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Detection and monitoring of super sandstorm and its impacts on Arabian Sea—Remote sensing approach

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ABSTRACT

The present study addresses an intense sandstorm event over the Persian Gulf and its transport over the Arabian Sea region and the Indian sub-continent using satellite observations and measurements. MODIS data are used to analyze the temporal variation of the dust events that occurred from 17 to 24 March 2012 with the strongest intensity on 20 March over the Arabian Sea. MODIS images are examined to provide an independent assessment of dust presence and plume location and its migration over the Arabian Sea to the Indian sub-continent. Dust enhancement and dust detection procedure is attempted to demarcate the dust event. Dust source, formation, transportation path, and dissipation is studied using source-back-tracking, surface wind, and surface pressure, wind speed and direction, geo-potential height for different pressure level, and remote sensing methods. Finally, an attempt is made to investigate the impact of super sandstorm on the Arabian Sea by studying sea surface temperature and chlorophyll *a* variability during the events. It is noted that sea surface temperature is decreased and chlorophyll *a* concentration increased during the post-event period. The present study demonstrates the use of remote sensing data and geospatial techniques in detecting and mapping of dust events and monitoring dust transport along specific regional transport pathways over land and ocean.

1. Introduction

Large quantities of dust with particle size less than 10 μm are dispersed in earth's atmosphere by wind-driven processes. This dust is of significant scientific interest owing to its ability to potentially alter climate, reduce local visibility, cause health problems in humans, and affect biogeochemical cycles in the world's oceans (Redmond et al., 2010). The erosion, transport, and deposition of this kind of particle matter create hazards when it affects human activities (Boccone, 2010). Locally, dust storms result in a low visibility, creating dangers for road and air transport. There is also an environmental concern because of the severe dust erosion occurring, and also because it has an impact on the nutrient budget of oceanic ecosystems by providing a source of Fe to fertilize ocean regions that would otherwise be nutrient starved (Liss and Turner, 2000).

Despite the increased anthropogenic emissions due to the population growth, the air quality in south Asia is also affected by mineral particles from dust storms and smoke from naturally occurring biomass burning (Ichoku et al., 2004). Deserts in western Asia produce large amounts of mineral dust particles that enter in the atmosphere. Dust is considered to be one of the major sources of tropospheric aerosol loading and constitutes an important key parameter in climate aerosol-forcing studies (Kaufman et al., 2002; Tegen, 2003; Huang et al., 2006; Slingo et al., 2006). Therefore, the real-time monitoring of dust storms is essential for sustainable development and for climate change and environmental research in the world. Satellite-based measurements for monitoring these atmospheric constituents are a viable proposition since ground-based measurements are limited in space and time (Liu et al., 2008; Papadimas et al., 2008).

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It is well known that dust mineral particles influence the earth's radiation balance and the climatology mainly in two ways: first by reflecting and absorbing incoming and outgoing radiation and second by acting as cloud condensation nuclei. Dust aerosols strongly affect visibility, perturb the radiation balance in the Earth–atmosphere system, and also cause serious biological and ecological effects (Boccone, 2010). The significant dust effects on global climate, meteorology and atmospheric dynamics, ecosystems, and human health are highlighted in detail in review studies (Goudie and Middleton, 2001; Engelstaedter et al., 2006; Choobari et al., 2014).

Desert wind can transport dust to thousands of kilometers away from the source regions. Particle sizes are initially determined by their source regions. Therefore, due to the high spatial variability of the dust plume characteristics along its transport, remote sensing is an established method for the detection and mapping of dust events (Kaskaoutis et al., 2008; Badarinath et al., 2010) and has recently been used to identify the dust-source locations with a varying degree of success (Washington et al., 2003; Alpert et al., 2004; Vachon et al., 2004; Bullard et al., 2006; Baddock et al., 2009). To this respect, the passage of dust over land and ocean and the variation along its transport have been monitored by satellite sensors with resolutions varying from high (hundreds of meters) to low (hundreds of kilometers), among others AVHRR (Li et al., 2013), METEOSAT (Banks et al., 2013), MODIS (Baddock et al., 2009), TOMS AI (Gao and Washington, 2009), MSG-SEVIRI (Schepanski et al., 2007), and SeaWIFS (Antoine and Nobileau, 2006). However, the ability to use remotely sensed data both to detect a dust plume and to identify the location from where it has originated is affected by several factors, including the radioactive transfer properties of the material emitted, the radioactive properties of the ground/ocean surface over which the plume is transported, the size and density of the dust plume, the time of satellite overpass relative to dust emission, the presence or absence of cloud, the horizontal and vertical plume trajectory, and the sensor characteristics and radioactive transfer model used to detect dust (Baddock et al., 2009).

