Optical Properties of Mineral Dust Aerosol in the Thermal Infrared

IRS 2016

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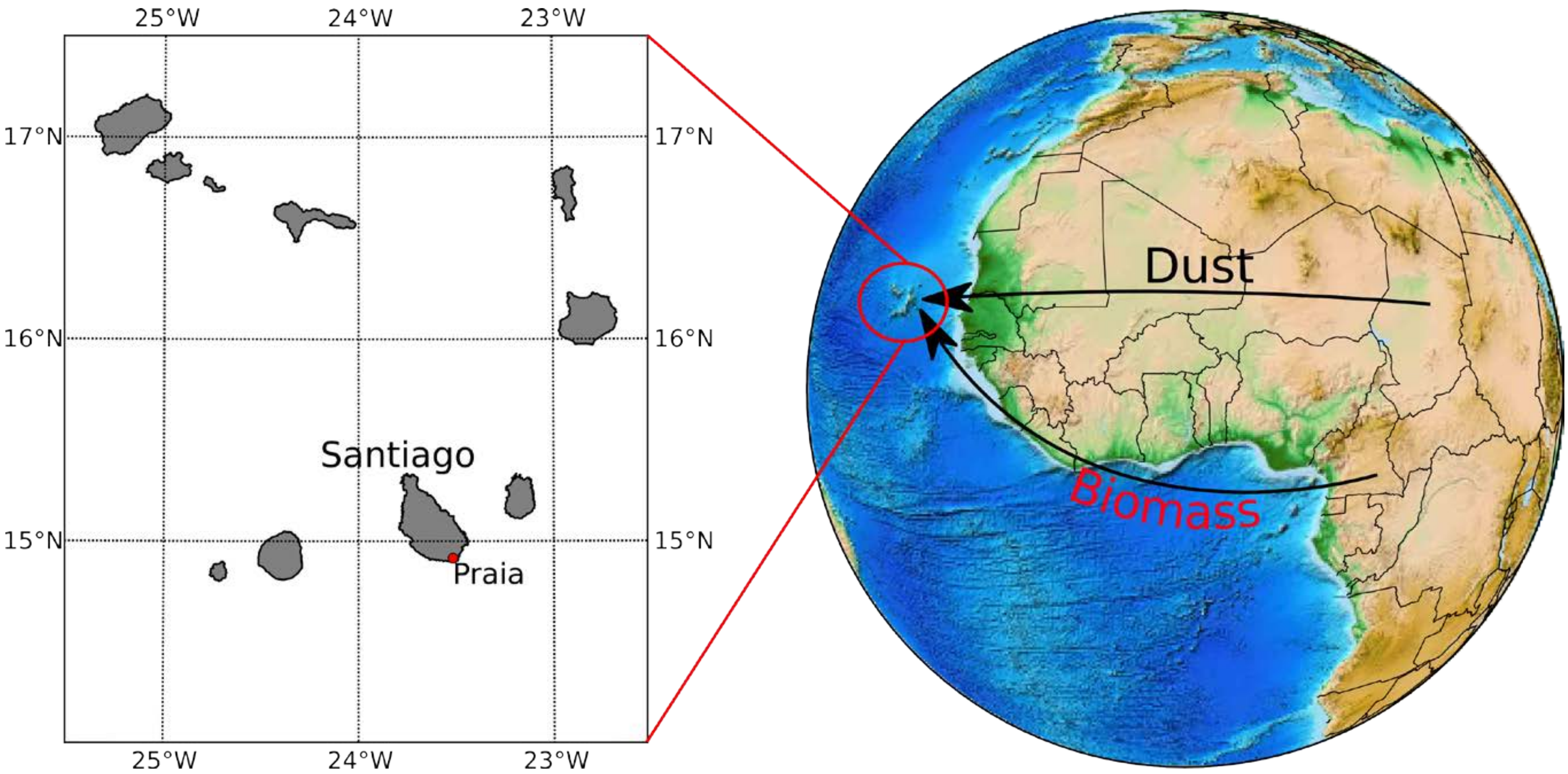
DLR

Research Goals

- Measure atmospheric radiance in the spectral range 800–1200 cm^{-1} (8–12 µm) during SAMUM-2
- Set-up a simulation environment (PIRATES) capable to compute thermal infrared (TIR) atmospheric radiation in the presence of aerosols
- Identify a microphysical aerosol model suited to reproduce the measured radiation at bottom/top of the atmosphere (BOA/TOA) with special attention to refractive index and particle shape

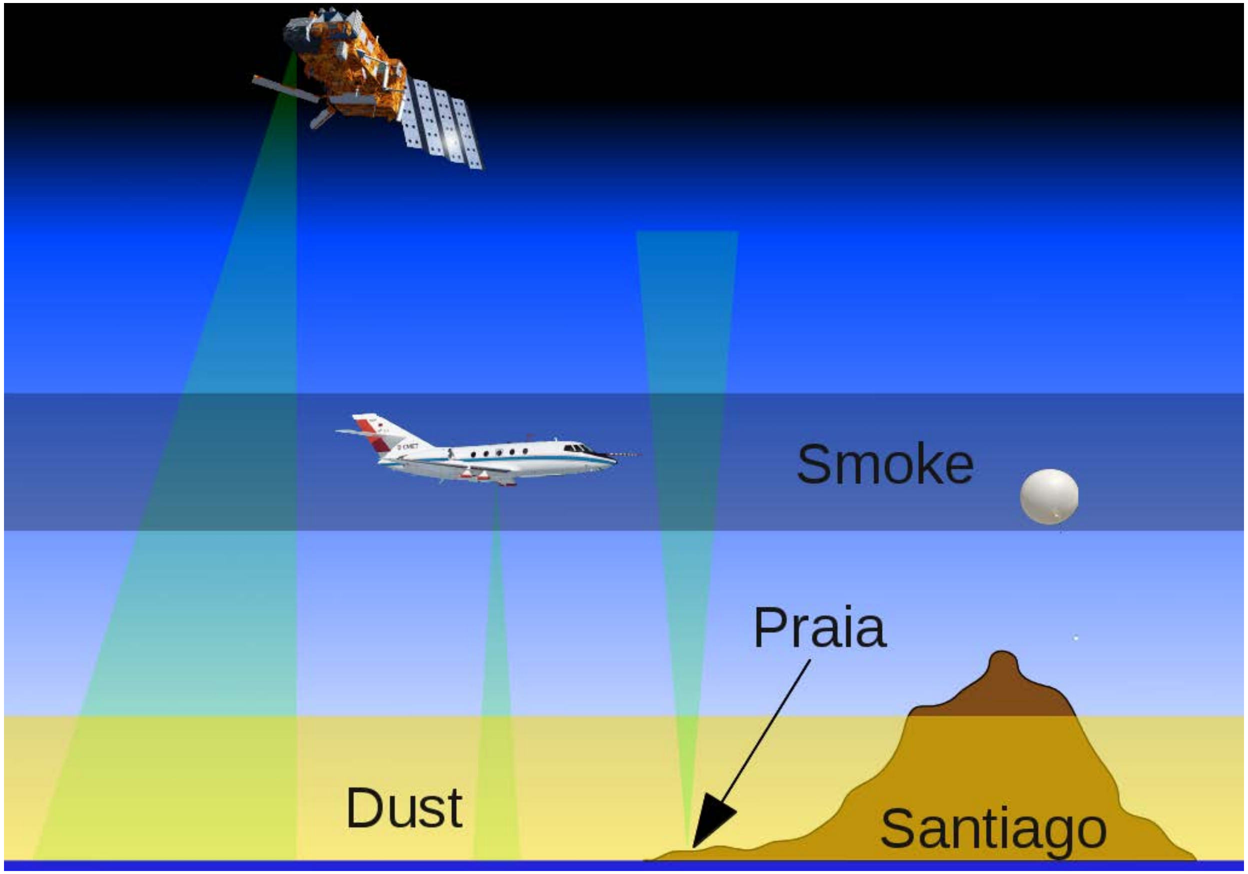
C. H. Koehler, Radiative Effect of Mixed Mineral Dust and Biomass Burning Aerosol in the Thermal Infrared, 2014, http://elib.dlr.de

The SAharan Mineral dUst ExperiMent (SAMUM-2)



