SPATIOTEMPORAL MODELLING OF DUST STORM SOURCES EMISSION IN WEST ASIA

E. Khodabandehloo[a*], A. Alimohamdadi[a], A. Sadeghi-Niaraki[a], A. Darvishi Boloorani[b], A.A. Alesheikh[a]

[a] GIS Dept. Faculty of Geodesy and Geomatics Eng, K. N. Toosi Univ. Of Tech., Tehran, Iran.
ekhodabnandehloo@mail.kntu.ac.ir, (alimoh_abb, a.sadeghi, alesheikh)@kntu.ac.ir

[b] University of Tehran Faculty of Geography, Dep. Of Remote Sensing & GIS, Geoinformatics Research Institute (UT-RGI) and University of Tehran, ali.darvishi@ut.ac.ir

KEY WORDS: Dust, spatiotemporal modeling, NDVI, regional model, GIS

ABSTRACT:

Dust aerosol is the largest contributor to aerosol mass concentrations in the troposphere and has considerable effects on the air quality of spatial and temporal scales. Arid and semi-arid areas of the West Asia are one of the most important regional dust sources in the world. These phenomena directly or indirectly affecting almost all aspects life in almost 15 countries in the region. So an accurate estimate of dust emissions is very crucial for making a common understanding and knowledge of the problem. Because of the spatial and temporal limits of the ground-based observations, remote sensing methods have been found to be more efficient and useful for studying the West Asia dust source. The vegetation cover limits dust emission by decelerating the surface wind velocities and therefore reducing the momentum transport. While all models explicitly take into account the change of wind speed and soil moisture in calculating dust emissions, they commonly employ a "climatological" land cover data for identifying dust source locations and neglect the time variation of surface bareness. In order to compile the aforementioned model, land surface features such as soil moisture, texture, type, and vegetation and also wind speed as atmospheric parameter are used. Having used NDVI data show significant change in dust emission, The modeled dust emission with static source function in June 2008 is 17.02% higher than static source function and similar result for Mach 2007 show the static source function is 8.91 % higher than static source function. we witness a significant improvement in accuracy of dust forecasts during the months of most soil vegetation changes (spring and winter) compared to outputs resulted from static model, in which NDVI data are neglected.

1. INTRODUCTION

Dust storms are common phenomena over many parts of the world and their environmental impact has been increasingly recognized (Mbuh, 2011). Dust particles transported in the Earth's atmosphere have strong effects on air quality because of its effects upon radiation, ocean biogeochemistry, and human health, soil formation, ground water quality, crop growth and, more broadly, on local and global climate at different spatial and temporal scales (Mbuh, 2011; Menut, 2013).

Dust storms are produced by wind erosion in arid and semi-arid surfaces. While dust distribution and dust effects are important at global scales, they strongly depend on dust emission, which is a threshold, spatially heterogeneous phenomenon, locally controlled on spatial and temporal scales. Since dust plays a key role in air quality because of its effects upon radiation, ocean biogeochemistry, and human health, it is necessary to accurately represent its emission, transport and deposition at different spatial and temporal scales (Menut, 2013).

Determine dust concentration is necessary to evaluate the dust impacts. An important key to reproduce dust concentration is modeling dust emissions. More than 10 years effort doing to develop an exact dust emission model based on processes. Use pertinent datasets of meteorological and soil is necessary to develop of accurate model .Despite major efforts, the spatial and temporal distributions of mineral dust remain uncertain. Therefore, the nature and magnitude of dust feedbacks on climatic processes, bio-geochemical cycles, and human life are not well constrained. (Artaxo and Hansson, 1995)

Observations show that vegetation cover may play an important role in magnitude of dust emissions on seasonal scales (Zhao et al., 2004,Lee and Sohn, 2009). Numerous studies have shown the importance of dust to affect the Earth's radiation budget, atmospheric dynamics, air quality, and ocean biogeochemistry over spatial and temporal scales (Haywood et al., 2005,Jickells et al., 2005). Desert dust plays an important role in the climate system. Dust activity is sensitive to many environmental parameters, and the identification of major sources will enable us to focus on critical regions and to characterize emission rates in response to environmental conditions. With such knowledge we will be better able to improve global dust models and to assess the effects of climate change on emissions in the future (Prospero et al., 2002).

