Zurich Airport

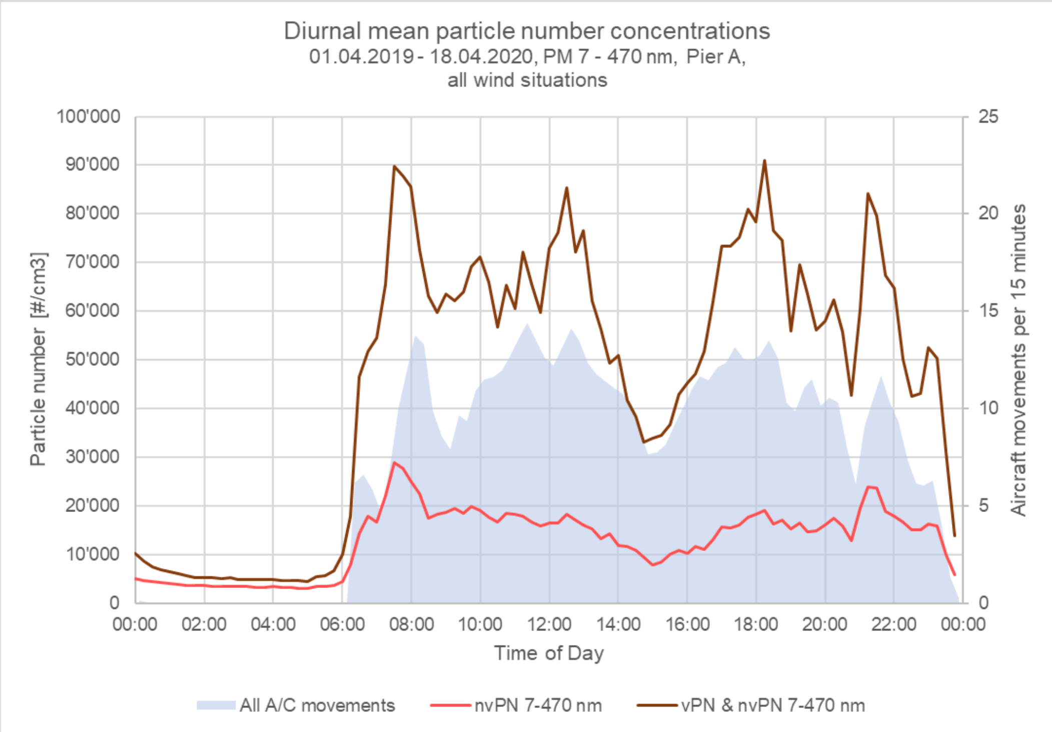
Ultrafine Particles

STUDY ON VOLATILE AND NON-VOLATILE ULTRA-FINE PARTICLES AT ZURICH AIRPORT

Management Summary

Airports are sources of ultrafine particles being emitted from a range of different individual sources. The predominant source of particles is the aircraft, emitting large quantities of non-volatile and volatile small particles. This study discusses the differentiation of volatile and non-volatile UFP in the range of 7-470 nm at Zurich airport's Pier A automated monitoring station during the time period from April 2019 to April 2020.

The overall results (following figure) demonstrate the high variability of the total number of particles (brown) over the day with varying aircraft activity and the similar variability at a much lower absolute level for non-volatile particles (red), with an average share of volatile particles of 74% during daytime and only 36% during nighttime.



The study furthermore discusses the influence of particle size, different wind situations and different aircraft activity intensity on the absolute and relative number of particles and particularly on the share of volatile particles.

More measurements at different locations would be needed to better understand the spatial variability of volatile particles. Other current limitations exist in the precision of assessing the non-volatile particles – and hence calculating the volatiles – and the physical/chemical transition processes.

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1. Air Quality Monitoring Zurich Airport

1.1. Introduction and Overview

The concentration of ultrafine particles at airports has become an area of interest over the past years that has led to increased monitoring and evaluation. Ultrafine particles are in the size range of 4-100 nm and are emitted from various combustion and industrial processes at and around airports, at airports predominantly from the aircraft main engines.

Zurich airport has started as early as 2012 to specifically monitor ultrafine particles through dedicated measurement campaigns. So far, studies have been performed on particle concentrations on the apron (2012), the airport area (2017), the approach to runway 14 (2019) and the Airside Center indoor air quality (2019)[1].

This study here discusses the differentiation between volatile and non-volatile ultrafine particles at the airport monitoring station (fig. 1). The airport's automated monitoring station is located in the center of the airport, on the roof of the passenger Pier A. It is exposed to arriving and departing aircraft and likewise to taxiing aircraft and aircraft handling activities at Pier A (cf. Annex A).

Figure 1: Airport Layout and Monitoring Station (yellow)

[1] For specialists – Flughafen Zuerich (flughafen-zuerich.ch) (as of December 2021)

1.2. UFP Monitoring Equipment

The particle monitoring equipment as it has been operated since 2018 consists of four basic components (fig 2 and 3).

1. The Fidas 200 monitoring device measures the particle mass in different size fractions. The fractions of importance are PM2.5 and PM10, both being regulated by the Swiss Clean Air Act[2]. The device is coupled with the meteorological sensor that captures temperature, pressure and relative humidity.
2. The Scanning Mobility Particle Sizer (SMPS) classifies the particles according to their size of 7-1,200 nm in 128 size bins and with a concentration of maximum 10^8 particles/cm^3 (Palas GmbH, Envi-SMPS 2100X) with a scan duration of approx. 3 minutes.
3. The Condensation Particle Counter (CPC) counts particles in the size range from 4-5,000 nm and up to 10^5 particles/cm^3 (single count mode). The working fluid is butanol (Palas GmbH, Envi-CPC 100).
4. The Catalytic Stripper removes the semi-volatile aerosols in the air flow (cs. chapter 1.3, Catalytic Stripper CS15-SS).

Figure 2: UFP Monitoring Equipment

[2] LRV; SR 814.318.142.1; Annex 7.

