Journal of Arid Environments 116 (2015) 1–10

Contents lists available at ScienceDirect

Journal of Arid Environments

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

Newly desertified regions in Iraq and its surrounding areas: Significant novel sources of global dust particles

Ali Moridnejad [a, *], Neamat Karimi [c], Parisa A. Ariya [a, b, **]

[a] Department of Atmospheric and Oceanic Sciences, McGill University, 805 Sherbrooke St. W. Montreal, H3A OB9, Canada
[b] Department of Chemistry, McGill University, 805 Sherbrooke St. W. Montreal, H3A OB9, Canada
[c] Remote Sensing Research Center (RSRC), Sharif University of Technology, Azadi Ave, Tehran, Iran

ARTICLE INFO

Article history:
Received 30 June 2014
Received in revised form
7 November 2014
Accepted 8 January 2015
Available online 21 January 2015

Keywords:
Desertification
Middle East
Dust storm
Source identification

ABSTRACT

Using the newly developed Middle East Dust Index (MEDI) applied to MODIS satellite data, we consider a relationship between the recent desertified regions, over the past three decades, and the dust source points identified during the period of 2001–2012. Results indicate that major source points are located in Iraq and Syria, and by implementing the spectral mixture analysis on the Landsat TM images (1984 and 2012), a novel desertification map was extracted. Results of this study indicate for the first time that *c.a.*, 39% of all detected source points are located in this newly anthropogenically desertified area. Using extracted indices for Deep Blue algorithm, dust sources were classified into three levels of intensity: low, medium, and high. A large number of low frequency sources are located within or close to the newly desertified areas. These severely desertified regions require immediate concern at a global scale.

1. Introduction

In recent decades, there has been increasing interest in understanding atmospheric physics and chemistry of aerosols, and aerosol–cloud interaction processes. Atmospheric aerosols are defined as condensed matter (liquid, solid or heterogeneous) suspended in the air. These aerosols consist of natural and anthropogenic species in particle form with aerodynamic diameters ranging from a few nm to several micrometers. The two ubiquitous and important natural kinds of aerosols are sea salt and mineral dust, which are emitted into the atmosphere as a result of wind stress at the ocean surface and arid land areas, respectively (Grini, 2004).

Aerosols and their interactions with clouds and radiation "contribute the largest uncertainty to the total radiative forcing estimate" affecting climate change. Dust aerosols can significantly impact the Earth's climate system (Mahowald et al., 2013; Choobari et al., 2014) by changing the radiation budget (Sokolik and Toon, 1996; Hansell et al., 2010, 2012; Valenzuela et al., 2012), cloud optical properties and lifetimes (Mahowald and Kiehl, 2003; Ou et al., 2012), and precipitation processes (Solomos et al., 2011; Creamean et al., 2013). They can also influence the Earth's ecosystems through marine and terrestrial biogeochemical cycles (Jickells et al., 2005; Mahowald et al., 2005; Okin et al., 2008), hydrologic processes (Painter et al., 2007; Neff et al., 2008) and human health (Griffin, 2007). Desertification, the damage to land that creates deserts, is a serious environmental threat for inhabitants of deserts and a main element of global change, causing wide scale land degradation in arid and semi arid regions of the world (Okin et al., 2009). Different forms of desertification take place in terms of patterns and processes. In this study, this term has been used to refer to the removal of vegetation and soil salinization and is driven by a number of social, political, economic, and natural factors (such as population growth, drought, climate variations or changes, tillage for cultivation and overgrazing). Indeed, vegetation cover and soil salinity (alone or combined) plays a major role in determining the biological composition of the soil and has been the main driver the development and increase in desertification. The concept of desertification and dust plumes is well incorporated. Such that, the term of desertification became well known in the 1930s when parts of the Great Plains in the United States turned into the Dust Bowl.

By studying the interactions between desertification and dust storms, scientists will be better able to understand the role human and natural induced factors play in the magnitude of dust storms

* Corresponding author. Department of Atmospheric and Oceanic Sciences, McGill University, 805 Sherbrooke St. W. Montreal, H3A OB9, Canada.
** Corresponding author. Department of Atmospheric and Oceanic Sciences and Department of Chemistry, McGill University, 805 Sherbrooke St. W. Montreal, H3A OB9, Canada.
E-mail addresses: ali.moridnejad@mcgill.ca (A. Moridnejad), parisa.ariya@mcgill.ca (P.A. Ariya).

http://dx.doi.org/10.1016/j.jaridenv.2015.01.008
0140-1963/

(Ginoux et al., 2012; Rashki et al., 2013). Okin et al. (2001) in a study over the Mojave Desert found that abandoned agricultural fields can introduce deflationary surfaces by wind-transported materials into stable desert surfaces and can change their spectral reflectance (Okin and Painter, 2004). Additionally, wind-blown sand can lead to the expansion of desertification by burying, abrading, or stripping leaves from plants that are in the flow direction and potentially lengthen the pathway (Okin et al., 2009).

Human contribution to the mineral dust abundance has been estimated to be as high as 30–50 % (Sokolik and Toon, 1996; Tegen and Lacis, 1996). Some researchers have provided a sensitive link between desert dust emissions and climate; yet, how humans affect desert dust emissions is not well characterized (Mahowald et al., 2010), partly due to the fact that the anthropogenic forcing is very sensitive to models and meteorological conditions (Mahowald et al., 2002; Luo et al., 2003; Tegen et al., 2004).

