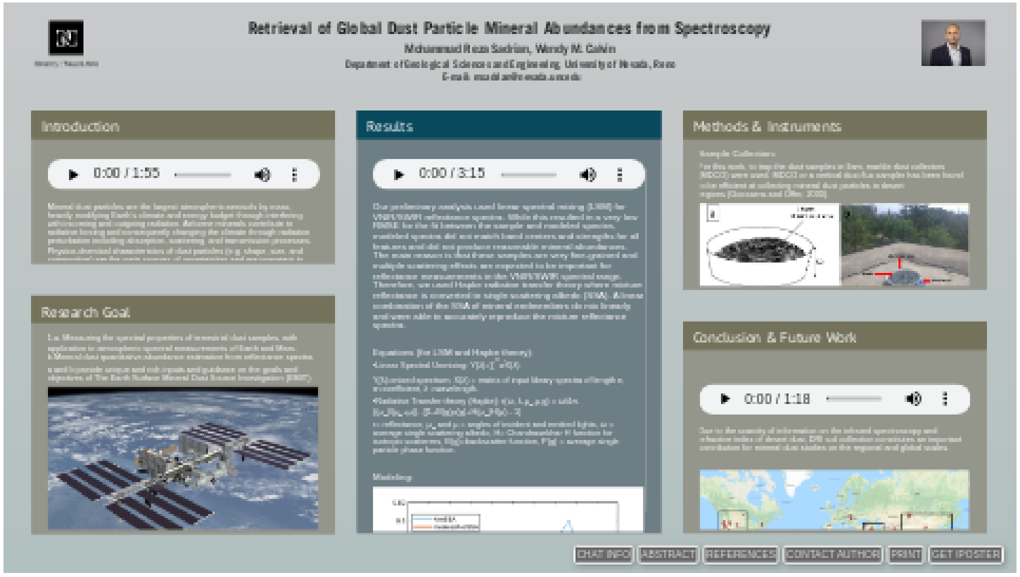
Retrieval of Global Dust Particle Mineral Abundances from Spectroscopy



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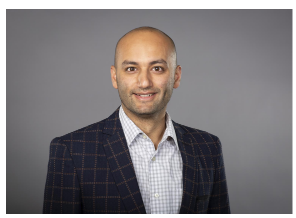

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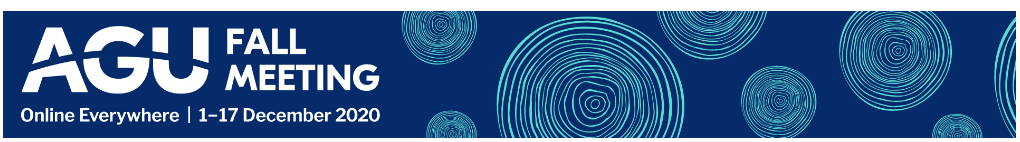


INTRODUCTION

Mineral dust particles are the largest atmospheric aerosols by mass, heavily modifying Earth's climate and energy budget through interfering with incoming and outgoing radiation. Airborne minerals contribute to radiative forcing and consequently changing the climate through radiation perturbation including absorption, scattering, and transmission processes. Physico-chemical characteristics of dust particles (e.g. shape, size, and composition) are the main sources of uncertainties and are important to estimate dust radiative impact.