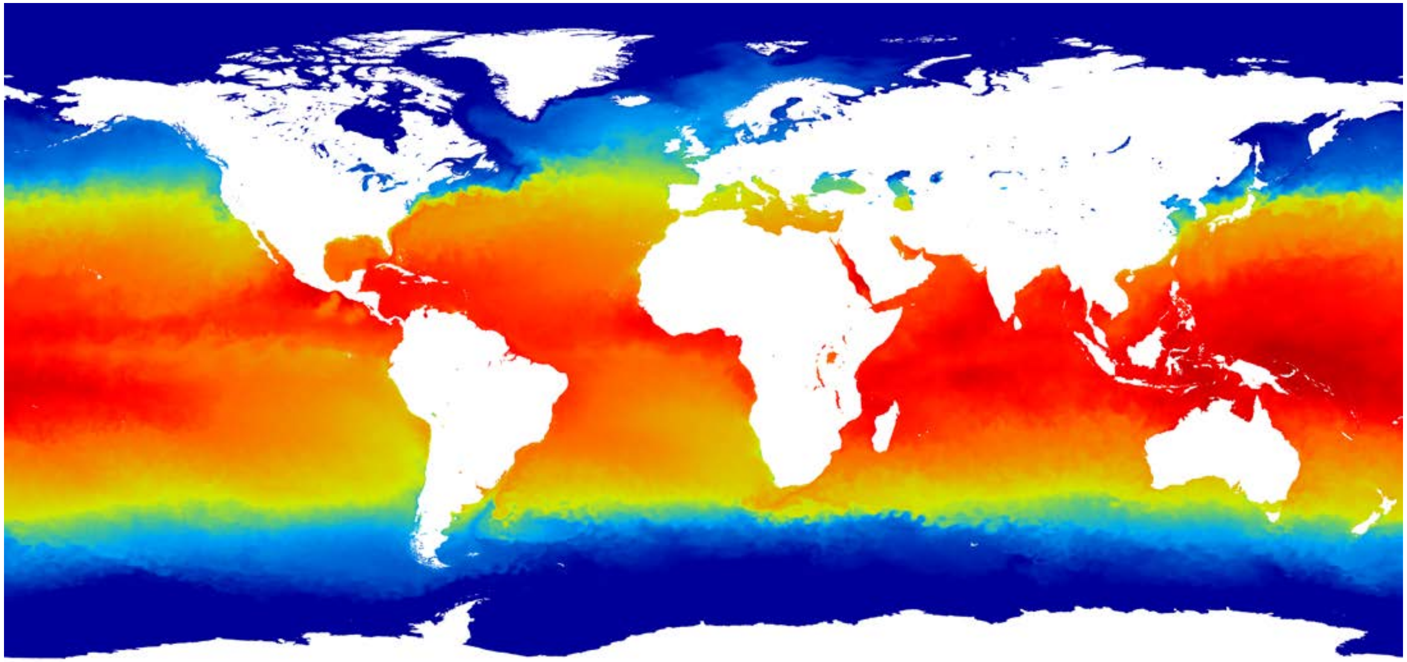
The SAharan Mineral dUst ExperiMent (SAMUM-2)

- LIDAR (IfT, LMU, DLR)
- In-situ size distributions (DLR, TU Darmstadt)
- Sample analysis (TU Darmstadt)
- Radiosonde measurements (IfT)
- Radiation Measurements (Uni Leipzig, LMU, DLR)



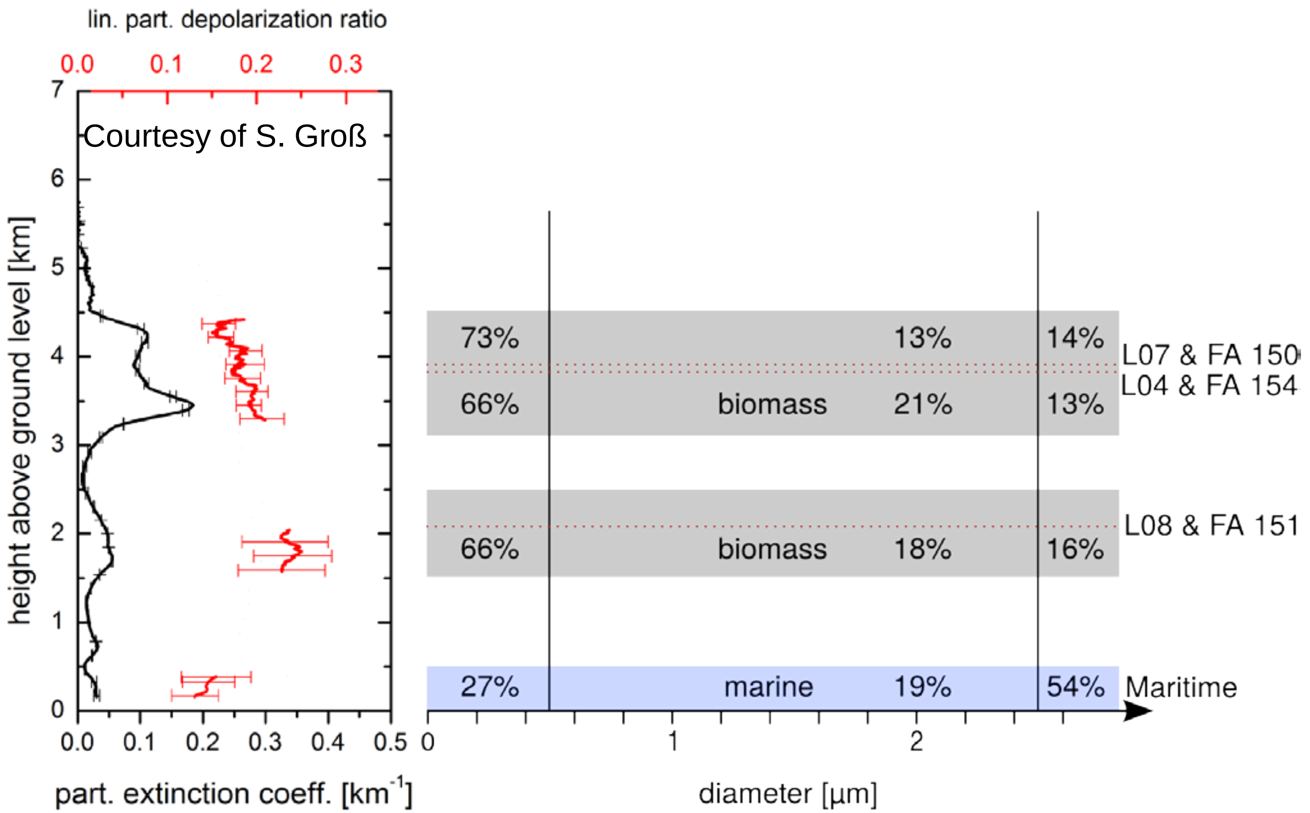
TOA Radiative Effect of Mixed Smoke / Dust Aerosol

- Investigate influence of a thin mixed layer on TIR remote sensing applications
- Example: IASI sea surface temperature (SST) product for 25 Jan 2008