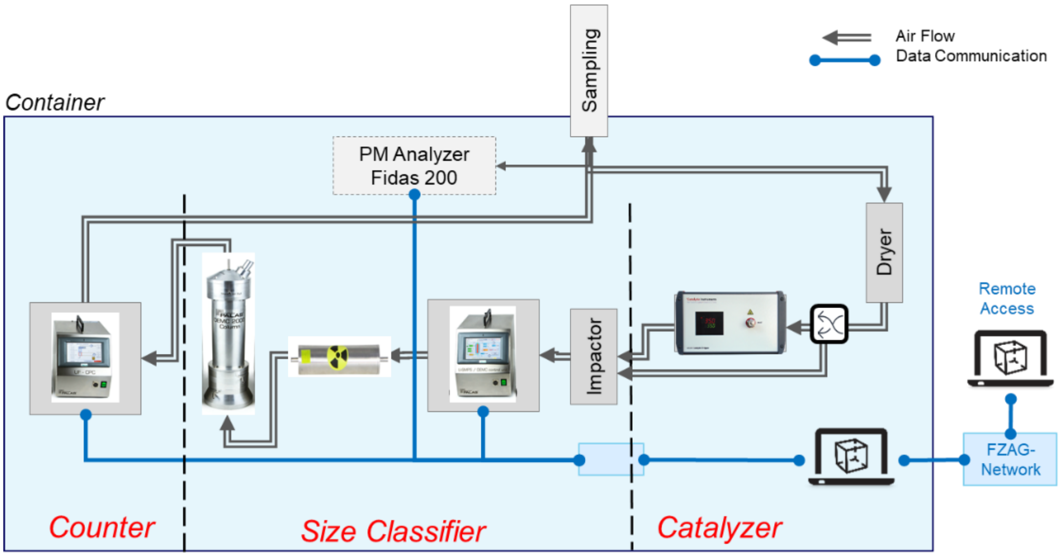

Figure 3: UFP Monitoring Setup

1.3. Differentiation between volatile and non-volatile particles

The determination of the volatile particles is done by calculating the difference between the total measured number of particles and the number of non-volatile particles, whereas the amount of the non-volatiles is determined by removing the volatile components. Removing the volatile fraction is done through the catalytic stripper at a temperature of 350°C. Solid particle losses are specified as "<40% at 100 nm".

An automatic switch in front of the catalytic stripper switches the air flow from scan to scan to either go through the stripper or bypass it. This allows for a continuous and almost parallel monitoring of both the total UFP concentration and the non-volatile UFP concentration.

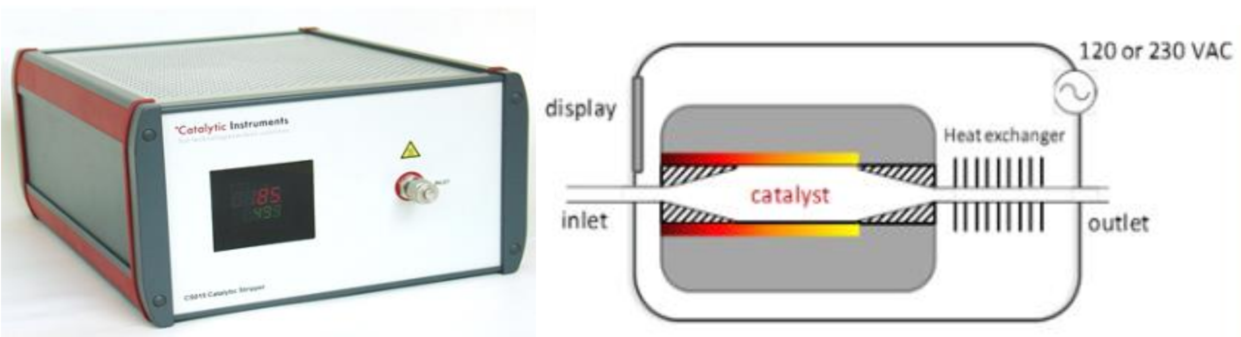

Figure 4: Splitting particles into total amount and non-volatile components

Figure 5 displays a typical set of scans from 4 nm to 750 nm for the total number and the non-volatile number and size of particles in the SMPS. Specifically, the device always displays the latest four scans in sequence (1 through 4). Given the alternatively sample taking through the catalytic stripper and the by-pass, each other curve is either total UFP or the non-volatile UFP. The time laps between each scan is approximately 3 minutes. Depending on the ambient emission and concentration situations, the scans are thus not necessarily connected or comparable.

Even though no direct analysis between the scans is possible, the examples seem to indicate that the majority of the volatile particles seem to be in the size band from 7nm to approx. 40nm. To which degree the differences between non-volatiles and volatile particles are due to the actual particles or the losses in the catalytic stripper, would require further research.

