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MicroPoem: Experimental investigation of birch pollen emissions

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Abstract

A new generation of pollen forecast models, relying on transport models, is currently being developed in various European countries. They may range from fully dynamical dispersion modelling embedded in a numerical weather prediction (NWP) model to statistical/NWP combinations - in order to provide full spatial coverage of pollen forecasts. The most important flaw in these pollen dispersion systems is the modeling of the emissions. This is largely due to the missing knowledge in the physical and biological processes that determine the emission. It is apparent, however, that biological processes, i.e., maturation of the pollen and preparedness to release are governed by atmospheric conditions such as temperature, radiation and humidity. Then the release itself occurs by means of turbulent mixing and/or wind transport. What remains unknown is the dependence of the emission rate on physical processes such as turbulence intensity or wind speed and other meteorological elements. The quantification of the pollen emission and determination of the governing synoptic and micrometeorological factors is subject of the project MicroPoem including experimental field as well as modeling work. The goal is to derive an emission parameterization based on meteorological parameters.
Experimental data have been collected in a large field campaign, which has been conducted in Illarsaz, Switzerland in April 2009. The set-up was designed to derive the emission from the observed downwind concentrations of a well-defined pollen source. In order to have a well-defined source, an isolated group of birch trees has been chosen. The site was located in a valley where the wind blew with persistent wind directions and considerable velocities during day- and nighttime. Pollen concentrations and meteorological factors have been measured at locations upwind and downwind of the birch trees in a high spatial and temporal resolution. Key features of the set-up were the horizontal as well as vertical profile measurements of pollen concentrations and meteorological conditions.
Micrometeorological analyses focus on reproducing the observed downwind pollen distribution by using a local dispersion model. The micrometeorological observations will thereby yield the necessary input on turbulence characteristics. The new emission parameters will be tested by applying them to an operational pollen dispersion model.

Keywords: Emission parameterization, pollen dispersion, Lagrangian dispersion modeling, transport modeling

1 Introduction

Diseases due to aeroallergens increased over the last decades and affect more and more people. The overall prevalence of seasonal allergic rhinitis in Europe is about 15 precent and increasing. Adequate protective and pre-emptive measures require both the reliable assessment of production and release of various pollen species, and the forecasting of their atmospheric dispersion. A new generation of pollen forecast models, which may be either based on statistical knowledge or full physical transport and dispersion modeling, can provide pollen forecasts with full spatial coverage (Ambelas Skjøth et al., 2006; Helbig et al., 2004; Schueler and Schlünzen, 2006; Sofiev et al., 2006a,b). Such models are currently being developed in many European countries. Basically, the central part of these recent pollen forecast models corresponds to traditional air pollution transport and dispersion models (Venkatram and Wyyngaard, 1988). The main difference between traditional air pollutants and pollen consists of the fact that the latter are heavy and thus subject to gravitational forces. The most important shortcoming in these pollen dispersion systems is the description of the emissions. This is largely due to the missing knowledge in the physical and biological processes that determine emissions, namely the dependence of the emission rate on physical processes such as turbulent exchange or mean transport and biological processes such as ripening and preparedness for release. Thus the quantification of the pollen emission and determination of the governing synoptic and micrometeorological factors are subject of the present project *MicroPoem*, which includes experimental field work as well as numerical modeling. The overall goal of the project is to derive an emission parameterization based on meteorological parameters, eventually leading to enhanced pollen forecast models.

Within the COST Action ES0603 (*EUPOL*), which is dedicated to the assessment of production, release distribution and health impact of allergenic pollen in Europe, one working group focuses on pollen production and release and their quantitative description. It includes analysis of observational and modeling information for revealing key characteristcs of these processes. From this framework the project *MicroPoem* emerged as a collaboration of the Federal Office of Meteorology and Climatology MeteoSwiss and the Institute of Meteorology, Climatology and Remote Sensing at the University of Basel, Switzerland.

The overall goal of the current research is investigating pollen production and emission by combining experimental and modeling work in order to quantify the released pollen as function of meteorological parameters. As an example, birch trees are used because their pollen are among the most important allergens in Europe. Micrometeorological analyses focus on reproducing the observed downwind pollen distribution by using a local dispersion model. The micrometeorological observations will thereby yield the necessary input of turbulence characteristics. The goal is to derive an emission parameterization based on meteorological variables. The new emission parameters will be tested by applying them in an operational pollen dispersion model.

1.1 State of research

Several studies on the impact of meteorological factors on pollen concentration, emission and dispersion have been published, of which some included modeling and/or experimental work. In the context of diseases due to aeroallergens in Europe Nieddu et al. (1997) investigated the intensity and timing of olive pollination in relation to phenological stages and the influence of meteorological parameters on pollen emission and dispersal. They found a significant positive correlation between pollen concentrations and hourly air temperature and a negative correlation between pollen concentrations and air humidity. These findings were confirmed by Méndez et al. (2005), who measured airborne birch pollen and several meteorological parameters between 1992 and 2000. A positive correlation between pollen count and both temperature and shortwave downward radiation and a negative correlation for relative humidity were observed. They conclude that air temperature is the determining factor for flowering onset and intensity. A predictive model for the calculation of the total annual airborne olive pollen output on the basis of a set of meteorological and pollen data is described by Galán et al. (2001). The results indicated an agreement of less than 10 % between modeled and observed data.

