Name of research institute or organization:

Laboratory of Atmospheric Chemistry, Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland

Title of project:

The Global Atmosphere Watch Aerosol Program at the Jungfraujoch

Project leader and team:

Prof. Dr. Urs Baltensperger, project leader
Dr. Ernest Weingartner, co-leader
Dr. Nicolas Bukowiecki, Dr. Martin Gysel, Dr. Zsófia Jurányi,
Günther Wehrle, Paul Zieger, Marie Laborde, Emanuel Hammer
Dr. Martine Collaud Coen (MeteoSwiss, Payerne)

Project description:

Airborne aerosols affect our climate primarily by influencing the atmospheric energy budget through direct and indirect effects. Direct effects refer to the scattering and absorption of radiation and their influence on the planetary albedo and the climate system. Indirect effects refer to the increase in available cloud condensation nuclei (CCN) due to an increase in anthropogenic aerosol concentration. This could lead to an increase in cloud droplet number concentration and a decrease in cloud droplet effective radius, when the cloud liquid water content (LWC) remains constant. The resulting cloud droplet spectrum could lead to reduced precipitation and increased cloud lifetime. The overall result would be an increase in cloud albedo which cools the Earth's climate. Despite the uncertainty, it is believed that in regions with high anthropogenic aerosol concentrations, aerosol forcing may be of the same magnitude, but opposite in sign compared to the combined effect of all greenhouse gases.

The Global Atmosphere Watch (GAW) program is an activity overseen by the World Meteorological Organization (WMO). It is the goal of GAW to ensure long-term measurements in order to detect trends and to develop an understanding of these trends. With respect to aerosols, the objective of GAW is to determine the spatio-temporal distribution of aerosol properties related to climate forcing and air quality up to multi-decadal time scales. Since the atmospheric residence time of aerosol particles is relatively short, a large number of measuring stations are needed. The GAW monitoring network consists of 27 global (including the Jungfraujoch) and about 300 regional stations. While global stations are expected to measure as many of the key variables as possible, the regional stations generally carry out a smaller set of observations.

The Jungfraujoch aerosol program is among the most complete ones worldwide. By the end of 2010 it has reached 16 years of continuous measurements. Table 1 shows the current GAW instrumentation that is continuously running at the Jungfraujoch. For these measurements, ambient air is sampled via a heated inlet (25°C), designed to prevent ice build-up and to evaporate cloud particles at an early stage, ensuring that the cloud condensation nuclei and/or ice nuclei are also sampled. This inlet is called the *total* inlet.

Table 1: Current GAW aerosol instrumentation

Instrument	Measured parameter
CPC (TSI 3010 or 3772)	Particle number density (particle diameter D_p>10 nm)
Nephelometer (TSI 3563)	Scattering coefficient at three wavelengths
Aethalometer (AE-31)	Absorption coefficient at seven wavelengths; black carbon (BC) concentration
MAAP	Absorption coefficient at one wavelength; black carbon (BC) concentration
Filter packs	Aerosol major ionic composition (PM1 and TSP)
Betameter and HiVol[1)]	Aerosol mass, PM1 and TSP[1)]

[1)] measured by EMPA

Since 2008, additional aerosol parameters have been continuously measured at the Jungfraujoch (see Table 2). These measurements were conducted as part of the "GAW plus" and two EU Projects (EUSAAR and EUCAARI).

Table 2: Additional aerosol instrumentation operated in 2010.

Instrument	Measured parameter	Measurement period
SMPS, OPC	Particle number size distribution, d_p = 20 - 22'500 nm	10.1.2008 - ongoing
CCNC	Number concentration of cloud condensation nuclei	10.1.2008 - ongoing

The permanent GAW monitoring activities include measurements of the total concentration of particles with diameters larger than 10 nm. However, the number size distribution of aerosol particles, which plays a key role for direct and indirect aerosol climate interactions, was not yet monitored on a permanent basis. Therefore, a scanning particle mobility sizer (SMPS) and an optical particle counter (OPC) were installed at the JFJ in January 2008. These instruments have been fully operational since then and provide a complete size distribution from 20 nm to 20 μm.

