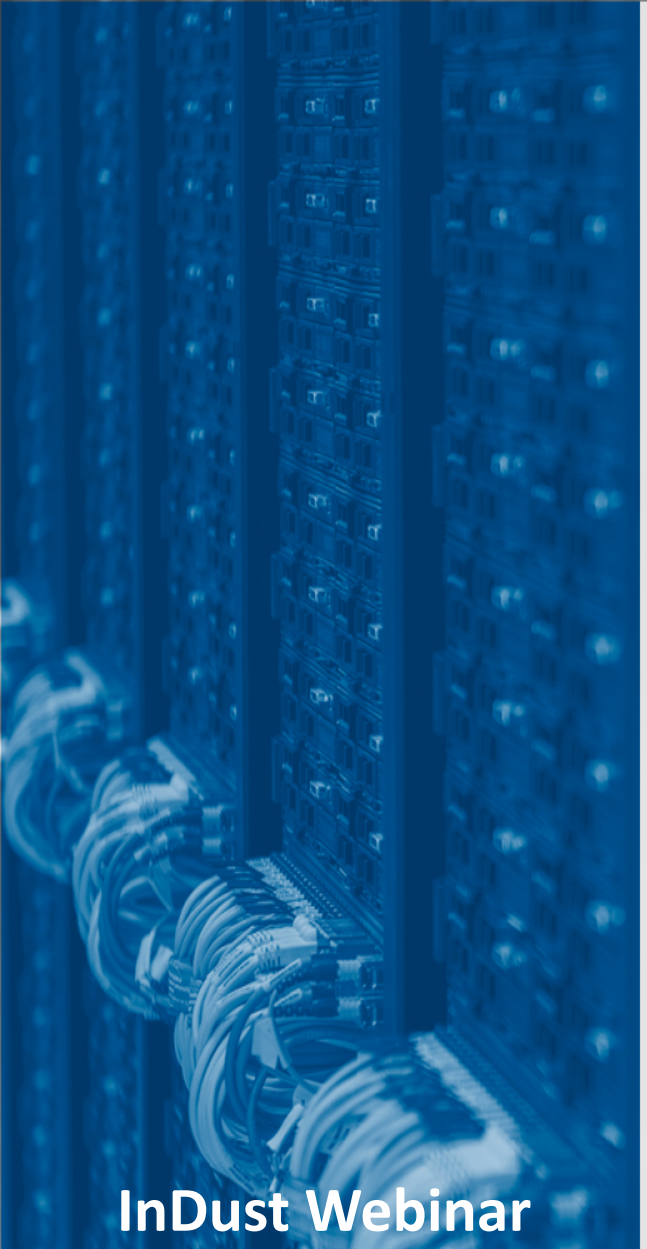


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AXA Research Fund

Dust composition in climate models

Carlos Pérez García-Pando

ICREA and AXA Professor

Barcelona Supercomputing Center and ICREA

Acknowledgements:

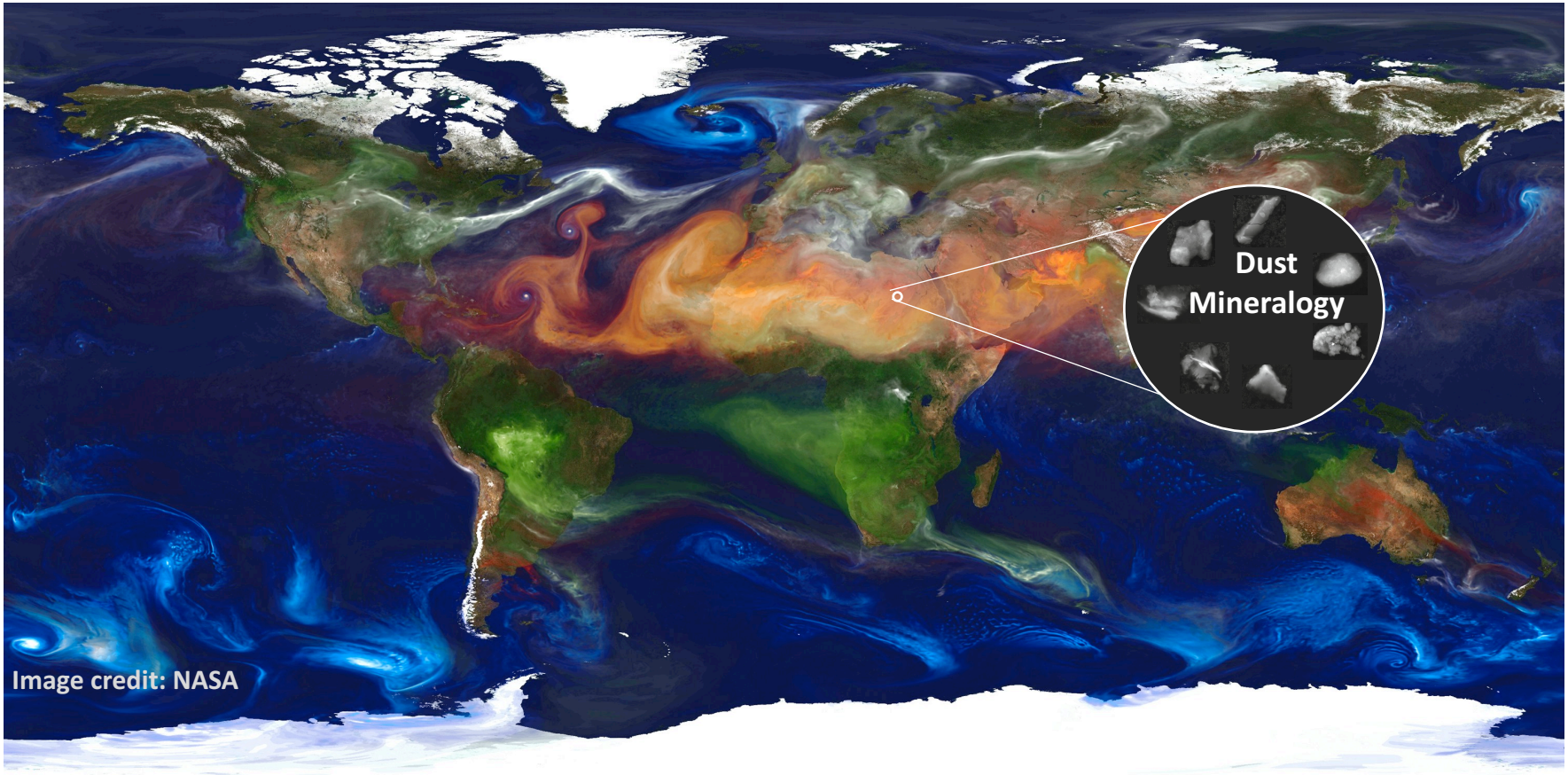
NASA EMIT and ERC FRAGMENT colleagues

InDust Webinar

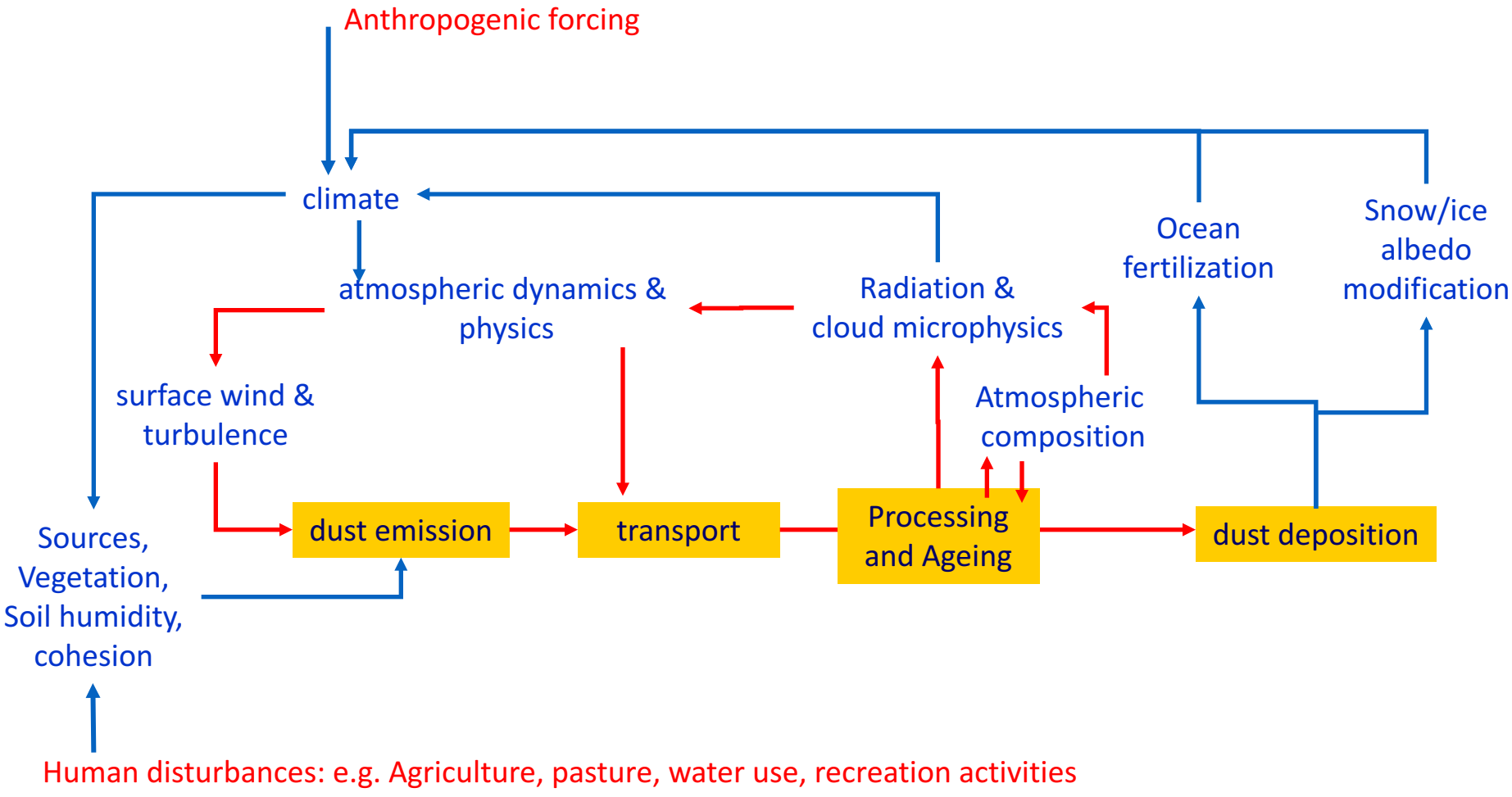
30/06/2021

Dust mineralogical composition

Desert dust is the dominant particle by mass and a key component of the Earth System

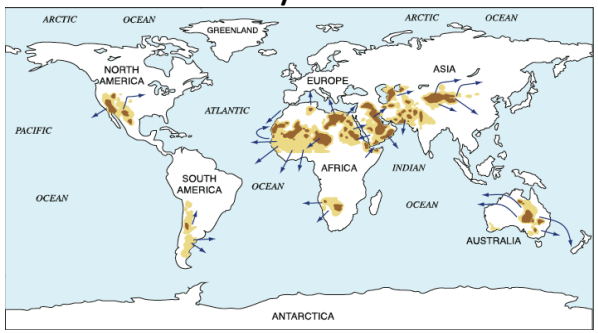


Dust effects and feedbacks

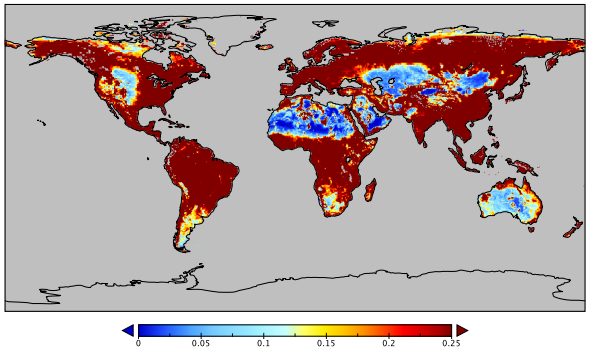


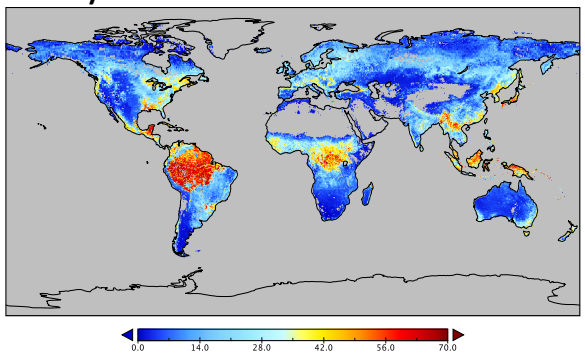
Key challenges in representing the dust cycle and its effects