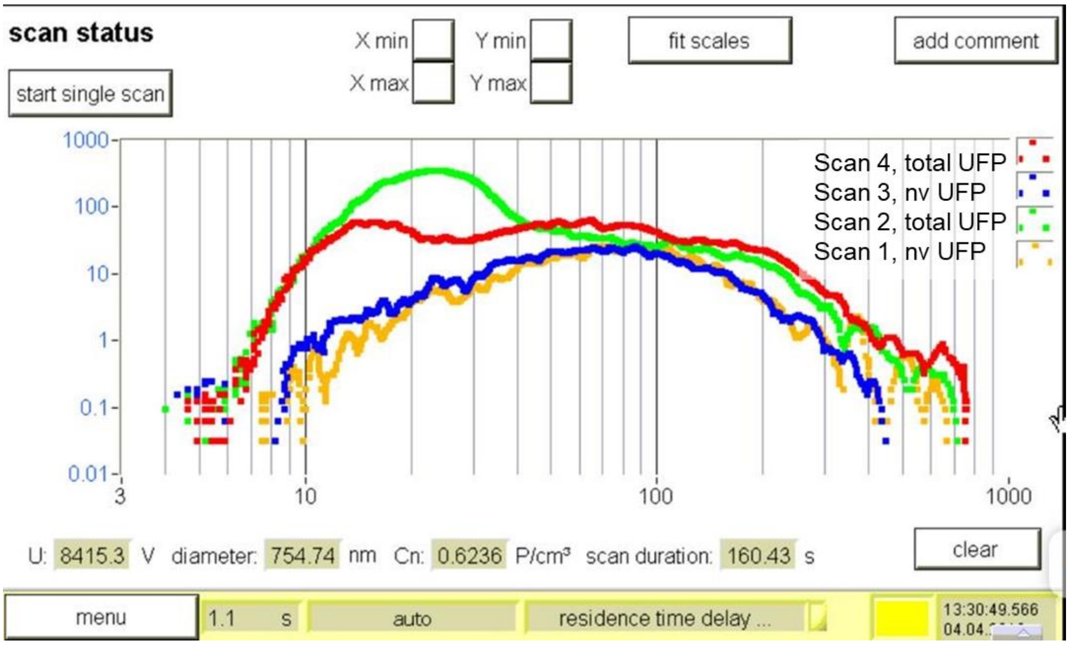

Figure 5: Scan picture of total and non-volatile particle numbers and size distribution

2. Volatile/non-volatile Particles

2.1. Total particle number differentiation

The measurement period for all results is from April 1st 2019 to April 18th 2020 when the first Covid-19 related travel lockdown started. All particles in the range of 7 – 470 nm are considered.

Figure 6 shows the overall results during the evaluation period, over 24 hours and broken down in periods with significant aircraft and airport activity (07:00-21:00) and no aircraft activity, but also far less other activities (handling, maintenance, regional road traffic, 00:00-05:00).

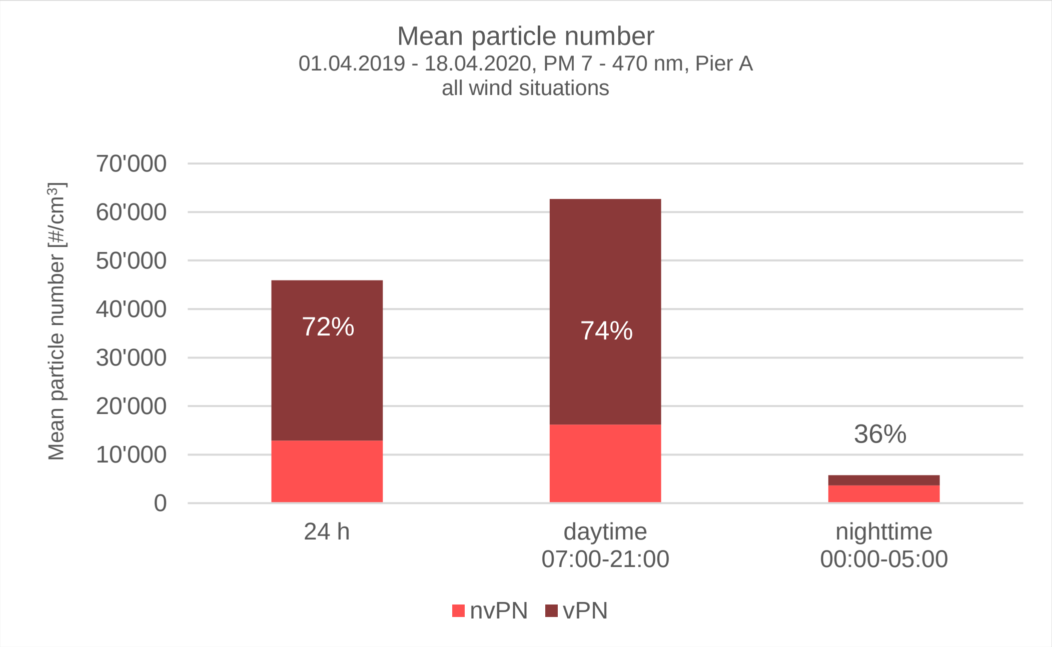

Figure 6: Total volatile and non-volatile particles

During daytime period from 07-21 hours with significant aircraft and associated activities, and likewise high regional activities, the measured total concentrations were 62,700 #/cm³, with a split of 74% volatiles and 26% non-volatile particles. During the non-activity time from midnight to 05 AM, the total average concentration was only 5,700 #/cm³ with split of 36% volatiles and 64% non-volatile particles.

The results indicate a very high share of volatile particles during the time of airport operations with a lot of aircraft traffic that decreases to a much lower share during times with no aircraft and generally reduced airport and background activities.

2.2. Time Differentiation

A more detailed picture can be seen by looking at the diurnal mean particle number concentrations in comparison with air traffic (following figure). The aircraft activity is both presented as the total number of movements at the airport (light blue) and the number of aircraft operations at Pier A where the monitoring station is located (dark blue, as a subset). Aircraft operations at Pier A only could have a larger impact due to their proximity to the monitoring device (see Annex 1). However, the PN-measurements correlate well with both aircraft perimeters. Particle number concentrations start picking up in line with air traffic after 6 AM. The higher the aircraft traffic intensity is, the higher and also more variable the total number of particles becomes.

The variability of the total particles lies between 10,000 and 90,000 #/cm³ while the non-volatile particles only vary between 5,000 and 27,000 #/cm³. Within an hour, the mean total number increases from 10,000 to 90,000 #/cm³ (06:30-07:30) and drops within two hours from 85,000 to 33,000 #/cm³ (12:30-13:30).

