Volcanic Ash and Saharan Dust Loads derived from Airborne Observations

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with contributions by
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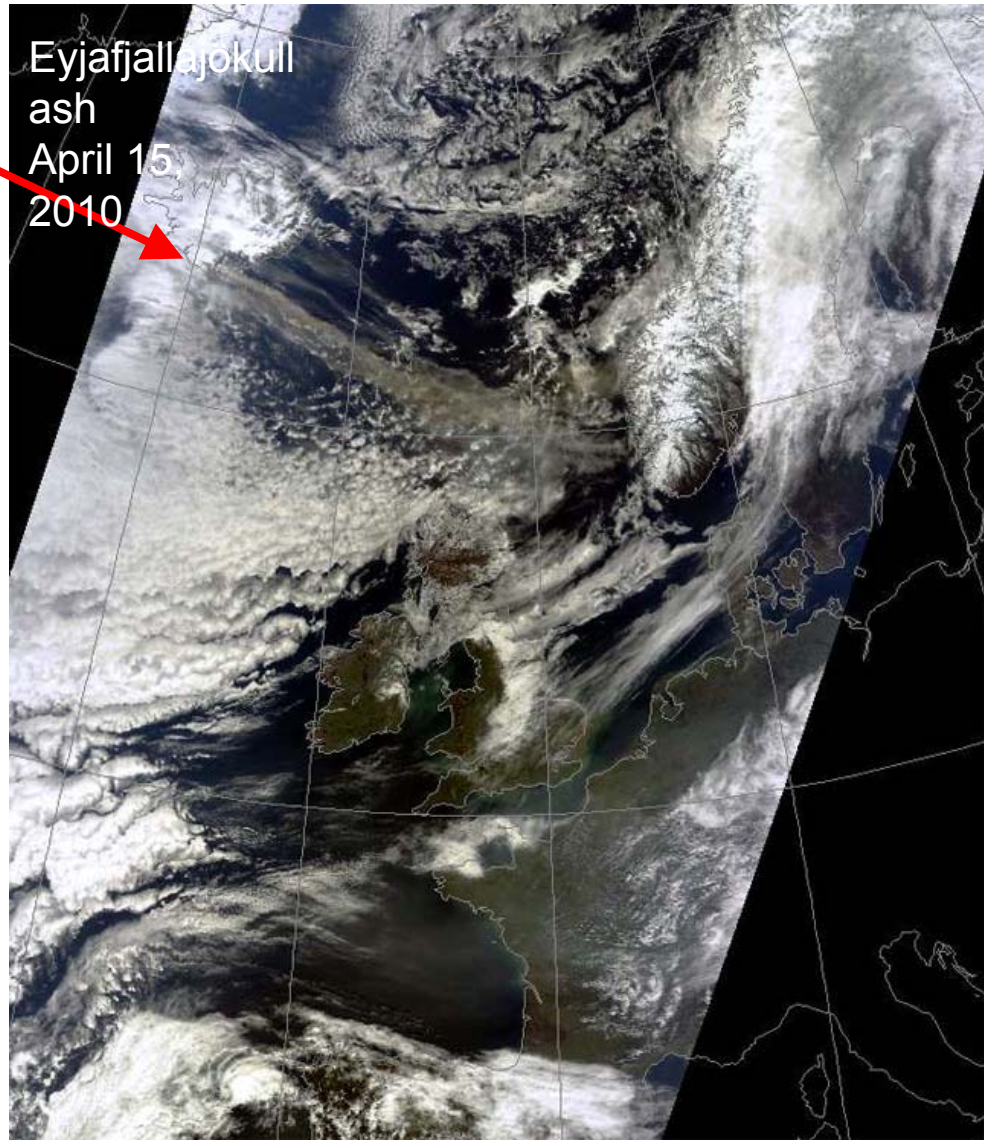
100 JAHRE Luft- und Raumfahrtforschung in Deutschland

Desert dust and volcanic ash



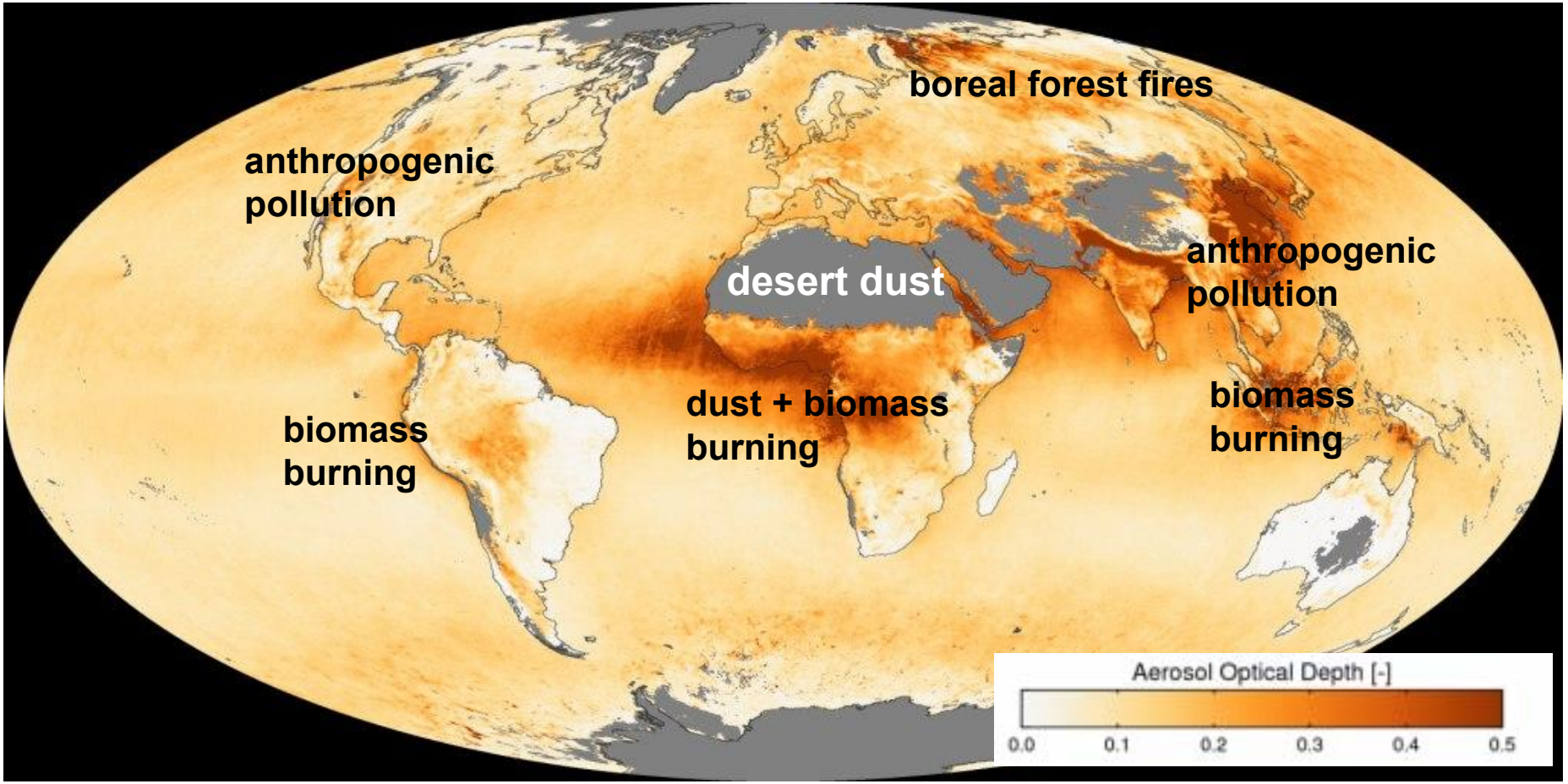
MODIS on NASA Terra
Satellite at 11.39 GMT
Thursday April 15, 2010

Quelle: NASA Earth Observatory

Comparison Saharan dust – Volcanic ash (preliminary)

Parameter	Desert Dust	Volcanic Ash
Altitude	0-6 km	3-15 km
Depth	3-5 km	0.5-2 km
width	100-500 km	50-300 km
Critical ages	< 3 days	< 6 days
Max concentration	100 mg/m3	1 g/m3
Concentration after one day	< 5 mg/m3	< 10 mg/m3
Annual mean at airports	0.2 mg/m3	
Max. particle diameter in lofted layers	< 50 μm	< 30 μm
Particle shape, aspect ratio	aspherical , 1-2	aspherical, 2
Lidar Depolarization 532 nm	0.3	0.4
Refractive index, typical, real	1.55±0.03	1.57±0.03
Imaginary (550 nm)	0.003±0.003	0.005±0.005
morphology	crystalline	glassy or crystalline
Main composition	like carbonates and clay	quartz, silicate more variable?
Melting temperature	960 to 1700 °C, low for clay etc., high for quartz	lower ???
Optical appearance	Yellow to brownish	dark grey, brownish
Aerosol optical depth, after one day	< 1 away from source region	< 2
Impact on aviation	Close to airports, LTO	Free troposphere, cruise

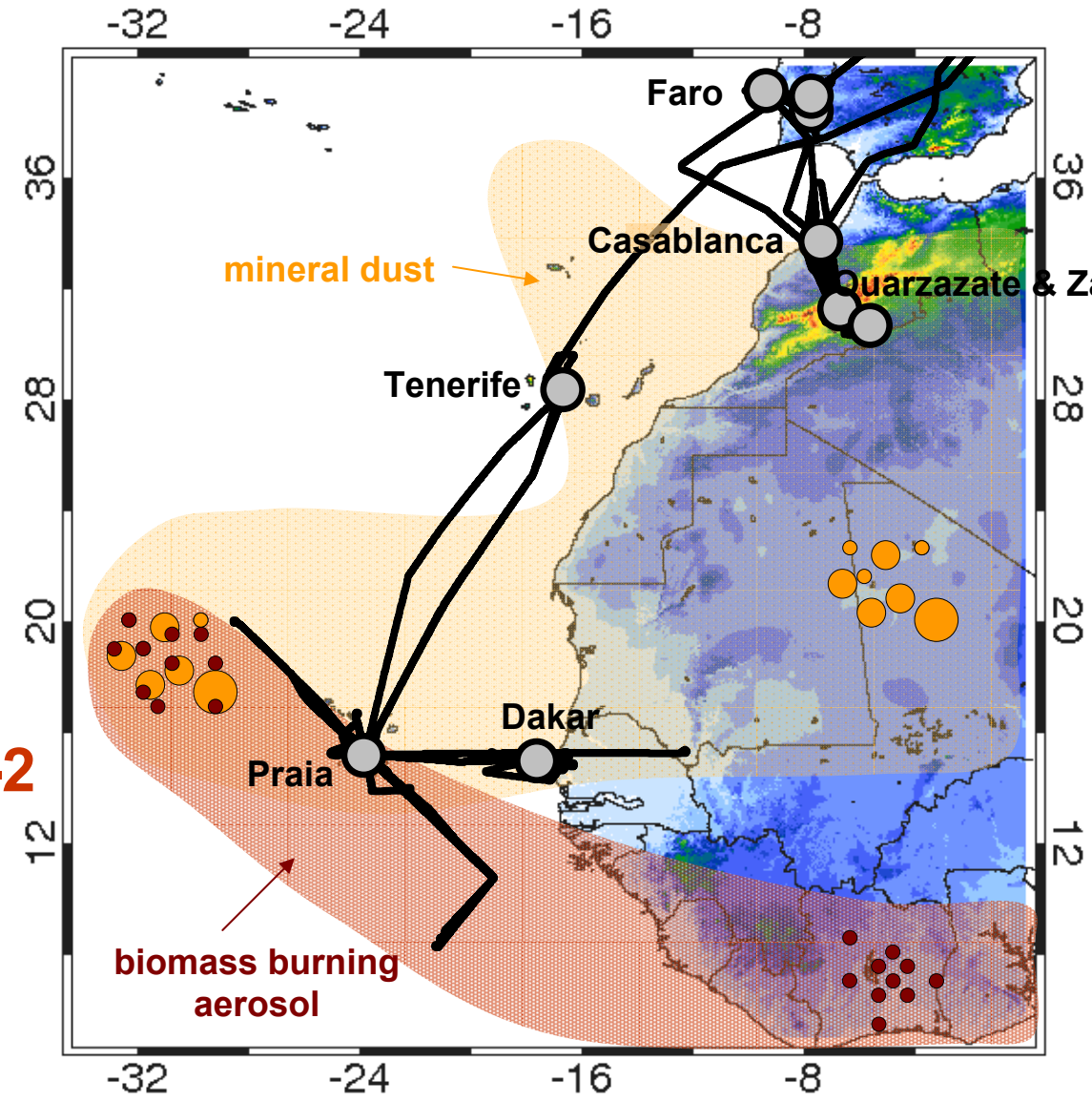
Global Aerosol Sources



2006 annual average of MODIS AOT (@550)

http://climate.gsfc.nasa.gov/viewImage.php?id=199
Image of the Week - February 18, 2007