The Middle East region has been considered to be responsible for approximately 25% of the Earth's global emissions of dust particles (Zender et al., 2003; Ginoux et al., 2004). This region, which has been experiencing severe environmental challenges is also most vulnerable to climate and human induced changes. Dust storms are one of the traditional outcomes of extreme weather events in arid and semi-arid countries located in this region and these have been more frequent and intense in the past decade (Karimi et al., 2012). Recent studies in the area have shown that Iraq and Syria are the major countries generating dust storms, noting that there is currently no consensus on the factors driving enhanced dust storms. Some contributing factors include inappropriate agricultural practices (UN SDS Report, 2013), unsustainable water resources management and climate change (Al-Ansari, 2013), military operations (Gibson, 2012) and land degradations (Sissakian et al., 2013). Gibson (2012) in a thorough study assessed whether cultivated areas in Iraq changed during or as a result of war and sanctions. The results indicate that cultivated areas changed little between the Iran–Iraq War (1980–1988) and the Gulf War (1990–1991), increased by 20 percent (from 1.72 to 2.04 Mha) during the period of the United Nations sanctions (1990–2003), and dropped to below pre-sanction levels (1.40 Mha) during Operation Iraqi Freedom (2003–2011). Also, more information on the impact of haphazard driving and military operations (thousands of trucks and heavy vehicles, explosion of numerous bombs and rockets) on compacted top soil layers, causing emissions of dust, can be found in the work of Sissakian et al. (2013). These factors have been suggested as having major impacts on desertification in the region, and the increased challenges linked to regional dust storms.

The aim of our study was to provide insights on the location, frequency and intensity of the new and mostly man-made dust storms. Also, the main objective of the present study is to determine the role of desertification in the process of the growing frequency and intensity of dust storms in the Middle East region. We herein concurrently deploy: (a) satellite data (NASA/MODIS and NASA Landsat TM), (b) dust source point identification techniques (using the newly developed Middle East Dust index to map the region); (c) spectral mixture analysis (for further desertification information extraction), and (d) change vector analysis (to study intensity of desertification change in the Middle East).

1.1. Background of study region

The Middle East, which consists largely of the Arabian Plateau and the Tigris-Euphrates Basin, is one of the world's active wind erosion regions (Shao, 2008). The Arabian Plateau is generally considered to be from the southwest high terrains (1500–3000 m) bordering the Red Sea towards the northeast flat lands (50–200 m) next to the Persian Gulf (Idso, 1976) identified as Arabia, one of five world regions where dust storm generation is intense (Fig. 1). The area of desert, which stretches across Iraq, Iran, Afghanistan, Pakistan, and northwest India, has long been recognized as a source of atmospheric mineral dust (Bryson and Baerreis, 1967; Grigoryev and Kondratyev, 1981). The major southern interior of the Arabian Peninsula is made up of the Rub Al-Khali (or Empty Quarter, 582750 km^2), which is one of the largest sand deserts in the world and is connected to the An Nafud sand sea in the north by the Ad Dahna (a sand corridor 1287 km long) (Shao, 2008).

Previously, researchers have recognized two major dust regions in the Middle East: (I) In 1986, Middleton carried out a preliminary analysis of the distribution and seasonality of dust storms using meteorological data and demonstrated that the Lower Mesopotamian plains (Iraq and Kuwait) exhibited the highest number of dust storm days per year (especially from April to August). Central Saudi Arabia showed a moderate level of dust storm. Note that previous studies have indicated the alluvial plains (Safar, 1980), off the Omani coast (Tindale and Pease, 1999) and Arabian Sea (Prospero and Carlson, 1981) have a considerable number of dust storms in the Middle East.

There are four dominant climate systems in the Middle East: (1) in winter, the Siberian anticyclone over central Asia; (2) the Polar anticyclone over east of Europe and the Mediterranean Sea, in the summer; (3) the monsoon cyclones over the Indian Subcontinent, the south and southeast of Iran and southeast of the Arabian peninsula, in the summer; (4) the depressions traveling from north of Africa and south and east of the Mediterranean sea across the Middle East and southwest of Asia in the non-summer seasons (spring and winter) (Hamidi et al., 2013). Two winds in particular generate dust in the region: The Shamal wind, which blows from mid-June to mid-September, creates severe summer Shamal dust storms, and prefrontal and postfrontal winds which generate frontal dust storms in other seasons (Wilkerson, 1991).

2. Data and methodology

2.1. NASA/MODIS

Moderate Resolution Imaging Spectroradiometer (MODIS) data were used to compare several dust retrieval algorithms and to apply a new approach to identify dust source points by a combination of the visible (VIS) and thermal infrared (TIR) bands. This sensor makes observations using 36 bands with wavelengths ranging from 0.41 to 14.4 μm and nadir spatial resolution of 0.25, 0.5, and 1 km. MODIS, launched in December 1999 and May 2002, respectively, is operating onboard the NASA Earth Observing System (EOS) Terra and Aqua satellites. MODIS data were obtained from the Level 1 Atmosphere Archived and Distribution System and processed to convert the digital numbers into radiometrically calibrated and geo-located data products. The daily MODIS Level 2 Aerosol data were also used. These data are produced at spatial resolutions of about 1 × 1 km pixel arrays.

2.2. NASA/Landsat TM

The Landsat Thematic Mapper (TM) sensor was carried onboard Landsats 4 and 5 from July 1982 to May 2012 with a 16-day repeat cycle. Images consist of seven spectral bands with a spatial resolution of 30 m for Bands 1 to 5 and 7. Spatial resolution for Band 6 (thermal infrared) is 120 m. This data was used in change detection analysis and desertification extraction. Since we are looking for the trend and potential impact of desertification on the dust source point developments, the study tried to define a possible longer period of time for better analysis. On the other hand, the availability