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Impacts of Saharan dust on photosynthetically available radiation and optical water properties

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Abstract

In the study area of the Tropical Eastern North Atlantic the impacts of dust on photosynthetically available radiation (PAR) and on optical water properties were quantified using satellite measurements, laboratory experiments and model simulations. In a ten years time series of 2003 to 2012 the Saharan dust storms were characterized by dust aerosol optical depths using MODIS data. Statistics of the reduction of PAR by atmospheric dust were derived in areas of eutrophic, mesotrophic and oligotrophic waters. Laboratory experiments with real dust samples as well as model simulations were performed to study the influence of deposited dust in the water column on light climate.
The highest reductions of up to 44 % in the PAR by atmospheric dust were observed in March and especially in July and the lowest in the winter months between November and January. The attenuation became less from on- to offshore areas due to the deposition of the atmospheric dust load. In the 10 years data set no systematic changes or trends could be verified in strong dust storms and in the reduction of PAR by atmospheric dust. Dust in the water column reduced the light penetration depth and decreased the euphotic depth particularly in the blue spectral range.

Keywords: Saharan dust, photosynthetically available radiation, optical water properties, mass specific absorption coefficient, light attenuation coefficient, statistics of dust storms, Tropical Eastern North Atlantic

1. Introduction

Atmospheric dust modifies the energy flux in the oceans and influences the spectral distribution of the incident solar radiation and the photosynthetic available part. The incident solar radiation above the water surface can be attenuated up to 22 % (di Sarra et al., 2002; Otto et al., 2009). Reductions in the photosynthetically available radiation (PAR) of up to 12.3 % were observed (Ohde & Siegel 2012a, 2013). Deposited dust in the water column changes the absorption and backscattering properties of the water body and alters

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by that the downward radiation in the water column (Stramski et al., 2007). Dust in the atmosphere and the water column influence the phytoplankton development with impact on their primary productivity, biomass and biodiversity (Claustre et al., 2002; Wozniak and Stramski, 2004; Stramska et al., 2008).

One objective of this paper was the quantification of the dust impact on PAR in a more general manner using a 10 years data set of satellite data. Other aims were the determination of the mass specific absorption of different dust samples to apply that in optical models to study the dust impact on light climate.

2. Study area, data basis and methods

The study area (Fig. 1) was separated into three subareas of eutrophic, mesotrophic and oligotrophic conditions according to Morel et al. (1996). In the ten years period from 2003 to 2012 the dust storms in these subareas were analyzed on the basis of dust aerosol optical depths (AOD_{dust}). The AOD_{dust} values were calculated from MODIS data (Moderate-Resolution Imaging Spectroradiometer) of the Giovanni archive (http://daac.gsfc.nasa.gov) using the approach of Kaufmann et al. (2005). The PAR values were determined from the AOD_{dust} dataset with an equation derived by Ohde & Siegel (2012b).

The grain sizes of three Saharan dust samples (1: dust from dust storm near the NW-African coast - Körtzinger (GEOMAR), 2: dust sample of Cape Verde Atmospheric Observatory – Müller & Fomba (TROPOS), 3: dust from island Sao Vicente - Siegel & Ohde (IOW)) were determined. The dust samples were separately suspended in water, filtered through Whatman GFF filters and the mass specific absorption coefficients were measured with spectrophotometer Perkin Elmer.

The impact of deposited dust on the attenuation coefficient of irradiance was calculated with the simple model assuming $k_d^{dust} \approx a + 0.02b; a \approx b; a = a_w + a_p + a_y + c_{dust} * a_{dust}^*$ (Højerslev, 1986) with the total absorption coefficient (a) and total scattering coefficients (b), the absorption coefficients of water (a_w), phytoplankton (a_p) and yellow substances (a_y) as well as the dust concentration in the water column (c_{dust}) and the dust specific mass absorption coefficient (a_{dust}^*). The impact of dust in the water column on the euphotic depth was determined with the approach $z_{dust} = z_{no\ dust} * k_d^{no\ dust} / k_d^{dust}$. The euphotic depth without dust $z_{no\ dust}$ was measured in the coastal area of Northwest Africa during a cruise in February 2008. The attenuation coefficients of irradiance without ($k_d^{no\ dust}$) and with dust (k_d^{dust}) were calculated with the given equation.