The cloud condensation nuclei counter (CCNC) exposes ambient aerosol particles to a defined water supersaturation (SS, in the range between SS = 0.07-1.18%) and measures the concentration of cloud droplets that were activated at this SS. This instrument was installed in January 2008 and has been running since then. It provides valuable information on the variation, absolute value and SS dependence of the CCN concentration (Jurányi et al. 2010).

Long-term aerosol data and trend analysis

Hourly and daily averages are calculated and the data is visualized in real-time for different time periods in the internet, see
http://aerosolforschung.web.psi.ch/onlinedata or
http://gawrtl.psi.ch

In warm months, the Jungfraujoch is influenced by injection of planetary boundary layer (PBL) air into the free troposphere during sunny afternoons due to thermal convection, while in winter it is usually in the undisturbed free troposphere. A detailed analysis of a 14-year dataset (1995-2008) of meteorological and aerosol variables as well as gaseous compounds was performed for different synoptic weather types[1]. Subsidence, lifting and advective weather types present three different seasonalities and lead to various PBL influences at the Jungfraujoch. The Jungfraujoch is found to be negligibly influenced by the PBL during winter for advective weather types. The largest PBL influence is found during summer for the convective anticyclonic weather type, when residual layers influence also the Jungfraujoch during the night.

A thorough statistical trend analysis was performed for the measured absorption (AE31 only) and scattering coefficients with data measured before December 2005[2]. The summer months at the Jungfraujoch, which are strongly influenced by planetary boundary layer air masses, do not show any statistically relevant long-term trend. In contrast, a significant and distinct positive trend of 4-7% yr^{-1} was encountered for most aerosol parameters during the September to December period before 2006. A possible explanation for this increase involves a European-wide, large-scale increase of the injection of planetary boundary layer air masses into the lower free troposphere (FT) coupled with large scale transport, or long-range transport from even more distant sources. In this sense this positive trend in this time period is interpreted as an increase of the lower FT aerosol concentration. An important future field of activity will be a careful reanalysis of trends using the entire dataset.

On-line notification service for the presence of mineral dust at the Jungfraujoch

The continuously measured wavelength dependent scattering coefficients (b_s) and absorption coefficients (b_{abs}) can be used to determine the presence of mineral dust events at the Jungfraujoch with an analysis of the wavelength dependence of the aerosol single scattering albedo, defined as $b_s/(b_s+b_{abs})$ (see Collaud Coen el al. (2004)[3] for details). This analysis is done on a regular basis at MeteoSwiss with quality controlled aerosol data from the Jungfraujoch. External groups expressed their interest to have a much faster notification service for the presence of mineral dust events. Therefore, a real-time notification service was established by a continuous analysis of the measured optical aerosol data. Computer generated notification emails are sent to interested users as soon as a possible mineral dust event is detected at the Jungfraujoch (a second email is sent as soon as the event stops). During 2010, 17 emails alerting a possible mineral dust event were sent out.

[1] Collaud Coen, M., Weingartner, E., Furger, M., Nyeki, S., Prévôt, A.S.H., Steinbacher, M., Baltensperger, U.: Planetary boundary influence at the Jungfraujoch analyzed by aerosol cycles and synoptic weather types, Atmos. Chem. Phys. Discuss. **2010**, submitted.

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[3] Collaud-Coen, M.; Weingartner, E.; Schaub, D.; Hueglin, C.; Corrigan, C.; Henning, S.; Schwikowski, M.; Baltensperger, U., Saharan dust events at the Jungfraujoch: detection by wavelength dependence of the single scattering albedo and first climatology analysis. *Atmospheric Chemistry and Physics* **2004,** 4, 2465-2480.

Detection of the Eyjafjallajökull aerosol plume

The eruption of the volcano Eyjafjallajökull in Iceland in April and May 2010 has strongly impaired the flight traffic in large regions of Europe. In central Europe, it caused an almost complete closure of the airspace during several days in Mid-April 2010. Since the lead time for actions to be taken in the predicted areas of concern was very short after the initial eruption, data from existing and operational monitoring networks were highly valuable considering the urgency of the situation.

In Switzerland, the volcanic ash plume was clearly detected at the High Altitude Research Station Jungfraujoch. Figure 1 shows the clear presence of volcanic aerosol at the Jungfraujoch on several days in April and May 2010, indicated by a strong simultaneous increase in mass concentration (PM10), sulfur dioxide (SO2) and coarse mode ash particles.