Sources / emission

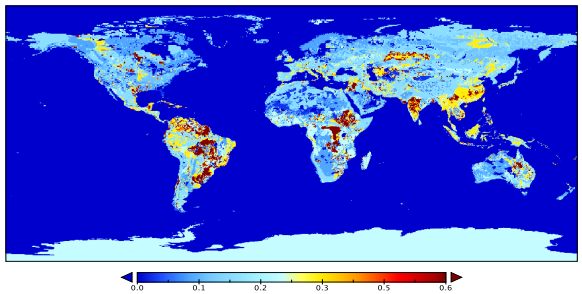


Roughness / vegetation / soil moisture

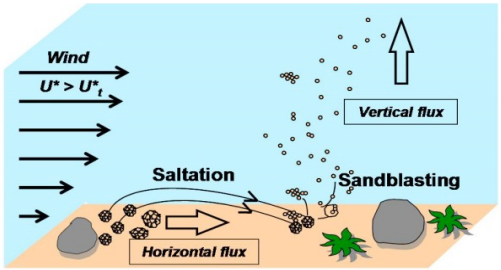




Soil texture / size distribution



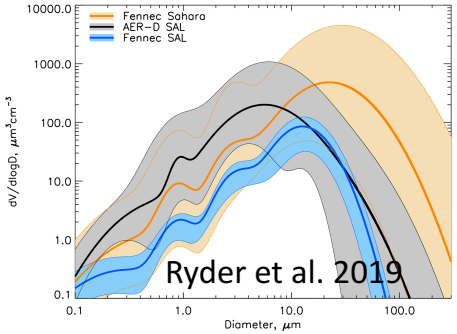
Size-distributed dust emission



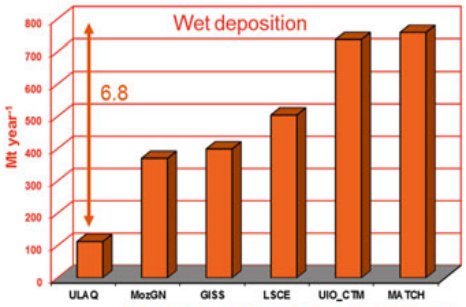
Wind gusts/haboobs



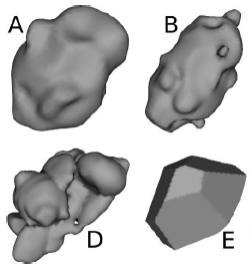
Coarse dust



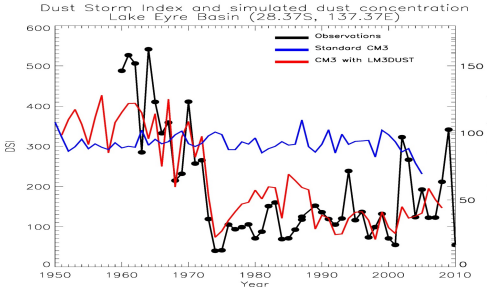
Deposition



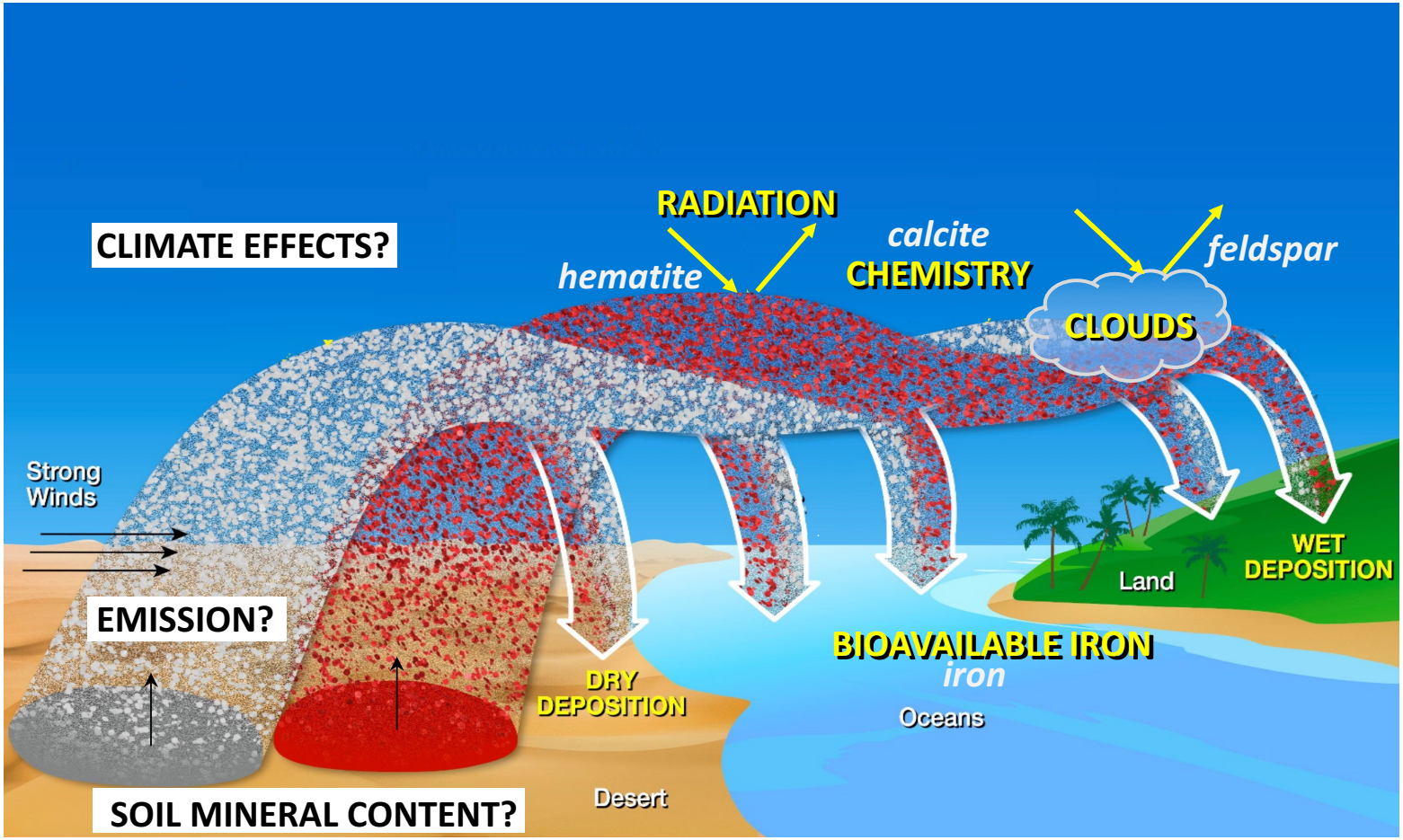
Shape/optical properties



Long term variability



Why is dust mineralogy important?



Earth System Models neglect dust mineralogical composition variations

- Traditionally: Model an 'average' mineral aerosol
- Mineral aerosols are from different minerals depending on surface composition

Each mineral has different properties and interactions with Earth System



Illite

hematite



Iron oxides:
Absorb short wavelength (SW), iron for ocean biogeochemistry, low pH

Aerosol



kaolinite

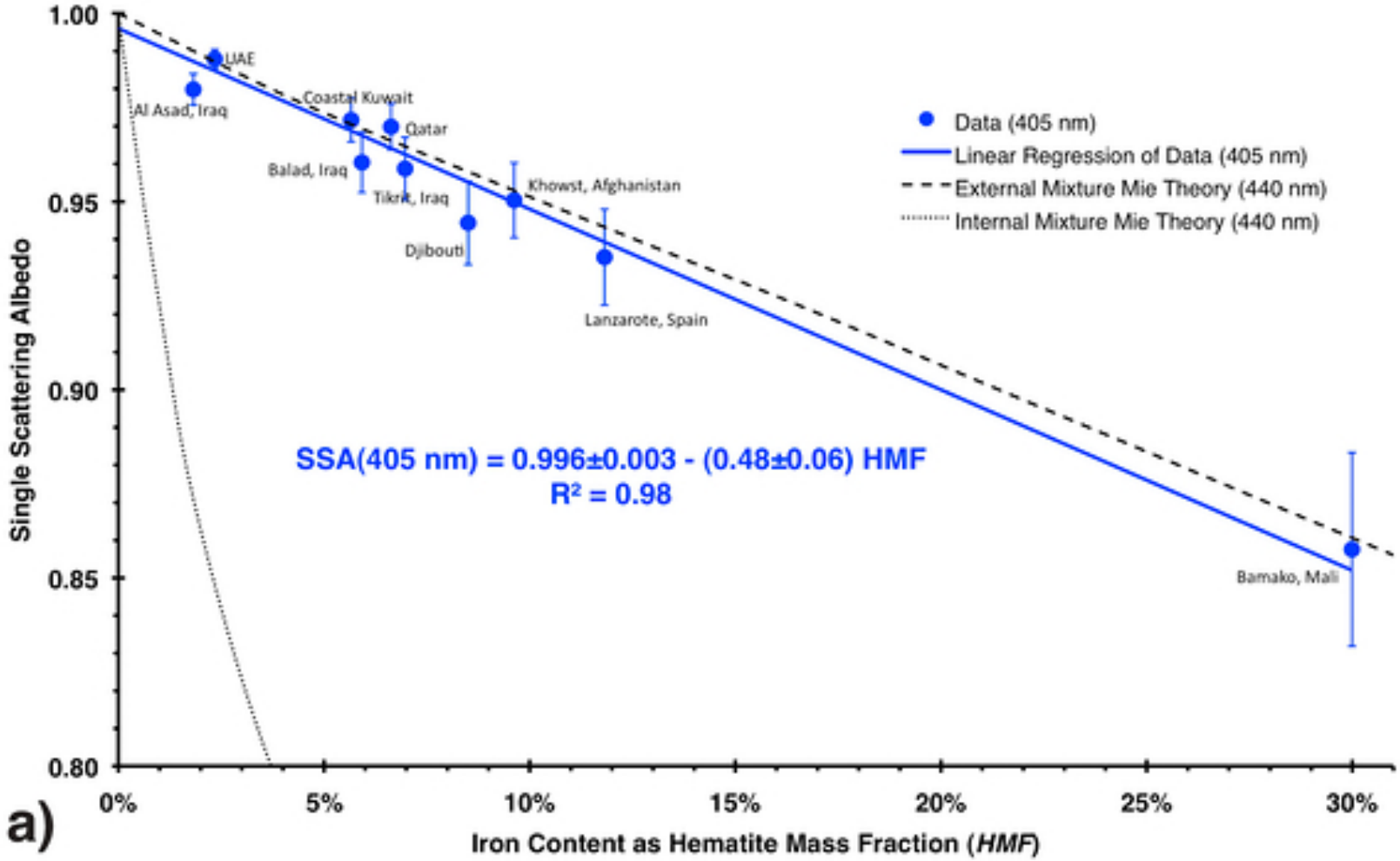
Kaolinite:
Reflects SW, high pH



montmorillonite

Clays, large particles:
Reflects SW

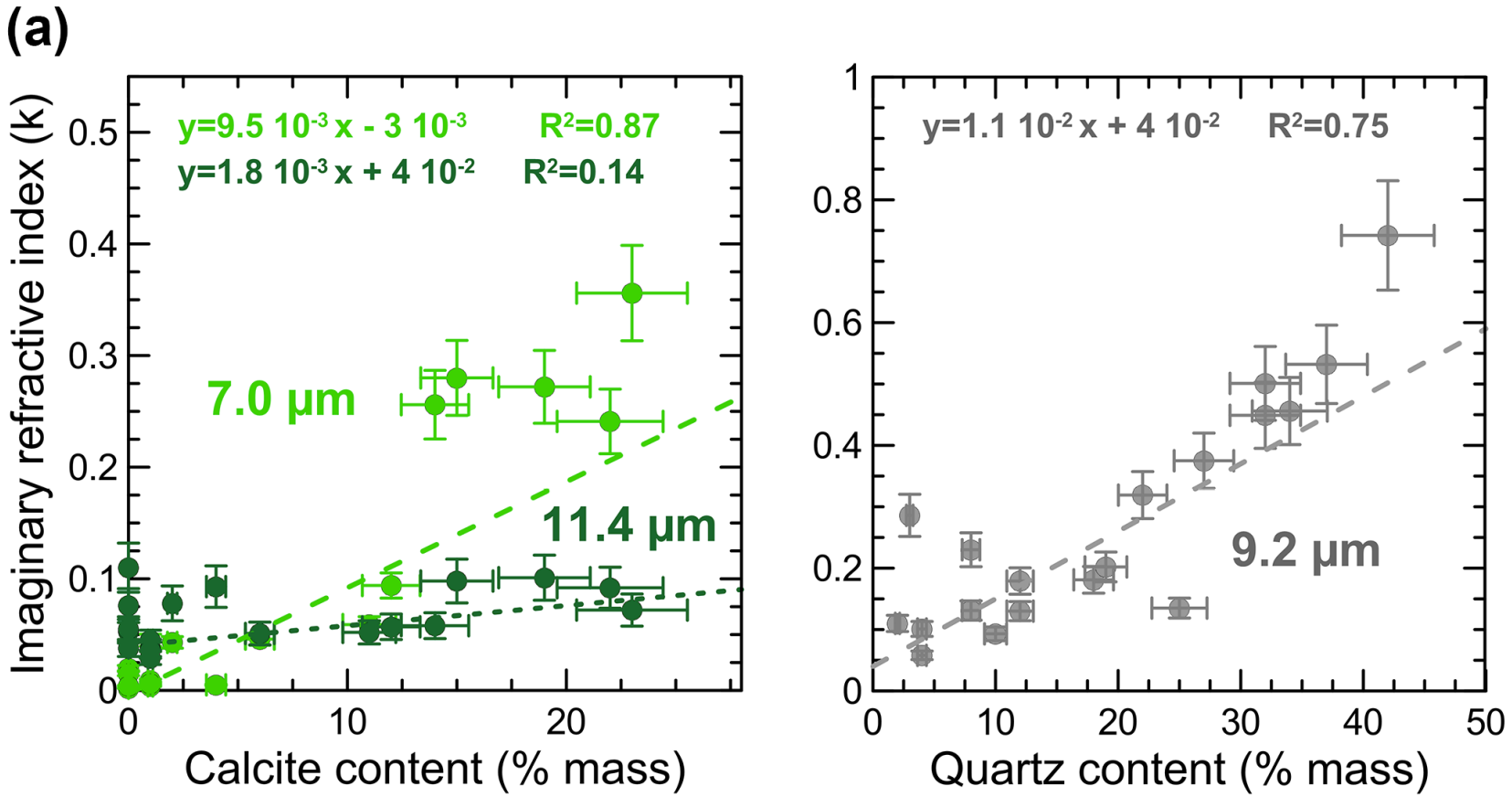
Shortwave forcing



Moosmüller et al. (2012)

Iron oxides
Hematite

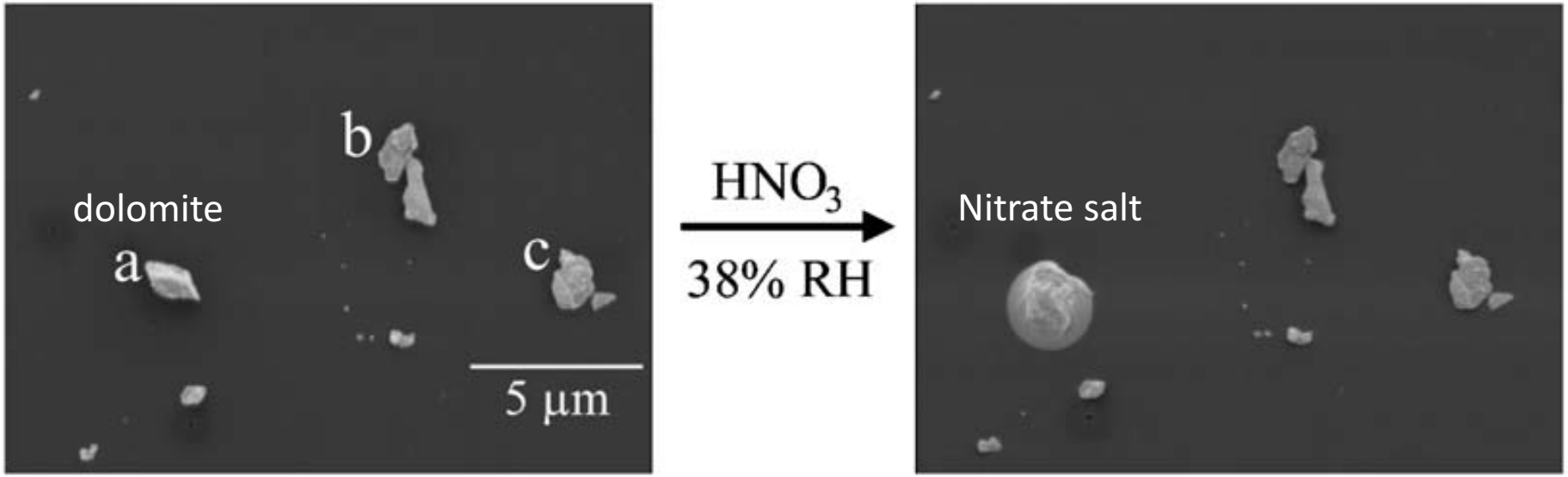
Longwave forcing



Di Biagio et al. (2017)

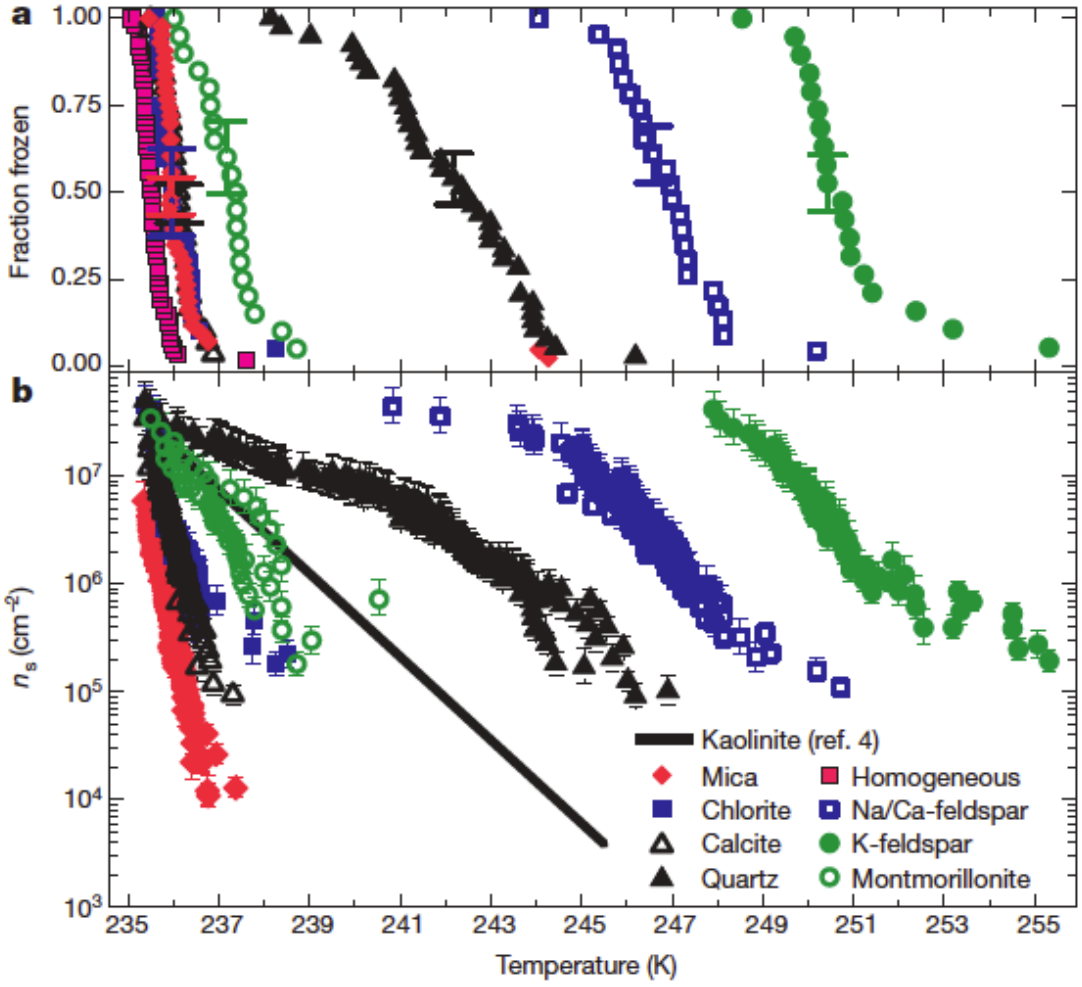
Calcite
Quartz

Heterogeneous chemistry & warm clouds



Krueger et al. (2004)

