Linking dust observations from space-borne hyperspectral infrared sounders with alluvial source regions through particle size and dust mineralogy

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Optical properties of desert dust from different sources

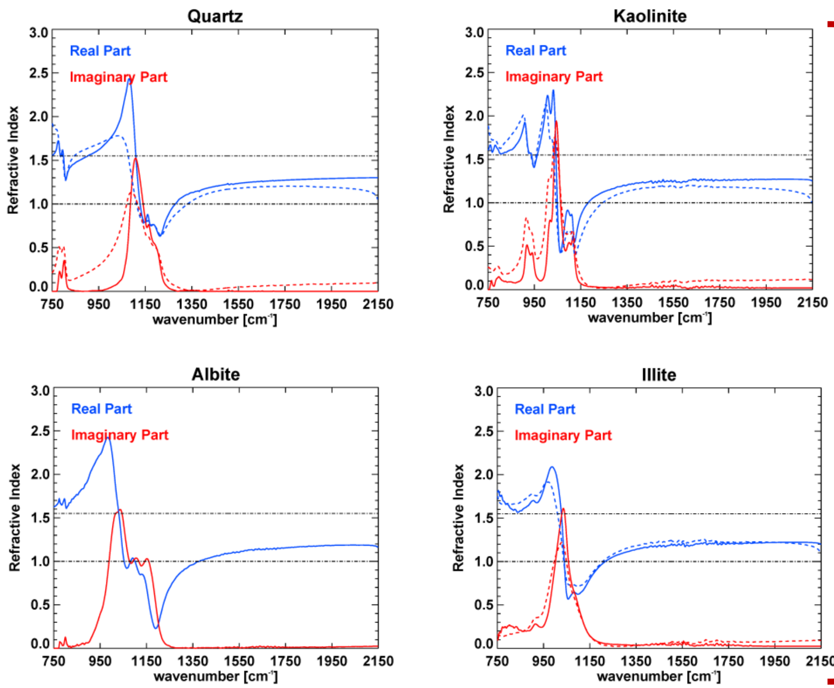
source region determines mineralogy and thus optical properties

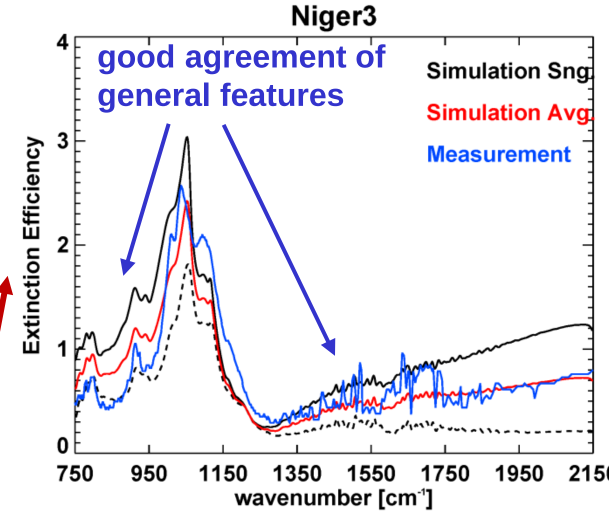
FTIR extinction measurements, dust particles in Rayleigh mode

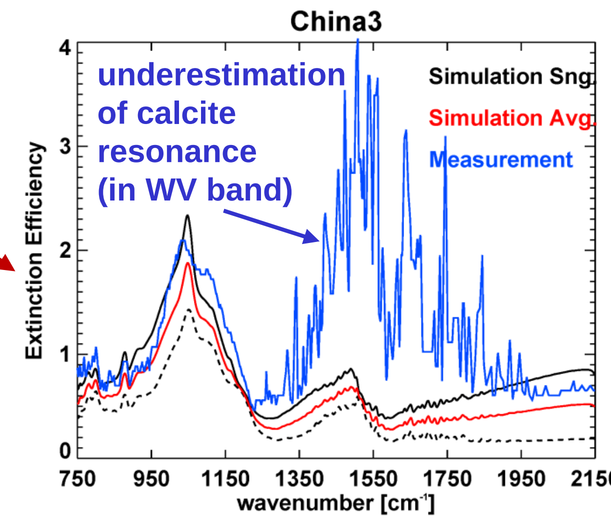
$$n_i(\lambda) = -\frac{3\lambda\beta_e(\lambda)}{16\pi^2 N r_{eff}^2}$$

