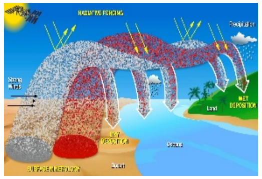
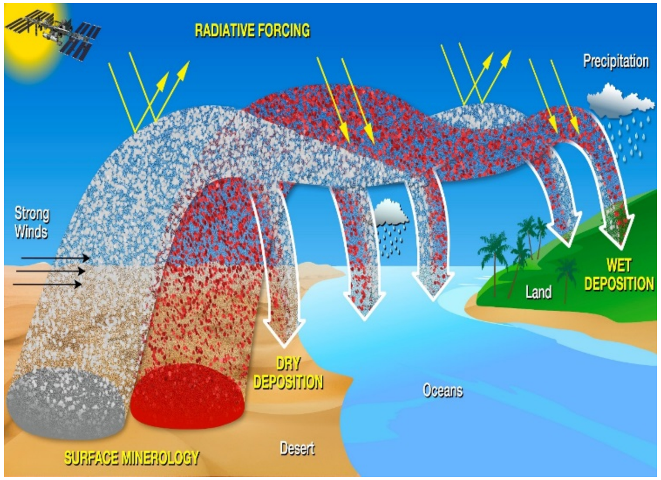
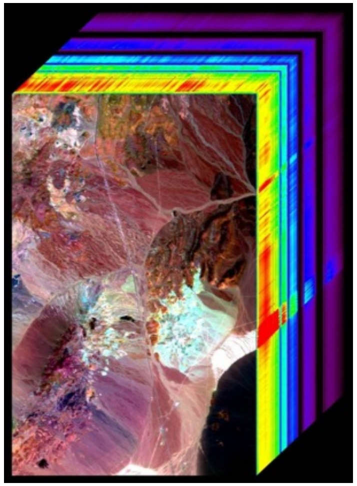


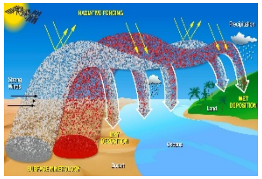
Measuring the Earth’s Surface Mineral Dust Source Composition for Radiative Forcing and Related Earth System Impacts





Decadal Survey RFI2 Input

Authorship



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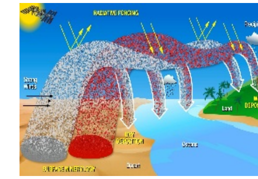
Description

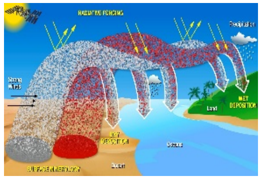


- Mineral dust impacts direct & indirect forcing, tropospheric chemistry, ecosystem fertilization, human health & safety. Global source composition is poorly constrained by <5000 mineral analyses. Global spectroscopic measurement of surface mineralogy closes this gap to advance understanding & Earth system modelling of current & future impacts

- **Theme IV.** Climate Variability and Change: Seasonal to Centennial. Forcings and Feedbacks of the Ocean, Atmosphere, Land, and Cryosphere within the Coupled Climate System

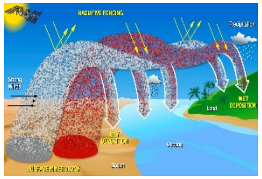
https://hyspiri.jpl.nasa.gov/downloads/RFI2_HyspIRI_related_160517/RFI2_final_Mineral_Dust_Composition_150514a.pdf

Impacts of the Earth Mineral Dust Cycle

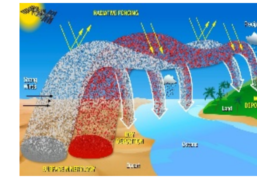


- Mineral dust emitted by the surface into the atmosphere affects climate through direct radiative forcing and indirectly through cloud formation as well as changes in the albedo and melting of snow/ice.
- Based on their chemistry, the minerals in dust react and modify tropospheric photochemistry and acidic deposition.
- Mineral dust aerosols affect ocean and terrestrial ecosystem biogeochemical cycling by supplying limiting nutrients such as iron and phosphorus.
- In populated regions, mineral dust is a natural hazard that affects human health and safety.