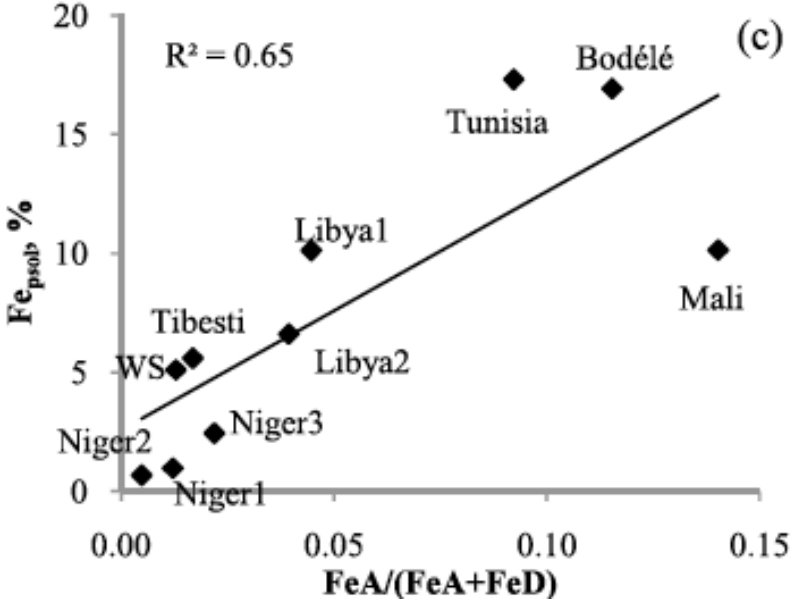
Ice nucleation and mixed-phase clouds (Cloud-phase climate feedback)

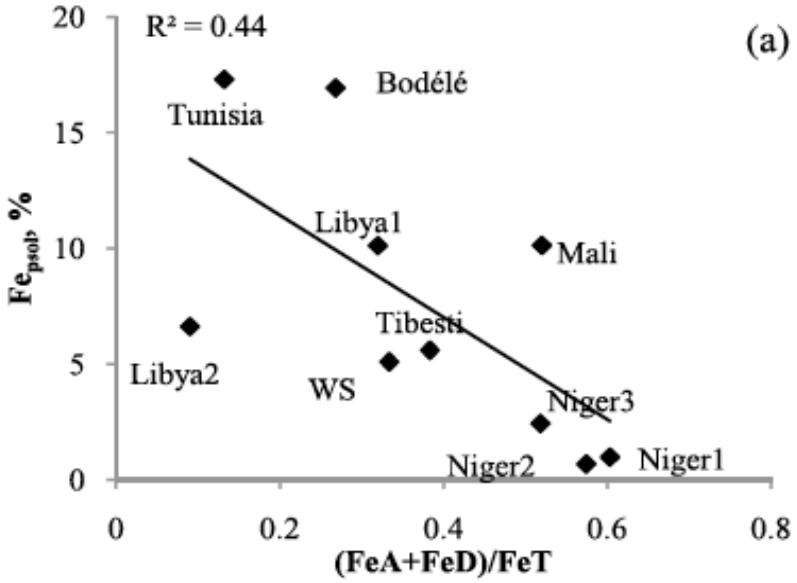


K-Feldspar

Atkinson et al. (2017)

Iron mineralogy and solubility

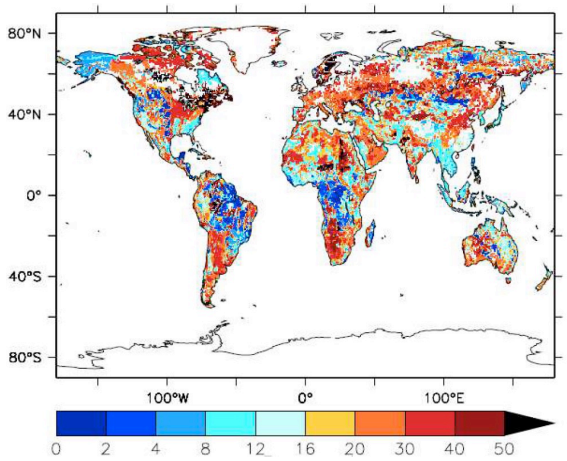




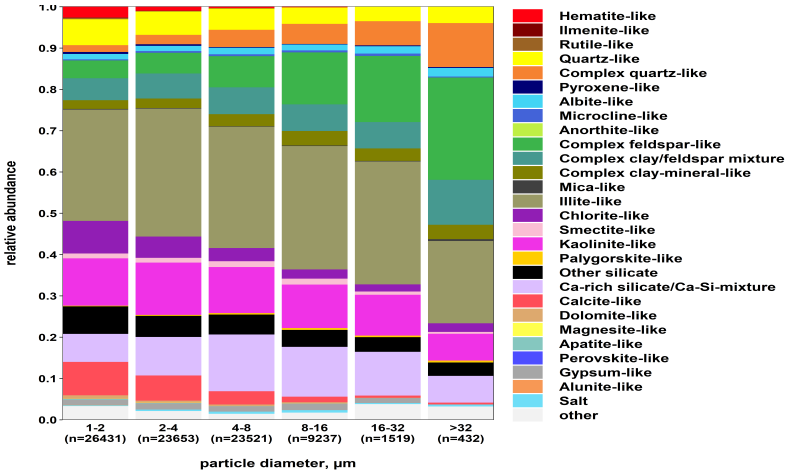
FeA: amorphous and/or poorly crystalline and nanoparticulate Fe (ascorbate Fe)
FeD: crystalline Fe(III) oxides, mainly goethite and hematite (dithionite Fe)
FeT: Total Fe including Structural Fe (FeSt)

Shi et al. (2011)

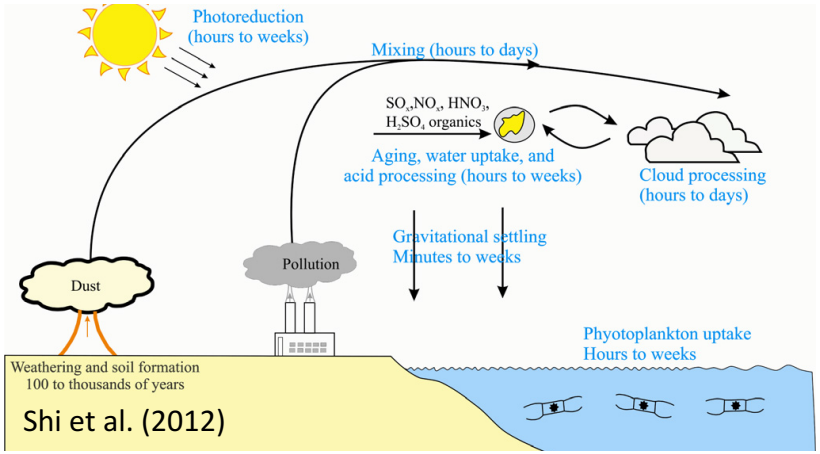
Causes for dust composition variations and associated effects



Variations in soil-surface mineralogy



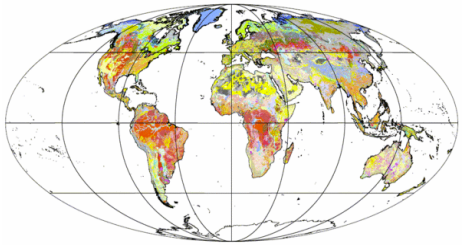
Size sorting during emission and transport



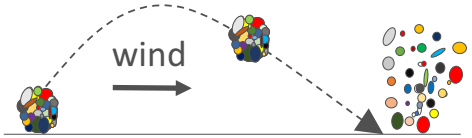
Chemical transformations during transport

Main challenges

Global soil mineral content

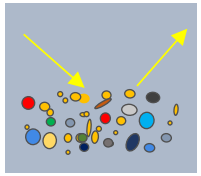


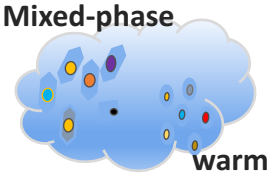
Emission of minerals



FRAGMENTation of aggregates

Role of mineralogy



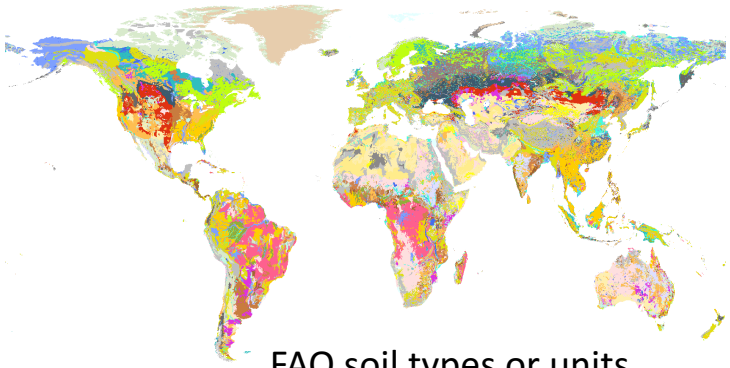


Radiation, Chemistry and Clouds

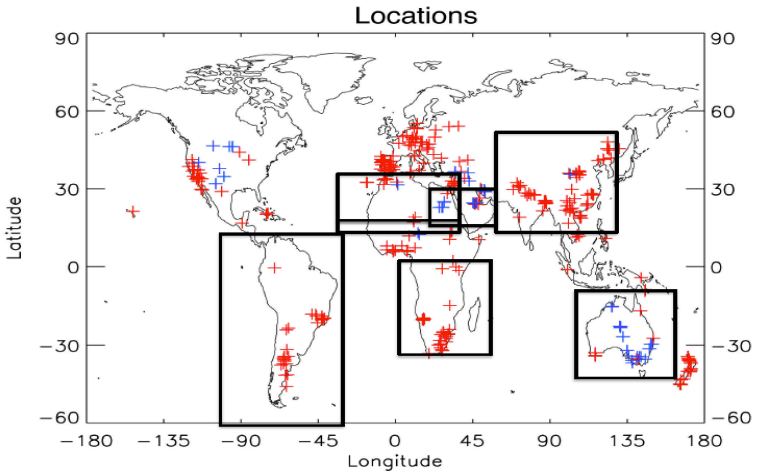
Mapping of soil-surface mineralogy

- Claquin et al., 1999; Journet et al., 2014

- Currently 12 key minerals estimated
- 700 soil descriptions sampling 55 % of FAO soil units
- Many regions including prolific sources not sampled
- Massive extrapolation based on soil unit/type
- A number of assumptions to overcome the lack of data: for example on hematite and goethite size

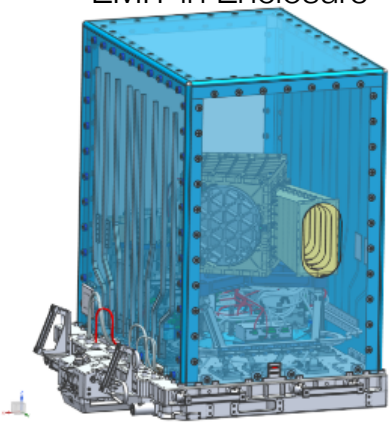


FAO soil types or units



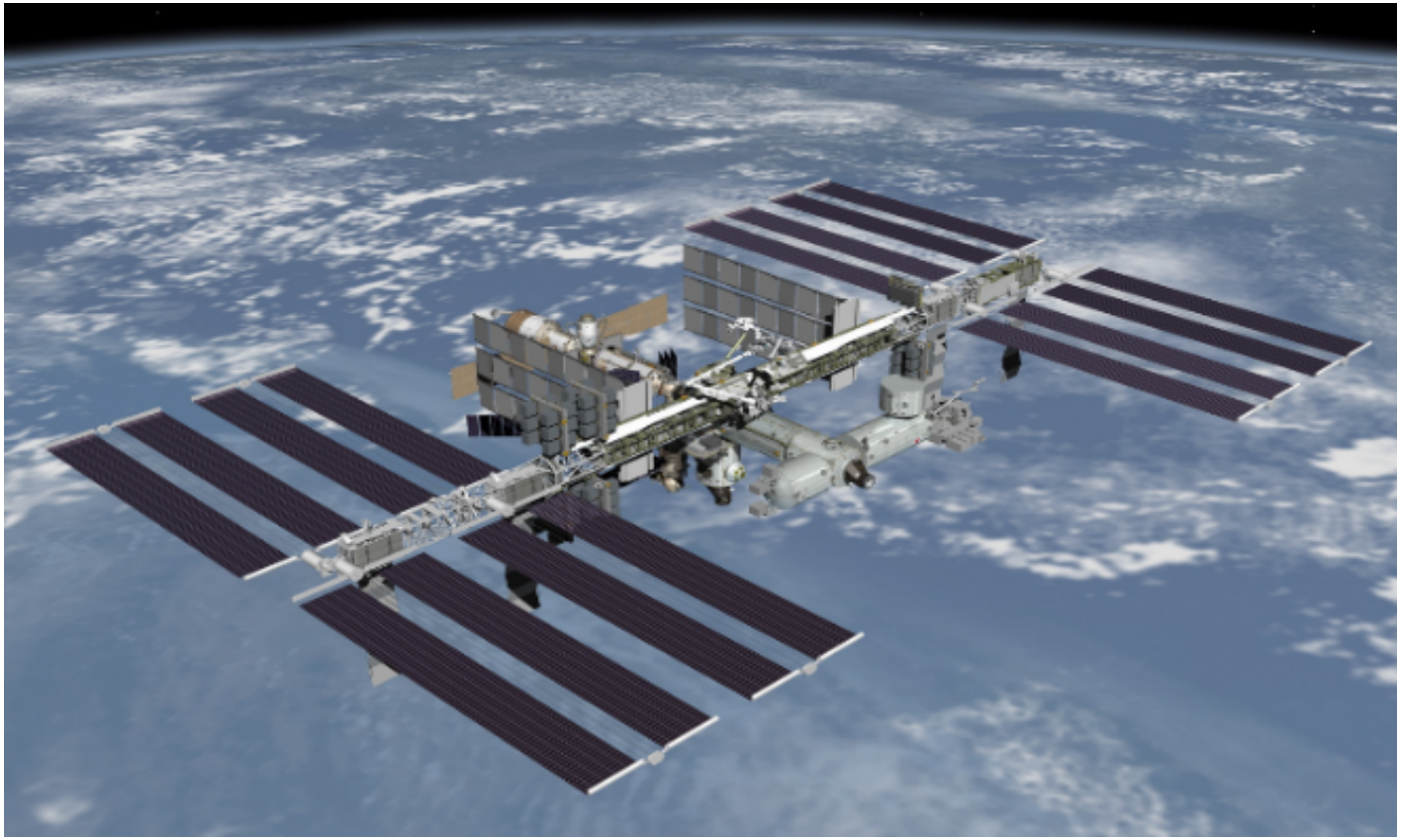
EMIT will Begin Measuring Spectra from the ISS in 2022

