The Global Atmosphere Watch Aerosol Program at Jungfraujoch

Benjamin Brem[1], Martine Collaud Coen[2], Ghislain Motos[1], Günther Wehrle[1], Martina Burger[1], Urs Baltensperger[1] and Martin Gysel Beer[1]

[1]Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, Villigen PSI, Switzerland
[2]Federal Office of Meteorology and Climatology, MeteoSwiss, Payerne, Switzerland

martin.gysel@psi.ch

Part of this programme and projects: GAW, ACTRIS, BACCHUS

Keywords: atmospheric aerosol particles; aerosol climatic effects; aerosol optical properties; aerosol size distribution; cloud condensation nuclei

1. Project description

Aerosols affect the Earth's climate by influencing the atmospheric energy budget through direct and indirect effects. Direct effects (aerosol – radiation interactions, ARI) are the scattering and absorption of radiation by aerosol particles. Indirect effects (aerosol – cloud interactions, ACI) refer to the role of particles as cloud condensation nuclei (CCN) and ice-nucleating particles (INP). The number of CCN available under certain conditions affects the droplet number and size in a cloud and thus the cloud optical properties and lifetime. Both characteristics are also impacted by INPs that play an important role in initiating precipitation. The climate relevance of both ARI and ACI results from their effect on the planetary albedo (incoming shortwave radiation). ACI furthermore affect the Earth's outgoing longwave radiation. The IPCC report states ARI and ACI as the major uncertainties in the anthropogenic radiative forcing due to their limited scientific understanding.

The Global Atmosphere Watch (GAW) programme is an activity coordinated by the World Meteorological Organization (WMO). The goal of GAW is 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 spatial-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 31 global (including the Jungfraujoch site) and about 400 regional stations. While global stations measure as many of the key variables as possible, the regional stations generally carry out a smaller subset of observations. The aerosol programme at Jungfraujoch is also part of the European Research Infrastructure ACTRIS (Aerosols, Clouds, and Trace gases Research Infra Structure).

The aerosol observations at Jungfraujoch are among the most comprehensive worldwide. By the end of 2019, some specific observations have been performed continuously for 24 years (see Figure 1). 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 droplets at an early stage, ensuring that the cloud condensation nuclei and/or ice nuclei are also sampled. The sampling complies with GAW recommendations, and the operation and data handling of the individual instruments follows the most recent ACTRIS recommendations. Data delivery to EBAS occurs both hourly in near real time (selected instruments, raw data) and annually (quality controlled and flagged data).

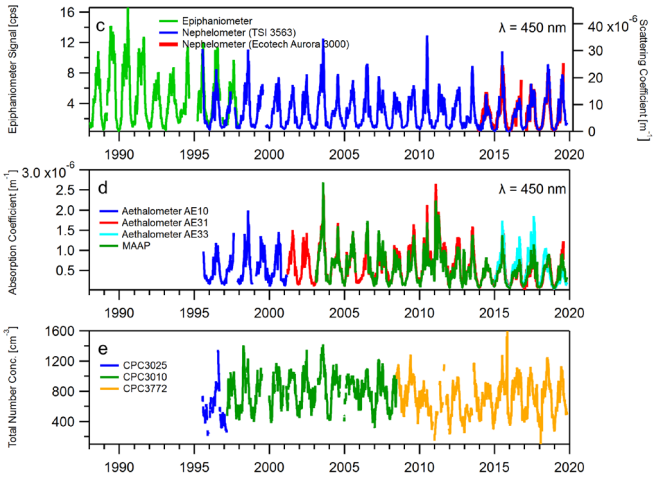

Figure 1 (updated from Bukowiecki et al., 2016). Panels c–e: Temporal evolution of the continuously measured aerosol parameters at the Jungfraujoch (30-day running average of the daily average values).

Table 1. Current GAW aerosol instrumentation at Jungfraujoch.

