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# Aerosols physical properties at Hada Al Sham, western Saudi Arabia

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## HIGHLIGHTS

- Comprehensive physical properties of aerosols was measured at a rural background area in Saudi Arabia.
- New particle formation events were observed 80% of the days.
- New particle events dominated total number concentrations.
- High particle mass concentrations was dominated by coarse mode related to dust outbreaks.
- High black carbon concentrations were observed during night time.

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## ABSTRACT

This is the first time to clearly derive the comprehensive physical properties of aerosols at a rural background area in Saudi Arabia. Aerosol measurements station was established at a rural background area in the Western Saudi Arabia to study the aerosol properties. This study gives overview of the aerosol physical properties ($PM_{10}$, $PM_{2.5}$, black carbon and total number concentration) over the measurement period from November 2012 to February 2015. The average $PM_{10}$ and $PM_{2.5}$ concentrations were $95 \pm 78$ μg $m^{-3}$ (mean ± STD, at ambient conditions) and $33 \pm 68$ μg $m^{-3}$ (at ambient conditions), respectively. As expected $PM_{10}$ concentration was dominated by coarse mode particles ($PM_{10}$–$PM_{2.5}$), most probably desert dust. Especially from February to June the coarse mode concentrations were high because of dust storm season. Aerosol mass concentrations had clear diurnal cycle. Lower values were observed around noon. This behavior is caused by wind direction and speed, during night time very calm easterly winds are dominating whereas during daytime the stronger westerly winds are dominating (sea breeze). During the day time the boundary layer is evolving, causing enhanced mixing and dilution leading to lower concentration. $PM_{10}$ and $PM_{2.5}$ concentrations were comparable to values measured at close by city of Jeddah. Black carbon concentration was about 2% and 6% of $PM_{10}$ and $PM_{2.5}$ mass, respectively. Total number concentration was dominated by frequent new particle formation and particle growth events. The typical diurnal cycle in particle total number concentration was clearly different from $PM_{10}$ and $PM_{2.5}$.

## 1. Introduction

The Arabian Peninsula is one of the strongest aerosol particle

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source areas in the world because of a frequent occurrence of dust storms, its own pollution emissions from road traffic, petroleum industry and local construction (Khodeir et al., 2012). The size distributions, optical properties, and physico-chemical properties of aerosol particles are highly variable in such regions. In addition, the Arabian Peninsula exhibits extremely complicated meteorology with typically very warm and highly variable sea surface temperatures leading to enormous latent heat fluxes, abrupt topography and associated strong mesoscale circulation. These features make modeling difficult in this region. Also, satellite remote sensing over bright desert surfaces is very challenging.

While a number of studies have investigated the properties of aerosol particles over the Arabian Sea and Indian Ocean (Johansen et al., 1999; Lelieveld et al., 2001; Ramanathan et al., 2007) the properties of aerosol particles in the Arabian Peninsula region has remained mostly unstudied until very recently. Strong winds uplift easily dust from the deserts and fraction of it will reach also free troposphere, from where the dust can be transported over very large distances (Prospero, 1999; Guelle et al., 2000). The dust particles may have both local and regional influences on both climate and air quality (Guelle et al., 2000, Sokolik et al., 2001). In addition, minerals in the desert dust are an important source of nutrients for the Red Sea (e.g. Jish Prakash et al., 2015).

Dust particles are not the only problem in Saudi Arabia. The increased anthropogenic emissions due to rapid economic and social growth have increased the pollution levels in Saudi Arabia (Khodeir et al., 2012). To capture these features with long-term observations, The Finnish Meteorological Institute, together with the King Abdulaziz University and the University of Helsinki established a background measurement station to study aerosols in the Western Saudi Arabia. The object of this work is to present properties of mass and total number concentrations, number size distribution, and black carbon (BC) concentrations at this site. To our knowledge there are now long term detailed aerosol measurements conducted in background area at Arabian Peninsula.

## 2. Methods

### 2.1. Measurements

Detailed properties of atmospheric aerosols were measured on a rural background site at Hada Al Sham (21.802° North, 39.729° East, 254 m a.s.l.). The site is situated about 60 km east of the coast of the red sea and the city of Jeddah with a population of around 3.4 million, Fig. 1. The surroundings of the station represent a rural area. The station was located in King Abdulaziz University's Agriculture Research Station. Measurements of the aerosol properties were conducted from November 2012 to February 2015.