$$n_r(\lambda) = 1 + \frac{2}{\pi}\int_0^\infty \frac{\left(\frac{2\pi c}{\Lambda}\right) n_i(\Lambda)}{\left(\frac{2\pi c}{\Lambda}\right)^2 - \left(\frac{2\pi c}{\lambda}\right)^2}\, d\Lambda$$

extinction simulations for bulk dust







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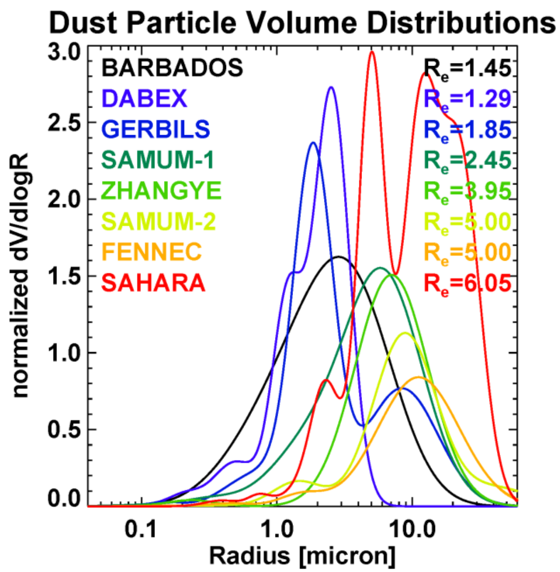
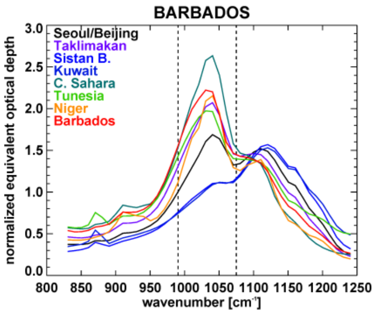
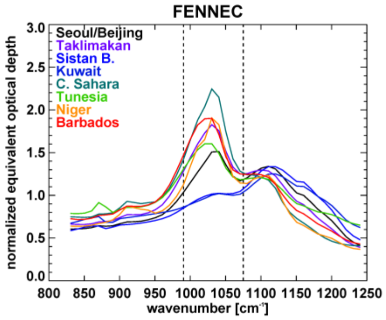
Signal impact of varying dust properties

	Quartz	Illite	Kaolin.	Smectite	Anhydrite	Calcite	Feldsp.
Seoul/Beijing	31.7%	11.2%	1.5%	28.0%	0.0%	0.0%	14.8%
Taklimakan	19.4%	32.1%	2.0%	27.0%	1.0%	5.1%	13.3%
Sistan Basin	42.8%	10.9%	0.0%	0.0%	2.1%	25.6%	18.6%
Kuwait	30.6%	2.4%	0.4%	4.6%	6.7%	45.1%	10.2%
Central Sahara	1.4%	31.3%	16.2%	33.6%	0.0%	8.8%	8.7%
Tunesia	15.0%	40.0%	0.0%	7.0%	0.0%	38.0%	0.0%
Niger	20.0%	25.0%	40.0%	6.0%	0.0%	2.0%	0.0%
Barbados	14.8%	64.8%	7.4%	0.0%	0.0%	7.2%	5.8%







knowledge (assumptions) needed about:

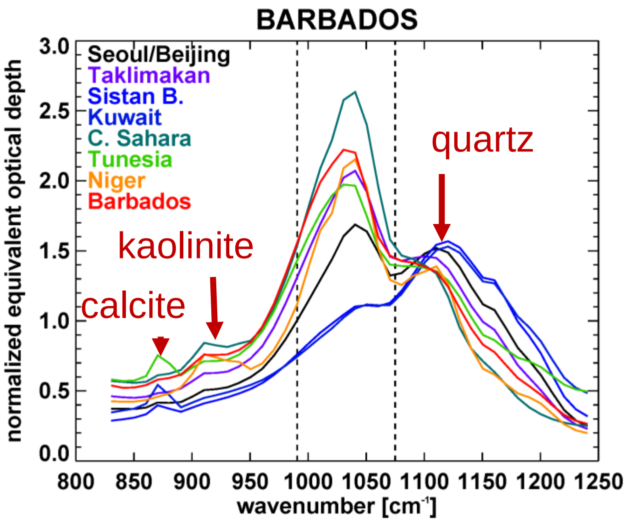
- dust composition
- dust size distribution
- optical properties

