have sourced the calcite. More likely, calcite may have been derived from the Mesozoic carbonate sequences cropping out in the eastern rim of the Taoudeni Basin (Bertrand-Sarfati et al., 1991) (Fig. 10b). A source area lying at the Algerian/Mali border was also suggested for a chlorite and calcite bearing dust sample collected on the Canary Islands (Alastuey et al., 2005). The winter dust sample trapped at site Iwik was further characterized by the lowest feldspar percentage (~ 5 %), highest mica percentage (~ 40 %) (Fig. 8b) and lowest modal grain size (~ 38 μm) among all Iwik dust samples analysed for mineralogy. The Stokes terminal settling velocity is smaller for platy particles than for spherical particles of similar diameter (Santamarina and Cho, 2004). Therefore, a long-distance transport of dust from the eastern Taoudeni Basin to Iwik may have resulted in a depletion in spherical quartz particles (Fig. 5a,b,c) and an enrichment in platy mica particles (Fig. 5b).

806 The summer sample of 2013 was proposed to be sourced from the near-by northern Tidra Island (**PSA 2**) (Fig.
807 11a). **Again, the absence of the mineral palygorskite is noteworthy which may point to the sampling of a localized**
808 **dust source.**

809 The sample was further characterized by the mineral gibbsite (Table 7). The northern Tidra Island is famous for
810 the local occurrence of west Africa's northernmost mangroves (Proske et al., 2008) which grow in humid and
811 warm climates. Humid and warm conditions are also beneficial for the formation of gibbsite which forms through
812 tropical weathering (Deer et al., 1992). Therefore, we argue that the soils of Tidra Island supplied the gibbsite
813 found in the sample. A localized small gibbsite maximum was outlined for the surface sediments offshore Cape
814 Blanc (Biscaye, 1964) which further supports the view that gibbsite is supplied from a local source. The sample
815 was further characterized by anomalously large moderately spherical quartz grains (Fig. 5c) emphasizing a short
816 travel distance of the dust.

817

818 The summer sample of 2014 was most likely sourced by sediments of the Western Sahara (**PSA 2**) (Fig. 12a,b).
819 The palygorskite content of the sample (5 %) matches with the proposed bulk palygorskite content of **PSA 2**
820 (Scheuvens et al., 2013) (Table 7). **Hence, dust may have been supplied from several dust sources of PSA 2 which**
821 **were mixed during transport.**

822 The sample was further characterized by calcite and dolomite (Table 7). Sediments outcropping in the Western
823 Sahara are composed of Tertiary sediments (Wissmann, 1982) with limestone deposits (Bosse and Gwosdz, 1996)
824 that may explain the calcite found in the sample (Fig. 12a). Upper cretaceous outcrops in the Aaiun-Tarfaya Basin
825 near Laâyoune comprise dolomites (Bosse and Gwosdz, 1996) and could have sourced the dolomite found in the
826 sample (Fig. 12b). A further evidence for dolomite-bearing dust transport from the Aaiun-Tarfaya Basin is a local
827 dolomite maximum outlined for the surface sediments offshore the Western Sahara (Johnson, 1979). A Saharan
828 dust sample trapped in NE Spain also contained dolomite and calcite and was related to a source area lying in the
829 Western Sahara (Avila et al., 1997).

830

831 **4.2.2 Dust collected at the marine sites**

832

833 The seasonal contrast in the dust transport patterns (high-level SAL vs. low-level Trades) potentially led to
834 strongly deviating dust sources for the material deposited in the marine trap samples. During winter, the back
835 trajectories indicated that the potential dust source areas were located NE of the sampling site (Fig. 9b, Fig.
836 10c,d,e), while those during summer were located NE, E and SE of the sampling site (Fig. 11b, Fig.12c,d,e). This
837 large variability in wind patterns can clearly be recognized in the clay-mineralogical compositions of the samples
838 throughout the seasons.

839 Considering the much larger catchment area of the traps, several dust sources may have been sampled with the
840 traps. As a result, the composition of the analyzed samples fit well to the bulk composition of the chosen **PSA**.
841 The back trajectories indicate that the winter sample of 2014 originated from the shoreline of the Western Sahara
842 (**PSA 2**) (Fig. 9b). The observed C/K ratio (C/K=1) and the palygorskite content (11 %) are in agreement with the
843 bulk compositional C/K ratio (C/K=0-1) and palygorskite content of **PSA 2** (Scheuvens et al., 2013) (Table 7).

844 **The sample was further characterized by the presence of garnet, fluellite and anhydrite (Table 7).** The characteristic
845 occurrence of garnet together with the highest quartz content (33 %, Fig. 8b) among all CBI samples confirms a

846 short transport distance of the trapped dust. The mineral fluellite which is a weathering product of phosphate may
847 have been derived from outcropping phosphate deposits near the Bucraa phosphate mine (Moreno et al., 2006)
848 (Fig. 9b). **Anhydrite could originate from evaporites along the coast.**

849

850 The back trajectories of the winter sample of 2014 to 2015 lead to the Reguibat Shield (**PSA 2**) (Fig. 10c), the
851 coastal Western Sahara (**PSA 2**) (Fig. 10d) and the southern Senegal-Mauritania Basin (Fig. 10e). The observed
852 C/K ratio (C/K=0) and palygorskite content (1 %) fall within the ranges of these minerals in **PSA 2** (Scheuven et
853 al., 2013) (Table 7). Therefore, the **PSA 2** may have been the dominant source area of the sampled dust.