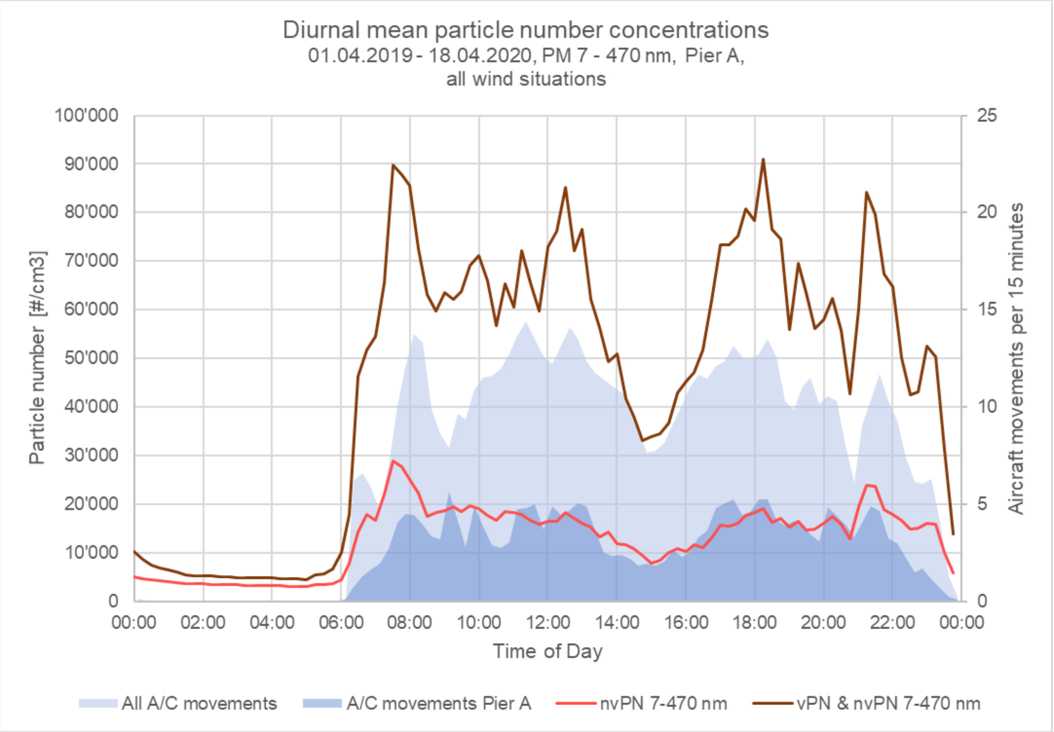

Figure 7: Diurnal total and non-volatile particle numbers Pier A

An additional indicator is the size of the particles (figure 8). Particle sizes are between 40 and 65 nm during the nighttime and drop to 19-27 nm during daytime with all the airport and regional activities. This confirms that aircraft engines tend to release smaller particles than other combustion engines from machinery and vehicles or the heating plant even if their activities are lower during the night time as well. The daytime difference in size between total and non-volatile particles is rather small compared to the difference in numbers.

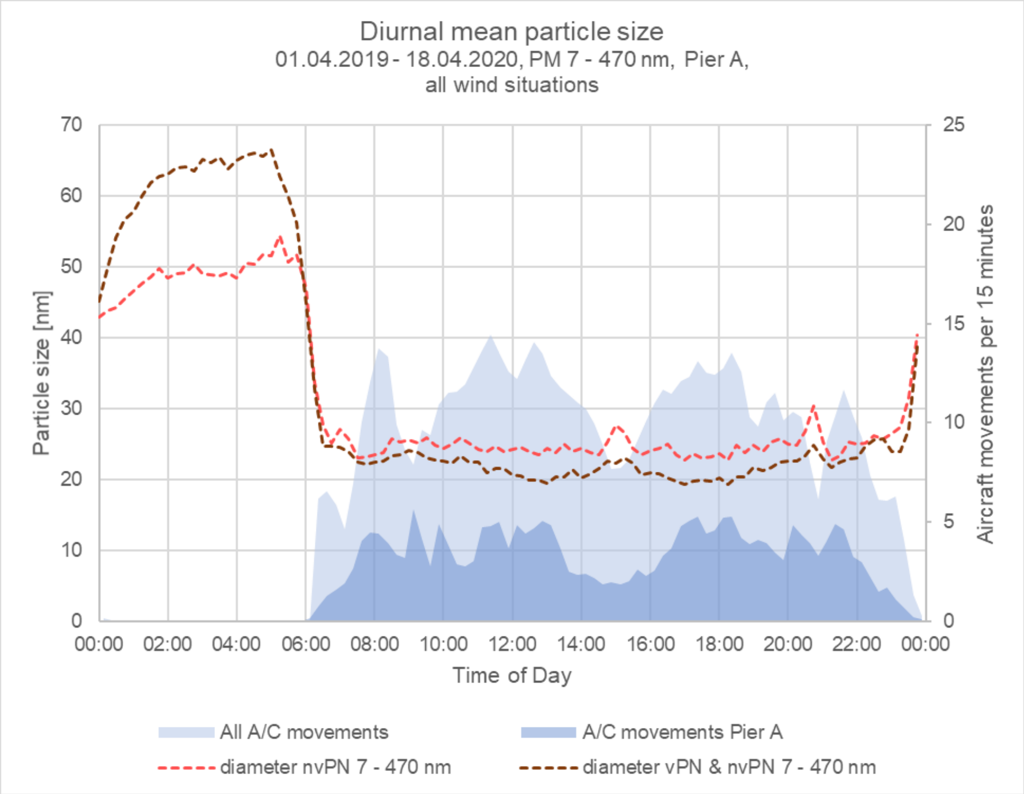

Figure 8: Diurnal total and non-volatile particle sizes Pier A

2.3. Size resolution

The SMPS measurements allow for size-resolved analysis of the particle concentrations both for total and non-volatile particles. Figures 9 (in %) and 10 (absolute numbers) show the respective size distribution of both non-volatile and total particles during daytime and night-time.

During daytime the peak of the shares can be found at 10 nm for non-volatile particles and at 16 nm for the total amount of particles. These peaks are followed by a sharp decline between 20 and 45 nm and remain very low for the rest of the range to 470 nm.

During the night-time however, there are less small particles in these size range of 10-16 nm than in the range of 20 – 50 nm and peaks are generally missing in the absence of many combustion engines.

The volatile particles from 7 to approx. 15 nm during daytime (total minus non-volatiles) can be largely attributed to the aircraft activities, as there are hardly any volatile particles of the same size-range existent during the night-time.

