Mass closure study of submicron particles and their light scattering properties in the Mediterranean and Middle East regions during the AQABA shipborne campaign.

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Abstract

In the framework of the AQABA (Air Quality and climate change in the Arabian BAsin) project led by the Max Planck Institute of Chemistry, a two-month long (1st July - 1st September 2017) intensive campaign was performed onboard a research vessel, during which we measured with high time resolution the physical, optical and chemical properties of the ambient aerosol around the Arabian Peninsula. The campaign consisted of a round trip from south of France (Toulon) to Kuwait crossing the Mediterranean Sea, Red Sea, Indian Ocean and Arabo-Persian Gulf, thus exploring the optical and chemical properties of the atmosphere in the region.

Both the non-refractory and refractory submicron particulate chemical composition was monitored by means of a HR-AMS and a MARGA, respectively. Refractory material, such as sea salt and dust particles, was always present and ranged from about 11% (in the Mediterranean Sea) up to half of the PM_1 mass in the pristine environment of the Arabian Sea and Aden Gulf.

The light scattering coefficient of submicron aerosols was reconstructed using either calculated mass scattering efficiencies in combination with measured chemical composition, or Mie calculations using both size distribution and chemical composition as input. The reconstructed light scattering coefficient was compared with that measured on-board using a polar nephelometer and discussed for each marine region crossed by the ship (Mediterranean Sea, Red Sea, Indian Ocean and Arabian Gulf).

1. Introduction

Although the Eastern Mediterranean and the Middle East (EMME) region is a global change hot spot with very high loads of air pollutants and atmospheric dust from the two largest deserts worldwide, it has received only little attention (e.g. in reports of the Intergovernmental Panel on Climate Change; IPCC, 2013). One reason is that observational data (especially in the Middle East) are insufficient, unavailable or of limited quality. How air pollutants, of anthropogenic origin, and dust particles, of natural origin, are combined is unclear because no other areas in the world are subjected to both and in such elevated concentrations.

2. Instrumentation - Methods

Aerosol scattering and absorption of submicron particles was monitored using a polar nephelometer (Model: Aurora 4000, Ecotech Inc) and a dual-spot aethalometer, (Model AE33, Magee Scientific) along with the water soluble composition using a Monitor of AeRosol and Gases in ambient Air (MARGA; Model 2S, Metrohm, Applikon). A high resolution aerosol mass spectrometer (HR-AMS; Aerodyne Inc) monitored the non-refractory composition, including the organic fraction. The size distribution of particles with diameter smaller than 500 nm was monitored using an Fast Mobility Particle Sizer Spectrometer (FMPS, TSI Inc Model 3091). Sampling took place 2 or 4 m above the roof of the regulated temperature container the instruments were installed in, to minimize contamination. All samples were dried prior to sampling.

The light scattering coefficient was reconstructed based on Mie calculations using the submicron size distribution and calculated refractive indices. The upper size of the size distribution was extended to 1 μm by fitting a log-normal distribution. Refractive indices were calculated by using (1) non-refractory chemical composition derived by the HR-AMS alone, or (2) by including the complete chemical composition which combined MARGA and HR-AMS measurements. For each set of measurements (non-refractory and combined) the water mass was derived using the E-AIM model.

The ship route, was subdivided into 6 sections for each leg (see Fig. 1), in each of which multivariate regression analysis was performed to derive the mass scattering efficiencies (MSE) for each chemical component monitored. The calculated MSE were quite stable from the Mediterranean Sea till the Arabian Sea and were lumped together. Based on these calculations, shown in Table 1, the light scattering coefficient was additionally reconstructed.

	Sulfates	BC	OM	Dust	Sea Salt
Arabian Gulf	3.4	2.7	1.6	4.5	2
Rest of route	3.8	2.7	4.8	3.5	5.5

Table 1. Mass scattering efficiencies ($m^2\ g^{-1}$) calculated for each route section, shown in Fig. 1, via multivariate regression analysis. Because only the calculated values for the Arabian Gulf differed from the rest, they are listed separately.

3. Sampling Route

The goal was to travel along the coast of the Arabian Peninsula, starting from Toulon, France, and ending in Kuwait. (departure and return). The departure and return trips took place during July and August 2017, following the same path. Each leg was separated into 6 sections (Mediterranean Sea, Suez Canal, Red Sea, Aden Gulf, Arabian Sea and Arabo-Persian Gulf, depicted in Fig.1. The overlap of the four instruments used in this study is poor, therefore the mass closure shown in Section 4, corresponds mainly to the second leg, while the optical closure shown in Section 5 to the first leg.