Mineral Dust Impacts

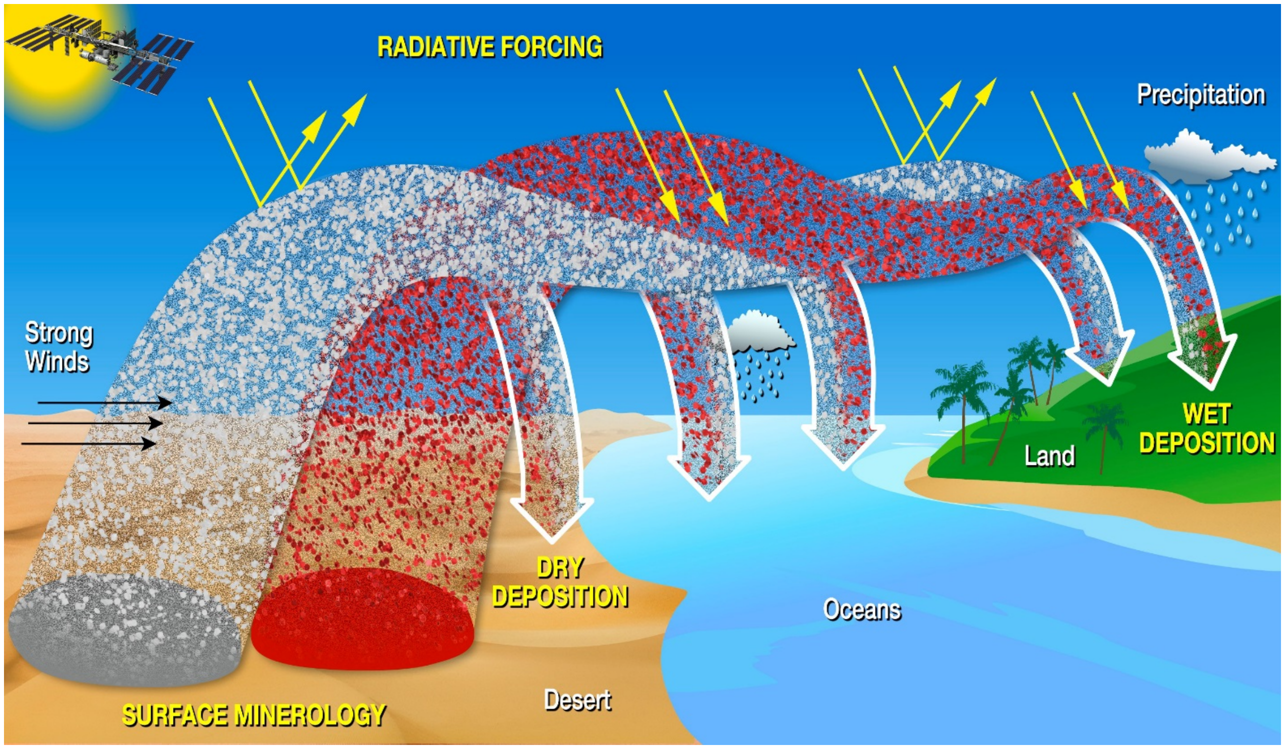


Process	Example References
Direct radiative forcing	Tegen et al., 1996; Sokolik and Toon, 1999; Dufresne et al., 2002, Boucher 2013
Indirect radiative forcing by modifying cloud properties	Kauffman et al., 2005, Forster et al., 2007, Mahowald et al., 2013, Rosenfeld et al., 2001, Atkinson et al., 2013, DeMott et al.,2003, Mahowald and Kiehl, 2003
Melting of snow/ice	Krinner et al., 2006, Painter et al. 2007, 2012
Modification of regional precipitation	Miller et al., 2004, 2014; Yoshioka et al., 2007
Modification of atmospheric sulfur cycle and mitigation of acidic aerosol deposition	Dentener et al. 2006; Vet et al. 2014
Modification of tropospheric ozone through nitrogen uptake	Bian et al. 2003; Dentener; Crutzen 1993; Dentener et al. 1996
Modification of carbon cycle through supply of iron to aquatic ecosystems	Jickells et al., 2005, Krishnamurthy et al., 2009, (Mahowald et al., 2010), Okin et al. 2011
Modification of carbon cycle through supply of phosphorous to terrestrial ecosystems	Swap et al., 1992, Okin et al., 2004, Yu et al., 2015
Impacts on air quality, visibility, and respiratory health	Gills, 1996; Prospero, 1999; Morman 2013; Buck et al., 2013; Metcalf et al, 2015; Mahowald et al. 2007; Huszar and Piper, 1989



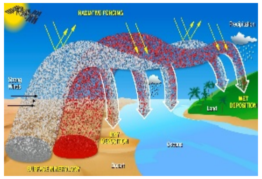
The Earth Dust Cycle

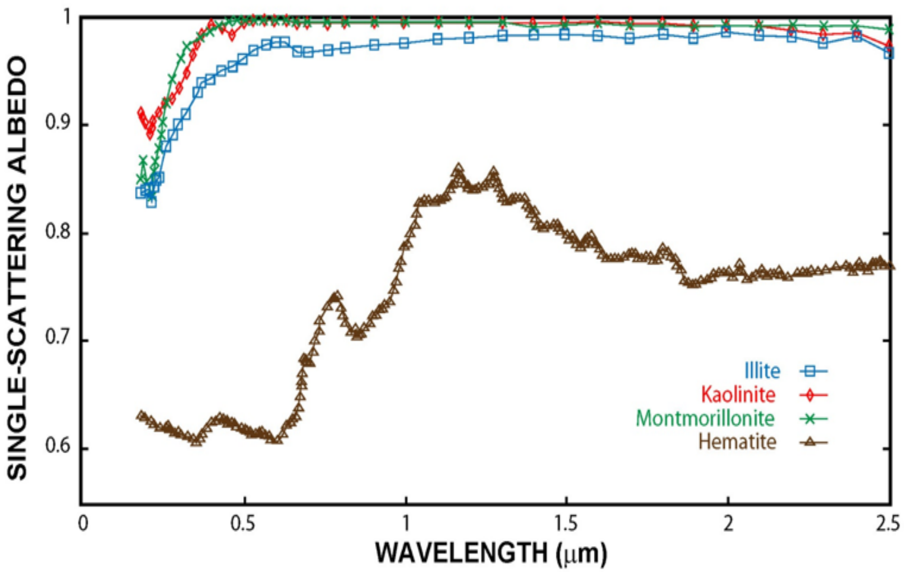
- The dust cycle consists of a source, transport, and deposition phase.

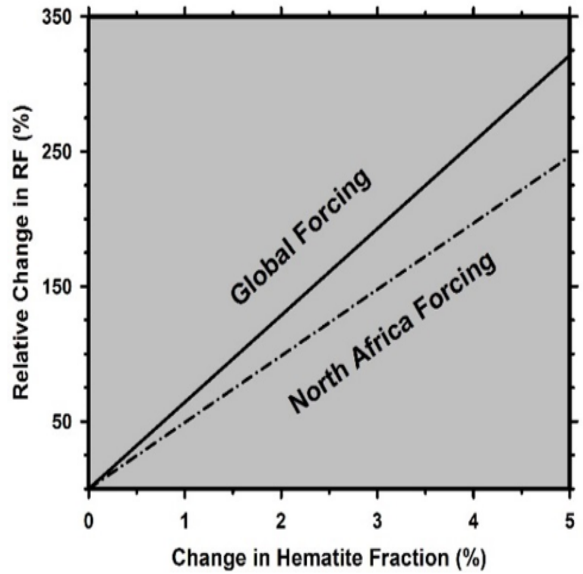


- Considerable investment is being made to measure mineral dust in the transport phase of the cycle.
- Less investment has been made in understanding the composition of mineral dust sources.