SAMUM-1 and SAMUM-2 research flights



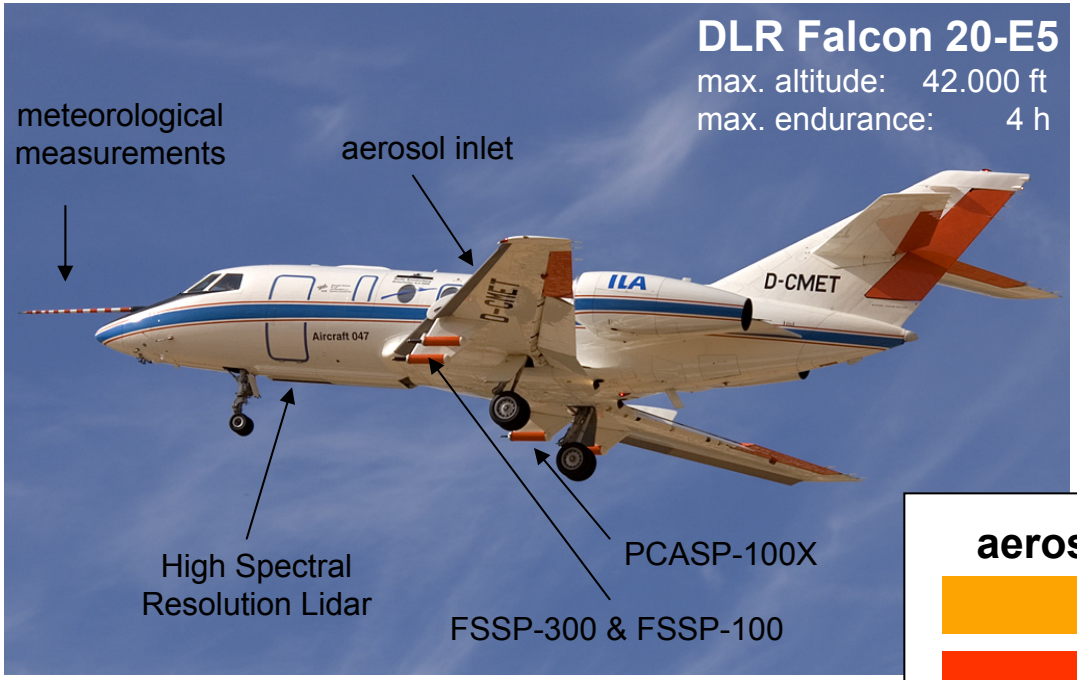
SAMUM-1

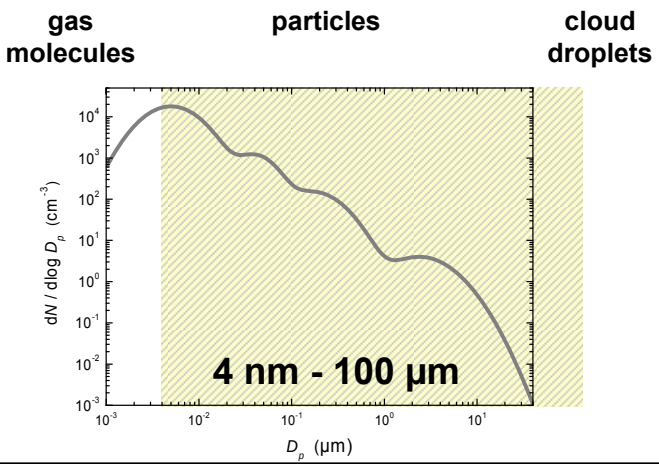
SAMUM-2

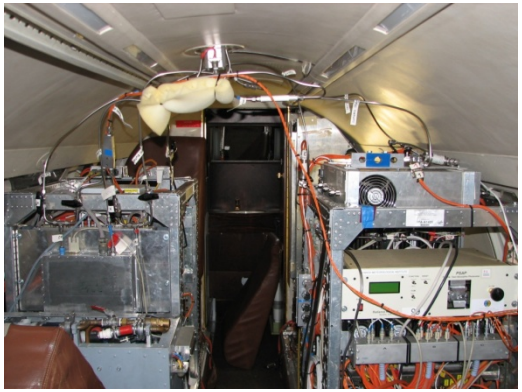
Sahara:
- largest desert on Earth (9 Mio km²).
- 50-70% of global annual mean dust emissions (Mahowald et al., 2005)

SAharan Mineral DUst ExperiMent (SAMUM)

Airborne instrumentation during SAMUM-1 and SAMUM-2



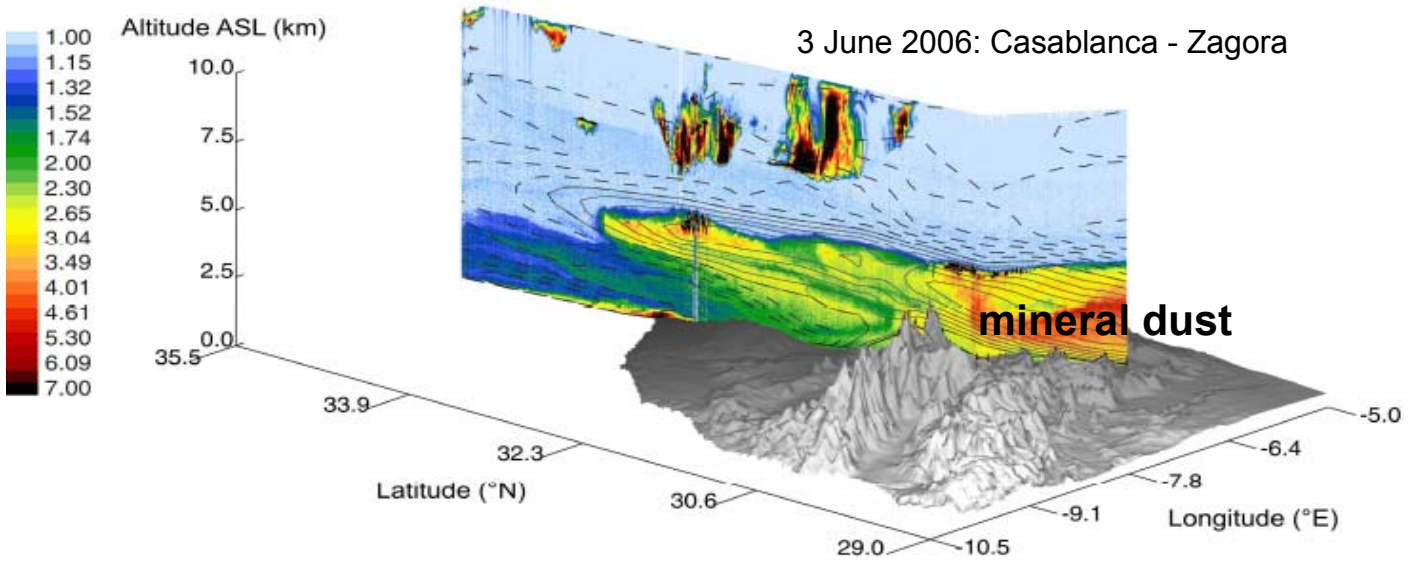




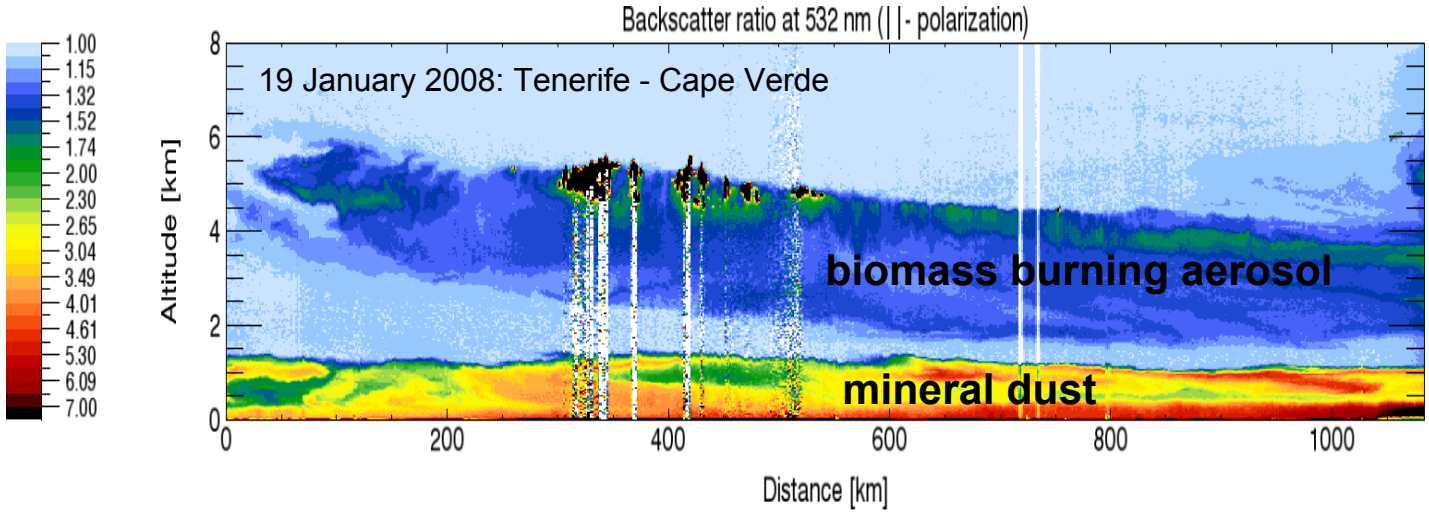
aerosol in-situ measurement techniques

- condensation (CPSA/CPC)
- deposition (CPC + DS)
- electrical mobility (DMA)
- light scattering (PCASP-100X, FSSP-300, FSSP-100)
- light transmission (3-λ-PSAP)
- thermo-optic (thermal denuder + CPCs and Grimm OPC)
- filter sampling: chemical composition & particle shape

Lidar: vertical structure: SAMUM-1 versus SAMUM-2

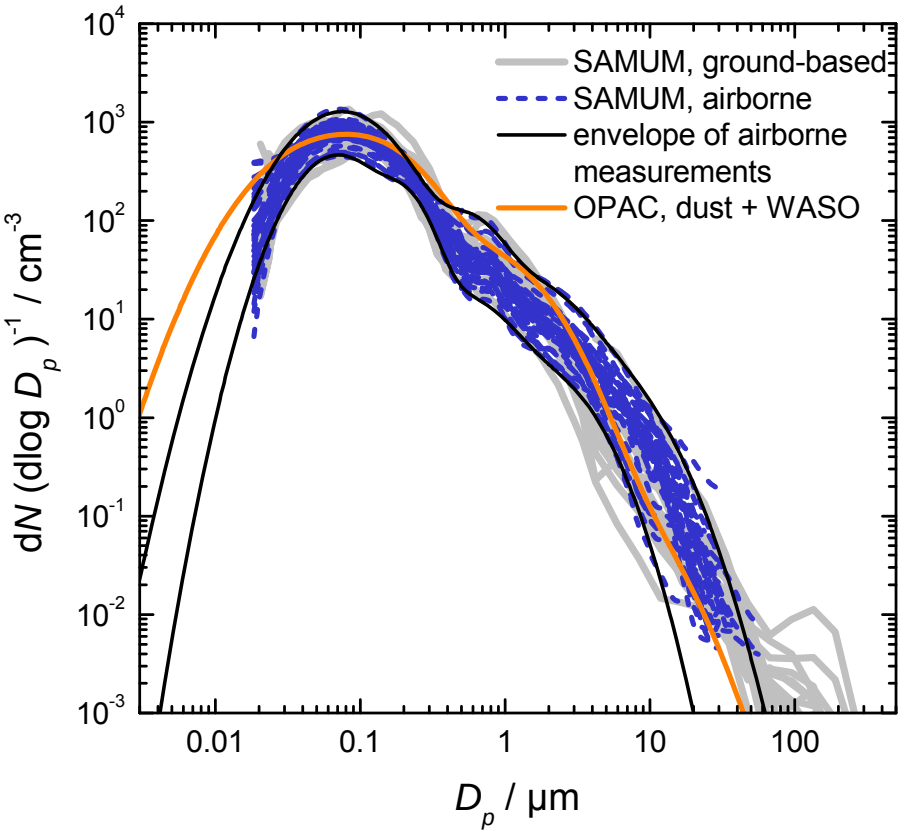


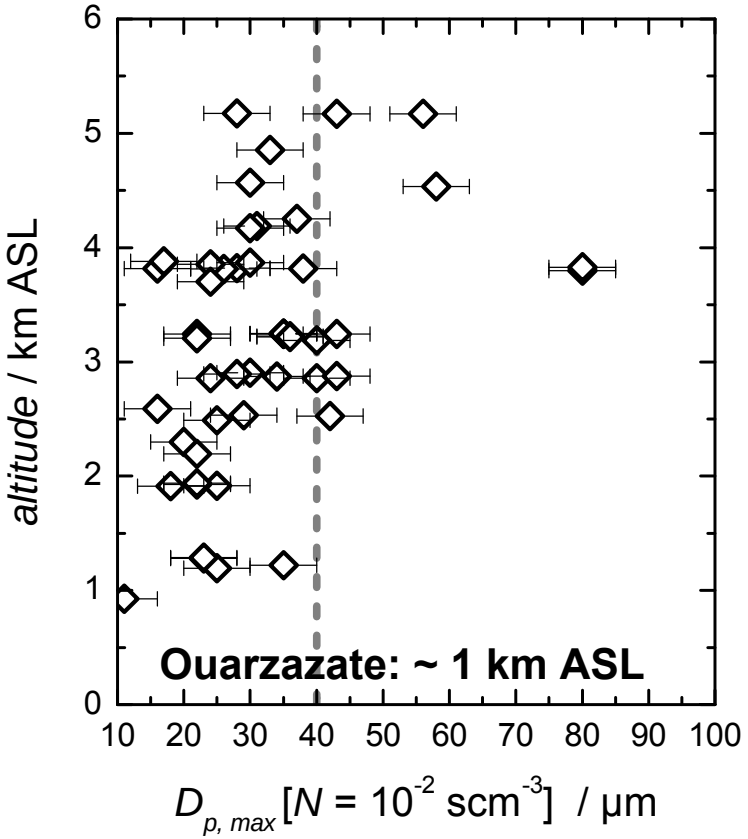
SAMUM-1
May/June 2006



SAMUM-2
January 2008

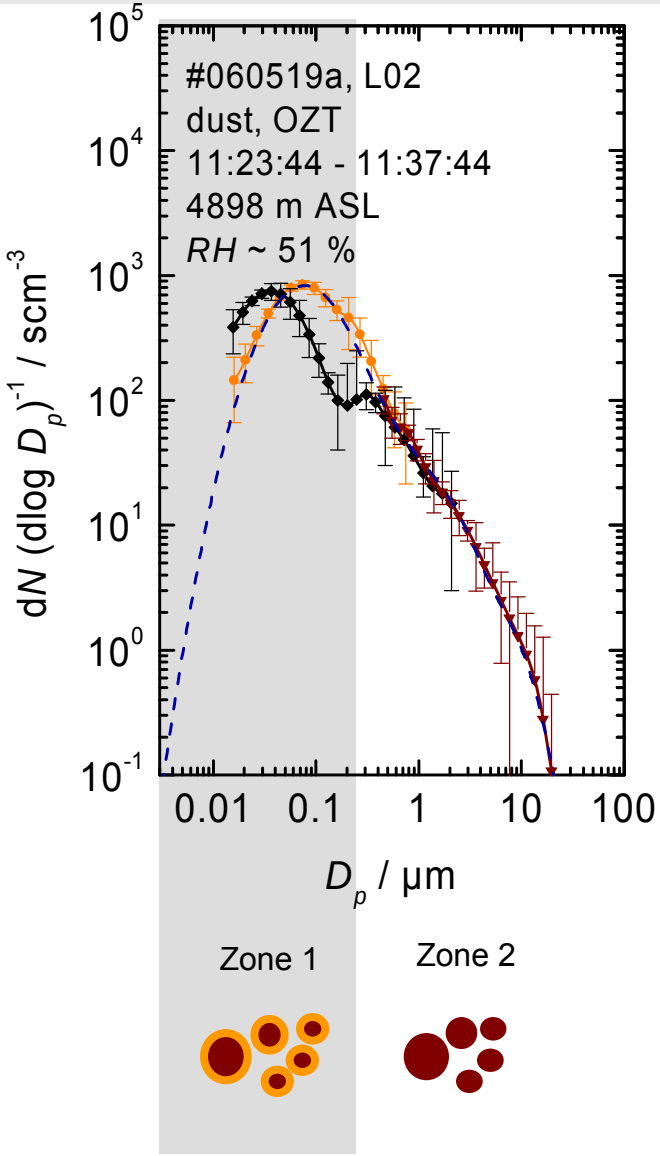
SAMUM-1: Size distributions



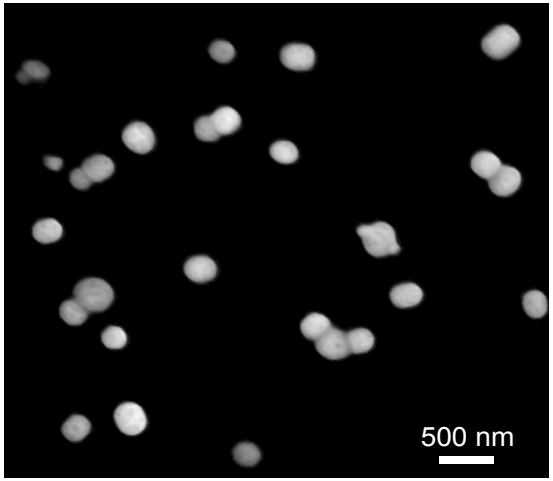


- ⇨ **Good agreement between airborne and ground measurements**
- ⇨ **„Saltation mode" at ground.**
- ⇨ **in all cases, particle diameters D_p > 10 µm**
- ⇨ **Mostly (80%) particles smaller than 40 µm**
- ⇨ **No height dependence**

