Report of Falcon Flight 19 April 2010

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Summary

A successful Falcon measurement flight was performed on 19 April 2010 for probing plumes over Germany from the Iceland Eyjafjallajökull volcano eruption. Layers of volcanic ash were detected by Lidar and probed in-situ with aerosol instruments. Under suitable viewing conditions, the ash layer was visible as a brownish layer to the observer. The horizontal and vertical distributions of the volcano layers were variable. In the plume layers particles larger than 3µm were detected at concentrations, not present in the free troposphere during unpolluted conditions. The concentrations of large particles measured in the volcano layers are comparable to concentrations measured typically in Saharan dust plumes but smaller compared to particle concentrations in the polluted boundary layer. An estimation of the particle mass concentration in the volcanic ash plume probed as part of a vertical profile over Leipzig at about 4 km altitude yield 60 µg/m^3.

After the flight the Falcon was inspected. So far no damages were observed including engines (after boroscopy) and windows. Further engine inspection is ongoing. Silver foils attached to under-wing stations showed no visible impact from volcanic ash.

Flight Route and meteorological situation

The flight route is shown in Figure 1. Take off and landing in Oberpfaffenhofen were at 14:12 UTC (16:12 MES) and 17:53 UTC (MES), respectively. The flight route was from Oberpfaffenhofen to Leipzig, Hamburg, Bilthoven (Netherlands), Stuttgart and back to Oberpfaffenhofen. The Falcon was mainly cruising at 8 km altitude for Lidar observations. Vertical flight profiles were performed at Leipzig and Stuttgart. Near Aachen the Falcon climbed to 11 km for measurements in the stratosphere.

During the flight, air masses with aged volcanic emissions were measured in the southern and middle part of Germany (Figure 2). These air masses first arrived in Germany on 16 April (originating from the first strong volcanic eruption on 14-15 April) but then circulated around a high pressure system over France before arriving in Germany a second time on the 19 April (~4-5 days old).

Visual and METEOSAT impression of the volcanic aerosol layer

During the flight volcanic ash layers were clearly visible as shown in Figure 3. This picture was taken from the Falcon over Leipzig around 15 UTC, where the volcanic ash layer had a vertical depth of about 2 km. The volcanic ash plume was also visible by METEOSAT (Figure 4).