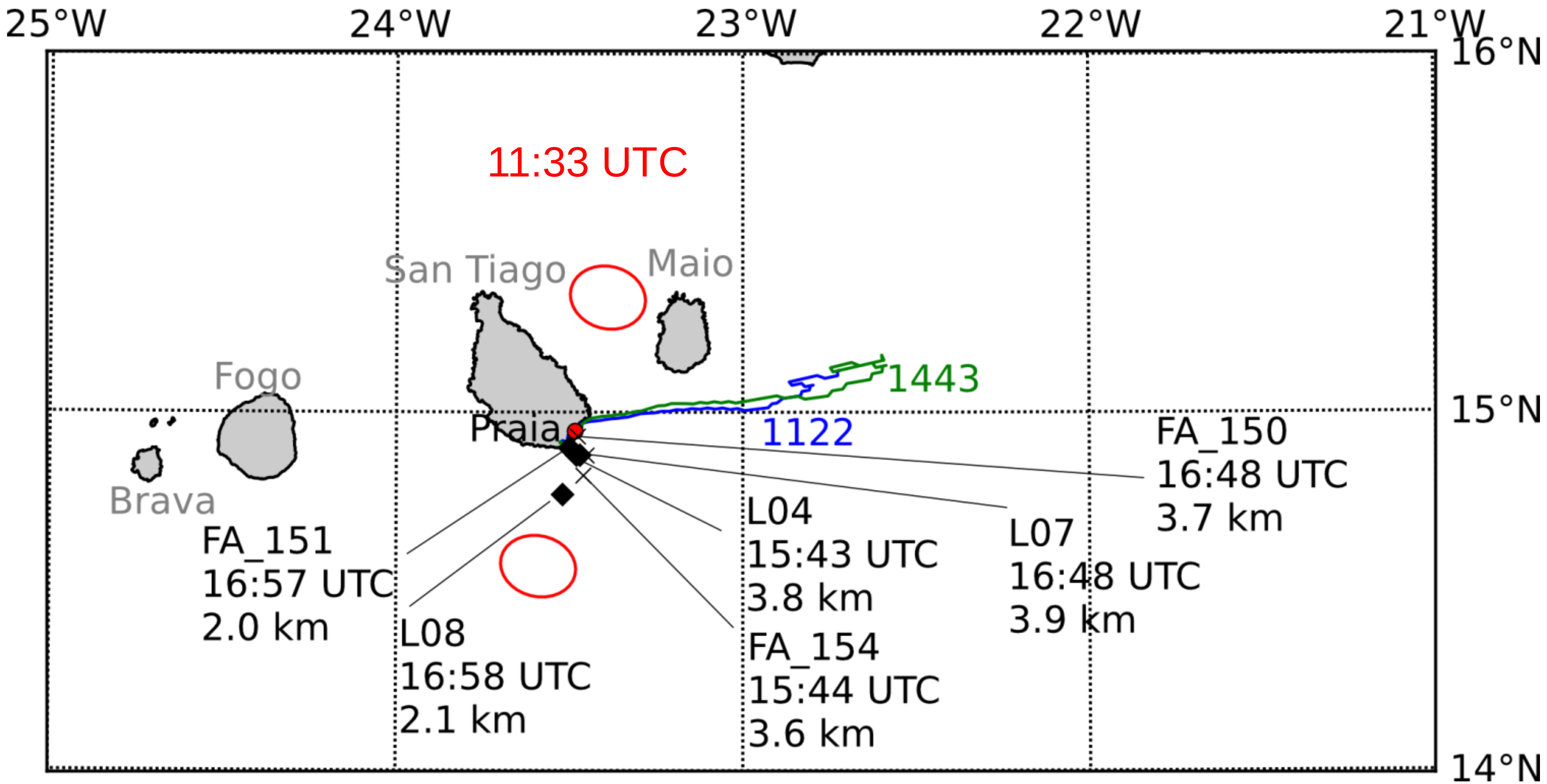


www.ghrsst.org

Vertical Aerosol Distribution on 25 Jan 2008

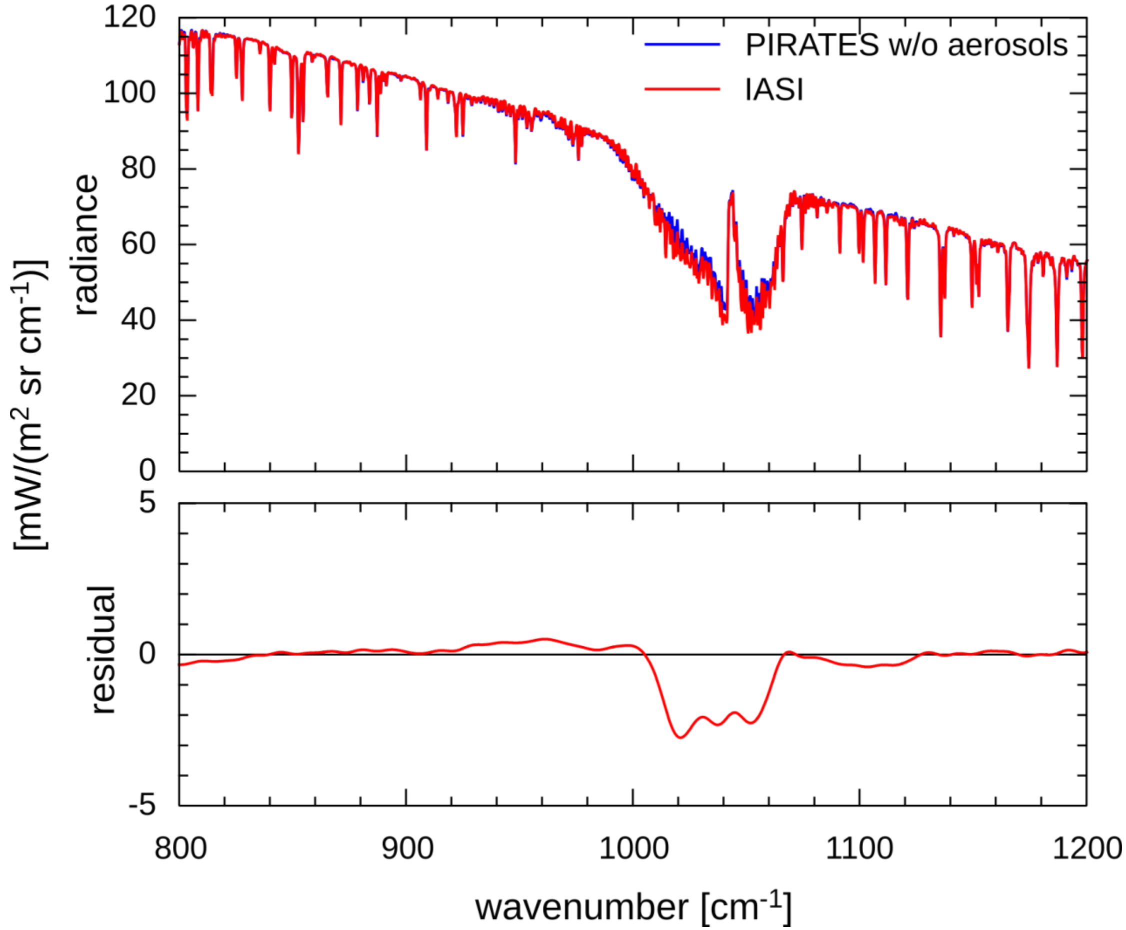


Measurements Entering the Simulation



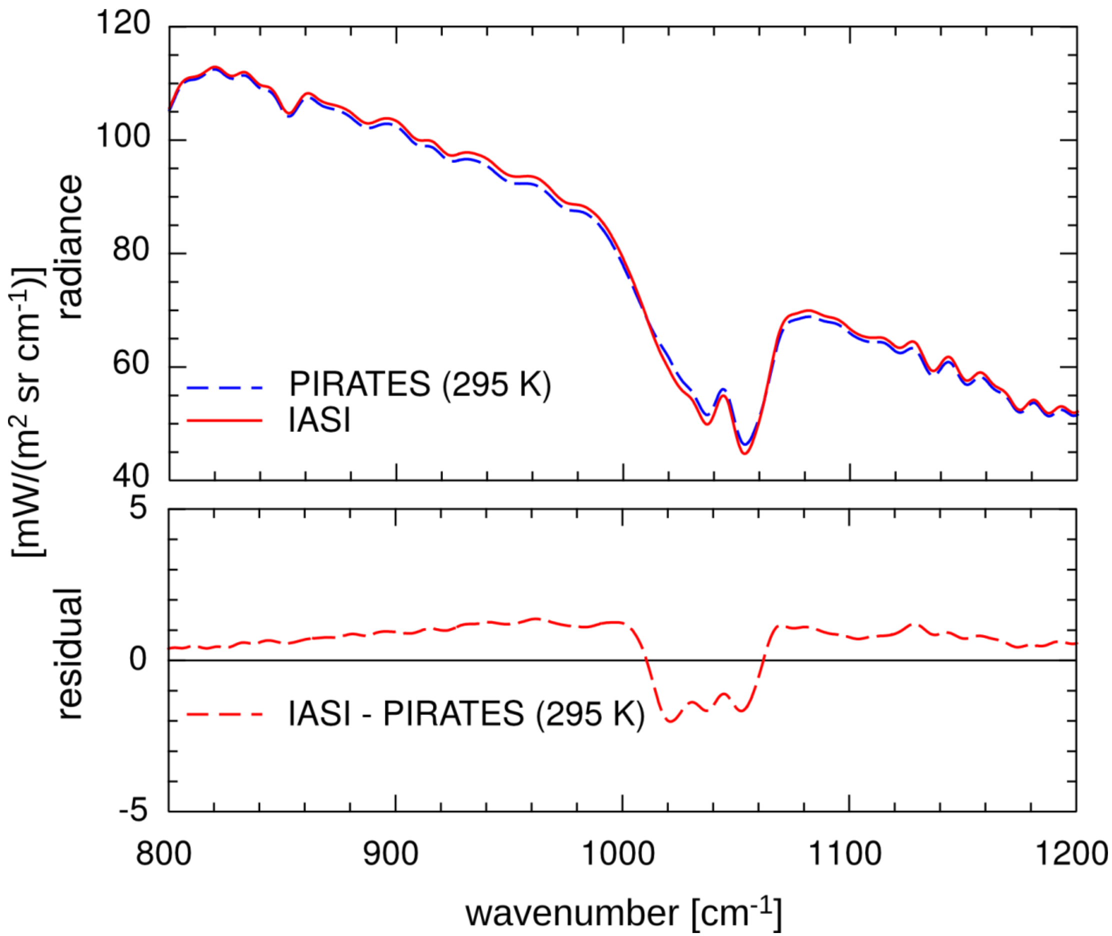
Comparison of Simulation and IASI Measurements

- Simulation w/o aerosols
- SST: 295 K
- Deviations in ozone band (1000 – 1080 cm^{-1}) due to profile mismatch
- Good agreement, so aerosols can be ignored ?



