Constraining dust mineral and elemental composition in climate models

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Improved estimates of dust aerosol effects upon climate require the characterization of the regional and temporal variability of dust mineral and elemental composition (typically assumed to be uniform in current climate models).

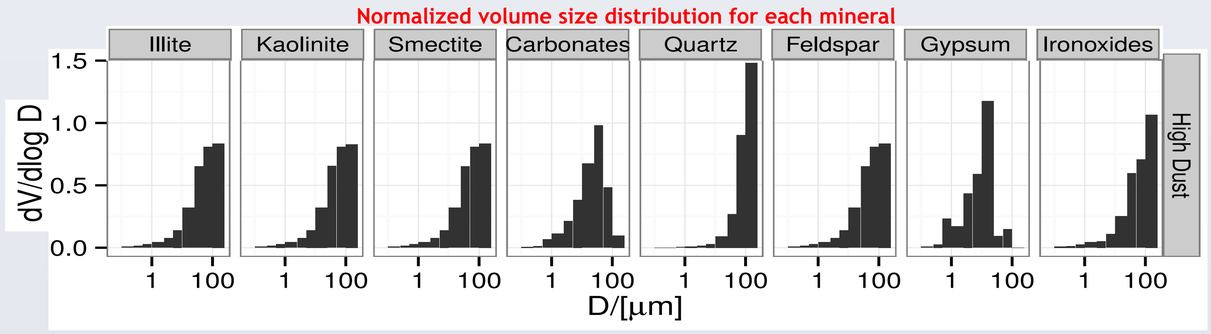
CHALLENGES

- Soil mineral grains and aggregates fragment during emission through saltation and sandblasting of the soil bed. These processes modify the size distribution and abundance of mineral phases of the emitted aerosols compared to the parent soil.
- Global datasets of soil texture and composition are based on wet sieving, a technique that breaks the aggregates that are encountered in natural soils, drastically altering the original soil size distribution that is subject to wind erosion
- Aggregation state and advection of Iron oxides to remote locations is uncertain.
- Observations are scarce and typically episodic.

A SEMI-EMPIRICAL METHOD

- Aerosol measurements show the presence of clay minerals in the silt size range, and the presence of feldspar, iron oxides, and gypsum in the clay size range.
- We constrained the dust size distribution using a normalized volume size distribution for each mineral derived from observations at one location (Kandler et al. 2009).
- With the exception of Iron Oxides, each mineral tracer is transported independently. Iron Oxides have high densities and they are found as impurities/aggregates on the surface of other minerals after long-range transport.
- We calculated the partition of Iron oxides into aggregated and unaggregated dust aerosols based on their mass fractions in the soil, i.e., we assume that the probability of aggregation depends on soil weathering.