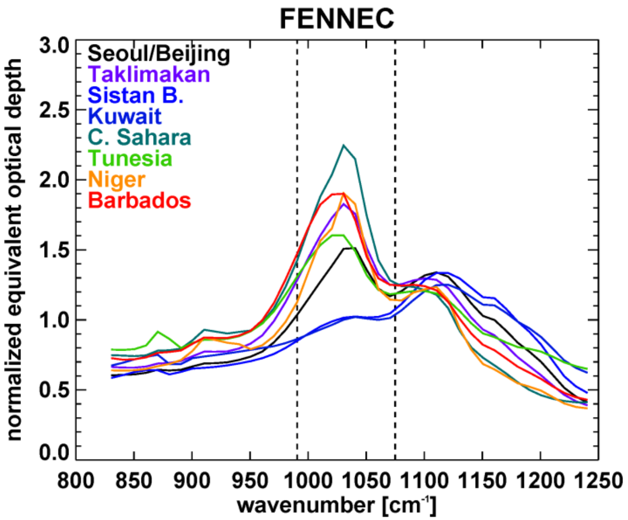
Describing the dust signal for satellite retrieval

8 size modes
(from campaign measurements)

8 mineralogical mixtures
(from measurements at ground and airborne)

- 7 mineral components
(quartz, illite, kaolinite, montmorillonite, feldspar, calcite, gypsum)
- optical properties: Mie calculations with nonsphericity adaptation
- radiative transfer solution: δ-Twostream approximation
- probabilistic retrieval approach based on Singular Value Decomposition
- Bayesian weighting of mixtures and size distributions





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Describing the dust signal for satellite retrieval

definition of a quantity we call *equivalent optical depth* τ_{eqv}:

$$L_{obs}(\lambda) = e^{-\frac{\tau_{atm}(\lambda)}{\cos(\Theta_v)}} \varepsilon_{sfc} B_\lambda(T_{sfc}) + (1 - e^{-\frac{\tau_{aer}(\lambda)}{\cos(\Theta_v)}}) B_\lambda(T_{aer})$$

observed radiance

extinction term

surface emission

aerosol emission (neglected in initial approach)

$$\rightarrow \quad \underbrace{\ln(\varepsilon_{sfc}) - \frac{\tau_{gas}(\lambda) + \tau_{aer}(\lambda)}{\cos(\Theta_v)}}_{= -\tau_{eqv}(\lambda)} = \ln\left(\frac{L_{obs}(\lambda)}{B_\lambda(T_{base})}\right)$$

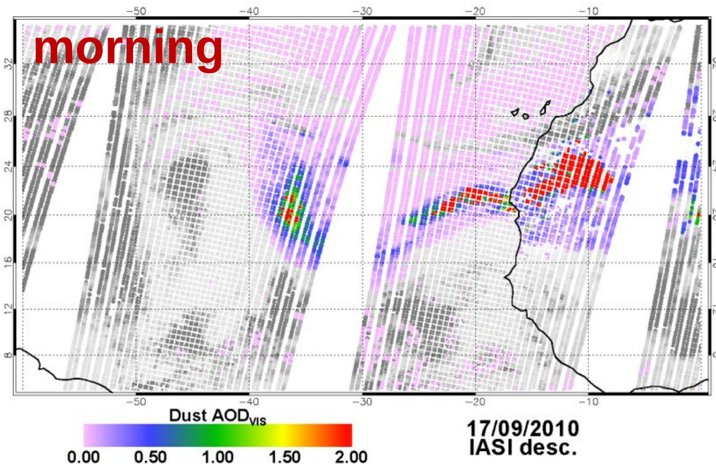
observation

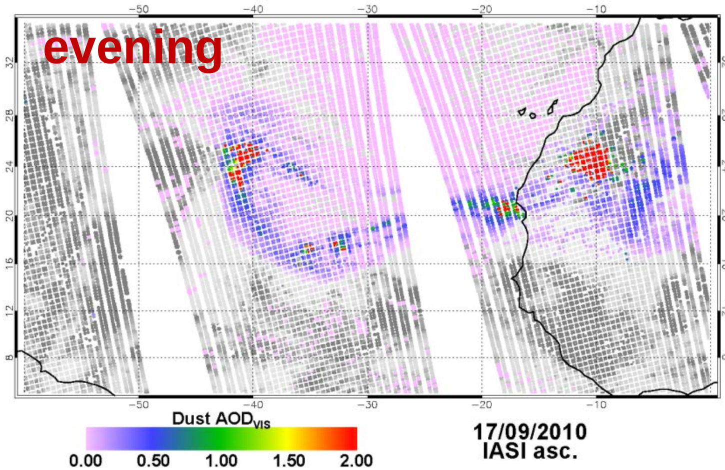
→ the problem of signal unmixing can be approached with *linear* methods