SAMUM-1: Microphysical dust properties



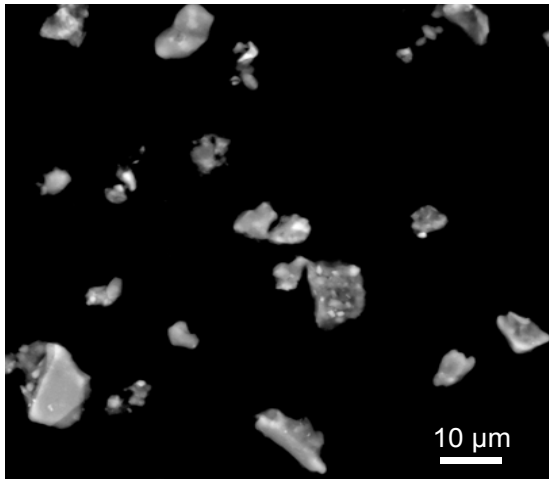
Zone 1



particles with nonvolatile core and volatile coating (ammoniumsulfat)

$m_{mean,\ 532nm} = 1.531 + 0i$

Zone 2



Nonvolatile particles with absorbing material

$m_{mean,\ 532nm} = 1.555 + 0.0032i$
$n_{sd,\ 532nm} = 0.0053$
$k_{sd,\ 532nm} = 0.0012$

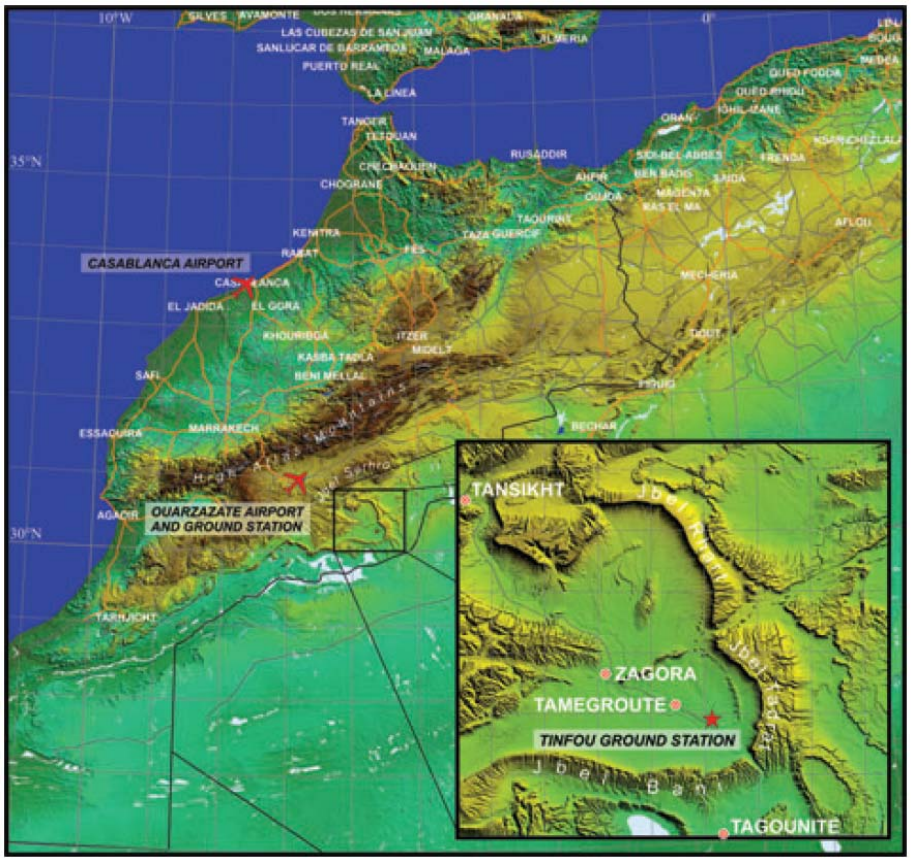
(Weinzierl et al., 2009)

Data from SAMUM mass concentrations up to 5 mg/m3

Table 4. Microphysical properties of pure dust aerosol over Ouarzazate (OZT) and Zagora (ZGA)

Mission ID	Layer ID	Site	Start time (UT)	Altitude (m a.s.l.)	D_{mode1}	GSD_{mode1}	N_{mode2} (cm^{-3})	CMD_{mode2} (μm)	GSE	GSD_{mode1}	TSP (data) ($\mu g\ m^{-3}$)	PM2.5 (data)	$f_{PM2.5/TSP}$	$f_{sec-vol2.5}$	D_{eff} (data) (μm)
060519a	L02	OZT	11:23:44		77	2.10	30	0.44	1.90						6.5
060519a	L03	OZT	11:44:02		79	2.30	10	0.55	1.50						6.8
060520a	L02	ZGA	11:38:16		77	1.90	75	0.24	1.60						9.9
060520a	L03	ZGA	11:48:36		74	1.93	80	0.32	1.70						12.2
060520a	L04	ZGA	11:55:32		76	1.90	75	0.20	1.55						8.8
060520a	L05	ZGA	12:10:36		75	1.90	85	0.20	1.90						5.9
060520a	L07	OZT	12:41:48		77	2.30	15	0.55	1.50						8.2
060520a	L08	OZT	12:54:36		71	2.40	15	0.55	1.50						5.9
060520a	L09	OZT	13:11:44		78	2.15	15	0.55	1.50						13.7
060522a	L04	OZT	15:53:15		77	1.70	120	0.22	1.60						8.6
060522a	L05	OZT	15:58:15		75	1.75	120	0.22	1.60						8.6
060522a	L06	OZT	16:01:51		76	1.65	100	0.23	1.60						9.4
060522b	L01	OZT	17:21:36		73	1.70	125	0.21	1.67						7.8
060522b	L02	ZGA	17:34:48		75	1.67	125	0.22	1.67						4.4
060522b	L03	ZGA	17:56:26		73	1.70	125	0.21	1.67						11.0
060528a	L03	ZGA	11:26:37	4853	72	1.90	7.5	0.60	1.50		1189				6.5
060528a	L04	ZGA	11:41:07		69	2.05	18	0.55	1.50						4.8
060528a	L05	ZGA	11:46:01		74	2.05	9.5	0.62	1.45						5.1
060528a	L06	ZGA	11:51:47		69	2.05	18	0.55	1.50						4.2
060528a	L10	OZT	12:42:42	3246	77	2.07	11	0.69	1.50		1026				6.8
060528a	L11	OZT	12:52:02		77	2.05	9	0.67	1.45						6.1
060528a	L12	OZT	12:55:57		72	2.05	9	0.67	1.45						4.6
060603a	L04	OZT	03:39:53		77	1.70	100	0.20	1.50						6.5
060603a	L05	OZT	03:46:41		75	1.75	100	0.22	1.50						5.5
060603b	L03	ZGA	08:16:58		83	1.80	15	0.55	1.70						6.0
060603b	L04	ZGA	08:31:07		83	1.90	50	0.55	1.69						5.1
060603b	L05	ZGA	08:44:07	5169	72	1.80	100	0.40	1.73		2800				9.9
060603b	L06	ZGA	08:55:16		77	1.85	100	0.20	1.50						4.0
060603b	L07	OZT	09:01:43		75	1.75	120	0.22	1.50						2.5
060603b	L08	OZT	09:04:16		73	1.80	100	0.20	1.50						5.4
060604a	L03	OZT	10:02:18		75	1.80	75	0.22	1.48						6.7
060604a	L04	OZT	10:12:26		73	2.00	70	0.20	1.50						5.2
060604a	L05	OZT	10:24:14	5170	10	2.96	330	0.13	1.70		5065				12.2
060604a	L07	ZGA	11:36:06		77	1.85	90	0.16	1.70						5.1
060604a	L08	ZGA	11:45:38		72	1.85	90	0.16	1.65						4.4
060604a	L09	ZGA	11:53:10		72	1.80	90	0.16	1.65						4.8
															4.3
															4.2

(TSP: total suspended particulate matter; Weinzierl et al., 2009)



(Kandler et al., 2009)

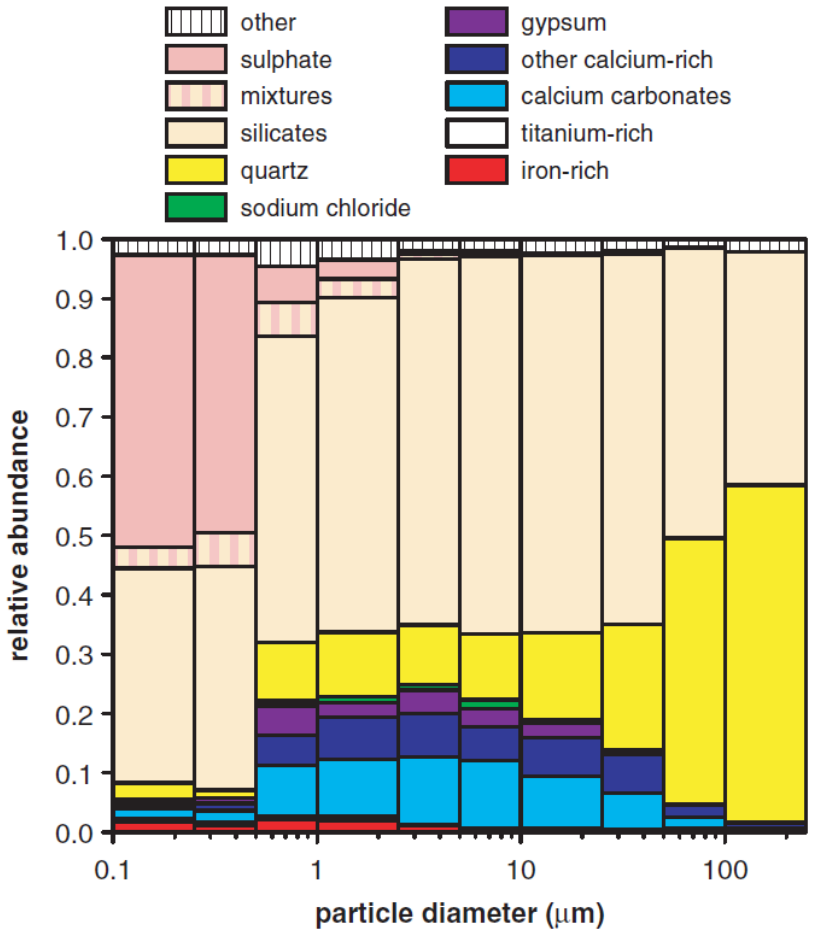


Fig. 11. Average relative volume abundance of the different particle classes at Tinfou ground station.

