The Global Atmosphere Watch Aerosol Program at Jungfraujoch

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1. Project description

Aerosols affect Earth's climate primarily by influencing the atmospheric energy budget through direct and indirect effects. Direct effects (aerosol – radiation interactions, ARI) refer to 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 cloud brightness and cloud life-time. Both characteristics are also impacted by INPs which, with regard to life-time, play a key role in initiating precipitation. The climate relevance of both direct and indirect effects results from their effect on the planetary albedo. The IPCC report states that a major part of the uncertainty with respect to anthropogenic radiative forcing is caused by our limited understanding of these aerosol effects.

The Global Atmosphere Watch (GAW) programme is an activity overseen 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 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 31 global (including the Jungfraujoch site) and about 400 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. From April 2011 to March 2014, the aerosol programme at Jungfraujoch was also part of the European FP7 infrastructure project ACTRIS (Aerosols, Clouds, and Trace gases Research Infra Structure), followed by the currently running project phase ACTRIS-2 IA H2020 (May 2015 to April 2019).

The Jungfraujoch aerosol observations are among the most complete worldwide. By the end of 2018 they have reached 23 years of continuous measurements for part of the observables (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 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. The sampling is in accordance 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-realtime (selected instruments, raw data) and annually (quality controlled and flagged data).

Data from the CCNC (cloud condensation nuclei counter for the measurement of the number of particles that are able to form a cloud droplet at specified supersaturations) are part of an ongoing effort to characterize CCN variability world-wide. While the initial step in the form of a synthesis of measurements within the FP6 project EUCAARI was completed in 2015 (Paramonov et al., 2015), a new study goes one step further and provides a set of co-located particle number size distribution, CCN number concentration and aerosol composition data from long-term observations all over the globe (Schmale et al. 2018). Figure 2 shows three of the variables for the twelve stations that participated in the effort. The stations are grouped according to the type of environment they represent. The first four stations (starting with Barrow) are coastal locations, the next two central European, the next two boreal forest, then tropical rain forest, the next two represent alpine environments and the last a city. It is evident that the CCN number concentrations, the geometric mean diameter of the size distribution and the critical diameter values vary widely across and within the different types of environments and with seasons (not shown). This means that long-term observations in a number of representative locations are necessary to capture the different processes that modulate the CCN number concentrations. This harmonized data set is currently used as benchmark for global model simulations.

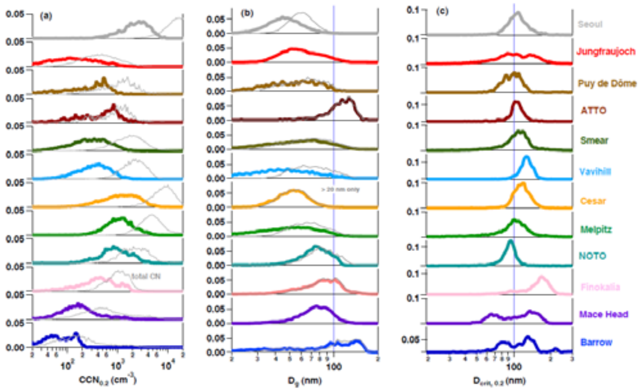

Figure 2 (from Schmale et al. 2018a). Normalised frequency distributions of CCN number concentration at SSD 0.2% and total particle number in light grey, (b) geometric mean diameter D_g, and (c) critical diameter D_{crit} at SSD 0.2 %. The grey lines in (b) are based on size distributions starting at 20 nm. The critical diameter is derived from the total CCN concentration (SSD 0.2 %) and the integrated particle number concentration starting from the largest diameter. Note that seasons are not represented by an equal number of data points at each station which can lead to small biases in the frequency distributions. In (a) and (c) all ordinate scales start at 0.00.

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 & Ecotech Aurora 3000 & Airphoton INI101)	Scattering coefficients at three wavelengths
Aethalometers (AE-31 & 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 = 20 - 22'500 nm
CCNC	Number concentration of cloud condensation nuclei at different supersaturations

[1)] measured by Empa

Observations at Jungfraujoch East Ridge

In October 2014, an aethalometer (AE-33) and a condensation particle counter (TSI 3775) were installed at the Jungfrau East Ridge station (3705 m a.s.l., former Swisscom station), to measure aerosol microphysical properties. These measurements will be compared to those performed at the Sphinx Laboratory with a similar setup, to determine the impact of local pollution at Jungfraujoch and to investigate the small-scale spatial variability of aerosol parameters. Figure 3 shows a comparison of the total number concentration at both sites for a couple of days in autumn 2014. While concentrations are nearly identical during night-time, data from the Sphinx show large spikes during the day which indicate tourism-related local pollution (Fröhlich et al., 2015). By the use of appropriate statistical filters, the baseline at the Sphinx can be sufficiently well recovered from the raw data series influenced by spikes. Figure 4 furthermore shows the occurrence of high pollution days at the Jungfraujoch, which are defined as days with more than 8 strong peaks at the Jungfraujoch and less than 2 strong peaks at the East Ridge site. In the 3 years of parallel measurements (Oct 2014 to Oct 2017), the percentage of high local pollution days was 9%. During these days, the daily CPC averages including the spikes are 25% percent higher compared to the daily baseline values. During normal days, this value is only 10%. In the median the influence of the spikes is not seen. The invitation to refrain from smoking on the public Sphinx terrace in March 2017 leads to less days with high local pollution.