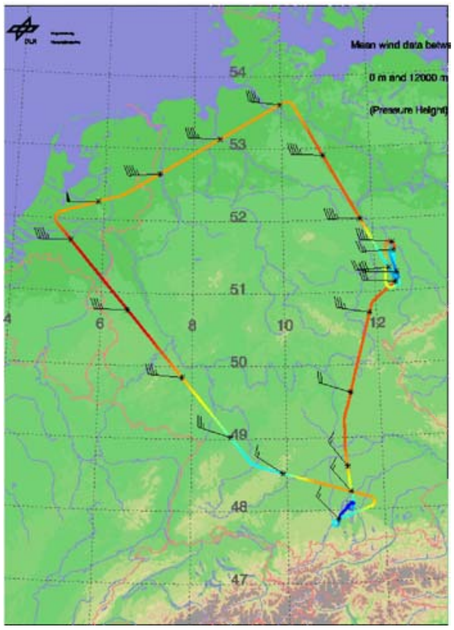

Figure 1: Flight route of the DLR Falcon on 19 April 2010

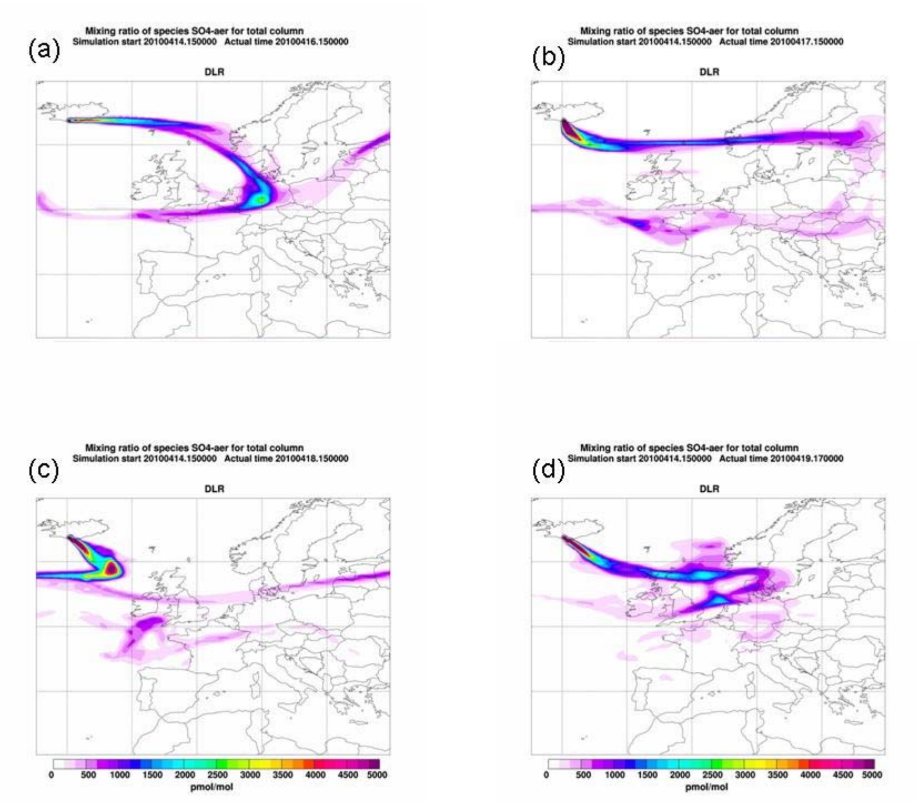

Figure 2: FLEXPART simulations of the time evolution of an aerosol tracer released from the Iceland volcano (release rate inferred from MSG observations) since 14 April 2010. Total columns (pmol/mol) on 16 April, 15 UTC (a), 17 April, 15 UTC (b), 18 April, 15 UTC, and 19 April, 17 UTC (conditions during the Falcon flight).