Saharan dust mass concentration at ground in Morocco

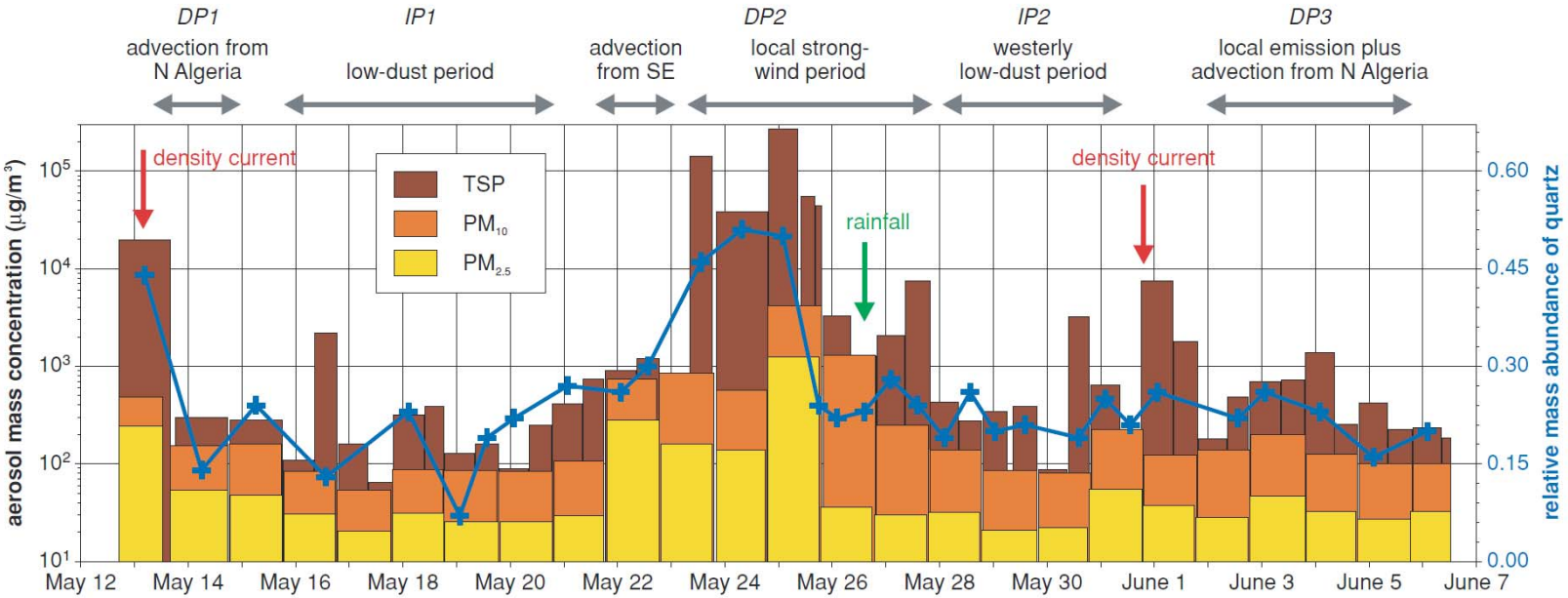
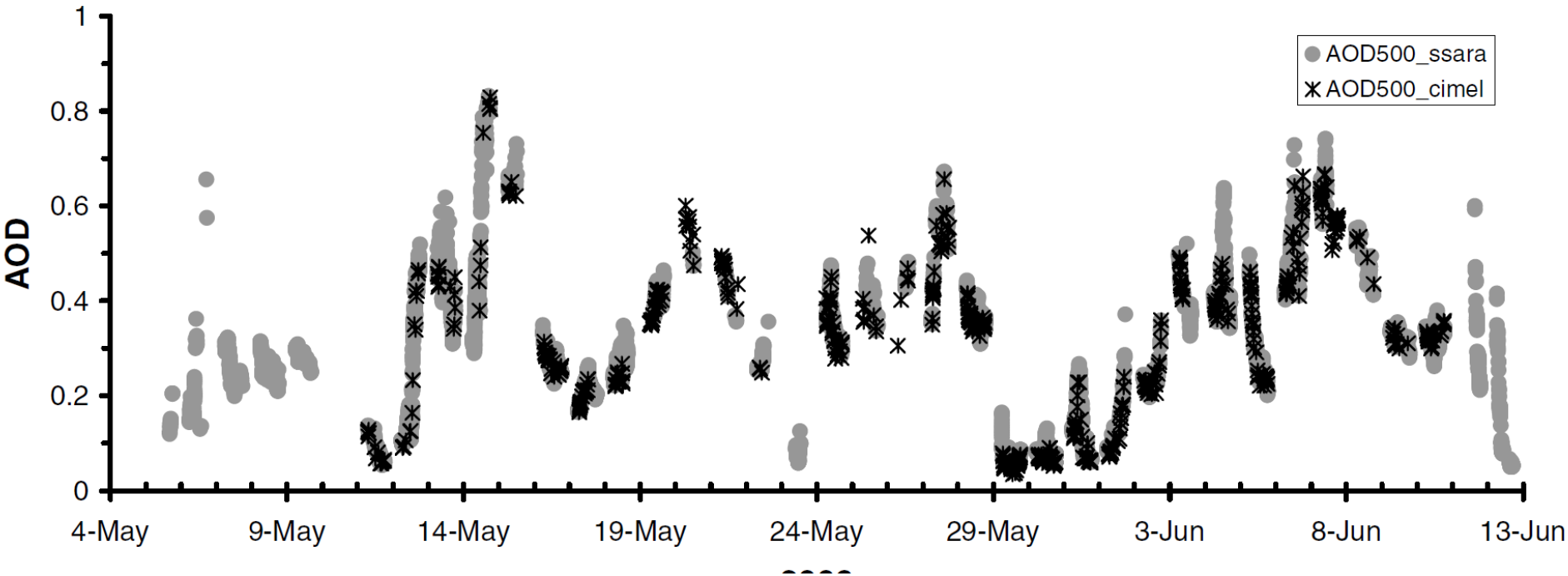


Fig. 5. Time series of mass concentrations measured at Tinfou, Morocco. In addition, the relative abundance of quartz is shown as crosses. In the top row, prevailing advection situations are given. Individual meteorological events are marked.

$< 200\ mg/m^3$

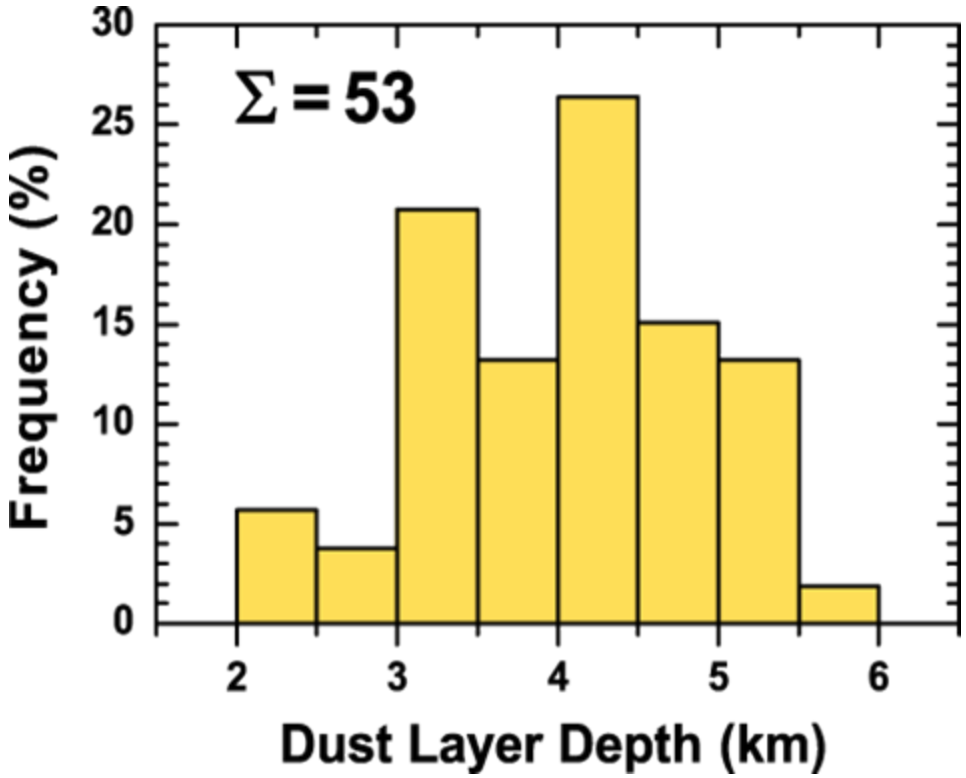
(Kandler et al., 2009)

Dust aerosol optical depth at Quarzazate, Morocco



(at Quarzazate, in 2006, Toledano et al., 2009)

Altitudes from LIDAR dust measurements



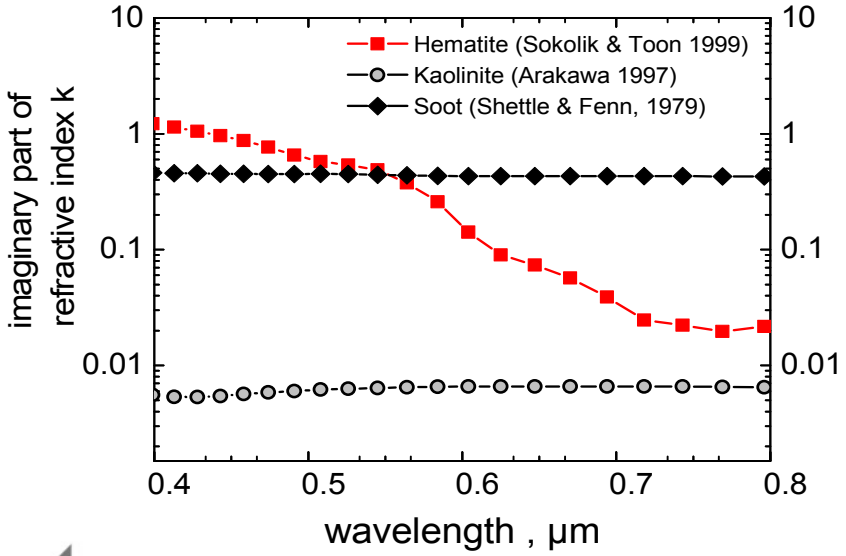
Occurrence frequencies of dust layer depth above ground near to the source during SAMUM 1

Tesche et al. (2009).

Light-absorbing aerosol components

dust (Morocco) hematite

dust (Burkina Faso) soot



VIS + IR	black carbon brown carbon
"green"	Fe_2O_3
near IR	H_2O
	$(NH_4)_2 SO_4$
9 µm	SiO_2

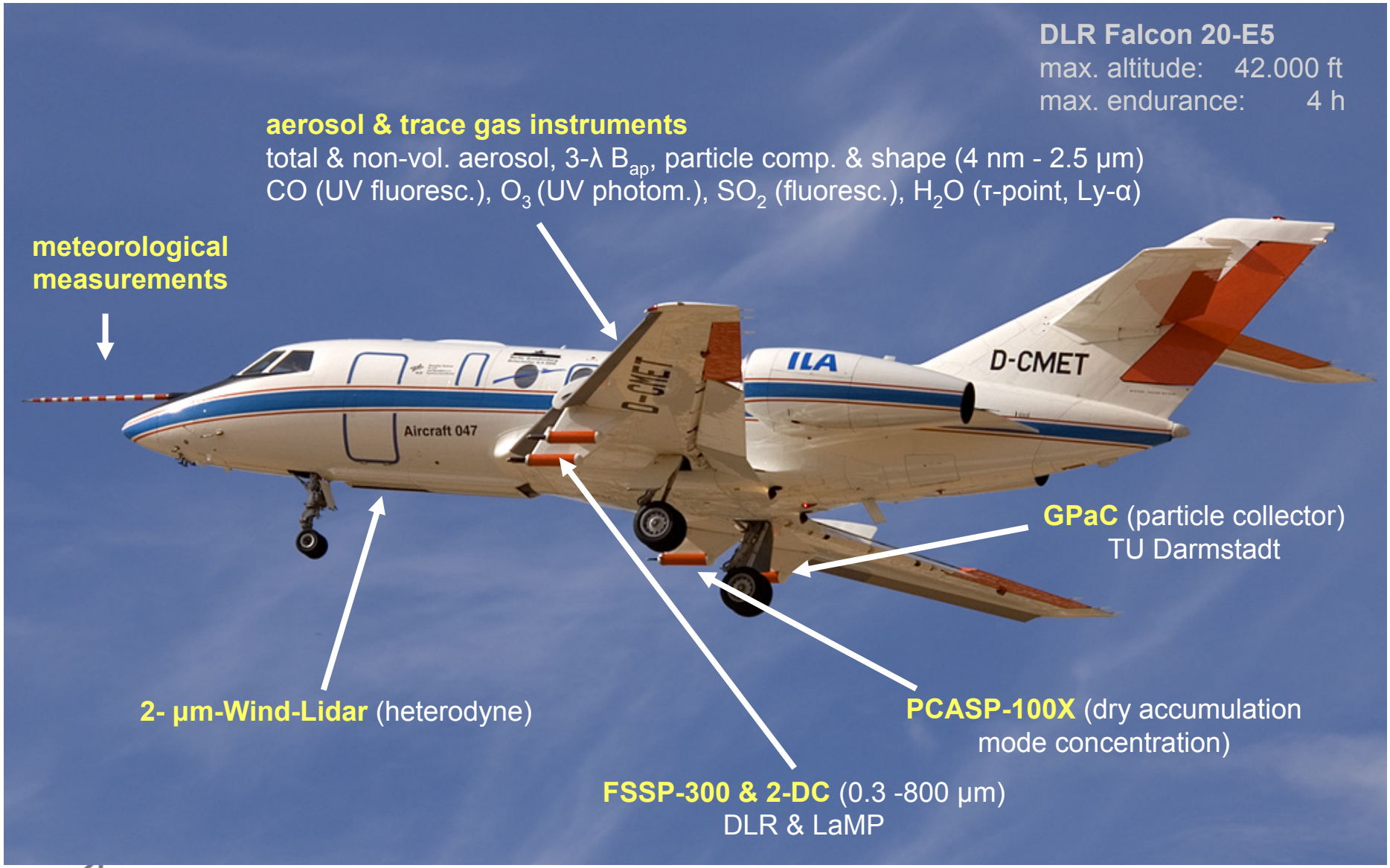
Light-absorbing properties of dust are determined by the iron oxides content.

Soot mixed with dust "closes" the transparent window in the red to near IR region.

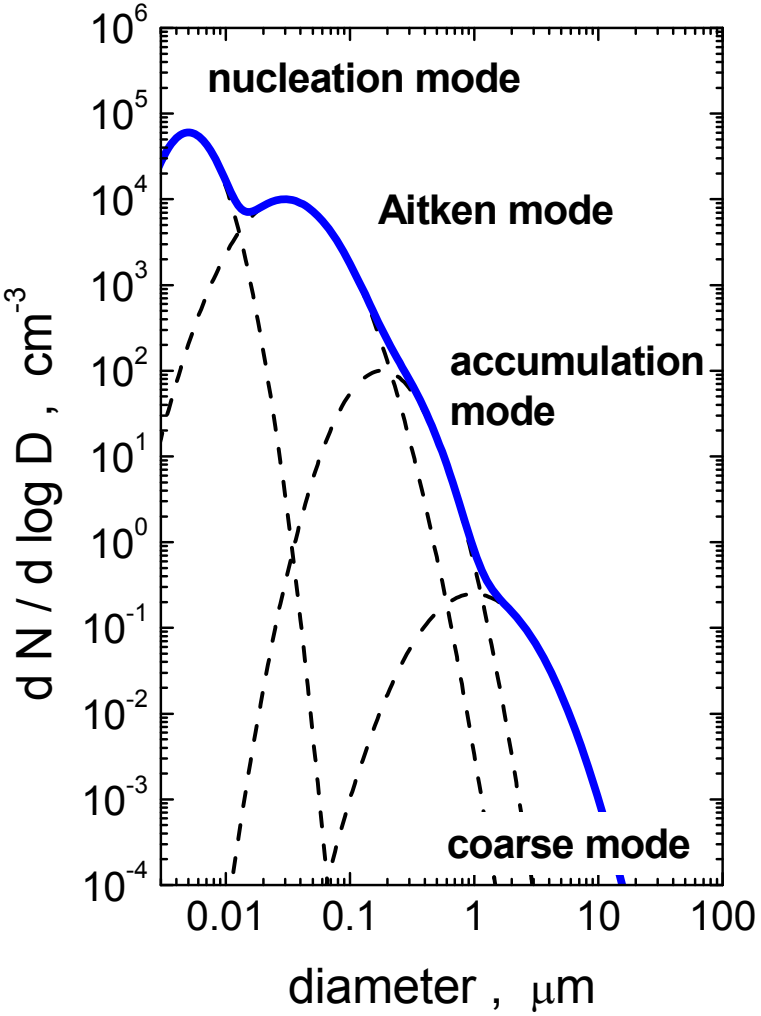
Eyjafjallajökull volcano plume, May 1, noon time

