SYLVA: A SYstem for ReaL-Time ObserVation of Aeroallergens In situ bioaerosol monitoring at high altitudes

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1 Project description

1.1 Background

Pollen allergies and asthma impact an estimated 20–30 % of Europe's population and the number of allergy sufferers has been increasing steadily over the past few decades, with children being particularly vulnerable to this problem (Laatikainen et al. 2011; Rönmark et al. 2009). Currently, allergies impact about 100 million people in Europe only. Pollen allergies pose a substantial burden on Europe's economy with direct and indirect costs related to allergies ranging between €50 and €150 billion annually. Additionally, fungal spores and invasive plant species have a negative impact on agriculture and forestry, leading to crop and forestry losses, and to the increased use of fungicides and pesticides.

The current situation is a major concern for public health authorities and agricultural organizations. In the context of climate change, an even more alarming scenario may emerge: global warming and increased CO_2 emissions significantly impact the lifecycle and geographic distribution of plants, altering pollen seasons. Plants may shift both northward and upward in altitude due to rising temperatures, exposing populations to new allergens or new combinations of allergens that can trigger stronger or new allergies. Warmer temperatures also result in earlier flowering and longer pollen seasons (Ziska et al. 2019). Additionally, certain plants produce more allergenic pollen due to the stress caused by higher CO_2 concentrations, heatwaves and air pollution.

Pollen information provided by European monitoring networks is commonly based on measurements that use a more than 60-year-old manual technology burdened with long delays, which limit the quality of both measured data and forecasts. Given the severity of the current situation and the concerning outlook, there is a clear need for change. Horizon Europe SYLVA project is laying down the foundations of an entirely new Europe-wide pollen and fungal spore monitoring system, which will provide freely available real-time information. These measurements and the accurate forecasts that can be produced using them are crucial for optimizing the diagnosis and treatment of allergies and for planning cost-efficient agricultural activities.

In SYLVA, academic and industrial partners from Finland, Norway, Switzerland, Spain, Italy, Lithuania, Germany, Belgium, and Serbia are working together with meteorological services on testing potential real-time monitoring solutions that include automated microscopy, holographic imaging combined with fluorescence, e-DNA and remote sensing as potential operational solutions. SYLVA is devoted to bringing these technologies to higher technology readiness. One of the main goals of SYLVA is to demonstrate that these technologies are applicable in Europe's harshest environments: hot and arid Southern Europe, extreme cold Northern Europe and high altitudes in the Swiss and Bavarian Alps.

1.2 Objectives

The Jungfraujoch campaign is a cornerstone of the high altitude pilot of the SYLVA project which aims to test, characterize, and optimize the performance of in situ bioaerosol monitoring technologies under high altitude alpine conditions. The major challenges for in situ monitoring technologies at high altitudes are frosting, low temperature, low pressure, the presence of clouds, strong wind, and potentially the stability of internet connection at remote locations. The pilot is aimed at demonstrating that the instruments tested in SYLVA are able to provide continuous and high-quality bioaerosol concentrations under these conditions and therefore can be used in operational pollen monitoring networks. The test is performed for two full years of operation and covers two complete pollen season.

2 Methodology

2.1 The Swisens Poleno Jupiter

The Swisens Poleno Jupiter (Figure 1) is an airflow cytometer: an analytical instrument designed to measure and characterize airborne particles, such as pollen, fungal spores, or dust. It samples particles directly from the ambient air and directs them in an airstream through a sensing region where different

