Early Adopter Presentation:

Estimating and Mapping the Extent of Saharan Dust Emissions Using SMAP–derived soil moisture data

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To explore the potential of SMAP-derived soil moisture to improve existing dust detection tools in desert and arid environment.

- Anomalies in dust generation are closely related to water content in the upper soil layer which has a direct effect on the availability of loose sediments.
- In addition to wind speed and direction, other land features such as vegetation cover and soil type would also affect the dynamic of dust generation.
Frequency of Occurrence **TOMS Aerosol Index** (Version 7) greater than 0.5 per year averaged from 1980 to 1992.
Uncertainty in Aerosol Retrieval

- All graphs are for July
- Scales are the same! (0 – 1.5)
- Large differences in Aerosol values and distribution

GADS

NASA GISS v1 / GACP

Toms

NASA GISS v2 1990

GOCART

AeroCom

Linke Turbidity
Dust storm event over the UAE captured by METEOSAT-SEVIRI on February 12, 2009
Dust storm event over the UAE captured by METEOSAT-SEVIRI on February 28th, 2009

- Bright Surface (desert)
- Dark Surface (water)
- Originating location
- Downwind location
Energy-generating of PV modules can be reduced by as much as 40% in dusty weather.
Temporal and Spatial Variability of Atmospheric Turbidity in the UAE

Linke Turbidity Factor Variance Throughout the Year Over the UAE

Eissa, Ghedira and Chiesa (2011)
Clear Day

February 1, 2009

Graph showing solar radiation data for different components (GHI, DNI, DHI) over the course of the day on February 1, 2009.
Moderate Dust  
February 28, 2009
Heavy Dust

February 12, 2009

Graph showing solar radiation with lines indicating GHI, DNI, and DHI.

W/m²

8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00
MODIS Data
Dust detection using thermal channels

- $\text{BT}_{11} - \text{BT}_{12}$ is negative in the presence of dust\(^2\)
- $\text{BT}_{8.5} - \text{BT}_{11}$ varies from positive to negative depending upon the concentration of dust\(^2\)
- $\text{BT}_{11} - \text{BT}_{12}$ generally positive for clouds and negative for dust\(^1\)

Both differences increase with the increase in aerosol optical thickness, AOT\(^1\)

\(^{(1)}\) Ackerman, 1997 \hspace{1cm} \(^{(2)}\) Zhang, Lu, Hu, & Dong, 2006
Daily variation of T04-T09

- Dusty day (Feb 12, 2009)
- Clear day (Feb 1, 2009)
Aerosol optical depth

Temporal variation of MODIS Deep blue and wind speed

AOT (MYD08_D3)

DOY, 2009

WS (m s⁻¹)

DOY, 2009
Study site

United Arab Emirates

- AERONET stations locations
- Wind stations locations
- SMAP grid centre
- MODIS grid centre

Dubai

Abu-Dhabi

Madinat Zayed
Study site

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Abu-Dhabi

Dubai

Madinat Zayed

N

0 25 50 100 Kilometers
Temporal variation of Dust index, MODIS Deep blue, wind speed, AMSR-E soil moisture

MSG/SEVIRI, aerosol optical thickness, wind speed and AMSR-E soil moisture over Madinat Zayed

- **a)** SEVIRI TBD (K)
- **b)** Aerosol Optical Thickness
- **c)** Wind speed (m/s)
- **d)** AMSR-E soil moisture

DOY: 2009 - 1:30 local time
Temporal variation of Dust index, MODIS Deep blue, wind speed, AMSR-E soil moisture
Temporal variation of MODIS Deep blue, wind speed, SMAP soil moisture

Aerosol optical thickness, wind speed and SMAP soil moistures over Madinat Zayed

a) Aerosol Optical Thickness

b) Wind speed

c) SMAP-active soil moisture

d) SMAP-passive soil moisture
Dust emission

Suspension (d<20μm)

Vertical flux

Saltation (~70μm≤d≤~500μm)

Creep (d>~500μm)

Horizontal flux

Gherboudj et al., 2016
Alfaro and Gomes parameterization scheme for dust emission (2001)

1a. Friction velocity:
\[ u_* = \frac{U_s(z)}{k} \ln \left( \frac{z}{z_0} \right) \]

1b. Threshold friction velocity for smooth surface:
\[ u'_{ts} = \sqrt{a_n \left( \frac{\rho_p g D_s}{\rho_a} + \frac{\Gamma}{\rho_a D_s} \right)} \]

2. Corrected threshold friction velocity:
\[ u_{st} = f_w \frac{u'_{ts}}{u_{eff}} \]
\[ u_{eff} = \left[ 1 - \left( \frac{\ln(z_0/z_{0s})}{\ln(0.35(10/z_{0s})^{0.8})} \right) \right] \]
\[ f_w = \begin{cases} 
1 & \text{for } w \leq w_t \\
\frac{1}{\sqrt{1 + 1.21(w-w_t)^{0.68}}} & \text{for } w > w_t
\end{cases} \]
\[ w_t = 0.17\%_{\text{clay}} + 0.0014\left(\%_{\text{clay}}\right)^2 \]

3a. Horizontal flux:
\[ F_h = E(1-V)k \frac{\rho_p g}{a} u_*^2 \left( 1 + \frac{u_*}{u_t} \right) \left( 1 - \frac{u_*^2}{u_t^2} \right) \int dS_{rel}(D_p) dD_p \]