The potentially perceived error of having less total particles than just non-volatiles <10 nm could also be attributed to the only “quasi”-simultaneous measurements – in fact, there is always a 3 minute offset – as well as the uncertainty in the measurement corrections for line losses and particle losses in the system.

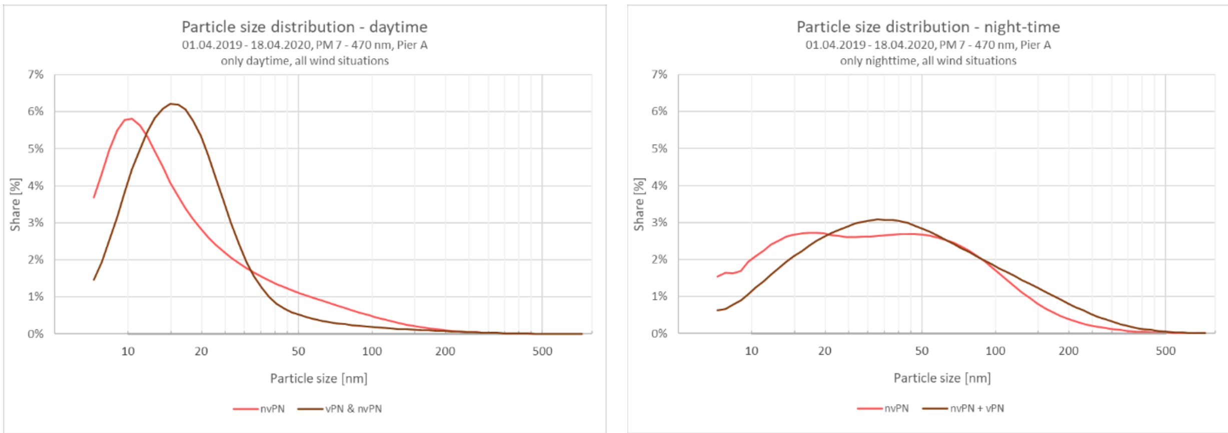

Figure 9: Particle-size resolved total and non-volatile particles in % (daytime and night-time)

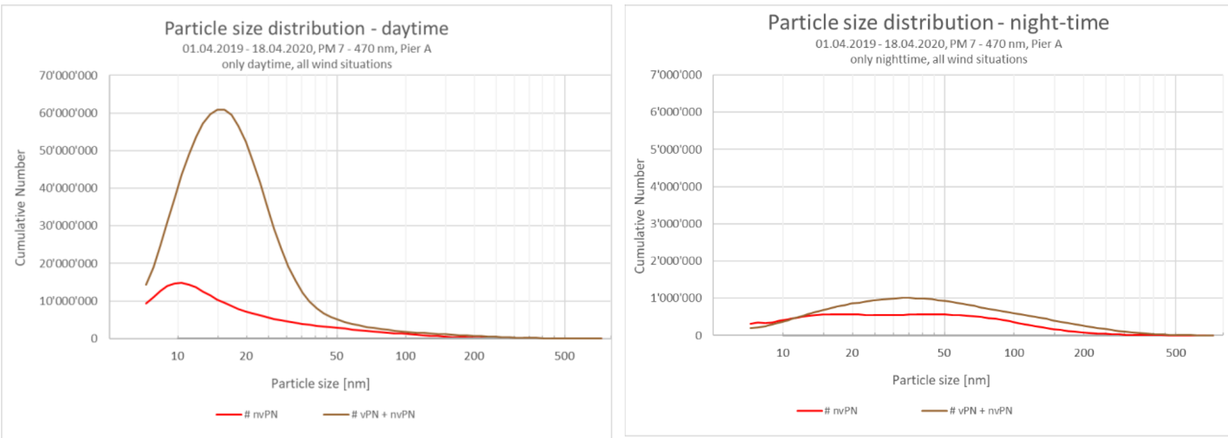

Figure 10: Particle-size resolved total and non-volatile particles absolute (daytime and night-time; daytime scale 10x larger)

Figure 10 also demonstrates the non-linear share of volatile particles with increasing size. At 10 nm, the share of volatiles is approx. 72%, at 15 nm approx. 83%, at 20 nm 86%, at 30 nm 76% and at 50 nm 44%. During the night-time, with up to 83% less particles in total than during daytime, the share of volatile particles is always <50%, irrespective the size.

2.4. Impact of various wind situations

The following figure shows the wind situations at Zurich airport and confirms the predominant Southwest wind.

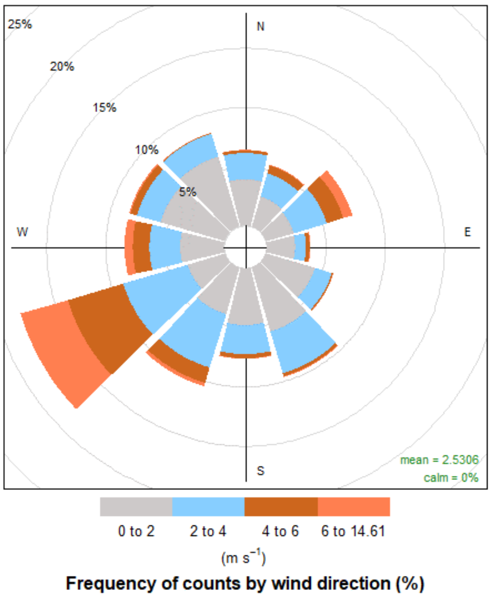

Figure 11: Wind field analysis Zurich Airport

For the purpose of this study, four analyses with three specific wind situations have been performed (figure 12).

