Simulating Dust Regional Impact on the Middle East Climate and the Red Sea

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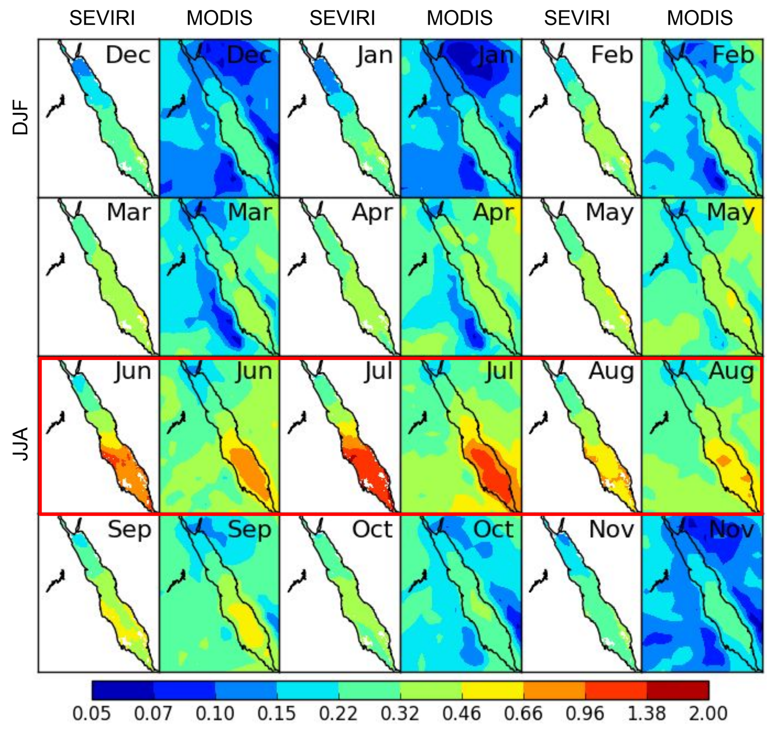
Introduction

Scientific question: assess and quantify the climatological impact of the dust aerosol on the Red Sea.

Brindley et al., 2015 reported enhanced dust loading with a distinct north to south gradient across the Red Sea basin especially in summer. Aerosol optical depth (AOD) retrievals from SEVIRI instrument were validated against MODIS and ground-based hand-held sun photometer measurements.

Figure 1 shows 2008-2012 monthly mean AOD derived from SEVIRI at 0.63 μ m (first, third, fifth columns) and MODIS at 0.55 μ m (second, fourth and sixth columns) measurements covering each month from January to December (left to right, top to bottom).