→ 35 bins with 10cm^{-1} width in TIR window regions (800cm^{-1}-1250cm^{-1})

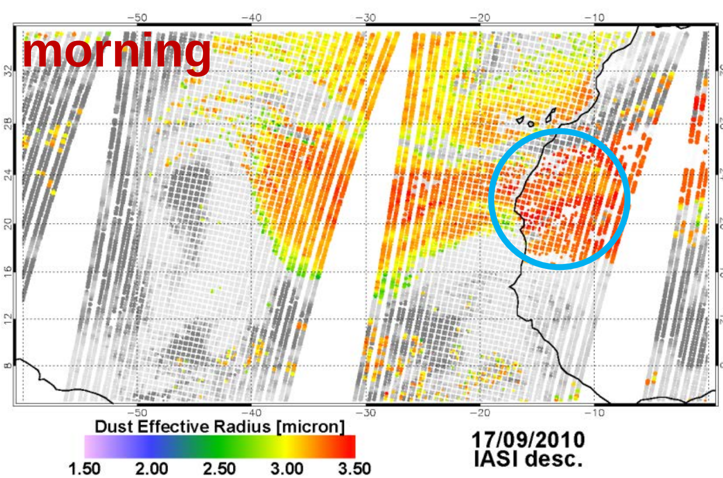
→ analysis of information content of IASI spectra and retrieval description: *Klüser et al.* (2015)

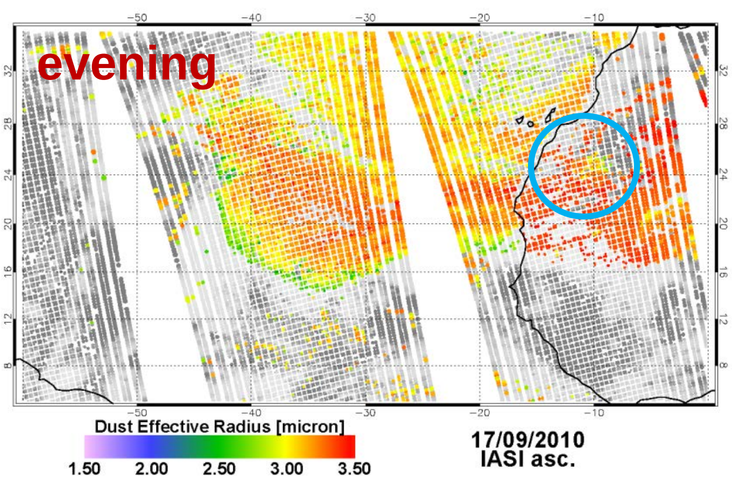
Example 1: Dust outbreak over the Atlantic Ocean





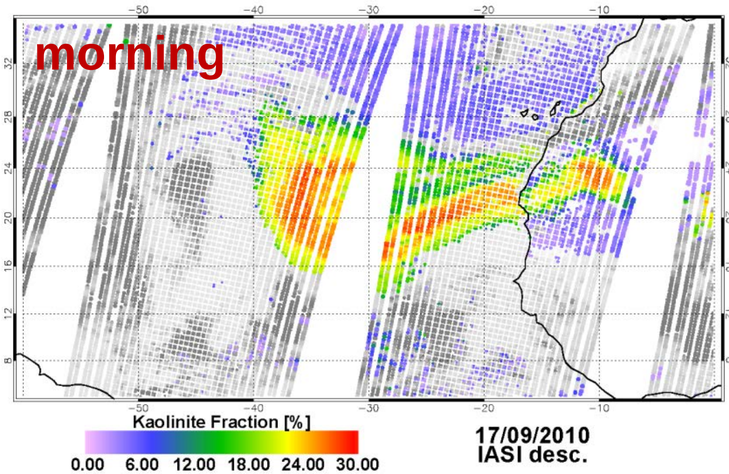
dust sources at southern margins of Atlas Mountains