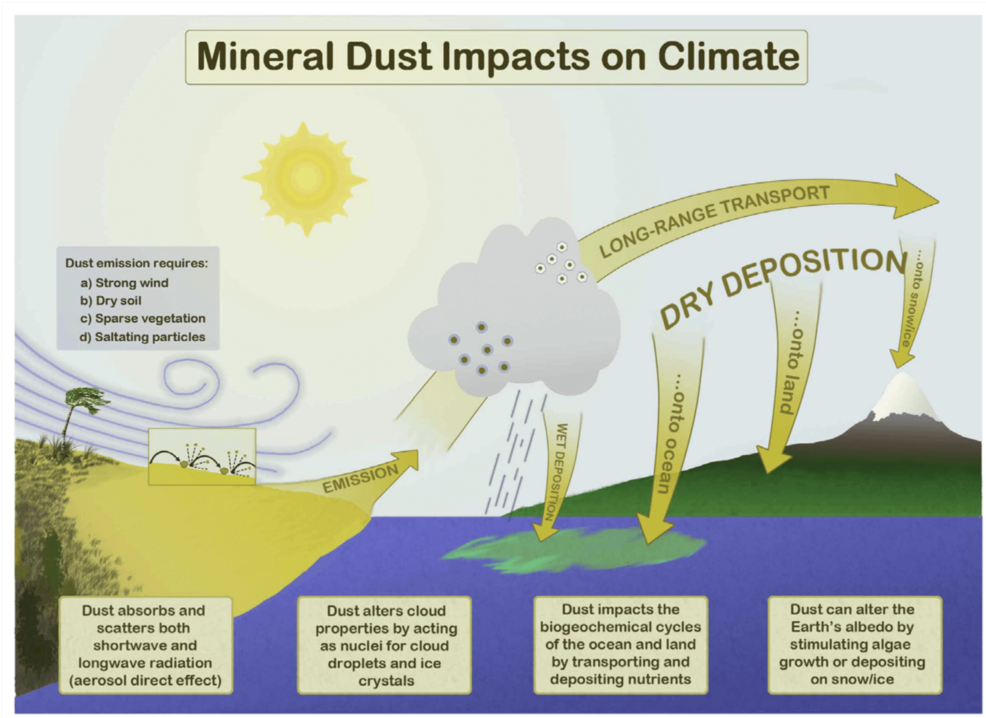


Figure 1. Schematic of interactions between dust and climate and biogeochemistry (N. Mahowald et al., 2013).

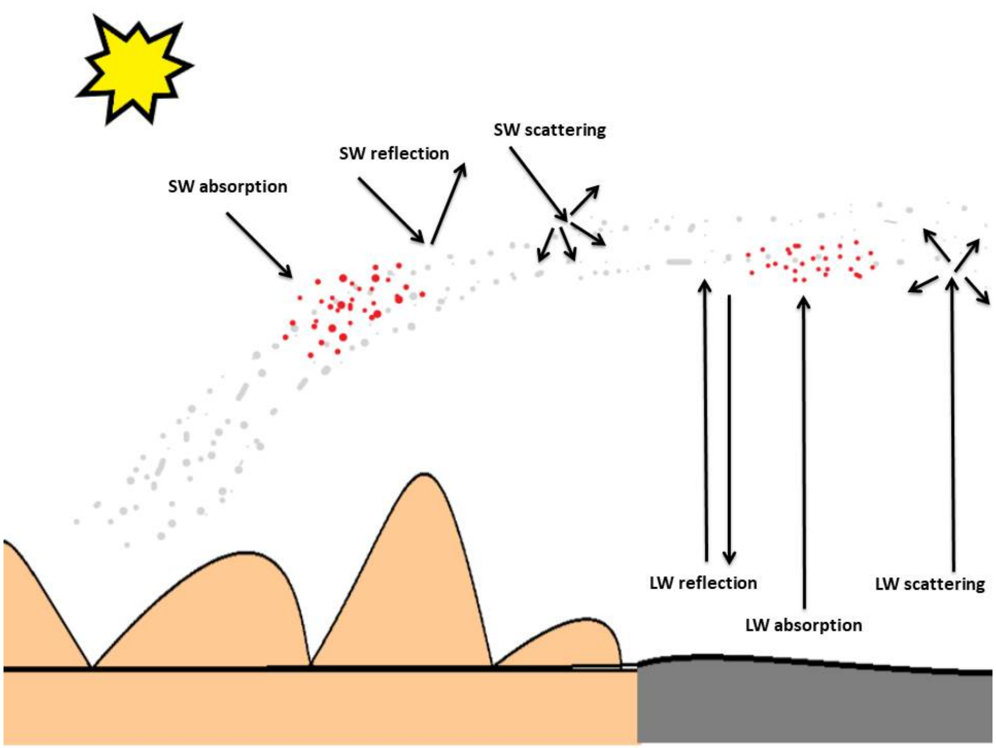


Figure 2. Schematic illustration of mineral dust influences on the atmosphere by absorbing, scattering, and reflecting solar and terrestrial radiation.