Normalized volume size distribution for each mineral

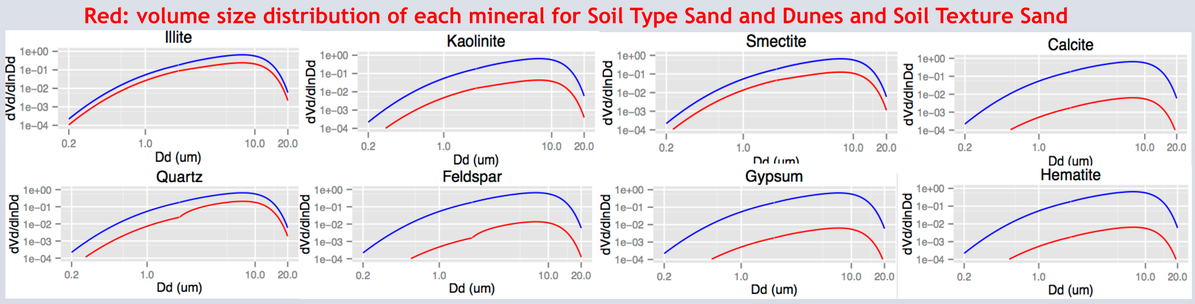


A THEORETICAL METHOD

- We extended the brittle fragmentation theory of Kok (2011) to estimate the size distribution of each mineral for each soil texture and soil type.
- In the original theory of Kok (2011) the number of aggregates of diameter D suffering fragmentation are proportional to the volume fraction of soil disturbed particles with diameters < D, and dust emission is predominantly due to fragmenting impacts. This work assumed an average disturbed soil size distribution based on measurements.
- We reconstructed the disturbed and undisturbed size distribution for each mineral as a function of soil texture and soil type and calculated the emitted size distribution applying brittle fragmentation assuming homogeneous fragmentation properties for the mineral aggregates.
- As before, the partition of Iron oxides into aggregated and unaggregated dust aerosols depends on soil weathering

Blue: normalized dust volume size distribution

Red: volume size distribution of each mineral for Soil Type Sand and Dunes and Soil Texture Sand

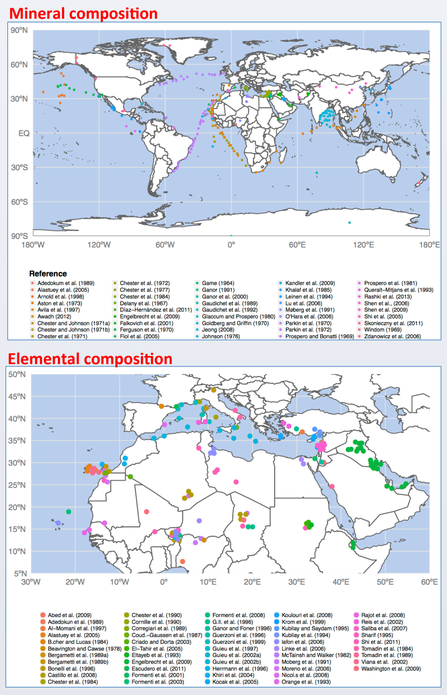


DATASETS

1. FAO-UNESCO Digital Soil Map of the World providing global soil types
2. Mean Mineralogical Table (MMT) by Claquin et al. (1999) providing the (wet sieved) mass fractions of 8 minerals in the clay and silt size ranges of the soil for 28 arid soil types
3. FAO/STATSGO Soil Texture Types providing the (wet sieved) fractions of clay and silt in soil

Clay fraction (0-2 μm)	Silt fraction (2-50 μm)
Illite	Iron oxides
Kaolinite	Gypsum
Smectite	Feldspar
Carbonates	Carbonates
Quartz	Quartz