Mineral Dust Radiative Forcing



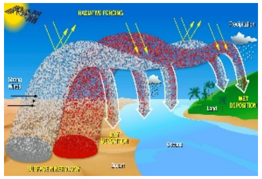




(left) Mineral composition is a key control of SSA, which describes how particles scatter and absorb energy. Iron-bearing minerals (represented here by hematite) are strong absorbers (SSA < 1.0) in the solar spectral region, while clay minerals (illite, kaolinite, and montmorillonite) are strong scatters (SSA ≈ 1.0). Particle radius is 0.5 μm. Figure modified from Sokolik and Toon (1999).

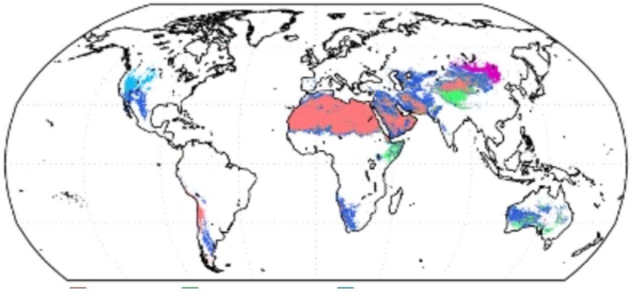
(right) The relative abundance of hematite in dust source regions has a significant impact on dust-related radiative forcing. A 2% increase in the hematite content of soils results in increases of 130% and 100% in simulations of global forcing (solid line) and regional forcing over North Africa (broken line), respectively. Modeling results courtesy of R. Scanza, Cornell.

Global Dust Source Regions and Current Constraints

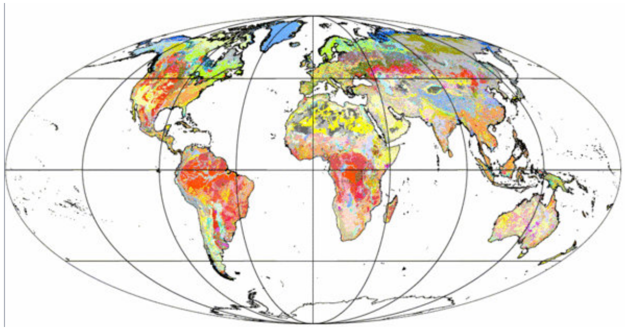


- Arid source regions for mineral dust are identified by the World Meteorological Organization (WMO) globally.
- Currently, estimates of surface dust source composition for Earth system models are derived primarily from the 1:5,000,000 scale United Nations, Food and Agriculture Organization (FAO) soil map.
- This FAO source has challenges
  - Derived from about 5000 soil measurements mostly in agricultural regions
  - The soil surveys focus on agricultural soil with limited sampling of nonagricultural regions
  - The FAO records soil descriptions and many assumptions are required to infer surface mineralogy
  - The gridded spatial sampling of ~9 x 9 km points is coarse for the heterogeneity of many mineral dust generating regions.

