Atmospheric Research 169 (2016) 171–182

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Investigation of the relative fine and coarse mode aerosol loadings and properties in the Southern Arabian Gulf region

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ARTICLE INFO

Article history:
Received 7 May 2015
Received in revised form 14 September 2015
Accepted 26 September 2015
Available online 14 October 2015

Keywords:
Arabian Gulf
Dust aerosols
$PM_{2.5}$
Trace metals
Positive matrix factorization

ABSTRACT

The aerosol chemistry environment of the Arabian Gulf region is extraordinarily complex, with high concentrations of dust aerosols from surrounding deserts mixed with anthropogenic aerosols originating from a large petrochemical industry and pockets of highly urbanized areas. Despite the high levels of aerosols experienced by this region, little research has been done to explore the chemical composition of both the anthropogenic and mineral dust portion of the aerosol burden. The intensive portion of the United Arab Emirates Unified Aerosol Experiment (UAE^2), conducted during August and September 2004 was designed in part to resolve the aerosol chemistry through the use of multiple size-segregated aerosol samplers. The coarse mode mass (derived by subtracting the $PM_{2.5}$ aerosol mass from the PM_{10} mass) is largely dust at 76% ± 7% of the total coarse mode mass, but is significantly impacted by anthropogenic pollution, primarily sulfate and nitrate. The $PM_{2.5}$ aerosol mass also contains a large dust burden, at 38% ± 26%, but the anthropogenic component dominates. The total aerosol burden has significant impact not only on the atmosphere, but also the local population, as the air quality levels for both the PM_{10} and $PM_{2.5}$ aerosol masses reached unhealthy levels for 24% of the days sampled.

1. Introduction

The large aerosol burden in the Arabian Gulf (also known as Persian Gulf) region is well recognized. Significant dust events result in the region being classified as the world's third largest dust source (Prospero et al., 2002). Comprehensive analyses of this region are rare, but literature suggests that consistently high Aerosol Optical Thickness (AOT) levels are typical. Aerosol Robotic Network (AERONET) based studies throughout the Arabian Gulf region suggest mean 500 nm AOTs on the order of 0.4 to 0.5 (e.g., Smirnov et al., 2002; Eck et al., 2008; Kim et al., 2011; Alam et al., 2014). Similarly, Arabian Gulf level 3 AOT calculated from the MODIS dataset from 2002 to 2014 suggest that mean total 550 nm AOT ranges from 0.3 to 0.5 punctuated by frequent significant aerosol events produced by perennial dust storms creating maxima as high as 0.8 depending on location and satellite (e.g., Zhang and Reid, 2010; Hsu et al., 2012; Peyridieu et al., 2013).

The contribution of mineral dust to the regional aerosol burden is well-known and has been explored in depth in the literature. Kunte and Aswini (2015) deduced that super sandstorms are often the result of the convergence of two separate sandstorms. Reid et al. (2008a) found a mean dust concentration of 125 μg/m^3 at one site in the United Arab Emirates (UAE), and was able to identify six distinct dust sources based on mineral dust chemical composition and size distributions. Engelbrecht et al. (2009a,b) explored the chemical composition of the mineral dust in multiple sites throughout the Arabian Peninsula as well as the ramifications of the high regional dust concentration on human health. Modaihsh (1996) measured the mineral composition and trace element contamination of urban dust in Riyadh City, Saudi Arabia and Rashed (2008) measured the trace metal contamination of road dust resulting from urban traffic in Aswan City, Egypt.

While Southwest Asia has considerable dust loadings, there is also substantial contribution from anthropogenic fine mode particles to the

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http://dx.doi.org/10.1016/j.atmosres.2015.09.029
0169-8095/

high AOTs experienced by the region. Anthropogenic aerosol particle sources result from large oil production centers and refineries, as well as mobile sources and local industries. AOT levels are further elevated by mid-tropospheric transport from Eastern Europe, the Indian Subcontinent, and potentially Africa (Reid et al., 2008b). Eck et al. (2008) and O'Neill et al. (2008) examined the fine mode contribution to the total AERONET-derived 500-nm AOT over a two month period in the UAE and found significant anthropogenic influence in the aerosol burden, with pollution aerosols predominant some days, and the 500 nm fine mode fraction (FMF) ranging from below 0.2 to higher than 0.8. While the importance of these anthropogenic aerosols for both regional health issues and their contribution to the total global aerosol burden is known, little research has been done on the Arabian Gulf fine mode aerosols' climatology and chemical composition. Past studies have focused on the unique aerosols associated with post-Gulf War oil fires (Hobbs and Radke, 1992; Cahill et al., 1992). More recent studies published have examined filters collected in three urban centers in Saudi Arabia and analyzed via X-ray fluorescence (XRF; Khodeir et al., 2012; Rushdi et al., 2013; Shaltout et al., 2013) and examined soluble aerosols deposited by dry deposition in Bahrain via ion chromatography (IC; Ali-Mohamed and Ali, 2001). While it is known that air quality parameters are measured by individual agencies throughout the region (e.g., Habeebullah, 2014a), such data and important metadata are not generally available to the scientific community. While these studies have provided us with some information on the high PM_{10} levels at isolated urban Arabian Peninsula receptors, there has yet to be a study of any location that could be considered regionally representative and the use of single technologies for chemical analyses in past studies has limited the possible conclusions. In situ fine mode size distributions are also yet to be published, and the shoulder of the coarse mode particle size distribution from species such as dust can swamp $PM_{2.5}$ measurements thus masking anthropogenic components (Atwood et al., 2013).