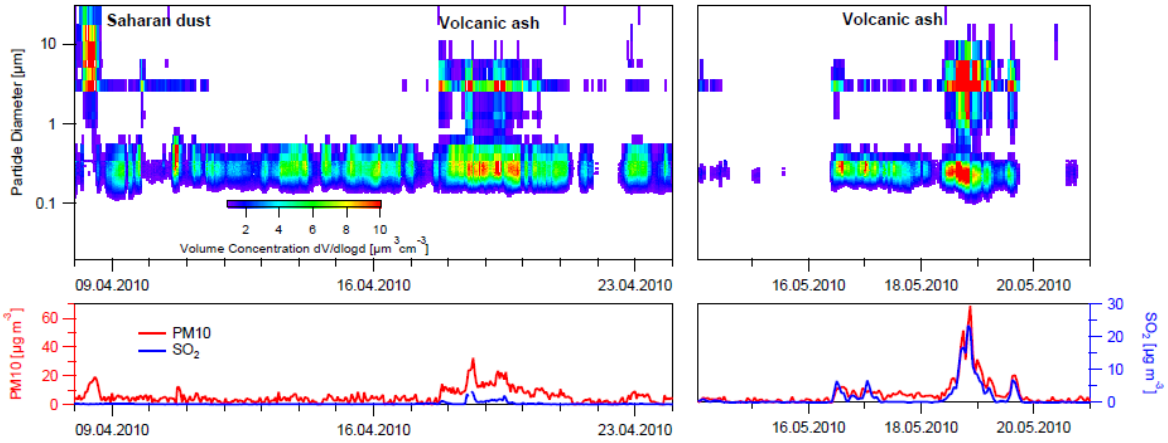

Figure 1: Volcanic aerosol was detected at the Jungfraujoch by a strong simultaneous increase in mass concentration (PM10), sulfur dioxide (SO_2, lower panel) and by the presence of ash particles with a diameter of 3 µm in the aerosol volume size distribution (upper panel). (PM10 and SO_2 data: Courtesy of Empa/NABEL).

Figure 2 shows that the aerosol volume size distributions, measured during the time periods with maximal influence by the volcanic aerosol plume, exhibited a clear bimodality. They are characterized by an accumulation mode in the diameter range 0.1 - 0.8 µm and a coarse mode with a maximum around 3 µm. The chemical composition of the volcano related accumulation mode particles was dominated by ammonium and sulfate. Depending on the transport time, the volcanic sulfur dioxide is transformed to sulfuric acid via chemical processing, which then is neutralized to ammonium sulfate based on its time of contact with the planetary boundary layer. The coarse mode ash particles were found to have a similar composition as found in rock samples collected near the volcano, and showed both crystalline and glass-like structures[4] (Figure 2).

[4] Bukowiecki, N., P. Zieger, E. Weingartner, Z. Jurányi, M. Gysel, B. Neininger, B. Schneider, C. Hueglin, A.Ulrich, A. Wichser, S. Henne, D. Brunner, R. Kaegi, M. Schwikowski, L. Tobler, F.G. Wienhold, I. Engel, B.Buchmann, T. Peter, and U. Baltensperger, Ground-based and airborne in-situ measurements of the Eyjafjallajökull volcanic aerosol plume in Switzerland in April and May 2010, Atmos. Chem. Phys. Discuss., **2011**, in preparation.