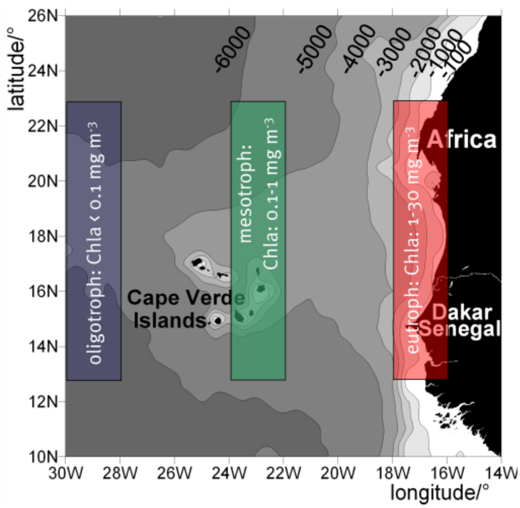

Fig. 1. Study areas with eutrophic, mesotrophic and

3. Statistics of dust storms

The ten years statistics of the period from 2003 to 2012 delivered right skewed distributions of AOD_{dust} values in the different subareas (Fig. 2a). The median AOD_{dust} values decreased from onshore to offshore areas (eutrophic area: 0.27, mesotrophic area: 0.20, oligotrophic area: 0.16) due to the decrease of the atmospheric dust load as a result of dust deposition into the Atlantic Ocean (Fig. 2b). Sporadic strong increases of AOD_{dust} values were observed with highest values in the eutrophic area (Fig. 2a and 2b). In the investigation period the highest AOD_{dust} values were 3.67, 3.07 and 2.54 in the eutrophic, mesotrophic and oligotrophic subareas, respectively. The most number of smallest dust events were identified in the oligotrophic area.

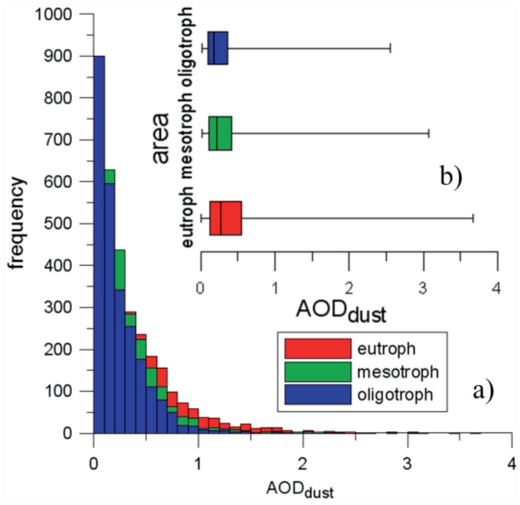

Fig. 2. 10 years statistics (01.01.2003-31.12.2012).

All days of the observation period were separated according to low, moderate and high dust content in the atmosphere with AOD_{dust} values of <= 0.1, > 0.1 to <= 0.7 and > 0.7, respectively (Fig. 3). Moderate dust events were observed in average on 60 % to 66 % of the days per year in the different subareas. The days per year with high content of atmospheric dust decreased from eutrophic to oligotrophic subarea. In the eutrophic subarea the dust content was high on about 15 % to 20 % of the days per year. The 10 years data set did not contain any trend meaning that no increase or decrease of strong Saharan dust storms occurred.

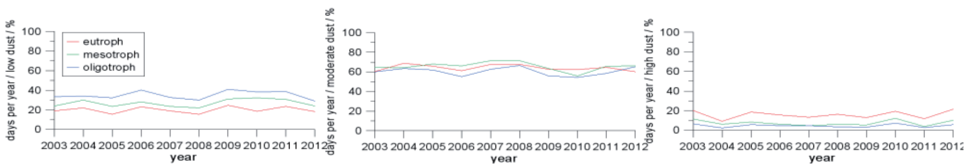

Fig. 3. Days per year in percent with low, moderate and high amount of dust in the three considered areas.

4. Impact of dust on PAR

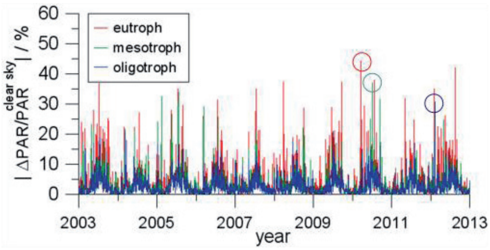

Fig. 4. Daily reductions of PAR by dust. The highest reductions in the subareas were marked by colored circles.

Characteristically attenuation of PAR by atmospheric dust were observed in the observation period (Fig. 4). The reductions were low in November to January and increased in March of each year up to a first maximum caused by sporadic dust storms in spring (Fig. 4 and 5d). The highest reductions cumulated in a second maximum in July in summer as a result of stronger and longer dust events. The highest reductions of PAR were 44 %, 37 % and 31 % in the eutrophic, mesotrophic and oligotrophic area, respectively (colored circles in Fig. 4). The PAR is mostly lower in the eutrophic area (Fig. 4 and 5d). The mean number of days of a year with strong reductions of PAR decreased from onshore to offshore areas due to the decrease of the atmospheric dust load as a result of dust deposition into the Atlantic Ocean (Fig. 5a-c). No trend in the reduction of PAR was observed in the 10 years data set.