Figure 1. Dust climatological AOD



Methodology

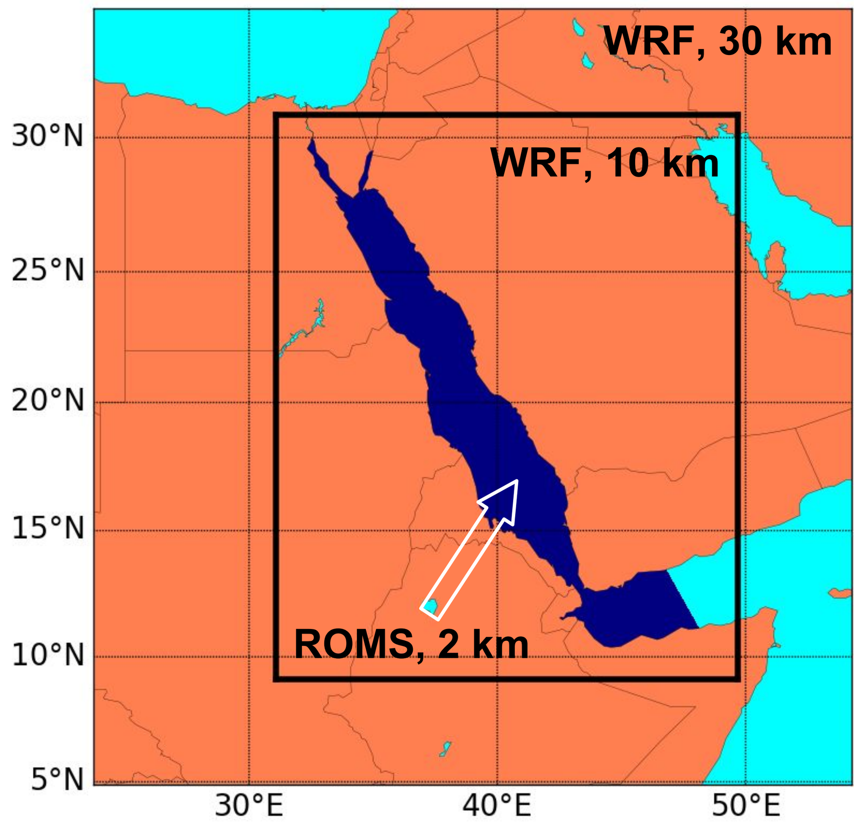
Background: Standalone ocean modelling approach [Cahill et al., 2017] results in unrealistically strong Red Sea response to the imposed dust aerosol radiative forcing.

Solution: Employ coupled ocean-atmosphere modelling approach and prescribe dust optical properties.

We employ Weather Research and Forecasting (WRF) [Skamarock et al., 2008] as atmospheric model and Regional Ocean Modeling System (ROMS) [Shchepetkin and McWilliams, 2009] as oceanic model coupled in the Coupled Ocean Atmosphere Wave Sediment Transport (COAWST) framework [Warner et al., 2010].

Dust spectral optical properties in SW and LW are precomputed using Mie, T-matrix, and geometric optics approaches, and are based on the daily SEVIRI climatological optical depth [Osipov et al., 2015; Brindley et al., 2015]. They are introduced into the atmospheric model code as additional daily input and are propagated into the radiation driver.

Figure 2. Modelling domains



Results

Dust radiative forcing and heat budget redistribution

Figure 3. Temporal distribution of the sea surface fluxes perturbation

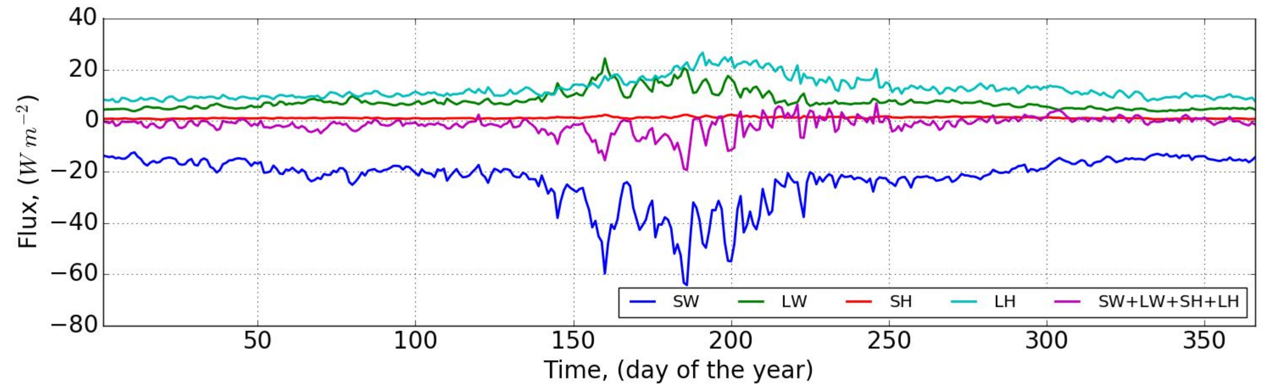


Figure 3 shows climatological daily net (downward minus upward) flux anomalies (perturbed with dust minus control without dust runs) as a response to the dust radiative forcing at the sea surface spatially averaged over the Red Sea.