Figure 3: Picture taken on board the DLR Falcon near Leipzig on 19 April 2010

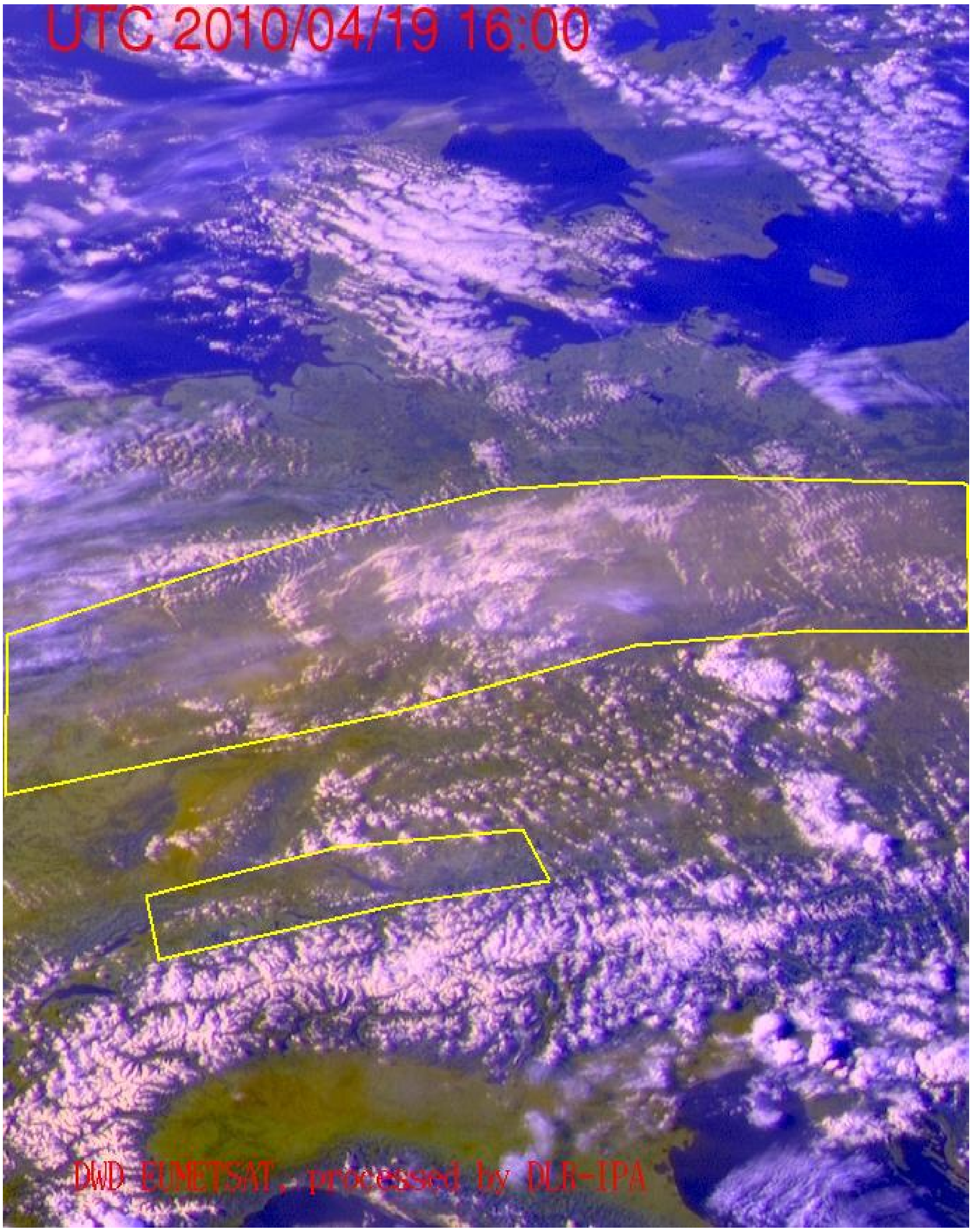

Figure 4: False color composite including information from the METEOSAT-SEVIRI high resolution visible channel with a resolution of 1 km at the sub-satellite point. Due to the low sun at 1600 UTC, aerosol layers become visible mainly due to a reduction of the contrast of surface features.
The yellow polygons enclose areas, showing such a reduced contrast not only in this image, but also in the time series. A distinction between the ash layers and boundary layer pollution is not possible, but trajectory analysis indicates a good agreement to the aerosol from the Eyjafjallajokull volcano eruption from April 14 2010.

Lidar results

With a 2-µm lidar (light detection and ranging) measurements of aerosol and particle layers (upper and lower boundary, height, horizontal extent) were performed. The quicklooks made during the flight show clearly elevated particle layers above the atmospheric boundary layer. The lidar detected several layers of higher particle content at altitudes between 3.5 km to 6 km. Near Munich two layers of 500-1000 m thickness were observed. Near Leipzig these two layers were partly combined into one layer of 2 km thickness. In general, the layers were horizontally and vertically very inhomogeneous and change their properties on scales of 100-200 km. The particle concentrations in the elevated layers (above 3.5 km) are lower compared to the particle concentration in the boundary layer (below 3 km). In northern Germany (around Hamburg) no particle layers were observed above the boundary layer. Quicklooks of lidar vertical cross sections are shown in Figures 5 – 7.
Note: this and the following figures are quicklooks still showing the about 45 s oscillations due to scanning mode.

