Airborne and satellite observations of volcanic ash from the Eyjafjallajökull eruption

Stuart Newman and co-authors

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Photo credit: Arnar Thorisson 17.4.10

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Met Office

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A case study of observations of volcanic ash from the Eyjafjallajökull eruption: 2. Airborne and satellite radiative measurements

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[1] An extensive set of airborne and satellite observations of volcanic ash from the Eyjafjallajökull Icelandic eruption are analyzed for a case study on 17 May 2010. Data collected from particle scattering probes and backscatter lidar on the Facility for Airborne Atmospheric Measurements (FAAM) BAe 146 aircraft allow estimates of ash concentration to be derived. Using radiative transfer simulations we show that airborne and satellite infrared radiances can be accurately modeled based on the in situ measured size distribution and a mineral dust refractive index. Furthermore, airborne irradiance measurements in the 0.3–1.7 μm range are well modeled with these properties. Retrievals of ash mass column loading using Infrared Atmospheric Sounding Interferometer (IASI) observations are shown to be in accord with lidar-derived mass estimates, giving for the first time an independent verification of a hyperspectral ash variational retrieval method. The agreement of the observed and modeled solar and terrestrial irradiances suggests a reasonable degree of radiative closure implying that the physical and optical properties of volcanic ash can be relatively well constrained using data from state-of-the-science airborne platforms such as the FAAM BAe 146 aircraft. Comparisons with IASI measurements during recent Grímsvötn and Puyehue volcanic eruptions demonstrate the importance of accurately specifying the refractive index when modeling the observed spectra.

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Talk contents

- FAAM aircraft and instrumentation
- Case study from 17 May 2010
- Radiative transfer modelling of infrared spectra
- IASI retrievals of ash mass concentration (ULB)
- Choice of ash refractive index

FAAM aircraft and instrumentation

FAAM BAe146-301 ARA Instrumentation

ARIES interferometer (Bomem MR200)
Radiances: spectral range 550-3000 cm^{-1}
HgCdTe and InSb detectors
Max. resolution 1 cm^{-1} (0.5 cm^{-1} sampling)
Multiple viewing geometries (up and down)
Field of view 44 mrad (full angle)

ARIES with starboard side removed showing electronics modules (top), detector/cooler unit (bottom right), heater controller (mid left) and folding/focusing optics (bottom left).

Lidar Observations of Volcanic Ash

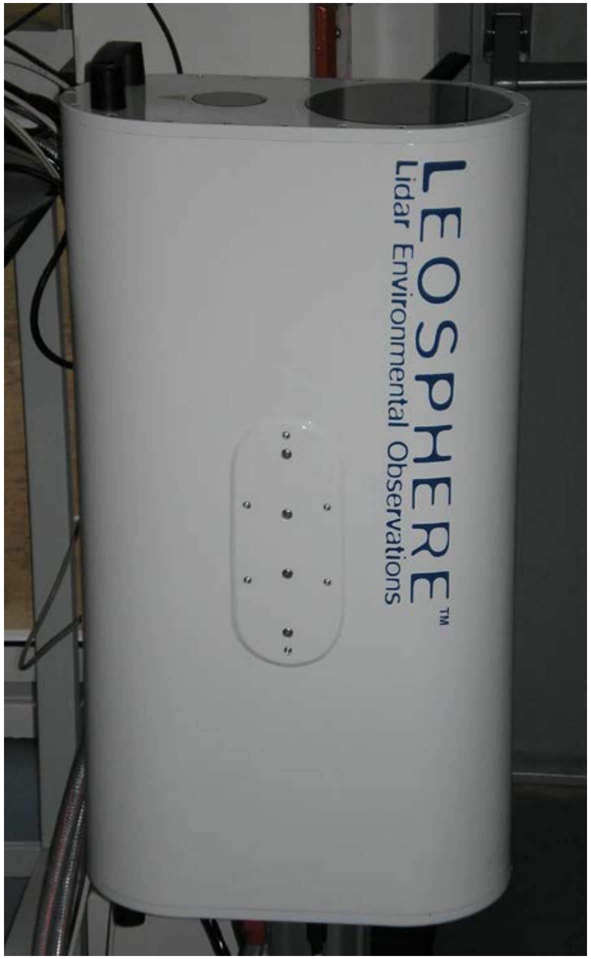


Table 1: Nominal specifications of the ALS450 lidar system.

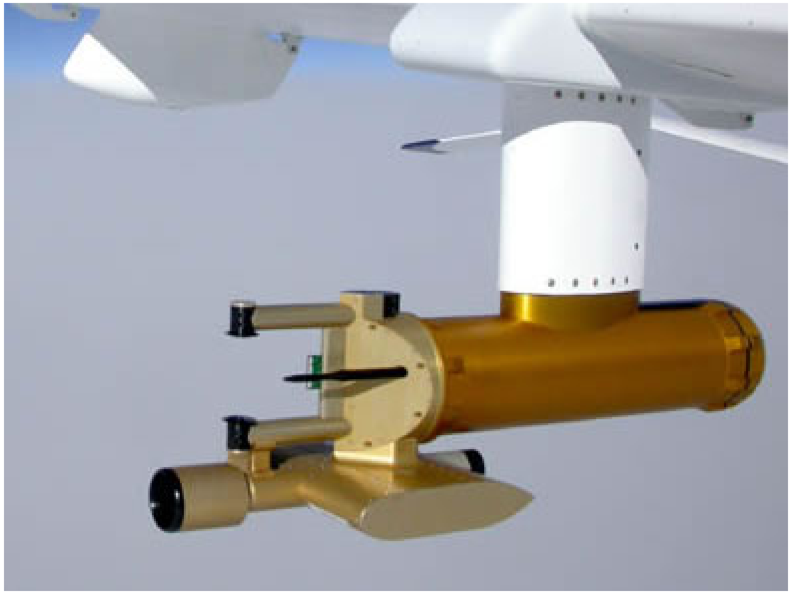
Emitted wavelength	354.7 nm
Receiver bandwith	0.36 nm
Pulse Energy	16 mJ
Pulse repetition Frequency	20 Hz
Pulse duration	4 ns
Pulse-to-pulse stability	5–7%
Beam diameter	2.5 mm (laser), 30 mm (beam exp.)
Beam divergence	$\leq$ 1 mrad (laser), 0.2 mrad (beam exp.)
Vertical resolution	1.5 m
Overlap range	150 m (95%), 300 m (100%)
Maximum range	user defined, typ. $\leq$ 15 km
Integration time	user defined, typ. 5 – 30 s
N.D. filter optical density	0.7 $\parallel$, 0.3 $\perp$
Channel 0	analog, $\parallel$
Channel 1	analog, $\perp$
Channel 2	photon count, $\parallel$
Channel 3	photon count, $\perp$
Flashlamp lifetime	$30 \cdot 10^6$ shots (415 hours operation)
Coolant	water, or ethalene glycol 20% solution
Coolant freezing point	0°C or -8.9°C, respectively
Eye-safety compliance	EN60825-1

Franco Marenco

Particle measuring instrumentation on FAAM BAe 146

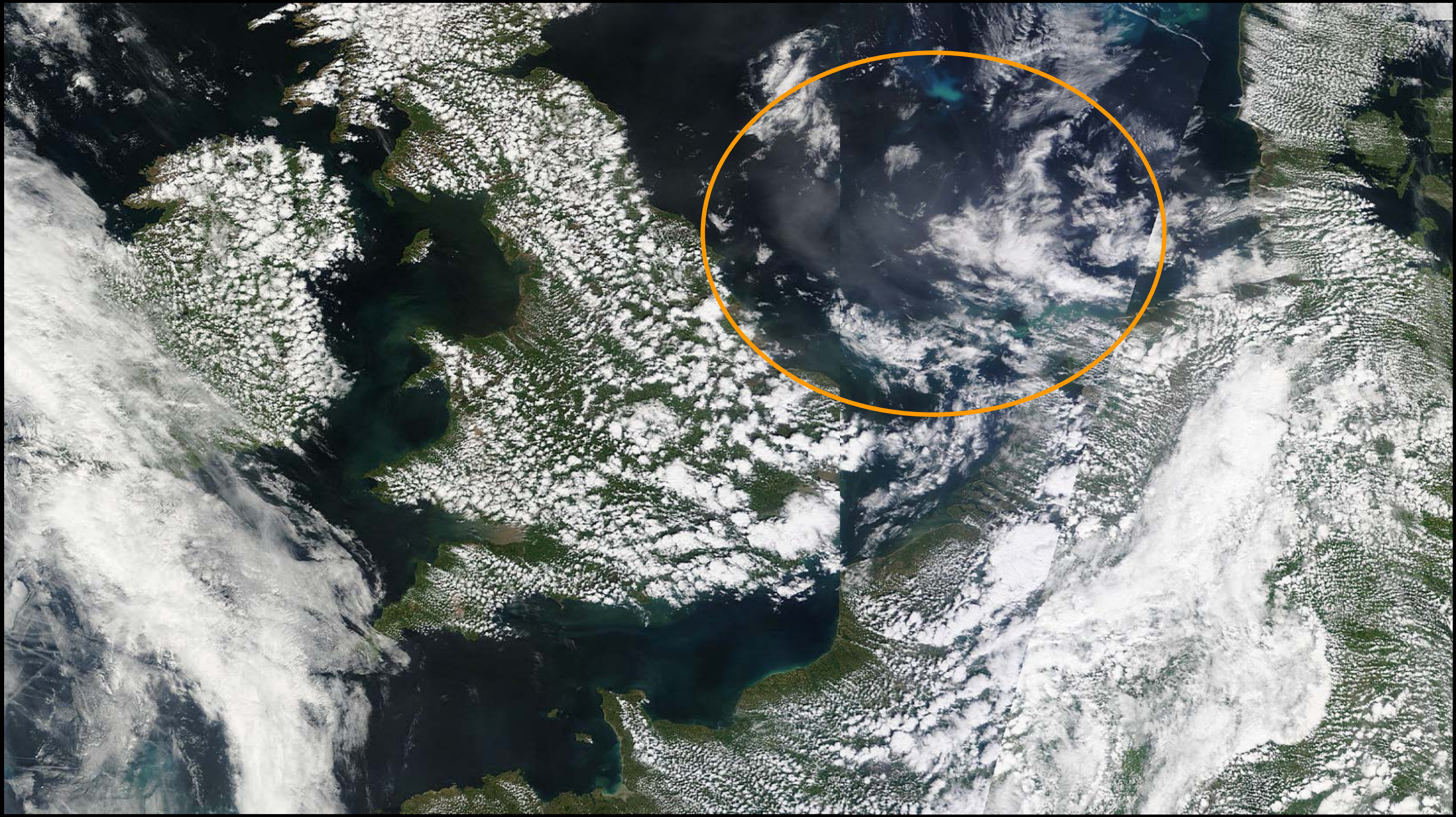
Particle counter name	Effective size range	Aircraft flown on
CAPS/CAS	0.5 – 50 µm	FAAM BAe146-301
PCASP	0.1 - 3 µm	FAAM all | Dornier 18 19 & 20 April