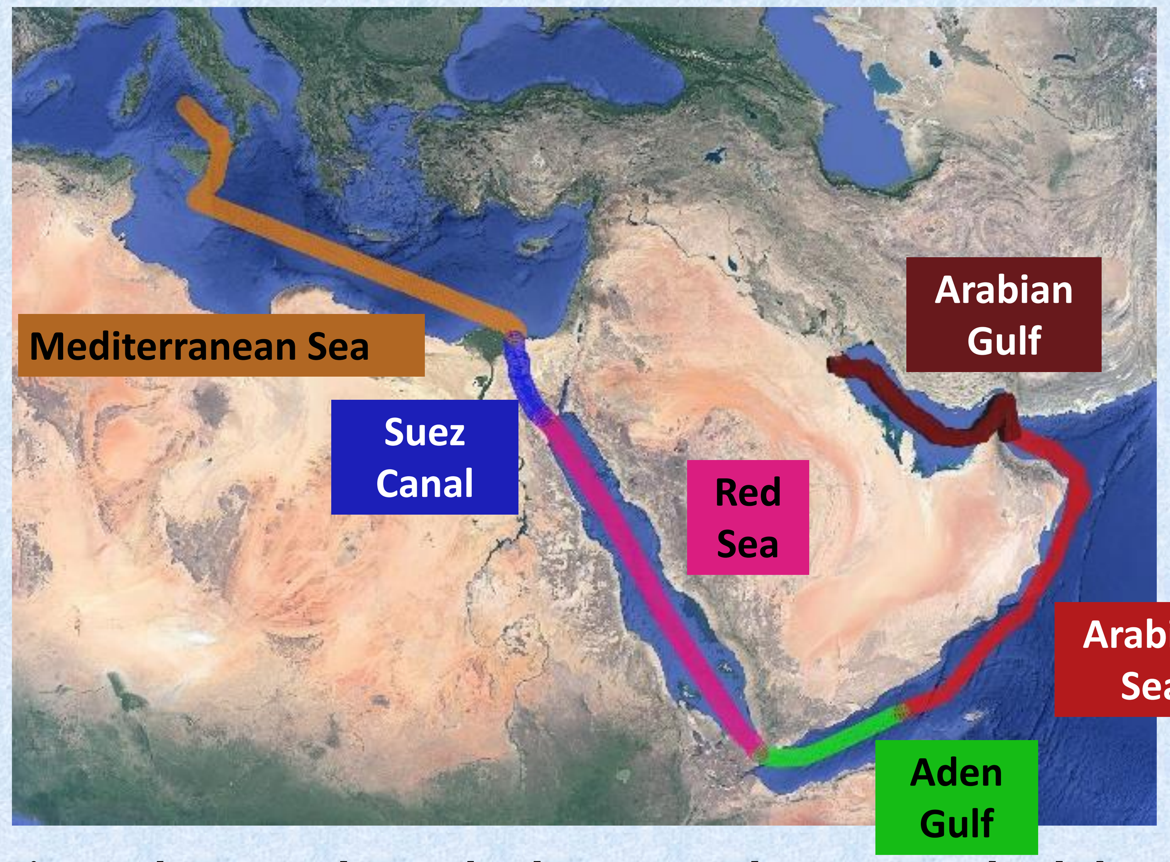
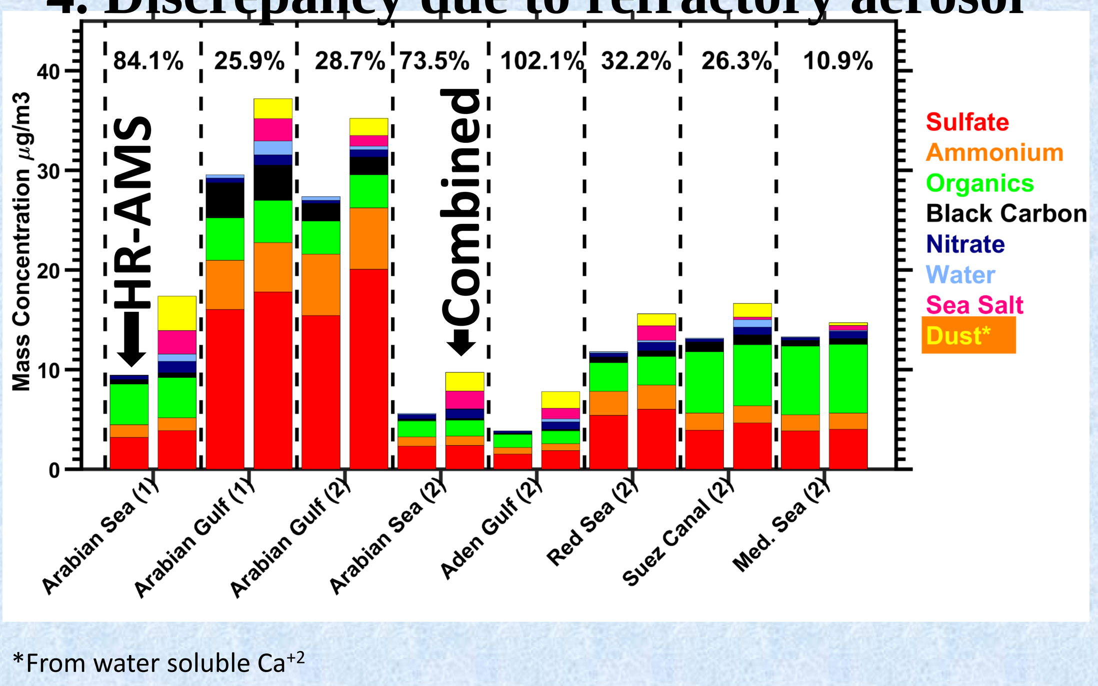