In the last decade in particular the extensive adoption of genetically modified crops has led to the need to better understand the pollen dispersion in the atmosphere because of the

potential for unwanted movement of genetic characteristics via pollen transport. Lavigne et al. (1998) performed a pollen-dispersal experiment in the framework of the assessment of gene flow associated with the release of transgenic oilseed rape (Lavigne et al., 1996). Brunet et al. (2004) investigated the presence of viable maize pollen within the Boundary Layer as an evidence for long-range transport. At all heights pollen concentrations of the order of concentrations near the ground were observed. They also found that maize pollen seem to behave like a gas or small particles, since their settling velocity is small compared to the vertical velocities found in the Convective Boundary Layer. Aylor et al. (2006) and Boehm et al. (2008) assessed the agreement between horizontal and vertical profile measurements of maize pollen concentrations and the results of a Lagrangian stochastic model. Chamecki et al. (2009) validated Large Eddy Simulations of pollen dispersal with experimental data of pollen emission and downwind deposition. They conclude that the main parameter governing the shape of the dispersion is the turbulent transport and the ratio between settling of the pollen due to the gravitational effect.
In the field of agroecology several experiments and modeling works on the concentration and aerial transport of fungal species causing foliar disease have been performed at the Computational Epidemiology and Aerobiology Laboratory (CEAL) at Pennsylvania State University (Isard et al., 2007; Magarey and Isard, 2005).
In terms of investigating plant reproduction and dispersion Raynor et al. (1970) performed a study on the correlation of meteorological factors to the dispersion and deposition of ragweed pollen released both naturally and artificially. They conclude that the variation of pollen dispersion and deposition rates is regulated not only by meteorological but both biological and meteorological factors. Van Hout et al. (2008) performed field experiments including vertical profile measurements to study the diurnal cycle of corn pollen immission and its relation to meteorological and micrometeorological conditions. They found a strong decrease of pollen concentrations with increasing height. The diurnal cycles of pollen concentrations were characterized as uni-modal or bi-modal with peak values during the morning and decreasing values during the afternoon. They conclude that humidity and solar radiation may be important variables that govern the release of pollen. They also found a correlation of high pollen concentration periods to ejection periods in coherent structures within the Canopy Boundary Layer. The behavior of different airborne pollen concentrations at different heights in relation to meteorological factors was studied by Comtois et al. (2000). They found evidence for a layer of pollen transport at about 500 m above the ground with pollen concentrations higher by 30 % compared to ground level.

Concerning its goal and set-up, the experiment presented here is unique and ambitious. The obtained meteorological and micrometeorological data allow to describe the characteristics of the local-scale conditions around the pollen source. The pollen counts, however, indicate a significant variability due to several errors incorporated in pollen sampling methods. The calibration of pollen counts, therefore, is necessary prior to the assessment of the influence of meteorological and micrometeorological factors on pollen concentrations.

2 Experiment site

Experimental data have been collected in a large field campaign, which has been conducted in Illarsaz, Switzerland in April 2009. The start of the measurements was determined by applying a time of flowering prediction model based on growing degree days (GDD). The set-up was designed to derive the emission from the observed downwind concentrations of a well-defined pollen source. Pollen concentrations and meteorological factors have been measured at locations upwind and downwind of a pollen source at a high spatial and temporal resolution. Key features of the set-up were the horizontal as well as vertical profile measurements of pollen concentrations and (micro-)meteorological conditions. In order to have a well-defined source location, an isolated group of birch trees has been chosen, which

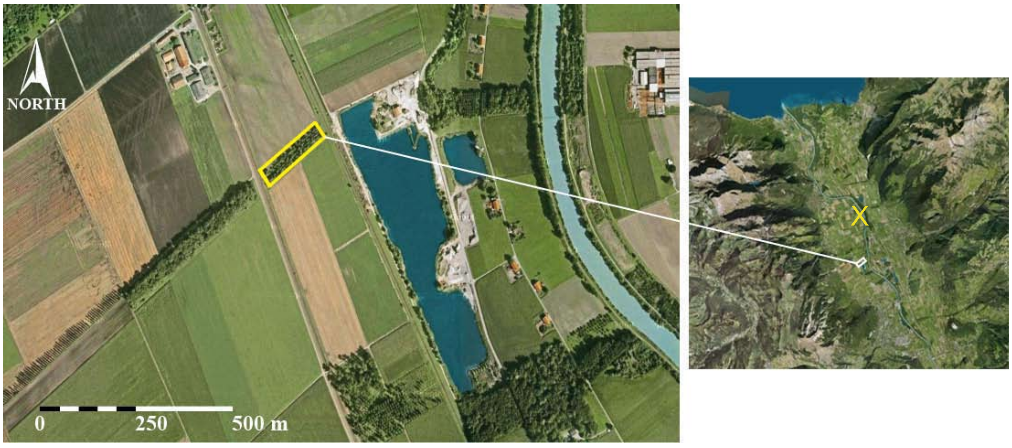


Figure 2.1: Satellite image of the experiment location at Illarsaz (Valais), Switzerland. The source location is indicated with the yellow (left) and white (right) rectangle. The image on the right shows the exposition of the valley and the terrain. The yellow cross denotes the location of the SwissMetNet station. The image was taken March 5 , 1997.

