The Earth Surface Mineral Dust Source Investigation (EMIT)

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Mineral Dust in the Earth System

- Mineral dust emitted from the surface impacts a broad set of elements of the Earth system including radiative forcing.
- Different mineral compositions of the emitted dust lead to different physical, chemical and radiative impacts.
- Accurate Earth System Models are required to understand the role of mineral dust now and in the future.
- The mineral composition of the Earth’s dust source regions is currently uncertain.
The Mineral Dust Cycle

Diagram showing the mineral dust cycle involving radiative forcing, strong winds leading to dry deposition, and precipitation leading to wet deposition. The cycle involves interactions between deserts, oceans, and the atmosphere, with the EMIT (Earth Surface Mineral Dust Source Investigation) satellite on the left and the Earth's surface on the right.
The relative abundance of the mineral hematite in dust source regions has a significant impact on dust-related radiative forcing

- 2% increase in the hematite content of North Africa (NA) source region results in increases of 130% and 100% in simulations of global (solid line) and regional forcing over NA (broken line) [Modeling courtesy of R. Scanza, Cornell University, 2015]

Large variation in hematite mass fraction (HMF) over arid dust source regions (Moosmuller wt al., 2012)

- United Arab Emirates: ~2% HMF
- Afghanistan: ~10% HMF
- Mali: 30% HMF
Current Tests of ESM Skill

- Impact of dust mineralogy in the Community Atmosphere Model (CAM4/5) on forecast skill of the Community Earth System Model (CESM)

- Forecasts of AOD and SSA are not well-correlated with AERONET-based retrievals

- Forecasts of mineralogy of dust deposits are not well-correlated with observed mineralogy

(Figures modified from Scanza et al., 2015)
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Imaging spectroscopy provides a tested method for direct comprehensive measurement of the mineral composition for the Earth’s mineral dust source regions.
Earth System Models and Mineral Dust

- Earth System Models are used to simulate, understand and investigate the past, present and future state of the Earth system.

- Until recently, ESMs have modeled mineral dust as a single bulk composition. However:
  - Different minerals have different physical, chemical and optical characteristics.
  - Mineral dust optical properties (complex refractive index) have a strong influence on the radiative forcing impact.

- Today ESMs (e.g. NSF-CESM and GISS-ModelE2) are being adapted to accept more complex representations of the mineral dust and related source regions on the Earth’s surface.
Earth System Models are ready to accept more detailed Earth surface mineral dust source information.
Identified Minerals of Key Interest

- Montmorillonite \((Na, Ca)_{0.33}(Al, Mg)_{2}Si_{4}O_{10}(OH)_{2+n}H_{2}O\)
- Gypsum \(CaSO_{4}.2H_{2}O\)
- Calcite \(CaCO_{3}\)
- Hematite \(Fe_{2}O_{3}\)
- Chlorite \((Mg, Fe)_{3}(Si, Al)_{4}O_{10}(OH)_{2-(Mg, Fe)}3(OH)_{6}\)
- Kaolinite \(Al_{4}Si_{4}O_{10}[(OH)_{8}\)
- Goethite \(FeO. OH\)
- Dolomite \(CaMg(CO_{3})_{2}\)
- Illite \((K,H)_{3}(Al, Mg, Fe)_{2}(Si, Al)_{4}O_{10}[(OH)_{2},(H_{2}O)]\)
- Vermiculite \((Mg, Fe+2, Al)_{3}(Al, Si)_{4}O_{10}(OH)_{2*4}H_{2}O\)

Reflectance vs Wavelength (nm)

- Y-axis: Reflectance
- X-axis: Wavelength (nm)
Minerals can be mapped with Imaging Spectroscopy.

Image Cube

1000s of Parallel Spectrometers

Reflectance vs. Wavelength (nm)

Dust Source Regions

Prototype Spectrometer

International Space Station

Detector Array

Spectrometer

Telescope
AVIRIS imaging spectroscopy measurements of the Salton Sea region in Southern California acquired as part of the NASA HyspIRI campaign.

Hematite
Goethite
Carbonates
Clay Minerals
Illite
Validating the Spectroscopy at Salton Sea, CA
Existing Mineralogy versus Imaging Spectroscopy

Inferred Clay Minerals
Based on agricultural soil maps

Measured Clay Minerals
Based on Imaging Spectroscopy

Clay Minerals
$R^2 = 0.070$

Inferred Iron Oxides
Based on agricultural soil maps

Measured Iron Oxides
Based on Imaging Spectroscopy

Iron Oxides
$R^2 = 0.10$
EMIT Planned for ISS in 2021 (Arid Lands)
EMIT: Earth Surface Mineral Dust Source Investigation

Instrument Overview
EMIT is a Class C implementation of a mature F/1.8 VSWIR-Dyson Spectrometer that leverages NASA Research and Technology investments, including the ESTO IIP SWIS Dyson spectrometer.

EMIT measurement
Spectral: 380-2510 nm
Radiometric: ≥100 SNR in retrieval wavelengths, without saturation over bright land
Spatial: 30 m sampling
• The mineral dust cycle impacts many elements of the Earth system.

• To understand these impacts and predict how they may change in future climate scenarios the dust cycle must be modeled.

• Current Earth system models now incorporate the mineral dust cycle, however the predictions do not match observations.

• A key problem is poor constraint of the surface mineral dust composition for the dust source regions of the Earth.
Summary and Conclusion (2)

- As tested with the Salton Sea measurements, VSWIR imaging spectroscopy provides a direct and straight-forward method to measure the surface mineral dust source composition.

- This spectroscopic approach can reduce uncertainty in global models by delivering comprehensive measurement of the surface mineral composition of dust source regions. Factors of $10^6$ improvement in knowledge can be achieved.

- New accurate and comprehensive constraints can also improve prediction of the evolution of mineral dust sources and Earth system feedbacks under differing future climate scenarios.

- EMIT is scheduled to launch in 2021