COMPILATION OF MEASUREMENTS AND EVALUATION



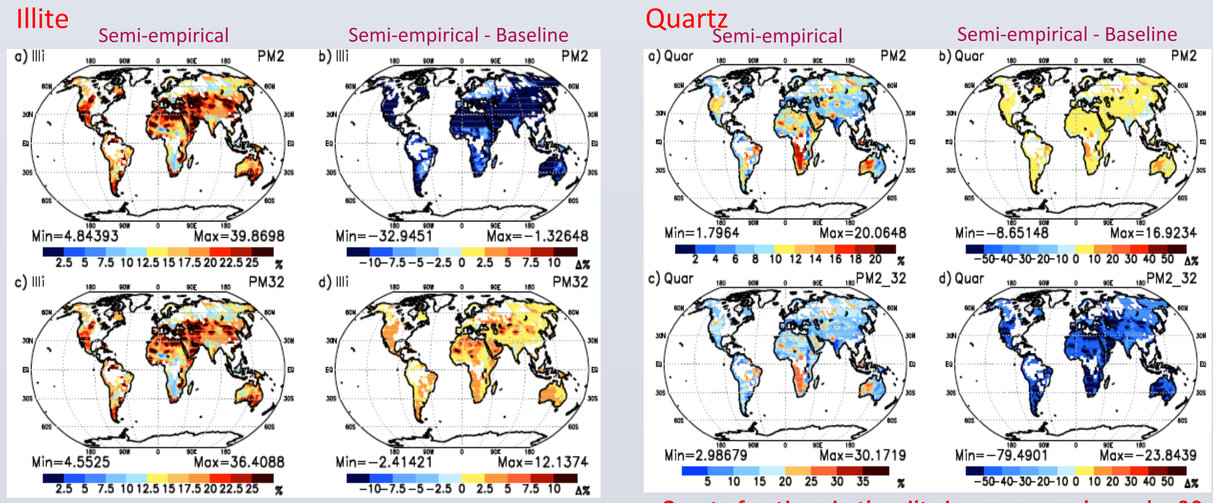
- We compiled mineral and elemental composition observations from literature.
- We used monthly and yearly model output for the comparison.
- Mineral composition measurements were renormalized.
- We compared multiple size ranges including fine, coarse, super-coarse and total suspended particles (TSP)
- Many measurements are TSP and they include dust with particles sizes beyond the upper limit of 32 μm of our largest model size bin.
- When a sufficient sample size was available, we calculated confidence intervals for the observations assuming a Beta distribution of the data and using the method of moments for the derivation, since the mineral fractions are bound by zero and one.
- In addition to the confidence intervals of the measurements, we calculated two types of confidence intervals for the model data (one based on the monthly standard deviation and another constructed as an approximation to the unknown standard deviation of samples of data using the central limit theorem.
- We also used 9 years of size-resolved dust and elemental composition measurements at the Izaña Observatory

EXPERIMENTS

- We present the results of 3 simulations constrained by reanalysis covering the period 2002-2010.
- The BASELINE experiment assumes that the soil clay and silt mineralogy obtained after wet sieving is a reasonable estimate of the size-resolved mineralogical composition of the suspended dust.
- The SEMI-EMIRICAL and THEORETICAL experiments are run with approaches representing the aggregation of particles in the soil and their fragmentation during emission.

Illite — Semi-empirical | Semi-empirical - Baseline

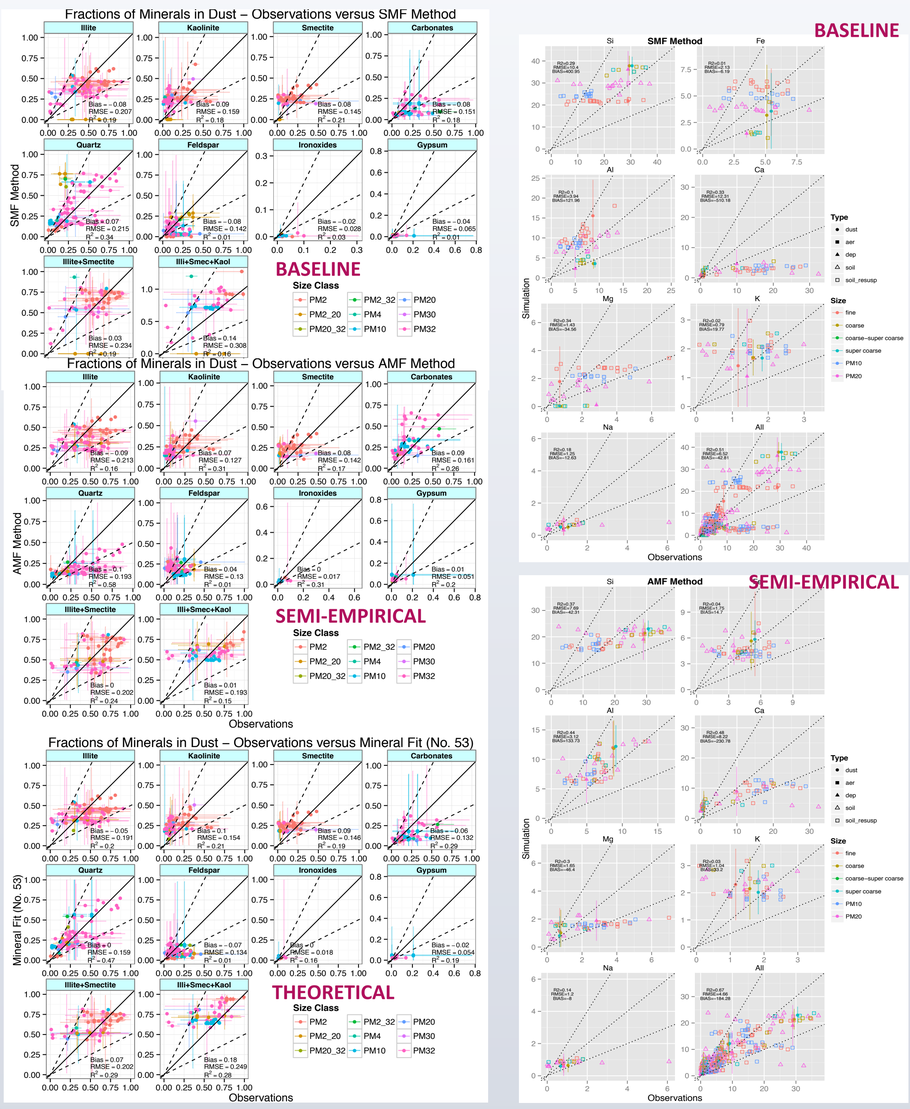
Quartz — Semi-empirical | Semi-empirical - Baseline