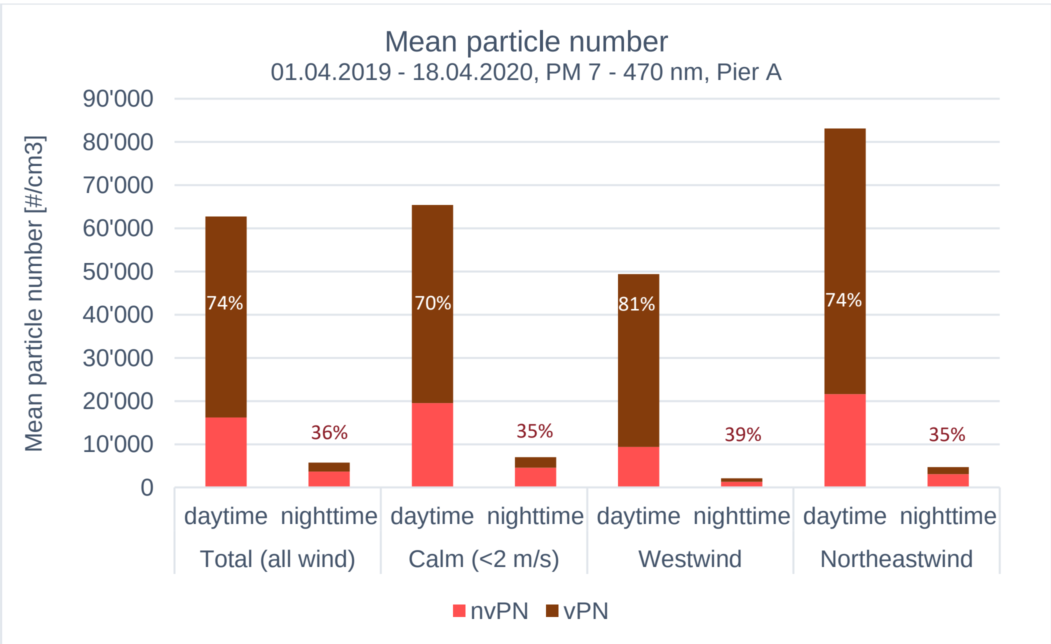

Figure 12: Wind-dependent volatile and non-volatile particle concentration (with/without aircraft activity)

The total result is presented for all the various wind situations. Again, the particle number concentrations are split in daytime activities (07:00-21:00) and night-time (00:00-05:00) and for volatile and non-volatile particles. During daytime, volatiles dominate the number of particles with 74%, but are much lower during night-time with 36%.

The calm wind situation, with winds of <2 m/s shows only slightly higher particle number concentrations than the average, mainly from volatile concentrations (70% during daytime). The typical Westwind situation (wind from 240°-300°, >2 m/s) shows that dwelling particle concentrations are being shifted away. Even though some taxiways and a busy runway (Runway 16 with long-haul take-offs) are contributing, the overall concentrations are significantly lower, in the case of the non-volatile particles even by 50% compared to the calm wind situation during daytime. The remaining wind direction of significance is from the Northeast (0°-90°, >2 m/s). As can be seen from the map in Annex A, there could be quite more airport and aircraft activity in the upstream direction of the station, with additional apron and handling areas and a busy runway (Runway 28 with most short-haul take-offs). And furthermore, just outside the airport perimeter fence, is a busy motorway. While non-volatile particle concentrations are similar to those during calm conditions, the volatile particle concentrations are 50% higher.

In addition to just the total UFP numbers, the diurnal variations for different wind conditions are of interest (figure 13). During Westwind situations, with total particle numbers not exceeding 83,000 #/cm³, there is a high temporal variability from one 15-minute interval to the next. It seems the measurements are capturing very distinct plumes of air from the various sources. During Northeast wind situations with particles number concentrations going as high up as 160,000 #/cm³, the temporal variability is less pronounced. Reasons for this can be the larger downwind area (apron, runway, background motorway) and more mixing of exhaust plumes (see also Annex A).

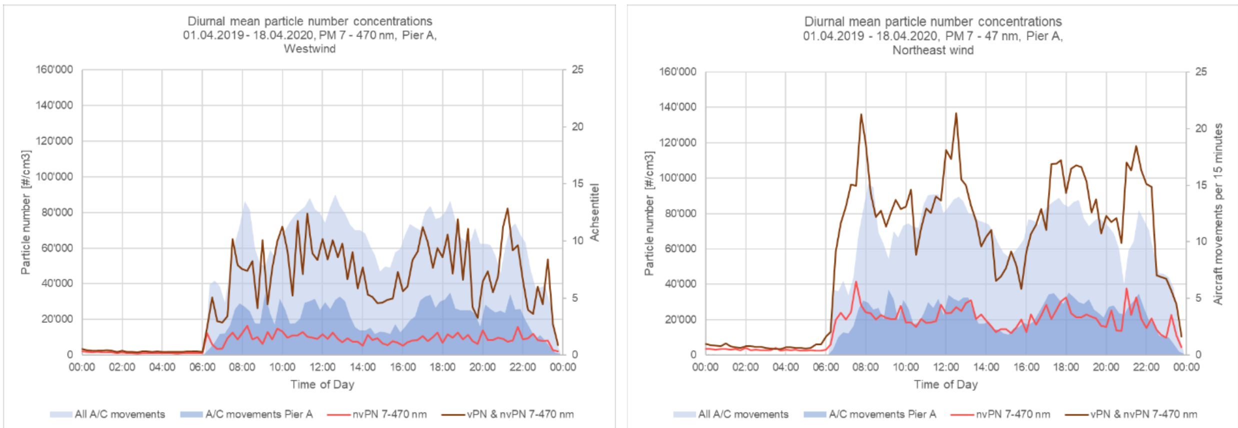

Figure 13: Wind-dependent variability UFP concentrations (same scale)

While the quantitative levels of UFP are distinct dependent on the wind direction, qualitatively the share of the non-volatile on the total particles remain very similar.

3. Analysis of volatile UFP

Figure 6 displays the average amount of volatile particles over 24 hours, during day time activities and during night time. Of interest is furthermore the diurnal variation of the share of volatile on all particles, as displayed in figure 14. After the night, with increasing aircraft traffic and other activities, the share of volatile particles quickly reaches 70% and goes as high as almost 80%. With decreasing traffic, the share reduces to 70% again.