RESEARCH GOAL

1.a. Measuring the spectral properties of terrestrial dust samples, with application to atmospheric spectral measurements of Earth and Mars. b.Mineral dust quantitative abundance estimation from reflectance spectra.

a and b provide unique and rich inputs and guidance on the goals and objectives of The Earth Surface Mineral Dust Source Investigation (EMIT).

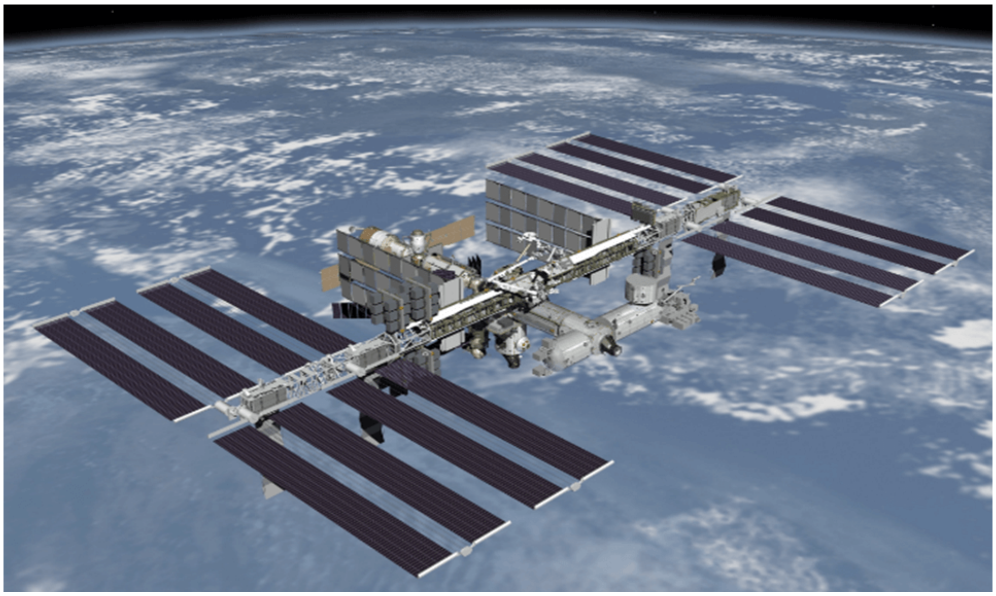


Figure 3.EMIT Planned for ISS in 2021.

2. Providing Earth System Models (ESMs) with realistic regionally and globally dependent spectral signatures and refractive indices obtained from mineral dust samples which encompass the largest possible variability of global soil mineralogical composition.

3. The derived terrestrial optical constant will be used to model the mineralogical abundance and atmospheric dust spectral profiles on Mars.

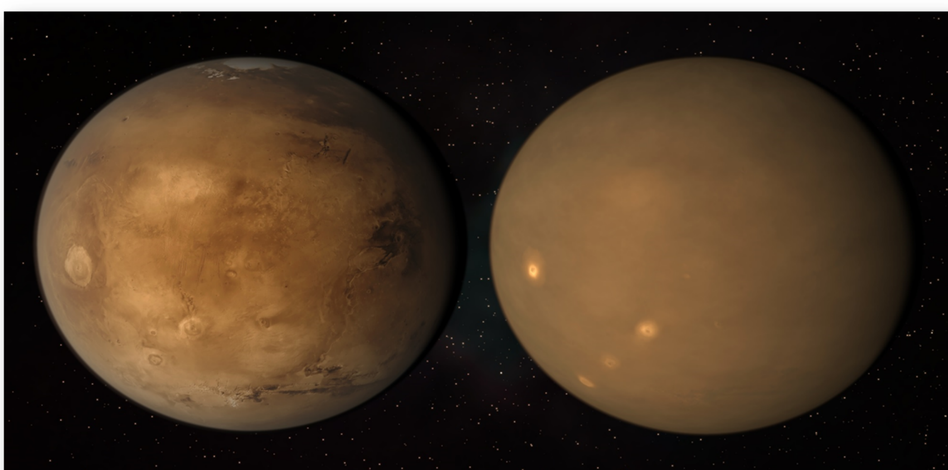


Figure 4. Dusty Mars.