854 The sample was further characterized by the minerals zeolite, kaolinite, sepiolite and smectite (Table 7). Zeolites
855 are formed from volcanic glass and tuff and form well-developed crystals in basalts (Deer et al., 1992). Therefore,
856 the source area of the zeolites may have been outcropping volcanic rocks in the northern Taoudeni Basin (Fig.
857 10c). These rocks belong to mafic dikes and sills which are commonly basalts with dotted patches of glass (Verati
858 et al., 2005). An additional indication for a distant dust source may be the lowest quartz content (4 %) among all
859 samples (Fig. 8b). **Palygorskite-sepiolite mafic clays were found in soil samples of the Western Sahara (Moreno**
860 **et al., 2006) which may supports a Western Saharan source (Fig. 10d).**

861 **Sepiolite belongs to the pyrophyllites which is a mineral that also may be considered indicative of tropical**
862 **weathering (Moore and Reynolds, 1989). Moreover, kaolinite is usually considered indicative of tropical**
863 **weathering and the laterites of the southern Sahara and Sahel (Lange, 1975;Biscaye, 1964;Lange, 1982). Outcrops**
864 **of quaternary laterites as well as outcrops of lower Eocene horizontal layers of palygorskite and sepiolite were**
865 **described near Thiès in Senegal (García-Romero et al., 2007). Therefore, the kaolinite-rich soils and outcrops in**
866 **the southern Senegal-Mauritania basin near Thiès (Fig. 10e) may have served the kaolinite, sepiolite and**
867 **palygorskite found in the sample.**

868 **Another explanation for the presence of kaolinite and smectite in the sample may be the transport of these minerals**
869 **from southern latitudes via the poleward-flowing undercurrent to the trap site CBi (Fig. 1). Kaolinite and smectite**
870 **were found in the clay fraction of the surface sediments off Senegal (Nizou et al., 2011) and may have been brought**
871 **into the ocean by the Senegal River, and redistributed by ocean currents (Biscaye, 1964). The season of high**
872 **Senegal River sediment supply is between July to October/November (Gac and Kane, 1986). Assuming a mean**
873 **speed of ~10 cm/s of the undercurrent (Mittelstaedt, 1991), it may take about two months for the particles to travel**
874 **a distance of ~500 km to the trap site CBi. This time delay might explain the observed occurrence of these minerals**
875 **in the trap samples during winter, but not during summer.**

876

877 Based on the back trajectories, the summer sample of 2013 was suggested to be sourced from the Mauritanides
878 (**PSA 2**) (Fig. 11c). This is confirmed by the palygorskite content of the sample (2 %) (Scheuven et al., 2013)
879 (Table 7). Outstanding minerals in this sample are chlorite and rutile (Table 7). Outcrops in the Mauritanides west
880 of the Taoudeni Basin feature strongly metamorphosed rocks (Villeneuve, 2005) and greenschist facies (Dallmeyer
881 and Lécorché, 2012) which may have been the source of the rutile and chlorite.

882

883 The reconstructed source area of the summer sample of 2014 was the Pharusian belt (**PSA 3**) (Fig. 12c), the
884 extrusive volcanics of the northern Taoudeni Basin (**PSA 2**) (Fig. 12d) and the Fezzan uplift (**PSA 4**) (Fig. 12e).
885 The lack of palygorskite in the sample does corroborate with **PSA 4** ('not detected') (Scheuven et al., 2013)
886 suggesting that the provenance of the dust sample may be mainly confined to **PSA 4** (Table 7).

887 The sample was further characterized by zeolite and ferryglaucophane (Table 7). The dike swarms and sills of the
888 northern Taoudeni Basin (Verati et al., 2005) (Fig. 10c, Fig. 12c) and/or the basalts of the Fezzan uplift (Fig. 12e)
889 may have sourced the zeolite. Indeed, zeolite was described as one of the main secondary minerals in the basaltic
890 rocks of the central Al-Harui Al-Abyas basalt flows (Abdel-Karim et al., 2013) and in vesicles of the east Al Haruj
891 basalts (Cvetković et al., 2010) of the Fezzan uplift. Traces of zeolite were also detected in the Iwik sample during
892 this sampling interval. It may be that the zeolite dropped out of the high-altitude dust cloud and was subsequently
893 transported via the surface trade winds to the continental trap site. The presence of ferryglaucophane and the
894 absence of feldspar and chlorite in the sample indicates highly metamorphous outcrops constituting the dust source.
895 Therefore, the sample may have been additionally sourced by the Pharusian belt (Fig. 12c) because blueschists
896 were observed in Timétrine (Caby, 2014) and glaucophane bearing eclogites in the Gourma fold and thrust belt
897 north of Gao (Caby et al., 2008). The sample was further characterized by the highest mica content (44 %) among
898 all samples (Fig. 8c) supporting a large dust transport distance.

