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Identification of dust storm source areas in West Asia using multiple environmental datasets

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HIGHLIGHTS

- We develop a three-step approach for the identification of SDS source areas.
- We map out SDS source areas in Syria, Iraq, Jordan, Iran and Saudi Arabia.
- The SDS source clusters and their main paths in West Asia are identified.

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ABSTRACT

Sand and Dust storms are common phenomena in arid and semi-arid areas. West Asia Region, especially Tigris-Euphrates alluvial plain, has been recognized as one of the most important dust source areas in the world. In this paper, a method is applied to extract SDS (Sand and Dust Storms) sources in West Asia region using thematic maps, climate and geography, HYSPLIT model and satellite images. Out of 50 dust storms happened during 2000–2013 and collected in form of MODIS images, 27 events were incorporated as demonstrations of the simulated trajectories by HYSPLIT model. Besides, a dataset of the newly released Landsat images was used as base-map for the interpretation of SDS source regions. As a result, six main clusters were recognized as dust source areas. Of which, 3 clusters situated in Tigris–Euphrates plain were identified as severe SDS sources (including 70% dust storms in this research). Another cluster in Sistan plain is also a potential source area. This approach also confirmed six main paths causing dust storms. These paths are driven by the climate system including Siberian and Polar anticyclones, monsoon from Indian Subcontinent and depression from north of Africa. The identification of SDS source areas and paths will improve our understandings on the mechanisms and impacts of dust storms on socio-economy and environment of the region.

1. Introduction

Sand and dust storms (SDS), which normally happen in arid and semi-arid, could cause areas uninhabitable and bring direct damage to human health (Goudie, 2009) as well as transport and deposition of sediments (Yang et al., 2001). These phenomena usually appear with strong and turbulent wind, blowing over desert or aridisol surface with a reduction of visibility. They could lift large quantities of dust particles into the air and transport them hundreds or thousands of kilometers away (Zoljoodi et al., 2013).

There has been a global concern on sand and dust storms considering their huge impacts on socio-economy, human health and environment. Dust storms could affect transportation industry with the reduction of visibility, cause damages to infrastructures, telecommunications and crops (JAPU, 2013). In addition, through intensifying desertification and drought, reducing water supplies and increasing soil salinity, dust storms will result in greater social-economic losses. Dust storms impact on human health through traffic accidents, respiratory complaints and other diseases (Small et al., 2001). For example, dust could carry many allergens including 107 types of bacteria and 106 fungi types (Almasi et al., 2014). The impact of dust storms on environment is also apparent. Dust transport and deposition could affect air temperatures through absorption and scattering of solar radiation, forming clouds and convectional activities (Wong and Dessler, 2005) and affect geochemical conditions of dust storms areas (Menéndez et al., 2007). In recent

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years, the role of dust storms in global system, such as sulfur dioxide levels, carbon dioxide levels, marine primary productivity, climate change and biogeochemical cycles, has become increasingly significant (Goudie, 2009).

Combating sand and dust storms needs multi-aspect approaches composed of politics, ecosystem management, economics and capacity-building. Before that, the regional identification of major SDS sources will enable us to focus on the critical regions and to characterize unique features in response to environmental conditions (Esmaili et al., 2006a). With such knowledge we will be able to understand the mechanism of dust generation and transportation, to assess the impacts of socio-economic and environmental consequences, and to find effective strategies in controlling and combating sand and dust storms. Many research methodologies are applied to identify the SDS source areas. Ground-based point measurements were used in the past, especially in the examining of aerosol-related climate issues, although their limitations in providing materials for studying large spatial scales are obvious (Esmaili et al., 2006b). With the development of satellite technology, remote sensing methods have gradually played an important role in identification of SDS source areas (Ekhtesasi and Gohari, 2013; Tsolmon et al., 2008). Using TOMS (Total Ozone Mapping Spectrometer) data, the general source areas of sand and dust storms in the global scope were mapped out (Prospero, 2002). Considering the unique characteristics of dust particles in thermal infrared (TIR) band, TIR was also applied for research on SDS hotspots (Mohammad, 2012). Besides remote sensing tools, many aerosol models have been developed to simulate or forecast the trajectory and dispersion of sand and dust storms (Barnum et al., 2004; Ginoux et al., 2001; Ashrafi et al., 2014; Liu et al., 2007; Lu and Shao, 2001; Wang et al., 2011). Among these models, The HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model is a complete system for computing simple trajectories to complex dispersion and deposition simulations using previously gridded meteorological data (Draxler and Hess, 1998). In recent years, researchers prefer to use synthetic analysis combining meteorological data, remote sensing technology, GIS tools or geological information (Al-Jumaily and Ibrahim, 2013; Boloorani et al., 2013; Hamidi et al., 2013; Taheri Shahraiyni et al., 2014; Tsolmon et al., 2008).