CAPS probe was essential to capture the larger particles



Case study from 17 May 2010

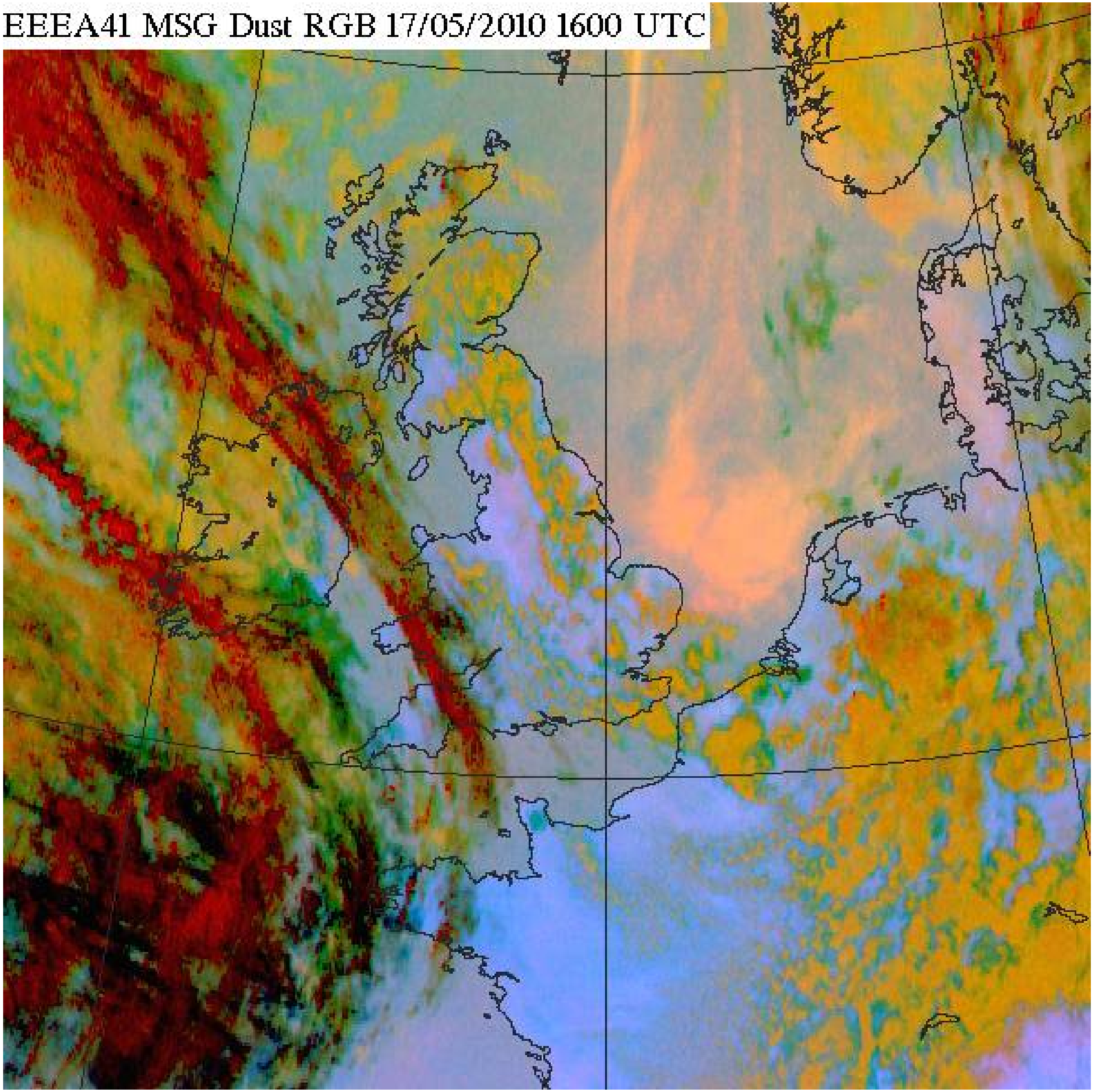
Case study
North Sea event on 17 May 2011



TERRA MODIS imagery
(thanks to Jim Haywood)