899

900

901 **5. Summary and conclusions**

902

903 The fluxes, grain-size distributions and the mineral assemblages of the continental trap samples and oceanic
904 sediment trap samples were well comparable to the characteristics of Saharan dust reported for the region. The
905 following main findings were made:

- 906 - A clear seasonal variability in the particle size of mineral dust deposited on land could be observed with
907 generally coarser modal grain sizes during summer compared to winter. The modal particle sizes could
908 be related to the trade wind speed.
- 909 - dust deposited on the continent was predominantly transported from near-by local sources (Mauritania,
910 Western Sahara and Mali), while dust deposited in the marine traps was transported from proximal
911 (Mauritania, Western Sahara and Mali) and distal sources (Senegal and Libya).
- 912 - Some rare characteristic minerals (e.g. ferroglaucophane, rutile, serpentine) could be related to local
913 outcrops in NW Africa.

914 To conclude, the particle size and mineralogy of Saharan dust recorded in continental climate archives should be
915 interpreted differently with respect to paleo-environmental conditions compared to marine climate archives; the
916 on-land archive seems to reflect a much more local signal as compared to the regional signal that is recorded in
917 the marine sediments. Given the relationship between particle size and wind strength, we suggest that the particle
918 size in the continental archive in NW Africa may indicate the paleo-wind strength of the trade winds. This is an
919 intuitively logical conclusion, but it has not been demonstrated before so clearly. **It should be kept in mind,**
920 **however, that the wind in the sampling location might differ from the wind in the source region if the source region**
921 **is further away. Moreover, the sizes of dust particles present in the source region will influence the grain sizes of**
922 **deposited dust.**

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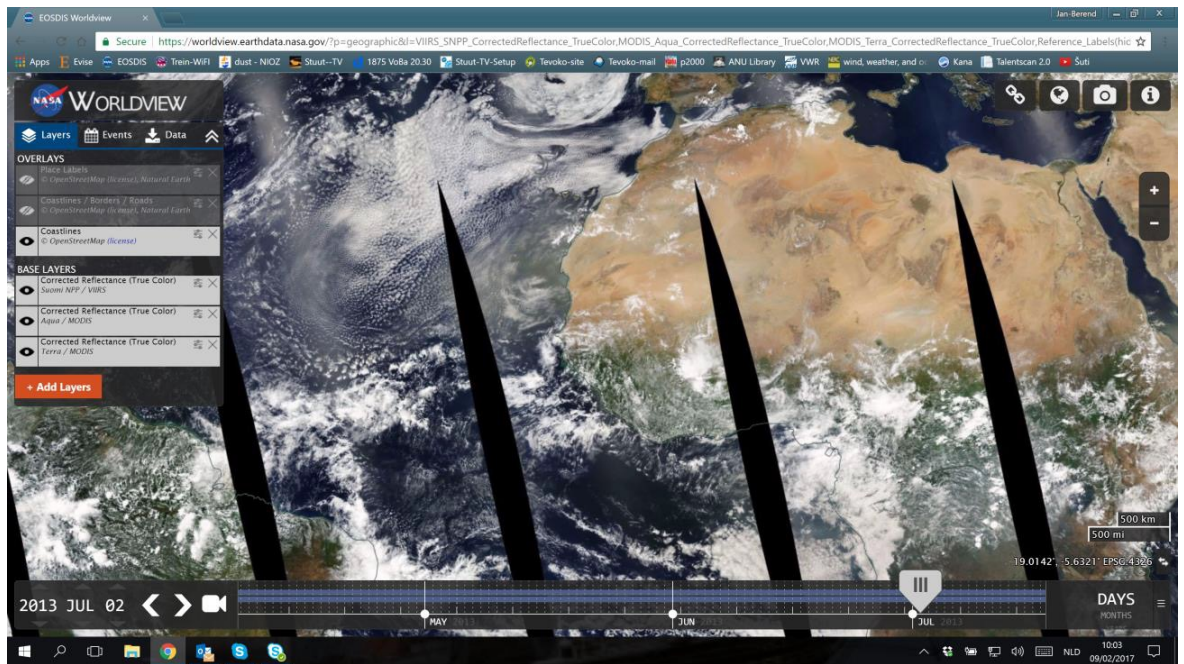
935 **6. Appendices**

936 **A1 Satellite RGB images**

937

938 In Fig. A1-4 satellite RGB true colour images are shown of the identified dust storms occurring during the sampling
939 interval of the samples analysed for dust provenance. On 31 July 2014 only few dust can be observed which
940 overlies the sampling location CBi (Fig. A2). This fits to the observed minor percentage of the mineral
941 ferryglaucophane (7 %) in the sample which was suggested to be sourced on 31 July 2014 from PSA 3. Zeolite,
942 which was more abundant (22 %) in the dust sample, was therefore most likely derived from PSA 4 due to the
943 major dust storm event occurring on 7 August 2014 (Fig. A3).