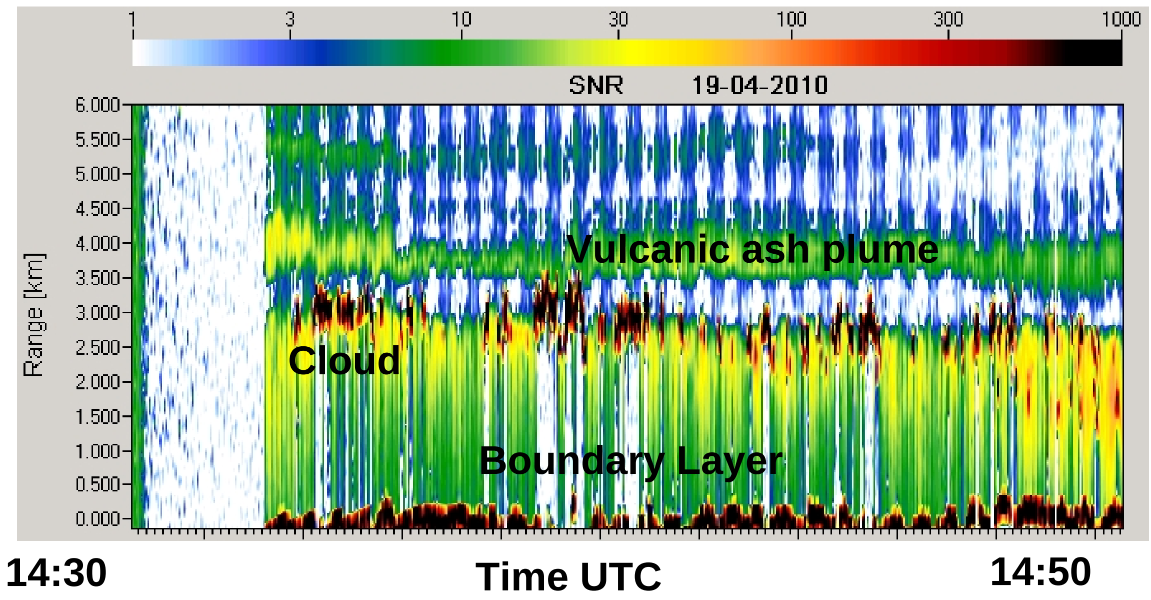

Figure 5: Quicklook from 2-µm lidar measurements from Falcon flight on April 19, 2010 showing Signal-to-Noise Ratio shortly after take-off from Oberpfaffenhofen from 14:30-14:50 UTC (16:30-16:50 LT) going north during 20 minutes (about 200-240 km flight track); red/black colors show high SNR from clouds (around 3 km) and ground (0 km); blue-green colors show layers with aerosol; white/blue colors indicate noise (no valid data); 2 layers of higher aerosol level are visible at 4 km and 5.5 km

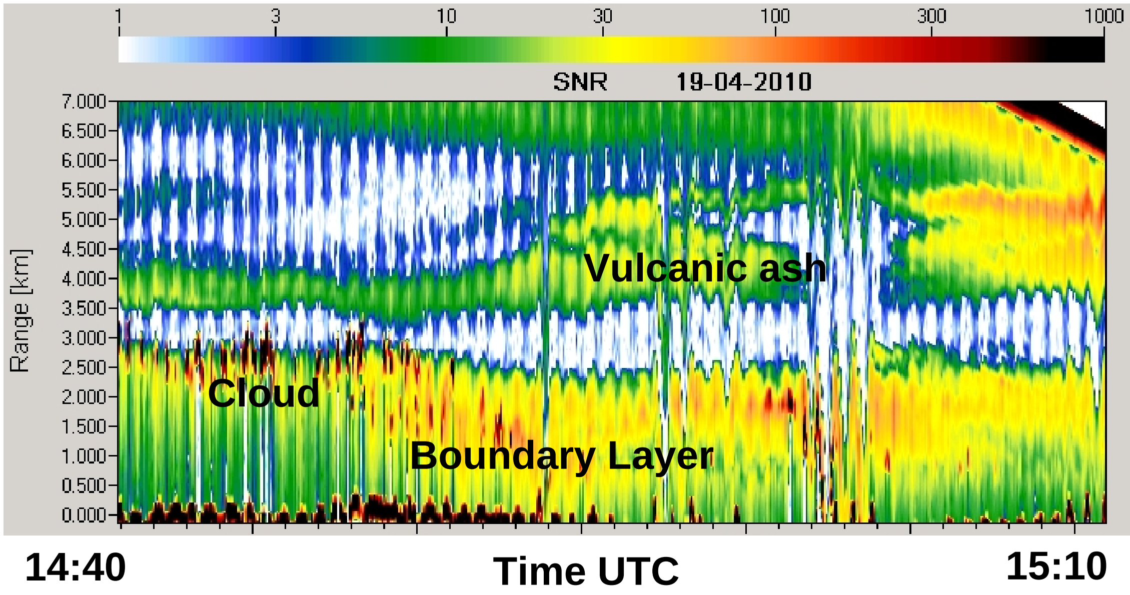

Figure 6: Quicklook from 2-µm lidar measurements from Falcon flight on April 19, 2010 showing Signal-to-Noise Ratio during 30 minutes south of Leipzig and around Leipzig from 14:40-15:10 UTC (16:40-17:10 LT); red/black colors show high SNR from clouds (around 3 km) and ground (0 km); blue-green colors show layers with aerosol; white/blue colors indicate noise (no valid data); the 2 layers of higher aerosol level (left side of Figure) at 4 and 5.5 km merge to 1 layer of almost 2 km thickness (right side of Figure).