EMIT in Enclosure



Planned SpaceX Launch



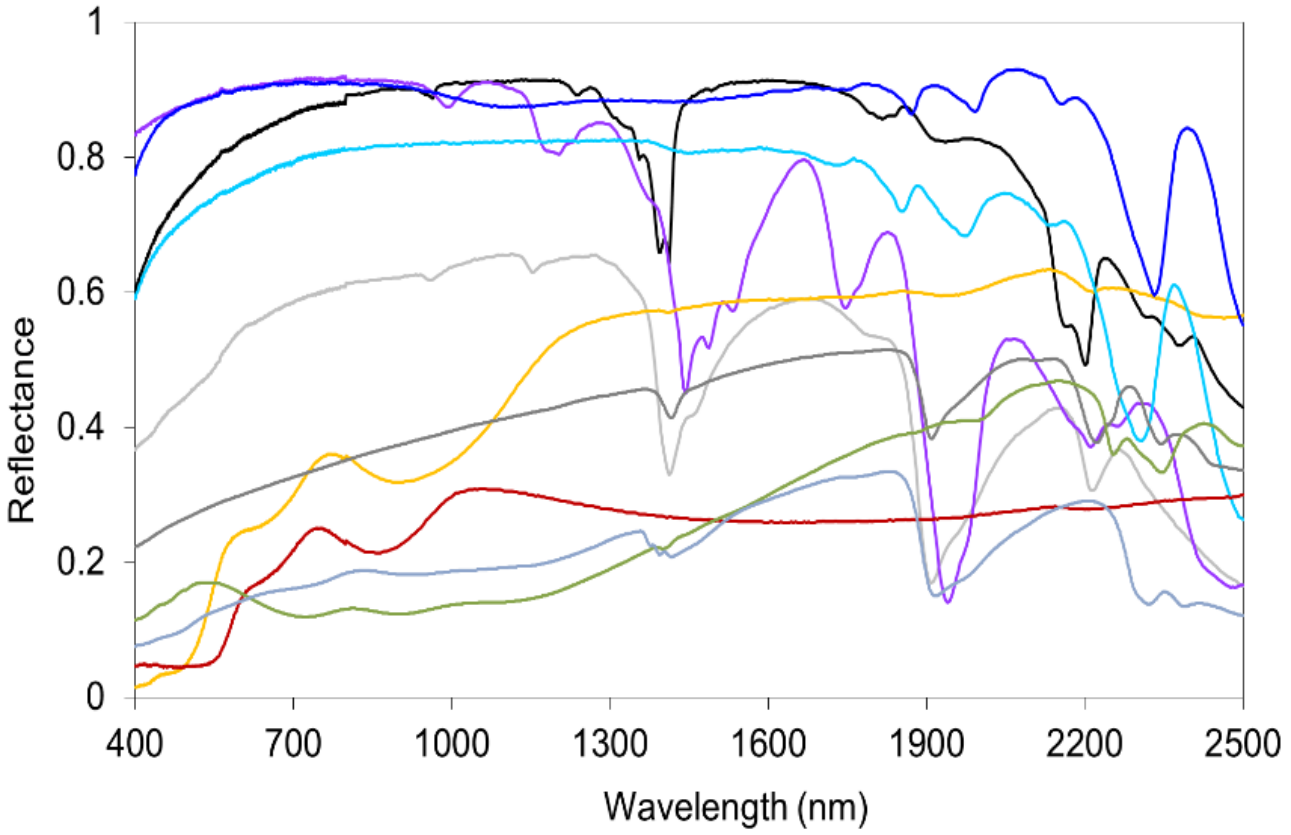


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EMIT Will Use Imaging Spectroscopy
Dust Minerals have Distinct Spectral Signatures



Kaolinite Al4[Si4O10[(OH)8
Goethite FeO.OH
Dolomite CaMg(CO3)2
Illite (K,H3O)(Al,Mg,Fe)2(Si,Al)4O10[(OH)2,(H2O)]
Vermiculite (Mg,Fe+2,Al)3(Al,Si)4O10(OH)2*4H2O

Montmorillonite (Na,Ca)0.33(Al,Mg)2Si4O10(OH)2*nH2O
Gypsum CaSO4.2H2O
Calcite CaCO3
Hematite Fe2O3
Chlorite (Mg,Fe)3(Si,Al)4O10(OH)2-(Mg,Fe)3(OH)6





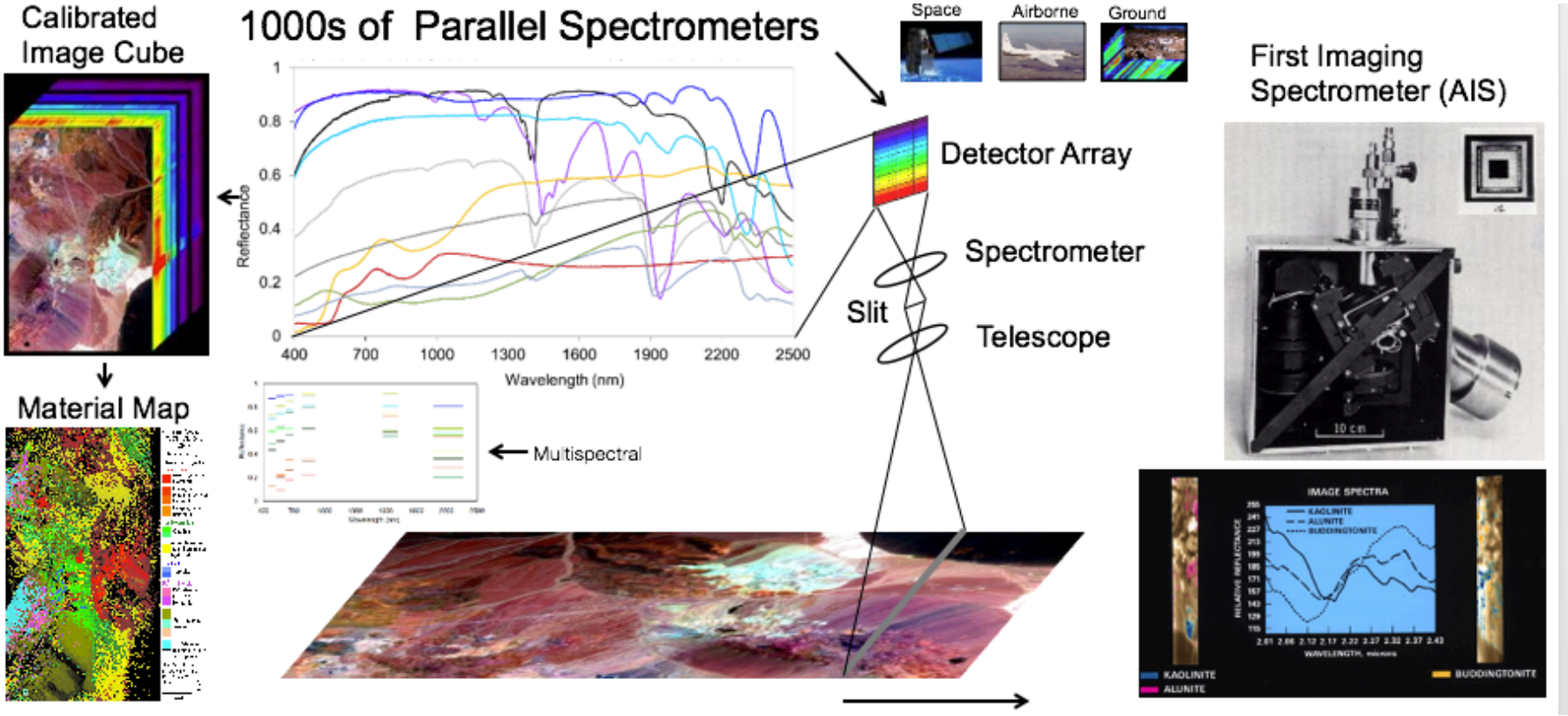

Visible to Short Wavelength Infrared Spectral Range (VSWIR) [400 to 2500 nm]

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NASA Imaging Spectroscopy Offers a Tested Approach to Measure Surface Mineralogy



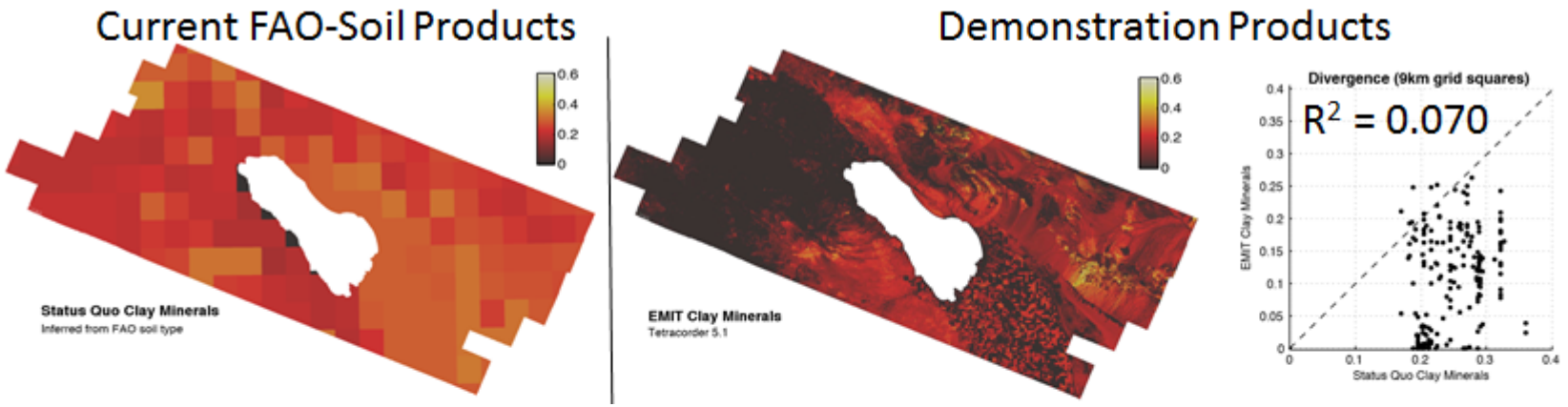
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

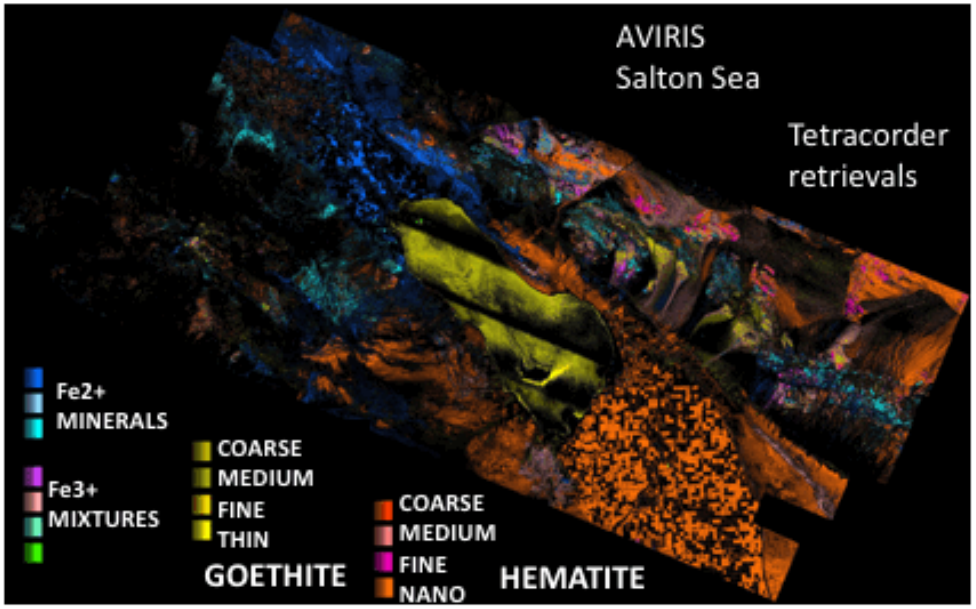
Jet Propulsion Laboratory
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Space borne hyperspectral imaging spectroscopy

Salton sea



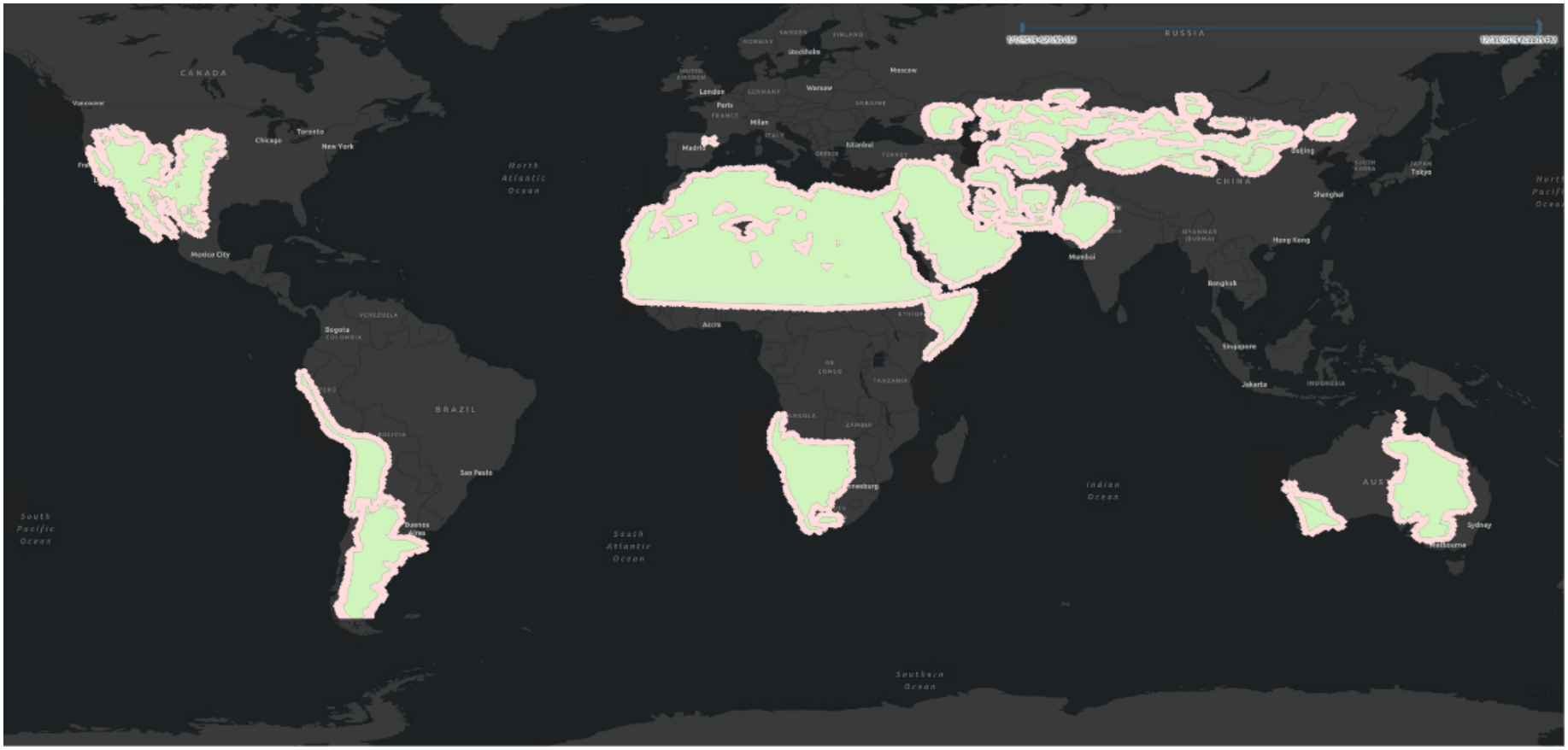


How to relate retrievals to mass/volume fractions?

Feldspar and quartz beyond spectral window

Courtesy Rob Green and Roger Clark

EMIT Planned Arid Land Coverage Area



EMIT on the ISS delivers >10^9 direct spectroscopic observations of arid land surface

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EMIT Data Products to NASA LP DAAC

Data Product	Description	Initial Availability to NASA DAAC	Median Latency in Product Availability to NASA DAAC after Initial Delivery	NASA DAAC Location
Level 0	Raw collected telemetry	4 months after IOC	2 months	LP DAAC
Level 1a	Reconstructed, depacketized, uncompressed data, time referenced, annotated with ancillary information reassembled into scenes.	4 months after IOC	2 months	LP DAAC
Level 1b	Level 1a data processed to sensor units including geolocation and observation geometry information	4 months after IOC	2 months	LP DAAC
Level 2a	Surface reflectance derived by screening clouds and correction for atmospheric effects.	8 months after IOC	2 months	LP DAAC
Level 2b	Mineralogy derived from fitting reflectance spectra, screening for non-mineralogical components.	8 months after IOC	2 months	LP DAAC
Level 3	Gridded map of mineral composition aggregated from level 2b with uncertainties and quality flags	11 months after IOC	2 months	LP DAAC
Level 4	Earth System Model runs to address science objectives	16 months after IOC	2 months	LP DAAC

Wet Sieving and emitted size distribution

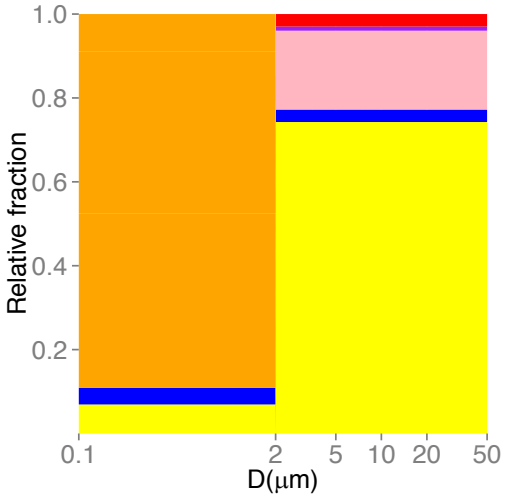
Sieves for mechanical analysis



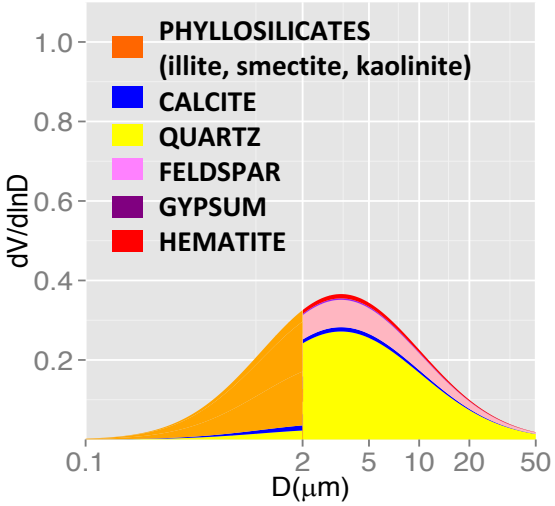
Soil Hydrometer apparatus



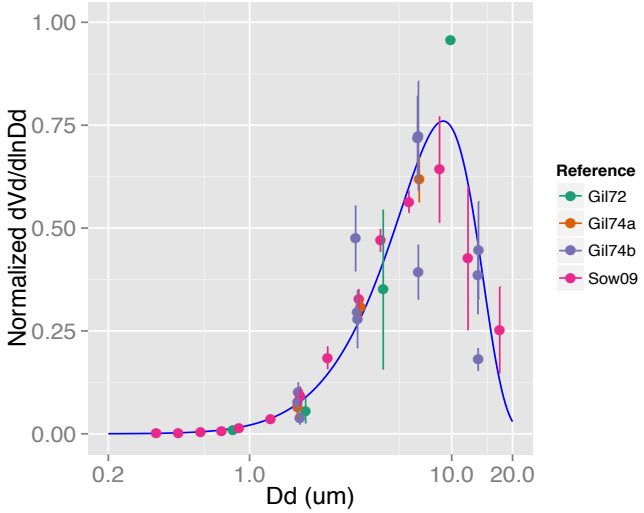
Soil measurements based on *wet sedimentation* ("*wet sieving*") techniques that disturb the soil samples, *breaking the aggregates* that are found in the undispersed soil that is subject to wind erosion.