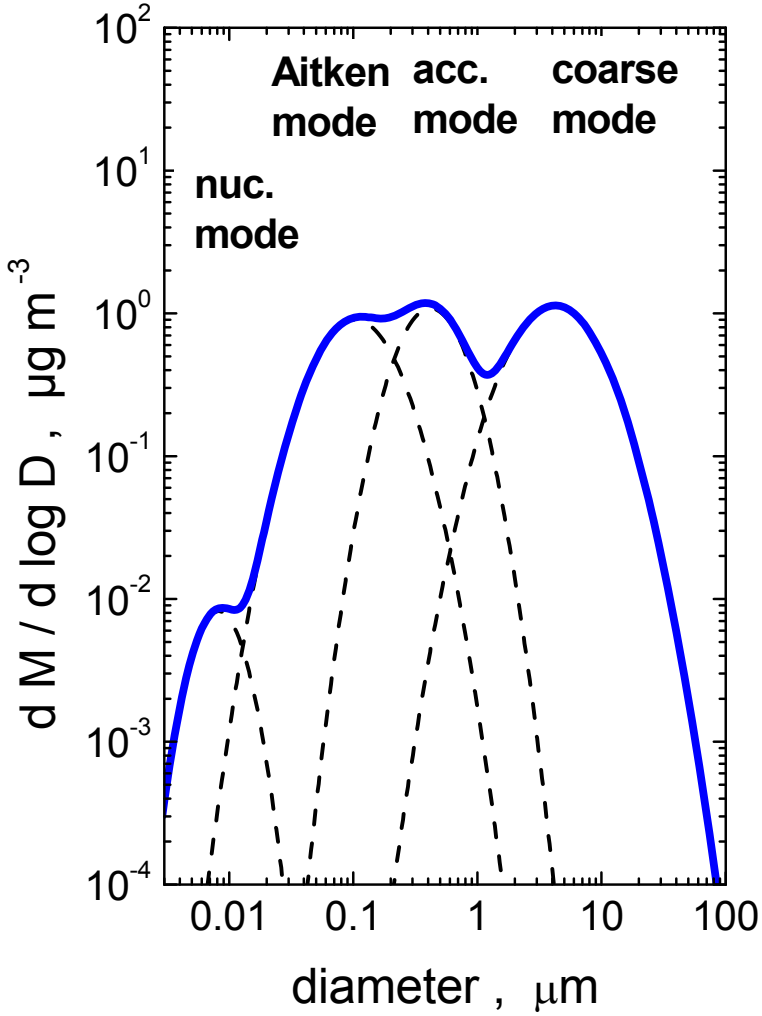
Eyjafjallajökull volcano plume, May 1, noon time

Emergency Aircraft, e.g. DLR-Falcon (future: HALO)