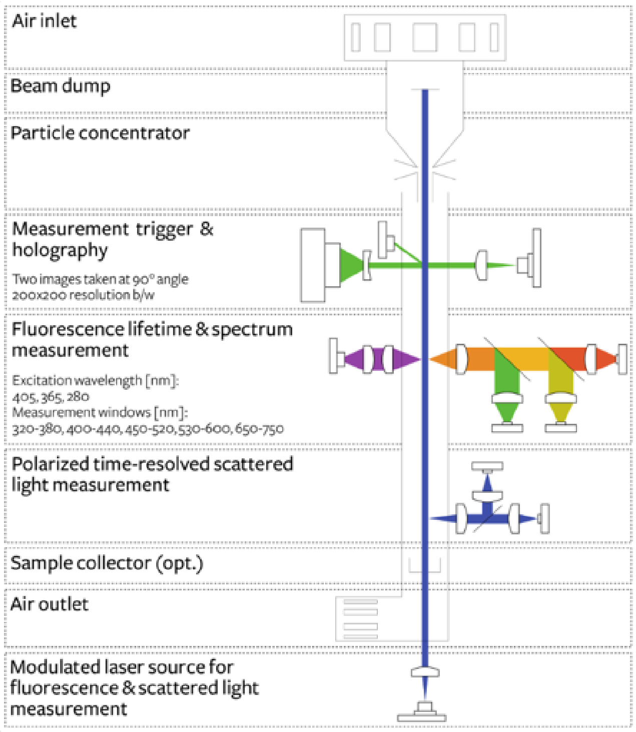

Figure 1: Structural schema of the Swisens Poleno Jupiter (Sauvageat et al. 2020).

measurement technologies are used to detect and identify particles that pass through the instrument in real-time. The measurement methods used by the Poleno are holographic imaging and laser induced fluorescence spectroscopy.

Air is sucked through the sigma-2 inlet at a flow rate of 40 l/min and is driven through a concentrator that allows for monitoring aerosol particles that are present at low concentrations. This step is crucial for bioaerosol monitoring as the concentration of pollen is typically 3–4 orders of magnitude lower than that of other aerosol particles, e.g.: dust. The particle interacts first with a trigger laser that launches a series of measurements. First two holographic images are taken from directions that are orthogonal both to the direction of the airflow and to each other. Then fluorescence spectra are captured in five measurement channels (333–381, 411–459, 465–501, 539–585, and 658–694 nm) after excitation at three different wavelengths (280, 365, and 405 nm). Fluorescence lifetime and light scattering measurements are also performed. Holographic images and fluorescence spectra are then fed to a classification algorithm that provides a predicted particle class for each measurement in real time.

Crucially important points in the operation of the Swisens Poleno at high altitude are: i) ensuring the continuous operation of the sigma-2 inlet by avoiding frosting, ii) evaluating the efficiency of the concentrator at the low atmospheric pressures experienced at high altitudes. The instrument at the pilot site is equipped with a heated inlet that protects the inlet from freezing. The performance of the concentrator was tested before the campaign at pressures expected at the altitude of the monitoring site using computational fluid dynamics simulations (COMSOL), and found to be reasonable therefore

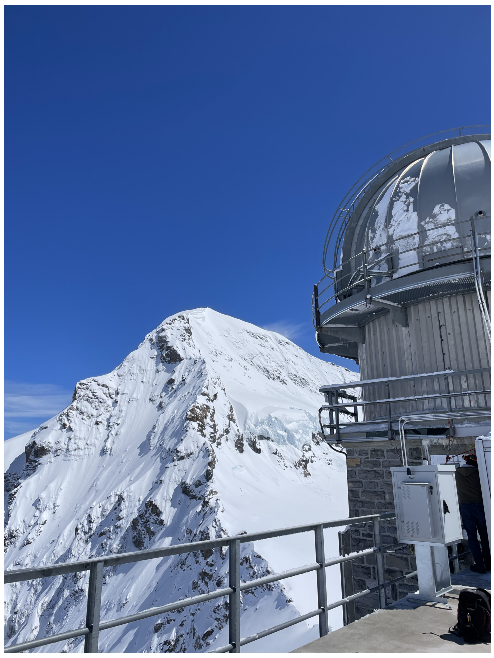

Figure 2: Location of the instrument on the terrace of the Sphinx observatory.

the concentrator has not been modified.

2.2 The monitoring site

The Jungfraujoch high altitude research station has been chosen for this campaign because this site is the highest alpine environmental monitoring station in Europe that is reachable by public transportation all year round. The instrument is placed on the terrace of the Sphinx observatory at an altitude of 3571 m a.s.l. Figure 2 shows the exact location of the instrument on the terrace. An additional advantage of the station is that it hosts multiple research projects in the fields of medical research, air pollution, climate science, and cloud and aerosol science, which can be potential stakeholders interested in the uptake of technologies developed in the scope of the SYLVA project.