was located in a valley floor. This condition allowed to presume a rather persistent wind direction and considerable velocity during day- and nighttime. The measurements provided a dataset covering twenty days with a large array of variables. These included both continuous and discontinuous pollen concentration measurements, as well as continuous meteorological information.
The pollen source (Fig. 3.1) consists of two different birch species, *Betula pubescens* (larger fraction) and *Betula pendula*, of which both were considered equally in the experiment. The birch trees were all of 17-22 m height. It consists of approximately 140 birch trees and around 50 individuals of various species, such as spruce, scots pine, ash and oak. The crop is approximately 200 m wide in the cross-wind direction and 40 m in the longitudinal direction. The source is, therefore, considered a line-source rather than a point-source. This instance lead to a number of consequences on the part of the assumed dispersion pattern and hence the set-up. The below-average number of catkins carried by individuals in this birch plot suggests that the vitality of the birch trees is mediocre. The largest part of the catkins was carried in the treetops or at least in the upper half of the trees. Thus, on the one hand a potentially below-average absolute pollen emission was expected, and on the other hand the duration of the emission period was presumed to be shorter than typical, i.e. less than four weeks (Gehrig pers. comm.). The emission potential of the source will be estimated on the basis of manual countings of the catkins, which will yield an approximate guidance level for the modeled emission. The understorey of the plantation mostly consists of grass of 0.3 to 0.5 m height.

3 Materials and methods

The set-up basically consisted of vertical and horizontal profile measurements. The vertical profiles have been aligned in the longitudinal direction of the valley and provided pollen concentration as well as turbulence data. An array of horizontally aligned traps measured pollen concentration profiles in the longitudinal and the cross-wind direction. The arrangement of the instruments, most important the longitudinal distance from the source, has been determined by applying a Lagrangian particle dispersion model (Rotach et al., 1996; De Haan and Rotach, 1998), using a set of probable input parameters. The model results should ensure that the peak of downwind pollen concentrations lies within the range covered

Figure 3.1: Picture of the profile tower 100 m south of the main pollen source (visible in the background).

Table 3.1: Tower instrumentation.

instrument	height a.g.	resolution	instrument	height a.g.	resolution
T_1			T_2		
CSAT3	1.8 m	20 Hz	CSAT3	1.9 m	20 Hz
CSAT3	8.9 m	20 Hz	CSAT3	4.4 m	20 Hz
CSAT3	17.8 m	20 Hz	CSAT3	9.0 m	20 Hz
Burkard	2 m	2 h	CSAT3	13.5 m	20 Hz
Burkard	18 m	2 h	CSAT3	18.0 m	20 Hz
T_3			Burkard Sc.	2 m	1/2 h
CSAT3	2.0 m	10/20 Hz	Burkard Sc	18 m	1/2 h
CSAT3	9.0 m	10/20 Hz	Psychr. I	2 m	1 min
CSAT3	18.0 m	10/20 Hz	Psychr. II	6 m	1 min
Burkard	2 m	2 h			
Burkard	18 m	2 h			

by the instrumental array and not beyond it even at higher wind velocities.

3.1 Profile measurements of micrometeorological parameters and pollen concentrations

The vertical atmospheric profile was monitored at three towers of 18 m height each, which corresponds approximately to the average canopy height of the pollen source (Fig. 3.2) and the lower part of the Roughness Sublayer. They were located 30 m north (T_1), 100 m south (T_2) and 350 m south (T_3) of the main pollen source and their instrumentation was the same in principle. They were equipped with CSAT3 ultrasonic anemometers (Campbell Scientific Ltd.) and a Burkard pollen sampler on top (for the individiual instrument mounting height see Table 3.1). The mounting of the Burkard sampler at this height above the ground was an outstanding feature of this campaign, since profile measurements using this sampling method are unique to date. Next to each tower a Burkard pollen sampler was set up at 2 m above the ground. CR1000 data loggers (Campbell Scientific Ltd.) were used at the towers T_1 and T_3 and a CR3000 (Campbell Scientific Ltd.) at T_2. T_1 was equipped with three ultrasonic anemometers and measured the diurnal background birch pollen concentration and upwind turbulence. These measurements were crucial because of the considerable number of birch trees in the surrounding area, and because they served as reference. South of the main pollen source T_2 and T_3 measured the diurnal downwind concentration and turbulence. T_2 was equipped with five ultrasonic anemometers and a Burkard Sc. (Fig. 3.1). The higher vertical resolution of turbulence makes it the principal station for diurnal turbulence characteristics downwind of the source. T_3 was equipped in the same way as T_1. The temporal resolution of the ultrasonic anemometers was 20 Hz for turbulence measurements during most of the experimental period and 30 minutes for the calculated fluxes. The Burkard samplers allow a maximum temporal resolution of one hour, which implies a rela-

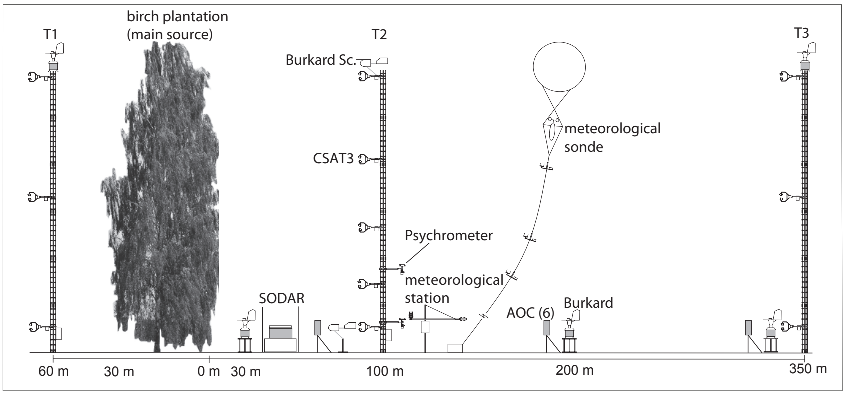


Figure 3.2: Longitudinal section of the experimental set-up. The indexed T's denote the profile tower number mentioned in the text.