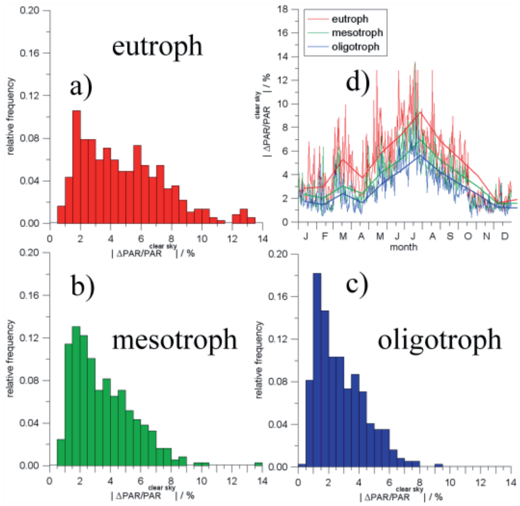

Fig. 5. Histograms of 10 years averages (a-c) and mean seasonal reductions of PAR by dust (d).

5. Laboratory experiments

Different dust samples (1: near the NW-African coast, 2: Cape Verde Atmospheric Observatory, 3: island Sao Vicente) represent different grain sizes, mineral composition (figures not shown) and mass specific absorption (Fig. 6). The grain size of dust samples in the coastal area of NW-Africa was higher compared to samples of the Cape Verde islands.

Deposited dust in the water column modifies the optical water properties (Fig. 6). The mass specific absorption coefficients decreased to red-wavelength range and increased with higher amount of small particles in the dust samples. The specific absorption coefficients of Saharan dust samples of Stramski et al. (2007) (SAH1) were rather similar to that of the Cape Verde Islands (Müller & Fomba and Siegel & Ohde).

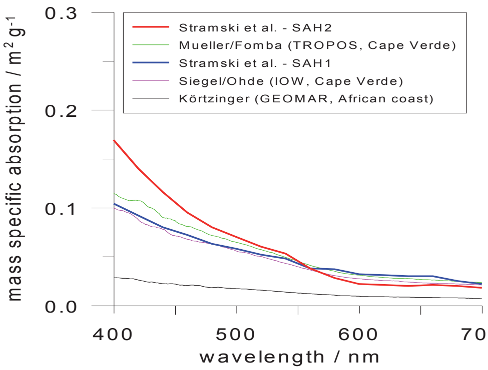

Fig. 6. Mass specific absorption coefficients of different dust samples.

6. Impact of dust on light climate

The impacts of Saharan dust on the light attenuation coefficient in the water column and on the euphotic depth were calculated with the simple models given in section 2. In Fig. 7a and 7b examples for the euphotic area near the coast off NW-Africa are presented. Dust in the water column decreased the vertical attenuation coefficient (Fig. 7a) and reduced the light penetration depth and the euphotic depth more in the blue than in the red spectral range (Fig. 7b). The light attenuation was more increased by dust in oligotrophic areas than in turbid coastal waters (not shown). Consequently, the euphotic depth was more decreased in the offshore than in the onshore areas (not shown).

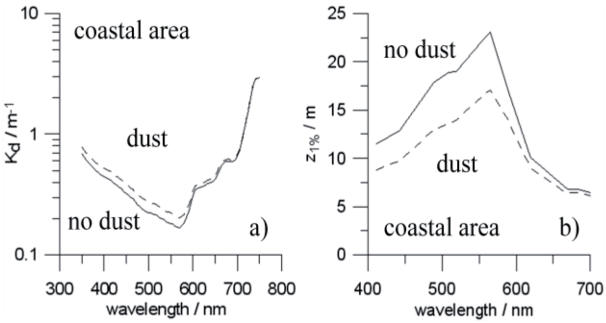

Fig. 7. Impact of dust on light attenuation and euphotic depth in the coastal area of NW-Africa.

7. Summary

Sporadic strong increase of AOD_{dust} values were observed with highest values in the coastal eutrophic areas. The AOD_{dust} values can be increased up to 3.67, 3.07 and 2.54 in the eutrophic, mesotrophic and oligotrophic area, respectively. The highest reductions of PAR by Saharan dust storms were observed in March and July. During these months the PAR can be decreased up to 44 %. The reductions were lowest in winter between November and January. The reductions of PAR decreased from onshore (euphotic) to offshore (oligotrophic) areas due to the continuous deposition of the atmospheric dust load on the transport ways. Trends in AOD_{dust} and PAR values did not exist in the 10 years data set. Deposited dust in the water column modifies the optical water properties. The wavelength dependent mass specific coefficients of our Saharan dust sample were rather similar to measurements of other authors. The coefficients were lower in coastal regions due to the coarser particles. The dust in the water column reduced the light penetration depth and decreased the euphotic depth mostly in the blue spectral range.

8. Acknowledgements

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