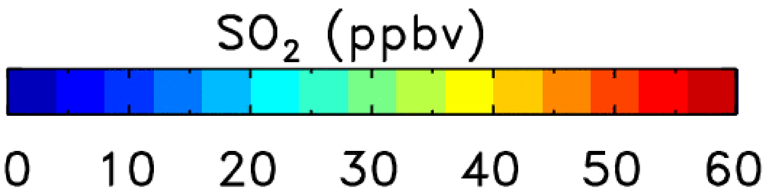
Met Office

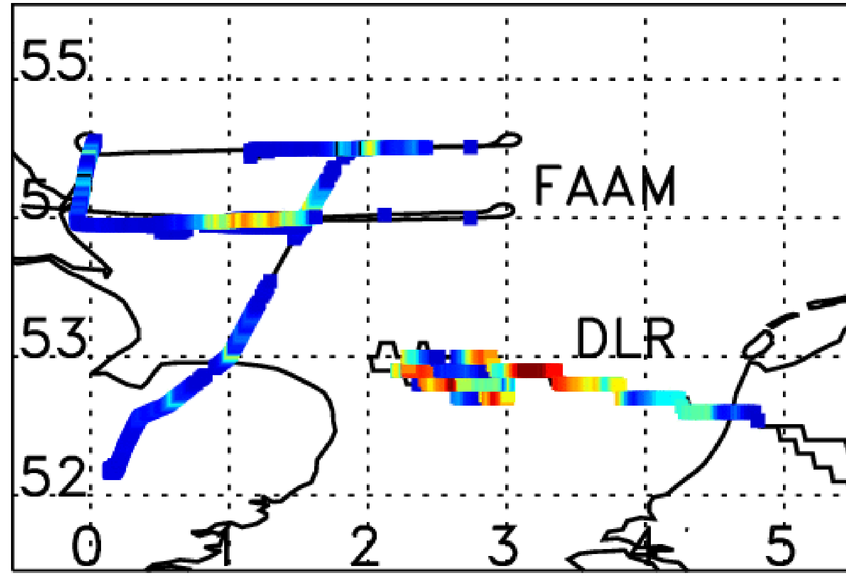
SEVIRI "dust" RGB imagery

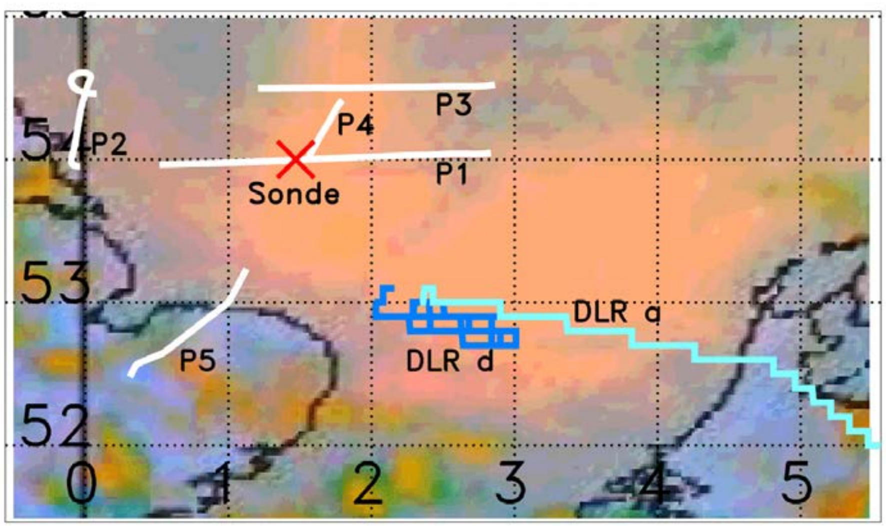


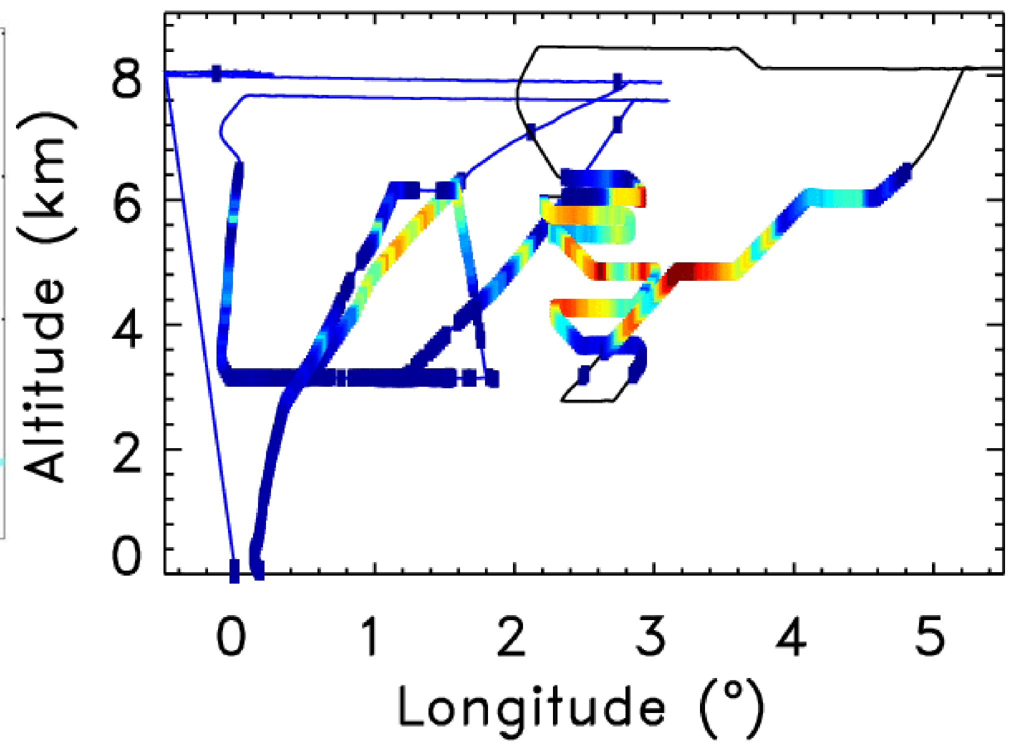
Flight tracks

FAAM and DLR aircraft sampled the same event







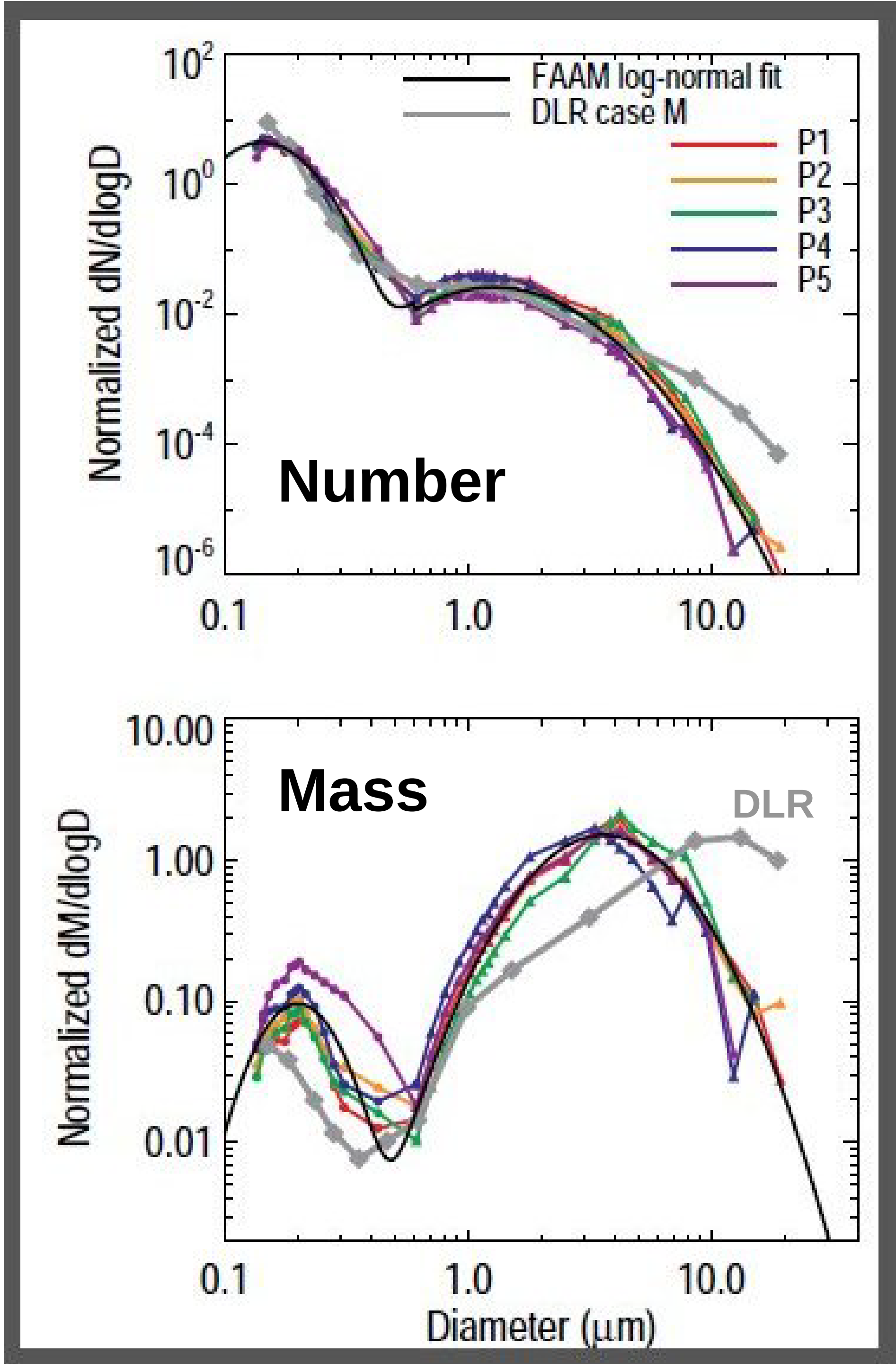


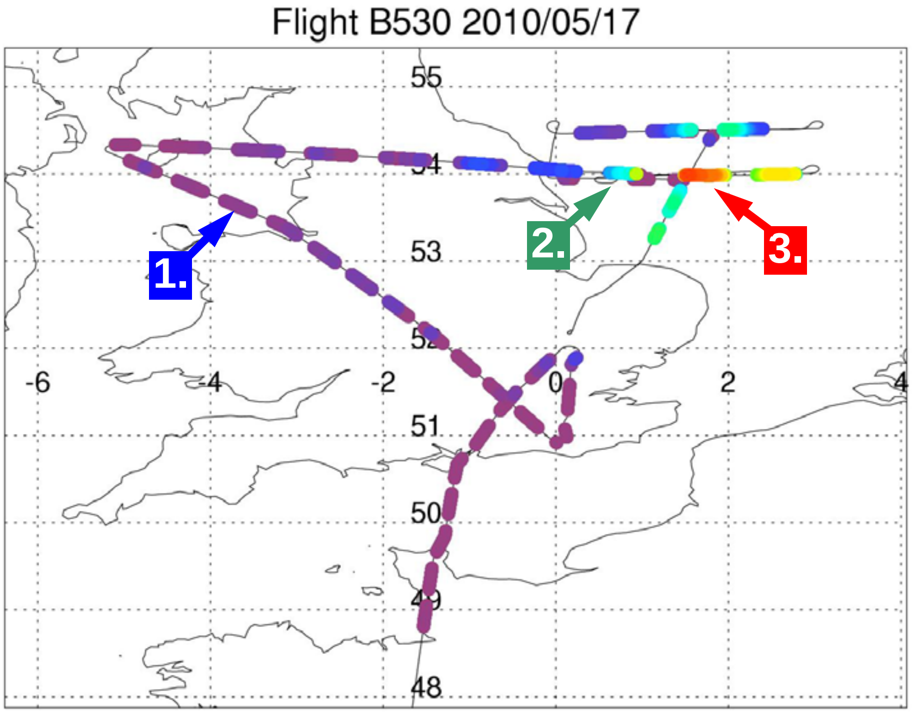
Thanks to University of Manchester for provision of CAS data

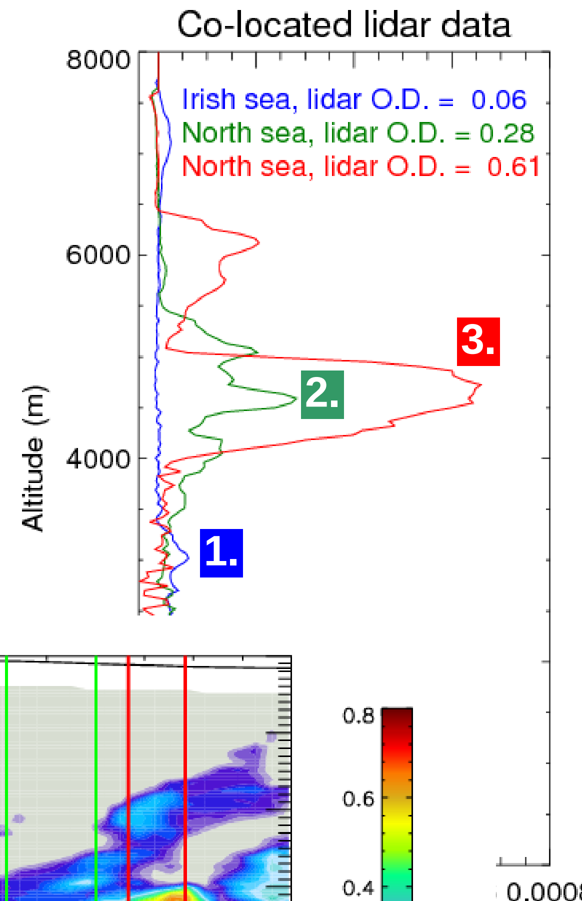
Met Office

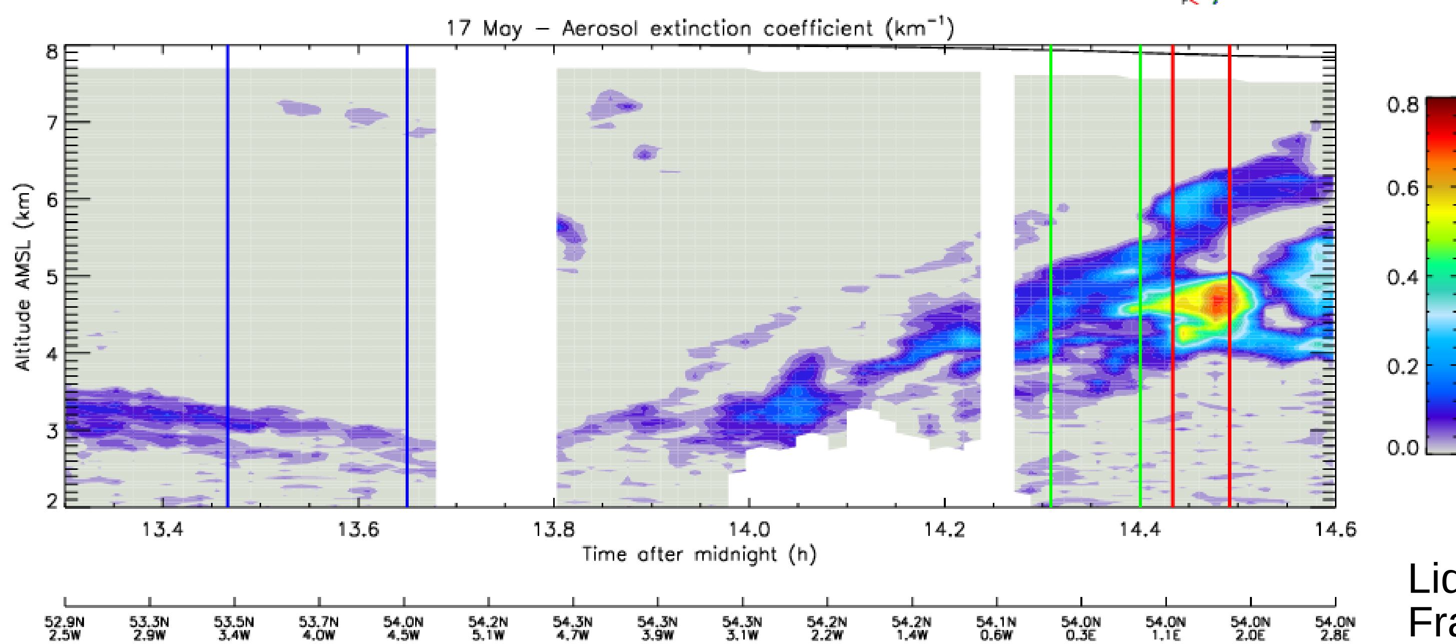
- Around 98% particles by mass were found in the coarse mode, around 2% in the fine mode
- DLR size distribution has mean diameter of approx. 9.6 μm, larger than estimated by CAS on FAAM BAe 146 (3.6-4.5 μm)
- Some support for CAS size distribution from ground-based AERONET retrievals