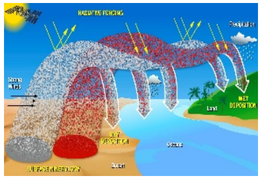
WMO Dust Source Regions



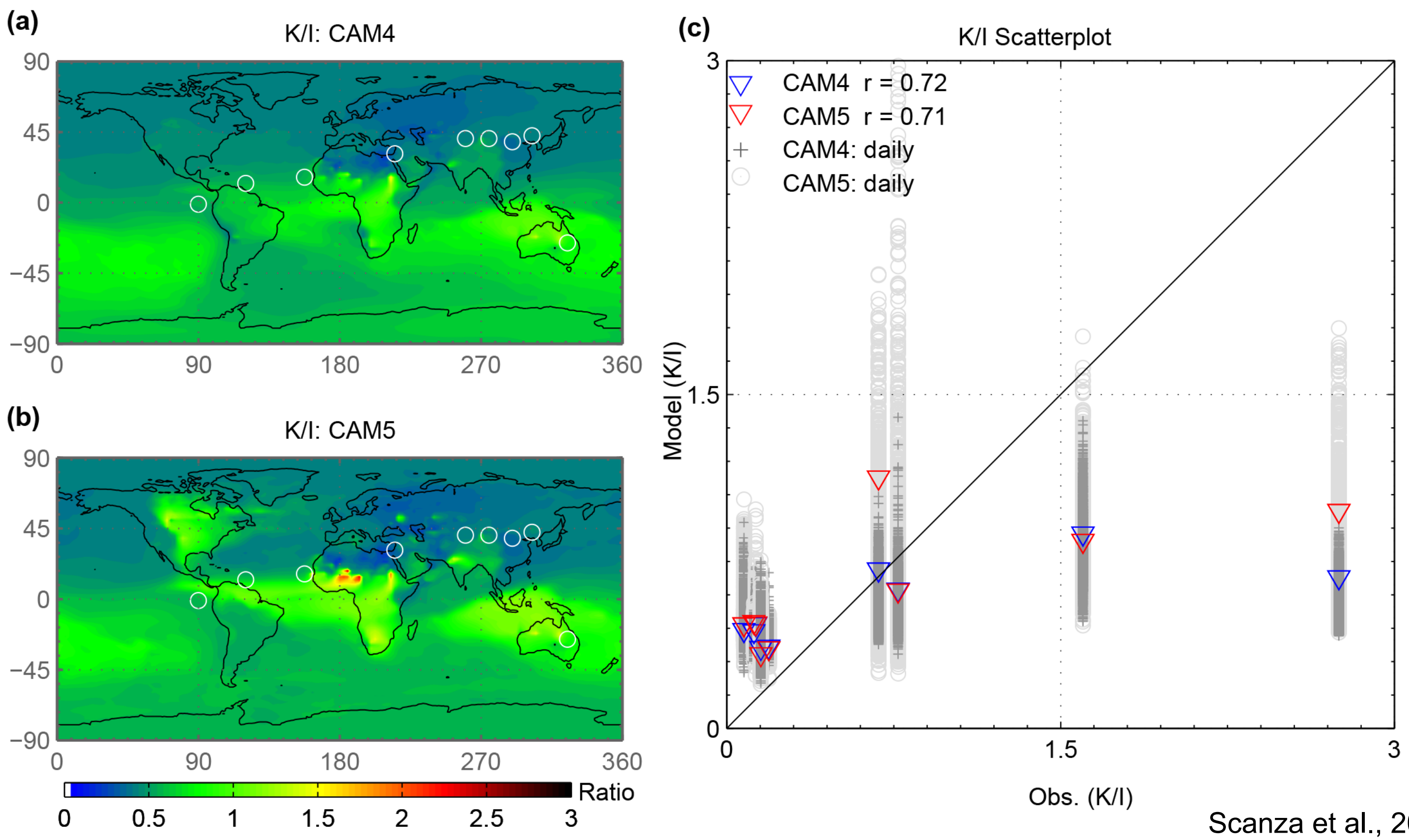
FAO Soil Map



Current Earth System Models Include the Mineral Dust Cycle

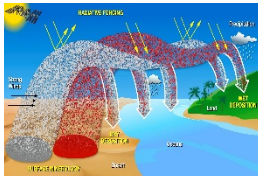


- Community Atmosphere Model (CAM4/5) in the Community Earth System Model (CESM)
- However, model predictions do not fit the observations (e.g. Kaolinite to Illite ratio)

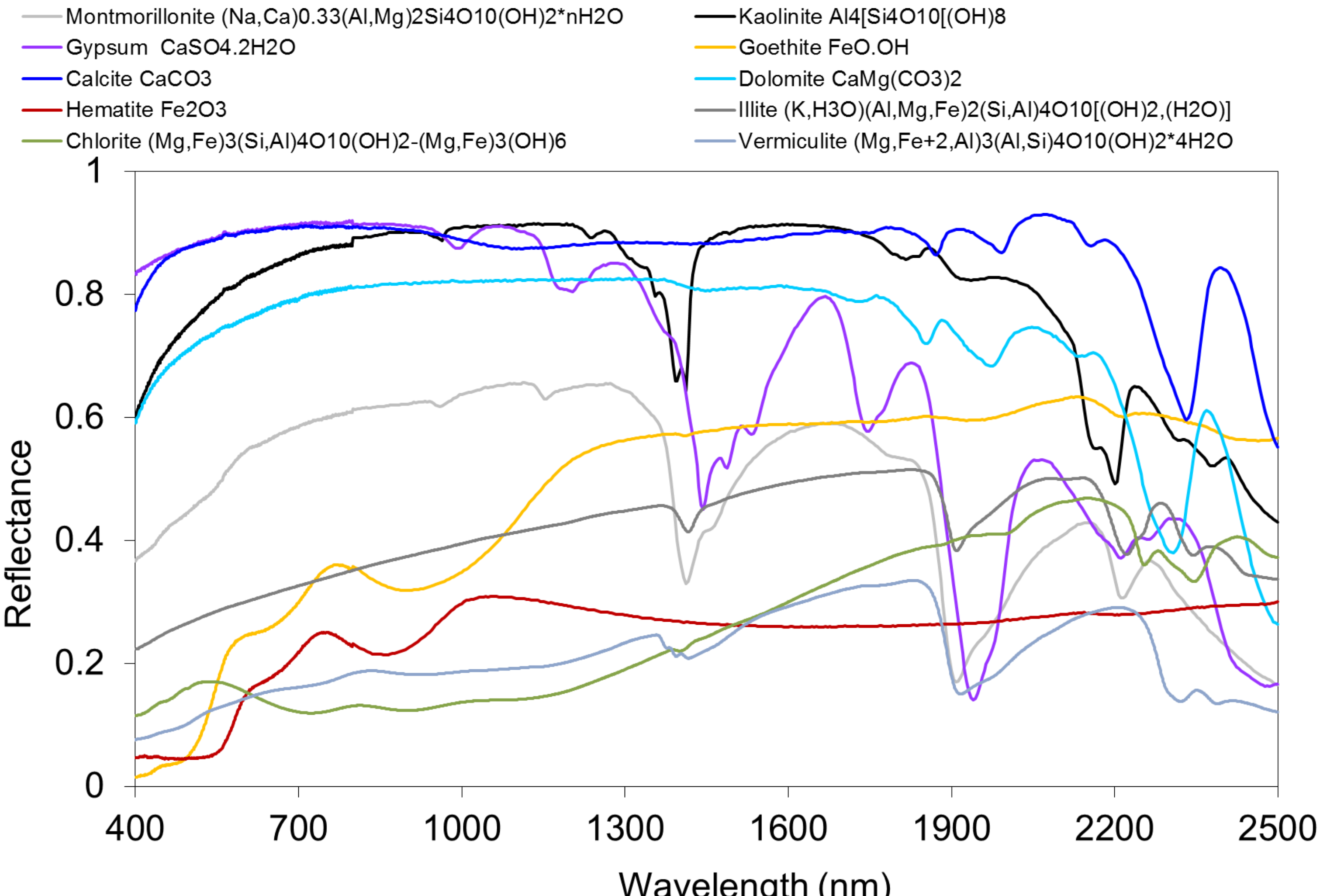


Scanza et al., 2015

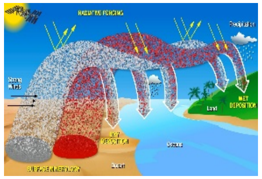
There is direct Spectroscopic Leverage to Measure Mineral Dust Source Composition