Fig. 1. Ship route during the departure and return trip, divided into sections based geography and particulate chemistry. These sections are the Mediterranean Sea, Suez Canal, Red Sea, Aden Gulf, Arabian Sea, and Persian Gulf. The Commandor Iona vessel where all the instruments were hosted is also shown. Sampling containers were installed in the front of the ship to avoid contamination from the ship's stack emissions.

4. Discrepancy due to refractory aerosol



- The highest PM_1 loadings were identified over the Arabian Gulf, dominated by sulfate.
- Refractory material was measured throughout the campaign and accounted for at least 11% of the PM_1 mass in the Mediterranean Sea during the second leg.
- In the relatively pristine environment of the Arabian Sea and Aden Gulf the refractory mass accounts for approximately half of the PM_1.

Fig. 2. Average chemical composition during each section of the route when both MARGA and HR-AMS measurements were available (see Fig. 1). The difference between non-refractory only (left bars for each section) and combined output (right bars for each section) is shown at the top of the graph.

5. Optical Closure

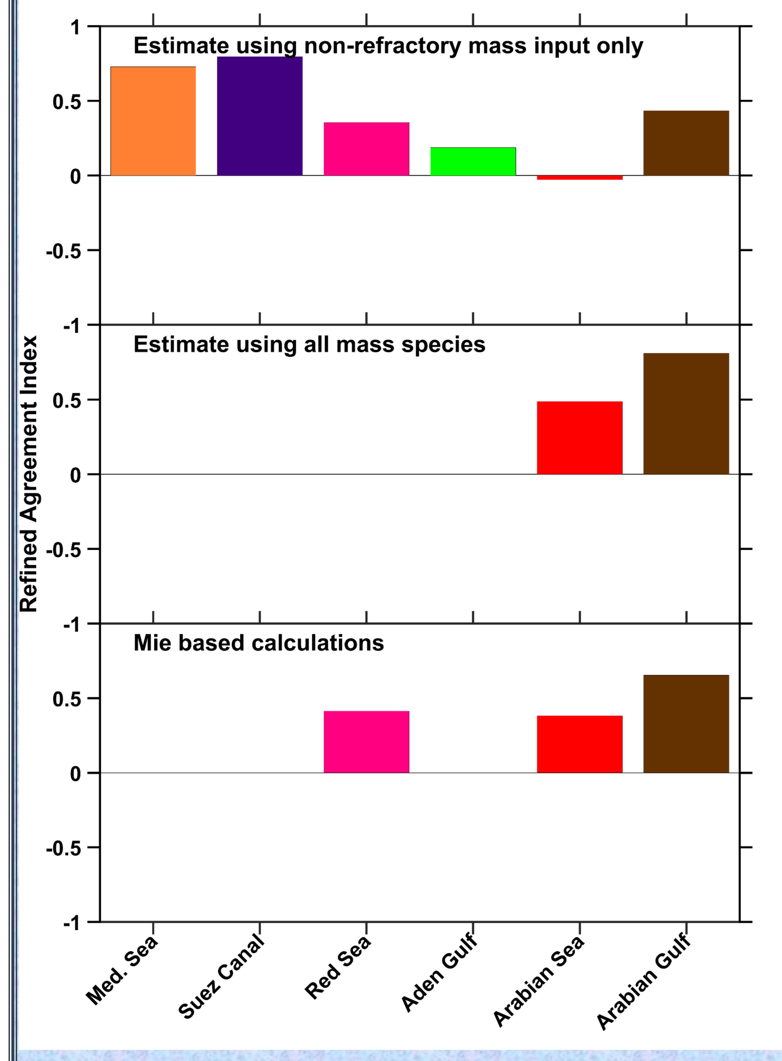


Fig. 3. Refined Agreement index between measured scattering and calculated using non-refractory composition as input only, using combined chemical composition and Mie calculations.