Turnbull, Kate; Johnson, Ben; Marenco, Franco; Haywood, Jim; Minikin, Andreas; Weinzierl, Bernadett; Schlager, Hans; Schumann, Ulrich; Leadbetter, Susan; Woolley, Alan
A case study of observations of volcanic ash from the Eyjafjallajökull eruption: 1. In situ airborne observations
J. Geophys. Res., Vol. 117, No. null, D00U12









Lidar:
Franco Marenco

Radiative transfer modelling of infrared spectra

Radiative transfer modelling

- **Infrared airborne radiances**: use Havemann-Taylor Fast Radiative Transfer Code (HTFRTC). Based on singular value decomposition of spectral information to speed up calculations. Ability to treat scattering by clouds and aerosol particles.
- **IASI mass retrievals**: code developed at ULB. Optimal estimation for simultaneous retrieval of trace gases, aerosol size and concentration. Treats multiple scattering in spherical geometry.

Can we model the infrared ash signature?

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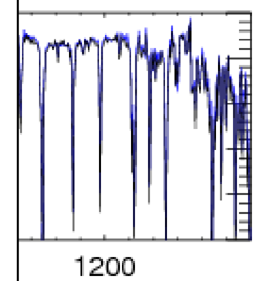
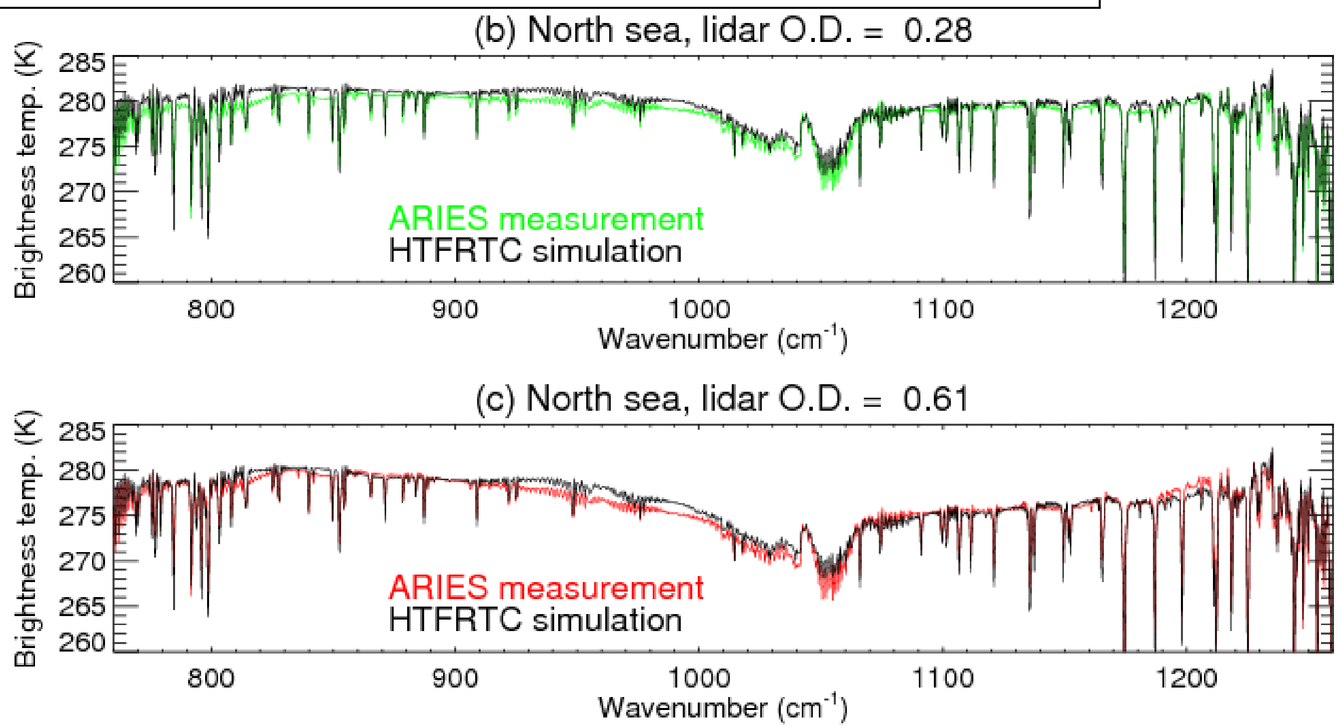
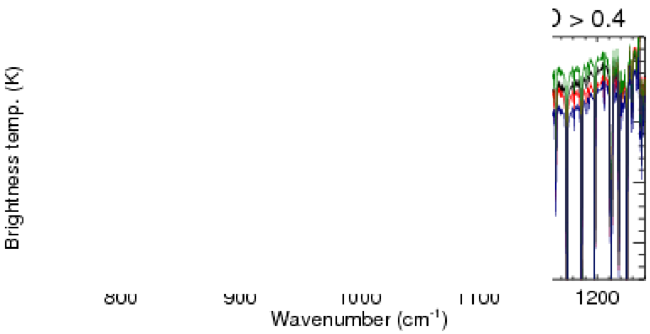
Lidar extinction profile has been used as input to forward calculation along with representative temperature and humidity profiles. Aerosol properties are based on measured size distribution and dust refractive index due to Balkanski et al. (2007)