- Spectra in the VSWIR range of important dust source minerals



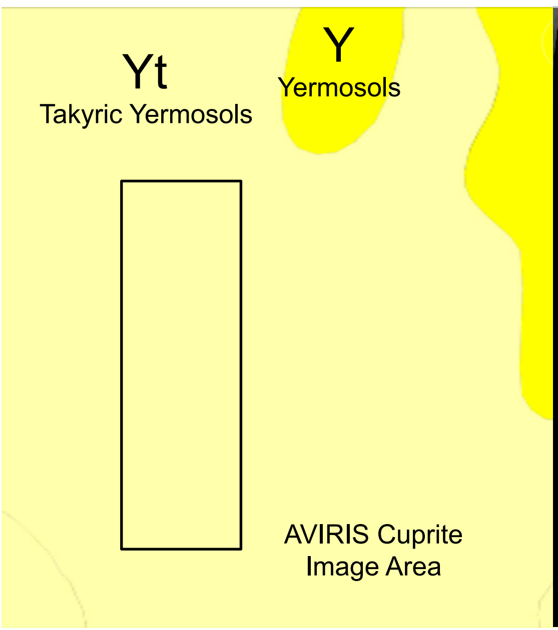
VSWIR Imaging Spectroscopy for Surface Mineral Composition Measurement



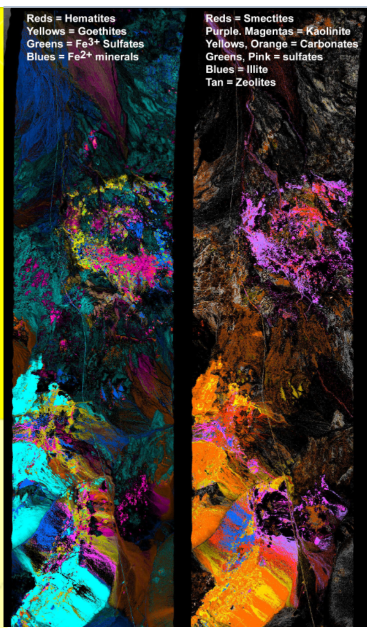
- Example of current mineral dust source constraint detail and example of VSWIR imaging spectroscopy measurement