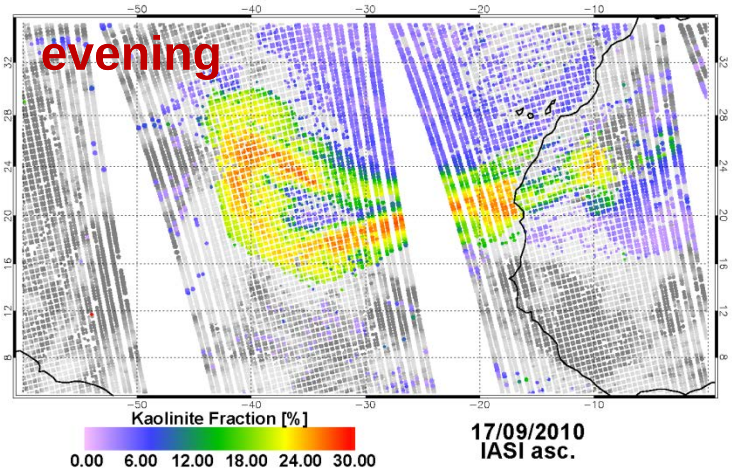




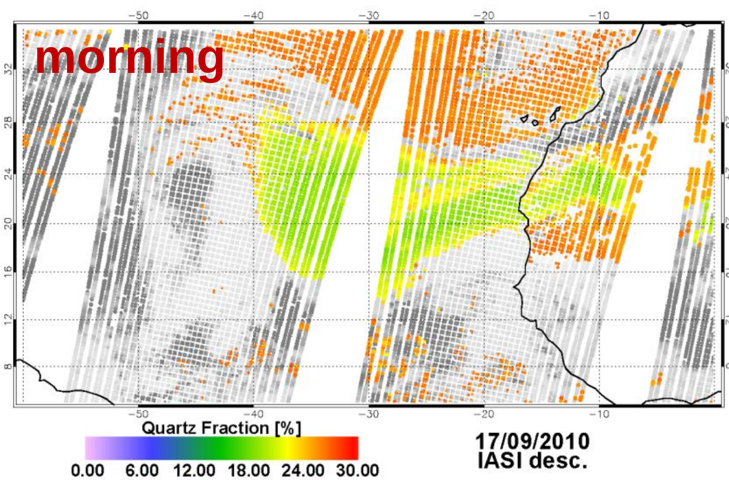
freshly emitted dust has smaller particles than the dust in sandy desert regions, but larger than pristine background

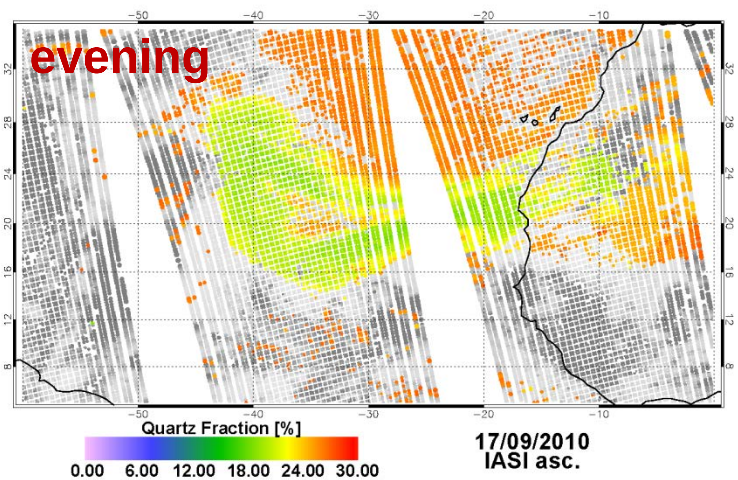
Example 1: Dust outbreak over the Atlantic Ocean