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Figure A1: Dust storm on 02 July 2013.

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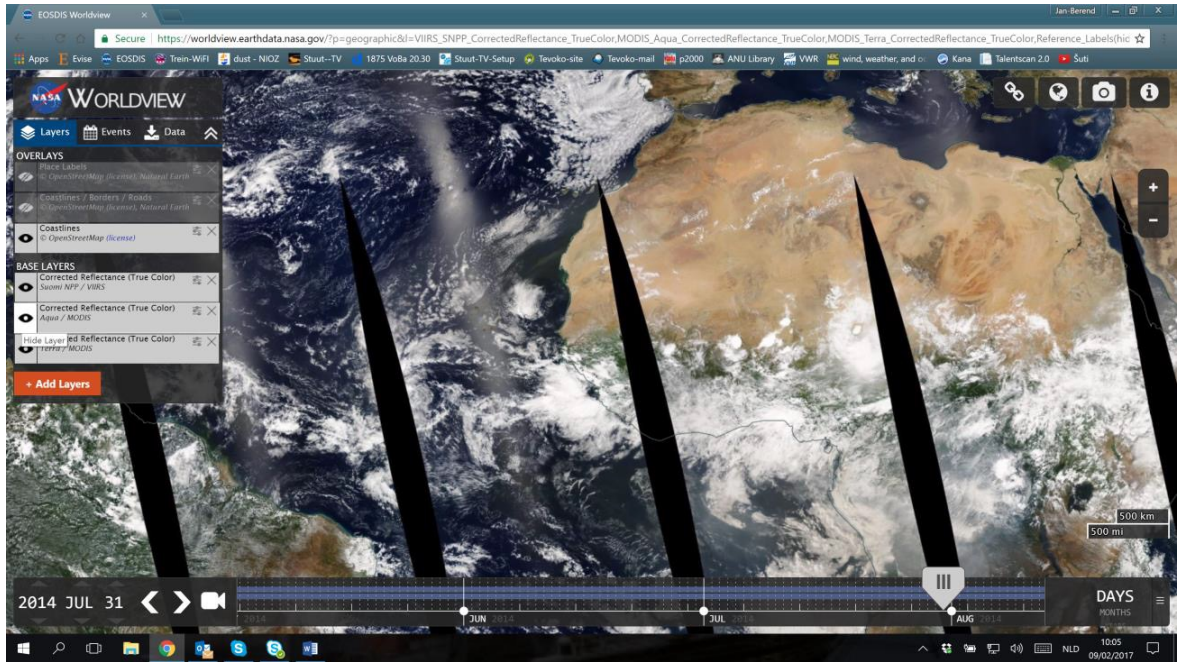


Figure A2: Dust storm on 31 July 2014.

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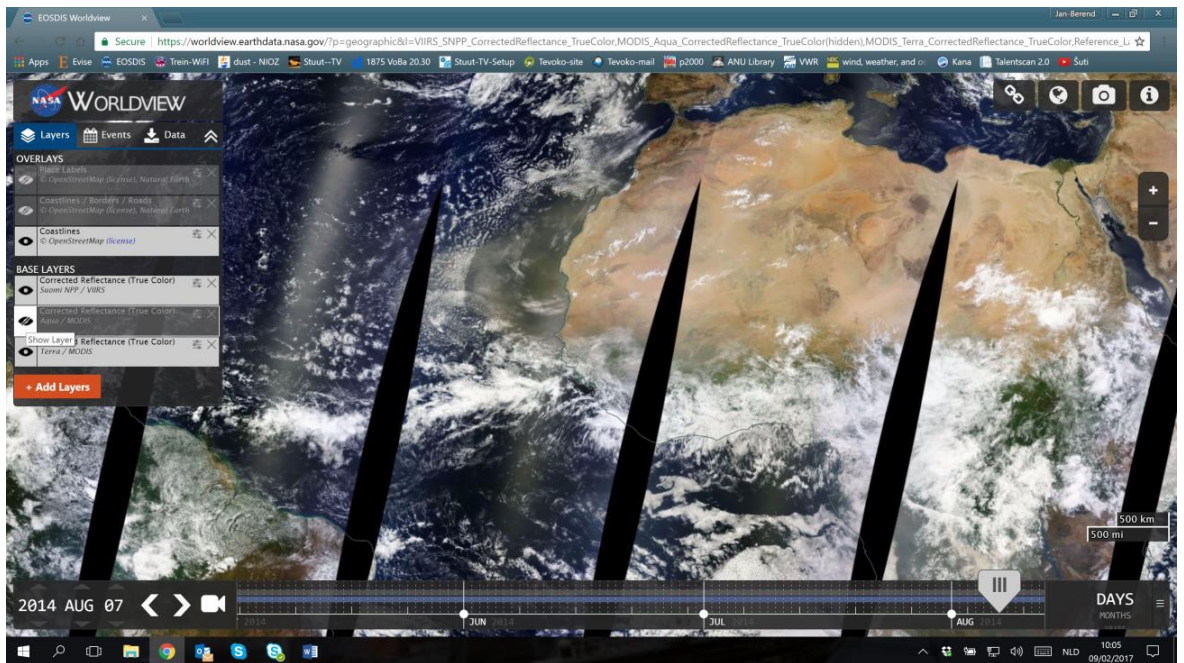


Figure A3: Dust storm on 07 August 2014.