2. EXPLICIT AND PROCESS-ORIENTED DUST EMISSION MODELS

Dust cycle consisting of the entertainment (dust emission), transport path (height and direction) and deposition (dust removal from the atmosphere) strongly depend on land surface conditions, environmental situation, atmospheric conditions during each step of the cycle. Soil particle mobilization into the atmosphere is mainly caused by wind. In the numerical models, such process is often parameterized as a function of the friction wind or near surface wind speed. Other factors affecting the dust mobilization include soil moisture (or surface wetness) and vegetation cover, and etc. Because of the spatial and temporal limits of the ground-based observations, remote sensing methods have been found to be more efficient and useful for studying the West Asia dust source locations and their characteristics with regard to the time of activity, dust flux, and transport, remote sensing data and spatial-temporal methods are required. Using these methods and data also compensate the lack of ground-based observations. In the below parameters affect to the dust emission are described:

2.1. Parameterizations of the erosion threshold

An important factor in dust emission is wind velocity, when wind velocity exceeds as fraction velocity, dust emission occurred, this wind friction velocity is called threshold wind friction velocity (Ut). Observation shows that it can considerate as a function of the soil grain diameter, when the grain size increase, it increases. For smaller soil particles, when the grain size decreases, U_t increases (Due to the inter-particle cohesive forces). So an optimum grain size around 80 µm, UT is the lowest (Iversen and White, 1982).

The main factor affecting the threshold velocity is cohesion forces which depend on the particle size and soil moisture (Pye, 1987). The cohesive force between the soil grains are reinforced by the soil water and thus the erosion threshold is increased. The relationship for use surface wetness in determining the threshold wind velocity by (Pye ,1987) is below:

$$u_t = \begin{cases} A\sqrt{\frac{\rho_p - \rho_a}{\rho_a} g \Phi_p}(1.2 + 0.2 \log_{10} w) & \text{if } w < 0.5 \\ \infty & \text{otherwise} \end{cases} \quad (1)$$

Where A=6.5 is a dimensionless parameter, w is the surface wetness, ϕ_p is the particle diameter, g is the acceleration gravity, ρ_p and ρ_a are the particle and air density, respectively.

2.2. Dust Source Function

Enclosed basins containing former lake beds or riverine sediment deposits provide an abundance of small clay-sized particles that are loosely bound, and dominate global dust emission. The origin of clay mineral as on the Earth's surface is in the majority of cases, a process of stream deposited sediments. Modelling studies show that inclusion of these 'preferred' source regions improves the realism of the model dust load in the vicinity of the sources (Zender, 2003). There are no data on distribution of alluvium over the land surfaces, so the potential location of accumulated sediments has been determined by a dust source function that calculated in grid cell surrounding basin.

We assume that a basin with pronounced topographic variations contains large amount of sediments which are accumulated essentially in the valleys and depression, and over a relatively flat basin the amount of alluvium is homogeneously distributed. To identify these regions, we test the source function S described in (Ginoux et al., 2001)based upon topography which is described as follows:

$$S = \left(\frac{z_{\max} - z_i}{z_{\max} - z_{\min}}\right)^5 \quad (2)$$

Where S is the probability to have accumulated sediments in the grid cell I of altitude me, and z_{max} and zooming are the maximum a minimum elevation in the surrounding $10^o \times 10^o$ topography, respectively. This function can define the most probable location of sediments (Ginoux et al., 2001).

2.3. Erosion horizontal flux (E_P)

Dust uplifting mainly occurs by sand blasting or soil bombardment, which is parametrized by (Ginoux, Chin et al. 2001) that assuming that vertical flux is proportional to the horizontal wind flux. This emission parameterization needs to wind speed in 10 m, the threshold velocity of wind speed and the surface condition that produce with dust source function and finally the condition of each dust size class. Dust emission flux for a size group p is determined as:

$$E_p = C \times S \times s_p \times u^2{}_{10} \times (u_{10} - u_t), if\, u_{10} > u_t \quad (3)$$

Where C is a dimensional factor (1 µg s^2 m^{-5}), S is the dust source function with a value between 0 and 1, S_p is the fraction of the size group p within the soil (Tegen and Fung 1995),u_{10} is wind velocity of 10 m and U_t is threshold wind velocity(Kim et al., 2013).

2.4. Dust emission

Dust emission is mainly initiated by sand blasting. (Marticorena and Bergametti, 1995) have developed a model for dust emission for this processing. The emission parameterization requires the knowledge of the 10m wind speed, the threshold velocity of wind erosion, and the surface condition for each dust size class. In this formulation the flux Fp of particle size class P is approximated by this expression:

$$F_p = \begin{cases} CSs_p u_{10m}^2 (u_{10m} - u_t) & \text{if } u_{10m} > u_t \\ 0 & \text{otherwise} \end{cases}$$

Where C is a dimensional factor equal to 1, S is the source function , u_{10} is the horizontal wind speed at 10 meters. It is the threshold velocity, and S_p is the function of each size class.

This study focuses on improving the seasonal variation of the dust source function, as described in the next sections.

3. MODELING DUST EMISSIONS

This research paper presents an integration of geographic information systems (GIS) and remote sensing for mapping dust emissions for the determination hotspots in this region and determining the exact range of emitted dust.