Agreement is (surprisingly) good



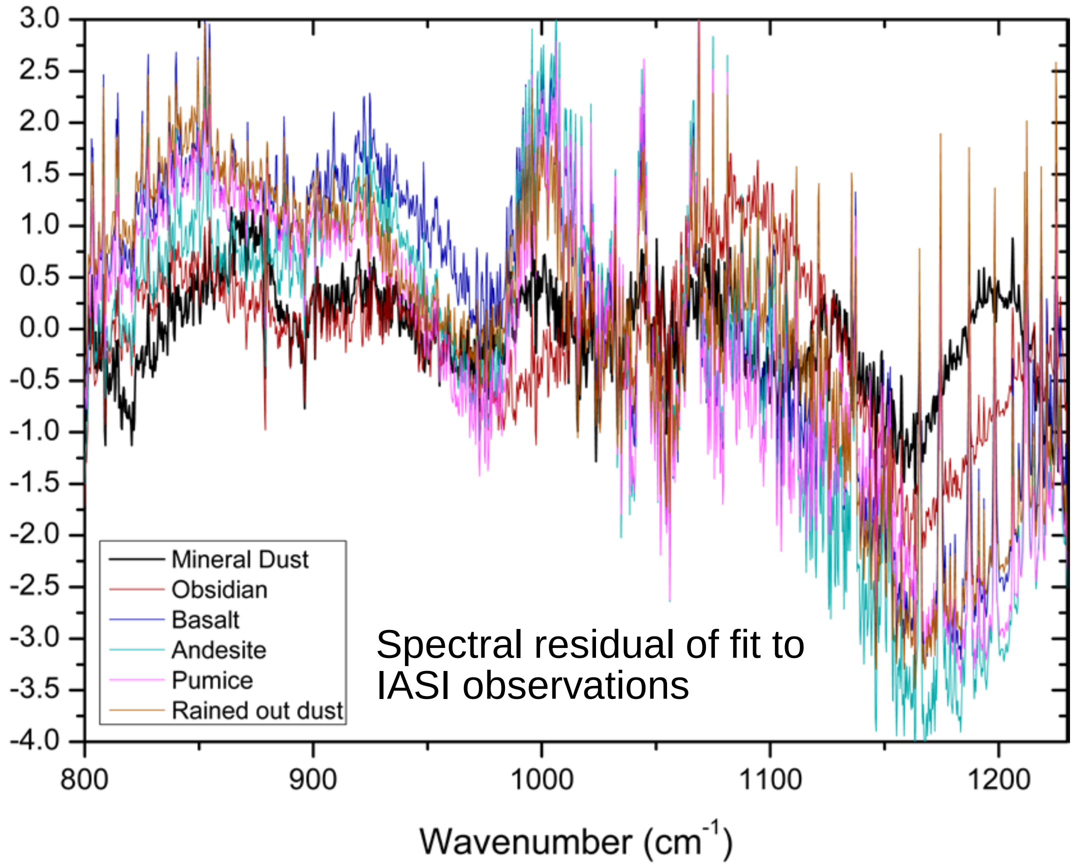
Increasing ash concentration





IASI: mineral dust refractive index is a good match here too

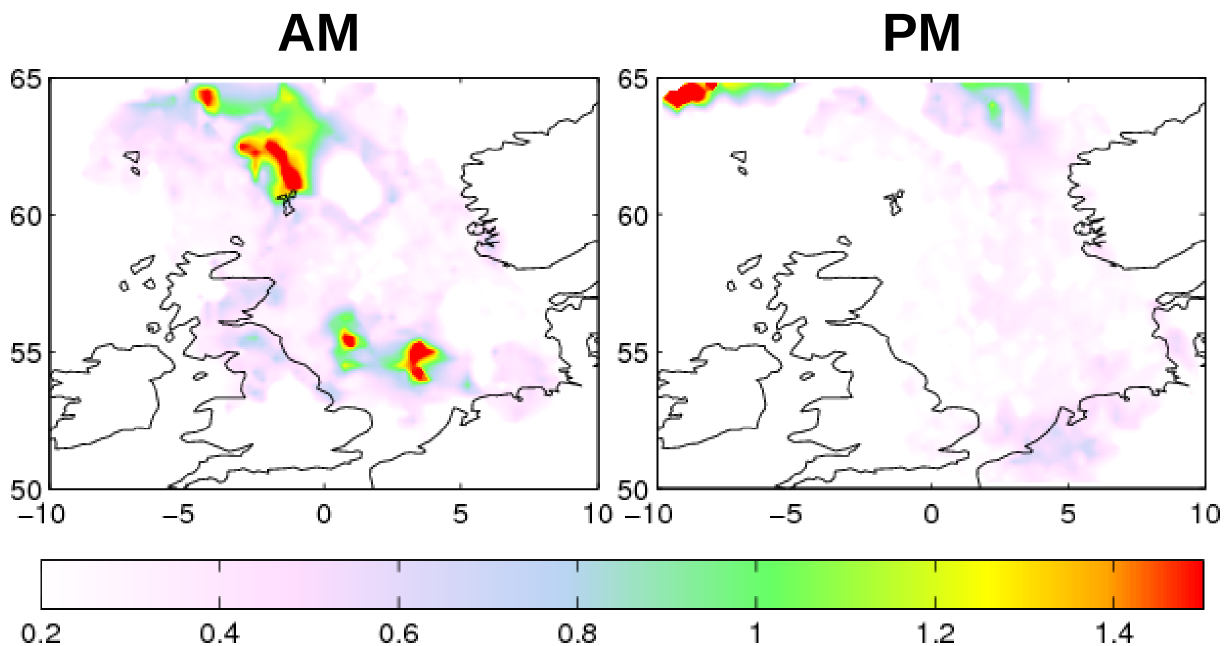
Name	**RMS of residual (in W m-2 m sr-1)**	**Mass (in % of first)**	**Reference**
Mineral Dust	$5.5\ 10^{-6}$	100	Balkanski et al., 2007
Obsidian	$7.2\ 10^{-6}$	79	Pollack et al., 1973
Basalt	$1.6\ 10^{-5}$	65	Pollack et al., 1973
Andesite	$1.5\ 10^{-5}$	63	Pollack et al., 1973
Pumice	$1.4\ 10^{-5}$	73	Volz, 1973
Rained out dust	$1.5\ 10^{-5}$	159	Volz, 1973



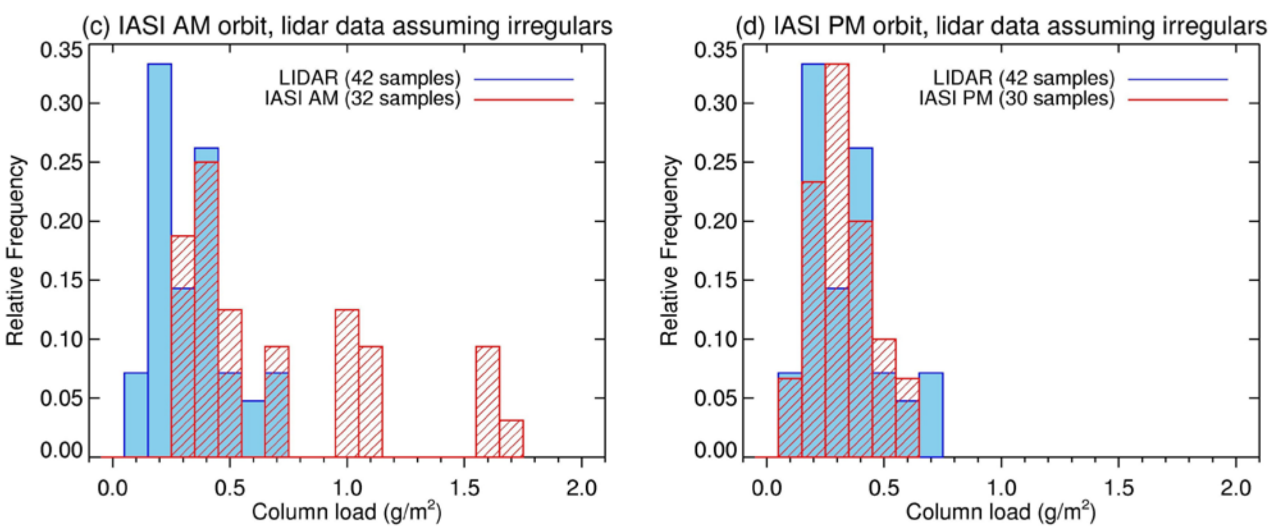
IASI retrievals of ash mass concentration

IASI ash retrievals

ULB IASI ash mass loadings (g/m^2) for 17 May am and pm overpasses



Lidar and IASI distribution of column loadings over same advected part of ash plume area



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Choice of ash refractive index

Why does mineral dust refractive index match ash cloud spectra?

This case study

2 May 2010 **17 May 2010**

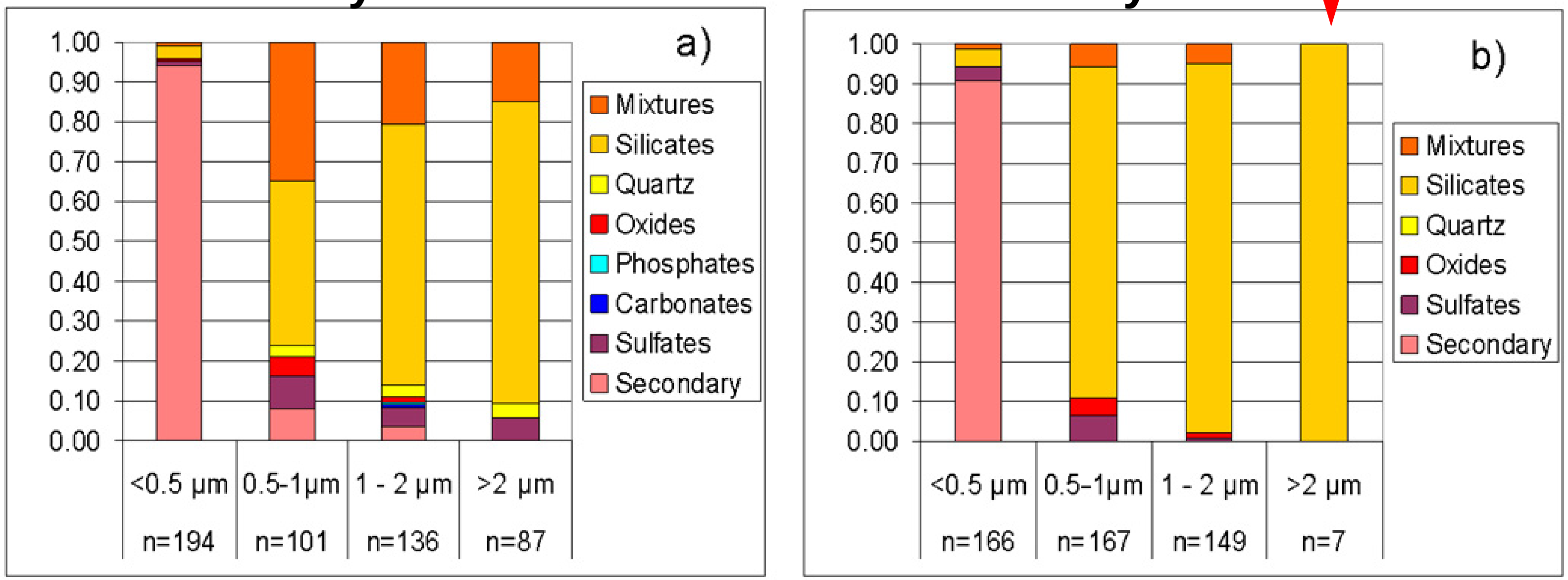


Fig. 6. Relative number abundance of particles with different chemical composition in different size bins for two sampling days ((**a**) 15:01–15:15 UTC 2 May, (**b**) 16:20–16:24 UTC 17 May). Here, *n* is the total number of particles analyzed in each size bin.

Citation: Schumann, U., Weinzierl, B., Reitebuch, O., Schlager, H., Minikin, A., Forster, C., Baumann, R., Sailer, T., Graf, K., Mannstein, H., Voigt, C., Rahm, S., Simmet, R., Scheibe, M., Lichtenstern, M., Stock, P., Rüba, H., Schäuble, D., Tafferner, A., Rautenhaus, M., Gerz, T., Ziereis, H., Krautstrunk, M., Mallaun, C., Gayet, J.-F., Lieke, K., Kandler, K., Ebert, M., Weinbruch, S., Stohl, A., Gasteiger, J., Groß, S., Freudenthaler, V., Wiegner, M., Ansmann, A., Tesche, M., Olafsson, H., and Sturm, K.: Airborne observations of the Eyjafjalla volcano ash cloud over Europe during air space closure in April and May 2010, Atmos. Chem. Phys., 11, 2245-2279

- Large particles are dominated by silicates on 17 May 2010
- This is less evident on 2 May 2010