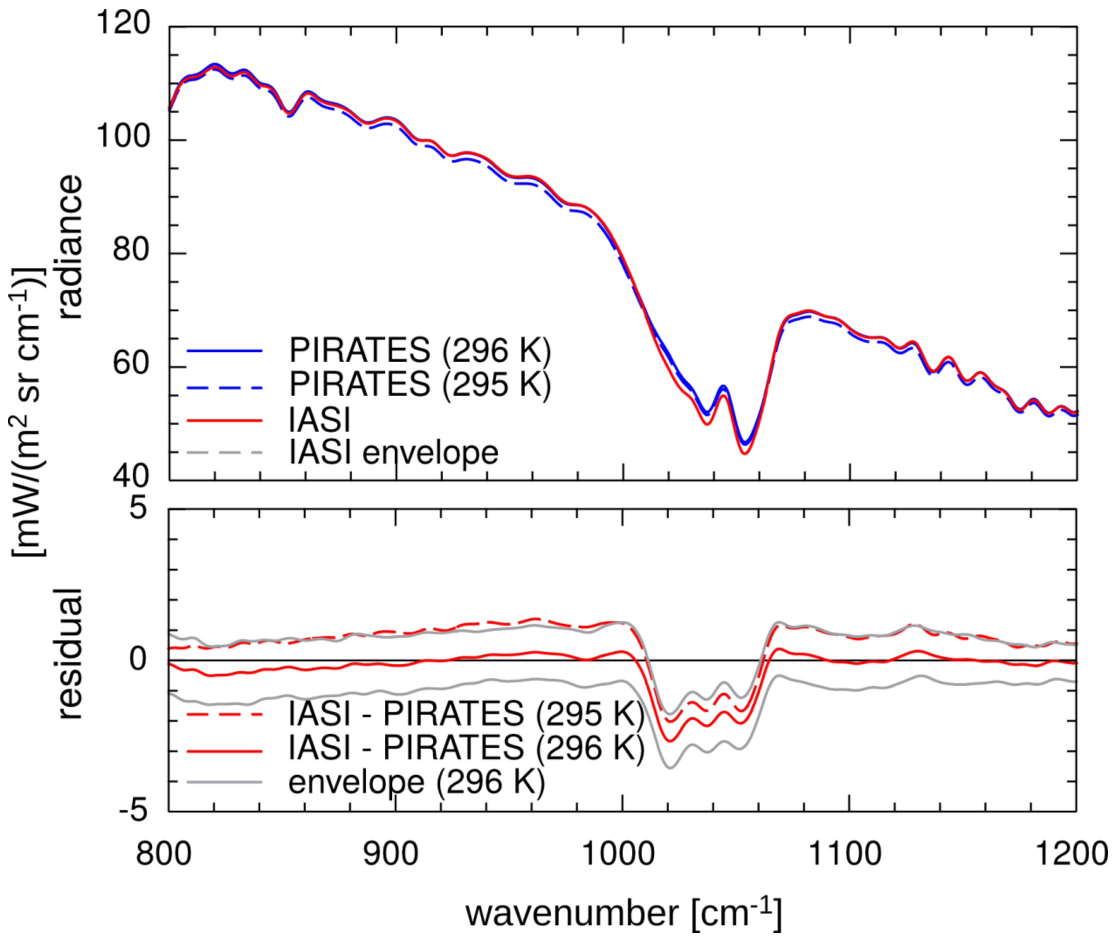
Comparison of Simulation and IASI Measurements

- Simulation with aerosols
- Aerosol absorbs terrestrial radiation
- Simulation underestimates upwelling radiation



Comparison of Simulation and IASI Measurements

- SST: 296 K (1 K increase)
- Better fit between simulation and measurement
- O'Caroll et al. (2012) report bias of IASI SST compared to in-situ measurements
- **Aerosol has to be taken into account for accuracy better 1 K**

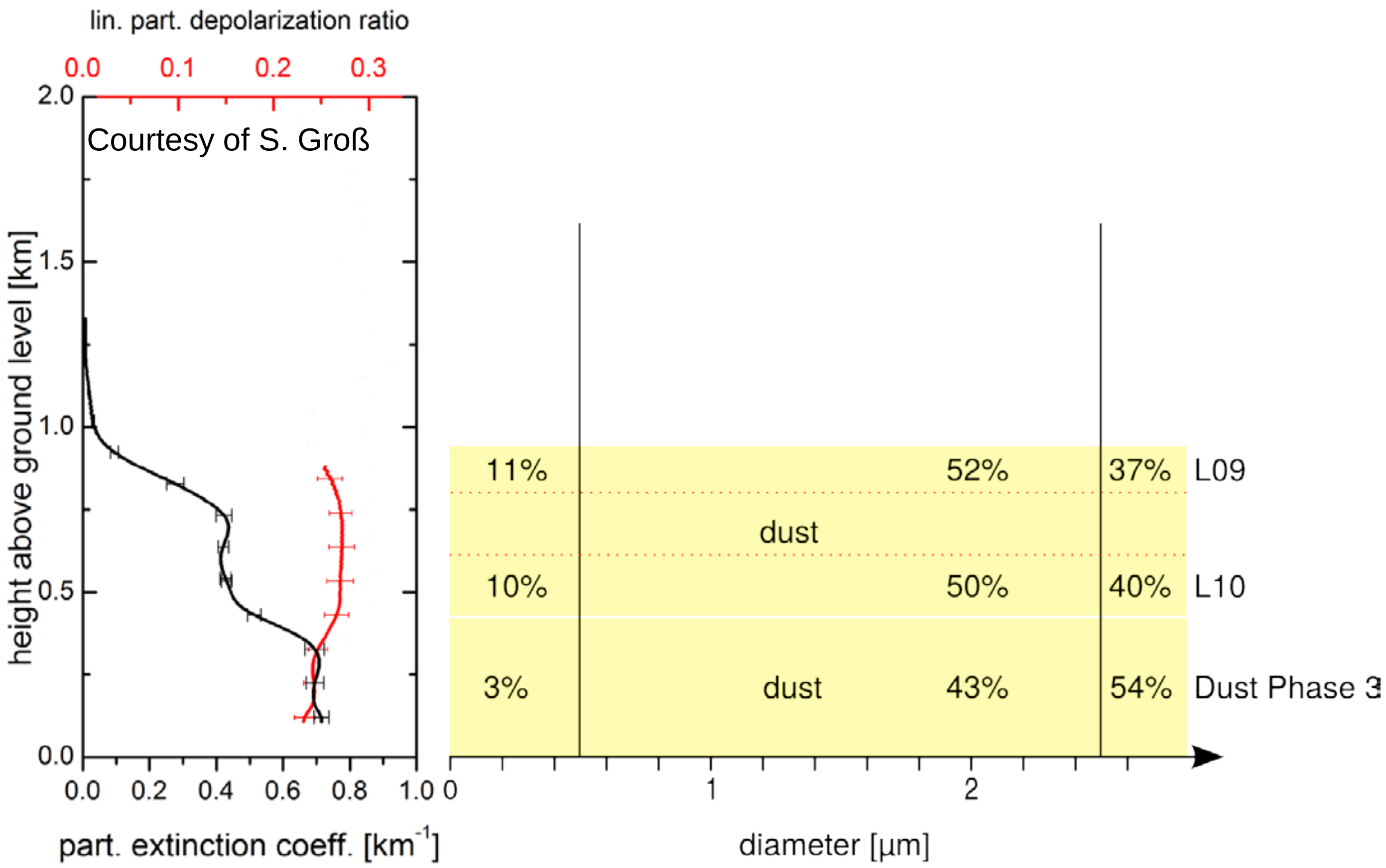


BOA Radiative Effect of Mineral Dust Aerosol

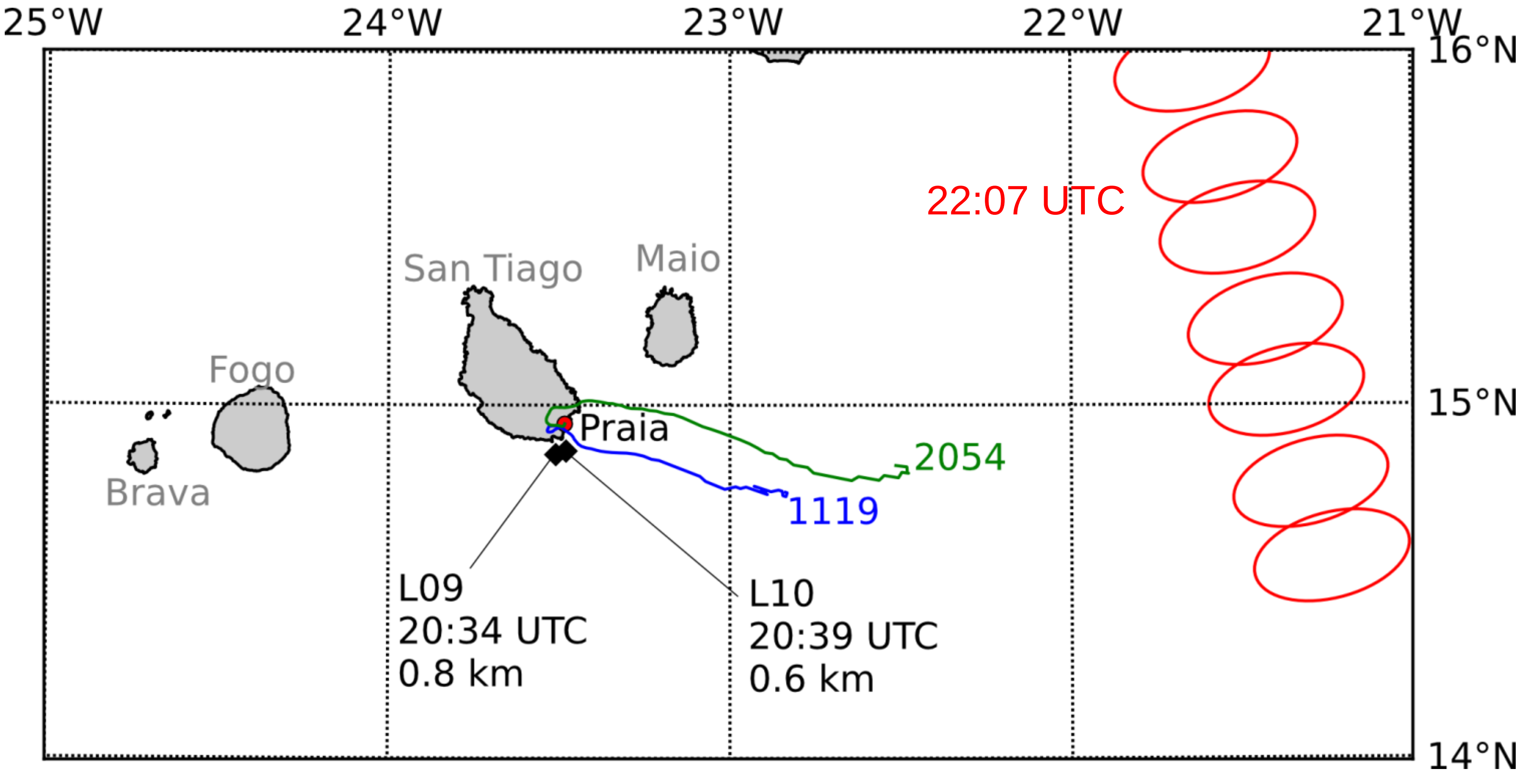
- Investigate influence of a low pure dust layer on BOA radiance