Currently there are only three other Swisens Poleno Jupiter instruments installed under similar conditions across Europe. The first is located at the Sonnblick Observatory in Austria (`https://www.sonnblick.net/en/news/vinar-new-measuring-instrument-for-aerosols-at-sbo-185/`). The second one under the management of the Finnish Meteorological Institute at the Pallas supersite in the Finnish Lapland in the framework of the SYLVA project. The third is part of the CleanCloud measurement (`https://projects.au.dk/cleancloud/cleancloud-project`)campaign and is located on Mt. Helmos in Greece.

2.3 The monitoring period

The instrument was installed on the 27.05.2024 and was operating in test mode until mid July, from which point we count the stable monitoring period that was only interrupted

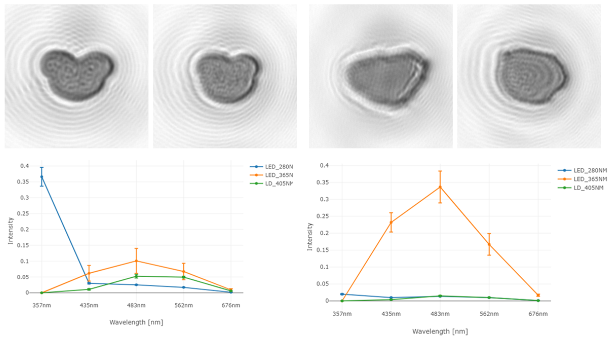

Figure 3: Holographic images and fluorescent spectra of pinus (left) and fagus (right) pollen grains sampled at the Jungfraujoch.

for brief time periods most related to maintenance work or electricity cuts at the station. The campaign will continue in the framework of the SYLVA project at least until the end of 2025. Further continuation and extension of the campaign to monitor other atmospheric aerosol (e.g.: microplastics or dust) is possible as a function of available funding.

3 Results

3.1 The impact of meteorological conditions on the measurements

Temperatures and windspeed data were monitored during the measurement period by MeteoSwiss national monitoring network, SwissMetNet. The daily average temperature was below the limit of extreme low temperature (−15 °C) for 4 days during the campaign (20.11.2024, 22.11.2024, 04.12.2022, 08.12.2024). The lowest daily average temperature was measured on the 22.11.2024 at −22 °C. The absolute minimum daily temperature recorded during the campaign is −24.9 °C, which was recorded on the 22.11.2024. The measurements were not impacted by the extremely low temperatures. The daily average windspeed varied between 5 and 52 km/h and the daily maximum windspeed exceeded 100 km/h for 11 days with the absolute maximum of 198 km/h measured on the 21.11.2024. On this day only 3 events were recorded by the Poleno, likely the flow rate of 40 l/min was too low to overcompensate the lateral airflow due to the strong winds which drastically reduced the sampling efficiency.

3.2 Pollen types identified

During the measurement period the following main pollen types have been identified at the Jungfraujoch: pine, grasses, beech. Examples holographic images and fluorescent spectra of detected events for some of these taxa are shown in Figure 3.

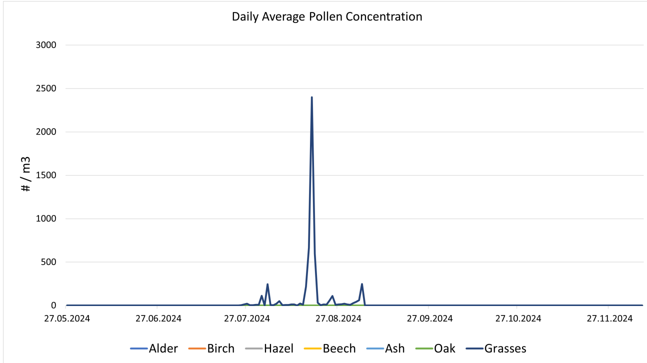

Figure 4: Daily average pollen concentrations.