Soil mineral fractions

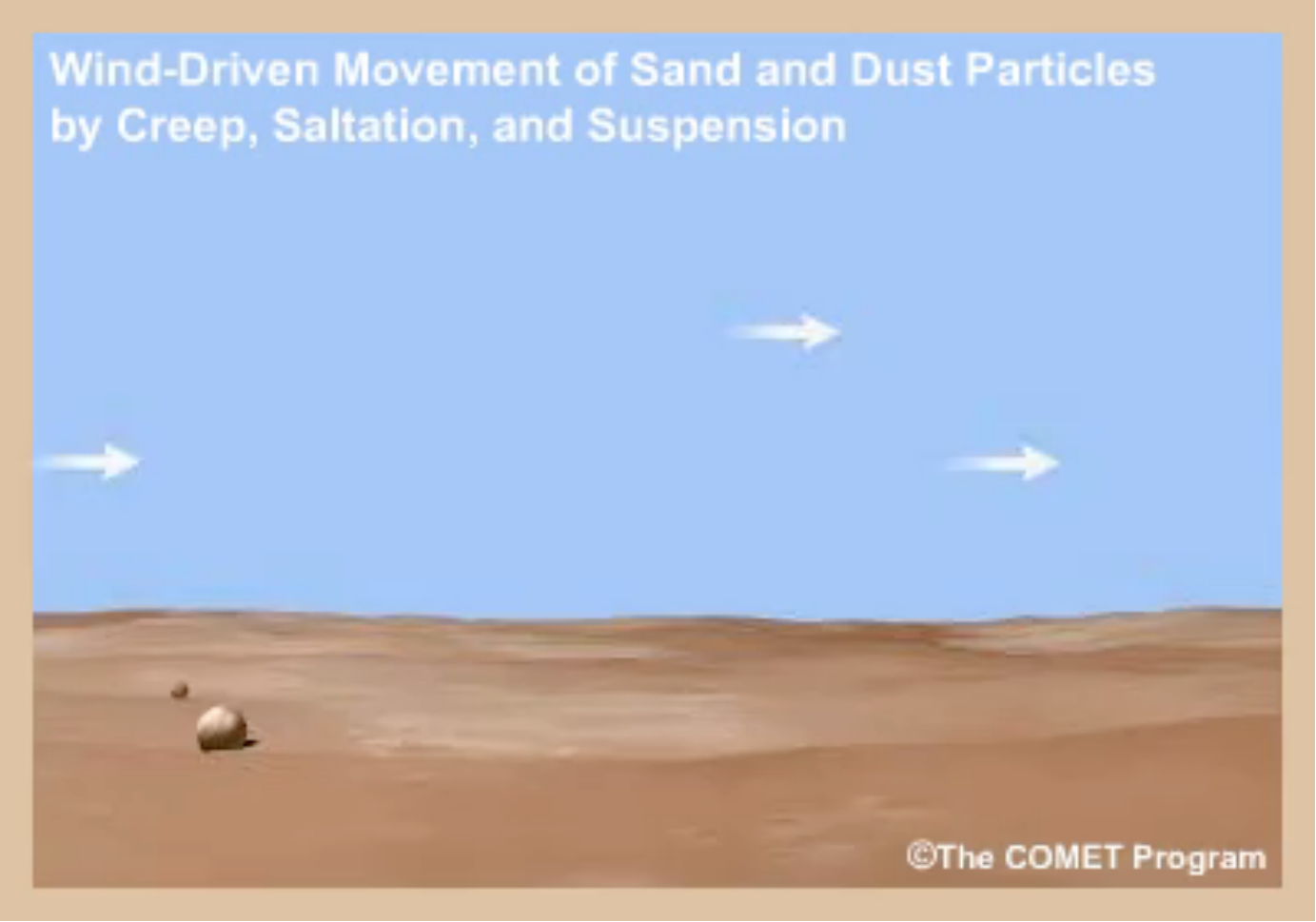


Typical arid soil size distribution



Observed emitted dust size distributions

Emission of dust minerals

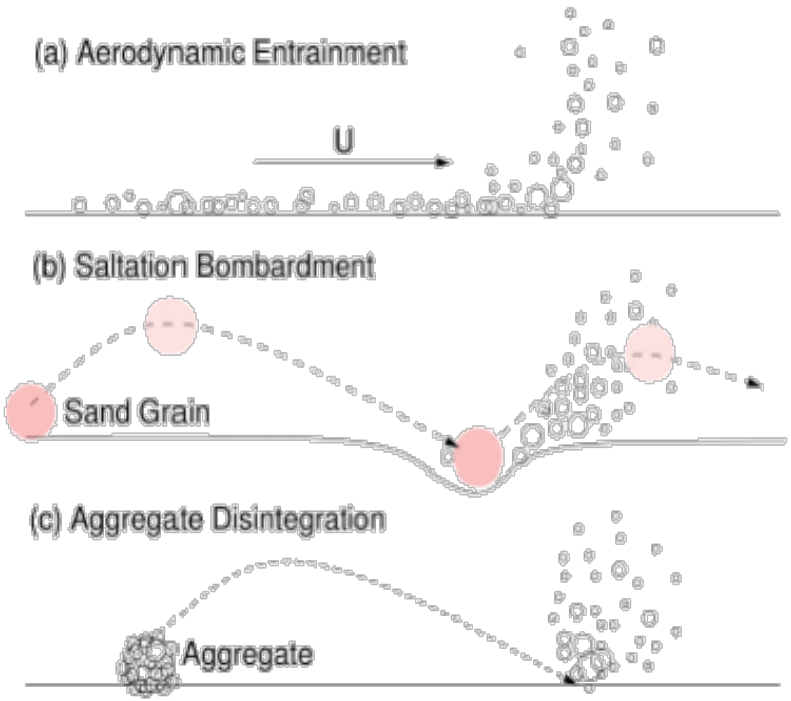


Emission of dust minerals

Emitted PSD of dust minerals is key to quantifying their climate effect

Even disregarding the added complexity of mineralogy

- Incomplete understanding of the physics
- Paucity and incompleteness of measurements
- Contradiction among theories, field observations and wind tunnel experiments
- Lack of (realiable) input data at global scale (e.g. soil PSD's)

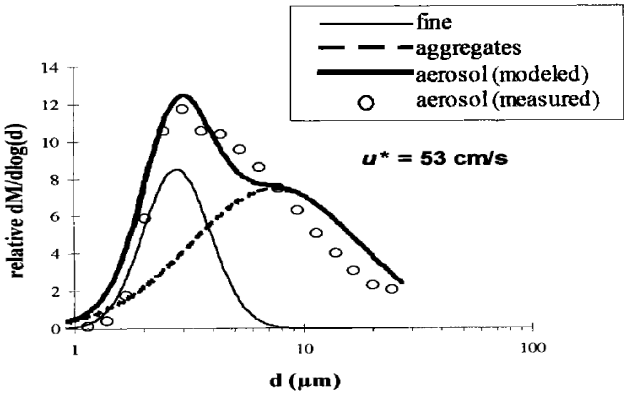


Dust emission mechanisms (Shao et al. 2008)

Emitted dust PSD

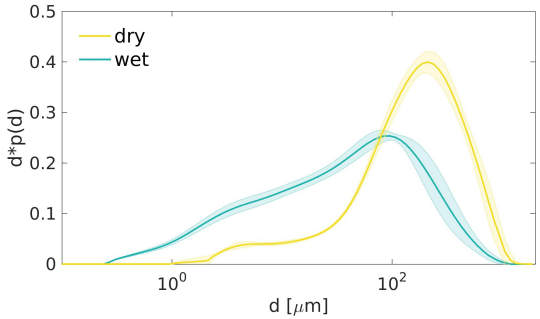
Alfaro et al. – Dust Production Model

- Three lognormal modes
- Bonding energy of aggregates
- Kinetic energy of saltators
- PSD depend on wind (based on wind tunnel)



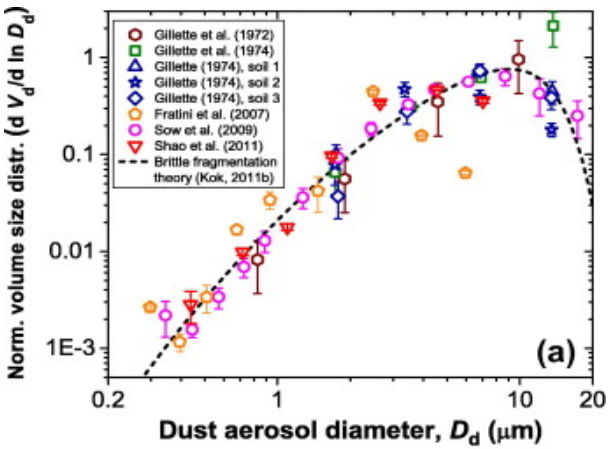
Shao model

- Weighted average between disturbed and undisturbed PSD
- Weighting factor ~ 2 empirical coeffs and wind
- PSD depends on wind (based on wind tunnel
- Revised version in 2011 based on measurements



Kok model (brittle fragmentation theory - BFT)

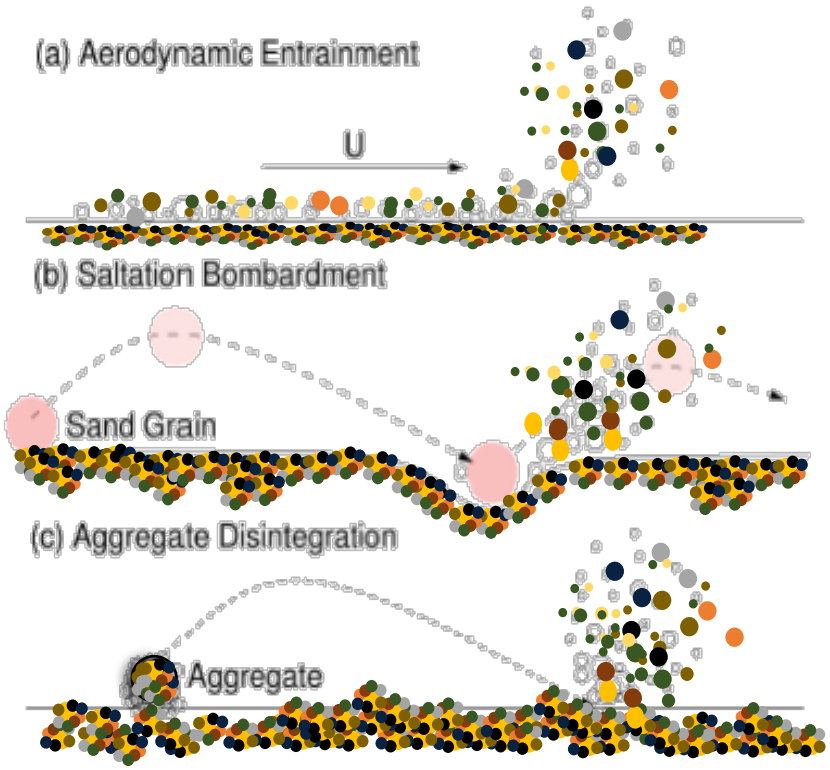
- Following the physics of brittle materials
- Emitted PSD up to ~ 12 μm independent of both the undisturbed soil PSD and the wind speed
- Dispersed soil PSD and the side crack propagation length (λ) assumed constant



Emitted size-resolved mineralogy? Relationship with the parent soil?

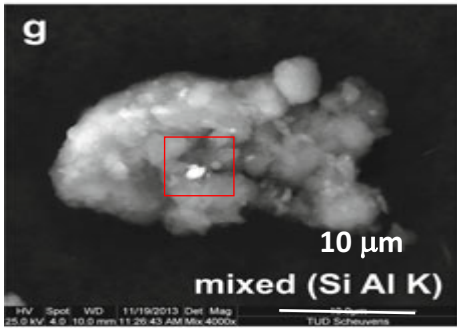
With mineralogy the picture becomes more complex

- Complete lack of experimental studies tackling the relationship of the emitted PSD and soil-surface mineralogy
- Soil analysis based upon wet sieving that disturbs the soil samples
- Internal and external mixtures of different minerals important for climate impacts

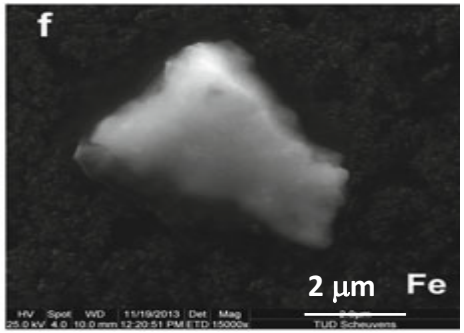


Mixing state of dust minerals

aluminosilicate



Iron oxide



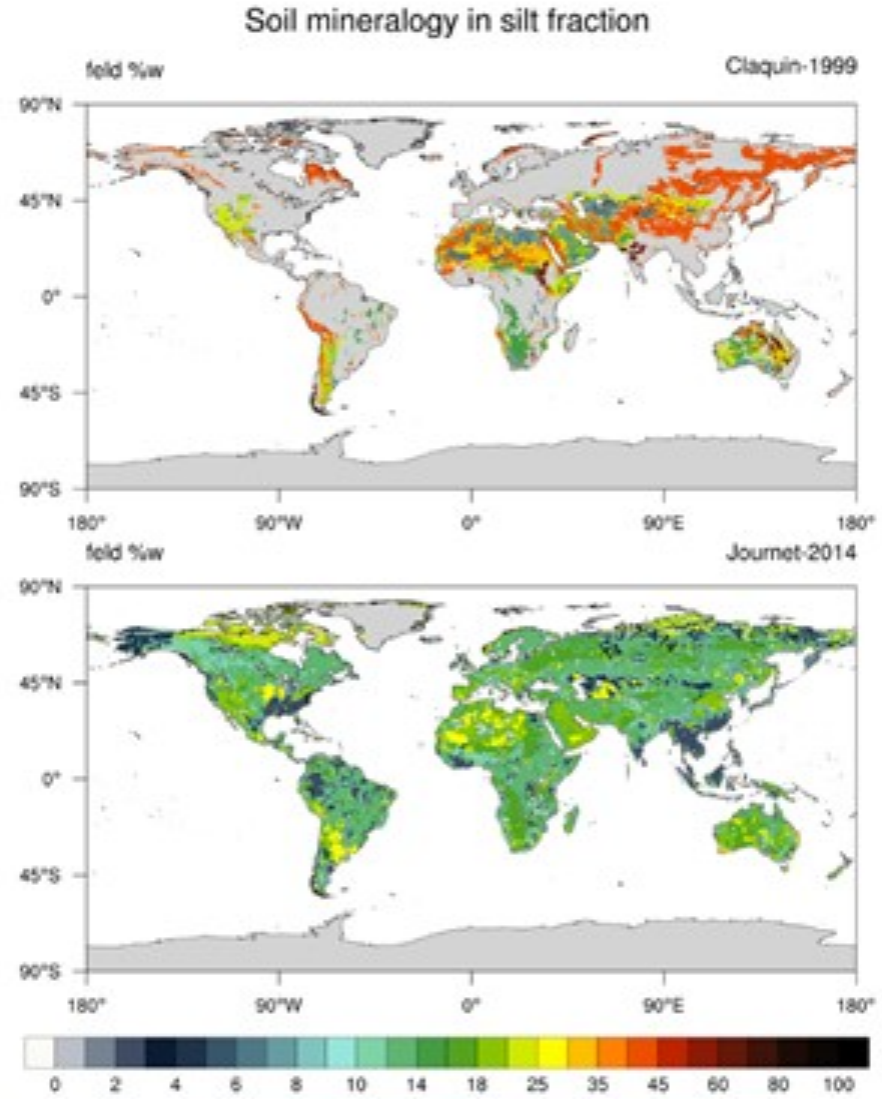
Secondary electron images of typical dust during the SAMUM I campaign in Morocco (Scheuvens and Kandler, 2014)

Aggregates partly *fragment* at emission by saltation and sandblasting.