Instrument	Measured parameter
CPC (TSI 3772)	Particle number density (particle diameter D_p>10 nm)
Nephelometers (TSI 3563 & Airphoton INI101)	Scattering coefficients at three visible wavelengths
Aethalometers (AE-33)	Absorption coefficient at seven wavelengths; equivalent black carbon (BC) mass concentration
MAAP	Absorption coefficient at one wavelength; equivalent black carbon (BC) mass concentration
Filter packs	Aerosol major ionic composition (PM1 and TSP)
Fidas and HiVol[1)]	Aerosol mass, PM1 and TSP[1)]
SMPS, OPS	Particle number size distribution, D_p = 17 – 10'000 nm
CCNC	Number concentration of cloud condensation nuclei at different supersaturations

[1)] measured by Empa

CCN and closure studies between measured and modelled CCN number concentrations are still a major focus of research. We participated in a global modelling benchmark study of particle and CCN concentrations, where the evaluation focused on the ability of models to simulate the average across time state in diverse environments (Fanourgakis *et al.*, 2019). There was no single model that systematically performed best across all environments represented by the observations. Models tend to underestimate the observed aerosol particle and CCN number concentrations, with average normalized mean bias of all models and for all stations, of - 24% and - 35%for particles with dry diameters > 50 and > 120 nm, as well as - 36% and - 34% for CCN at supersaturations of 0.2% and 1.0 %, respectively.

Aerosol cloud interactions were also studied specifically for black carbon (BC) particles. BC is a main component of carbonaceous particulate matter, mainly emitted from anthropogenic sources and it is the strongest light-absorber across the visible range, therefore causing substantial climate warming through ARI. Freshly emitted BC is often externally mixed, which makes it a poor CCN due to its insolubility. BC particles can acquire coatings during atmospheric ageing, thereby improving their CCN ability. This affects the ARI of BC, as increasing its wet removal efficiency reduces total atmospheric BC burden.

In Motos *et al.*, 2019 we address the activation of BC to form droplets in ambient fog and clouds, and assess whether BC activation can be predicted from measured BC properties. Field experiments were conducted at an urban site, where fog regularly occurs and where a mixture of fresh and aged BC was encountered, and at the Jungfraujoch site frequently exposed to clouds formed on highly aged free tropospheric aerosol. Aerosol was sampled with different inlets during fog/cloud periods to characterize i) exclusively interstitial particles and ii) the aerosol as a whole (interstitial plus droplet residual particles). This allows to compare the properties of particles that activated to cloud droplets with those remaining interstitial, *e.g.* size distribution (mobility particle size spectrometer) as well as BC core size distribution and mixing state (single particle soot photometer, SP2). The size distribution data provide the activation cut-off diameter representative of BC-free particles, from which the fog/cloud peak supersaturation is inferred. The SP2 provides the volume equivalent total particle and BC core diameters of BC-containing particles. SP2 data combined with coating hygroscopicity was used as input for κ-Köhler theory to infer the predicted critical supersaturation for CCN activation of BC on a single particle basis.

Figure 2 shows the key result of that study. In fog with very low peak supersaturation, BC particle activation agreed with predictions both qualitatively and quantitatively: activated fraction increased with increasing coating thickness for a fixed core size, the coating thickness at 50% activation decreased with increasing core size, and the observed dependence of the activation cut-off on size and mixing state matched theoretical predictions. Similar agreement between prediction and measurements was also found for the clouds at Jungfraujoch, though with more limited "data coverage" as higher peak supersaturations shift the activation cut-off diameters towards the lower limits of detection of the SP2.

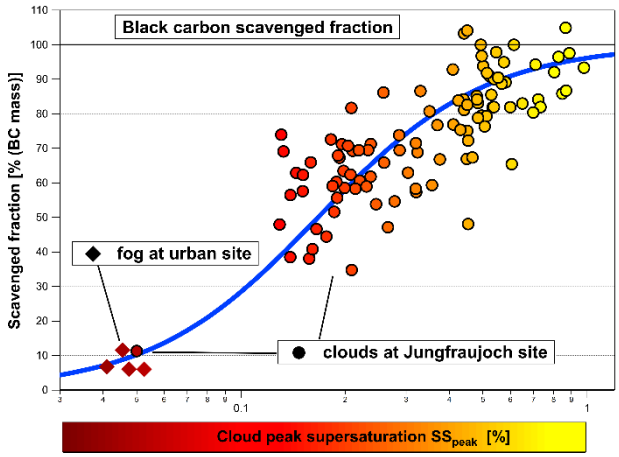

Figure 2. Scavenged fraction of black carbon (by mass) as a function of cloud peak supersaturation.

Assuming spherical core-shell morphology, which is implicitly done in both SP2 data analysis and κ-Köhler theory, describes activation behavior of atmospheric BC in good approximation. This validates application of κ-Köhler theory based on droplet activation in model simulations in which BC size and mixing state are available on a mass or volume basis.