Clay in the emitted silt size range can be very high, up to 70-80 %.

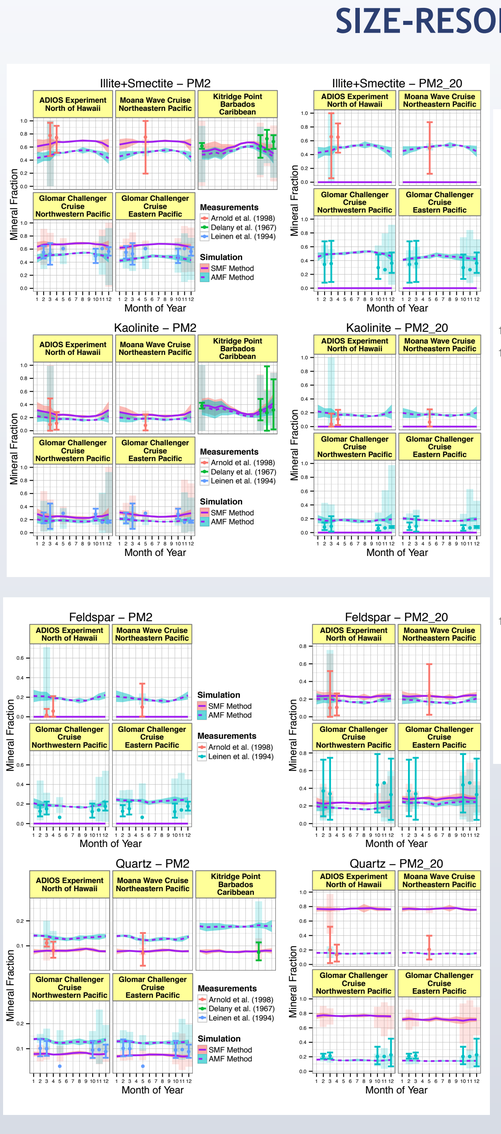
Quartz fractions in the silt size range are lower by 30 to 60%, globally, with respect to wet sieved soil.