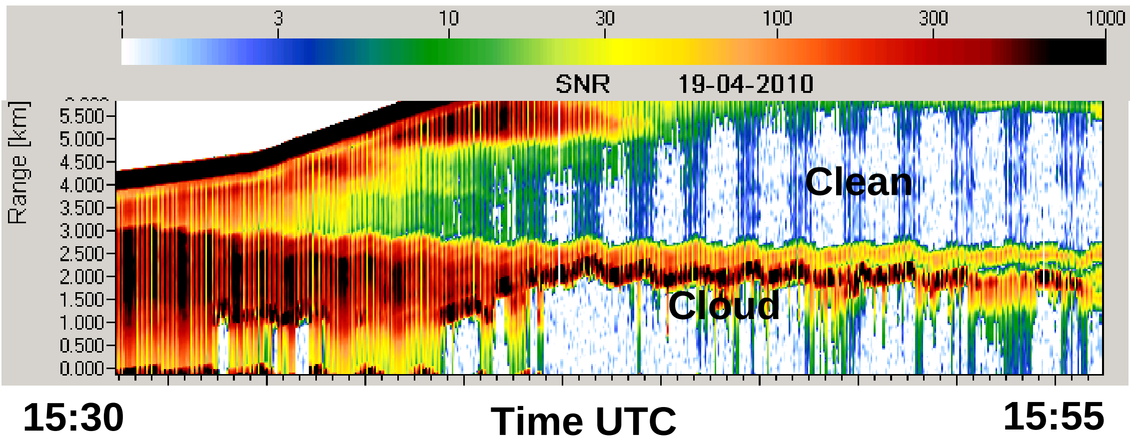

Figure 7: Quicklook from 2-µm lidar measurements from Falcon flight on April 19, 2010 showing Signal-to-Noise Ratio during 25 minutes from Leipzig to Hamburg from 15:30-15:55 UTC (17:30-17:55 LT); red/black colors show high SNR from clouds (around 2 km); above the clouds (>3 km) no aerosol layers are visible (middle to right side of Figure).

Results from in situ measurements

Figure 8-10 depicts the time series of in-situ measurements recorded during the flight. Total particle number concentrations in the size range 10 nm-2.5 µm are shown in red, non-volatile particles (dust/ash, black carbon, or sea salt) in black, and the flight altitude in green in Figure 8. Figure 9 displays volume mixing ratio of carbonmonoxide (CO) and ozone (O_3). Figure 10 shows the number concentrations of super-micron particles. The ash plume was probed at an altitude of 3.8-5.8 km during the descent over Leipzig between 15:00 and 15:15 UTC. Furthermore, it was again probed near Stuttgart at an altitude of 3.8 km around 17:20 UTC. In the volcanic ash plume, the total aerosol concentration is enhanced, as well as the number of super-micron particles (3-20 µm) which normally are not present at these altitudes in the free troposphere. No signatures in CO and ozone are observed. The boundary layer extends up to 3 km and is quite polluted (total fine particles >15.000 particles per cm ^{3}; CO up to 200 nmol per mol). Furthermore, the number concentration of super-micron particles is enhanced. Because of the high CO values the boundary layer probably is likely to be dominated by urban pollution. A contribution of volcanic aerosol can not be excluded due to the high super-micron particle concentration. The volcanic ash plume over Leipzig is also nicely illustrated in the vertical profile measurements (Figure 11).