RESULTS

Our preliminary analysis used linear spectral mixing (LSM) for VNIR/SWIR reflectance spectra. While this resulted in a very low RMSE for the fit between the sample and modeled spectra, modeled spectra did not match band centers and strengths for all features and did not produce reasonable mineral abundances. The main reason is that these samples are very fine-grained and multiple scattering effects are expected to be important for reflectance measurements in the VNIR/SWIR spectral range. Therefore, we used Hapke radiative transfer theory where mixture reflectance is converted to single scattering albedo (SSA). A linear combination of the SSA of mineral endmembers do mix linearly and were able to accurately reproduce the mixture reflectance spectra.

Equations (for LSM and Hapke theory):

•Linear Spectral Unmixing: $Y(\lambda)=\sum^{n}\alpha_i X(\lambda)$

$Y(\lambda)$=mixed spectrum, $X(\lambda)$ = matrix of input library spectra of length n, α_i=coefficient, λ =wavelength.

•Radiative Transfer theory (Hapke): $r(\omega, \lambda,\mu_{\circ},\mu,g) = \omega/4\pi.((\mu_{\circ})/(\mu_{\circ}+\mu)).\ \{[1+B(g)p(g)+H(\mu_{\circ})H(\mu) - 1\}$

r= reflectance, $\mu_{\circ}$ and μ = angles of incident and emitted lights, ω = average single scattering albedo, H= Chandrasekhar H function for isotropic scatterers, B(g)=backscatter function, P(g) = average single particle phase function.

Modeling:

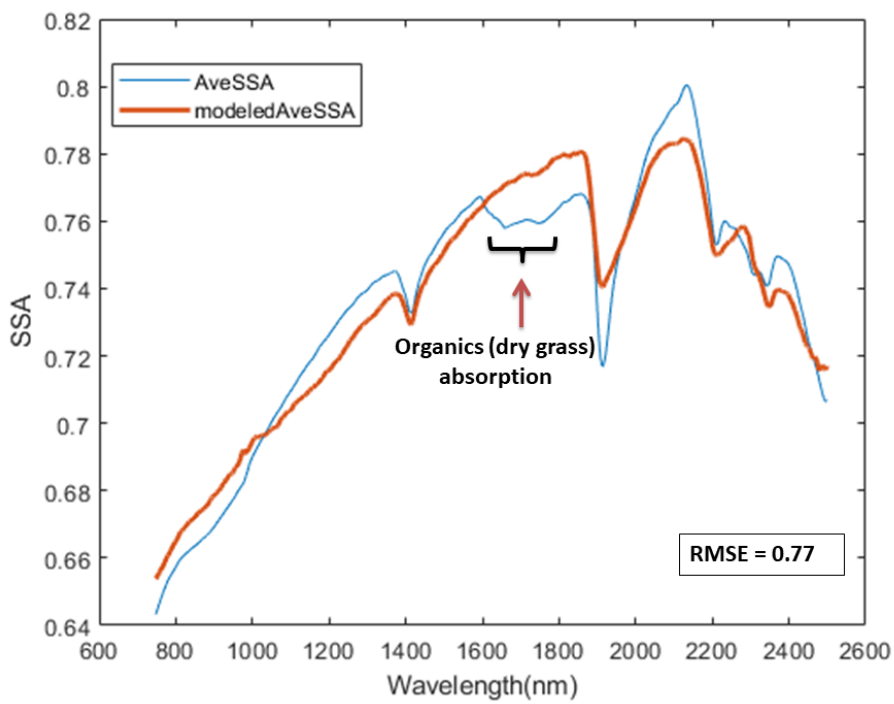


Figure 5. Measured and modeled single scattering albedo (SSA) for sample S16 are shown in this plot. The presence of organic materials (dry grass) is evident by absorption from 1630 to 1780nm
in the sample using the spectroscopy method.