MINERAL AND ELEMENTAL COMPOSITION



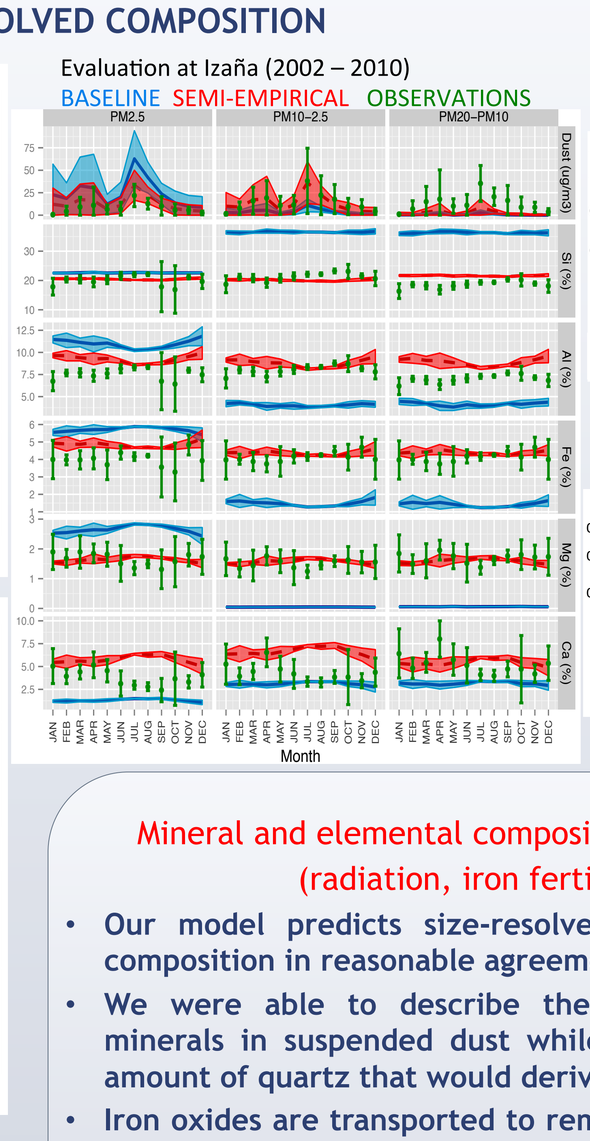
BASELINE

SIZE-RESOLVED COMPOSITION



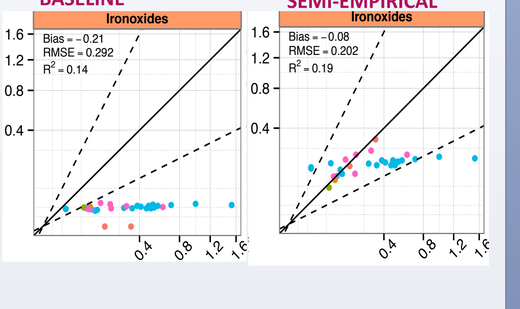
Evaluation at Izaña (2002 – 2010)

BASELINE SEMI-EMPIRICAL OBSERVATIONS

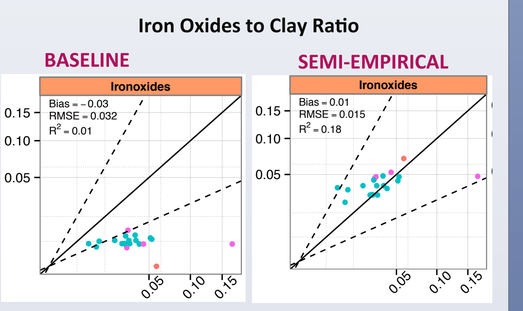


IRON OXIDES

Iron Oxides to Quartz Ratio



Iron Oxides to Clay Ratio



Mineral and elemental composition are key to dust effects (radiation, iron fertilization, clouds)

- Our model predicts size-resolved dust mineral and elemental composition in reasonable agreement with limited observations.
- We were able to describe the observed aggregation of clay minerals in suspended dust while reducing the disproportionate amount of quartz that would derive from a disturbed soil.
- Iron oxides are transported to remote locations in agreement with observations.
- These methods can be tested with a recently published (wet sieved) soil mineral database (Journet et al. 2014)

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