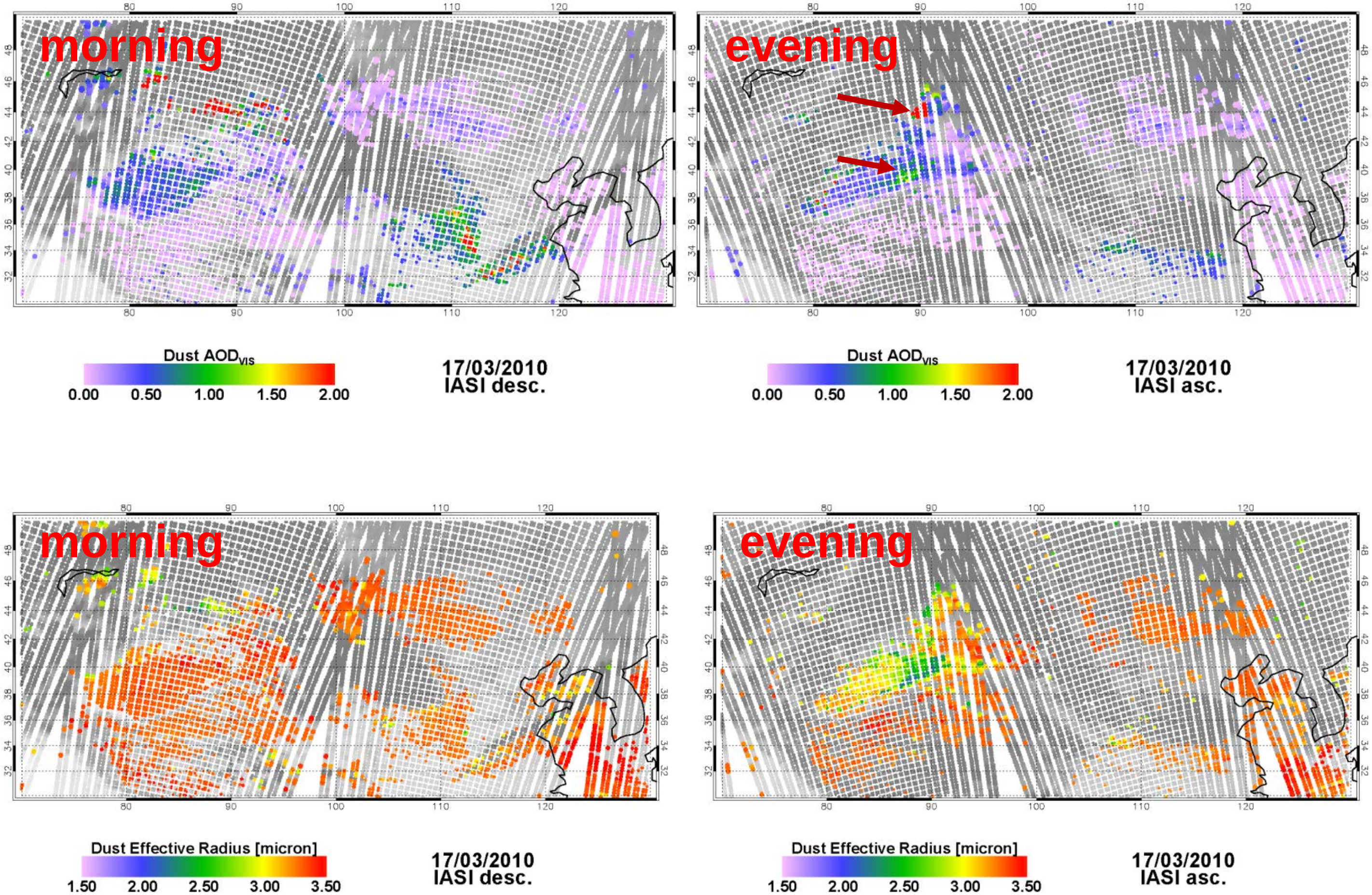
high kaolinite and low quartz fractions can be tracked from source to western margins of the dust plume