3.3 Time series of allergenic pollen

Allergenic pollen concentrations were measured continuously from the end of the test period. In Switzerland seven allergenic pollen taxa are monitored operationally: alder, birch, hazel, beech, ash, oak, and grasses. Figure 4 shows daily average pollen concentrations for the above mentioned taxa. Only grass pollen is observed in non-negligible concentrations. The peak in grass pollen appears very close to the end of the grass pollen season (late August-early September) and can partly be due to misclassification with fungal spores or cloud droplets. Manual observation of the day with the maximum concentration of grass pollen supports this hypothesis.

3.4 Beyond bioaerosol: cloud droplets and ice particles

One of the largest concerns for in situ pollen monitoring using the Poleno is the presence of cloud droplets in the air. First off, the number of cloud droplets can be high enough to saturate the data handling pipeline or the instrument's built-in data processing system. Additionally, holographic images of cloud droplets are very similar to those of certain pollen taxa (e.g., grass), which may result in misclassification and severe overestimation of highly allergenic grass pollen particles. The difference between water droplets and grass pollen is that the former have in general very weak or no fluorescent signal. At other sites where cloud and fog droplets can cause problems (Helsinki, Pallas) they are either not saved by the instrument at all or manually removed from the dataset to save storage space. At the Jungfraujoch, water droplets were kept in the dataset, and the storage space of the instrument was augmented by an external hard drive to avoid the problem of saturation. Misclassified water droplets were removed from operational data by manual switching of the pollen season. Data sets containing more than 6000 droplet samples from the Jungfraujoch site were generated from this measurement campaign and used to train a new identification algorithm that relies on both holographic images and fluorescent spectra and helps to overcome the above-mentioned misclassification problem. A publication about the training data sets for the new classifier is in preparation.

Not only cloud droplets but cloud ice particles have also been recorded. A dataset of over 27 000 cloud ice crystals was recorded for instance on the 12.11.2024. The daily average temperature that day was −12.5 °C and the minimum

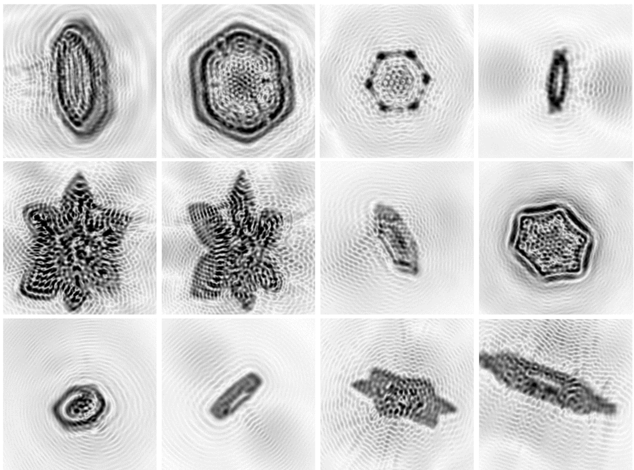

Figure 5: Examples of holographic images of ice crystals observed with the Poleno at the Jungfraujoch.

temperature was −14.1 °C. This temperature range roughly corresponds to the typical immersion freezing temperature on dust particles. Ice crystals were also observed on the 08.11.2024 when the daily average temperature was around −10 °C and minimum temperature was −12.2 °C. At these milder temperatures it is likely that ice crystals were formed on bioaerosol particles. Figure 5 shows examples of holographic images of ice particles. An interesting comparison of bioaerosol, cloud droplets, and ice crystals detected by the Poleno is possible with data obtained from continuous aerosol measurement system operated by PSI and MeteoSwiss at the Jungfraujoch `https://www.psi.ch/fr/lac/projects/gaw-aerosol-monitoring`.

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Internet data bases

SYLVA data portal (data from the campaign will be available from 01.2025). `https://data.sylva.bioaerosol.eu/`.

Collaborating partners / networks

EUMETNET AutoPollen. URL: `https://autopollen.net/`.
Swisens AG. URL: `https://www.swisens.ch/`.

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