- Investigate influence of particle shape and refractive index

Vertical Aerosol Distribution on 29 January 2008

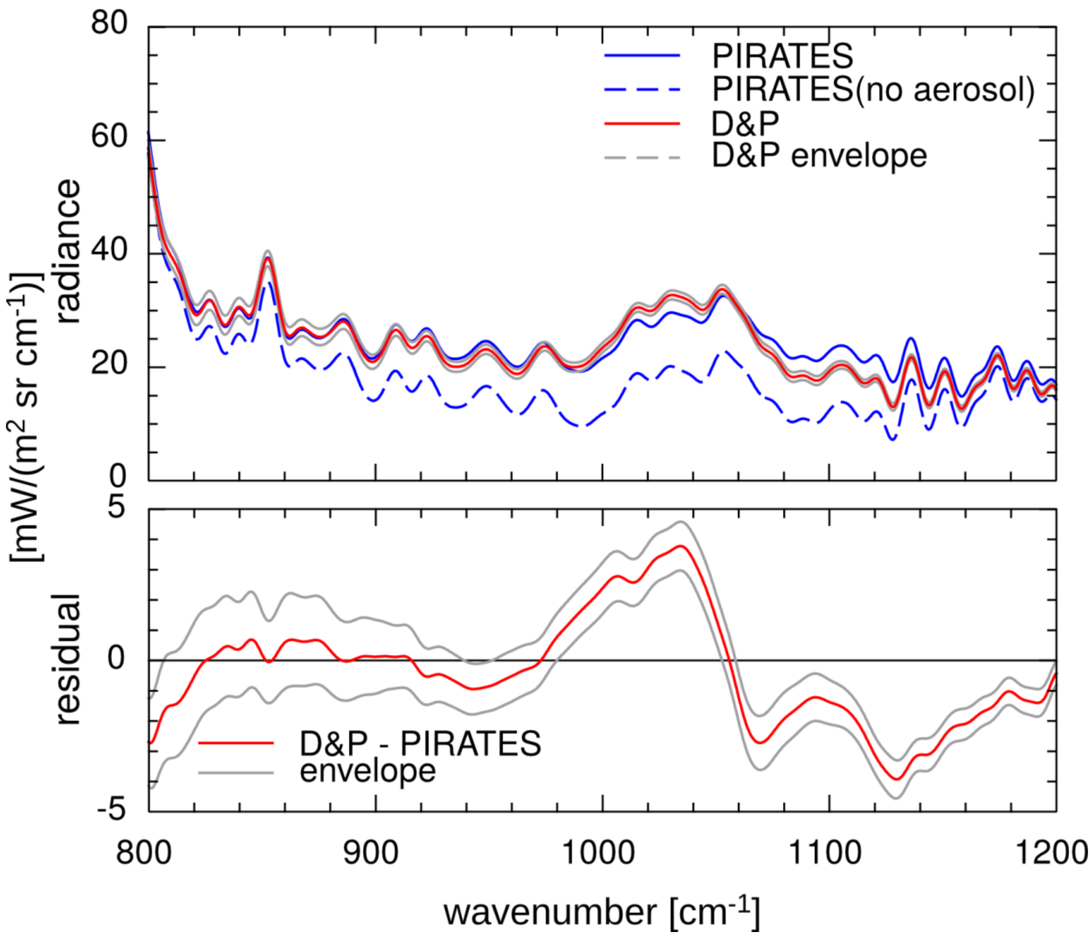


Measurements Entering the Simulation

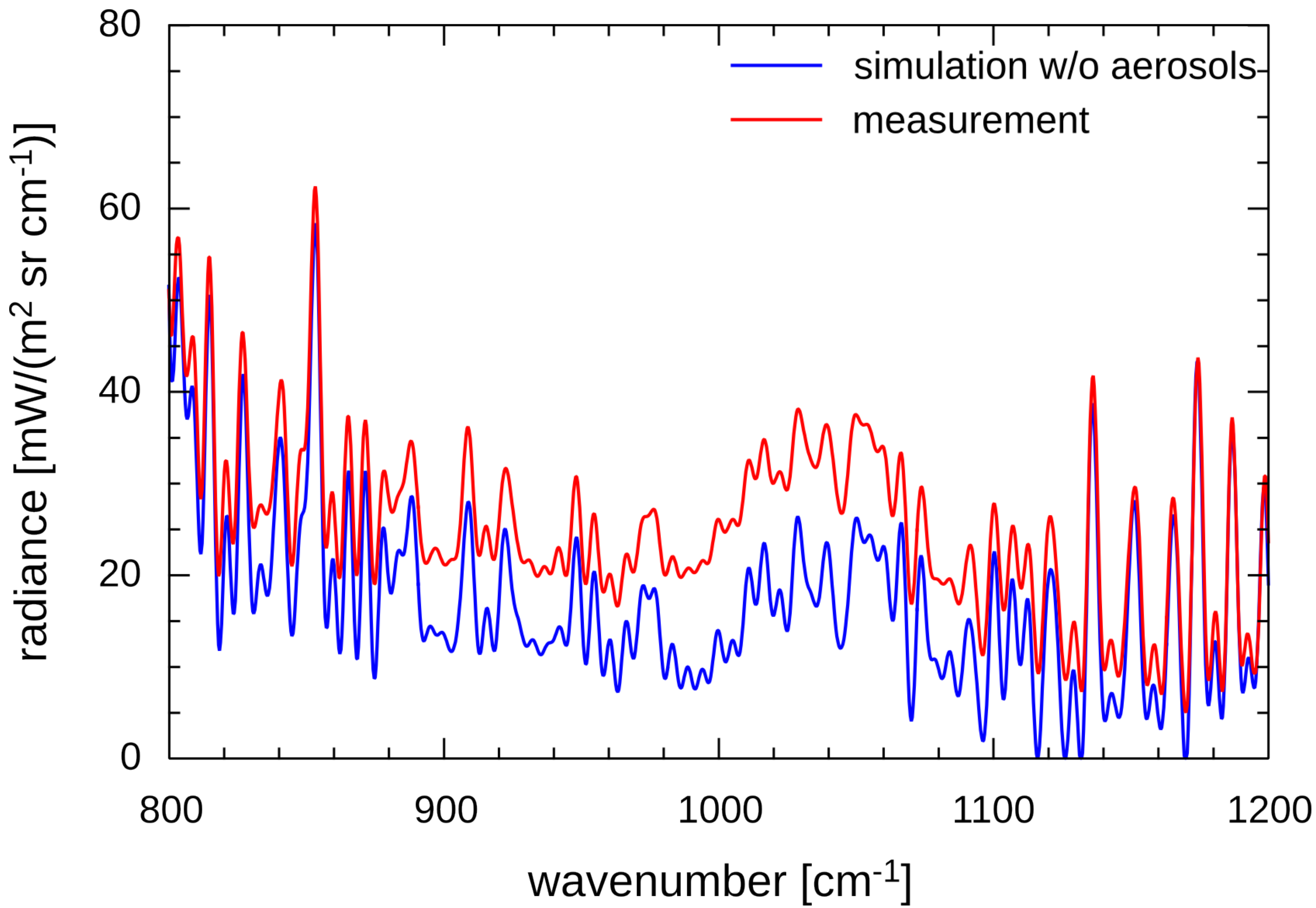


The Spectral Signature of Mineral Dust

- FTIR measurements from 2024 UTC to 2105 UTC
- Mineral composition from samples collected on 25 Jan (similar source regions)
- Internal mixture of spherical particles
- Agreement not bad, but outside uncertainties