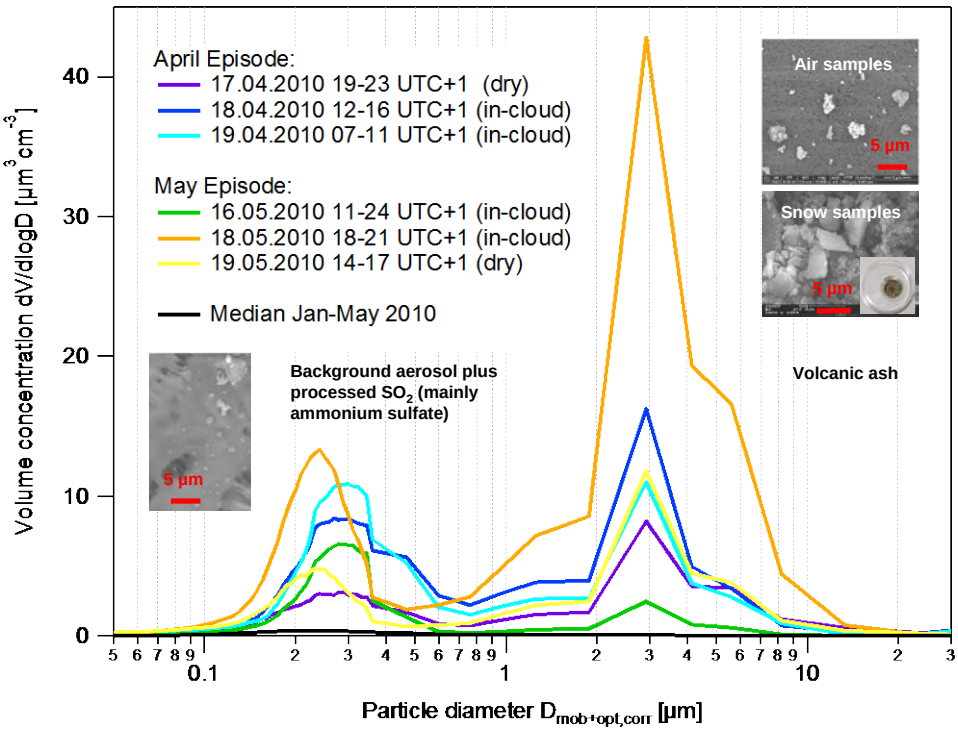

Figure 2: Volcanic aerosol volume size distributions observed at the Jungfraujoch.

Due to previous mixing and dilution of the volcanic aero-sol within the planetary boundary layer, the Jungfraujoch did not capture the maximum plume concentration of the ash. However, the combination of the collected data at the Jungfraujoch allows establishing the relationship between the mass concentration of the volcanic ash and its extinction coefficient. With this information, Lidar data can be converted into vertical profiles for mass concentrations, assuming similar size distributions. Most Lidars in Europe were operational during the Eyjafjallajökull eruption and were able to track the altitude of the volcanic ash layer.

The CLACE 2010 field campaign

From June to August 2010, researchers from three countries (Switzerland, Germany and Belgium) and seven national and international institutions met for a joint campaign (CLACE2010 — Cloud and Aerosol Characterization Experiment), as a follow-up of previous CLACE campaigns. The main goal was an in-depth characterization of the cloud microphysical processes at the Jungfaujoch, extending the knowledge gained during earlier CLACE campaigns. Additionally, the optical properties of the aerosol layer at and around the Jungfraujoch were examined using a variety of remote sensing equipment. The remote sensing experiments were also performed at Kleine Scheidegg for the first time. The routine GAW measurements at the Jungfraujoch were normally continued during the campaign. Figure 3 provides an overview of the activities. The following paragraphs describe the main features of the campaign along with first preliminary results. Detailed analysis is still in progress.