Figure 4. Spatial distribution of the sea surface fluxes perturbation

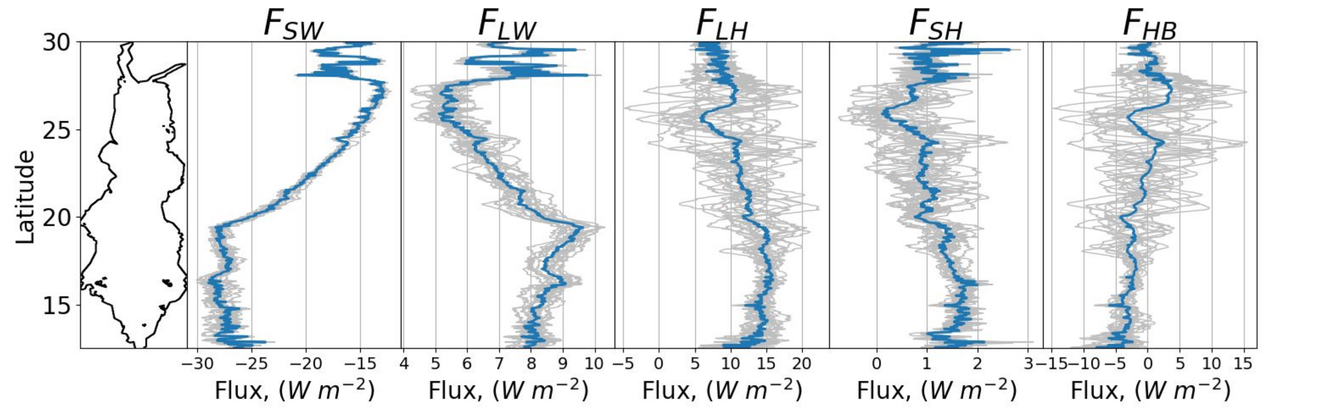


Figure 4 shows net fluxes anomalies due to dust at the sea surface. Hairline lines indicate individual years and their mean is shown by the thick line. Diagnostics variables are spatially averaged in the direction perpendicular to the Red Sea axis. Red Sea land mask contour is provided in the left column.

Conclusion 1: Dust aerosol significantly perturbs Red Sea energy balance, redistributes heat budget and reduces it by 1.4 W m^{-2}. This impact is caused by cooling in SW, warming in LW and reduced evaporation.

