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All-optical automatic pollen identification: Towards an operational system

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HIGHLIGHTS

- We present results of a monitoring campaign using an optical pollen detector.
- We propose criteria for the evaluation of automatic pollen monitoring devices.
- The detector is able to discriminate between different pollen taxa.
- We can monitor in real time the total pollen and the grass pollen concentration.
- Due to the high sampling, we obtain statistically significant hourly concentrations.

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ABSTRACT

We present results from the development and validation campaign of an optical pollen monitoring method based on time-resolved scattering and fluorescence. Focus is first set on supervised learning algorithms for pollen-taxa identification and on the determination of aerosol properties (particle size and shape). The identification capability provides a basis for a pre-operational automatic pollen season monitoring performed in parallel to manual reference measurements (Hirst-type volumetric samplers). Airborne concentrations obtained from the automatic system are compatible with those from the manual method regarding total pollen and the automatic device provides real-time data reliably (one week interruption over five months). In addition, although the calibration dataset still needs to be completed, we are able to follow the grass pollen season. The high sampling from the automatic device allows to go beyond the commonly-presented daily values and we obtain statistically significant hourly concentrations. Finally, we discuss remaining challenges for obtaining an operational automatic monitoring system and how the generic validation environment developed for the present campaign could be used for further tests of automatic pollen monitoring devices.

1. Introduction

The explosion of the prevalence of pollinosis over the last decades (Greiner et al., 2012; Wüthrich et al., 1995), which has reached 20% in many developed countries, has led to an intensive research activity and has contributed to the affirmation of aerobiology as an independent discipline. Monitoring airborne pollen concentration is of crucial importance in a context of dramatic anthropogenic changes influencing the airborne pollen quantity, spectrum and quality (Beggs, 2004; Ziska et al., 2011). Particularly important amongst human-driven factors relevant for pollen are climate change, urbanization and pollutant emission (D'Amato et al., 2001, 2007; Ring et al., 2001). Pollen concentrations provided by aerobiological networks are conveyed to various users, with different and sometimes contradictory needs. On one hand phenologists are principally concerned with continuous data series in order to be able to sort out significant trends in the plant annual rhythms, while on the other hand allergologists, pharmaceutical companies and patients principally need timely information on exposure levels. From the point of view of particle-transport numerical modeling, real-time data as input is a crucial factor for running precise simulations (Chamecki et al., 2009), which has led to the use of emission models in the absence of such data (Sofiev et al., 2006; Vogel et al., 2008; Zink et al., 2013; Pauling et al., 2012).

Traditionally, the pollen concentration is determined by Hirst-type volumetric samplers (Hirst, 1952): particles impact on a

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rotating tape and pollen and spores are identified by human operators using optical microscopy. The sturdiness of Hirst-type particle samplers has led to their adoption by various international aerobiological networks and efforts are being made towards standardization (Galán et al., 2014) and quality control (Oteros et al., 2013) in order to ensure continuity and comparability of time series. However, the strong dependence on (typically limited) human resources imposes trade-offs between spatial and temporal resolution. It is unfeasible to read complete tapes for a dense spatial coverage of a territory: the pollen concentration provided by aerobiological networks is thus usually not statistically significant below a daily time resolution, although bi-hourly values are sometimes presented (Comtois et al., 1999). Note that we do not refer here to the identification error, which is typically small as confirmed by so-called ring tests (Galán et al., 2014; Cotos-Yáñez et al., 2013). Coverage is also limited to a very small number of representative regions within countries. In addition, the tapes are usually changed for analysis once a week, leading to a delay between particle collection and diffusion of the information.

Motivated by users' demand for real-time pollen data, automatic monitoring systems have been tested over the last few years. The variety of systems reflects the compromises that need to be made with regards to an ideal automatic system. In this paper we propose the following four criteria for the evaluation of an automatic pollen monitoring device. The ability to *function reliably (1)* with minimal human intervention comes probably first. *Identifying (2)* and *counting (3)* different bioaerosols are two related but not equivalent tasks critical for evaluating a system. Together with counting come questions on the statistical significance of the sampling and its isokineticity. Finally, the ability for a system to *identify and count other aerosols than pollen (4)* could be critical in justifying investments for an automatic network: costs could be shared between different aerosol monitoring networks.