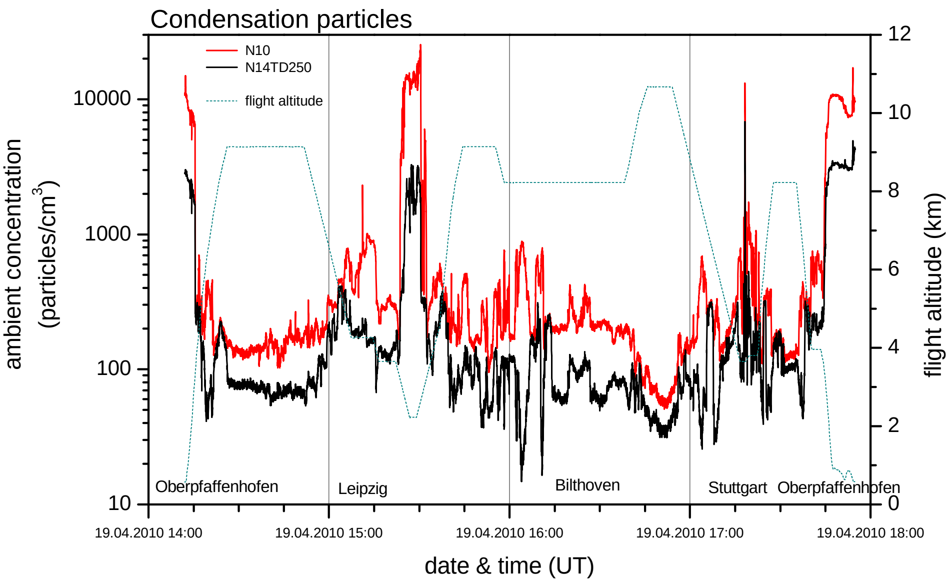

Figure 8: Time series of total particle fine number concentration (N10) and total non-volatile particle fine number concentration (N14TD250) measured during the research flight.

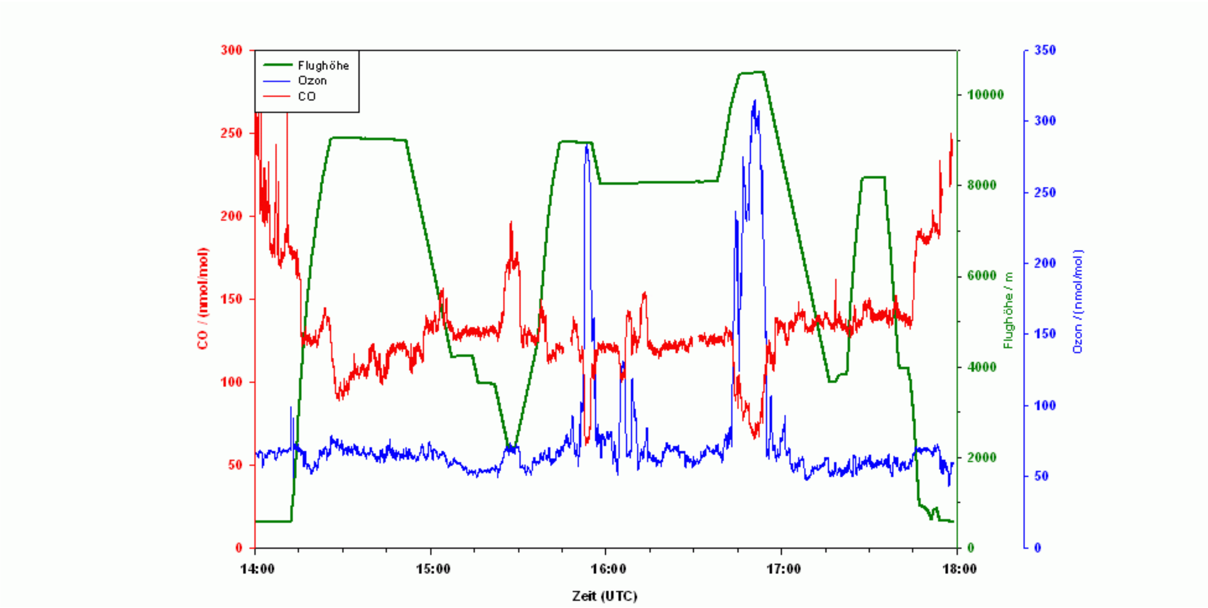

Figure 9: Time series of carbonmonoxide (CO) and ozone (O3) during the Falcon flight on 19 April 2010.