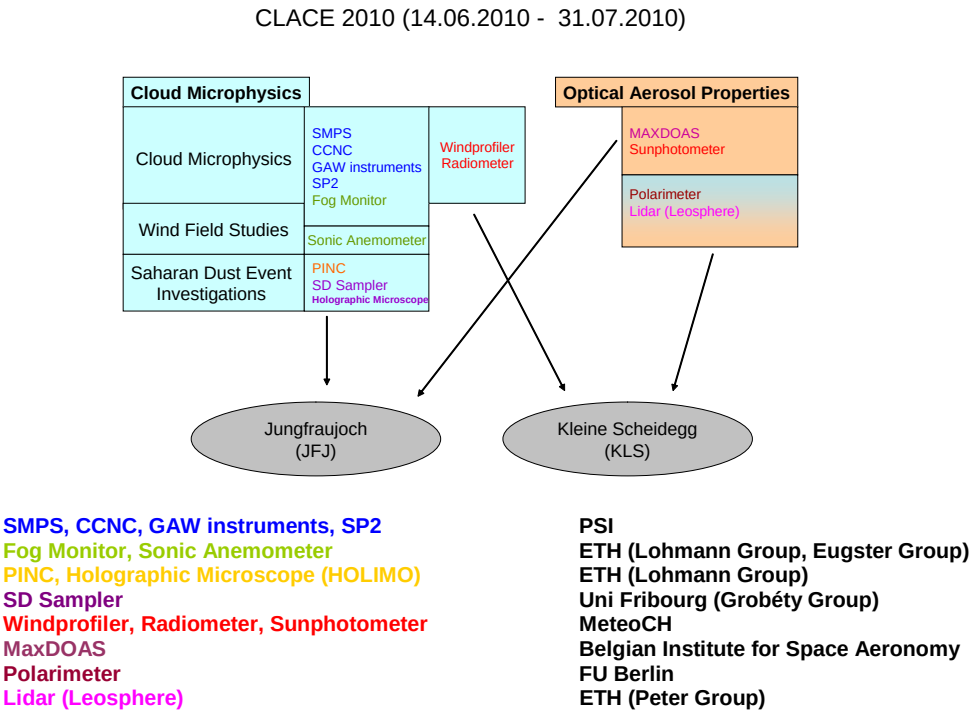

Figure 3: General overview of the CLACE 2010 experiments.

A) Cloud microphysics:

During earlier studies, the cloud forming potential of aerosol particles at the Jungfraujoch was predominately derived from measurements performed under laboratory conditions at elevated temperature after having dried the aerosol. During the CLACE 2010 campaign we compared in situ measured cloud droplet number concentrations with CCN number concentrations that were derived from laboratory measurements. These measurements will allow for the determination of the effective peak supersaturation in the prevailing ambient cloud which was responsible for the activation of aerosol particles to cloud droplets. In addition, these measurements represented an important part of a quality assurance procedure because the cloud droplet sampling process is critical and might bias the results derived from the laboratory based measurements. For the direct measurement of cloud droplet distributions, a cloud probe (Fog Monitor FM100) was operated by ETH.

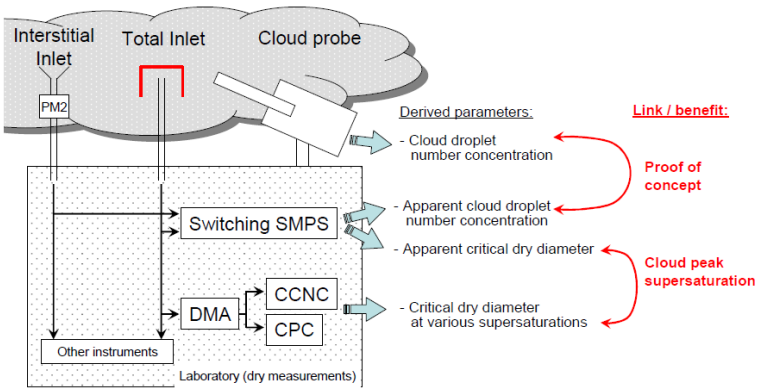

Figure 4: Setup of the cloud microphysics experiments performed during CLACE 2010.

We also operated a sonic anemometer (provided by ETH) at a favorable position for the estimation of the average vertical wind speed component in the cloud. This parameter is expected to influence the cloud peak supersaturation. The sonic anemometer was coupled with the fog monitor, allowing for the determination of the local up/downdraft of the prevailing cloud droplets. An important activity of future analysis will be to analyze whether the derived supersaturation can be predicted from the above mentioned meteorological parameters using a thermodynamic cloud model. The local measurements of the air mass updraft at the Jungfraujoch can however not give any information on the air mass behavior in the time period before it arrived at the Jungfraujoch. This information is very important for the interpretation of the CCN peak supersaturation measured at the Jungfraujoch. To find out more on the regional cloud dynamics, additional measurements were performed at Kleine Scheidegg using the following instruments:

- Windprofiler: Wind speed and direction at various elevations above the ground.
- Radiometer: Humidity and temperature profiles
- Ceilometer: Cloud height, height of mixing layer