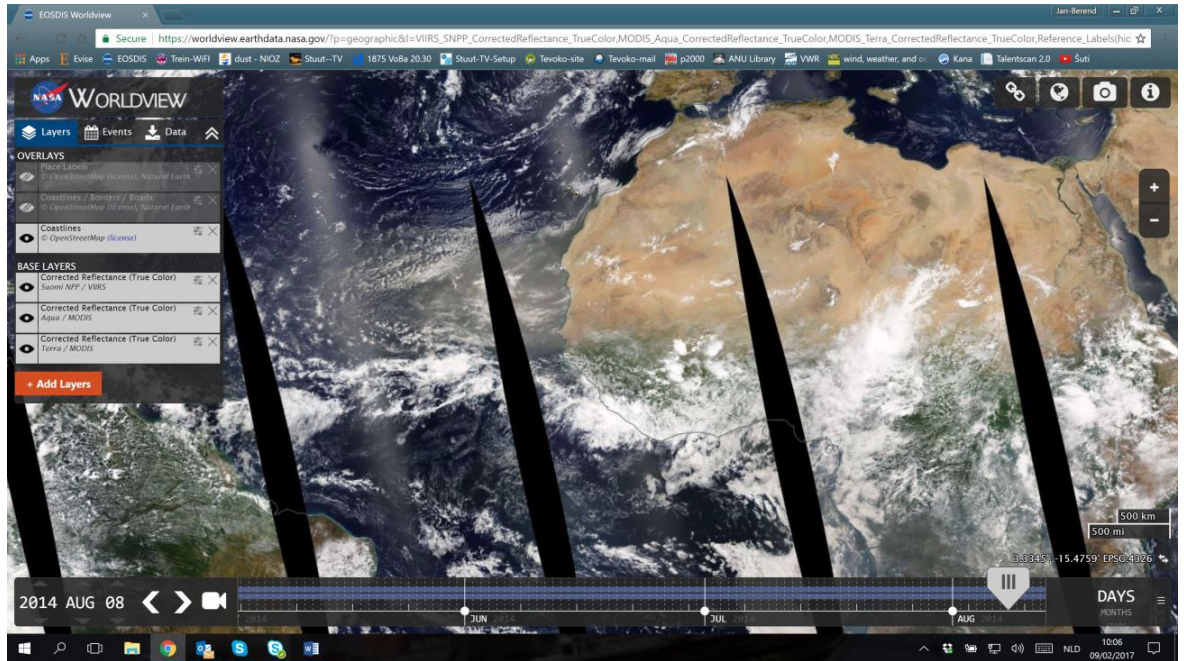


Figure A4: Dust storm on 08 August 2014.

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956 A2 Four day back-trajectories