Thermal and haline response

Figure 5. Thermal and haline anomalies

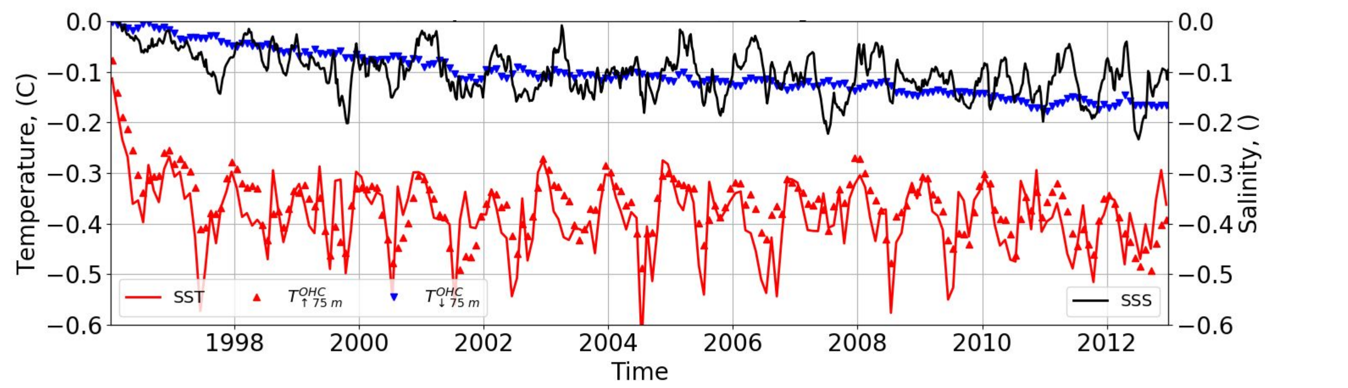


Figure 5 shows spatially averaged monthly potential temperature and salinity anomalies. Potential temperatures (SST, upper and deep ocean) are plotted against left vertical axis and sea surface salinity is plotted against right vertical axis.

Conclusion 2: Dust aerosol affects Red Sea thermal and haline regimes. Simulations show that dust cools upper and deep Red Sea waters by 0.4 and 0.2 K, respectively. Due to reduced evaporation sea surface salinity is reduced by 0.15.

Biological productivity implications

Figure 7. Exchange at the Bab-el-Mandeb strait

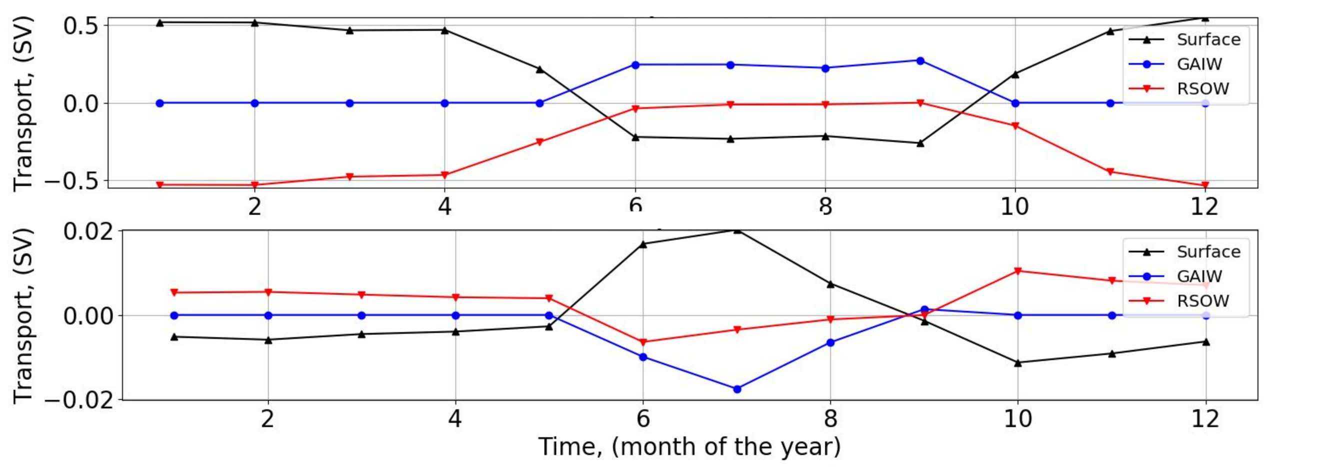


Figure 7 shows water transport through the Bab-el-Mandeb strait. Top and bottom panels show climatology and anomaly, respectively.

Conclusion 4: Dust aerosol reduces water exchange at the Bab-el-Mandeb strait and thus diminishes nutrients supply and regulates the Red Sea productivity. Dust deposition also supplies nutrients, which could compensate for the negative effect.

