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Dust storms backward Trajectories' and source identification over Kuwait

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ABSTRACT

Dust storms (DS) are considered a common environmental phenomenon in numerous countries of the world, especially in the arid and semi-arid regions. DS causes a significant impact on human health, climate, the environment and many associated socioeconomic factors. The main goal of this study is to assess the sources of DS in the State of Kuwait. The present study investigates DS over Kuwait using the backward trajectories' simulation with MODIS satellite observations at various latitudes (1000, 3000, 5000 m) during the four seasons; winter, spring, summer, and fall. The trajectories' simulation was modeled using the HYSPLIT model to create the seasonal climatologic of air parcel trajectories. The meteorological data (e.g., visibility, wind speed, wind direction, temperature, and humidity) were collected during a 12-year period from 2000 to 2012. Daily trajectories were computed backward for five days from a central origin at several altitudes above the ground surface. The variability of the DS was analyzed daily, monthly, seasonally and annually. A case study on 25 March 2011 and two cases from each season were selected for analysis. The results showed that the HYSPLIT model was consistent with the MODIS satellite images. The sources of DS were identified from both the Sahara Desert and the Arabian Desert. Furthermore, there is a significant influence of the atmospheric conditions on the DS sources. The most influential parameter was visibility, from the west and the northwest direction. The present work provides evidence and suggestions for the origins of DS and is expected to help in establishing guidelines for public protection against dust particles and provides significant information to the concerned officials to take proper actions.

1. Introduction

Dust storms (DS) are natural phenomena that arise globally with meteorological properties of gusty wind and occur when strong pressure gradients change through dry arid or semi-arid districts where loose sands are more prevalent, especially in the Middle East, Southwestern United States, Northern China, and Saharan desert. Essential conditions on the occurrence of DS include immense dust or sand sources, strong surface winds, and unstable atmosphere. DS cause problems environmental, economic, climate and human health problems, e.g., air quality, damage to crops and reduced soil fertility, reduction of solar radiation, and damage to telecommunications and mechanical systems (Al-Hemoud et al., 2017). DS also cause a decrease in visibility that limits various activities such as air and sea navigation movement and increases traffic accidents. Dense and intense DS can reduce the visibility to be near-zero in and near source regions. There are three main classifications for DS according to the reduced visibility: (a) Blowing dust - the horizontal visibility is less than 11 km; (b) DS - the horizontal visibility is less than 1000 m; and (c) Severe dust - horizontal visibility is less than 200 m. Suspended dust particles can rise by strong winds thousands of meters upward and downwind. Arid and semi-arid districts, approximating the boundaries of deserts occupied almost 20% of the earth's surface. Many factors make an area affected by DS, e.g., soil type, topography, climate and weather conditions.

Numerous previous studies have been conducted to identify DS transport and trajectories over different regions of the world, e.g., Prospero et al., 2002; Kutiel and Furman, 2003; Xiaodong et al., 2004; Lin et al., 2004, 2007; Kaskaoutis et al., 2008; Dementeva et al., 2008; Baddock et al., 2009; Yasunari and Yamazaki, 2009. Review studies (Yu et al., 2010) examined Asian DS activity from 1995 to 2006 and the associated atmospheric circulation using SYNOP and NCEP/NCAR reanalysis atmospheric data. Observations showed that the Gobi desert is the most common birthplace for severe dust in Asia, accounting for approximately 58% of total dust events, followed by about 32% from the Taklamakan Desert and nearly 10% from the Loess Plateau. DS from East and non-East Asian sources to Hong Kong over the period from 1996 to 2007 (76 dusty days) were studied by Lee et al. (2010). Results revealed that 73 out of the 76 DS events (96%) involved non-East Asian