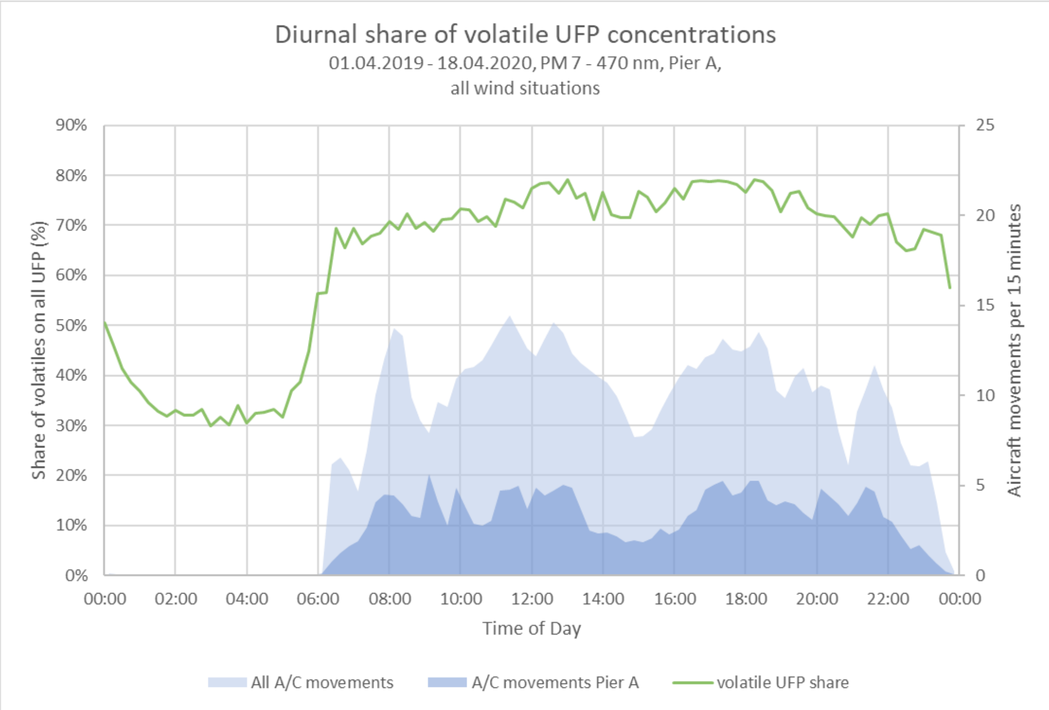

Figure 14: Diurnal volatile particle share

The background concentration share of non-volatile particles seems to be around 30% in the night, but a high of 70% to 80% during the day. Further analysis has been performed to see if the aircraft movement intensity has a significant influence on the share of volatile particles. Figure 15 shows the aircraft intensity in 15 minute-intervals and the respective mean share of volatiles.

Results indicate an increase of the median share of volatile particles with increasing activities. A level of 70% is reached with about 4 movements in 15 minutes and reaches 80% with about 18 movements per 15 minutes. This means not only the absolute number of particles increases, but there are also more volatile particles compared to the total number.

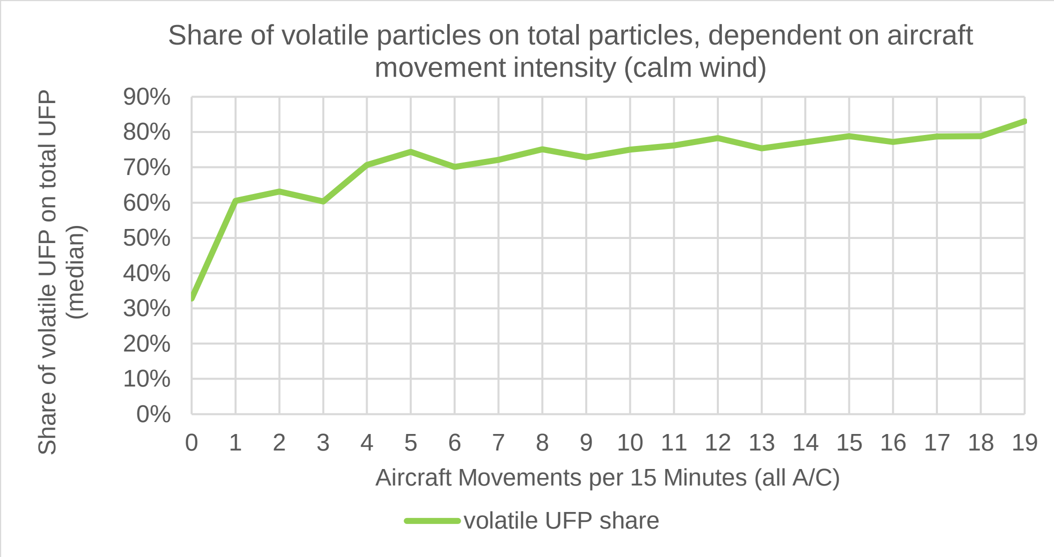

Figure 15: Median volatile particle share dependent on aircraft movement intensity (calm wind)

Wind also has some effects as shown in figure 16. There is more aircraft activity needed to reach a share of 70% with only a gradual increase. Overall, the variability increases which might simply be due to random results.