For high temporal and spatial resolution, satellite remote sensing could be an ideal method for studying the process of dust storms as they begin, develop, and fade away at large scales. Compared to other remotely sensed data, MODIS has advantages as more useful narrow channels and high spatial and radiation resolution. MODIS visible/near-infrared (VNIR) and thermal infrared (TIR) bands are helpful for cloud screening. Moreover, because MODIS are on EOS-AM1 Terra and EOS-PM1 Aqua satellites, MODIS can provide more real-time data (daytime and nighttime) to study dust storm motion processes.

The sandstorm event that occurred during the 2nd half of March 2012 period reduced the visibility drastically and Meteorologist termed it as "super sandstorm" (Fig. 1). While passing over the Arabian Sea, the storm might have dropped large amount of dust particles in the Sea, which might have affected the marine ecosystem.

1.1. Objective

The main objectives of this study are (1) to detect the storm and monitor migration of this super sandstorm using multi-sensor measurements and geospatial techniques, (2) to validate the existence and migration path of the super sandstorm with CALIPSO and back trajectory study, (3) to analyze the impact of this sandstorm event on the variability of chlorophyll *a* concentration and sea surface temperature of the Arabian Sea, and (4) to study the possible relation between the SST, chlorophyll, and dust storm loading.

2. Materials

The Moderate-resolution Imaging Spectroradiometer (MODIS) is a payload launched into Earth orbit by NASA in 1999 on board the Terra (EOS AM) Satellite, and in 2002 on board the Aqua (EOS PM) satellite. The instruments capture data in 36 spectral bands ranging in wavelength from 0.4 μm to 14.4 μm and at varying spatial resolutions (2 bands at 250 m, 5 bands at 500 m, and 29 bands at 1 km). Desert dust can be detected via satellite observations in the ultraviolet (0.315–0.4 μm) via absorption, visible (0.38–0.79 μm) via scattering, and thermal infrared via contrasting land/aerosol emissivity (Baddock et al., 2009). Each MODIS sensor passes the same site twice a day: one in the daytime orbit for all thirty-six bands and the other in the nighttime orbit only for the thermal bands 20–25 and 27–36. In total, four measurements are collected every day with two MODIS sensors. The data used in this study are of version 5 L1B measurements issued by NASA. Each MODIS file (referred to as a "granule") collects consecutive measurements within 5 min, typically 203 scans, covering an area with 2030 km (along-track) by 2330 km (cross-track) (Nishihama et al., 2000; Isaacman et al., 2003). Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite is part of the "A Train," flying in formation with several other satellites (Aqua, Aura, and CloudSat). CALIPSO data are used to study vertical column of dust storm. Other sensors on MODIS also provide information on sea surface temperature (SST) and chlorophyll *a* to study primary productivity.

3. Methods

Over the recent decades, several methodologies have been used to assess deflation, transport, and deposition of the dust: (1) Reconstruction of air-mass trajectories is calculated to trace dust deposits back to their source area. (2) Analysis of the concentration and composition of certain tracers in the dust itself, and comparing them to soils and sediments from possible source areas. This method has the advantage of being useable for palaeo-atmospheric circulation and palaeo-dust transport studies, whereas satellite imagery study and air-mass back trajectories are restricted to relatively recent times. (3) Regional or global atmospheric circulation models, mapping of dust deposition and analyses of source fingerprints.

In general, the dust detection algorithms use 7 of the 36 available MODIS channels to exploit the spatial and spectral contrast features of the dust (Guo and Liang, 2006). These algorithms are listed in terms of channel index, central wavelength, native spatial resolution, description, and increasing wavelength, which are as follows: (1; 645 nm; 250 m; red), (2; 853 nm; 250 m; reflective IR), (3; 469 nm; 500 m; blue), (4; 555 nm; 500 m; green), (26; 1.38 mm; 1 km; short- wave water vapor), (31; 11.0 mm; 1 km; IR clean window), and (32, 12.0 mm 1 km; IR dirty window). The over-water algorithm