References

Bukowiecki, N., E. Weingartner, M. Gysel, M. Collaud Coen, P. Zieger, E. Herrmann, M. Steinbacher, H.W. Gäggeler, U. Baltensperger, A review of more than 20 years of aerosol observation at the high altitude research station Jungfraujoch, Switzerland (3580 m asl), Aerosol Air Qual. Res., **16**, 764–788, doi: 10.4209/aaqr.2015.05.0305, 2016.

Internet data bases

http://www.psi.ch/lac
http://www.psi.ch/lac/gaw-monitoring-nrt-data
http://sites.google.com/site/jfjnrt/
https://www.meteoswiss.admin.ch/home/research-and-cooperation/international-cooperation/gaw.html
http://ebas.nilu.no
http://www.actris.net
https://www.bacchus-env.eu/
https://www.meteoswiss.admin.ch/home/climate/climate-change-in-switzerland/aerosol-and-climate.html
https://www.meteoswiss.admin.ch/home/climate/the-climate-of-switzerland/specialties-of-the-swiss-climate/saharan-dust-events.html

Collaborating partners / networks

Dr. A. Haefele, Dr. J. Klausen, MeteoSwiss, Payerne
Prof. U. Lohmann, Prof. T. Peter, Institute for Atmospheric and Climate Science, ETH Zürich
Dr. C. Hüglin, Dr. S. Henne, Dr. M. Steinbacher, and Dr. S. Reimann, Empa, Dübendorf
Dr. Franz Conen, Institut für Umweltgeowissenschaften, Universität Basel
Prof. M. Leuenberger, Climate and Environmental Physics, University of Bern
Prof. E. Weingartner, Institut für Aerosol- und Sensortechnik, Fachhochschule Nordwestschweiz, Windisch
Prof. A. Wiedensohler, Dr. T. Müller, Dr. S. Henning, ECAC and TROPOS, Leipzig, Germany
Dr. E. Andrews, NOAA, Boulder, USA
Prof. J. Curtius, Institut für Atmosphäre und Umwelt, Johann Wolfgang Goethe Universität Frankfurt am Main, Frankfurt, Germany
Dr. J. Schneider, University of Mainz, and Max Planck Institute for Chemistry Mainz, Particle Chemistry Department, Germany
Prof. M. Kulmala and Prof. F. Bianchi Department of Physics, University of Helsinki, Helsinki, Finland
Griša Močnik, University of Nova Gorica Centre for Atmospheric Research, Ljubljana, Slovenia

Scientific publications and public outreach 2019

Refereed journal articles and their internet access

Creamean, J. M., C. Mignani, N. Bukowiecki, and F. Conen, Using freezing spectra characteristics to identify ice-nucleating particle populations during the winter in the Alps, Atmos. Chem. Phys., **19**, 8123-8140., 2019. https://doi.org/10.5194/acp-19-8123-2019

Fanourgakis, G.S., M. Kanakidou, A. Nenes, S.E. Bauer, T. Bergman, K.S. Carslaw, … F. Yu, Evaluation of global simulations of aerosol particle and cloud condensation nuclei number, with implications for cloud droplet formation, Atmos. Chem. Phys., **19**, 8591-8617, 2019. https://doi.org/10.5194/acp-19-8591-2019

Gute, E., L. Lacher, Z.A. Kanji, R. Kohl, J. Curtius, D. Weber, H. Bingemer, H.-C. Clemen, J. Schneider, M. Gysel-Beer, S.T. Ferguson, and J.P.D. Abbatt, Field evaluation of a Portable Fine Particle Concentrator (PFPC) for ice nucleating particle measurements, Aerosol Sci. Technol., **53**, 1067-1078, 2019. https://doi.org/10.1080/02786826.2019.1626346

Motos, G., J. Schmale, J.C. Corbin, R.L. Modini, N. Karlen, M. Bertò, … M. Gysel-Beer, Cloud droplet activation properties and scavenged fraction of black carbon in liquid-phase clouds at the high-alpine research station Jungfraujoch (3580 m a.s.l.), Atmos. Chem. Phys., **19**, 3833-3855, 2019. https://doi.org/10.5194/acp-19-3833-2019

Conference Papers

Collaud Coen, M., E. Andrews, Methodology of long-term trend analysis applied to aerosol parameters, European Aerosol Conference (EAC) 2019, Gothenburg, Sweden, August 25-30,2019.

Address

Laboratory of Atmospheric Chemistry
Paul Scherrer Institute (PSI)
Forschungsstrasse 111
CH-5232 Villigen
Switzerland

Contacts

Dr. Martin Gysel-Beer
Tel.: +41 56 310 4168
e-mail: martin.gysel@psi.ch