Overturning circulation response

Figure 6. Overturning circulation climatology and anomaly

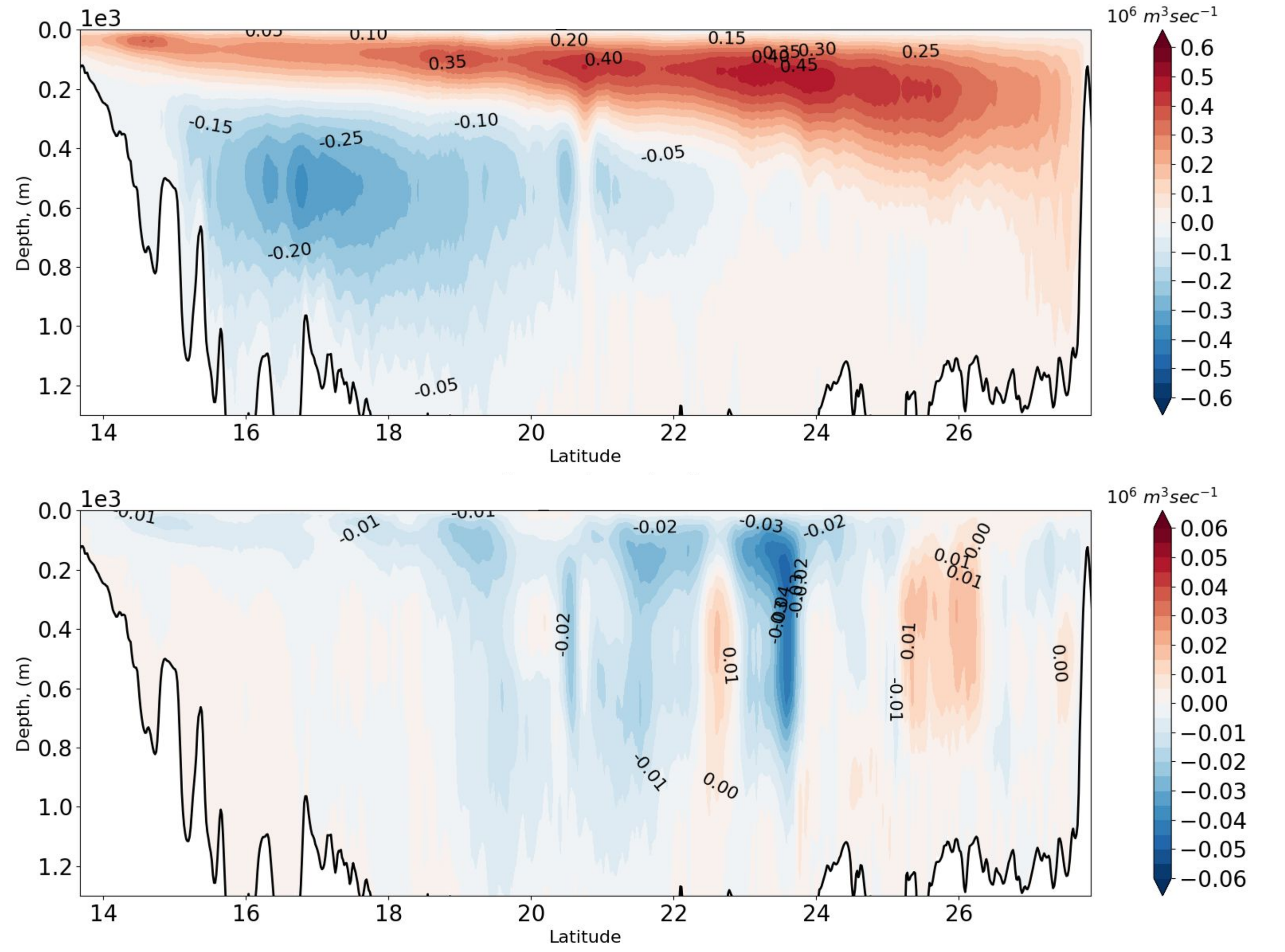


Figure 6 shows annual mean overturning circulation along the Red Sea axis in Sv. Top and bottom panels show climatology and anomaly, respectively.

Conclusion 3: Spatially nonuniform dust loading results in stronger cooling of the southern Red Sea, reducing meridional pressure gradient and inhibiting overturning circulation, reducing water transport by 5% in the upper Red Sea.

Acknowledgment and Contacts

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