West Asia, especially the Tigris–Euphrates alluvial plain, is suffering from severe desertification caused by many reasons including climate and human induced factors, such as global warming, mismanagement of land use, cultivation, overgrazing, marginal plowing and years of warfare (Hamidi et al., 2013; Keramat et al., 2011; UNDP, 2002). This area has been recognized as one of the most important SDS source areas in the world (Furman, 2003; Goudie, 2009). An analysis of the predicted climate change scenarios portrays a harsher situation for the West Asia Region in the coming years. Whether in the form of desertification, deforestation, or wetland destruction or in the form of population growth, food insecurity and water shortage (e.g. For Iran case, see (Amiraslani and Dragovich, 2011)), the countries in the Region are expected to experience environmental and socio-ecological catastrophic events more than ever before. Most of the countries in the Region are now grappling with frequent sand and dust storms as a result of destructive ecological footprints. This recent phenomenon of SDS has forced authorities in some of these countries, notably Iran and Iraq as the immediate sinks of these dusts, to set up specialized tasking groups at national and regional levels to tackle the issue including the identification of sand-source areas. The impacts of an increase in dust storm in Iran, as one of these affected countries studied in this research, are obvious. This phenomenon has forced the Government to declare a state of emergency for sensitive groups (elderly people, patients and children) and to close schools and public organizations in 70% of provinces, in particular western provinces adjacent to the Iraq border, several times over the recent years.

There is an urgent need to identify the SDS source in West Asia, and then to find efficient solutions in combating sand and dust storms accordingly. In this paper, Syria, Iraq, Iran, Jordan and eastern part of Saudi Arabia are focused as pilot countries in West Asia. Some research have provided direct or indirect proofs of SDS source areas in Iraq and eastern part of Syria, mainly located in Tigris–Euphrates plain while for Jordan, Iran and Saudi Arabia, only indirect clues such as vegetation types, bioclimatic zone or land use distribution have been considered for investigation of sand sources. Previous studies have shown evidence in Syria (Geerken and Ilaiwi, 2004; IFAD, 2007; UNDP, 2002) and Iraq (Alonso-Pérez et al., 2013; DRI, 2012; Yang et al., 2001; Zoljoodi et al., 2013); however sand and dust storms are resulted from various factors and thus any investigation necessitates incorporating multiple technologies and information to refine SDS hotspots.

2. Material and methods

2.1. Geographic data features

Thematic maps of West Asia Region, especially Syria and Iraq, were regenerated based on various sources such as scientific articles, project reports, PhD theses, conference proceedings, global or national reports and documents, etc. (Table 1). These thematic maps, extracting direct or indirect clues of SDS sources (dust source areas, SDS clusters, sand dunes, aridisols, dried alluvial fans and psammophytes, etc.), and were produced under unified mapping standards.

Geographic coordinates of the pilot countries were adopted as reference to digitalize the above-mentioned maps using WGS84 coordinate system and Albers Conical Equal Area Projection.

2.2. HYSPLIT model and meteorological data

HYSPLIT model was originally developed using the concept of a threshold friction velocity which depends on surface roughness (Draxler et al., 2001). Surface roughness is correlated with geomorphology or soil properties. The dust emission rate is computed where the local wind velocity exceeds the threshold velocity for the soil characteristics of that emission cell. Backward trajectory method is used to track sand and dust transport and interaction with the surface.

Meteorological station data for the pilot countries (Fig. 1) were downloaded from the website http://gis.ncdc.noaa.gov/map/viewer/#app=clim&cfg=cdo&theme=hourly&layers=1&node=gis in order to identify the dates of sand and dust storms. According to the definition of World Meteorological Organization, dust storms are resultant of weather turbulences which introduce a high dust mass in the atmosphere, and consequently decrease the horizontal visibility to less than 1000 m. A threshold of humidity is also set in case of other weather phenomena like mist although it seldom happens in West Asia Region.

In this paper, we regarded a meteorological station in relation to record dust storms if the visibility was less than 1000 m and the humidity lower than 80% (Fig. 2). In Fig. 2, the red spots represent the frequency of SDS, and larger spots mean more dust storms happening in the station from 2000 to 2013. To some extent, the SDS frequency can provide clues for the distribution of SDS source. Few stations had no recorded data or had limited data. In this case, we excluded the stations with SDS frequency lower than 10 times as they could hardly be used in our methodology. Number of days with SDS was calculated according to the date in which meteorological stations had recorded dust storms each year. As illustrated in Fig. 3, the number of days with SDS in West Asia had fluctuations prior to 2006 and increased significantly afterward. This diagram also manifests the increasing frequency and intensity of SDS events in West Asia, which need to be addressed with the regional cooperation and effort.

2.3. Remote sensing images

Moderate Resolution Imaging Spectroradiometer (MODIS) images provide near global coverage (95%) with high temporal and spectral resolutions (Zhang et al., 2008). This paper applies MODIS L1B data (from