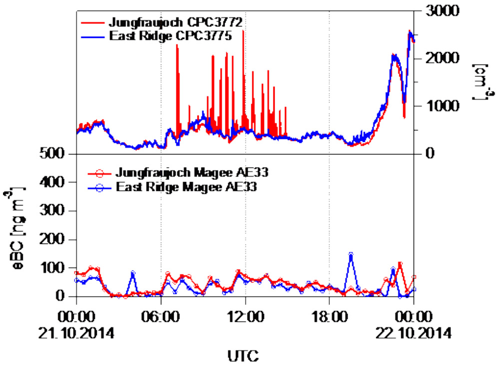

Figure 3. Total particle number concentrations (top panel) and equivalent black carbon concentrations (bottom panel) during a high local pollution day at Sphinx and East Ridge.

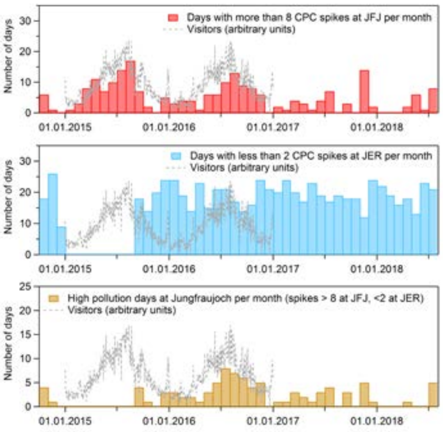

Figure 4. Number of high pollution days at the Jungfraujoch, derived from the CPC time series at the Jungfraujoch and Jungfrau East Ridge. A high pollution day is defined as day with more than 8 strong peaks at the Jungfraujoch and less than 2 strong peaks at the East Ridge site.

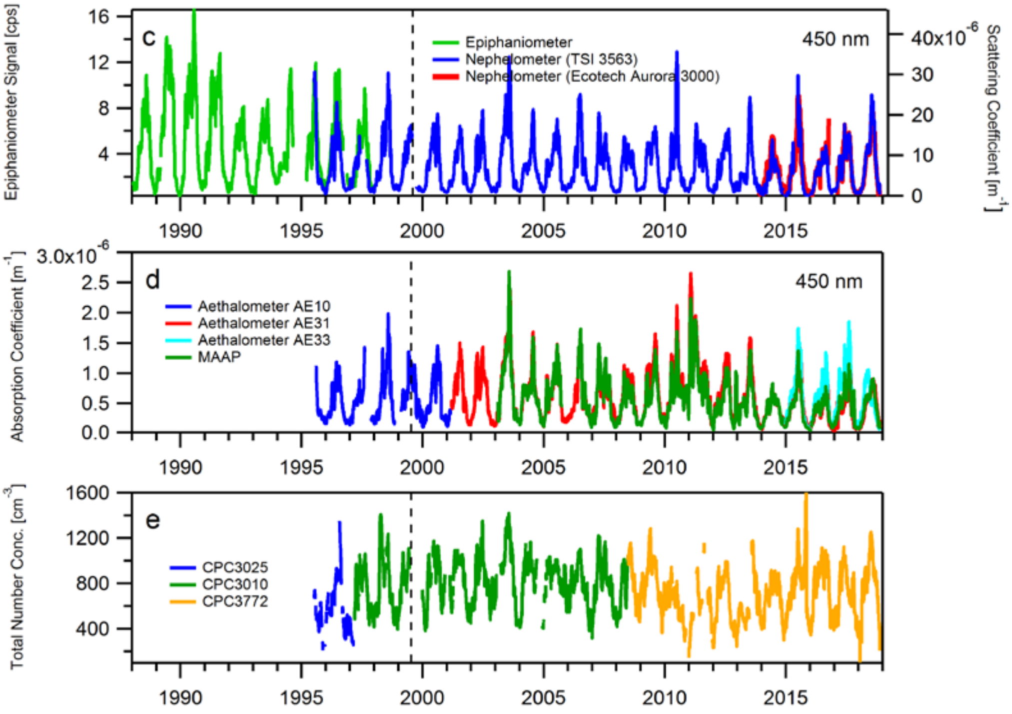

Figure 1 (updated from Bukowiecki et al., 2016). Panels c–e: Temporal evolution of the continuously measured aerosol parameters at the Jungfraujoch (30-day running average of the daily average values). The dashed vertical lines indicate that in January 1998, the entire aerosol laboratory was moved from the old JFJ research station (3454 m asl) to the JFJ Sphinx research station (3580 m asl) and a new inlet was employed.