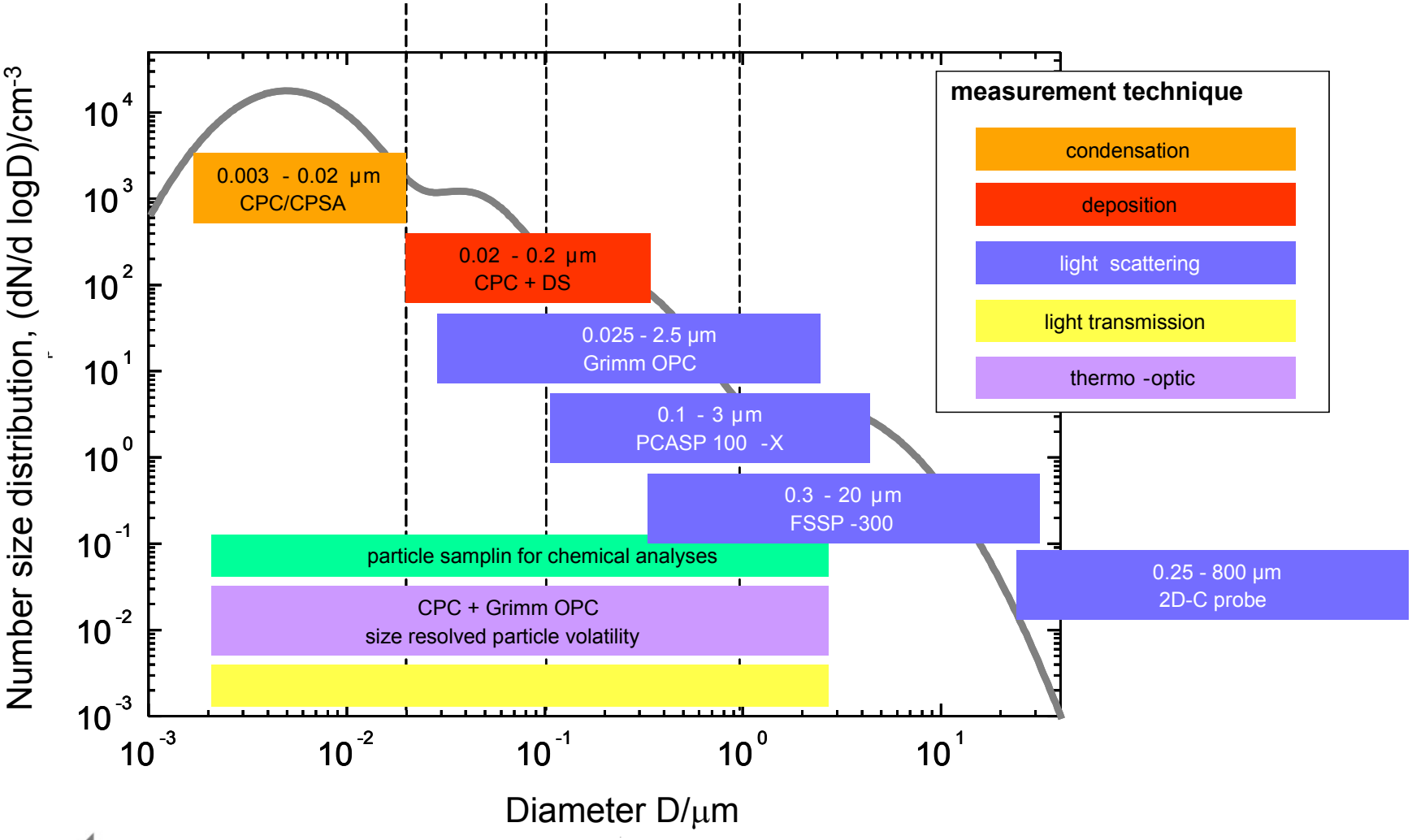


Number and volume - size distributions

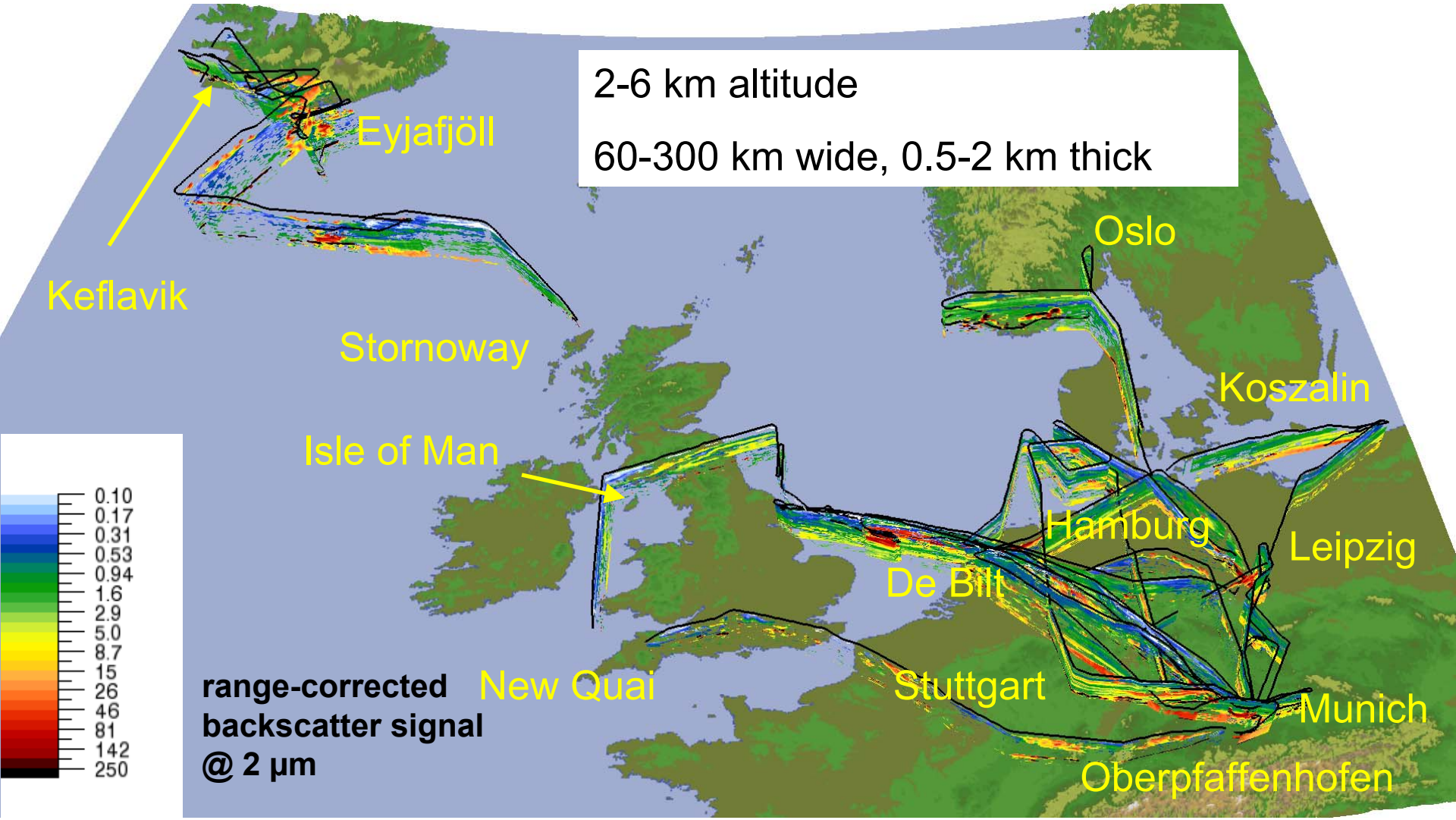




Nucleation, Aitken Accumulation, coarse, super coarse mode

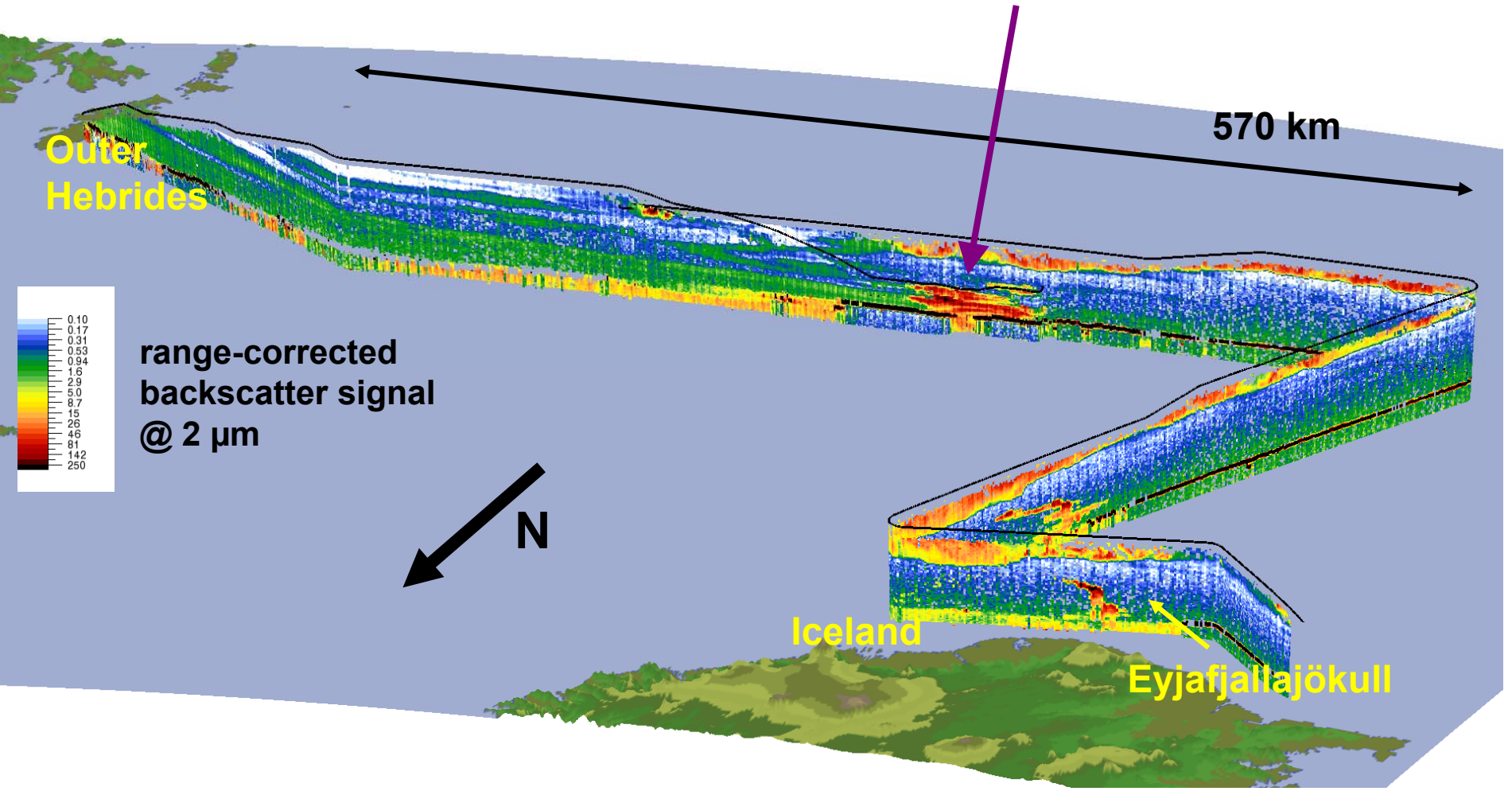


17 DLR Falcon flights, April 19 - May 18, 2010: OP - Iceland

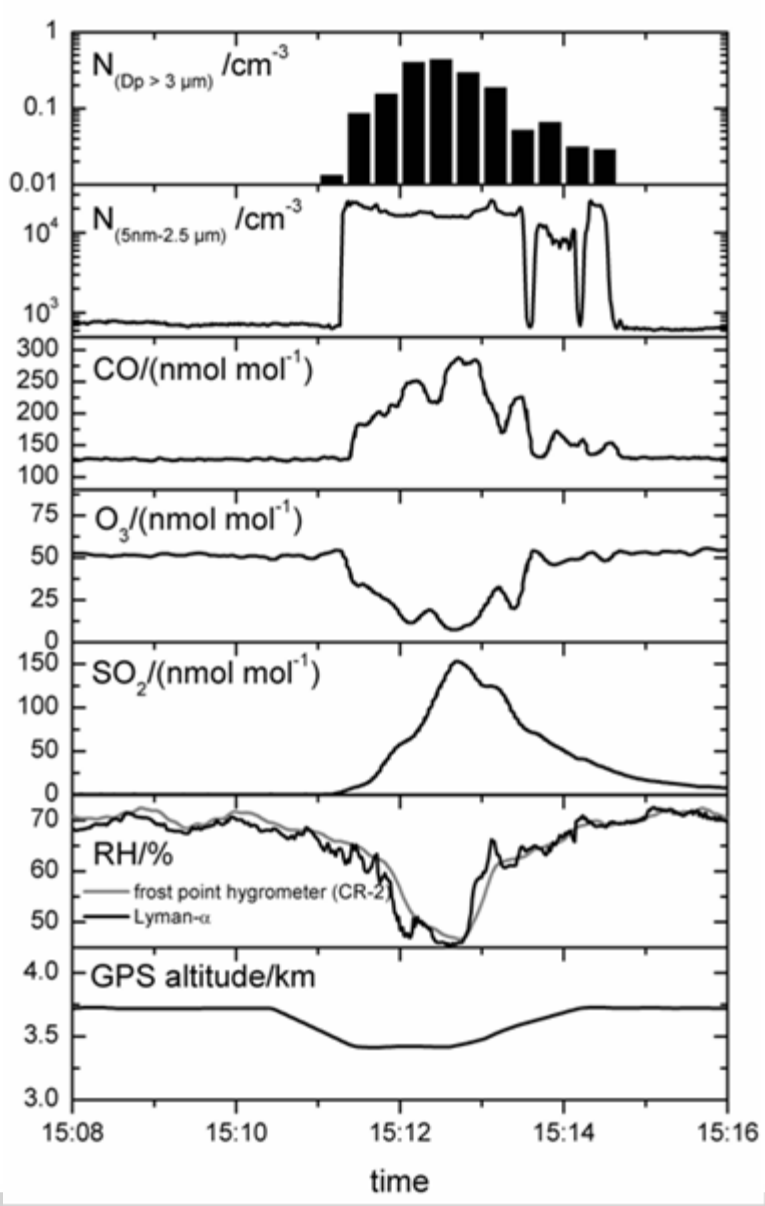


OP –Keflavik: 2700 km

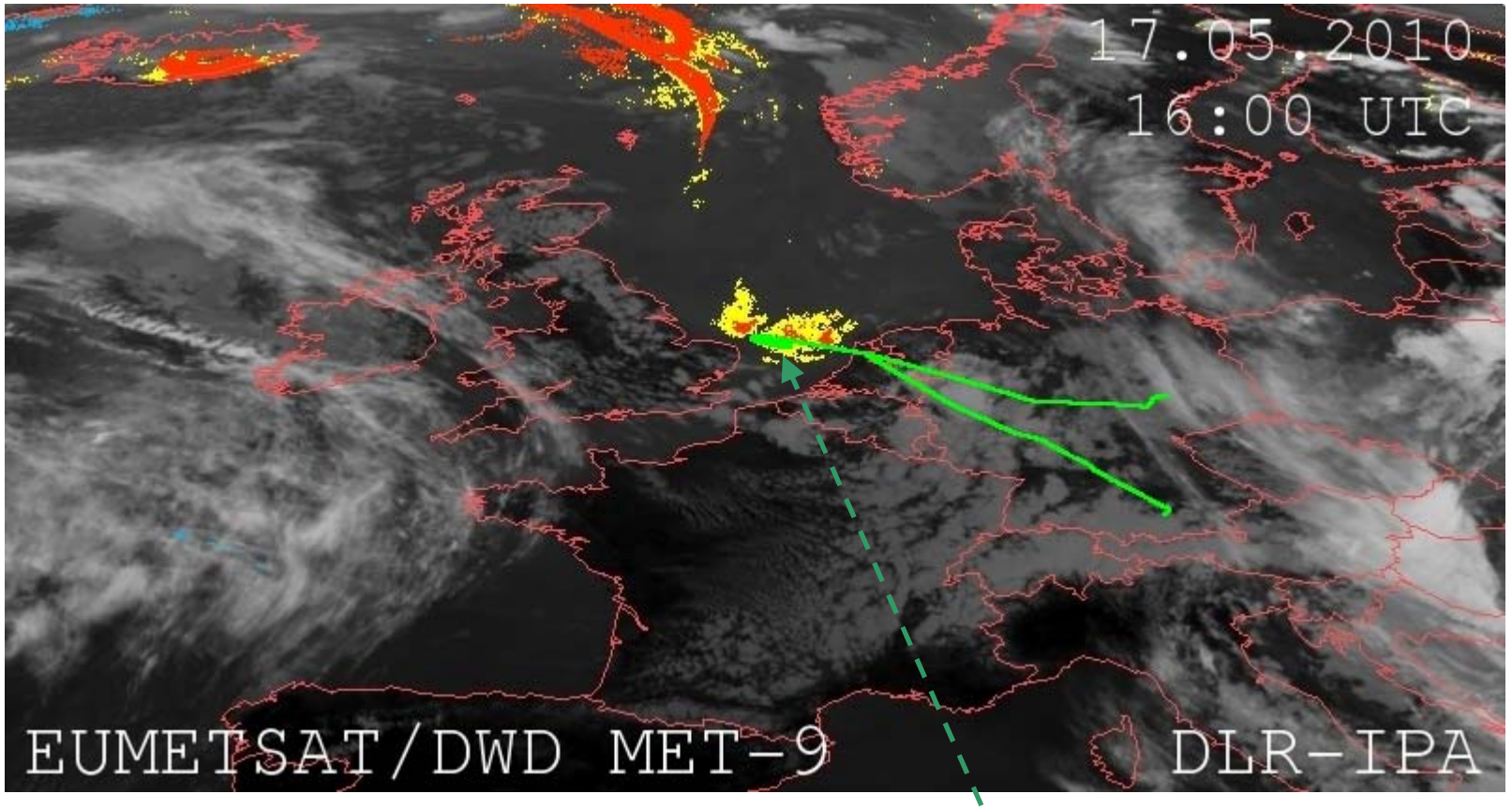
May 2: Plume sounded at 3.4 km altitude for 3 min



May 2: 3 min measurements in top of ash plume at 60°N



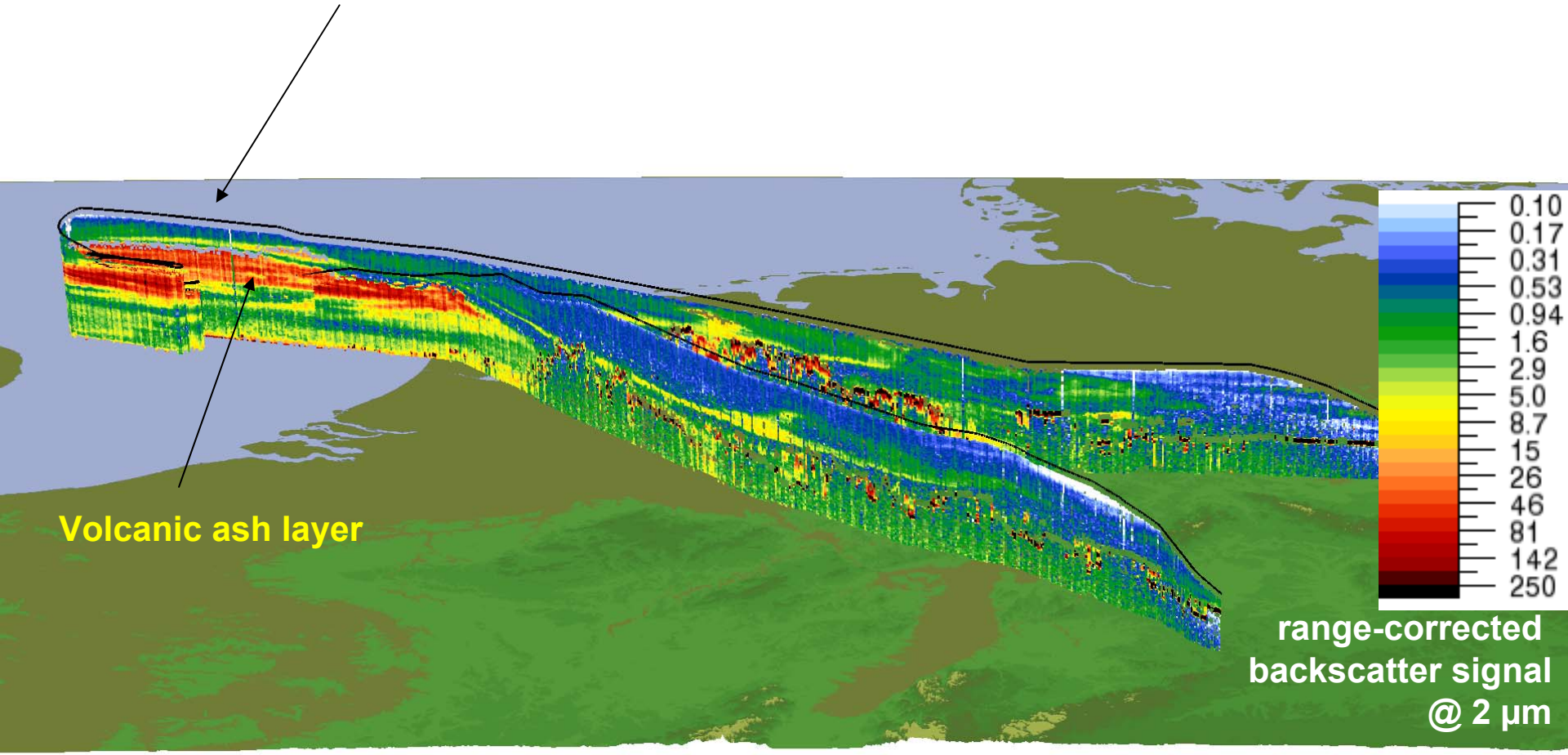
May 17, 1 hour in ash



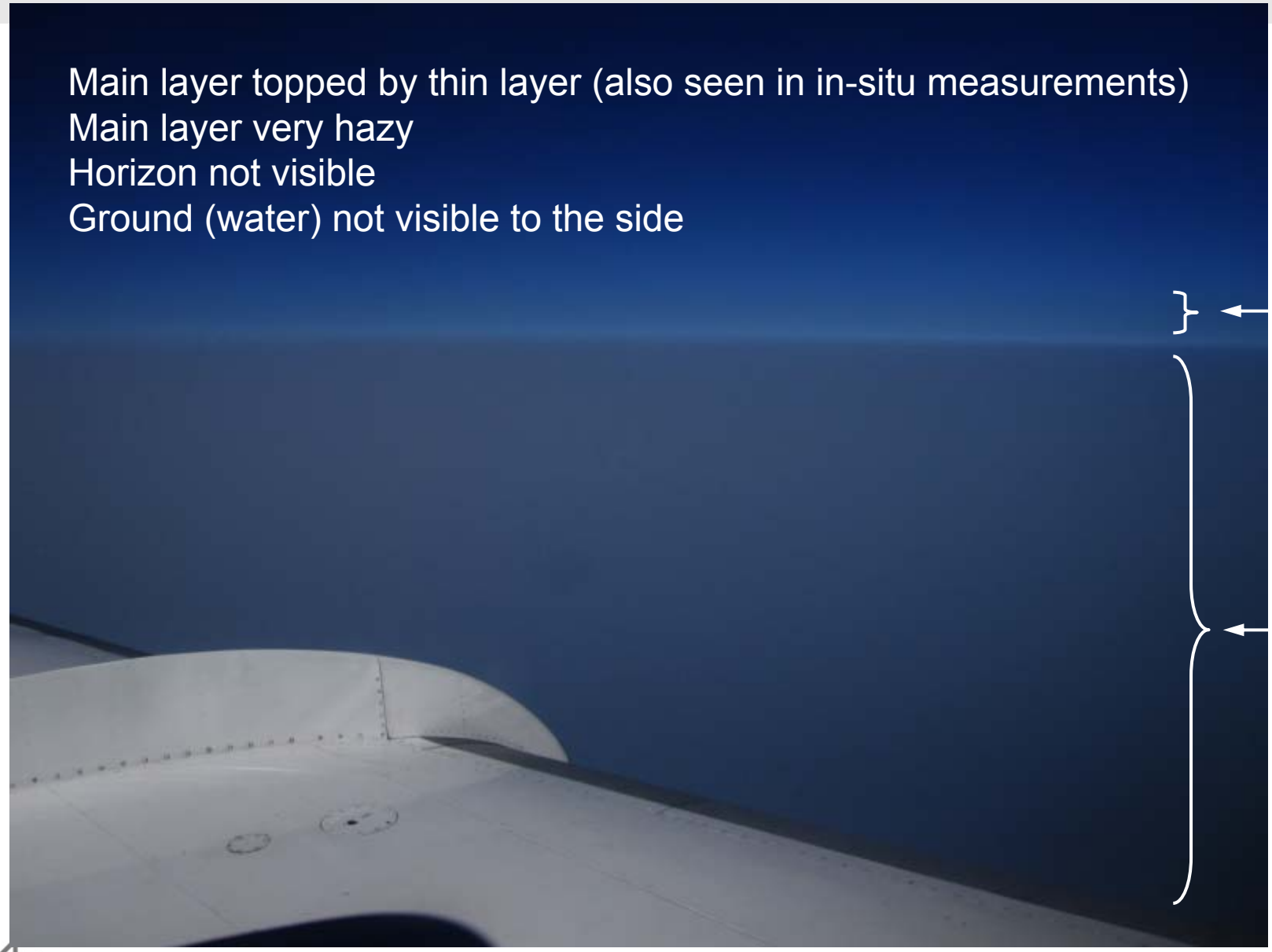
yellow = ash retrieval
red = ash + SO2 retrieval