Figure 5 shows two examples of the diameter dependent aerosol activation to cloud droplets. These activation curves were determined by the simultaneous measurement of the total and interstitial (total aerosol minus cloud condensation nuclei) aerosol number size distribution. The upper panel shows an example of complete activation of aerosol particles above 50 nm (critical activation diameter D_{50} = 50 nm), as indicated by an upper activation curve plateau very close to one. In other cases (lower panel) this plateau did not reach 1, indicating incomplete activation due to ice formation or entrainment. Further investigation of this phenomenon is subject to ongoing analysis. In addition, the critical activation diameter in the second example is higher (D_{50} = 80-100 nm). By comparison with the results from a CCN counter measuring the number of CCN at different supersaturations (Jurányi et al. 2010), the peak supersaturation (SS_p) which led to the activation of the aerosol in the real cloud can be retrieved. This analysis yields SS_p = 0.7 - 0.95 % in the first case and SS_p = 0.35 - 0.5 % in the second case.

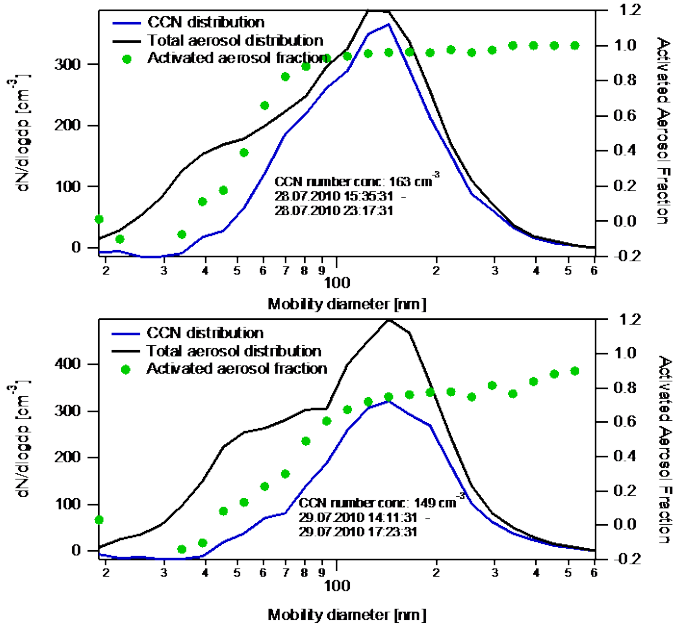

Figure 5: Two examples of aerosol activation to cloud droplets.

Figure 6 gives a summarized view on the estimated ambient peak supersaturations (SS_p) during CLACE 2010, which were deduced from a 17-month climatology of CCN number concentrations at 10 different supersaturations measured by a CCNC[5]. During the campaign the peak supersaturation of the cloud droplets arriving at the Jungfraujoch showed a mean value of 0.31% and a median value of 0.23%. These values are in quite good agreement with results from earlier studies[6]. Ongoing data analysis attempts to establish a link between the retrieved peak supersaturations and other parameters like temperature, updraft velocity and weather situation (i.e., cloud type).

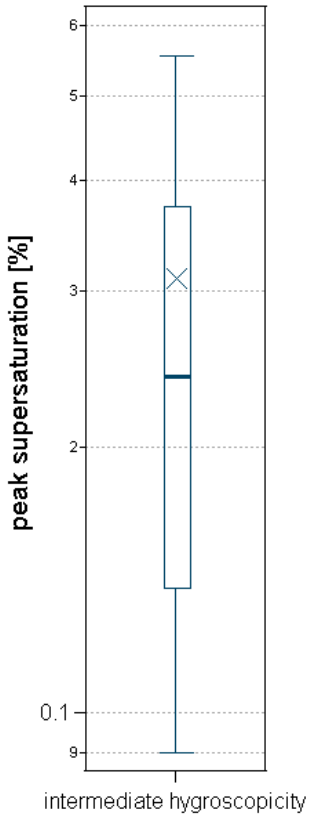

Figure 6: Box plot of the ambient peak supersaturations for stable clouds periods during CLACE 2010, assuming an intermediate aerosol hygroscopicity as determined in a long-term climatology at the Jungfraujoch[7]. To establish this link, the D_{50} values determined from SMPS measurements during CLACE 2010 were related to D_{50} values for the long-term climatology. Box: First, second and third quartile; cross: Average; whiskers: 5/95% percentile.