Dust aerosols are composed by *internal and external mixtures* of different minerals

Iron oxides occur as both *small accretions* and pure crystalline forms.

Current state-of-the-art for mineralogy in models (soil)

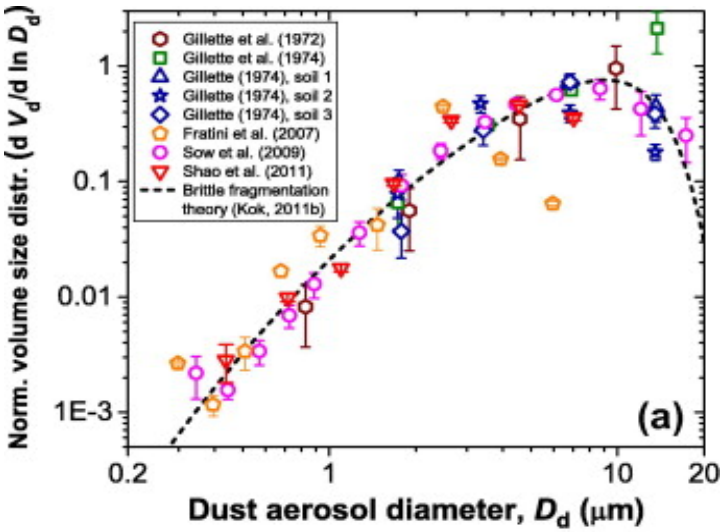


Claquin et al. (1999)

Journet et al. (2014)

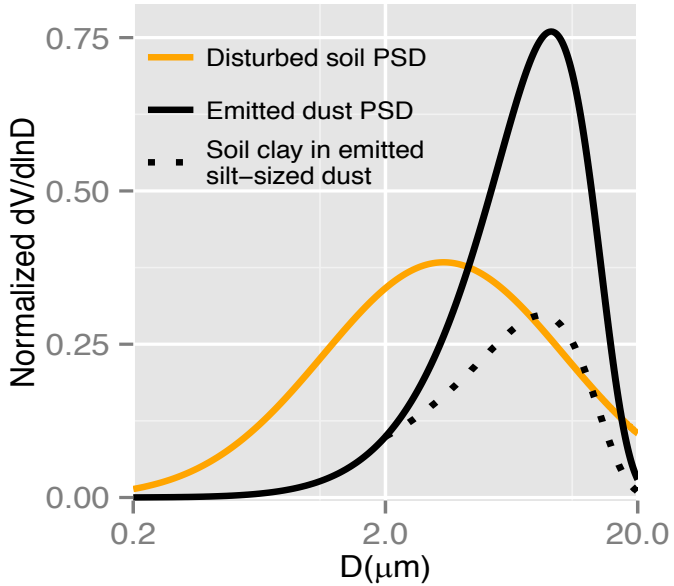
Current state-of-the-art for mineralogy in models (emitted PSD)

BFT auspicious for mineralogy as it is based on the soil dispersed PSD



$$\frac{dV}{d\ln D} = \frac{D}{C_V} u(D) \exp\left[-\left(\frac{D}{\lambda}\right)^3\right]$$

Kok (2011)

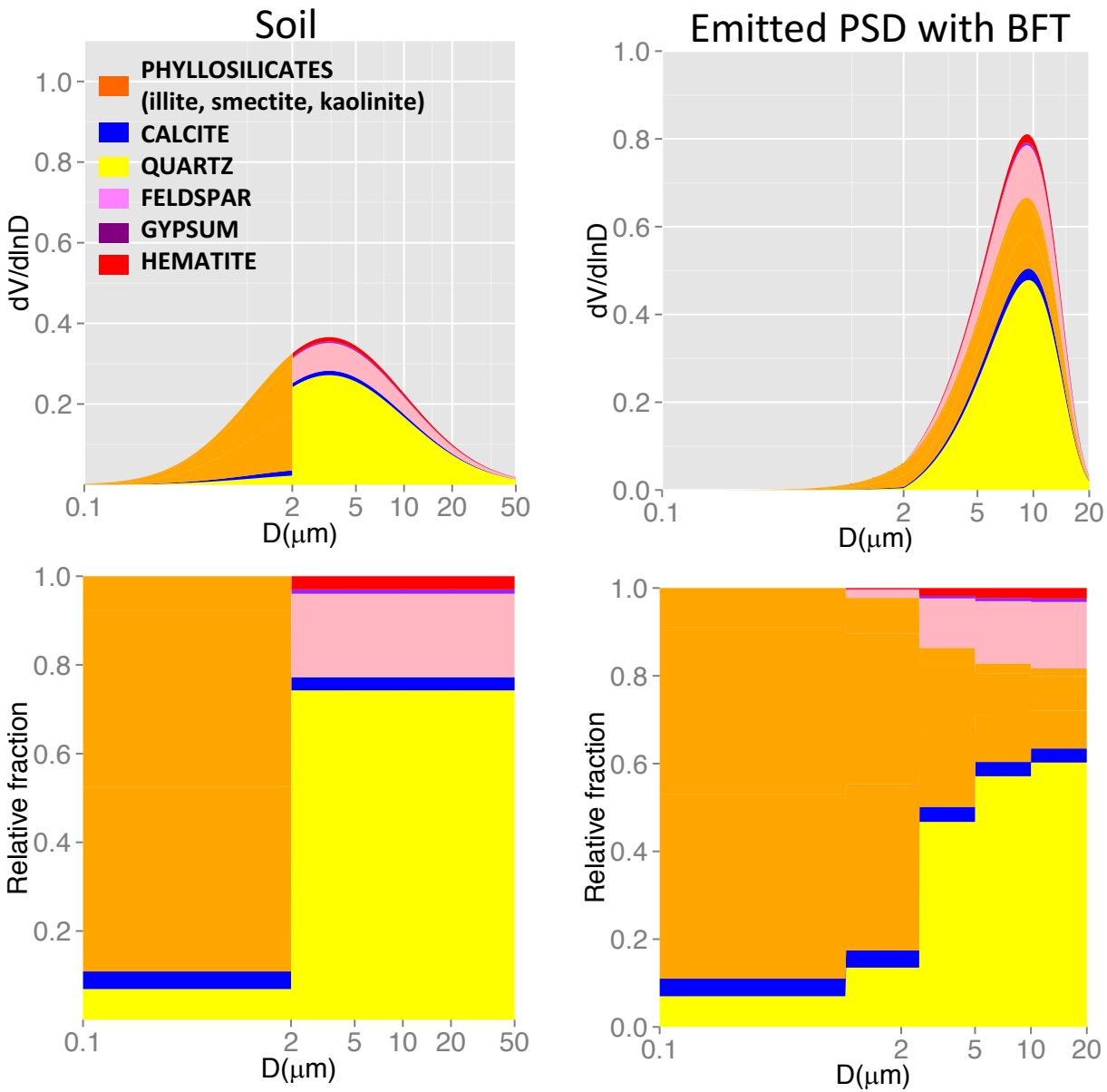


Scanza et al. (2015)

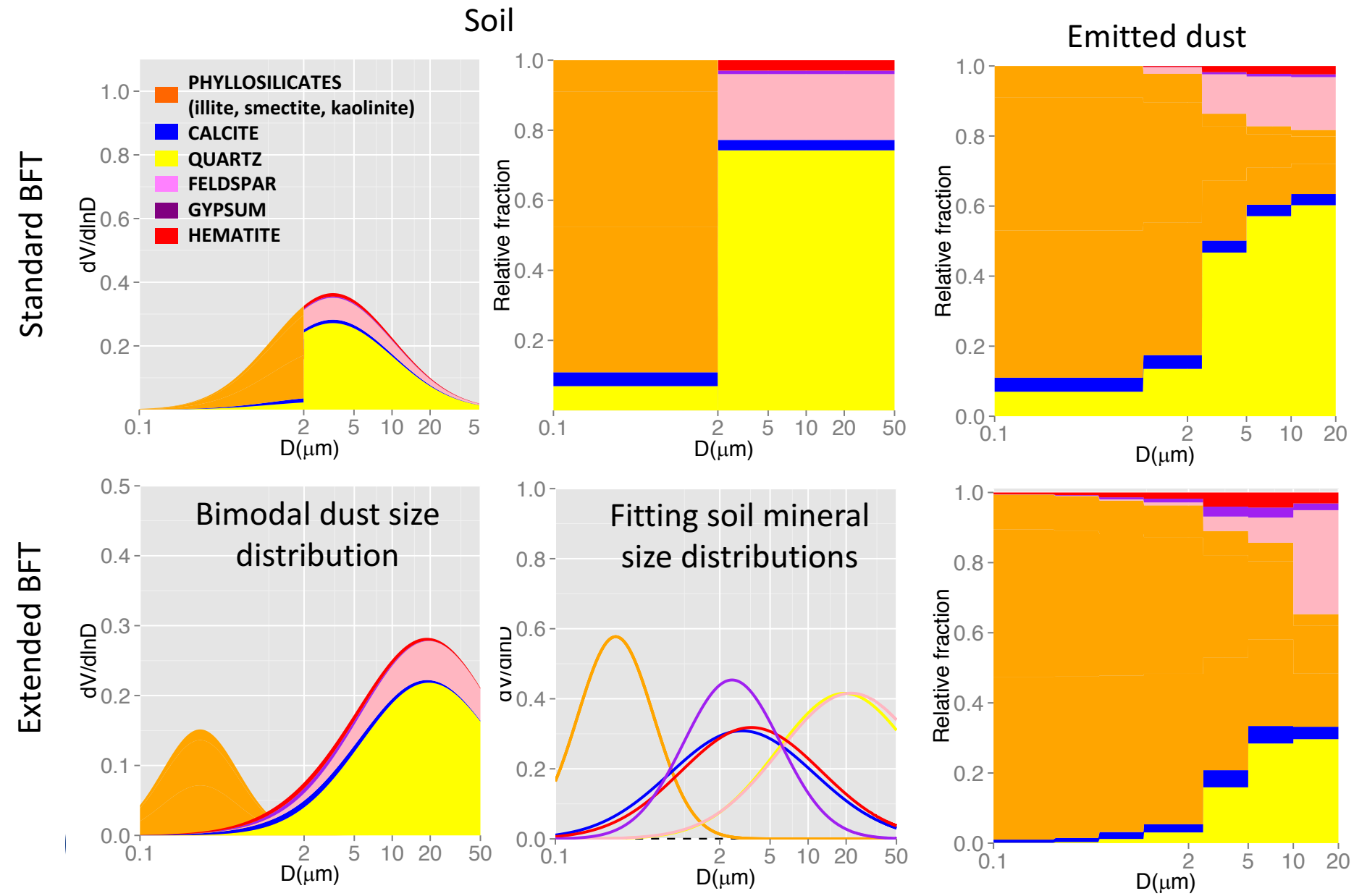
Perlwitz et al., 2015 (a,b)
Pérez García-Pando et al., (2016)

Pérez García-Pando et al., in prep

Emitted PSD and mineralogy

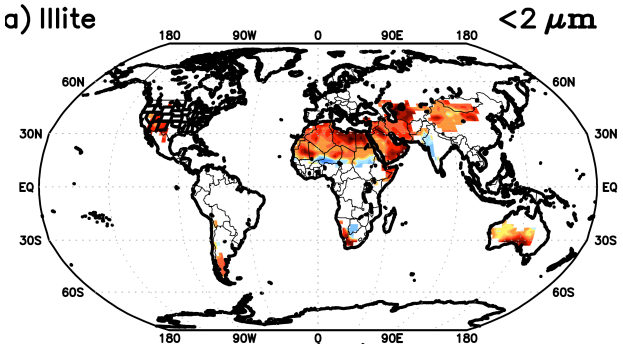


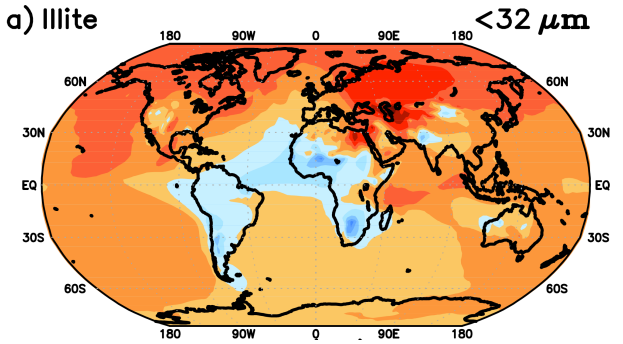
Emitted PSD and mineralogy

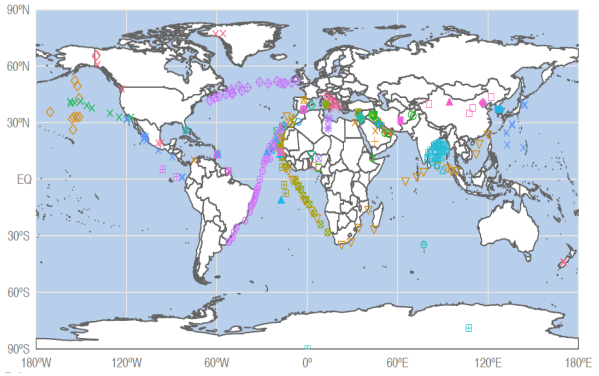


Model experiments and evaluation

- Soil composition: Claquin et al. (1999)
- NASA GISS/ModelE
- 2 x 2.5 deg, 40 layers
- 4 experiments
- Period 2002-2010, winds nudged to reanalysis
- Evaluation based on a new compilation of observations from 60 studies available in Perlwitz et al. (2015, ACP)

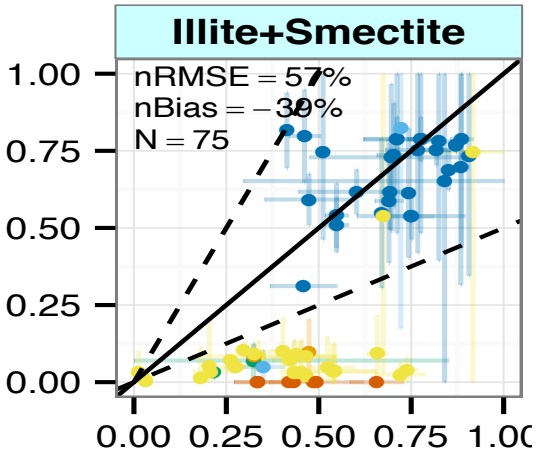


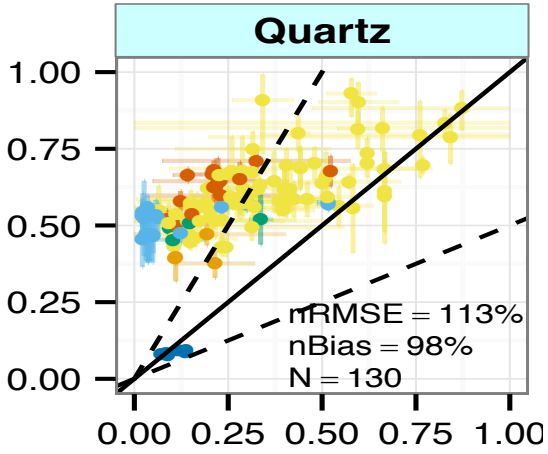




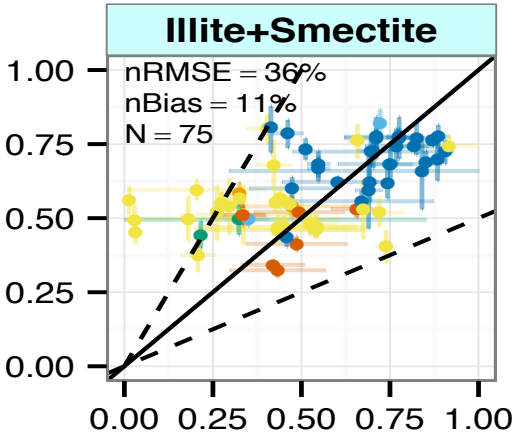
Improvements in the PSD of transported minerals