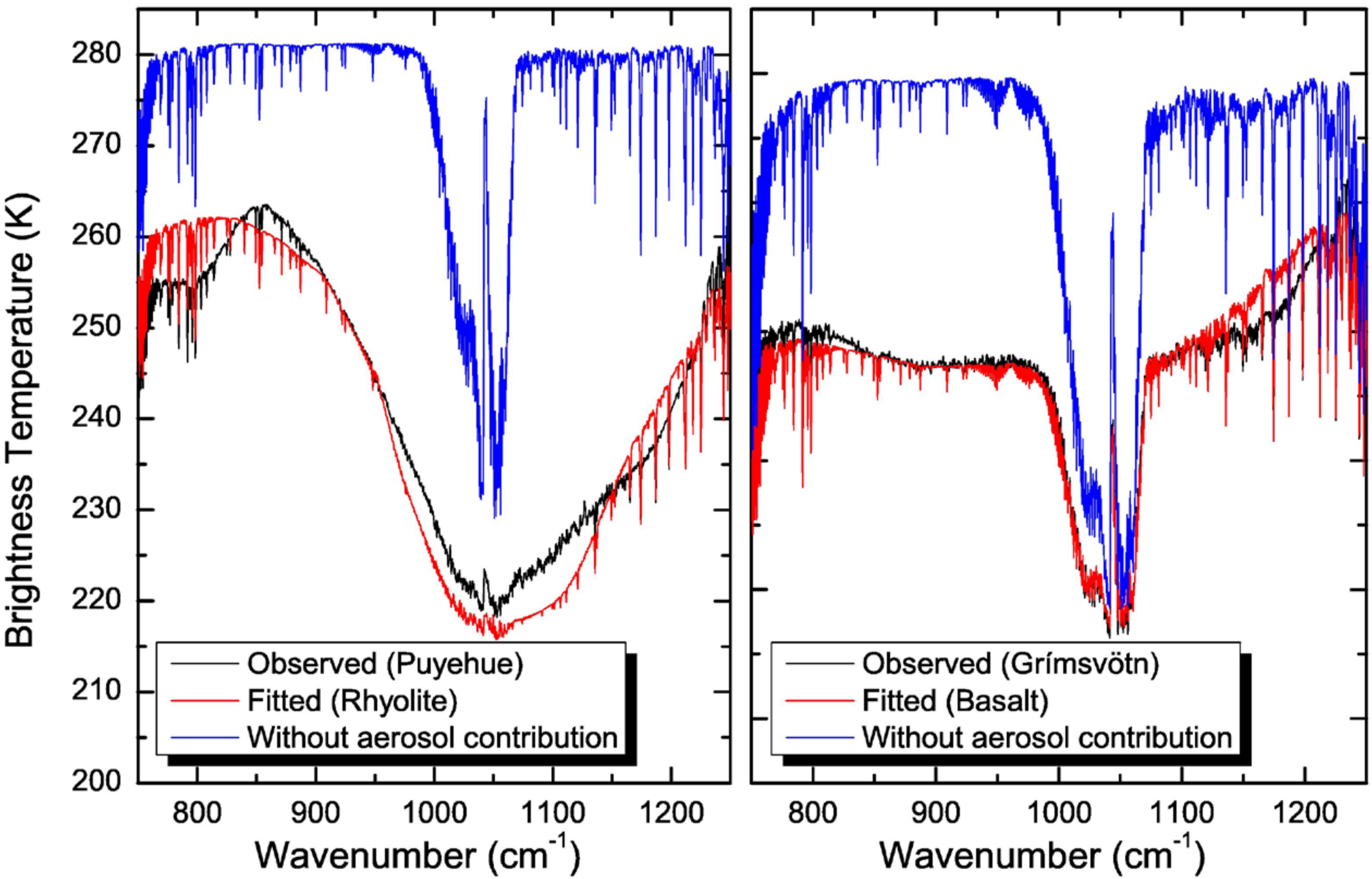
Summary and conclusions

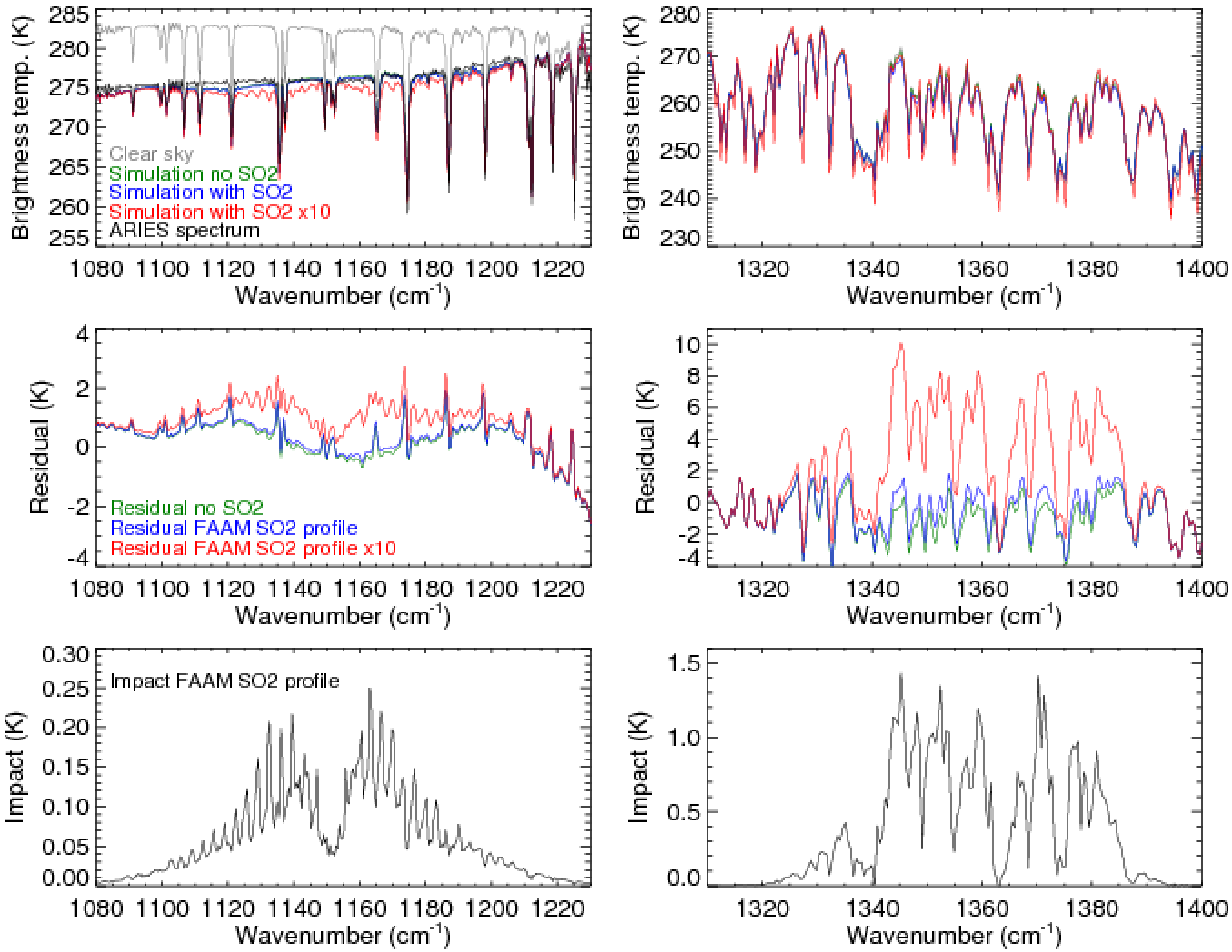
Met Office

- Airborne and satellite infrared radiances can be accurately modelled based on the in situ measured size distribution and a mineral dust refractive index
- Retrievals of ash mass column loading using IASI observations are in accord with lidar-derived mass estimates, giving a verification for the hyperspectral ash retrieval method
- Modelling of ARIES and IASI ash-affected spectra demonstrates the importance of accurately specifying the refractive index
- There is evidence that the composition of airborne ash from the Eyjafjallajökull eruption varied within the same event
- It was recognised in the UK that there is a requirement for a well instrumented airborne facility to be able to monitor ash concentrations – the Met Office now operates a twin piston engine aircraft for civil contingency use

Questions and answers

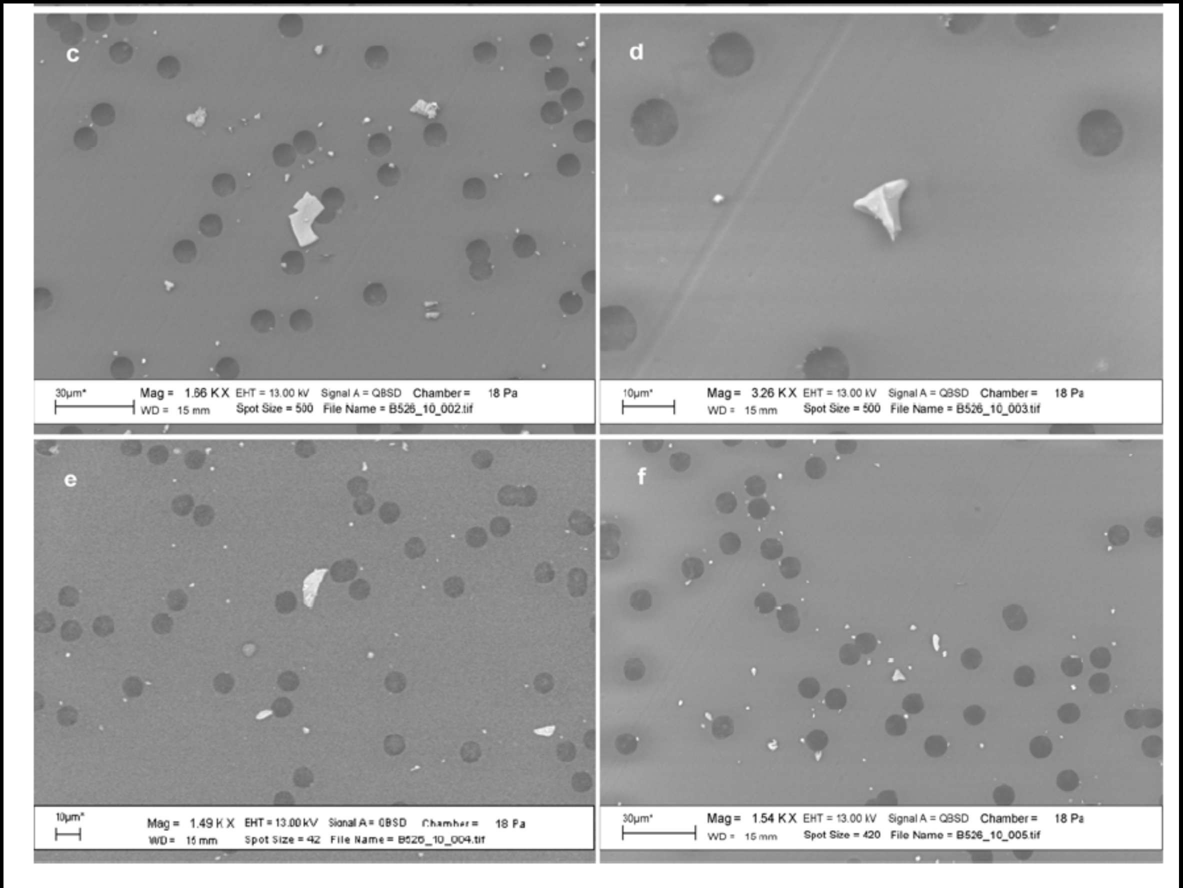
Other eruptions: Puyehue in Chile and Grímsvötn in Iceland as seen by IASI




Brightness temp. (K)
Clear sky
Simulation no SO2
Simulation with SO2
Simulation with SO2 x10
ARIES spectrum
Wavenumber (cm-1)
Residual (K)
Residual no SO2
Residual FAAM SO2 profile
Residual FAAM SO2 profile x10
Impact (K)
Impact FAAM SO2 profile