The topography contribution to the influence of the planetary boundary layer at high altitude stations

High altitude stations are often emphasized as free tropospheric measuring sites but they remain influenced by atmospheric boundary layer (ABL) air masses due to convective transport processes. A topography analysis was then performed allowing calculation of a newly defined index called ABL-TopoIndex (Collaud Coen et al., 2018). The ABL-TopoIndex is constructed in order to correlate with the ABL influence at the high altitude stations and long-term aerosol time series are used to assess its validity. Other important parameters influencing the aerosol load such as the wind, the soil state and the synoptic weather conditions were not taken into account.

Forty-three high altitude stations representative of 5 continents were analysed. The ABL-TopoIndex relies on the criteria that the ABL influence will be low if 1) the station is one of the highest points in the mountainous massif, 2) there is a large altitude difference between the station and the valleys, plateaus or the average domain elevation, 3) the slopes around the station are steep, and 4) the «drainage basin» for air convection is small. These principles are implemented by the calculation of 5 parameters involving the hypsometric curve, the steepness of the slopes around the station and the drainage basin for convection. The geometrical mean of these five parameters is the ABL-TopoIndex and allows ranking of the stations as a function of the ABL influence due to convection.

The first observation is that all stations on volcanic islands (in this study) have very low ABL-TopoIndex (i.e., low BL influence), whereas the stations in the Himalaya and the Tibetan plateau have high ABL-TopoIndex. The highest research stations in the alps have low ABL-TopoIndex, the JFJ being the alpine station with least ABL influence.

Statistically significant correlations between the ABL-TopoIndex and the aerosol parameters measured at 28 high altitude sites allow validation of the methodological approach. The greatest correlations are found with the minima of the aerosol parameters that represent the most likely FT air masses. The maxima of aerosol parameters are more representative of the intensity of aerosol sources and of advection of air masses with high aerosol concentrations. There are also strong anti-correlations between the slope local steepness and the particle number concentration, suggesting that new particle formation could be largely influenced by this topographical parameter. The amplitude of the diurnal cycle of the absorption coefficient is also correlated with the ABL-TopoIndex and is, thus, likely to be representative of ABL influence. The strength of the diurnal cycles of the scattering coefficient and the number concentration are, however, mostly explained by the latitude of the station, leading to the conclusion that the insolation drives the aerosol diurnal cycle.

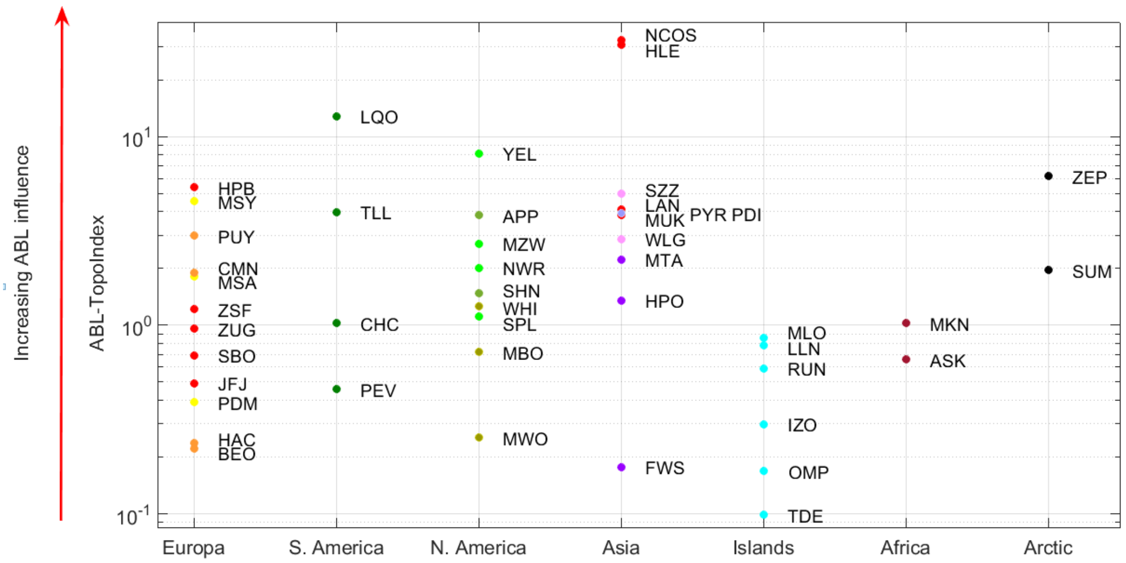

Figure 5. ABL-TopoIndex for all stations as a function of continents and mountainous ranges

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