Amongst the proposed candidates which have approached or reached operational level, one can roughly distinguish between devices based on automatic image recognition such as the Hund BAA500 (Oteros et al., 2015) and systems based on air-flow cytometry such as the Yamatronics KH-3000 (Kawashima et al., 2007) or the WIBS sensor (for a recent study performed with the WIBS, see for example Perring et al. (2015)). In order to distinguish biological particles from other aerosols, optical detectors typically make use of the fluorescence of bioparticles (O'Connor et al., 2011). The different systems score differently well regarding the four criteria introduced above. Unsurprisingly, simplicity is often associated with high reliability and good sampling but modest identification capabilities.

In this paper, we focus on an air-flow cytometer, the Plair PA-300 (Kiselev et al., 2011, 2013), currently in validation phase at the Federal Office of Meteorology and Climatology MeteoSwiss (denoted "MeteoSwiss" hereafter). We present the results of the 2015 calibration and validation campaign at the light of the criteria from the list proposed above. The capabilities of the Plair PA-300 for measurements on aerosols within the range $10 - 100$ μm were tested, although the device could have a potential for the detection of spores, particulate matter and bacteria. The principal task of the present campaign was to link light scattering and fluorescence data with the morphology and composition of pollen grains. Accordingly, with reference to the criteria introduced earlier, we focused on the *identification* of pollen types in order to prepare the following monitoring campaign and approach operational level. The results, allowed to go beyond the mere identification task and we could already follow to a good extent the pollen season of individual pollen taxa.

2. Material and methods

2.1. Study site

Calibrations and season monitoring were performed on the roof of the MeteoSwiss two-storey building (building height 7 m, ground altitude 490 m and WGS84 coordinates 46°48′48″ N, 6°56′35″ E), located in a rural environment close to Payerne, Switzerland (Fig. 1). The presence of two volumetric Hirst-type pollen traps operating in parallel on the site provided a reference for evaluating the results of the automatic device. One detector was used for reference and the other as backup in case of missing data. The choice of Payerne for running the campaign was motivated by the fact that various pollen types can be measured in Payerne and the combinations of pollens observed are typical for what can be found on the Swiss Plateau, by far the most populated region of Switzerland (home of over two-thirds of the Swiss population). These factors make Payerne a good site for testing and developing new devices.

2.2. Description of the optical device

We used the first unit of the commercially-available PA-300 detector produced by Plair SA in Geneva (see Fig. 2). Although we recall here some general features of the device, a comprehensive technical description can be found elsewhere (Kiselev et al., 2011, 2013). Particles first pass through a red laser beam (658 nm) and time-resolved scattering data is recorded by two photo-detectors. The scattering signal helps to characterize the optical size, the shape and the surface properties of the particles. A second laser beam in the UV range (337 nm) excites the particles and the wavelength-resolved fluorescence signal is recorded using diffraction grating and an array of 32 photo-detectors (32 equal bins with overall range 390–600 nm). In addition, the phosphorescence (long-time response) is recorded by the two photo-detectors used for the scattering signal and the short-time response by an ultrafast photo-detector. For a summary on the time resolution and the wavelength detection range of the different detectors, see Table 1.

2.3. Description of the inlet system

Air was pumped into the detector at a flow rate of 2 l/min. In order to increase aerosol sampling, a concentrator based on virtual impactor principle was used with the instrument. The concentrator was provided by Plair SA as an option to the PA-300. The major air outlet of the concentrator was connected to the second pump (flow rate 30 l/min) and the minor outlet to the device. Finally, a Sigma-2 inlet (Verein Deutscher Ingenieure, 2013) was put on top of the concentrator for particle sampling and protection of the detector from the rain (see panels A and C of Fig. 1).

2.4. Manual reference counts

As reference for the automatic counts, we used the current standard method in aerobiological networks (Galán et al., 2014; Hirst, 1952). Hirst-type volumetric samplers (we used a detector from Burkard Scientific Ltd.) collect airborne particles on a rotating drum (efficient impaction for particle size larger than 5 μm). Counting of pollen grains was performed at MeteoSwiss using the same procedure as for the operational monitoring of the pollen season (optical microscope Olympus BX45 magnification 600x). Results are summarized in tables with average daily concentration of 47 pollen types plus one category for unidentified pollen. As for operational pollen measurements, counting all the grains present on the tape was not feasible due to the duration of the pollen