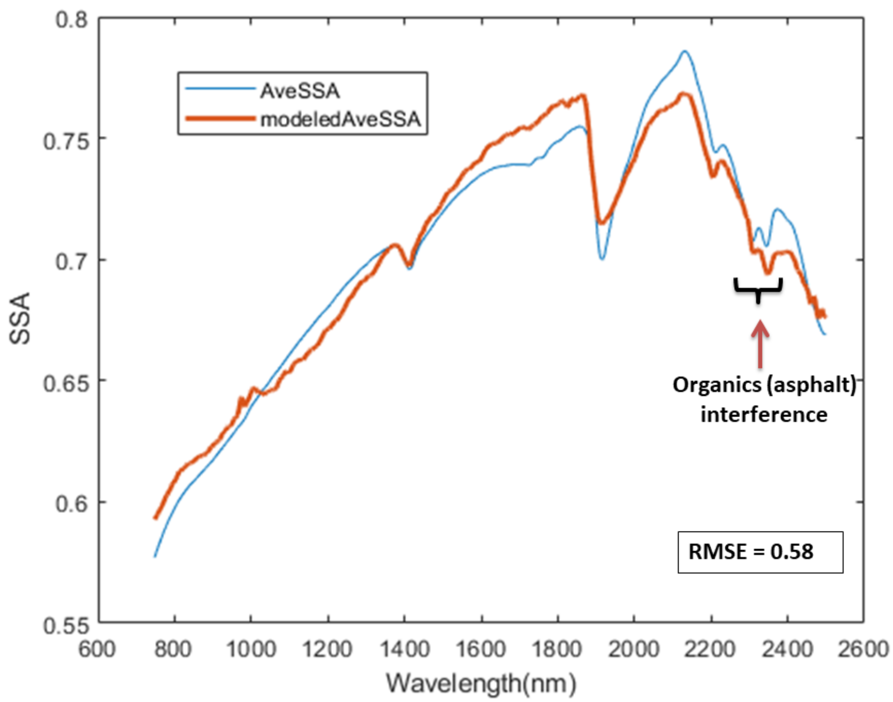


Figure 6. Measured and modeled single scattering albedo (SSA) for sample S17 are shown in this plot. Here, asphalt particles are interfering with the fit at 2300-2370 nm.

XRD Analysis:

Semi-quantification of the mineralogical composition of mineral dust samples made by XRD data will be compared with mineralogical identification determined from spectroscopy.

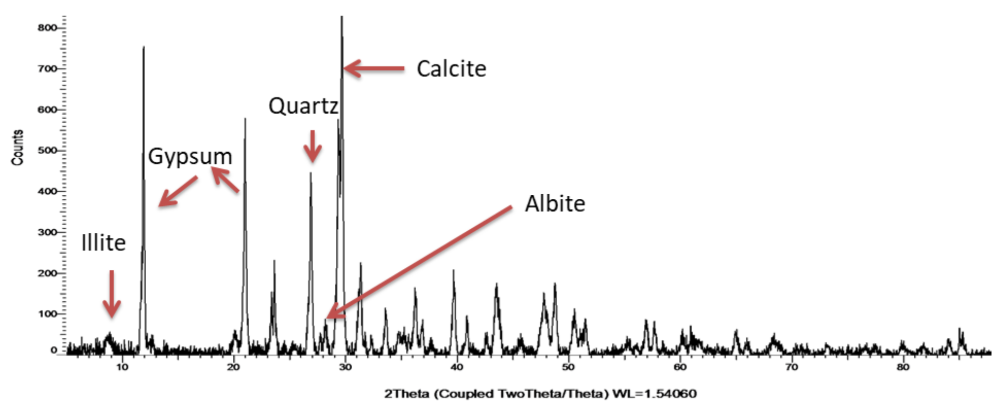


Figure 7. A sample XRD pattern.

METHODS & INSTRUMENTS

Sample Collection:

For this work, to trap the dust samples in Ilam, marble dust collectors (MDCO) were used. MDCO or a vertical dust flux sampler has been found to be efficient at collecting mineral dust particles in desert regions (Goossens and Offer, 2000).