for this case kaolinite seems to be an especially well suited tracer

Example 2: Asian dust sweep

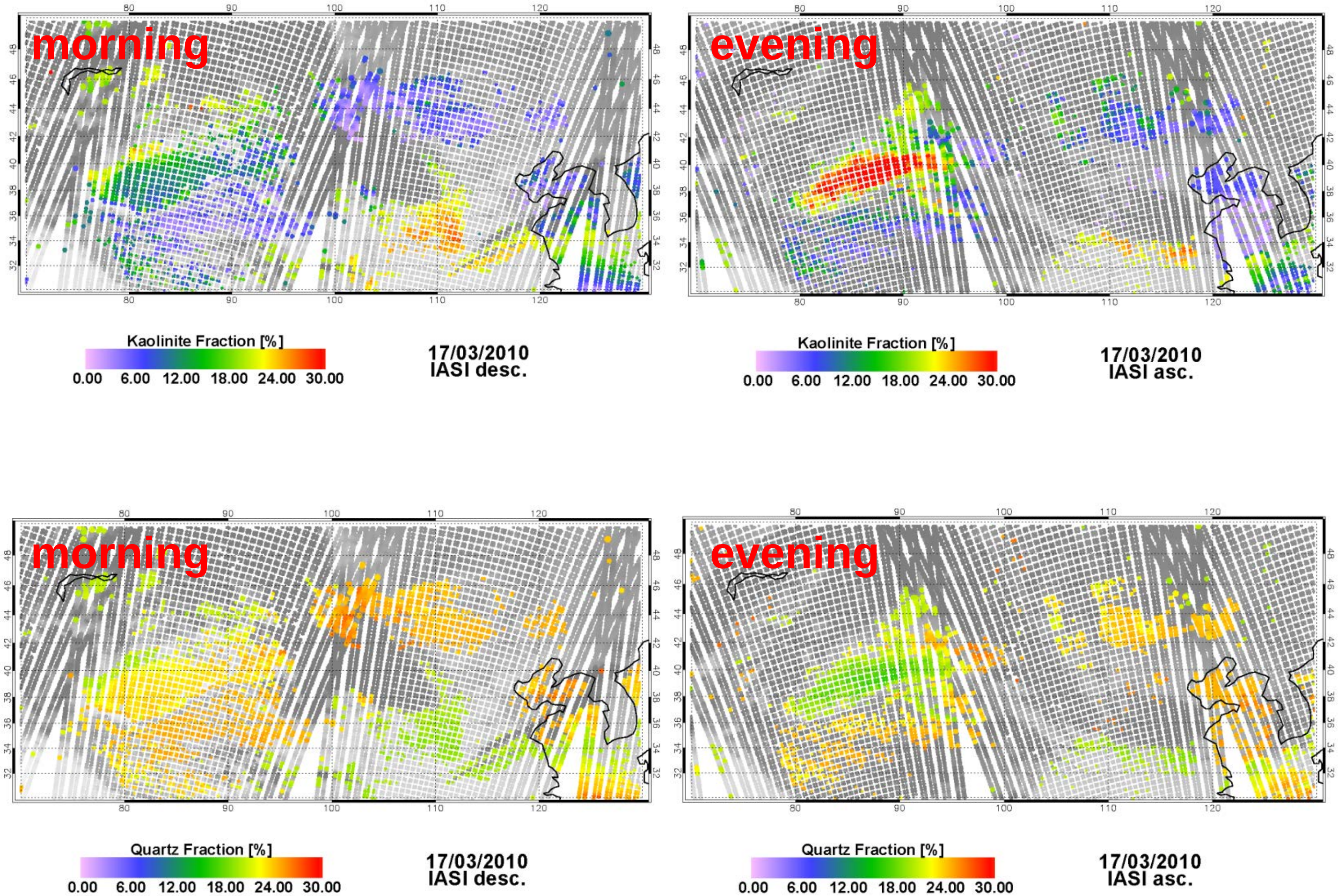


smaller particles at northern margins of Taklimakan (slopes of Tien Shan Mountains)

rapid intensification of dust sweep between morning and evening of March 17

strong aggregation of small particles in the western Taklimakan in the evening

Example 2: Asian dust sweep



the transported dust is strongly enriched in kaolinite and depleted in quartz

the source region for this dust cannot be the central Taklimakan with quartz-rich sands

alluvial basins from the slopes of the Tien Shan are the most likely source

Summary

- Refractive indices from laboratory dust extinction measurements strongly improve retrieval results compared to „classical“ refractive indices derived from reflectance measurements.
- First attempt ever to use satellite observations of dust mineralogy for dust source allocation, possible due to a novel sinular vector based probabilistic retrieval approach.
- Increased kaolinite and reduced quartz fraction points to dust from chemical weathering of feldspar bearing host rocks instead of quartz-rich sandy desert surfaces.
- In the Taklimakan case the large dust sweep seems to originate from the slopes of the Tien Shan mountains and thus very likely from alluvial sources instead of the sandy desert body.
- More research on larger scales needed for fully understanding the characteristics of dust from alluvial sources.