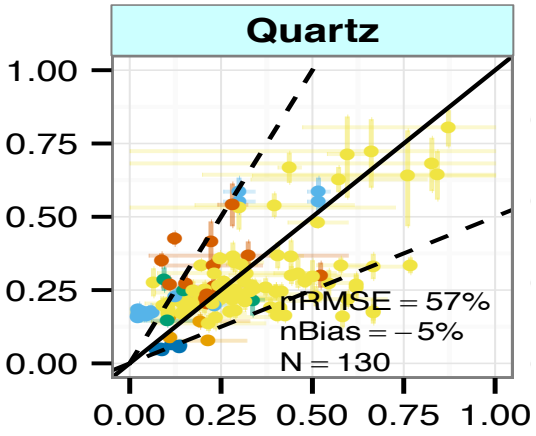
Emitted mineral fractions as in soil





BFT with extensions

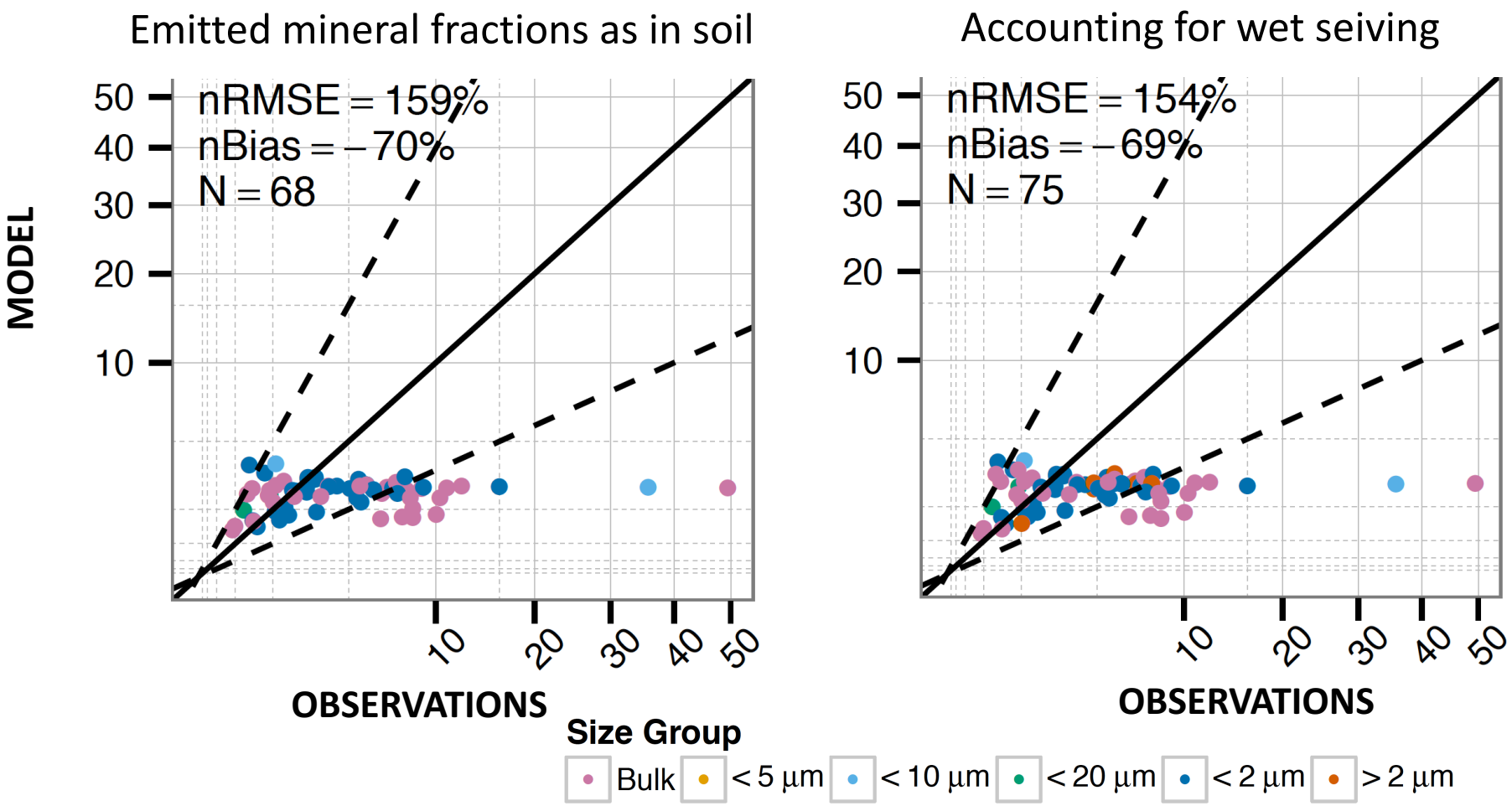




Perlwitz et al. (2015a, 2015b)
Pérez García-Pando et al. (2016)
Pérez García-Pando et al. in prep
Goncalves et al. in prep

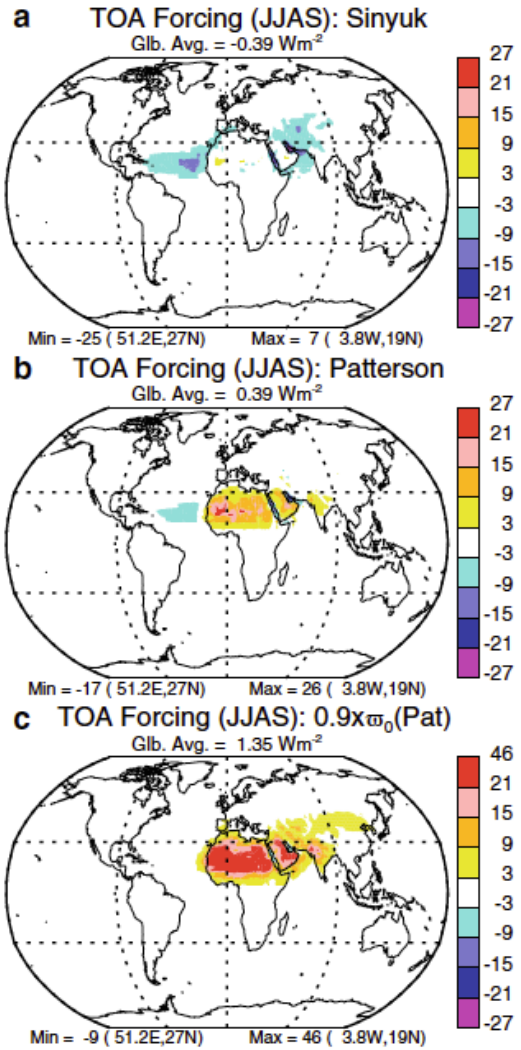
Bulk mineralogy not well captured

Illite/Kaolinite



Perlwitz et al. (2015b)

Modeling optical properties and direct radiative effect

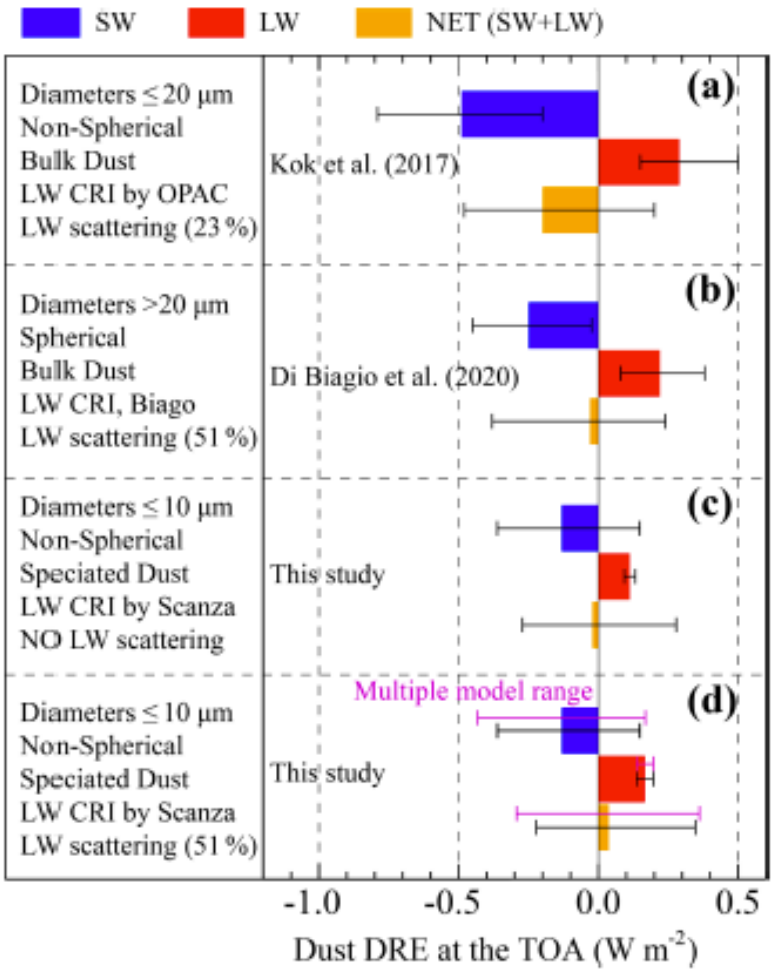


More scattering dust

More absorbing dust

Miller et al. (2014)

DRE uncertainty due to soil mineralogy



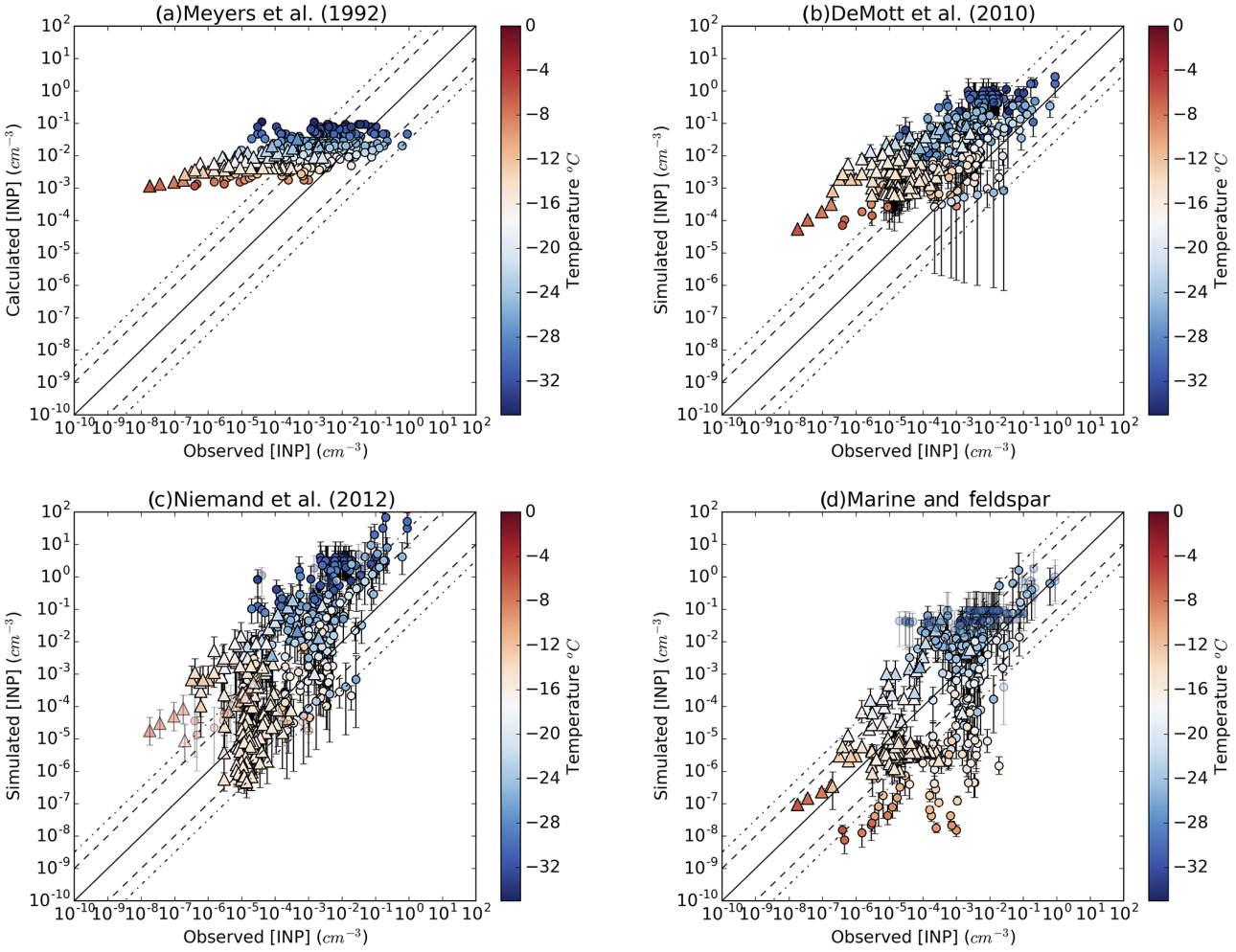
Today, when using mineral speciation in models:

- The global net TOA DRE is estimated to be -0.23 to +0.35 m^2 due to soil mineralogy uncertainty

- 97 % of this range is related to the abundance of iron oxides

Li et al. (2021)

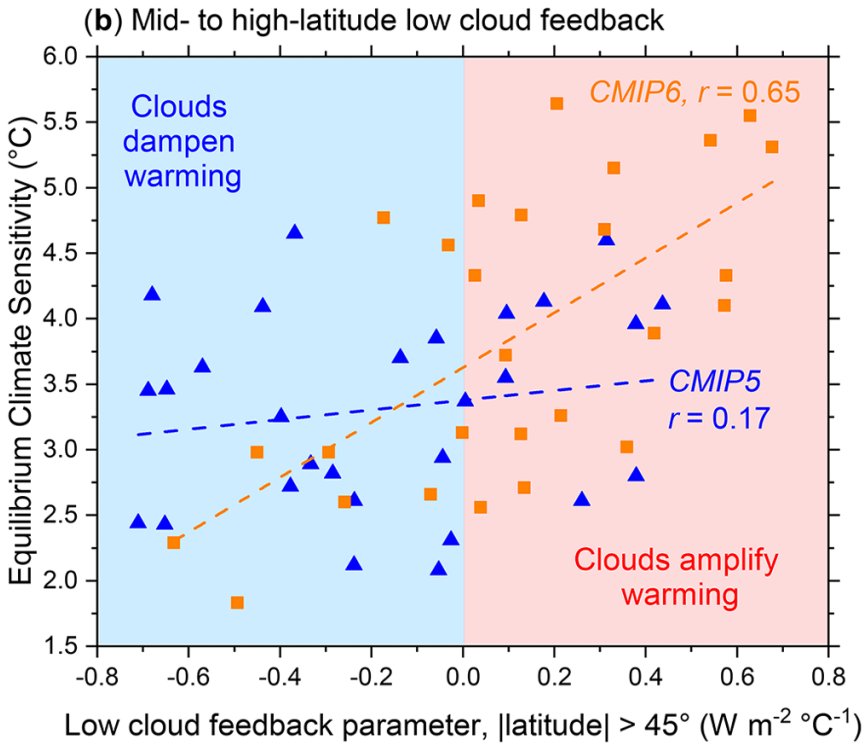
Modeling Ice nucleating particles



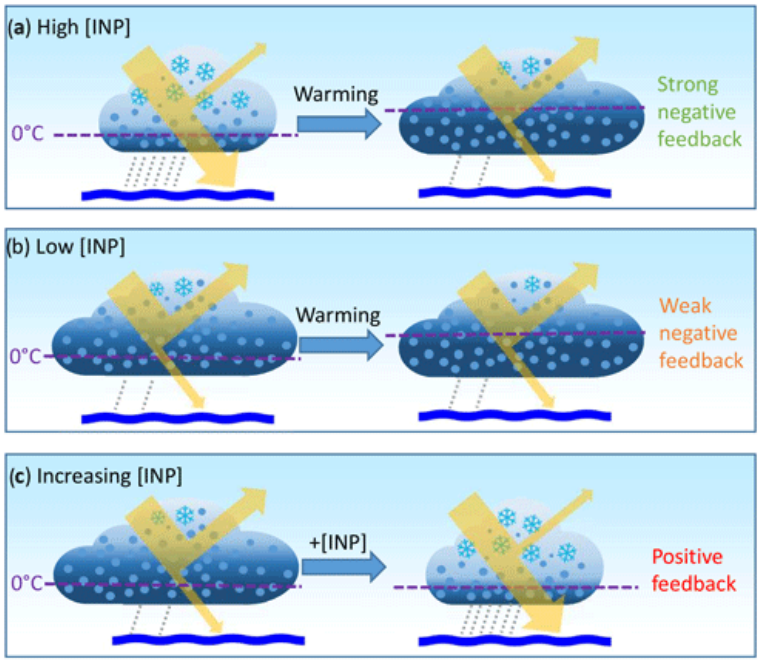
Vergara-Temprado et al. (2017)