The Spectral Signature of Mineral Dust



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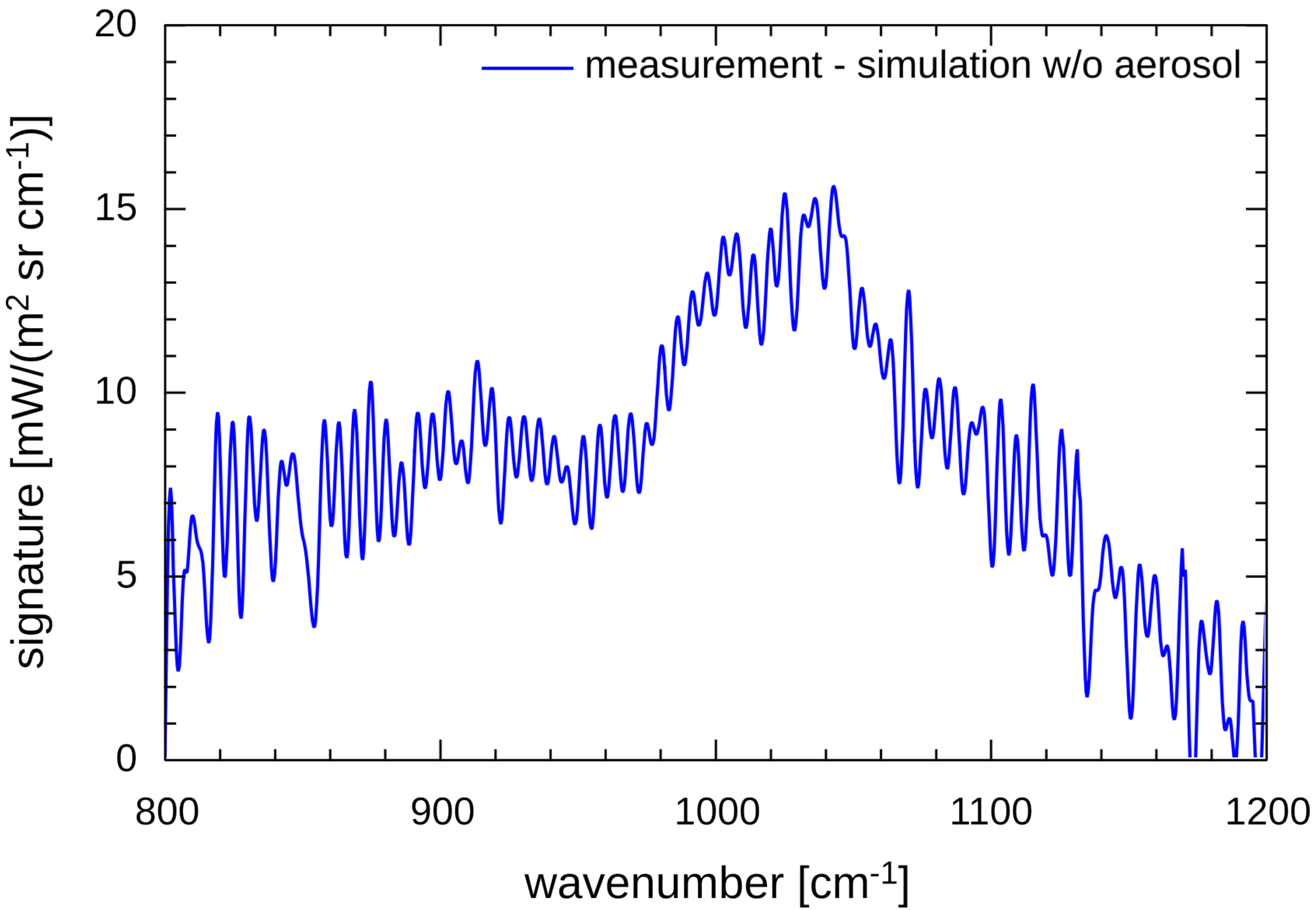
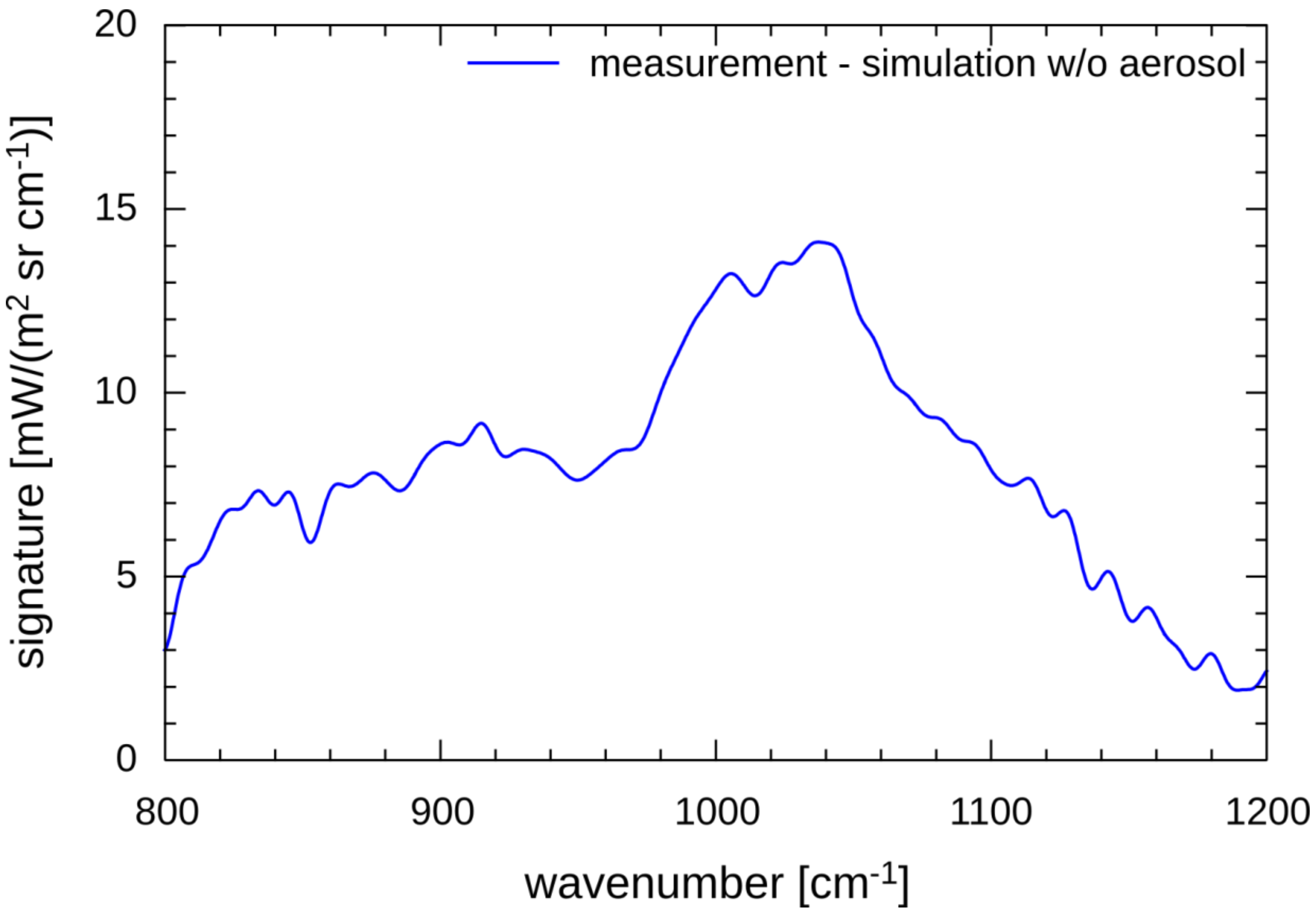
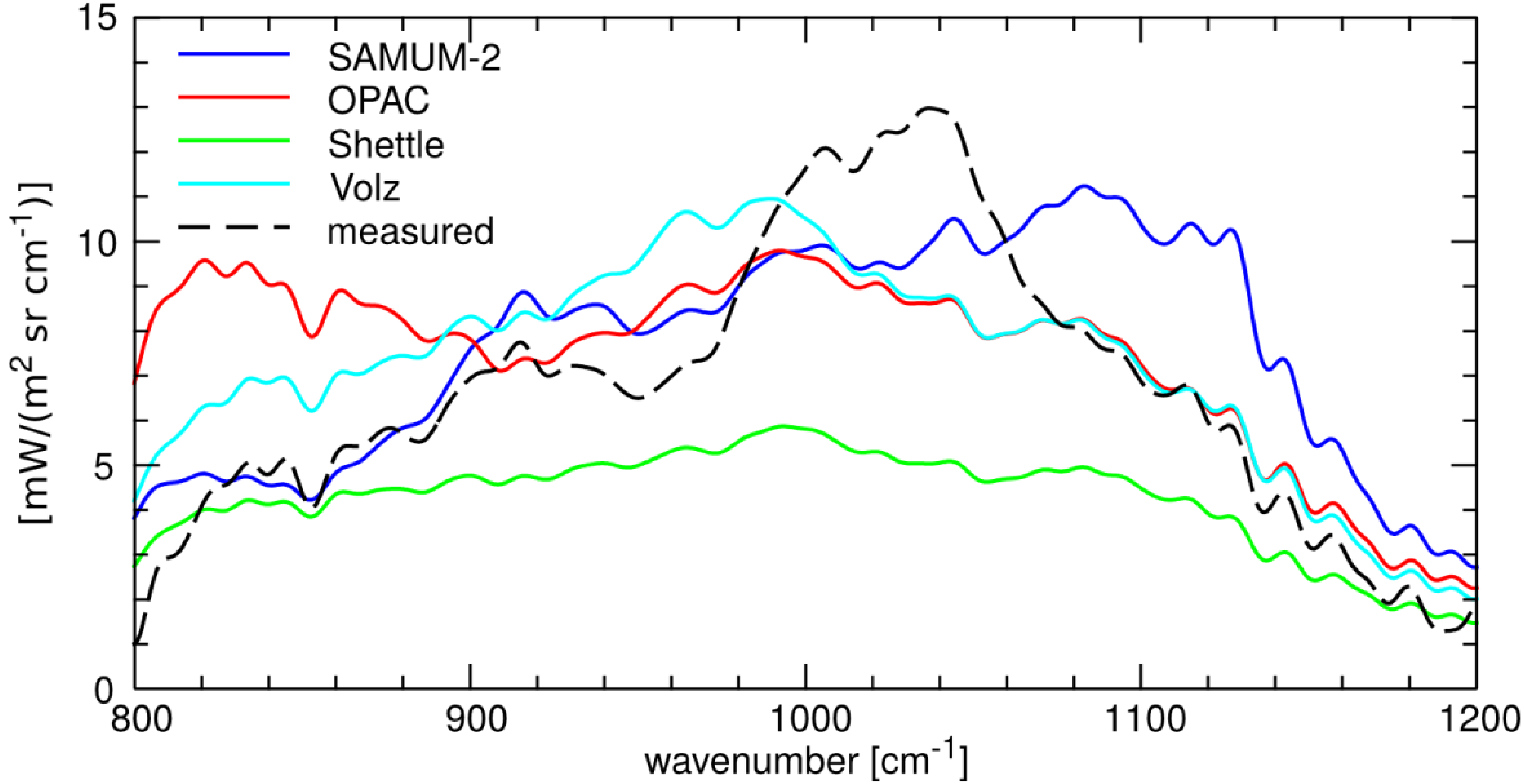