Falcon flight path within thick ash layer

One hour Falcon flight in 2 km layer with >0.2 mg/m3 ash

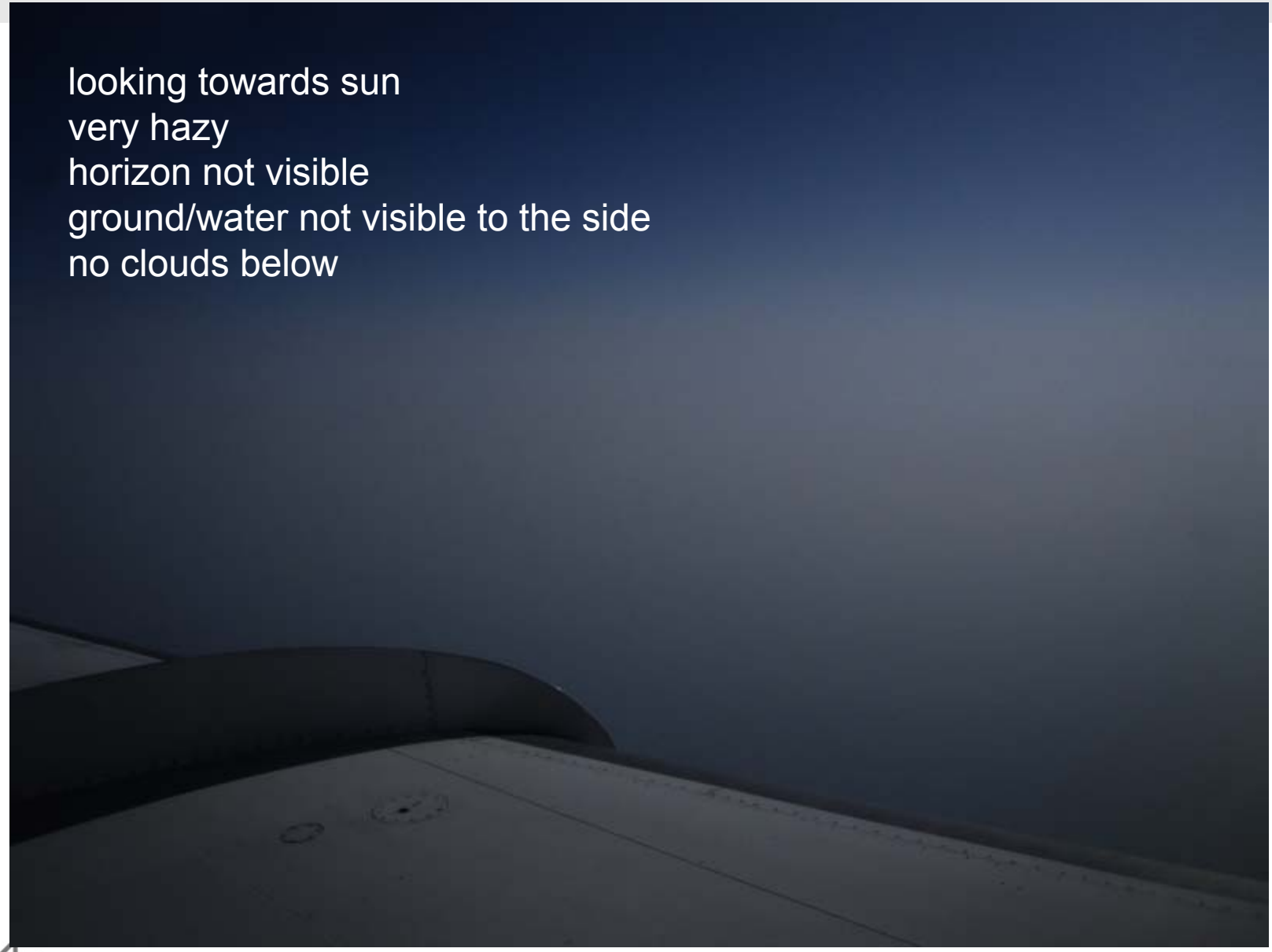


Just above volcanic ash layer



17-May-2010, 15:54 UT, 6.4 km altitude, North Sea area

Inside volcanic ash layer at 5.5 km altitude

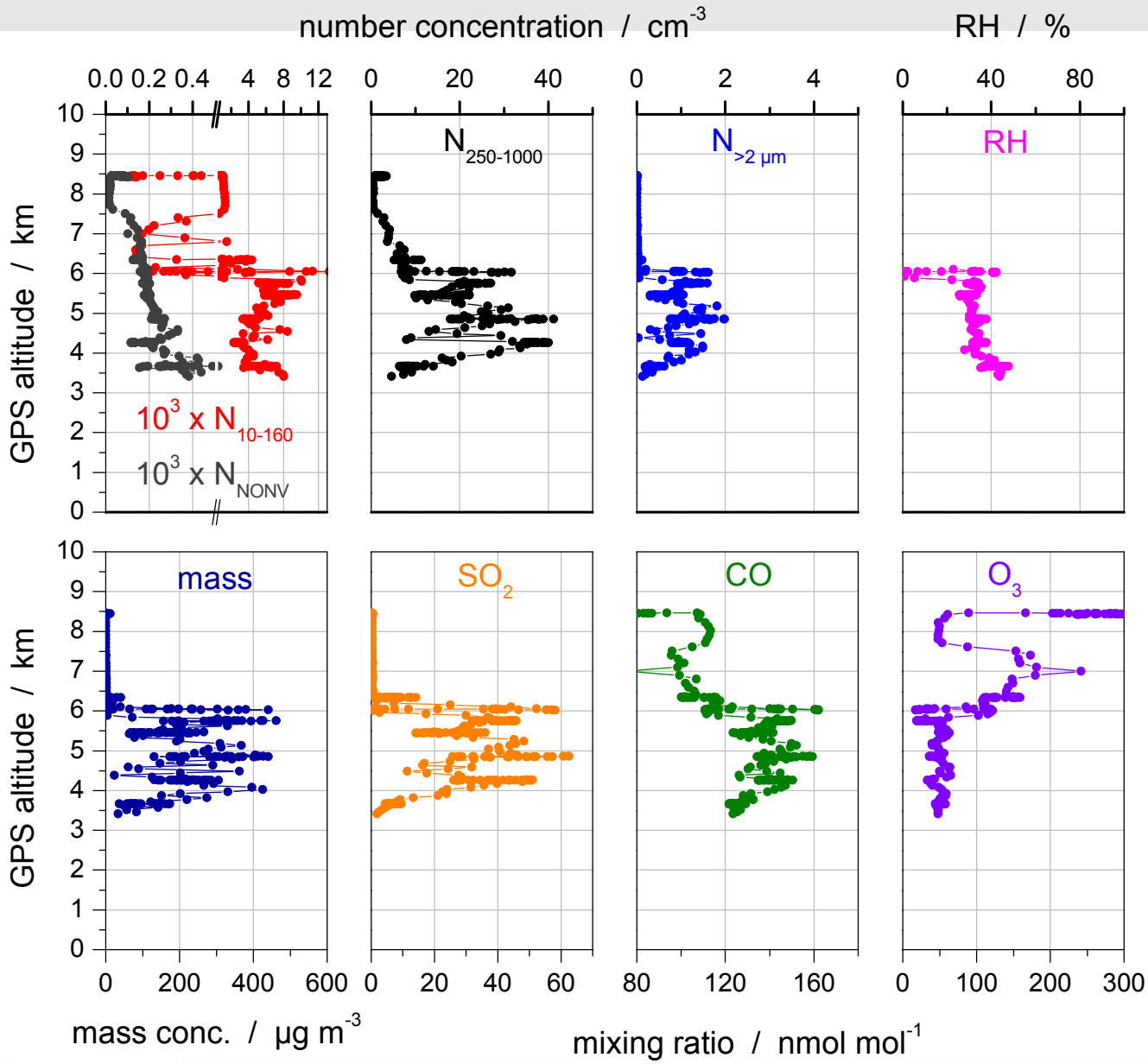


17-May-2010, 16:10 UT, 5.5 km altitude, North Sea area

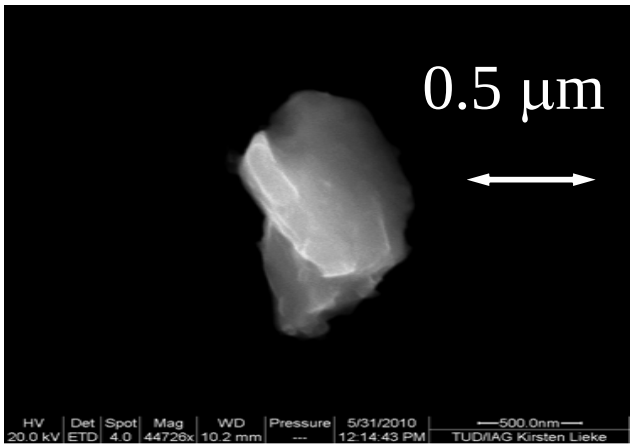
Below volcanic ash layer at 2.7 km altitude

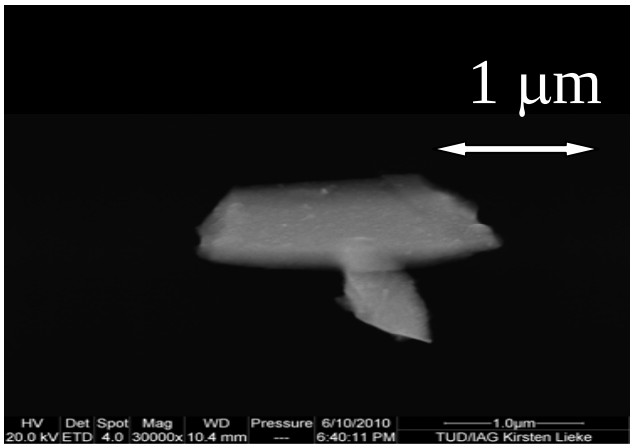
17-May-2010, 16:35 UT, 2.7 km altitude, North Sea area

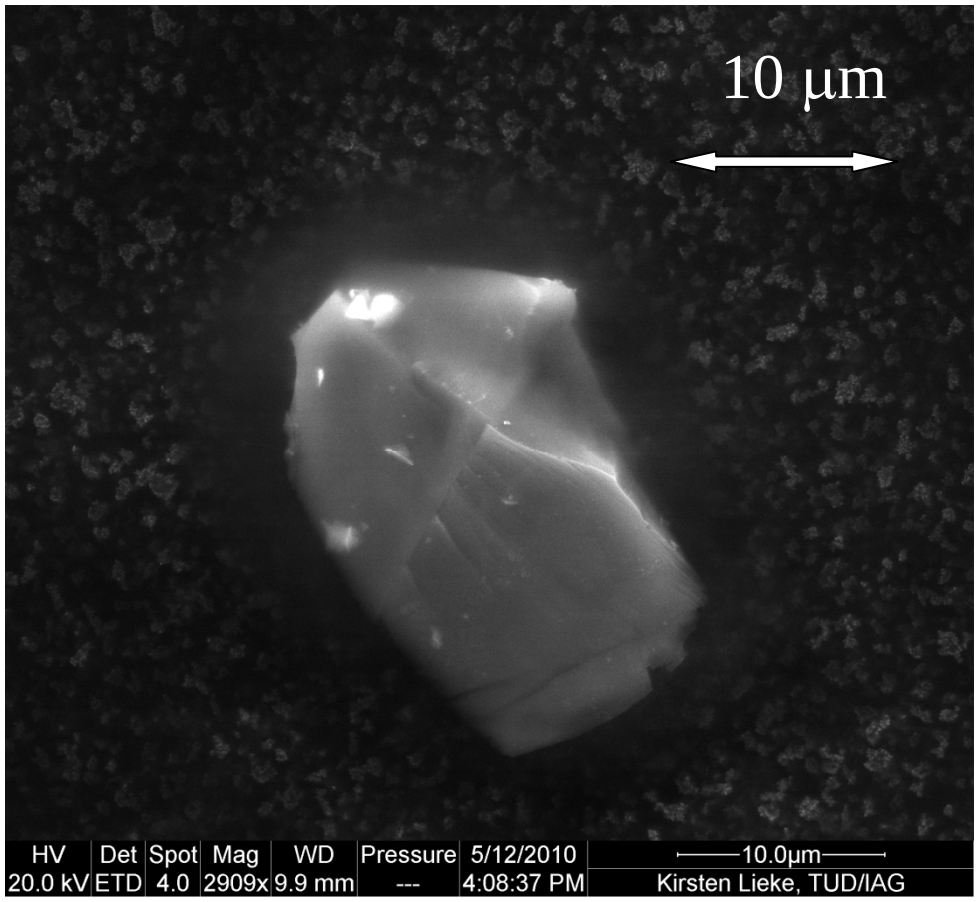
May 17


number concentration / cm-3
RH / %
0.0 0.2 0.4 4 8 12
0 20 40
0 2 4
0 40 80
GPS altitude / km
10
9
8
7
6
5
4
3
2
1
0
N250-1000
N>2 µm
RH
10^3 x N10-160
10^3 x NNONV
mass
SO2
CO
O3
0 200 400 600
0 20 40 60
80 120 160
0 100 200 300
mass conc. / µg m-3
mixing ratio / nmol mol-1

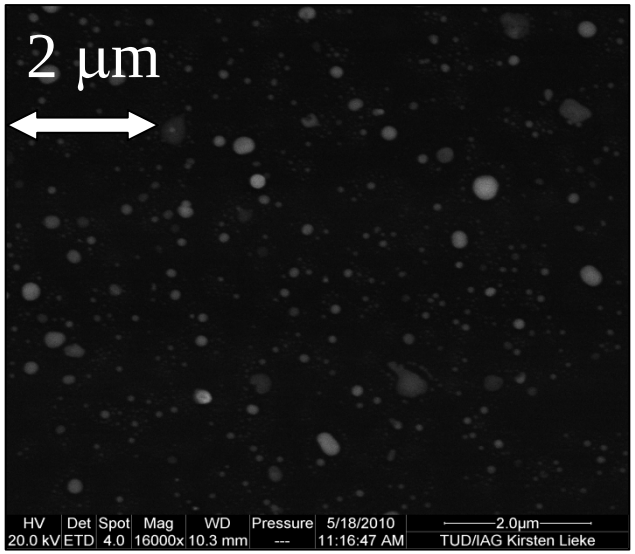
Particles collected inside the ash plume at 60°N, May 2