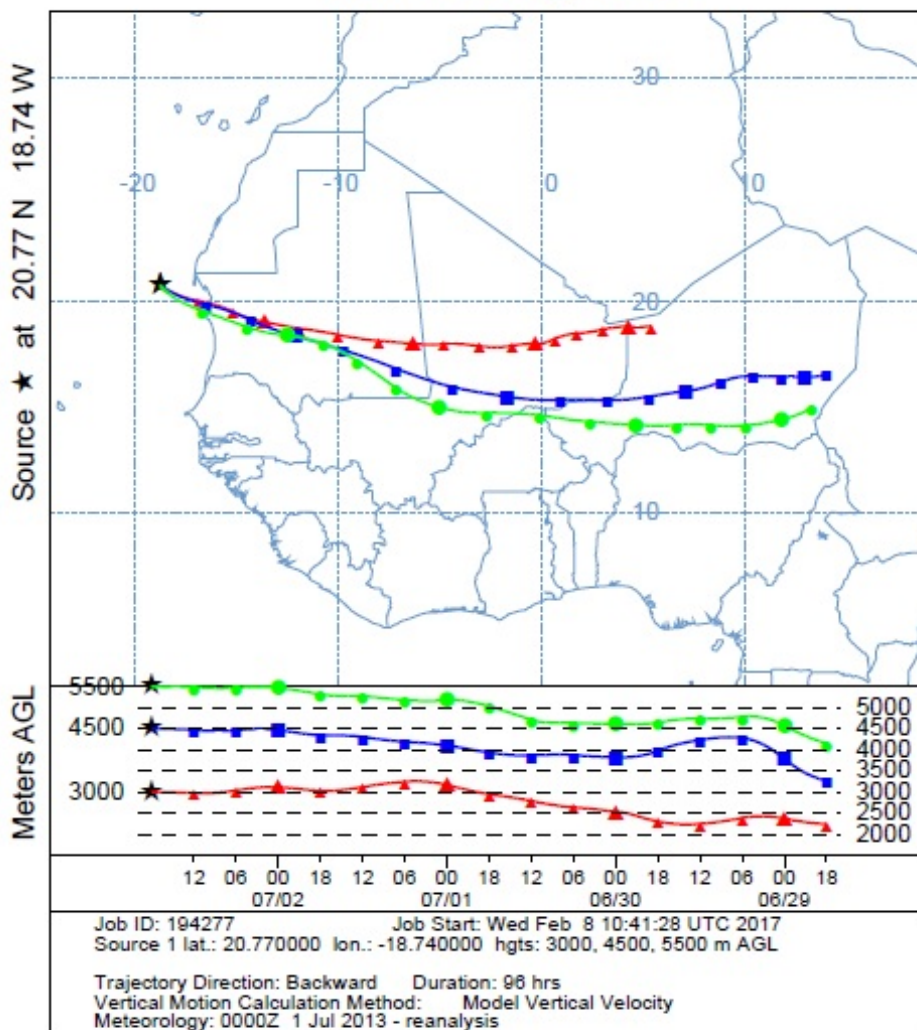
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958 In Fig. A5-8 the four day back-trajectories are shown calculated at the heights 3000 m, 4500 m and 5500 m ending
 959 at site CBI. These high altitude back-trajectories were calculated for the identified summer days with dust storm
 960 events (shown in Fig A1-4). On the one hand, a height of 4500 m was chosen by Skonieczny et al. (2013) in a dust
 961 provenance study to represent the Saharan air layer (SAL). On the other hand, a height of 5500 m was chosen by
 962 Ratmeyer et al. (1999a) in a dust transport study to represent the SAL. Maximum wind velocities within the SAL
 963 are observed at a height of ~ 3 - 4 km in the area of the Cape Verde Islands during summer according to Carlson
 964 and Prospero (1972). Therefore, we also plotted the back-trajectories at a height of 3000 m. In order to investigate
 965 which air layer should be chosen for provenance studies, the back trajectories of the different heights were
 966 compared.

967 The back-trajectories deviated slightly from each other regarding their direction and length. The back-trajectories
 968 at 3000 m showed the most deviation. Further, the back-trajectories at 4500 m showed the best agreement with the
 969 source areas and the minerals in the samples. Therefore, we chose to use the trajectories at 4500 m for provenance
 970 studies according to Skonieczny et al. (2013).

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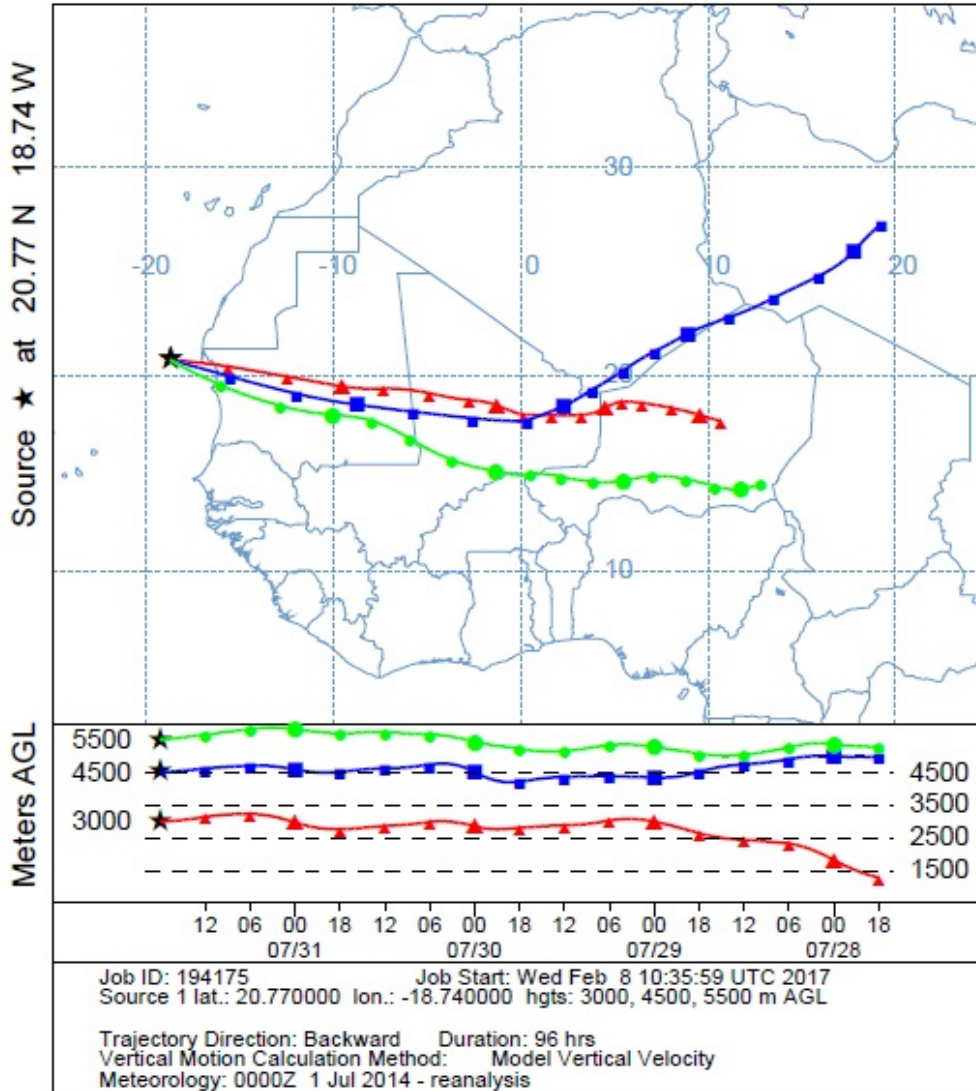
NOAA HYSPLIT MODEL
 Backward trajectories ending at 1800 UTC 02 Jul 13
 CDC1 Meteorological Data