The Spectral Signature of Mineral Dust

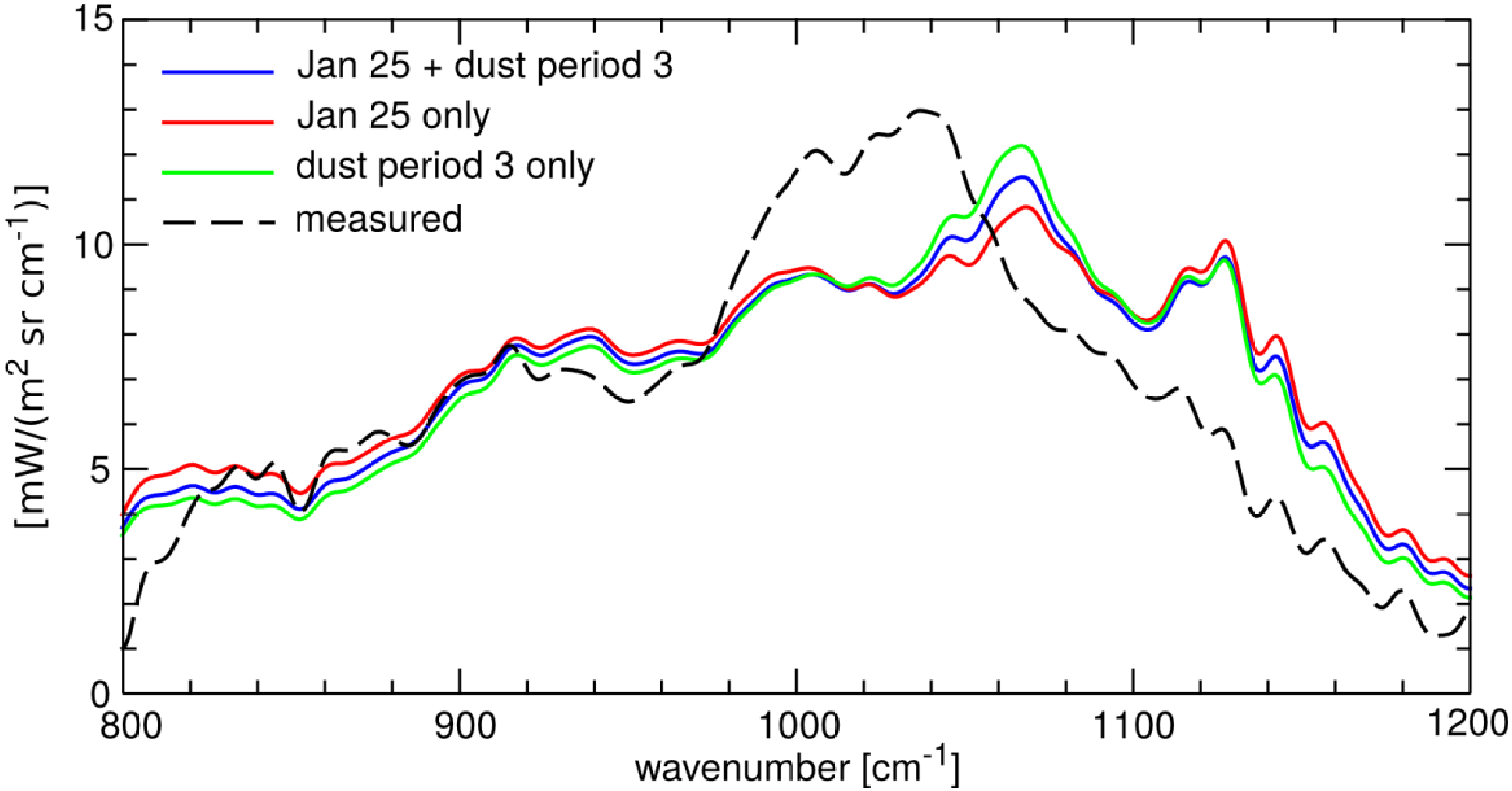


Internal Mixtures of Spherical Particles



- No internal dust model matches measured signature over the entire TIR window

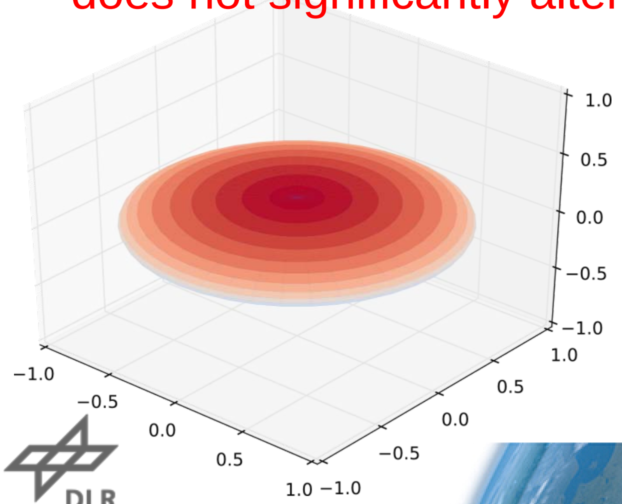
External Mixture of Spherical Particles



- No external dust model matches measured signature over the entire TIR window

Influence of Non-Spherical Particles

- Oblate spheroids with large aspect ratios (1:5) as suggested by Kleiber et al. (2009) based on laboratory studies
- T-Matrix does not converge for entire size distribution
- Use spheroids for $0.01 < x < 4$, and spheres otherwise
- Sensitivity studies suggest, that the replacement of spheroids with spheres does not significantly alter the results (estimated error < 0.2 mW / (m^2 sr cm^{-1}))



C. H. Koehler, Radiative Effect of Mixed Mineral Dust and Biomass Burning Aerosol in the Thermal Infrared, 2014, http://elib.dlr.de