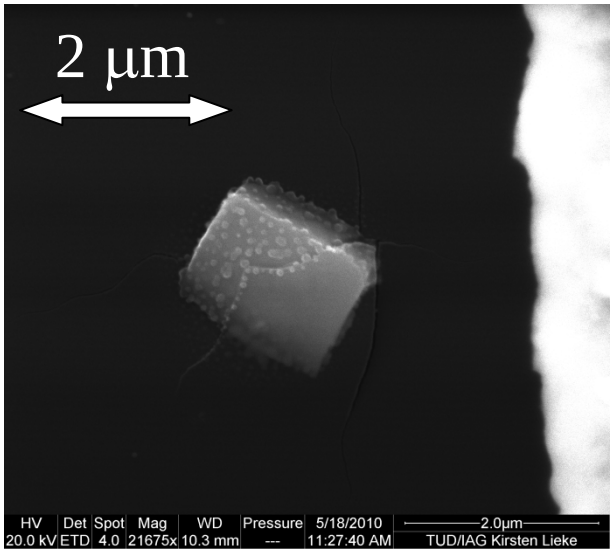


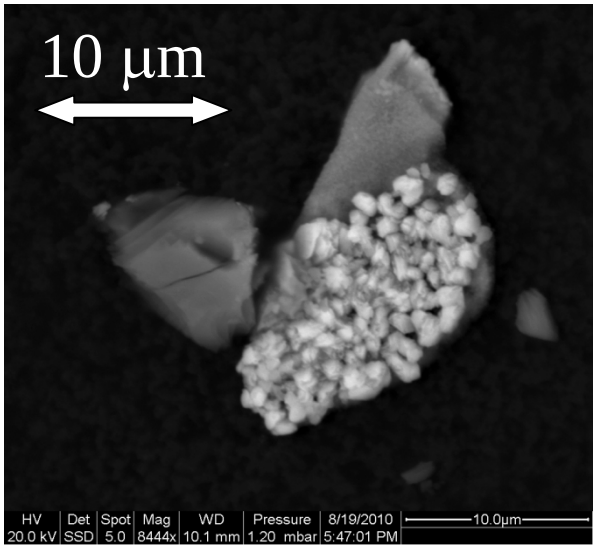




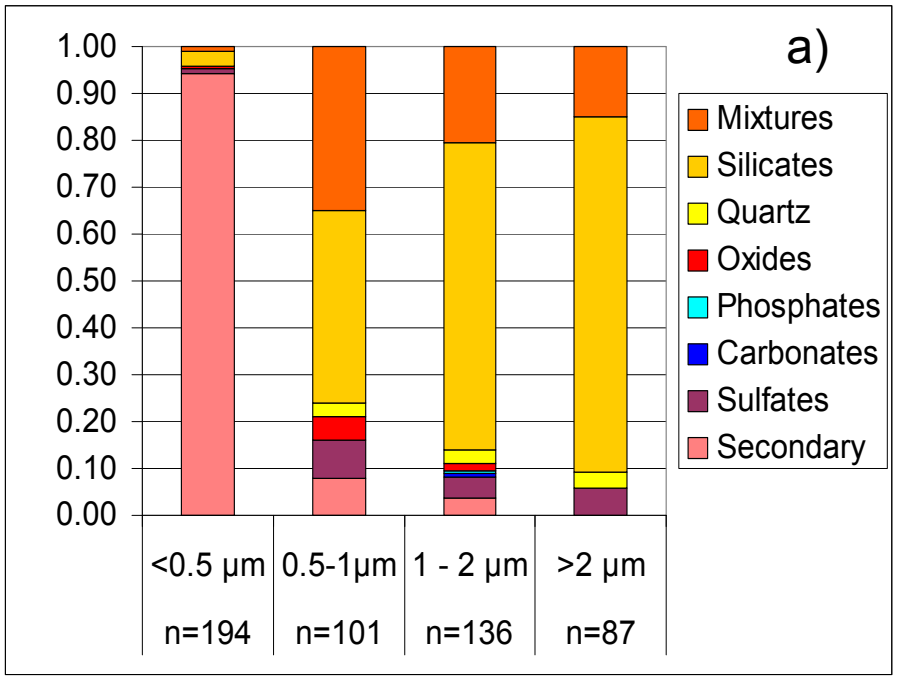
May 2, also found: ammonium sulfate, aggregates

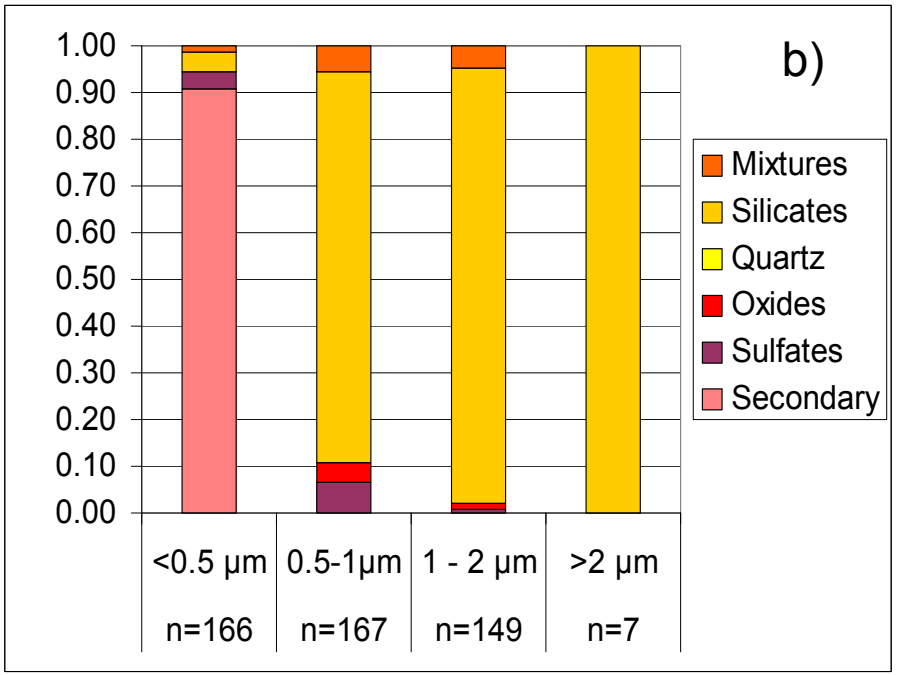






Particle composition for a) 2 May and b) 17 May





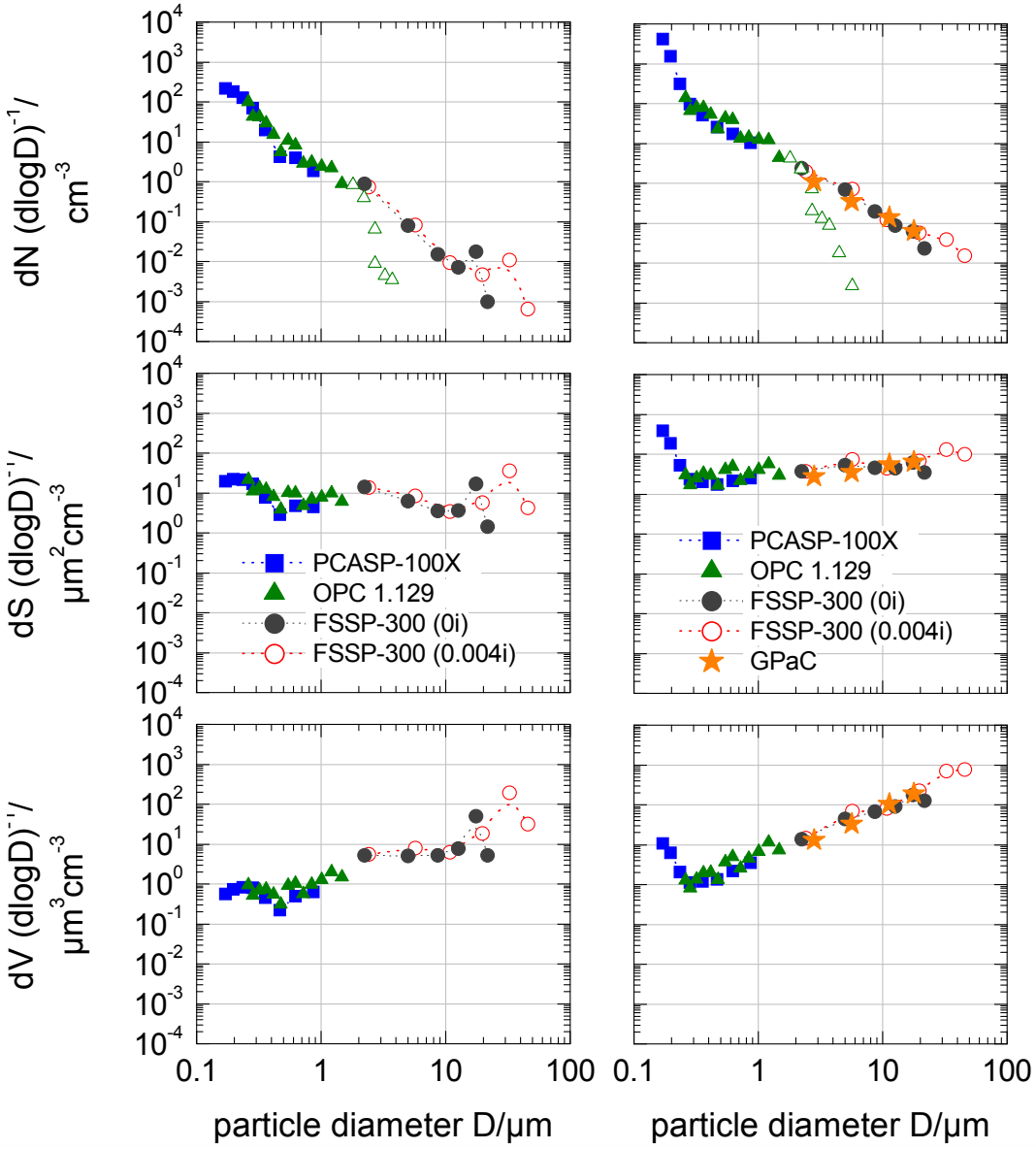
Particle properties derived from ESM analysis

Table 4. Number of investigated particles, measured two-dimensional aspect ratio and calculated density and complex refractive index values *m* for different particle size classes.

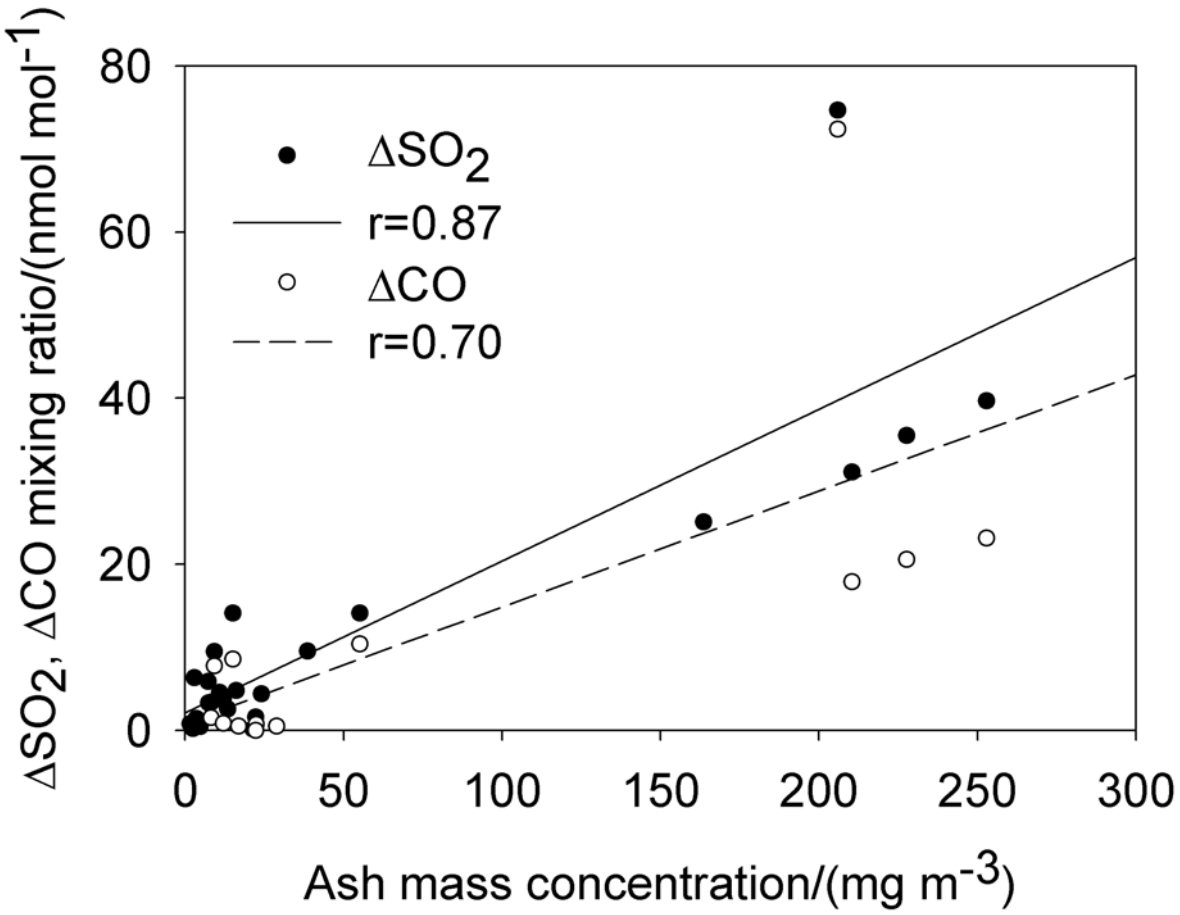
	2 May 2010				17 May 2010			
Size/μm	<0.5	0.5 - 1	1 - 2	>2	<0.5	0.5 - 1	1 - 2	>2
Number	194	101	136	87	165	166	149	7
Aspect ratio	1.9	2.2	2	2.1	1.8	2.1	2.1	2.
density	1.8	2.6	2.7	2.7	1.7	2.8	2.7	2.7
m (630 nm)	1.53 + 0.001i	1.60 + 0.004i	1.58 + 0.002i	1.56 + 0.001i	1.55 + 0.001i	1.59 + 0.003i	1.57 + 0.001i	–
m (2 μm)	1.50 + 2×10^{-6} i	1.56 + 40×10^{-6} i	1.55 + 20×10^{-6} i	1.54 + 10×10^{-6} i	1.53 + 7×10^{-6} i	1.56 + 20×10^{-6} i	1.55 + 10×10^{-6} i	–

Size distributions

19 April (left)
2 May (right)



Correlation between SO_2 and CO versus ash mass



Comparison Saharan dust – Volcanic ash (preliminary)

Parameter	Desert Dust	Volcanic Ash
Altitude	0-6 km	3-15 km
Depth	3-5 km	0.5-2 km
width	100-500 km	50-300 km
Critical ages	< 3 days	< 6 days
Max concentration	100 mg/m3	1 g/m3
Concentration after one day	< 5 mg/m3	< 10 mg/m3
Annual mean at airports	0.2 mg/m3	
Max. particle diameter in lofted layers	< 50 μm	< 30 μm
Particle shape, aspect ratio	aspherical , 1-2	aspherical, 2
Lidar Depolarization 532 nm	0.3	0.4
Refractive index, typical, real	1.55±0.03	1.57±0.03
Imaginary (550 nm)	0.003±0.003	0.005±0.005
morphology	crystalline	glassy or crystalline
Main composition	like carbonates and clay	quartz, silicate more variable?
Melting temperature	960 to 1700 °C, low for clay etc., high for quartz	lower ???
Optical appearance	Yellow to brownish	dark grey, brownish
Aerosol optical depth, after one day	< 1 away from source region	< 2
Impact on aviation	Close to airports, LTO	Free troposphere, cruise

Conclusions

- Mass concentration is difficult to measure
- High correlation between ash concentration and SO_2
- SO_2 is a well suited volcanic plume indicator
- Vulcano Ash and Saharan Dust were comparable in may respect