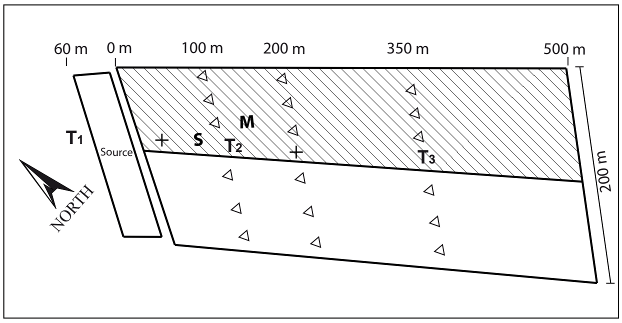


Figure 3.3: Top view of the experimental set-up. The hatched area denotes the pasture crop, the large plain denotes the potato crop covered with acryl sheets. The indexed T's denote the location of the profile towers, the plus signs denote singular Burkard samplers on the ground, S denotes the location of the SODAR, M denotes the location of the meteorological station and the triangles denote AOCs.

tively high uncertainty in the results. Thus, the applied temporal resolution used was two hours, which is more accurate. The two Burkard Sc. samplers used at T_2 allow an accurate resolution of one hour or two hours depending on the operation mode (Section 3.3).
The horizontal pollen concentration profile was monitored with an array of 18 Air-O-Cell (AOC) traps (Zefon International) mounted at 2 m above the ground. The grid-based set-up of pollen samplers is a further feature of the campaign, since it leads to a unique data set of spatially highly resolved ground pollen concentrations. The array consisted of three cross-wind aligned rows with six AOCs each (Fig. 3.3). Rather than a arcwise set-up, which one would choose for a point source, this rectangular alignement has been chosen. In a first approach it was assumed that the emission and transport of the pollen concentration is more or less homogeneous in the lateral direction. The distance between the AOCs in the lateral direction was 30 to 44 m in every column. The cross-wind width of the AOC array approximately corresponded to the width of the main pollen source only, since the terrain did not allow for extension in the lateral direction.

Another important feature of the campaign is the pollen profile measurement conducted during the IOPs using a tethered balloon. Rotorod pollen samplers were mounted on the balloon tether in order to reach the measuring heights of 25, 100 and 290 m, respectively, above the ground, when the balloon itself ascended to a maximal height of 300 m. Yet the actual measurement height depended on the decline of the tether. Hence, the heights were smaller during strong wind periods. The real height above the ground was estimated via the

Table 3.2: Pollen samplers and meteorological instruments.

instrument	height a.g.	temp. resoultion
pollen sampler		
AOC (18)	2 m	1 h
Rotorod	25 m	1 h
Rotorod	100 m	1 h
Rotorod	290 m	1 h
meteorol. station		
WXT	2 m	1 min
CNR1	2 m	1 min
CS107 (3)	-0.02 m	1 min
HF3 (3)	-0.04 m	1 min

measured air pressure gradient between the balloon height and the meteorological station.

3.2 Meteorological measurements

Meteorological data, such as long- and shortwave irradiance, wind direction and velocity, soil temperature, soil heat flux and precipitation have been measured continuously at a separate small tower within the area south of the main pollen source near the profile tower T_2. For the net radiation components a CNR1 net radiometer (Kipp & Zonen) was used without ventilation and heating and operated in the Four Separate Components Mode. Wind direction and velocity, humidity, temperature and pressure as well as precipitation and intensity were measured with a WXT510 weather transmitter (Vaisala Ltd). The soil temperature and the soil heat flux were measured using three CS107 probes (Campbell Scientific Ltd.) and three HF3 heat flux plates (McVan Instruments Inc.), respectively. A CR5000 data logger (Campbell Scientific Ltd.) was used at this station. Two psychrometers were mounted in two different heights (2 and 6 m) on the profile tower, providing air temperature and humidity profiles.
Fifty-eight meters south of the main pollen source a FAS Series SODAR (Scintec AG) was measuring the vertical wind profile (direction and velocity) of the lowest 600 m of the Planetary Boundary Layer. Additionally, a tethered balloon sonde provided vertical profile information on dry and wet temperature, air pressure, wind direction and velocity during the IOPs. For a list of the used instruments see Tables 3.1 and 3.2.

3.3 Pollen sampling methods

The Hirst-type pollen traps (Hirst, 1952) used in this experiment are volumetric Burkard samplers (Burkard Scientific Ltd.) (Mandrioli et al., 1998). The Burkard sampler (Fig. 3.4) is widely used and often serves as the standard pollen sampling method. Through a horizontally aligned horizontal slot orifice facing the wind, an electric air pump draws air past a cylinder,which is rotating on a horizontal axis. An air flow rate of 10 l/min is required to enable sampling a large spectrum of pollen species, i.e. from small to larger particle sizes. Due to inertia, air suspended particles accelerated by the suction collide with a silicone-coated synthetic strip attached to the cylinder instead of following the air flow through the device (impaction filter). The rotation rate of the cylinder is typically one rotation per seven days and determines the temporal sampling resolution. The Burkard Scientific pollen trap (Burkard Sc.) features an electronic control which allows adjustment of the temporal resolution by changing the rotation rate of the sampling cylinder. The control modes used in the experiment are seven days and 24 hours.
Samples of the pollen load are counted manually using a microscope. The total number is then extrapolated to represent the pollen number on the entire slide. The concentration is

determined from the pollen counts and the air volume that had passed through the orifice. The statistical significance of the count depends on the size of the microscope field (i.e. the visible slide area, dependent on the microscope magnification), the number of microscope fields, the applied analysis method (horizontal or vertical lines or random cells) and the number of pollen (see Comtois et al. (1999)).