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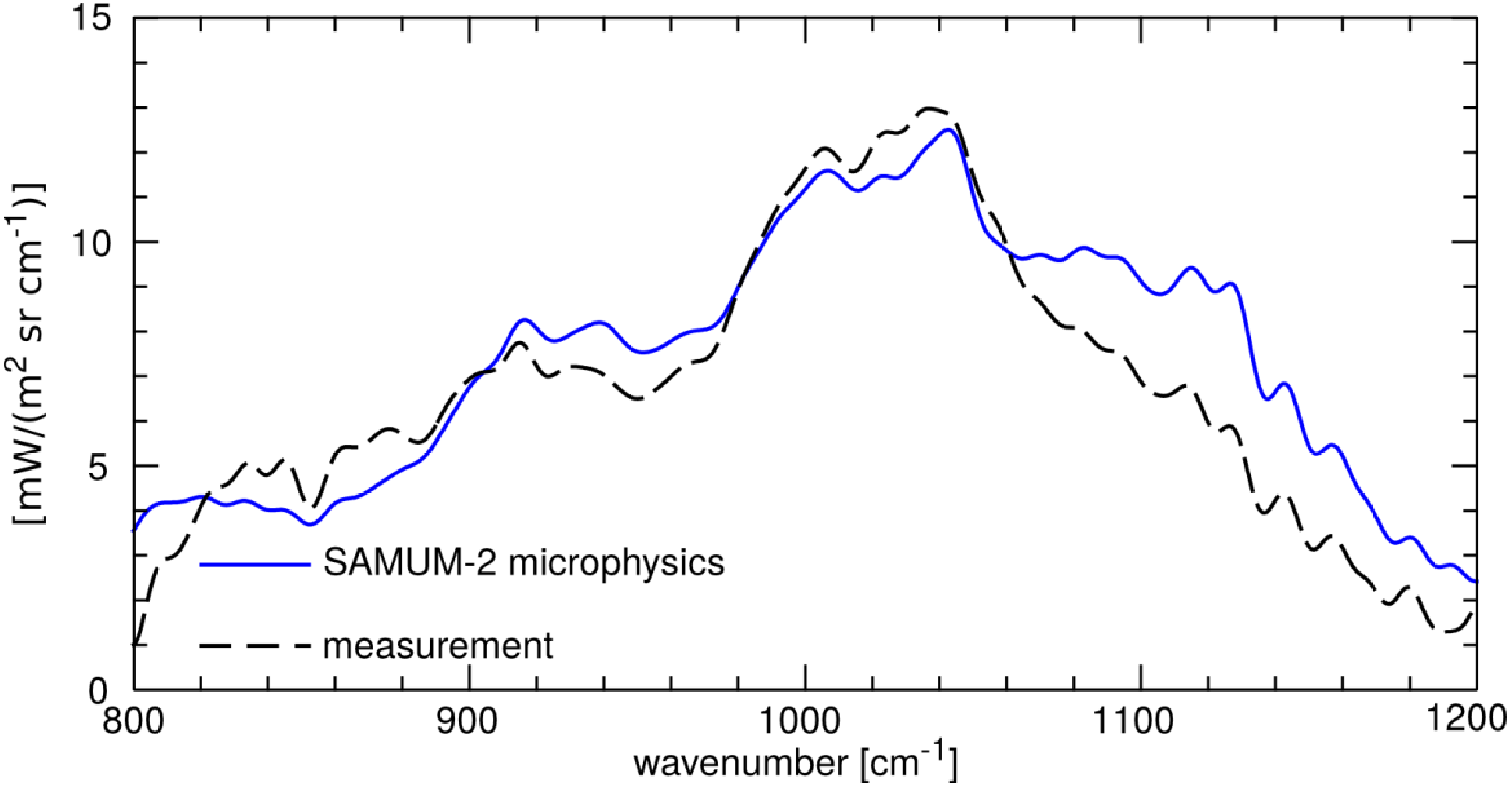
External Mixture of Oblate Spheroids (AR 1:5)



Influence of Non-Spherical Particles

- Much better fit than spherical particles, although simulated aspect ratios do not match laboratory analysis

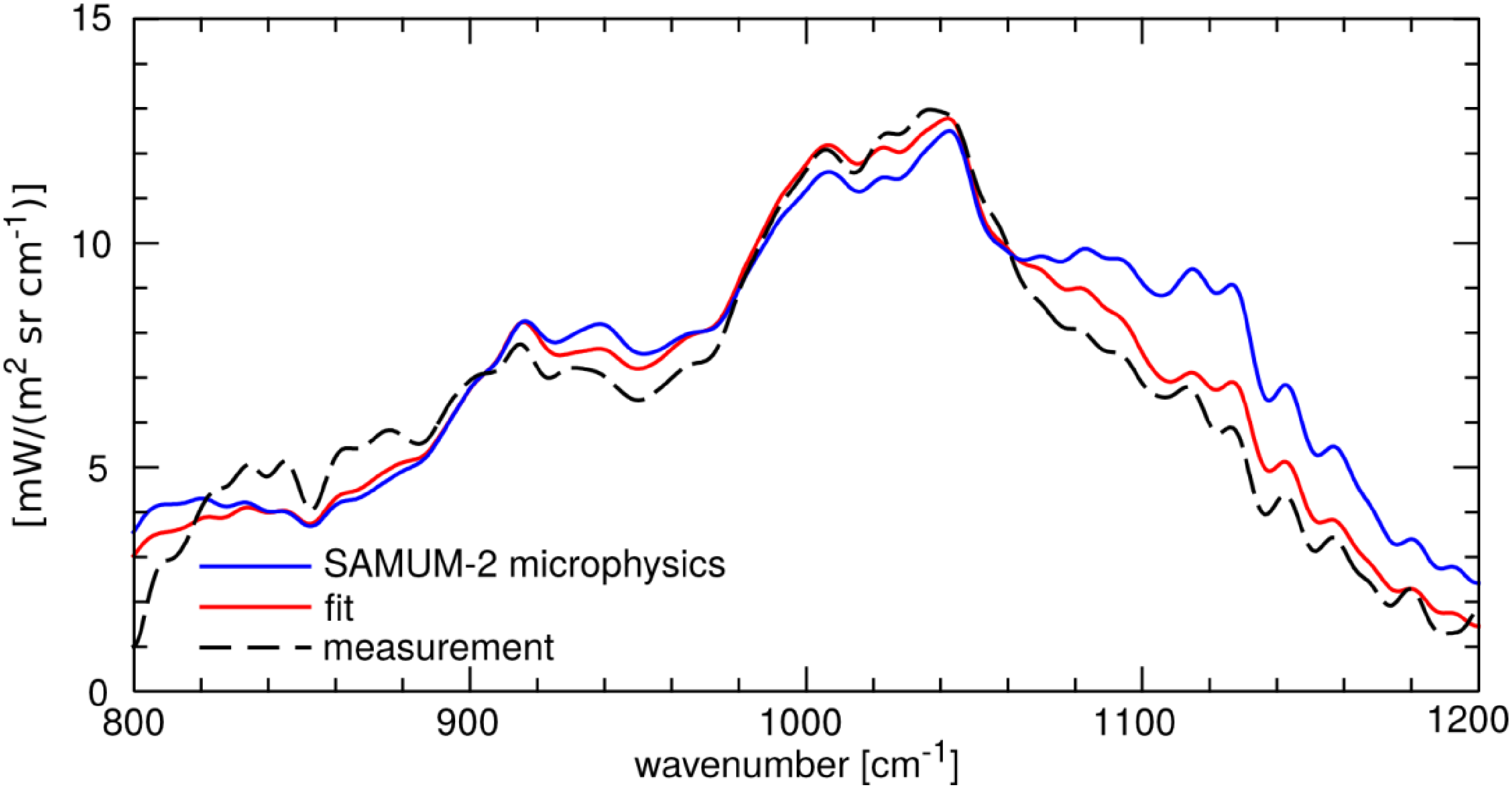
- Remaining deviations around 1100 cm^{-1} due to sulfates, quartz, orthoclase and illite

- Possible explanations
  - Illite might require larger aspect ratios (1:18), which cannot be simulated for the given size distribution (T-Matrix method diverges)
  - Sulfates might be modelled inappropriately by ammonium sulfate and gypsum since sea salt aging might result in peak shifts for other sulfates
  - Sodium sulfates have needle like shape with aspect ratio 1:10, but were modelled as spheres (or spheroids with aspect ratio 6:1)
  - Spheroids might be inadequate as well, e.g. due to missing surface roughness

Optimization of Mineral Composition and Particle Number Density

- Simulate dust signature for pure components (pure quartz, pure kaolinite …) with spheroidal model particles used before
- Size distribution from in-situ measurements
- Decompose measured spectrum into linear combination of pure signatures with least-squares fit (neglects interactions between individual components)
- Simulate aerosol signature of mixture assuming composition obtained from fit for verification purposes

External Mixture of Oblate Spheroids (AR 1:5)



Optimization of Mineral Composition and Particle Number Density

- Fitted microphysics does not match measured (laboratory) composition:

Material	Fitted number concentration [%]	Measured number concentration [%]
Illite	52	<10
Kaolinite	22	30
Montmorillonite	11	<2
Sea Salt	15	< 10
Other	0	50

- Fitted microphysics similar to results obtained by Boer (2010) for airborne FTIR (ARIES) measurements close to Sal in September 2000

- Dust model neither suited for retrieval of dust composition nor concentration

Summary

- Measured spectral signature of mineral dust/biomass burning aerosol mix in the TIR window (800 – 1200 cm^{-1}) including uncertainties
- Confirmed a distinct spectral signature at BOA and TOA and estimated the impact on remote sensing applications (e.g. SST retrieval)
- Oblate spheroidal model particles are much better suited than spherical particles to model mineral dust aerosols, unless optical depth is small
- Model based on spheroids not accurate enough to retrieve dust load/composition
- Further simulation studies with different shapes required

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