Cuprite, Nevada

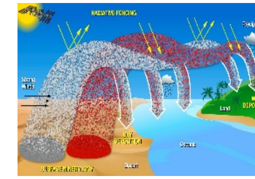
FAO Soil Map

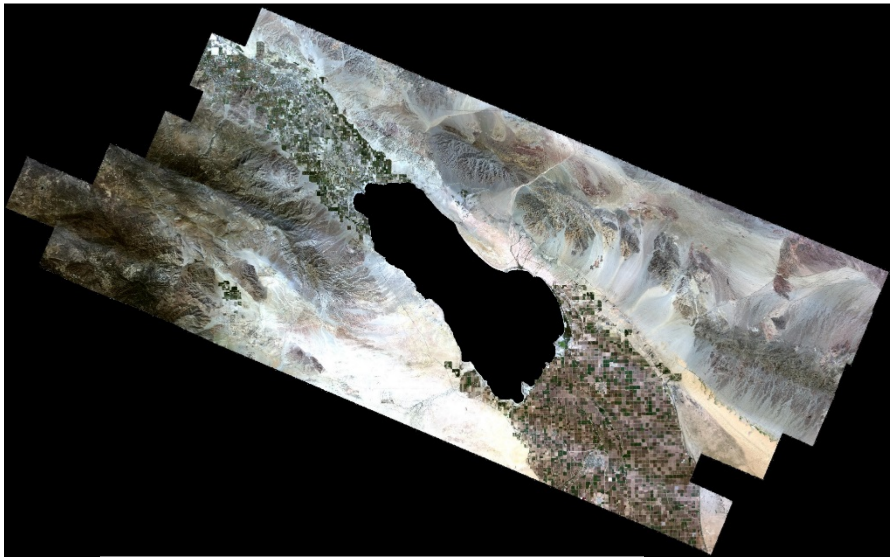


VSWIR Imaging Spectroscopy

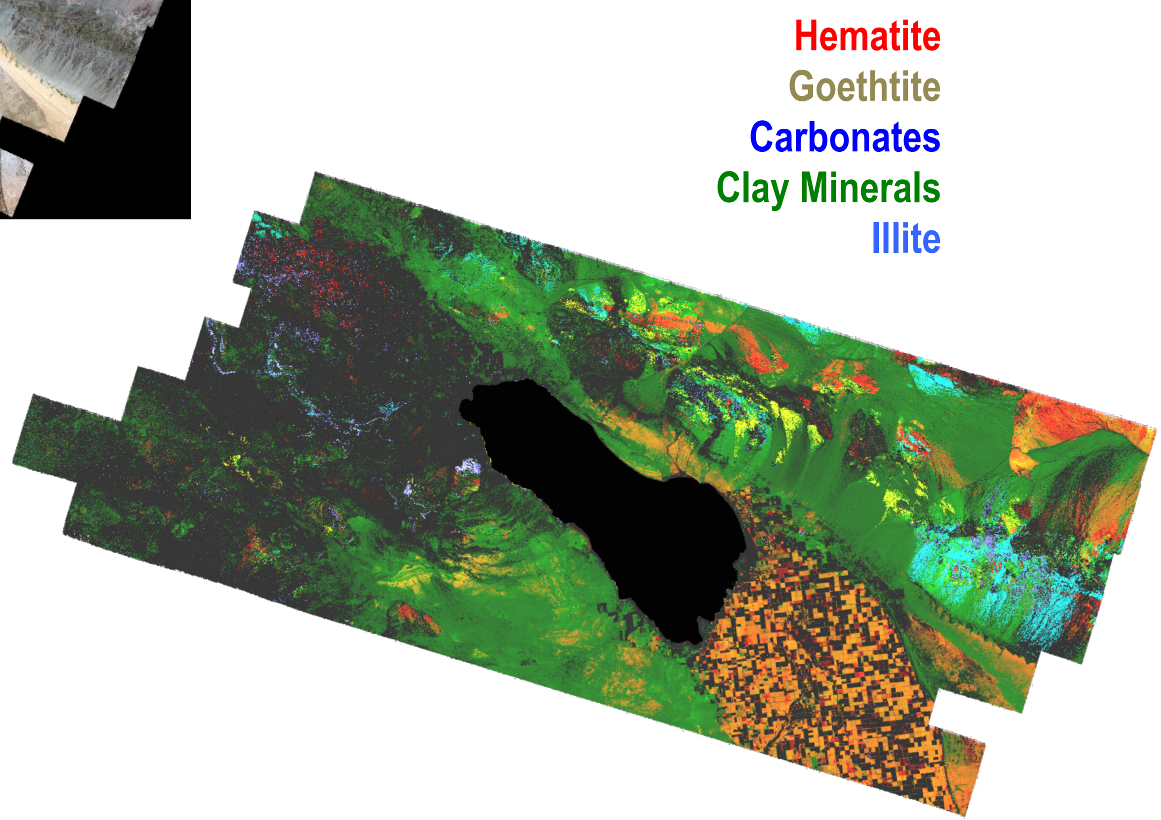


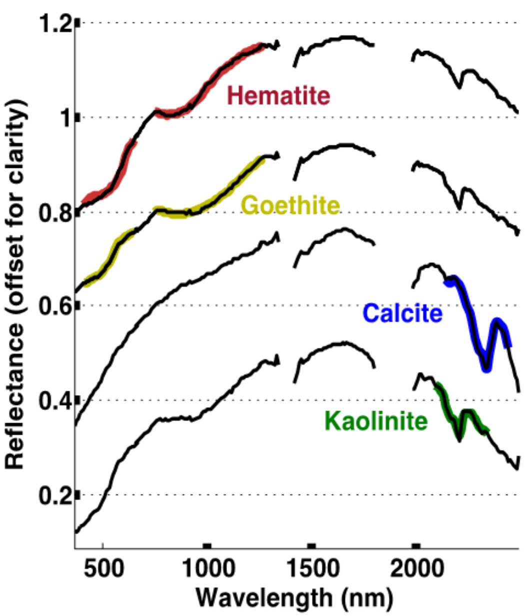
Spectroscopic Based Composition Retrievals at the Salton Sea, CA



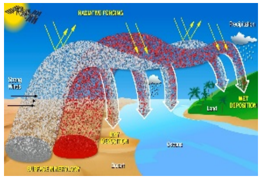


AVIRIS VSWIR imaging spectroscopy measurements of the Salton Sea region in Southern California acquired as part of the NASA HyspIRI campaign.