Figure 3.4: Burkard pollen sampler mounted on the towertop north of the pollen source.

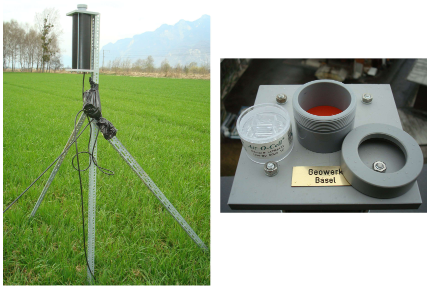


Figure 3.5: Mounting of the AOC pump (left) and AOC cassette and its fixture in the pump (right).

The AOC volumetric pollen traps (Levetin (2004), Fig. 3.5)is a plastic cassette containing a silicone-coated slide below a rectangular orifice which narrows to a slot similar to the Burkard slot. Continuous measurement can only be performed by exchanging the cassettes at the required intervals. In opposition to the counting procedure of the Burkard traps, the statistical significance of the pollen count is higher, since one slide corresponds exactly to one measuring interval and the entire slide is analyzed.
A different sampling method was applied using Rotorod Model 20 samplers (Sampling Technologies Inc.) (Mandrioli et al., 1998) attached to the tethered balloon for vertical profile measurements of pollen concentration. Basically, this pollen sampler consists of a electric motor which rotates two vertical four-sided rods. The particular side facing the clockwise rotating direction is coated with silicone. Hence, pollen are trapped as the rods move through the air. From the rectangular area moving ahead and the cyclic distance covered in a certain amount of time, a volume can be determined which corresponds to the sampling volume. The sampling period was one hour to match the temporal resoultion of the other pollen sampling devices used in the experiment.

4 Plausibility and characteristics of meteorological data

The wind conditions during the experiment, i.e. the wind direction and velocity, are of special interest, because the experimental design required specific conditions, as mentioned earlier. In addition to the wind measurements using ultrasonic anemometers (see Section 3.2) the data of the SMN station at Aigle are presented. The SMN sation is located centrally in the Rhone Valley 3.11 km north of the experimental site (Fig. 2.1). The surrounding area in the centre of the Rhone valley is free of obstacles and, therefore, undisturbed. The station thus represents the synoptic meteorological conditions of the northern valley region. The horizontal wind vectors were measured using a rotating propeller anemometer at 10 m above the ground. The spatially separated measurements give an indication of the difference between regional and local conditions at the experiment site.

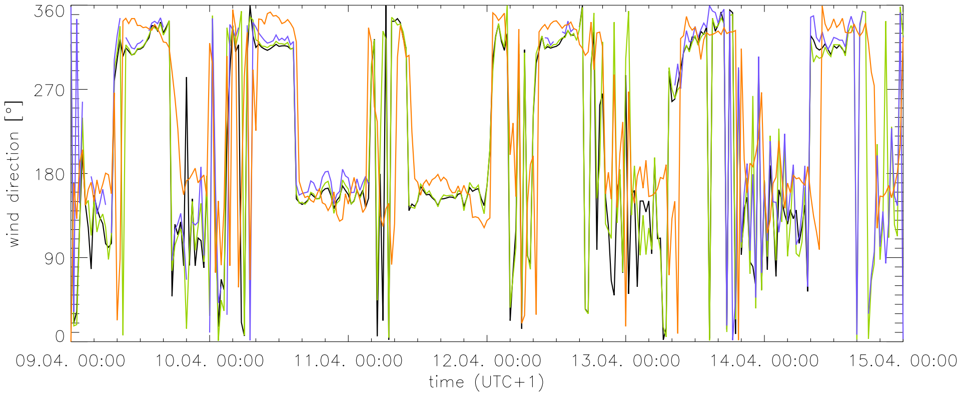


Figure 4.1: Intercomparison of 30 min averaged wind direction measured with a CSAT3 30 m north (black), 100 m south (green) and 350 m south (blue) of the pollen source at 9 m above the ground and at the SMN station in Aigle (orange) at 10 m above the ground.

4.1 Wind direction

Figure 4.1 presents the wind directions measured during six days covering all five IOPs at the three towers at 9 m and at the SMN station at 10 m above the ground. The wind direction measured at the SMN station (orange line) is compared to the experimental measurements 30 m north (black line), 100 m south (green line) and 350 m south (blue line) of the birch plantation. Note that from April 11 to 13 the data of the latter are missing. The figure indicates the existence of a mountain-plains wind system with alternating wind directions in a diurnal cycle. During the periods from approximately 10:00 to 16:00 a clear upvalley wind prevailed, when all sensors measured wind directions between 300 and 360 degrees. The phases between the upvalley wind periods were characterised by strong fluctuations of wind direction, which were also detected by all sensors. Note that the nighttime wind velocities at the experimental site, which will be discussed later, are significantly smaller than during daytime and therefore wind direction measurements are not as robust as during daytime. Yet the nighttime conditions can generally be identified as downvalley winds. The transition phase between up- and downvalley wind is not very distinct in the case of the sonic measurements.

4.2 Wind velocity

Figure 4.2 shows the 30 minutes averaged wind velocities corresponding to Fig. 4.1. The mountain-plains system cycles are represented by subsequent periods of alternately higher and lower average levels of wind velocities, whereas the higher levels correspond to the upvalley wind and the lower levels to the downvalley winds. There is a clear diurnal pattern of the wind velocity during the displayed period. On April 10 and 11, however, higher velocities were measured. These occurrences denote an observed south foehn with significantly increased wind velocities.