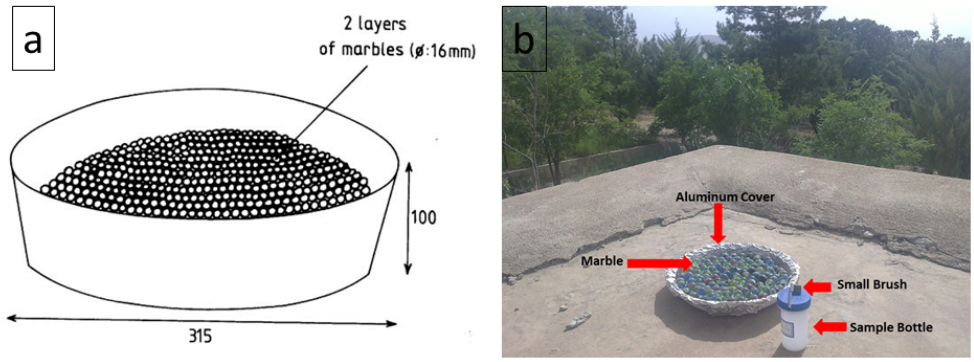
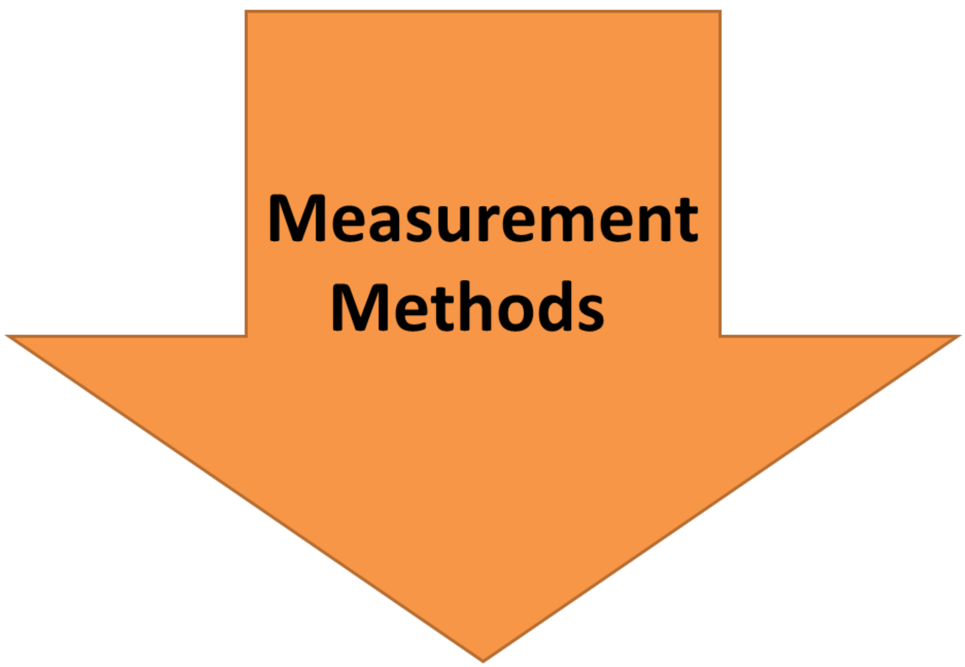


Figure 8. a. Construction scheme of the MDCO sampler (Goossens and Offer, 2000) and b. MDCO airborne dust collector in Ilam city.



Spectroscopy Measurements:

For this work, we used field portable spectroradiometers (with the wavelength range 400 to 2500 nm) to collect measurements in visible, near-infrared and short-wave infrared (VNIR/SWIR) for 37 dust samples from Ilam city, Iran-an arid region in the Middle East. Measurements for the long-wave infrared (LWIR) reflectance spectra of these samples were conducted using a Nicolet Fourier Transform Infrared spectrometer (ranges from 5 to 25 µm).

Figure 9. a and b are the Spectral Evolution (SE) and Analytical Spectral Device (ASD) instruments. They collect data in the visible, near-infrared, and short-wave infrared (VNIR/SWIR) (400 to 2500 nm).

Figure 10. Nicolet TM 6700 collects data in the long-wave infrared (LWIR) (5 to 25 µm, or 2000 to 400 cm-1).

X-Ray Diffraction Measurements:

Figure 11. Bruker AXS D2 phaser measures angles and intensities of the diffracted beams from a sample and plot peaks are attributed to specific minerals.

CONCLUSION & FUTURE WORK

Due to the scarcity of information on the infrared spectroscopy and refractive index of desert dust, DRI soil collection constitutes an important contribution for mineral dust studies on the regional and global scales.