During the CLACE 2010 campaign a single particle soot photometer (SP2) was used to investigate the activation behavior of BC containing particles in liquid clouds. The

[5] Jurányi, Z., Gysel, M., Weingartner, E., Bukowiecki, N., Kammermann, L. and Baltensperger, U., 17-month climatology of the cloud condensation nuclei number concentration at the high alpine site Jungfraujoch, Journal of Geophysical Research **2010**, submitted.
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SP2 measurements were alternately taken behind the total and the interstitial aerosol inlets. In the total aerosol the number fraction of BC containing particles was found to be ~20% and independent of optical particle diameter (Figure 7, left panel). The same number fraction of BC particles was found in the interstitial aerosol at optical particle diameters larger than ~350 nm, while it was significantly increased at diameters below 350 nm (Figure 7, right panel). This increased number fraction of BC particles shows that the minimum particle diameter required for cloud droplet activation is larger for BC particles than for purely scattering particles. Further analysis showed that the cloud droplet activation of BC particles increased with increasing coating thickness of other aerosol components. This clearly indicates that atmospheric aging processes, which typically increase the amount of material accumulated by BC particles, play an important role for the cloud droplet activation of BC particles and thus for their life cycle.

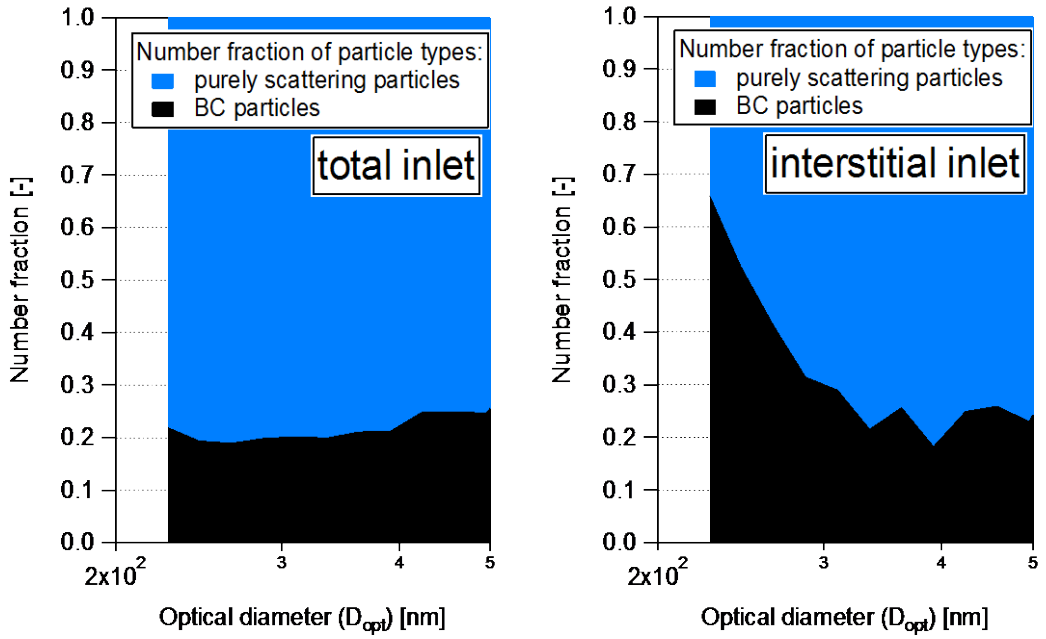

Figure 7: Size dependence of the number fraction of purely scattering and BC containing particles measured by the SP2 behind the total (left panel) and interstitial (right panel) aerosol inlet during the cloud event on 16/06/2010.

B) Aerosol optical properties:

The main goal of this activity was to get the closure between in-situ measurements of aerosol optical properties with different kinds of remote sensing data. The aerosol light scattering coefficient was measured in-situ in dependence of relative humidity (RH) with a humidified nephelometer (WetNeph). In combination with Aethalometer and MAAP measurements, the extinction coefficient at ambient RH could be determined at the height of the Sphinx station. This data will be compared to MAX-DOAS (Multi Axis Differential Optical Absorption Spectroscopy, operated by the Belgian Institute for Space Aeronomy) and Lidar (ETHZ) measurements. Since the MAX-DOAS can determine profiles of the aerosol optical properties and profiles of various atmospheric gases with higher sensitivity for the lower height levels it was installed directly at the Jungfraujoch station. It can give an estimate of the height of the injection layer, which is the height of the air mass above the Jungfraujoch that is influenced by injections from the PBL.