The difference between the locations is significantly larger than in te case of wind direction, because the roughness elements at the experimental site have a greater impact on wind velocity than on averaged direction. Only the day- and nighttime upwind fetches of the SMN station are free of obstacles. Hence, the highest wind velocities were generally reached at the SMN station (orange line) with daily maximum values between 5 and 5.5 m s^{-1} during the first three, and approximately 6.5 m s^{-1} during the last day of the displayed period. The nighttime maxima reached 2 to 3 m s^{-1} and were also higher than at the other locations. Among the tower measurements at 9 m height, the station 30 m upwind (black line) and 350 m downwind (blue line) of the birch plantation generally measured the highest wind ve-

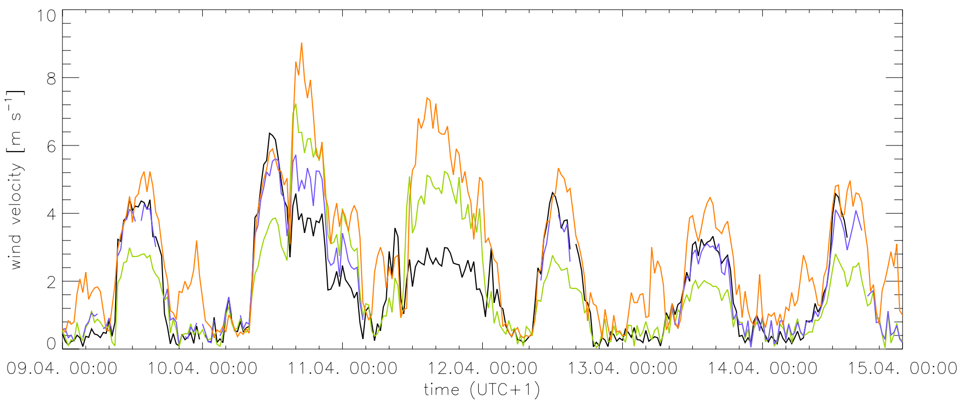


Figure 4.2: Intercomparison of 30 min averaged wind velocity measured with a CSAT3 30 m north (black), 100 m south (green) and 350 m south (blue) of the pollen source at 9 m above the ground and at the SMN station in Aigle (orange) at 10 m above the ground.

locities. The daily maxima reached however less than the SMN station, i.e. around 4 on the first three, and 5.5 m s^{-1} on the last day of the plotted period. During the night the sonic measurements agreed well to each other, yet with rather low wind velocities of less than 1 m s^{-1}. Comparing the wind velocities measured at the SMN station and the experimental site indicates that the downvalley wind is approximately half as strong than above rough terrain as above undisturbed terrain. The large and numerous roughness elements found in the upwind region effect a large decrease in wind velocity at all experimental stations.

An overview of the dicussed wind conditions valid for the IOPs is presented in Fig. 4.3 and 4.4. They display the temporal pattern of wind direction and velocity during all IOPs on a diurnal basis for the SMN station (green rectangles) and 100 m south of the birch plantation (blue triangles). Both figures show that the daytime upvalley wind was very distinct during the IOPs. This indicates that the arrangement of AOCs and Rotorods south of the birch stand was in the right place to cover the essential parts of the expected pollen plume.
The correlation of low wind velocity to fluctuation of wind direction, which was mentioned earlier for the measurements at the experimental site, is shown more clearly in Fig. 4.3 and 4.4. The wind direction measured at the SMN station when the velocity was generally higher, is quite persistent compared to the dispersed values at the experimental site, when the velocity was very low. The single branch of wind directions around 180 degrees in Fig. 4.3, which occurred between 15:00 to 22:00 and is seen at both stations consists of subsequent 30 min values during the second IOP on April 10, and denotes the foehn event mentioned earlier. The values of the same period shown in Fig. 4.4 confirm this statement with wind velocities twice as high as the temporal corresponding average level of velocity on the other days.
The wind direction also shows that the upvalley wind was generally developed earlier at the experimental site than at the SMN station.

4.3 Turbulence intensity

The sonic standard deviation of the vertical velocity component σ_w as a measure of turbulence intensity, normalized to the mean wind velocity $\overline{u}$ yields a dimensionless parameter for turbulence intensity. In Fig. 4.5 it is plotted against $\overline{u}$. The situations at the three towers at 2 m and 18 m height are compared for the periods from 10:00 to 18:00, when upvalley winds prevailed. It is shown that the turbulence intensity was mostly less than 0.5 and exhibits an asymptotic course when plotted against the mean velocity. In the case of 4.5a the turbulence intensity was strongest when the wind velocity was less than 2.5 m

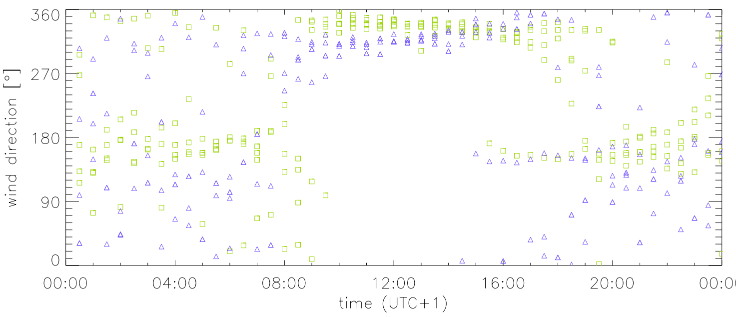


Figure 4.3: Diurnal cycles of wind direction measured at 100 m south of the source at 9 m above the ground (blue triangles) and at the SMN station at 10 m above the ground (green rectangles) during IOPs. 30 min averages are overplotted on a diurnal basis.