We hypothesize that both anthropogenic and mineral dust aerosol concentration behaviors frequently result in fine and coarse mode aerosol concentrations exceeding the air quality guidelines set by the US-based Environmental Protection Agency (EPA) and the World Health Organization (WHO) to prevent health effects linked to high concentrations in either of these aerosol size populations. With the goal of better understanding the regional aerosol burden, a research consortium implemented the United Arab Emirates Unified Aerosol Experiment (UAE^2) in the southern Arabian Gulf region (Fig. 1). The intensive phase of the field campaign took place August–September 2004 and was designed to provide a comprehensive dataset to study the sources, concentrations, and also the radiative impacts of regional aerosol particles. This period was selected to observe the peak of the boreal summertime northwest monsoon and start of the transitional period to winter. The research consortium included collaboration among over 20 laboratories from global entities including the US Naval Research Laboratory (NRL), NASA Goddard Space Flight Center (GSFC), the South African University of the Witwatersrand and the UAE Department of Water Resources, contributing to a network of resources including a research aircraft (South African Aerocommander 690) and 15 Aerosol Robotic Network (AERONET) sun photometers. The ground mission was anchored by an interior desert NASA Surface Based Mobile Atmospheric Research & Testbed Laboratories (SMART; Hansell et al., 2008) and the coastal NRL Mobile Atmospheric Aerosol and Radiation Characterization Observatory (MAARCO). This combination of resources allowed for collection of critical aerosol property information on a scale never before achieved in the Arabian Gulf region (Reid et al., 2008b).

In this paper, we reprocess previously unpublished aerosol chemistry data collected during the UAE^2 mission at the MAARCO coastal site. This site on the Arabian Gulf coast north-east of Abu Dhabi was selected as a regionally representative receptor for background conditions in the southern Arabian Gulf. The aerosol meteorology discussions within Reid et al. (2008b) suggest that the site was frequently impacted by local and regional dust sources and regional anthropogenic pollution including petrochemical emissions and emissions from mobile sources. The most severe pollution events were a result of the development of convergence zones over the Arabian Gulf (Reid et al., 2008b). While the UAE^2 study period is too short to ascertain climatological loadings, it nevertheless provides one of the first, and arguably the most thorough reported regional aerosol composition dataset. While the Arabian Gulf region is well known for its frequent coarse mode dust events, clearly fine mode anthropogenic pollutants are also important air pollutants and climate forcers. Based on trajectories to the MAARCO site reported by Reid et al. (2008b) the intensive chemical properties of aerosol particles presented here appear to be regionally representative over the Arabian Gulf and surrounding coastal areas.

We will first provide the basic aerosol chemistry of regional aerosol particles sampled during the UAE^2 campaign. Second, we will break our data into size segregated categories, examining the chemistry of coarse mode (CM) particulate matter (defined here as aerosols with a diameter between 2.5 μm and 10 μm), sub-2.5 μm particulate matter ($PM_{2.5}$) and

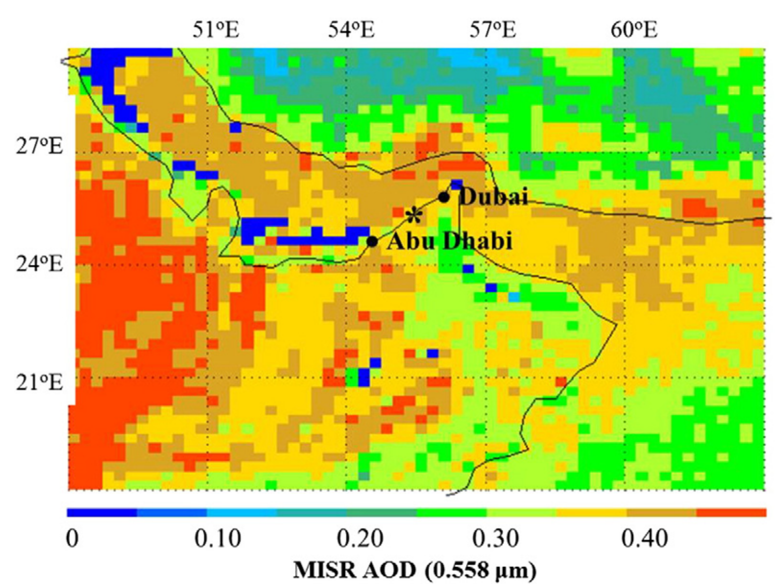

Fig. 1. The Multi-angle Imaging SpectroRadiometer (MISR) 0.558 μm Aerosol Optical Depth (AOD) from 2004–2006 plotted over the UAE^2 study region (Aug.–Sept, 2004). The star shows approximately where the MAARCO station was located. Details on the retrieval process can be found in Zhang and Christopher (2003) and Kahn et al. (2009).