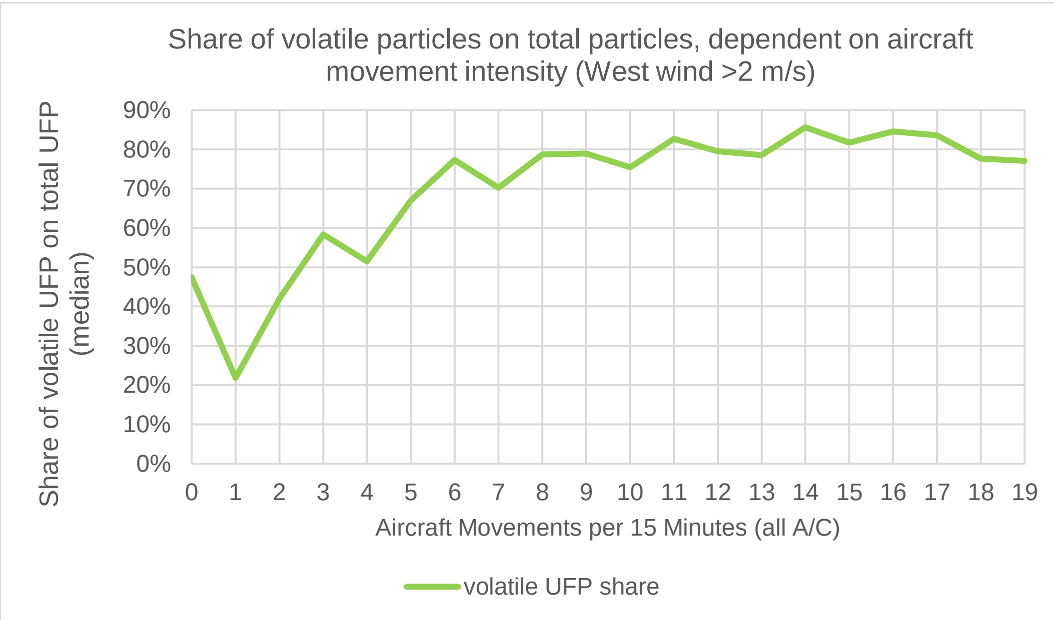

Figure 16: Median volatile particle share dependent on aircraft movement intensity (West wind >2 m/s)

4. Uncertainty Clusters

Measurements provide reality pictures of certain situations. However, measurements in themselves are subject to specific uncertainties. With regards to ultrafine particles from aircraft engines, there have four clusters of uncertainties been identified (figure 17):

1. Aircraft: Relevant parameters are the fuel used and particularly its sulfur content, the engine combustion technology (e.g. staged combustion, rich-quench-lean combustion) and the flight phase (low power, high power). Additionally, the accelerated, steady, or decelerated movement of the aircraft (4-dimensional) has a high relevance to measurement uncertainties.
2. Chemistry: Relevant are the nucleation or the condensation mode, the accumulation and transformation of the particles and their interaction with secondary aerosols. Of further importance are the ageing processes and the formation of new particles.
3. Meteorological conditions: The most important parameters are wind speed and direction together with other parameters like humidity, temperature and atmospheric turbulence.
4. Sensors: The highest uncertainties may be produced by the sensors themselves with the detection limits, distance to source, line losses of particles and the handling of the sample humidity.

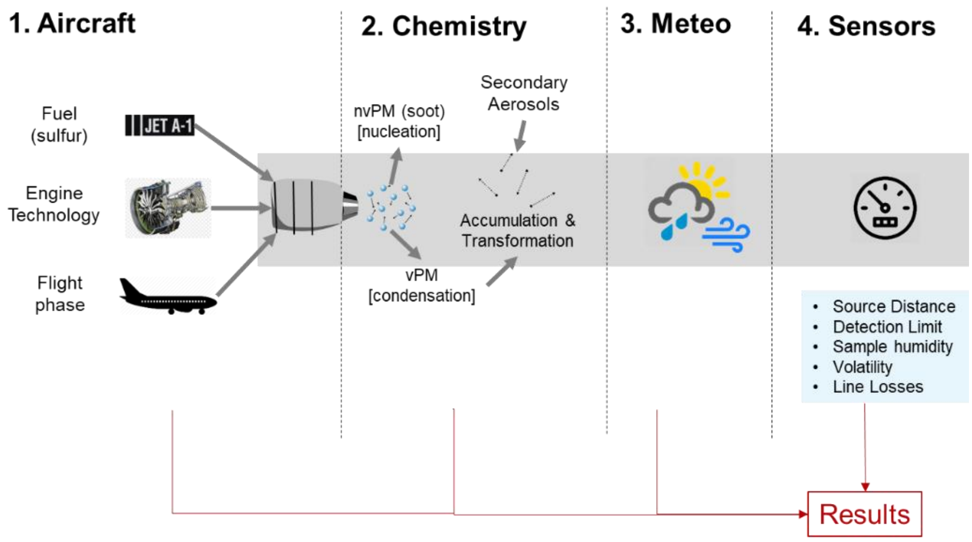

Figure 17: Uncertainty clusters in UFP measurements

5. Conclusions and Outlook

Current monitoring stations usually measure the total amount of ultrafine particles in the ambient air at airports or in the vicinity. In this study the use of a simultaneous dual total/non-volatile monitoring station is described, Results of volatile and non-volatile UFP concentrations at Zurich Airport have been presented for various activity-based and wind-specific situations. The special focus on the volatile UFP components indicate that aircraft-based emissions during daytime have a high share of volatile particles (70%-81%, depending on the wind situation).

In reverse it shows that the non-volatile particles that are generally of very high interest due to their concerns of adverse health effects are much lower in quantity than what is generally measured (20%-30% of all particles). During the night-time and with overall concentrations levels being much lower, the share of non-volatiles rise to 60%-65%.

However, several uncertainties remain that will likely influence the monitoring results:

- The spatial dimension is not further explored. The monitoring station only delivers results at that specific location. Further measurements would be needed upstream and downstream the airport to better understand the dispersion of the particles. Ideally, such measurements must take place simultaneously at several locations.
- The type of volatile particle is not further known. This relates to age, particle development and physical / chemical properties.
- And finally, all measurements come with uncertainties in the measurement technology, i.e. line losses and their respective corrections. Such uncertainties may falsify results to some degree and need to be reduced.

Zurich Airport is committed to continue assessing the UFP concentrations at the airport in the future and share results with the international aviation and science community.

Annex

A. Zurich Airport Map

Operating regime: main regime (exceptions possible)

List of figures

References

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Imprint

Contacts

Emanuel Fleuti
Head of Sustainability & Environment
Finance & Services

Emanuel.fleuti@zurich-airport.com
P +41 43 816 21 81

Silvio Maraini
Senior Project Leader Environment
Finance & Services

Silvio.maraini@zurich-airport.com
P +41 43 816 73 56

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