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Figure A5: Four day back-trajectories at a height of 3000 m, 4500 m and 5500 m on 02 July 2013.

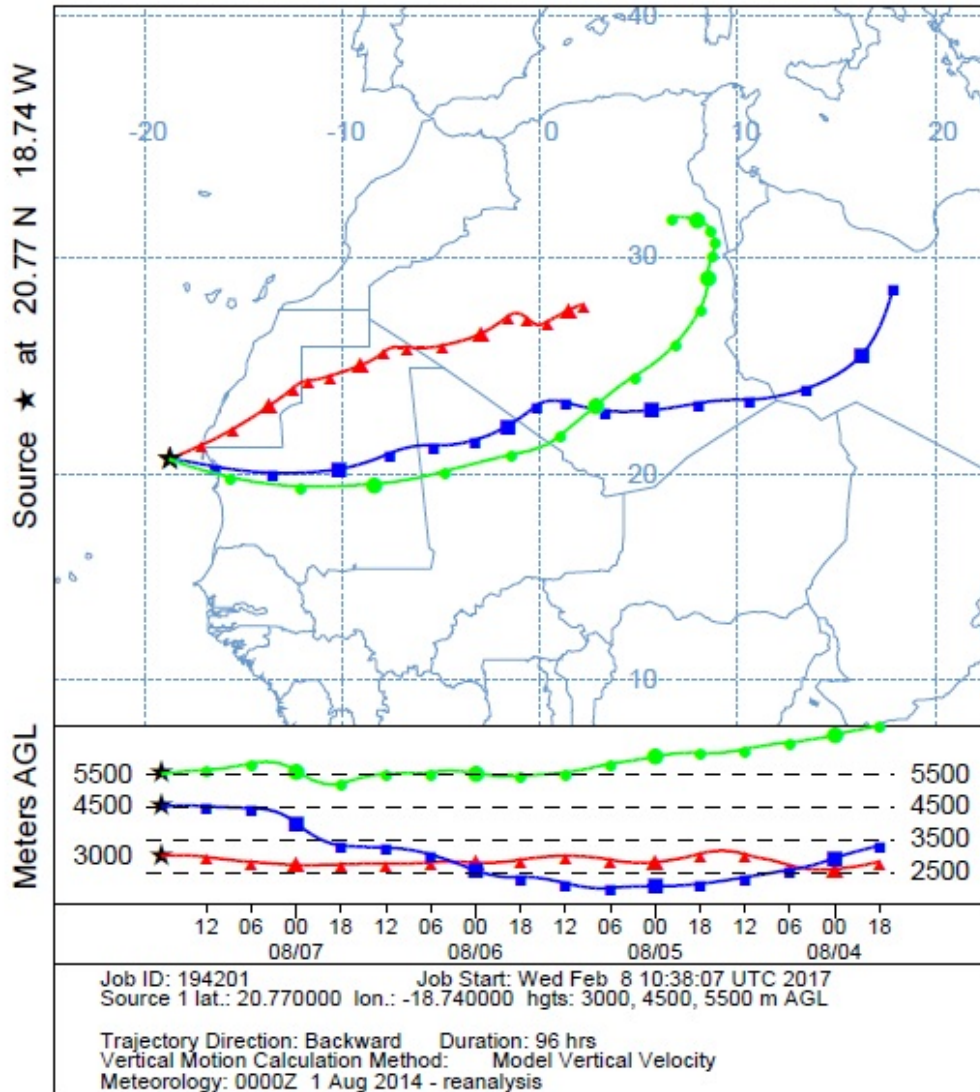
NOAA HYSPLIT MODEL
 Backward trajectories ending at 1800 UTC 31 Jul 14
 CDC1 Meteorological Data



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Figure A6: Four day back-trajectories at a height of 3000 m, 4500 m and 5500 m on 31 July 2014.