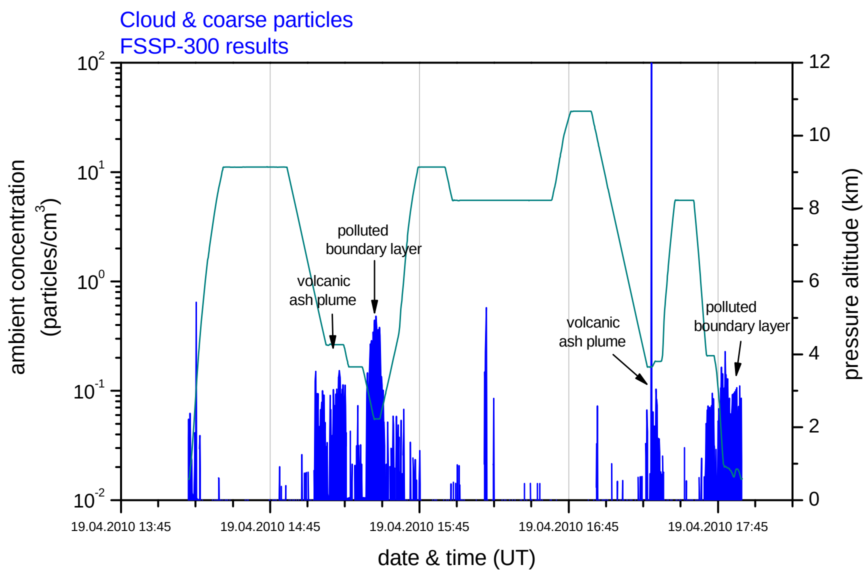

Figure 10: Time series of super-micron particle number concentrations measured during the research flight (FSSP-300, channels 18-31; assuming a refractive index of ammonium sulphate, this corresponds to the size range of approximately 3-20 µm).

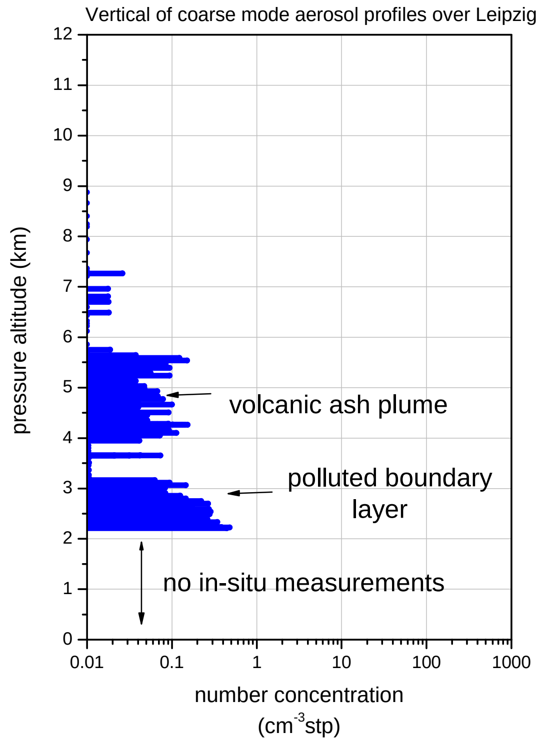

Figure 11: Vertical profile of coarse mode particles (3-20 µm) measured over Leipzig.

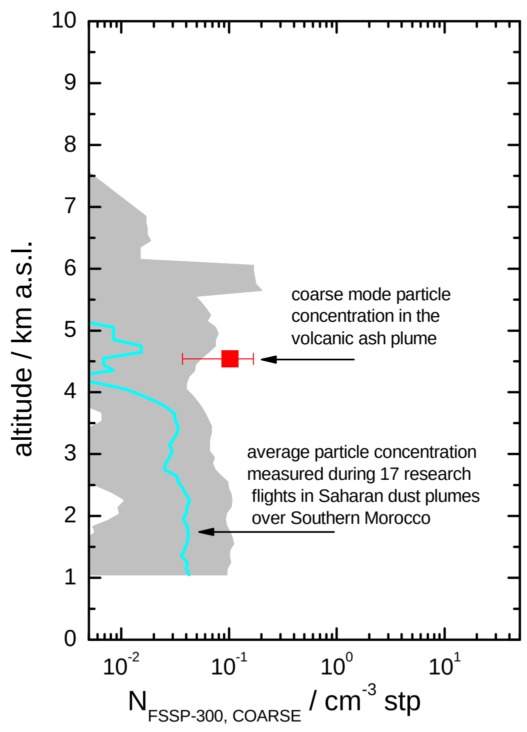

Figure 12: Intercomparison of coarse mode particle concentration measured in fresh Saharan dust plumes (aerosol optical depth 0.4 – 0.6) and coarse mode particle concentration measured in the volcanic ash plume measured over Leipzig (red symbol). The blue line shows the median particle concentration in the Saharan dust plumes, and the grey shaded area represents the range within 10-and 90-percentile values. All values in this graph are given for STP conditions (273.15 K, 1013.25 hPa).