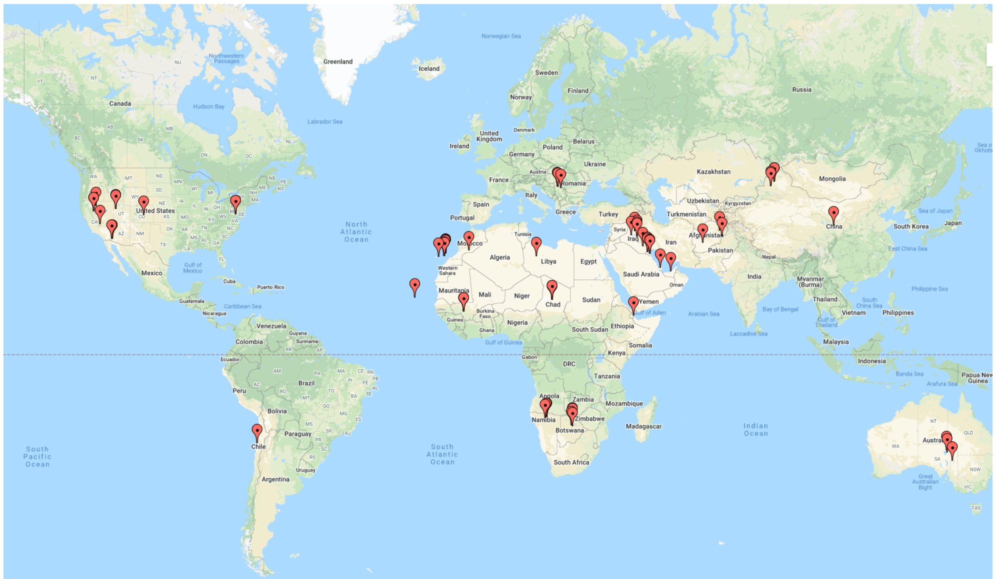


Figure 12. Red placemarks are the locality of the DRI soil sample collection (Engelbrecht et al., 2016). These collected samples are representative of major dust sources at the regional and global scales.

- Future work will:

(1) include transmission measurement in the long-wave infrared to identify primary silicates such as quartz and feldspar which were absent in LWIR reflectance spectra of samples.

(2) derive optical constant for global dust samples (fig. 12) using transmission and reflectance spectroscopy data.

(3) the resulting properties derived from the spectral measurements will be used to create a library of materials and indices that can be used in radiative transfer models of the earth system.

ABSTRACT

Direct radiative forcing is a major impact of atmospheric dust aerosols. Mineral dust is an important aerosol component that interacts with both incoming and outgoing radiation, modulating radiative fluxes on Earth and its atmosphere. Dust radiative impact directly depends on the particles physico-chemical characteristics (e.g. mineralogy, shape, size) which are the main source of uncertainties. Spectral signatures of dust particles in the visible/short-wave infrared (V/SWIR) and long-wave infrared (LWIR) are linked to mineral composition and variability. Obtaining the precise spectral signature and size distribution of dust particles can result in accurate derivation of refractive indices which are used as inputs to model radiative forcing.

In this work, V/SWIR and LWIR reflectance spectra of heterogeneous dust samples from the United States, East Asia, and Middle East were analyzed for their mineral abundances. For this study we used global well-characterized soil samples with comparable mineral compositions to windblown dust. The soil samples cover a wide range of mineral compositions and represent both arid and semi-arid regions [J P Engelbrecht et al., 2016].

Our preliminary analysis used linear spectral mixing for both V/SWIR and LWIR reflectance spectra. This approach is the simplest method to determine mineral abundances from reflectance spectra. While this resulted in a very low RMSE for the fit between the sample and modeled spectra, modeled spectra did not match band centers and strengths for all features. We also converted reflectance spectra to continuum removed (CR) and mean optical path (MOPL) which have the potential to eliminate nonlinear effects (e.g. multiple scattering) in spectral mixing. These approaches, which modify the reflectance hull, significantly weakened or removed the calcite absorption features at 2375 nm. Because these samples are very fine grained (< 38 µm [J P Engelbrecht et al., 2016]) multiple scattering effects are expected to be important for both V/SWIR and LWIR spectral ranges and as our initial results show linear mixing is insufficient to produce reasonable mineral abundances. Our next efforts will include full radiative transfer models of the measured spectra which we will present at the meeting.

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