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Importance of INP for cloud-phase climate feedback



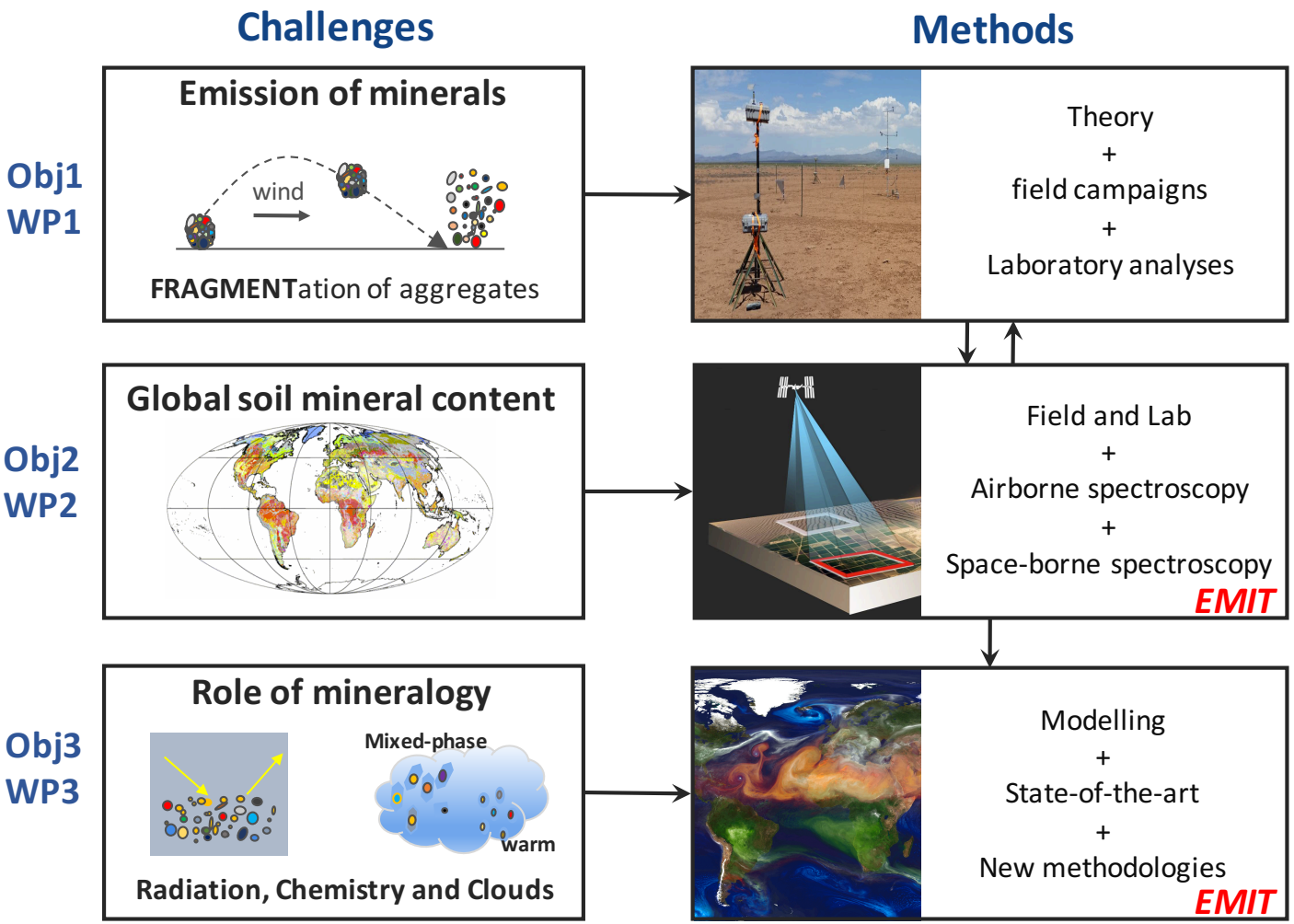
Zelinka et al. (2020)



Murray et al. (2021)

Understanding dust, its size-resolved feldspar content and dust emission changes will be key to constrain this important feedback

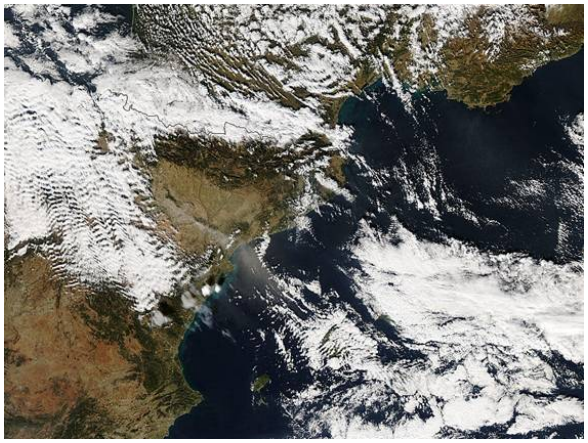
ERC FRAGMENT PROJECT



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Field campaigns (plan before COVID-19)

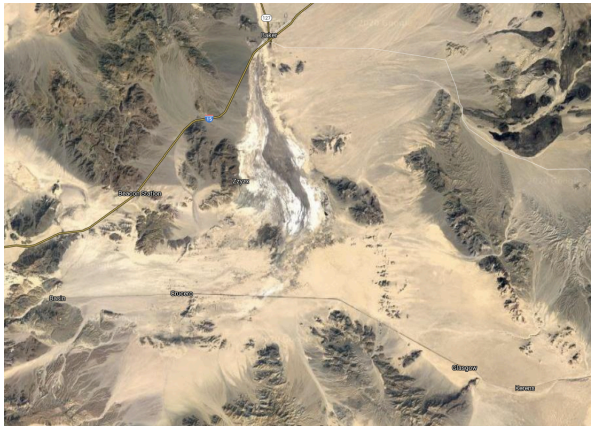
Testing in Aragón, Spain 2019



M´Hamid, Morocco Sept-Oct 2019



Mojave Desert, Spring 2020



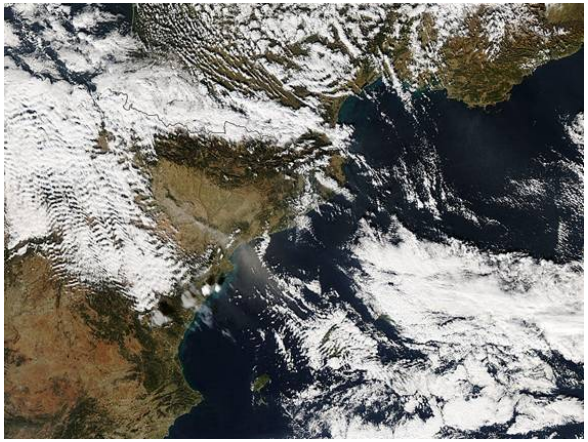
Icelandic sources (HiLDA!) August-Sept 2020



……Erfoud, Morocco in 2021-2022

Field campaigns (current plan)

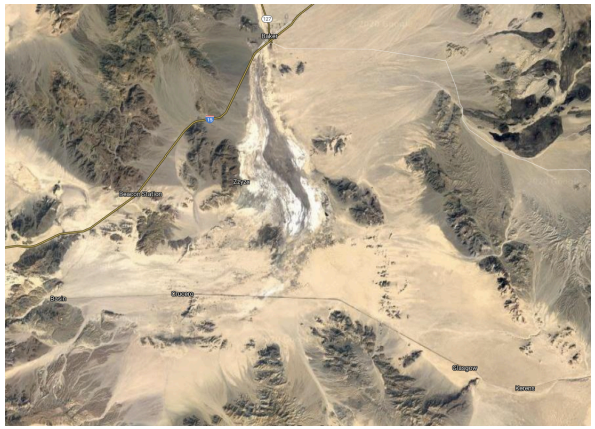
Testing in Aragón, Spain 2019



M´Hamid, Morocco Sept-Oct 2019



SouthWest US, Spring 2022
Only soil sampling and spectr



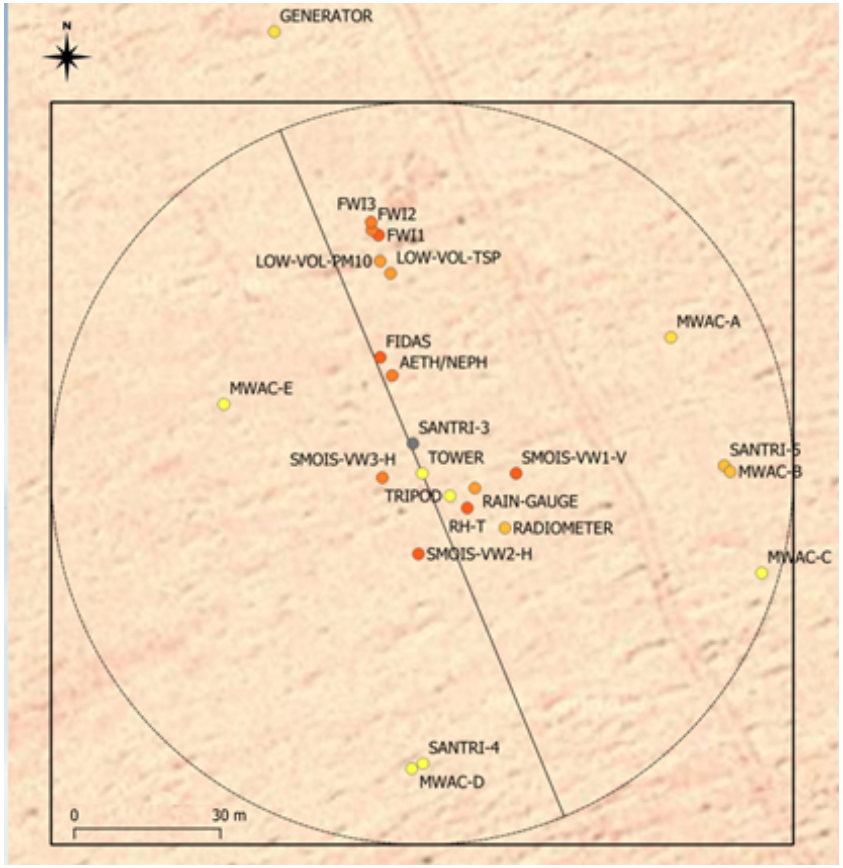
Icelandic sources (HiLDA!) August-Sept 2021



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……Erfoud, Morocco in 2022 (combined with other projects)

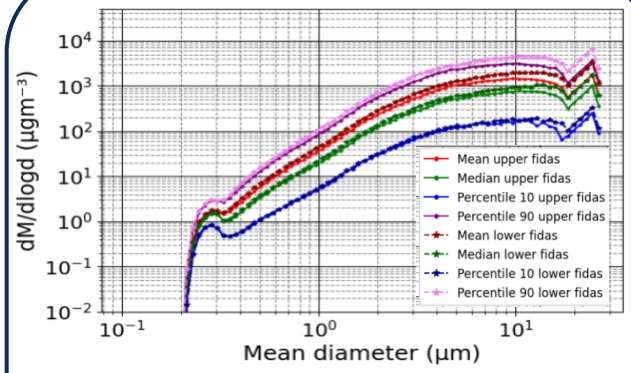
Campaign in L'Bour (M'Hamid)



- Meteorological tower of 10 m height holding wind and temperature sensors.
- Optical Particle Counters (Welas & Fidas) ~0.2 - ~ 20µm.
- Polar Nephelometer (AURORA4000 Ecotech) for aerosol scattering.
- Aethalometer (AE33 Acgee Scientific) for optical absorption.
- Multistage cascade impactors (MOUDI) for size-resolved particle collection.
- Free wing impactors for collection of fine and coarse particles.
- Flat plate deposition sampler.
- Low-volume sampler for Total Suspended Particulates (TSP).
- Modified Wilson and Cooke samplers (MWACs) to sample sediment transported in saltation.
- SANTRI (Standalone AeoliaN Transport Real-time Instrument) platforms to provide time and size-resolved counts of particles transported in saltation.
- Penetrometer for soil plastic pressure.
- Reflectometers for soil water content.
- Four component net radiometer for radiative fluxes.
- Tipping bucket rain gauge to measure precipitation.
- ASD spectrometer

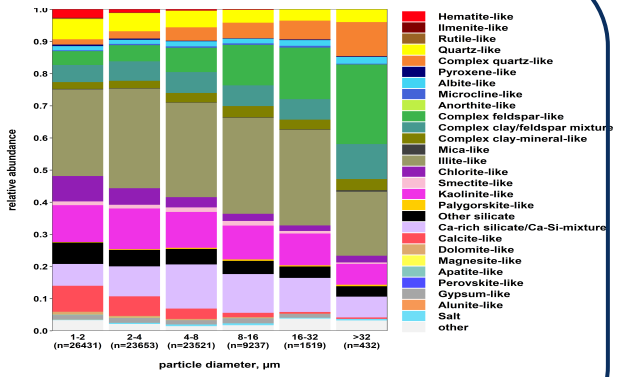
Some results from Morocco

Size distribution at emission



Coarser PSDs during haboob events

Mineralogy

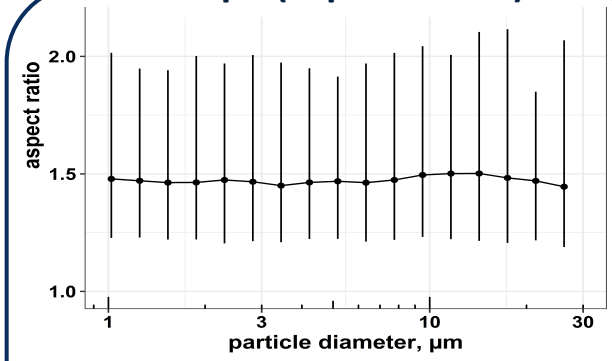


Clear size dependencies of key minerals

Measurements

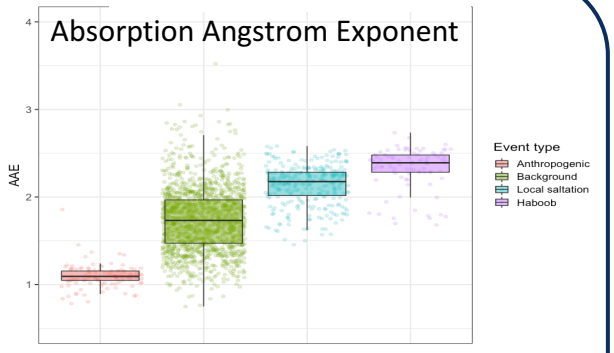
- Regional and local soil-surface sampling and spectroscopy
- Atmospheric forcing, radiative fluxes, size distributions, dust fluxes size segregated samples, saltation, scattering, absorption
- Lab: soil and dust, SEM (single particle analysis, composition, size, shape), X-ray diffraction (mineralogy), X-ray fluorescence (chemistry), spectroscopy

Shape (aspect ratios)



Small dependency on size and mineralogy

Optical properties



Distinct optical properties - type of event

Ongoing

- Quantitative iron speciation
- Comparison with spectroscopy
- Size-resolved dust fluxes and variability
- Relationship between wet and sieved soil size and mineralogy vs emitted size and mineralogy
- Discrimination of size and mineralogical dependencies in optical properties
- Dust emission schemes
- More campaigns!

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Key points

- Global VSWIR imaging spectroscopy will drastically improve our knowledge of Earth surface mineral dust source composition
- … but many challenges remain:
- How to use the new dataset and deal with its intrinsic (and new) limitations
- We have to rethink the methods to constrain the emitted mineral size distributions
- Optical constants of individual minerals are still uncertain and we need new efforts. Particularly problematic for iron oxides
- Optical properties: shape, coarse particles, composition, internal mixing
- Widespread measurements for evaluation are missing (also for INP)
- What is the minimal representation of mineralogy for climate models



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Established by the European Commission

AXA Research Fund

Questions?

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