Figure 12 shows an intercomparison of coarse mode particle concentration measured in fresh Saharan dust plumes (aerosol optical depth 0.4 – 0.6) and coarse mode particle concentration measured in the volcanic ash plume measured over Leipzig (red symbol). The coarse mode particle concentrations in the volcanic ash plume measured on 19 April 2010 (age: 4-5 days) is in the range seen in Saharan dust plumes.

The particle number size distribution in the volcanic ash plume over Leipzig is shown in Figure 13. It is a composite of three laser aerosol spectrometers (optical particle counters), a PCASP-100X and a FSSP-300, both mounted under the aircraft wings, and a Grimm-OPC 1.129 mounted in the cabin. PCASP and OPC data agree well in the overlapping size range. It is currently unknown if the FSSP-300 data in the size range of 3-4 µm could be affected by some overcounting due to electronic noise.

The conversion of the physical raw data of these instruments into size information depends on the assumption of the refractive index of the measured particles. The refractive index is connected to the chemical composition and structure of the aerosol particles and is unknown for this particular aerosol layer. The general effect is: If particles contain absorbing material, the particle size derived from the same raw data signal is larger. This is critical in particular for the large particles of some micrometer size which dominate the total volume of the aerosol population. For this preliminary analysis, a refractive index value in the coarse particle size range was used according to published data for volcanic particles (but not knowing if the particles investigated are of the same type). Therefore, the data here have to be used with care because of possible systematic errors.

Given these constraints, the total particle volume can be derived from the particle number size distribution. This in turn can be converted into a mass concentration if the particle density is known.

Assuming a particle density of 2 g/cm^3 our current best estimate for the particle mass concentration in the ash plume over Leipzig is 60 $\mu g/m^3$. The error is difficult to estimate without further analysis but at least a factor of 2 uncertainty should be assumed. It is possible that higher concentrations occur in other parts of the plume. In fresh volcanic plumes the concentrations will be much higher.

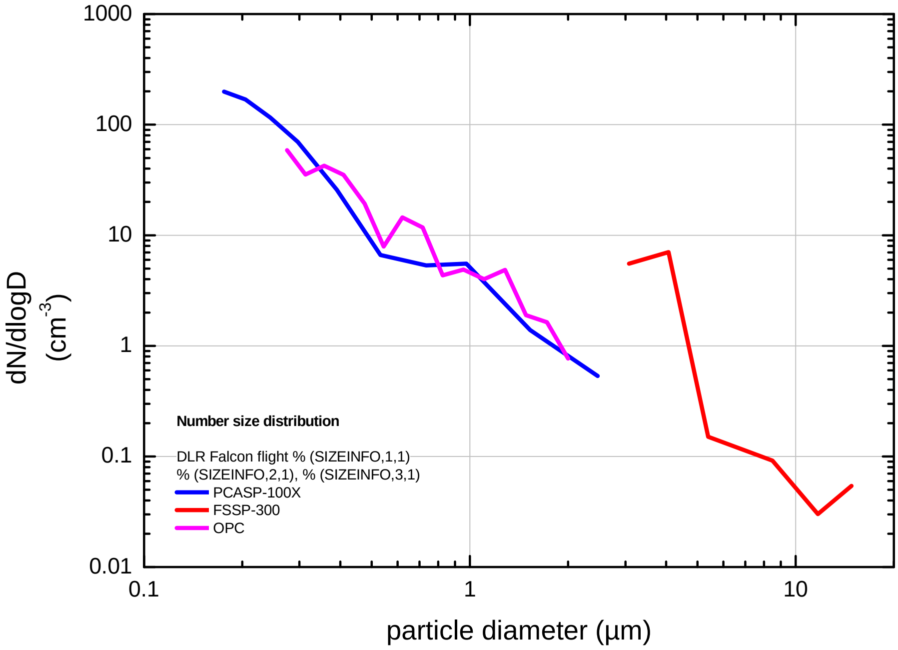

Figure 13: Preliminary aerosol number size distribution in the volcanic ash plume over Leipzig at 4.3 km pressure altitude.