Dust emission depends on the surface properties like vegetation cover, surface roughness, soil texture, soil moisture content and atmospheric conditions like the wind and stability. Therefore, dust emission can be described as the threshold phenomenon, whereby the friction wind velocity has to exceed a certain, local threshold depending on the local soil characteristics. For consideration of the soil characteristics databases describing soil size distribution the soil particle size distribution, texture and vegetation cover are required. The soil particle size distribution for the dust emission scheme implemented in the model classifies four different soil size classes including: clay, small silt, large silt and sand. As the size distribution does not follow the same proportion at each location beside the particle weight related to particle diameter as included in the soil size distribution, cohesion forces affect the sandblasting efficiency. The vegetation cover limits dust emission by decelerating the surface wind velocities and therefore reducing the momentum transport from the air towards the soil particles, and by providing cover to bare soils. Both of these effects depend mainly on the vegetation type and cover. As dust emission occurs over non-forest areas, the biomes are assumed to be important for dust mobilization description. Therefore, an effective surface area can be determined by the seasonal variation on the vegetation covers. Soil moisture content reduces the soil erodibility as it increases the cohesion forces between the adjacent particles.

Emission models allow to compute the dust flux emitted from arid and semi- arid areas , for providing parameters accurate databases (surface, soil, and meteorology) are Prerequisites to model mineral dust correctly.

Arabian dust source areas The second largest dust activity (after the Sahara) can be observed in the Middle East. Dust storms cover large areas almost all year long at the Arabian Peninsula. The dominant dust the main period of dust storms is spring and summer. At the northern territory of the Persian Gulf, floodplain deposits and extensive marshlands of the two large rivers provide the main source of deflated fine-grained mineral material. The seasonal cycle of dust emission observed by TOMS AI shows same variability; the maximum dust transport occurs in spring and summer and it is at a minimum in winter (GyÃ–rgy, 2012).

In general, it can be stated that in arid areas the seasonal maxima of dust entrainment occur typically during spring and summer, during the periods of highest wind-strengths and thermal convective activity. The peak of dust activity at some semi-arid and sub-humid, mid-latitude areas is in early spring before the vegetation-period, when the fields are plowed and the snow-cover has melted (GyÃ–rgy, 2012).

The amount of particles set into motion due to sandblasting depends on the particle size distribution and the mineralogical composition. Consequently, different sandblasting efficiencies have to be assumed for different soil types as shown by wind tunnel experiments and field experiments. Dust emission occurs when all relevant factors are suitable for wind erosion. However, it can be imagined that spatial and temporal variability in dust source areas is evident, mainly because of the varying local soil characteristics (i.e. Vegetation cover in semi-arid areas) and atmospheric conditions. Previous studies have shown that there is a statistically significant relationship between NDVI and dust loading in source regions and temporal changes of the vegetation coverage can significantly improve dust emission process. One of the best ways for modelling dust emission is using of spatiotemporal modelling. Local and regional atmospheric conditions like stability and wind can affect vertical mixing, transport height and direction of the emitted dust particles. While all models explicitly take into account the change of wind speed and soil moisture in calculating dust emissions, they commonly employ a “climatological” land cover data for identifying dust source locations and neglect the time variation of surface bareness. Although such an approach is adequate over permanent desert locations because of little vegetation coverage there, the static dust source does not reflect the dynamic land cover changes over other areas and could cause significant errors in estimating dust emissions in some seasons. Thus, stability, transport height and size distribution of the airborne dust, clouds and precipitation are major factors for dust removal from the atmosphere, affecting the location of the deposition.

4. RETRIEVAL OF RELEVANT INPUT DATA FOR THE SIMULATION OF DUST EMISSIONS

In the last decade, input databases have been developed to the advancements of explicit Dust emission models [e.g. (Marticorena et al., 1997,Callot et al., 2000,Tegen et al., 2002,Zender et al., 2003,Marticorena et al., 2004,Prigent et al., 2005,Laurent et al., 2006,Laurent et al., 2008). Some of the most important soil, Surface and meteorological input parameters for the modelling of dust emissions are used. In natural, various soil grains are present simultaneously. Since grains of different sizes have different threshold wind velocities, the in-situ soil size distribution has to be correctly described in emission models.

Soil maps classify soils according to the "textural triangle" defined by three sizes components: clay (0.73µm), small silt (6.10 µm), large silt (18 µm) and sand (38 µm).

The explicit dust emission model developed by (Ginoux et al., 2001) and coupled with relevant input datasets of the Surface characteristics allows to simulate the dust emission occurrences and their intensity over desert areas. The improvement of dust emission modelling and forecasting is necessary to determine and manage the risks and nuisances for the exposed populations living in these areas correctly. The validation of the simulated dust emissions is also a complex issue due to the lack of quantitative measurements directly over desert surfaces.