The Lidar instruments (a scanning backscatter Lidar provided by ETHZ and a ceilometer provided by Jenoptic) were installed at the Kleine Scheidegg (~2060m), which ensures to overcome the general overlap problem of the Lidar measurement. This setup enabled us to directly measure aerosol optical properties at the height of the JFJ. Additionally, the sun- and aureole spectrometer system (provided by FU Berlin) measured multi-spectral columnar values of aerosol optical properties like AOD or Angstrom exponent. The AOD measurements are also needed in combination with Lidar measurements to retrieve a simple estimate of the aerosol extinction coefficient during day time. The spectrometer systems were calibrated directly at the Sphinx station before and after the intensive operation period.

Key words:

Atmospheric aerosol particles, aerosol climatic effects, radiative forcing, light scattering, cloud condensation nuclei, hygroscopic growth, CCN concentration, aerosol size distribution, remote sensing of aerosol optical properties

Internet data bases:

http://www.psi.ch/gaw
http://www.psi.ch/lac
http://aerosolforschung.web.psi.ch
http://www.meteoschweiz.admin.ch/web/en/climate/climate_international/gaw-ch.html

Collaborating partners/networks:

Dr. D. Ruffieux, MeteoSwiss, Payerne
Prof. U. Lohmann, Prof. J. Stähelin and Prof. T. Peter, Institute for Atmospheric and Climate Science, ETH Zürich
Dr. W. Eugster, Institute of Plant, Animal and Agroecosystem Sciences, ETH Zürich
Dr. C. Hüglin and Dr. S. Reimann, EMPA, Dübendorf
Prof. Dr. B. Grobéty, Universität Fribourg
Prof. Dr. J. Fischer and Dr. T. Ruhtz, Freie Universität Berlin
Dr. Katrijn Clemer, Dr. Michel Van Roozendael, Belgian Institute for Space Aeronomy
Dr. Julian Gröbner, Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center (PMOD/WRC), Davos Switzerland
Dr. Martin Schnaiter, Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology (KIT) Germany
Prof. H. Burtscher and Dr. M. Fierz, Institut für Aerosol- und Sensortechnik, Fachhochschule Nordwestschweiz, Windisch
Prof. A. Wiedensohler, Institut für Troposphärenforschung, Leipzig, Germany
Dr. P. Laj, Laboratoire de Glaciologie et Géophysique de l'Environnement CNRS - Université J. Fourier, Grenoble, St Martin d'Hères Cedex, France
Dr. K. Sellegri, Laboratoire de météorologie physique, Université Blaise Pascal, 63170 Aubiere, France
Dr. A. Petzold, Institute of Atmospheric Physics, DLR Oberpfaffenhofen, Germany
Prof. J. Curtius, Institut für Atmosphäre und Umwelt, Johann Wolfgang Goethe Universität Frankfurt am Main, Frankfurt, Germany
Prof. H. Coe and Prof. T. Choularton, School of Earth, Atmospheric and Environmental Sciences (SEAES), University of Manchester, Manchester, England

Dr. J. Schneider and Prof. S. Borrmann, University of Mainz, Particle Chemistry Department, Mainz, Germany
Dr. U. Pöschl, Biogeochemistry Department, Max-Planck-Institut für Chemie, Mainz, Germany
Prof. S. Weinbruch, Universität Darmstadt, Institut für Mineralogie, Darmstadt, Germany
Prof. M. Kulmala, Department of Physics, University of Helsinki, Helsinki, Finland

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Refereed journal articles and their internet access

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Address:

Laboratory of Atmospheric Chemistry
Paul Scherrer Institut (PSI)
CH-5232 Villigen
Switzerland

Contacts:

Ernest Weingartner
Tel: +41 56 310 2405
Fax: +41 56 310 4525
e-mail: ernest.weingartner@psi.ch

Urs Baltensperger
Tel: +41 56 310 2408
Fax: +41 56 310 4525
e-mail: urs.baltensperger@psi.ch