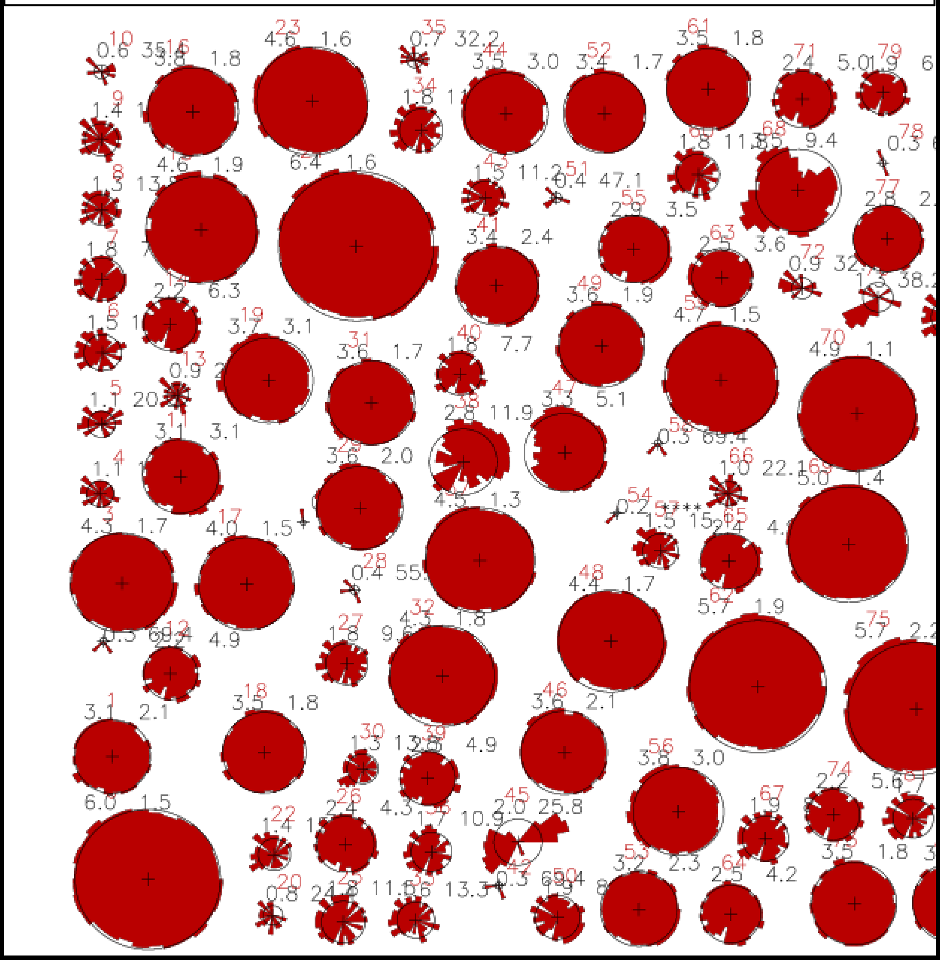
But ash particles are NOT spheres!

Electron microscope images of ash collected on filters during FAAM flight B526

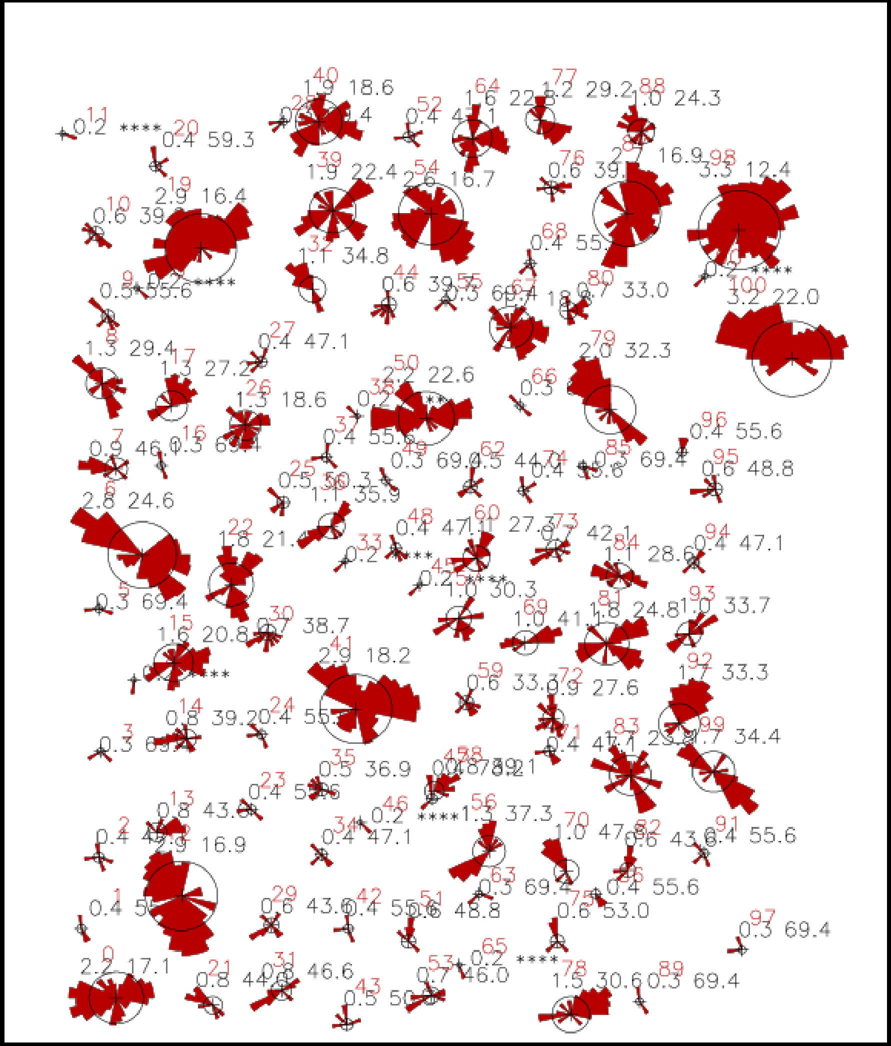


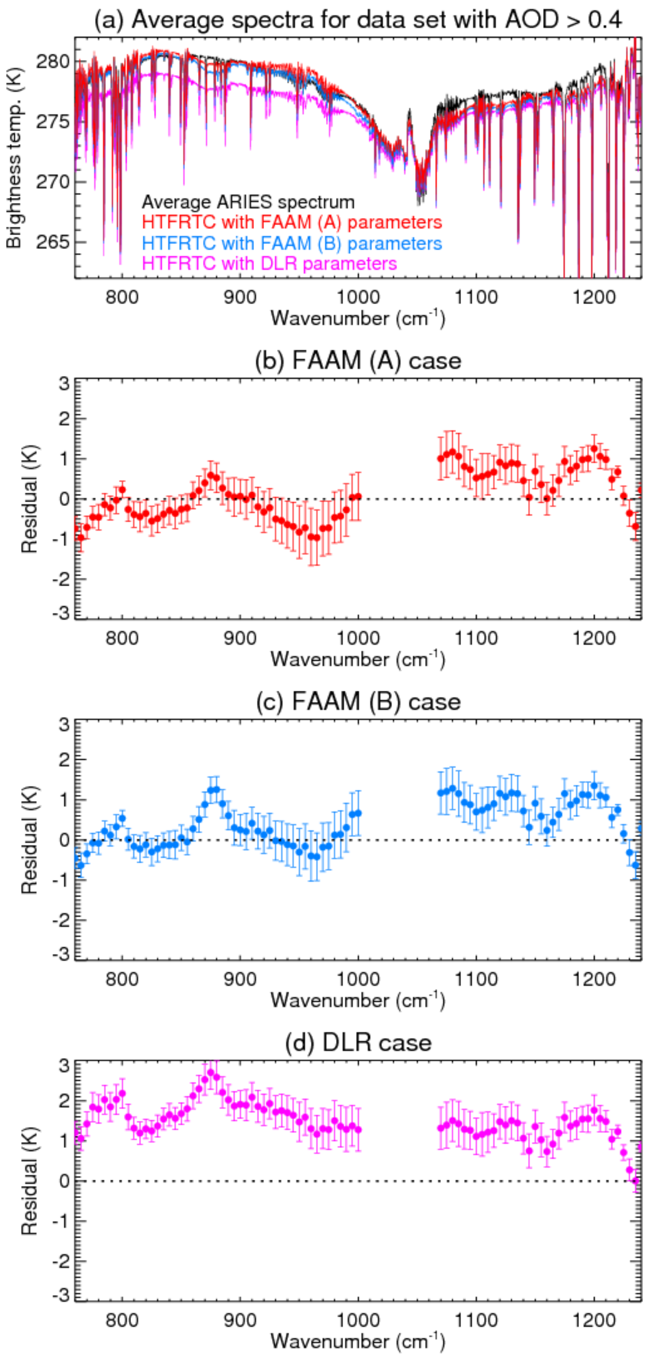
But ash particles are NOT spheres!