5. RESULTS AND DISCUSSION:

In the present study, dust event outbreaks in the west of Asia will be forecasted by developing a dust model, named (Dust emission). In order to compile the aforementioned model, land surface features such as soil moisture, texture, type, and vegetation and also wind speed as atmospheric parameter are used. Dust model algorithm which designed after Ginoux et al. (2001) and developed in MathWorks' Matlab (R2010) environment, was optimized by the determination of threshold for two dust-making factors, NDVI and wind speed.

Usnign S-dynamic and S-static for March 2007 and June 2008 which is an active dust month are doing. The modeled dust emission with static source function in June 2008 is 17.02% higher than static source function and similar result for Mach 2007 show the static source function is 8.91 % higher than static source function. More decreases the dust emission in the dynamic dust source function in the June indicates the improved function by the new source function. During the peak season (June) simulated dust emission form S-dynamic has significantly different and show the influence of NDVI as an important factor in temporal dust modeling. The dynamical source fiction shows better statistical performance than the static source function.

We choose a single NDVI threshold value of 0.15 globally to determine if the surface is bare or not. The present study shows the impact of the dynamic source function in spatiotemporal modeling of dust emission. By Comparison 2 month modeling we witness a significant improvement in accuracy of dust forecasts during the months of most soil vegetation changes (spring and winter) compared to outputs resulted from static model, in which NDVI data are neglected. Improvement of dust forecasts using NDVI data introduces land cover changes as an undeniable dust-making factor in the study area.

References

Artaxo, P. (1995). Size distribution of biogenic aerosol particles from the Amazon Basin. Atmospheric Environment 29:393-402.

Zhao, C., (2004). Relationship between climatic factors and dust storm frequency in Inner Mongolia of China. Geophysical research letters 31.

Lee, E. H. (2009). Examining the impact of wind and surface vegetation on the Asian dust occurrence over three classified source regions. Journal of Geophysical Research: Atmospheres ,114.

Haywood, J. (2005). Can desert dust explain the outgoing longwave radiation anomaly over the Sahara during July 2003? Journal of Geophysical Research: Atmospheres , 110.

Jickells, T. D., (2005). Global iron connections between desert dust, ocean biogeochemistry, and climate. Science 308:67-71.

Prospero, J. M., (2002). Environmental characterization of global sources of atmospheric soil dust identified with the Nimbus 7 Total Ozone Mapping Spectrometer (TOMS) absorbing aerosol product. Reviews of geophysics 40:2-1-2-31.

Iversen, J. D. (1982). Saltation threshold on earth, mars and venus. Sedimentology 29:111-119.

Ginoux, P., (2001). Sources and distributions of dust aerosols simulated with the GOCART model. Journal of Geophysical Research 106:20255-20220,20273.

Kim, D., (2013). The effect of the dynamic surface bareness on dust source function, emission, and distribution. Journal of Geophysical Research: Atmospheres.

Marticorena, B. a (1995). Modeling the atmospheric dust cycle: 1. Design of a soil-derived dust emission scheme. Journal of Geophysical Research 100:16415-16416,16430.

GyÃ–rgy, V. A. (2012). Spatio-temporal distribution of dust stormsâ€"a global coverage using NASA TOMS aerosol measurements. Hungarian Geographical Bulletin 61:275–298.

Marticorena, B., (1997). Modeling the atmospheric dust cycle: 2. Simulation of Saharan dust sources. Journal of Geophysical Research: Atmospheres , 102:4387-4404.

Callot, Y., (2000). Geomorphologic approach for modelling the surface features of arid environments in a model of dust emissions: application to the Sahara desert. Geodinamica Acta 13:245-270.

Tegen, I., (2002). Impact of vegetation and preferential source areas on global dust aerosol: Results from a model study. Journal of Geophysical Research 107:4576.

Zender, C. S., (2003). Spatial heterogeneity in aeolian erodibility: Uniform, topographic, geomorphic, and hydrologic hypotheses. Journal of Geophysical Research: Atmospheres ,108.

Marticorena, B., (2004). Mapping the aerodynamic roughness length of desert surfaces from the POLDER/ADEOS bi-directional reflectance product. International Journal of Remote Sensing 25:603-626.

Prigent, C., (2005). Estimation of the aerodynamic roughness length in arid and semi, arid regions over the globe with the ERS scatterometer. Journal of Geophysical Research: Atmospheres ,110.

Laurent, B., (2006). Modeling mineral dust emissions from Chinese and Mongolian deserts. Global and planetary Change 52:121-141.

Laurent, B., (2008). Modeling mineral dust emissions from the Sahara desert using new surface properties and soil database. Journal of Geophysical Research: Atmospheres , 113.