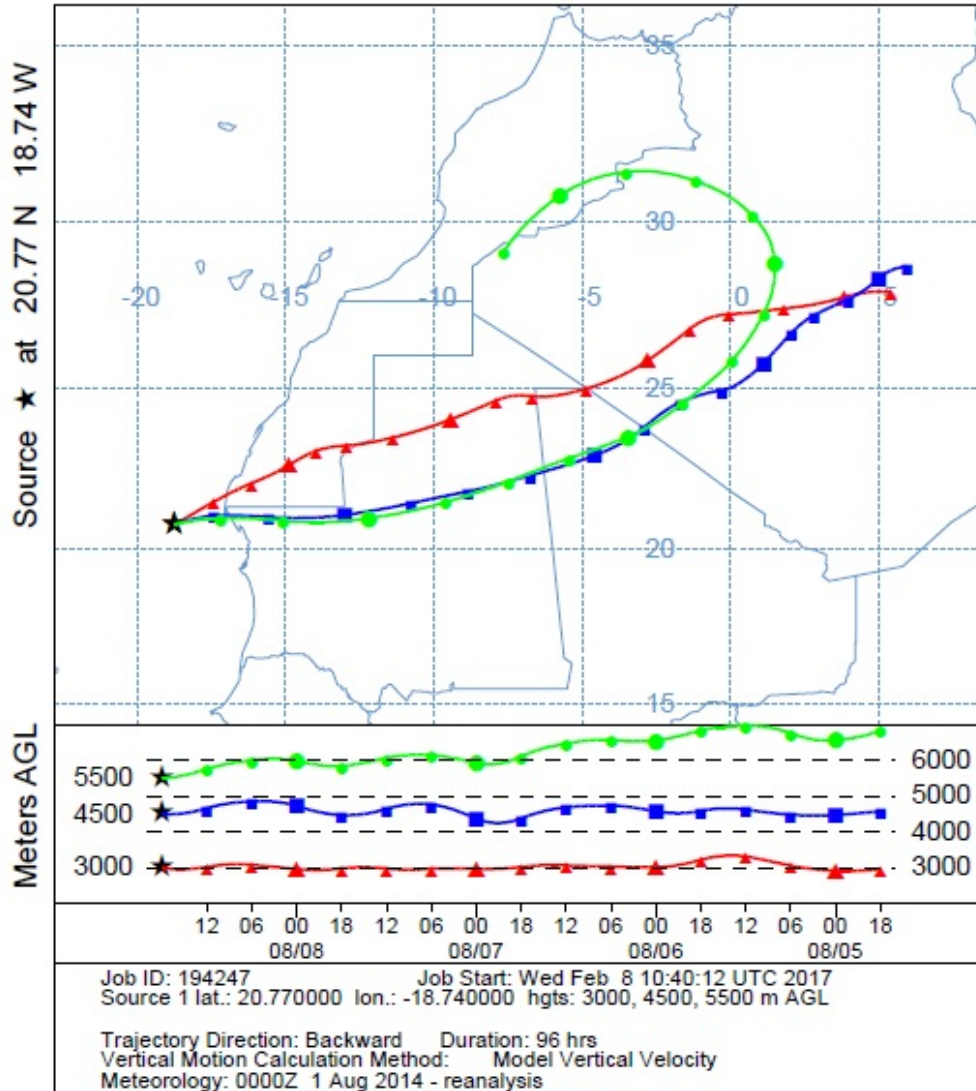
NOAA HYSPLIT MODEL
 Backward trajectories ending at 1800 UTC 07 Aug 14
 CDC1 Meteorological Data



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Figure A7: Four day back-trajectories at a height of 3000 m, 4500 m and 5500 m on 07 August 2014.

NOAA HYSPLIT MODEL
 Backward trajectories ending at 1800 UTC 08 Aug 14
 CDC1 Meteorological Data



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Figure A8: Four day back-trajectories at a height of 3000 m, 4500 m and 5500 m on 08 August 2014.

984 **7. Supplement link**

985 The data can be accessed on www.pangaea.de.

986 **8. Author contribution**

987 C. Friese carried out the particle size analysis of the sediment trap samples. H. van Hateren carried out the flux
988 and particle size analysis of the Iwik dust samples. G. Fischer provided the sediment trap samples and supervised
989 the flux analysis of the sediment trap samples. C. Friese prepared the samples for XRD analysis. C. Vogt carried
990 out the XRD analysis and was involved in the discussion of the results. J.-B. Stuut managed the projects through
991 which dust-collecting buoy ‘Carmen’ was constructed and deployed, supervised the particle-size analysis and the
992 writing of the manuscript. C. Friese prepared the manuscript with contributions from all co-authors.

993 **9. Competing interests**

994 The authors declare that they have no conflict of interest.

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1003

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