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sources, the Central/West Asian, and the Arabian and Sahara deserts, which were previously not shown to have any effect on Hong Kong. Prasad et al. (2010) studied the implications of high-altitude desert dust transport from Western Sahara to Nile Delta during the biomass burning season. They discovered that dust transport pathway along the Mauritanian-Malie-Algeria-Libya-Egypt axis significantly affected NE Africa, especially the Nile Delta region. The characteristics of the DS over Oman were studied by Desouza et al. (2011). They identified a weakening of inversion in the lower troposphere and the formation of a mixed layer due to the transfer of horizontal momentum from the upper air over the surface. DS simulation was investigated by Pineda-Martinez et al. (2011) and Wang et al. (2011) using the HYSPLIT model with two different dust emission schemes. The characteristics of DS based on daily observation data at meteorological stations in China were examined by Sai-Chun and Guang-Yu (2012). A significant correlation was found between dust events and chlorophyll concentration in the Yellow Sea. Other studies were conducted by Nava et al. (2012) and Indoitu et al. (2012) for the Saharan dust transport over long periods in the Central Asian region. Results showed that there was a significant decrease in DS frequency during the last decades and considerable changes in the active source areas. Furthermore, Hamidi et al. (2013) and Al-Jumaily and Ibrahim (2013) studied the synoptic patterns leading to the formation of DS in the Middle East, south-west Asian region and Iraq, based on the satellite images, aerosol's index and synoptic weather maps, and NCEP-NCAR Reanalysis Data. The results showed that the DS develop when a low-pressure is formed over Iran by the Shamal winds. Dagsson-Waldhauserova et al. (2013) calculated the frequency of dust events from Icelandic deserts using the records of dust observations. The study showed that Icelandic dust might be a substantial source for not only local but also larger scale air pollution in the Arctic zone. Wang and Lai (2014) established a theoretical model to estimate the relative distance of suspended dust particles according to grain size and wind speed. The results indicated that the Qaidam Basin could be a likely dust source of the Chinese Loess Plateau. Kok et al. (2014) evaluated the performance of the new dust emission scheme and tested the hypothesis to use empirical source functions in dust cycle simulations. They found that the new dust was shifted to the world's most eroded districts in a way that is strikingly similar to the effect of implementing widely used source functions based on satellite observations of dust source regions. Recently, identifications of sand and dust storms (SDS) source areas in Iran and West Asia were investigated by Cao et al. (2015a, 2015b) using HYSPLIT model, climate and geography, satellite images and thematic maps. Results indicated that the SDS source was transported from large cities, like Tehran, Isfahan, Sistan and Tigris-Euphrates plains. Moridnejad et al. (2015) presented a new inventory of dust source points in the Middle East region using the MODIS sensor on both Terra and Aqua satellites. Results indicated that 247 different source points participated in DS generation in the Middle East region in which Iraq and Syria were the highest sites for DS generation in the region. A method for DS detection was developed by Wong et al. (2015) based on a hybrid neural network (NN) retrieval model using a combination of geostationary satellite images (MTSAT), ground station observations (PM10 concentration, AERONET data), and numerical weather and climatic forecasting products (WRF/Chem). The accuracy of the near real-time detection using feed-forward multilayer perceptrons (MLP) with back propagation was 96.6%. Other studies by Awad and Mashat (2016) and Farahat et al. (2016) described DS observations from CALIPSO and MODIS, with AERONET ground observations during the spring season from 2003 to 2010 over Saudi Arabia. The mean AOD showed high aerosol abundance due to combined natural and anthropogenic sources. DS monitoring in the southern and central parts of Iran was investigated by Khamooshi et al. (2016) during the period from 2002 to 2009, using HYSPLIT Model and Normalized Dust Difference Index (NDDI). The results showed that west winds were caused by the low-pressure air mass in the center of Iran and the high-pressure air mass in the northeast of Africa. While, the effects on the global solar component, solar ultraviolet radiation, downward and outgoing long-wave radiation and surface meteorological variables were studied by Maghrabi and Al-Dosari (2016). The study showed that global solar radiation decreased by 57.5% immediately after the arrival of the storm. Extreme DS over the eastern Mediterranean in September 2015 was discussed by Mamouri et al. (2016) based on satellite, LIDAR, and aerosol observations. The visibility observations suggest peak values of the near-surface total suspended particle (TSP) extinction coefficients of 6000 Mm^{-1} and thus TSP mass concentrations of 10,000 $\mu g\, m^{-3}$. Another studies were conducted by Wang et al. (2017), Tan et al. (2017) and Wang et al. (2018) to investigate the transport of East Asian DS to the marginal seas of China and the southern North Pacific using backward trajectories, meteorological stations, the Cloud-Aerosol Lidar and Infrared Pathfinder Observation Satellite. The results indicated that the emissions of dust were as twice as that for the 44-year average from 1960 to 2003, and 35% higher than that of spring 2006. Solomos et al. (2017) analyzed the effects DS over the Middle East and the eastern Mediterranean. Results showed that the development of a thermal low in the area of Syria that results in unstable atmospheric conditions and dust mobilization in this area. Baddock et al. (2017) determined the dust pathways from Iceland's over 20 years using ARIMA model. The distributions of trajectories suggested that contributions of Iceland's dust were relatively more important for neighboring marine environments than the cryosphere. Furthermore, the impact of Middle Eastern Dust storms (MEDS) events on human health in the Iranian city of Ilam was conducted by Khaniabadi et al. (2017). The results showed the impact of the Middle-Eastern Dust (MEDS) events in Ilam on the increase in hospital visits due to the Chronic Obstructive Pulmonary Disease (COPD) and the Respiratory Mortality (RM) attributable to PM_{10}. Rashki et al. (2015) investigated the seasonality, variation, and transport characteristics of the DS over Sistan region during the summer months for the period 2001–2012 using local meteorological records, satellite observations (TOMS, OMI, METEOSAT, MODIS) and HYSPLIT forward trajectories. They found that the DS from Sistan affected central/south Arabian Sea and India, while controlling the aerosol loading over the northern Arabian Sea. Dust storm sources at the south-west of Iran in Khoozestan province was recognized by Broomandi et al. (2017). The results indicated the changes in metrological parameters located in South –West of Iran. A 3D multi-threshold scheme for identifying DS features from DS model simulations was investigated by Yu and Yang (2017). The model simulation showed high sensitivity for its parameters, and over time, hampered the tracking of identified features. While Kim et al. (2017) developed a high-resolution dynamic dust source in the NASA Unified-Weather Research and Forecasting (NU-WRF) model. The NU-WRF model with the new high-resolution dynamic dust source can capture the Phoenix DS. Another studied were conducted by Modarres and Sadeghi (2018), Namdari et al. (2018), Beegum et al. (2018) and Özdemir et al. (2018) to investigate the variations of DS in desert regions of in Iraq, Syria, Saudi Arabia, and Iran. Results showed both positive across south and southeastern regions and negative across the north and northwestern regions in the annual and a seasonal number of dusty days' time series. While the characterization of synoptic weather clusters causing dust outbreaks that affect the Arabian Peninsula was analyzed by Hermida et al. (2018) and Beegum et al. (2018). They found four significant atmospheric circulation patterns associated with dust outbreaks during the study days. The distribution of dust events by cluster indicates that cluster 4 had the most significant number of days with dust or sand events, a total of 30. Cluster 3 had the fewest days at 17, and clusters 1 and 2 had 22 and 26 dusty days. The synoptic characteristics and statistical of seasonal variability of the dust over southwestern Saudi Arabia were investigated by Mashat et al. (2018) using dust observations, the aerosol index (AI), and meteorological data. Results indicated that the synoptic forces that influenced the dust cases were the relative positions of high-pressure systems and low-pressure systems, alongside their