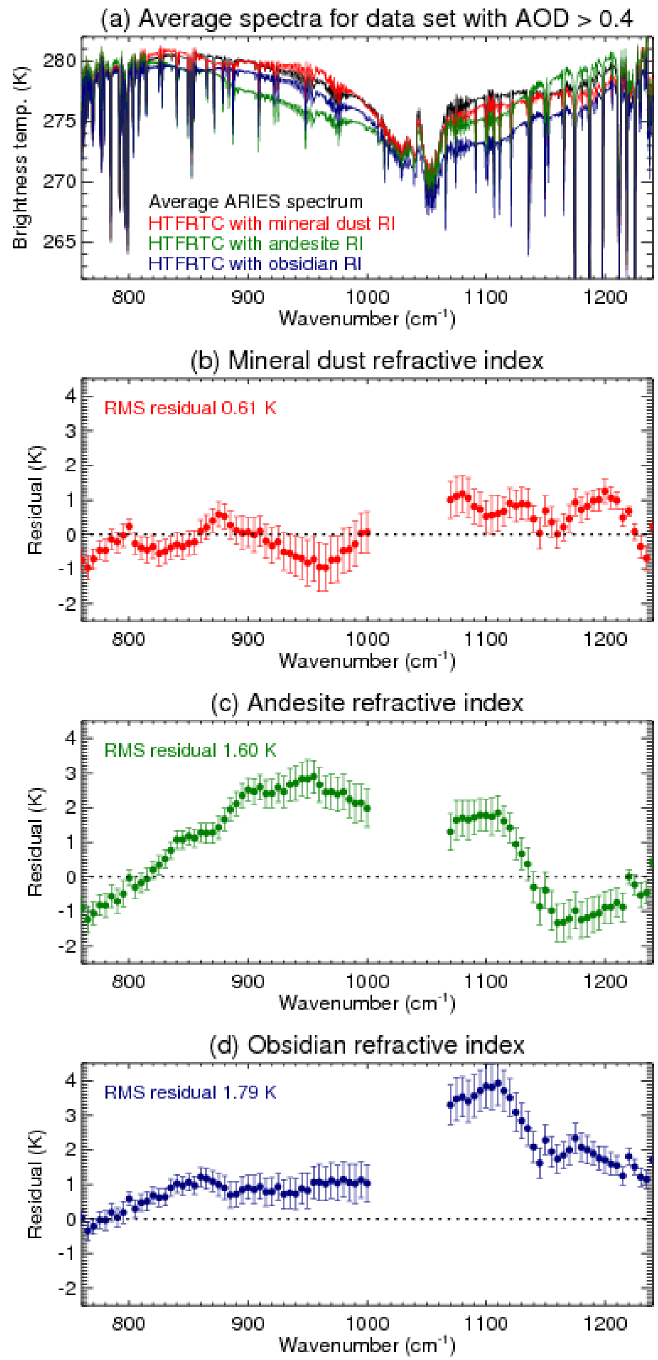
SID2h scattering patterns for hydrated sea-salt aerosol (spherical)



SID2h scattering patterns for ash

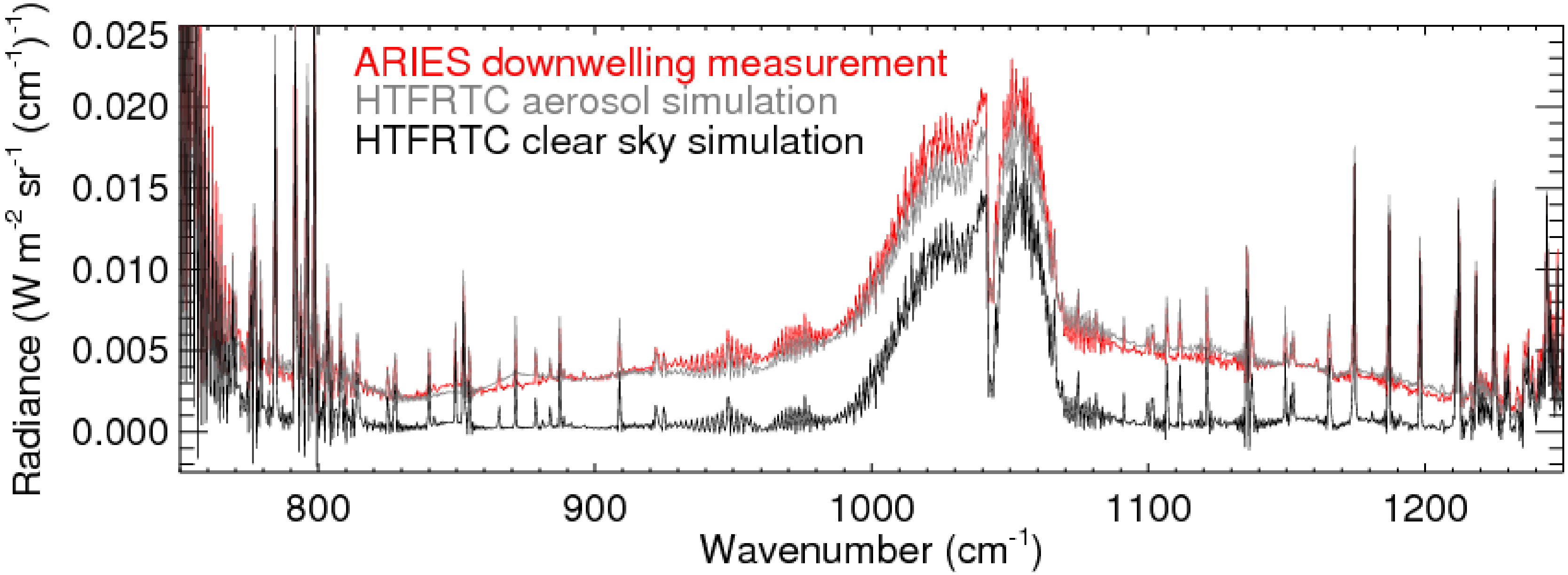






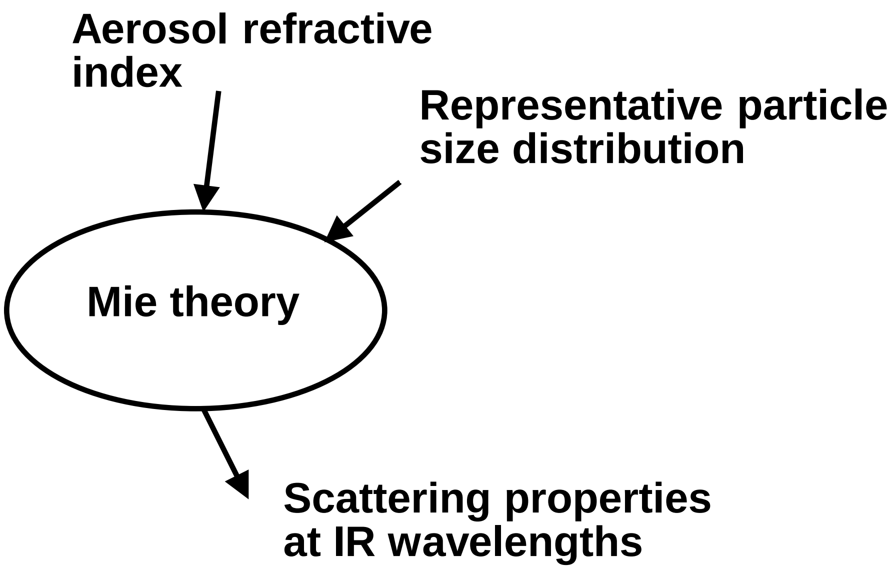
- Other refractive indices: Balkanski mineral dust gives best agreement
- Other choices (andesite and obsidian) fail to match observations

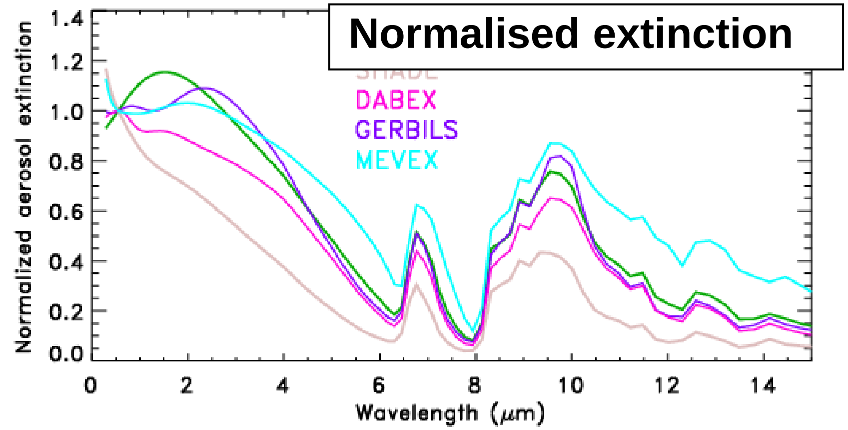
ARIES looking up under the ash…

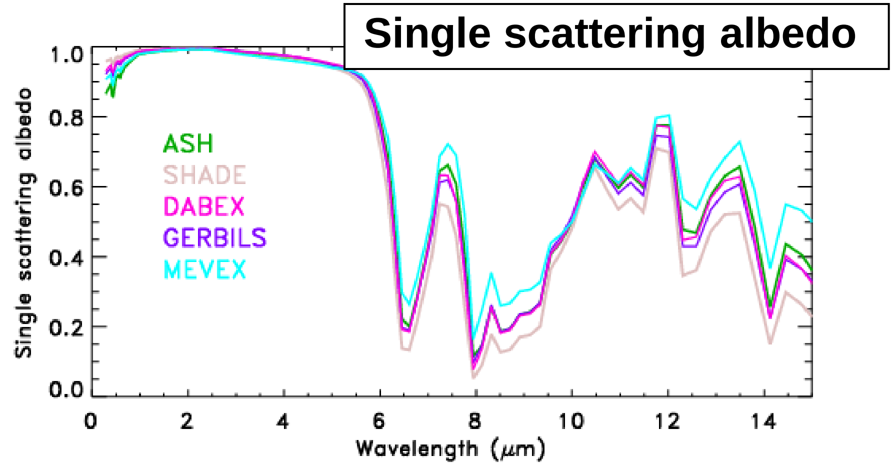


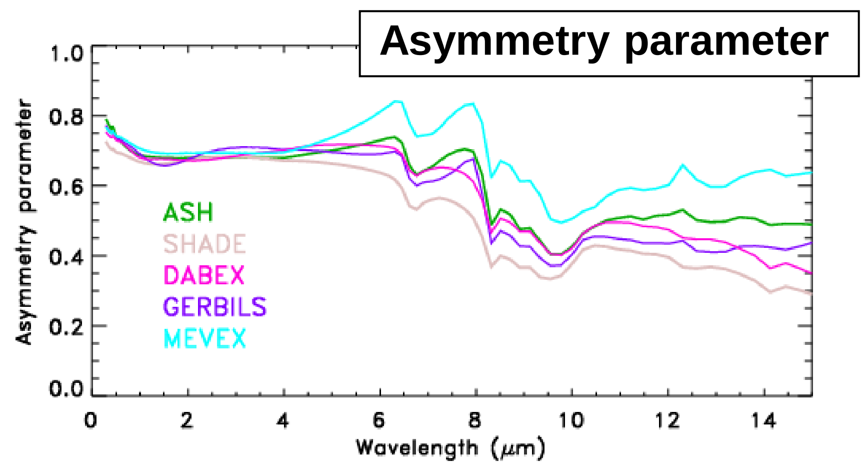
With scaled extinction profile agreement of simulation with measured brightness temperature is good

Aerosol scattering properties









(calculations by Ben Johnson)