3b. Vertical flux:
\[ F_{v,m,i}(D_p) = \sum_{k=1}^{N_{class}} \frac{\rho_p \beta p_i(D_{p,k}) d_{m,i}^3}{e_i} dF_h(D_{p,k}) \] (in $\mu g m^{-2}s^{-1}$)

Required parameters:
- \( a_n \): constant (0.0123)
- \( \Gamma \): constant (300 kg/m$^2$)
- \( g \): acceleration due to gravity
- \( D_s \): soil particle size distribution (m)
- \( w_t \): gravimetric soil moisture (%)
- \( z_0 \): surface roughness length (m)
- \( z_{0s} \): smooth roughness length (\(D_{med}/30\))
- \( D_{med} \): median diameter of coarsest mode (m)
- \( \rho_p \): soil particle density (2650 kg/m$^3$)
- \( \rho_a \): air density (1.23 kg/m$^3$)

- \( k \): Von Karman constant (0.4)
- \( U_s \): wind speed at height \( z \) (m/s)
- \( z_{0s} \): surface roughness length (m)
- \( S_{rel} \): relative surface area of each size bin
- \( e_i \): cohesion energy
- \( d_{m} \): log-normal modes (m=1, 2, 3)
- \( p_i \): fraction of kinetic energy
- \( \beta \): constant (163 m$^{-1}$)
- \( k \): constant (1 for desert surfaces)
- \( E \): erodibility factor of the soil
- \( V \): fraction of vegetation.

Gherboudj et al., 2016
Field operations for the Extensive Survey October 2006 - October 2007

Instruments used for measuring soil hydraulic properties and soil strength.

Soil survey was performed using standards of the USDA Soil Survey Manual (Soil Survey Division Staff, 1993; Schoeneberger et al. 2002)

More than 700 measurements were undertaken at more than 70 sites.
Plate 10: Typical landforms described during the field survey: a) saline sabkha plain; b) gyspic deflation plain; c) undulating sand sheet in the Madinat Zayed area; d) rolling dunes with Jabal Hafit in the background.
Soil Type Map

- Soil degradation: soil erosion, salinity are the main issues.
- Soil sealing (urbanization) of the already limited arable soils.
- Need to sustainable increase food production. Need of healthy soils.
Other soil parameters maps

Gherboudj et al., 2016
Level 2 Active Soil Moisture (SMAP_SM_L2_A)

2003 March 28, at 02:24
2003 March 30, at 00:00
2003 April 05, at 02:24
2003 May 04, at 02:12
2003 March, 20 at 02:24

Soil Moisture (cm$^3$/cm$^3$)
Threshold friction velocity increases with an increase in soil moisture

Adapted from (Bisal & Hsieh, 1966)
Effect of the soil moisture on the threshold friction velocity

- Mean threshold friction velocity (TFV) over the MENA region has high spatial variability, which is found to correlate with the high soil moisture variability,
- Spatial pattern of the TFV is high over the Arabian Peninsula and low over the North-Africa.

- Spatial and temporal variability of the effect of the soil moisture on the TFV (ESMTFV, ms⁻¹) is high over the semi-arid area (mean and STD values reach 0.85ms⁻¹ and 0.30ms⁻¹ at particle size of 75µm) and low over the arid area (higher temporal variability are associated with the sudden sporadic showers characterizing the desert climate)

Gherboudj et al., 2016
Gravimetric soil moisture and sandblasting flux are inversely dependent, i.e. an increase in the gravimetric soil moisture causes a decrease in the sandblasting flux.

Gherboudj et al., 2016
Sensitivity analysis of the dust flux to the friction velocity and gravimetric soil moisture

- No reduction in flux is observed for low friction velocity for all the considered soil moisture values.
- Significant reduction in the flux is observed when the soil moisture exceeded its threshold and the wind speed was greater than the threshold friction velocity.
- At any given friction velocity value, the percentage reduction of the sandblasting flux increased as the soil moisture increased. However, this dependence is dominant at low friction velocity, close to the TFV (~100%), and low at high friction velocity (~30%).
Project Milestones

- Import and adapt existing decision-support tools for dust retrieval. WMO SDS WS (Dust Retrieval from SEVIRI Images) and the US Air Force Weather Dust Transport Model.
- Use SMAP Algorithm Testbed to generate high resolution soil moisture fields coincident with the several dust events occurred between 2003 and 2010.
- Develop algorithm for soil moisture impact on dust generation using SMAP data attributes.
- Assess impact of boundary layer growth and buoyancy on dust generation and vertical transport.
- Gridding and analyzing meteorological (wind speed/direction; precipitation; visibility; humidity) and land cover data.
- Develop statistical experiment design to quantitatively assess the impact of SMAP data in the new dust generation and transport decision support model.
- Producing erosion threshold velocity ratios for different land covers (sand types).
Two quantitative metrics were identified to assess the impact of SMAP products on dust generation estimation:

- The cross-sectional correlation (or time series correlation)
- The root mean square error (RMSE)

The use of a higher spatial resolution of SMAP-derived SM is expected to improve the accuracy of estimating dust emissions since our dust maps have already a resolution of 4 km.
THANK YOU