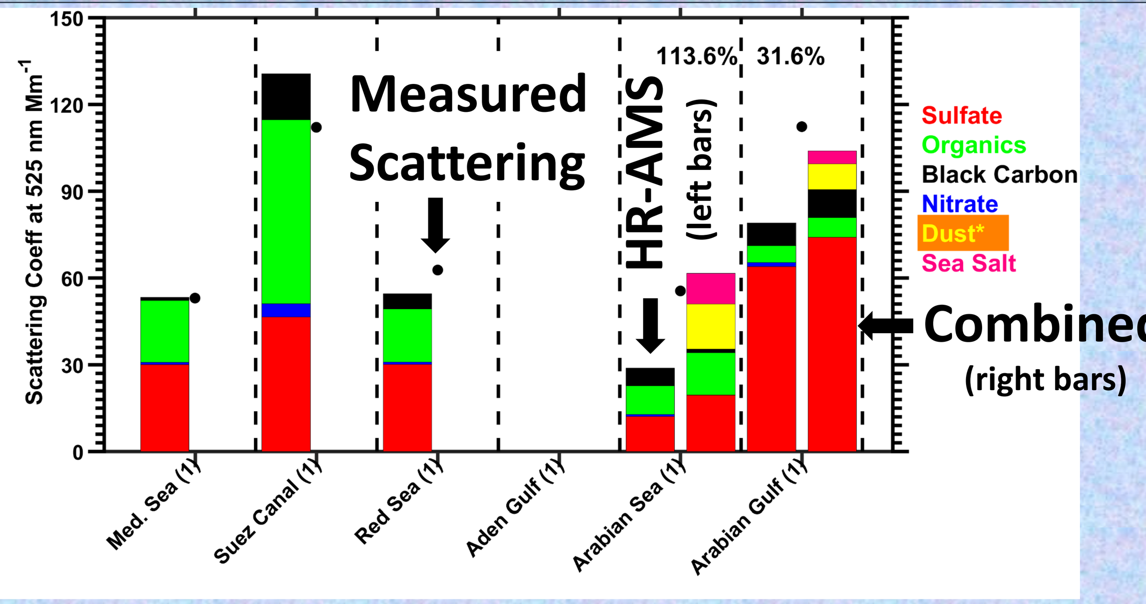


Fig. 4. Optical closure during first leg of ship route. Left and right bars in each section correspond to reconstruction of the scattering coefficient based on non-refractory material alone and on combined input, respectively. The average measured scattering coefficient for each section is shown as black dots.

Very good agreement between measured and reconstructed scattering coefficient using only non-refractory components is observed in the Mediterranean Sea, where refractory material account for 11% of the PM_1 mass. Over the Red Sea, the measured and reconstructed scattering coefficient, based on the same input, agree moderately.

If refractory components are accounted for, the agreement improves at least in the Arabian Sea and Arabian Gulf during the first leg of the AQABA campaign (Fig 3 and 4).

6. Conclusions

1. Refractory material in the submicron mode contributes an appreciable fraction to the PM1 mass over the Arabian Gulf and the Red Sea (20-30%) and a significant fraction over the Aden Gulf and Arabian Sea (>70%).

2. Optical closure could not be achieved without accounting for refractory material in these regions during the AQABA campaign.