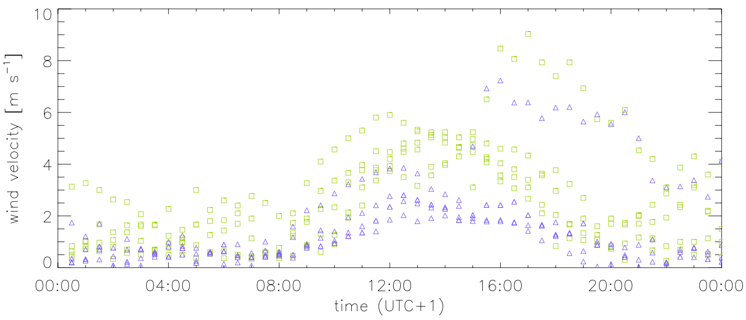
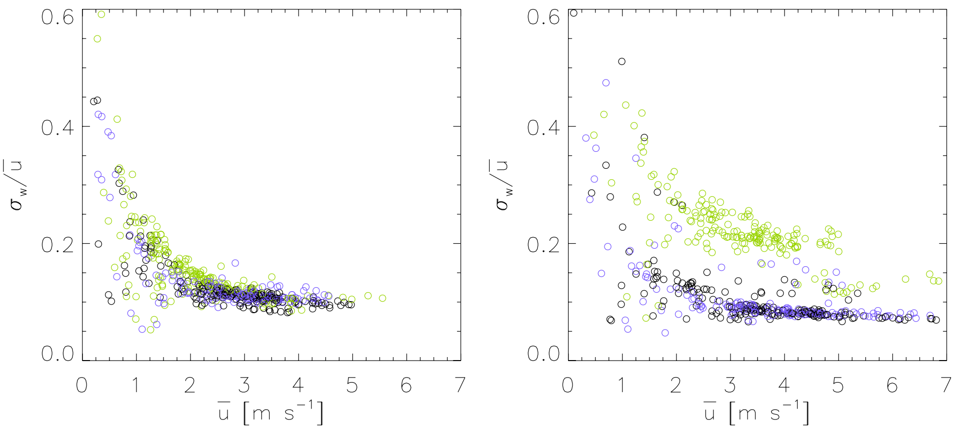


Figure 4.4: Diurnal cycles of wind velocity measured at 100 m south of the source at 9 m above the ground (blue triangles) and at the SMN station at 10 m above the ground (green rectangles) during IOPs. 30 min averages are overplotted on a diurnal basis.

s^{-1}. For larger velocities the turbulenc intensity was nearly constant around 0.15. The turbulence intensity near the ground was quite homogeneous throughout the experimental area. Only for wind velocities less than 3 m s^{-1} an effect of the birch plantation could be noticeable, in cases where the turbulence intensity 100 m south of the source (green circles) was larger than upwind (black circles) of the plantation or further downwind (blue circles). 4.5b indicates that the turbulence north and 350 m south of the plantation was weaker at 18 m height than near the ground for the same wind velocities. Yet it is shown clearly that the birch trees induced wake turbulence which yields turbulence intensities larger than 0.2 at the near downwind tower (green circles) for wind velocities less than 5 m s^{-1}. The turbulence intensity 100 m downwind of the plantation and at 2 m was weaker than at 18 m above the ground, possibly because less turbulence was induced in the trunk space than in the leaf area. The data points at wind velocities larger than 5 m s^{-1} in Fig. 4.5b account for the foehn event on April 10 and 11.

5 First assessment of the pollen data

Note that in the case of pollen monitoring the used instrument types apply different methods of pollen sampling. In terms of data comparison the determination of the instrument uncertainties is crucial and a subject of further analysis. At the current state of this work, pollen concentrations are calculated according to the manufacturer's recommendations. This section thus gives an indication of the plausibility and characteristics of the pollen data as well as on the agreement among instruments of the same type. The Burkard pollen traps



(a) 2 m above the ground

(b) 18 m above the ground

Figure 4.5: Normalized 30 minute average of turbulence intensity measured with CSAT3 at a) 2 m above ground and b) 18 m above ground; 30 m north (black circles), 100 m south (green circles) and 350 m south (blue circles) of the birch plantation. The sampling periods from 10:00 to 18:00 UTC+1 on April 4 to 13 are displayed.

represent the reference instrument for all pollen concentration measurements conducted in this experiment.
Figure 5.1 shows the course of pollen concentrations during three IOP days measured with Burkards (Sc.) and AOCs. The plot leads to three important statements: First, the dicrepancies between AOC (dashed lines) and Burkard (solid and dotted lines) measurements are significant and, therefore, can only be compared with extensive relative calibration. These results are, however, at odds with the conclusions of Aizenberg et al. (2000), who compared the performance of Burkard and AOC samplers under labatory conditions. They found a significantly better agreement of the two methods for smaller particles, however. This suggests that the validation of the pollen measurements performed under natural conditions is an important subject of investigation in the process of this project. Each sampling method underlies uncertainties that are involved in the counting work as well as in the impaction method, in which inertial effects become effective.
Therefore, detailed intercomparison of the different sensor types and relative calibration among the instruments in the field is urgently needed before firm statements about the spatial distribution of pollen can be made. Second, the pollen concentrations indicate a diurnal cycle with a daytime maximum and a nightime minimum, except for the night before April 12, where very large concentrations were measured. This is consistent with descriptions of the diurnal pollen immission pattern of different plant species (Ogden et al., 1969; Von Wahl and Puls, 1989; Van Hout et al., 2008) and among others for birch pollen (Jäger, 1990; Mahura et al., 2009). Third, the impact of the source on downwind pollen concentrations is visible only at some downwind distance: The daytime concentrations at 350 m distance from the source (solid purple line) exceeded those measured at 30 m (solid green line) and 100 m (solid orange line) downwind of the source, which more or less correspond to the background concentration (solid black line).