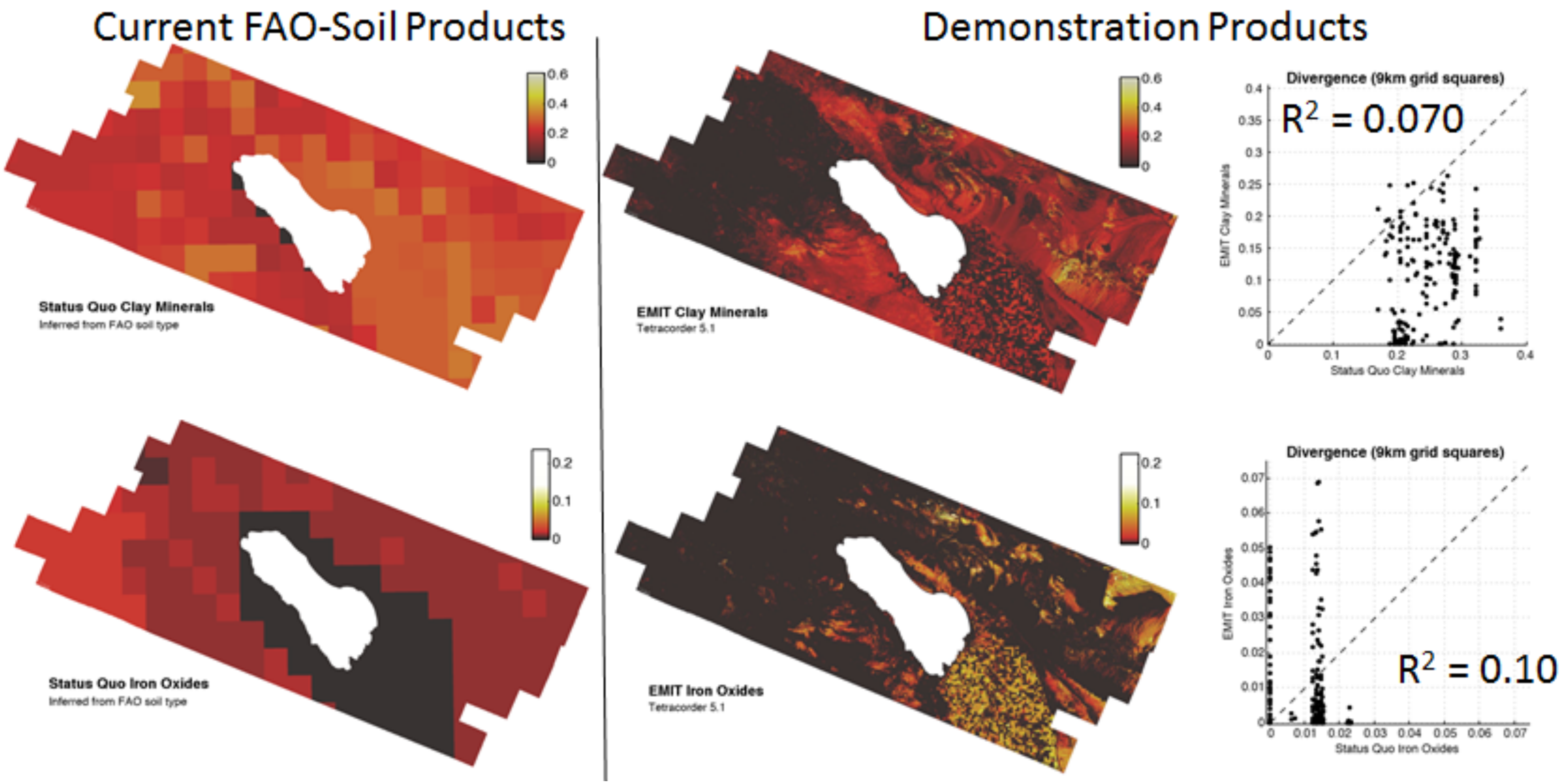




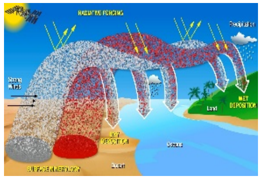
Comparison of Current FAO and Imaging Spectroscopy Products



- VSWIR imaging spectroscopy of the HyspIRI-type enable a 10^6 improvement in knowledge with respect to the current data used to constrain Earth system models.

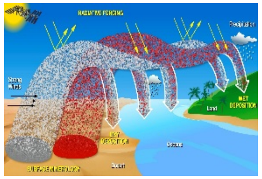


Science Traceability



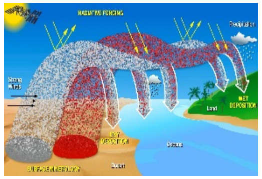
Science Target	Science Objectives	Scientific Measurement Requirements		Instrument Performance			Mission Requirements
		Physical Parameters	Observables	Parameter	Reqts		
Advance NASA's Climate, Atmospheric Composition and Earth Surface Research Goals: • Characterize the Emissions of Radiatively-Active Mineral Dust from the Earth's Surface • Describe and Predict the Role of Mineral Dust in Radiative Forcing • Refine/Augment Earth System Modeling Capabilities • Earth Surface and Atmosphere Interactions http://science.nasa.gov/earth-science/focus-areas/ • Reduce mineral dust RF uncertainty identified in the IPCC AR5	(QESO1) Acquire a comprehensive inventory of key surface minerals available for dust emission in arid regions, based on ≥28 X 10^6 km^2 of the surface, demonstrate improved model skill, and update climate RF predictions in dust impacted regions of the Earth.	Occurrence and fractional abundance (0-1.0 with uncertainty) of dust source minerals expressed at the surface of arid dust source regions and adjacent land at risk for desertification: • Montmorillonite • Kaolinite • Gypsum • Goethite • Calcite • Dolomite • Hematite • Illite • Chlorite • Vermiculite Confounding factors: • Fractional surface cover for green and non-photosynthetic vegetation • Identification and flagging of other materials (water, snow, human infrastructure)	**Top of Atmosphere Radiance Spectra** **Spectral Characteristics** • Mineral Composition with uncertainty: – Iron: 450–1250 nm – Sulfates, Clays & Carbonates: 1450–2450 nm • Atmospheric correction: – Aerosols: 410–780nm – Water vapor: 880–1250 nm – Cirrus clouds: 1360–1400 & 1845–1905 nm • Surface vegetation cover – Pigments/red edge: 450–800 nm – Non-photosynthetic components: 2000–2350 nm	**Spectral Requirements:** Minimum Wavelength (nm) Maximum Wavelength (nm) Sampling (nm) FWHM (nm) Spectral calibration uncertainty (%)	 ≤ 410 ≥ 2,450 ≤ 15 ≤ 20 ≤ 5		**Coverage:** Single cloud-free measurement for ≥80% of arid dust source and adjacent lands when local solar elevation ≥ 45° **Orbit Altitude:** 350 - 750 km **Mission Lifetime:** ≥At least 1 year
	(QESO2) Measure surface mineral composition available for new dust sources in agricultural and sparsely vegetated lands that border source regions (≥4 X 10^6 km^2), and predict evolution of dust sources and related RF under future climate scenarios.		**Spatial Characteristics** • Spatial resolution sufficient to resolve hectare-scale features (100x100 m) – Mineralogy of fallow fields and small exposed areas – Continuity with Landsat, Hyperion, and ASTER data records – Robust aggregation to L3 and Earth System model grids • Geolocation knowledge sufficient to composite, aggregate and tie to digital elevation data use in dust models. • Swath sufficient to measure required areas in a one year period	**Spatial Requirements:** Sampling @ nadir (m) FWHM @ nadir (m) Knowledge (m) post processing Swath (samples) Field of Regard (°)	 ≤ 100 ≤ 125 ≤ 100 ≥ 1000 ≥ 30		
			Radiometric Characteristics • Avoid saturation over highly reflective surfaces (≥ 80%) • Accurate radiometry for atmospheric correction (≤10% uncertainty) • 1% precision in depth of absorption features in accessible mineral absorption spectral regions	**Radiometric Requirements:** Range (% of max Lambertian) Radiometric uncertainty (%) Precision (SNR vs band depth)	 0 to ≥ 80% ≤ 10% Figure 5.		