The instruments were located in a modified 20 feet sea container. The temperature inside the container was kept stable, around 25 °C. The container was placed on top of a concrete platform. The container was located on a flat agricultural test field which was mainly sand. A perimeter of about 100 m around the station was clear of trees and other obstacles.

The air was sampled through three inlets, at height of 4–4.5 m above the ground, all with a flow rate of 16.7 l min$^{-1}$. Two separate inlets for the aerosols smaller than 10 μm ($PM_{10}$) and 2.5 μm ($PM_{2.5}$) in diameter were used for measurement of Particulate Mass ($PM_{10}$ and $PM_{2.5}$) with two identical monitors (Thermo Scientific 5030, beta hybrid mass monitors). The PM inlets used standard heaters for drying the sample air.

The following measurements are conducted from the main inlet with a $PM_{10}$ cut-off with total flow of 16.7 l min$^{-1}$:

- Twin-Differential Mobility Particle Sizer (DMPS, particle number size distribution over a mobility equivalent diameter range 7–850 nm, total particle number concentration)
- Condensation particle counter. (CPC, TSI 3772,total number concentration
- Aerodynamic Particle Sizer, TSI 3321 (APS, particle number size distribution over the aerodynamic diameter range 0.5–10 μm).
- Optical particle sizer, TSI 3330 (OPS, particle number size distribution over the optical diameter range 0.3–10 μm).
- Aethalometer, Mageé Scientific (AE31, aerosol black carbon concentration, absorption coefficient at 7 wavelengths; 370, 470, 520, 590, 660, 880, and 950 nm)
- Nephelometer, Ecotech Aurora (aerosol scattering coefficient at 3 wavelengths; 450, 535 and 635 nm).

The main inlet was made in FMI and used a twin diffusion drier that removes water vapor from the sample stream. In this system, seven 1 cm diameter netted tubes traveled for a distance of 1 m inside the drying media in two units. The drying media was molecular sieve granules. One drying unit was active (sampling) at a given time, while the molecular sieve of inactive unit was dried with 40 l min$^{-1}$ of compressed, dry and filtered air. The sampling/drying was switched between the units with a 2 h interval. This kept the relative humidity mainly below 50% (WMO/GAW report no. 153, 2003).

Weather parameters measured with a Vaisala WXT weather station included temperature, pressure, relative humidity, wind speed and direction, and rain intensity and accumulation. The sensor was about 7 m above the ground.

Aerosol Optical Depth (AOD) was measured with Cimel CE-318 sun photometer. The instrument was part of AERONET measurement network (Holben et al., 1998) and it measures direct irradiance at 340, 380, 440, 500, 675, 870, 1020 and 1640 nm wavelengths.

### 2.2. Data processing

The data were first quality checked against peculiar events, such as extreme high or low concentrations, which might have been caused, for example, by an instrument malfunction or instrument maintenance. The time resolution of the measurements was five minutes. Coarse mode mass concentration, defined as particles by mass of particles between 2.5 and 10 μm, was calculated by subtracting coinciding $PM_{10}$ and $PM_{2.5}$ values.

Black carbon concentration and absorption coefficients were measured with Aethalometer at seven wavelengths. The Aethalometer absorption measurement is known to suffer from filter loading artifacts. These artifacts can be corrected using different methods. Here, the approach presented by Weingartner et al. (2003) was chosen.

Aerosol data reported here are converted to standard temperature and pressure (STP) conditions (0 °C and 1013 hPa). Also the figures are in STP conditions. However, $PM_{10}$ and $PM_{2.5}$ statistical values are also reported at ambient conditions, since air quality related limits are usually reported at ambient concentrations. Hourly averages of measurement parameters were calculated if more than 50% of the data existed inside the hour in question. Monthly averages were calculated if more than 30% of data was available. Diurnal variation as well as variation with meteorological parameters of aerosol properties were calculated as an average over the whole measurement period if more than 100 data points existed in hour or weather parameter bin in question.