6 Conclusions

The meteorological measurements during the experiment suggest that the weather conditions coincided with the requirements for probing the downwind pollen concentration emitted

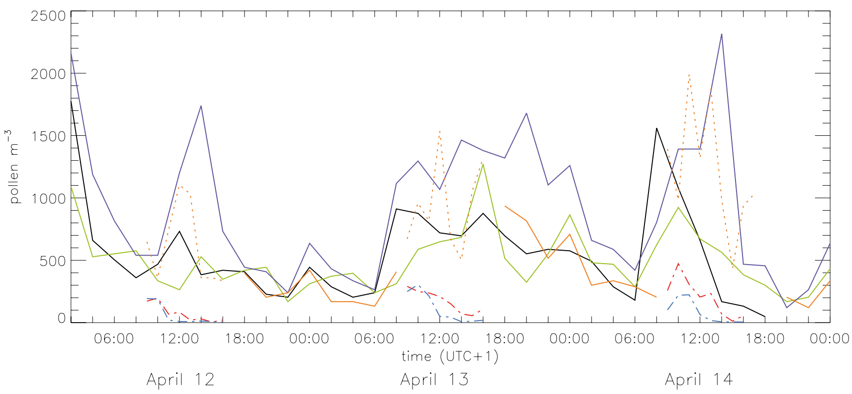


Figure 5.1: Diurnal course of pollen concentrations measured during IOP 3 to 5 at 2 m above the ground. Solid lines denote 2-hourly resolution, dashed and dotted lines denote 1-hourly resolution. Burkard data from 30 m north (black), 30 m south (green), 100 m south (orange) and 350 m south (purple) of the source shown. The dashed orange line denotes Burkard Sc data. AOC data from 100 m south (red) and 200 m south (light blue) of the source are shown. The lines denote the spatial average of the two AOCs adjacent to the corresponding Burkard trap (Fig. 3.3). A data point corresponds to the end of a 2-hourly or 1-hourly interval, respectively .

by a well-defined source. This is confirmed by the significantly high level of birch pollen concentration. The experimental period can altogether be accounted for a seasonal pollen emission cycle. The existence of a well-defined mountain-plains wind system during most of the experimental period allowed to determine the most appropriate instrumental set-up. The alternating wind direction was cyclically quite persistent. What remains uncertain and still needs to be analized, however, is whether the high spatial and temporal sampling resolution allowed to reliably assign the measured pollen to a known source.

The horizontal pollen profile measurements exhibit significant spatial variations, which have yet to be correlated to micrometeorological factors. The spatial variability during the down-valley wind cycles is substantial and appears to be characteristic if only one sensor type is considered. However, these spatial characteristics are very inconsistent for different pollen sensors. If the Burkard sampler is taken as reference, the AOC and Rotorod samplers generally underestimate the concentrations in the case of several different pollen types. The limited data set of available sensor intercomparison does however not allow for any firm conclusions concerning relative comparability. The large difference of pollen concentrations when applying manufacturers calibration was certainly unexpected at the outset of the experiment and will have major impact on the future progress of data evaluation. The knowledge of the uncertainties and standard variances of each sampling methods is crucial for a significant analysis of the pollen dispersion downwind of the source.

Several (large) gaps in the data series of different instruments impede the analysis of certain periods, i.e. the two first IOPs. The data availability and quality presented and discussed here seem however very promising in terms of eventually leading to a better understanding of pollen emission characteristics, above all the parameterisation of pollen emission and its implementation into operational pollen forecast systems. Furthermore, the large data set collected during this experiment covers a variety of different important micro- and biometeorological parameters of which each could contribute to associated fields of study.

The preliminary results highlight the importance of counting pollen probes in-situ to optain an indication of the plausibility of pollen data before the end of the experiment. It is also important to perform a regular checking of the pollen samplers, since they are rather prone to malfunctions than electronic devices. Despite the ample experience in measuring meteorological and micrometeorological parameters it turned out that pollen sampling incorporates rather large variabilities due to the statistical evaluation on the one hand and uncertainties in the impaction method on the other hand. Performing a calibration of the used sensors is essential and should be done in the framework of similar experiments.

7 Outlook

The most critical issue in the current work is the relative calibration of the different pollen sampling methods. For this reason, several measuring intervals of the reference instrument (Burkard trap) are revised and statistically analyzed. In spring 2010 a third intercomparison experiment has been conducted at the experimental site in Illarsaz. The three sampler types used in the main experiment (Burkard, AOC and Rotorod), have been tested against each other under similar meteorological conditions and also with birch pollen. Additionally, the effects of the AOC sensor orientation (i.e. horizontal and vertical) will be investigated. The data of this intercomparison should provide more information about the uncertainties of the samplers compared to each other.
In a further step the spatial and temporal pattern of pollen concentrations will be characterized and their dependendence on micrometeorological variables determined. The results will lead to a better understanding of the influence of meteorological variables on pollen emission.

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