Summary and Conclusion (1)



- 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)



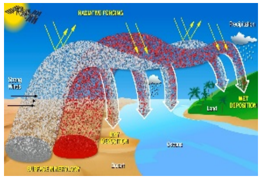
- As tested with the Salton Sea measurements, VSWIR imaging spectroscopy provides a direct and straight-forward method to measure the surface mineral dust source composition.

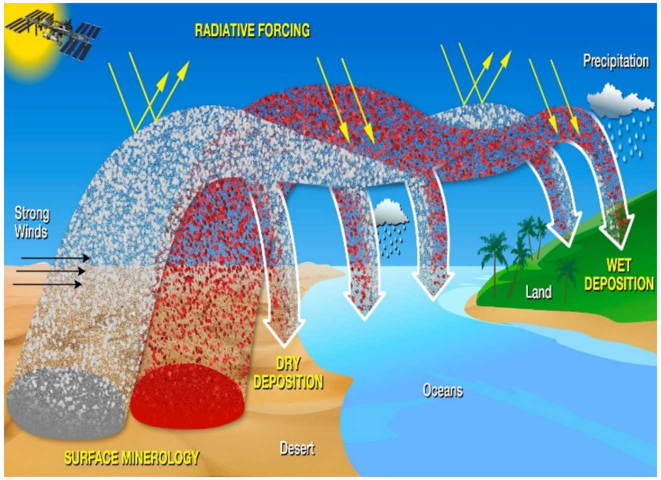
- This spectroscopic approach can reduce uncertainty in global models by delivering comprehensive measurement of the surface mineral composition of dust source regions. Factors of 10^6 improvement in knowledge can be achieved.

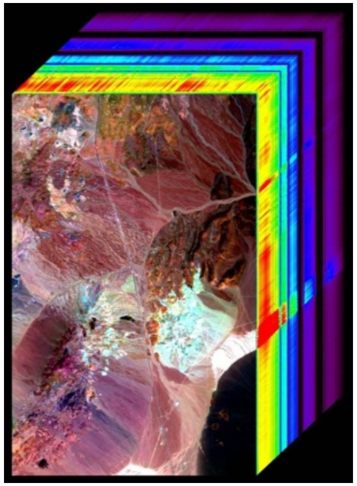
- New accurate and comprehensive constraints can also improve prediction of the evolution of mineral dust sources and Earth system feedbacks under differing future climate scenarios.

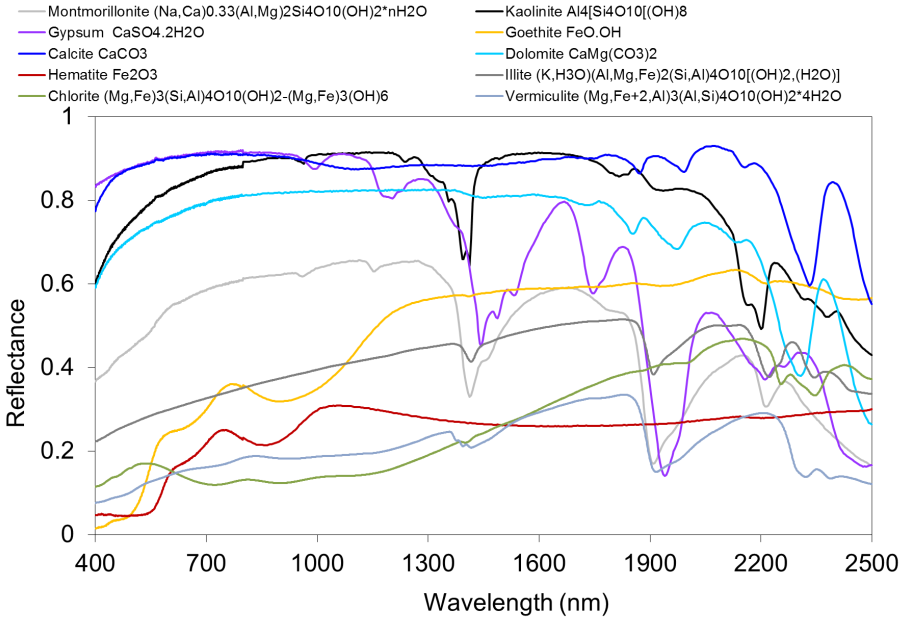
https://hyspiri.jpl.nasa.gov/downloads/RFI2_HyspIRI_related_160517/RFI2_final_Mineral_Dust_Composition_150514a.pdf

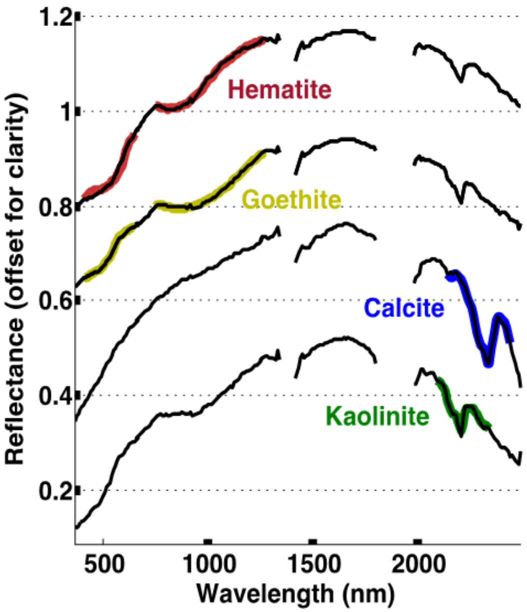
Thank You











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