

Air Quality Annual Report 2018

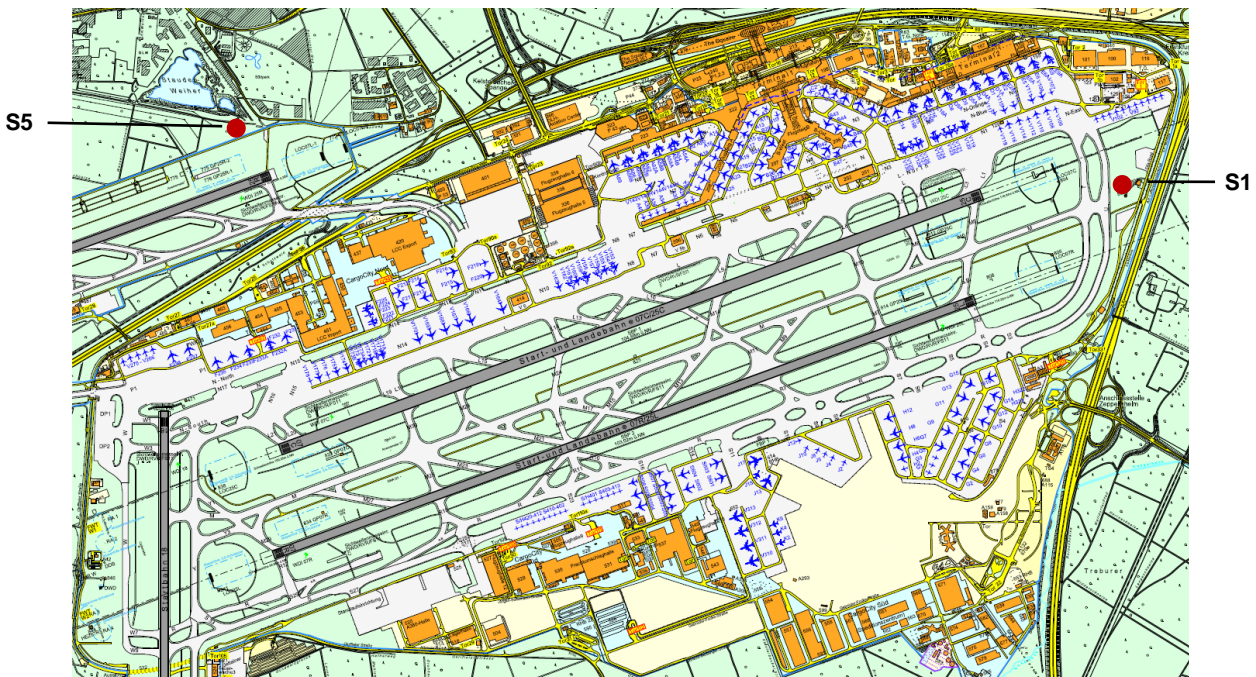
Report on Ambient Air Quality Monitoring at Frankfurt Airport

As has already become apparent in recent years, air quality at Frankfurt Airport is basically independent of the air traffic development. It is characterized by general trends of the preexisting levels of pollution due to regional emissions and by meteorological patterns in particular. Therefore, the annual pollution key figures 2018 were again unremarkable, in common with previous years, i.e. on a level ranging between the urban background level and the levels of sites exposed to road traffic.

So far, there is no new knowledge regarding the conventional pollution components that are regulated by limit values. A topical issue of public perception remains in the matter of ultrafine particles, which we chose again for our special theme in the current edition of the Annual Report. This complex field is still a subject of research, especially with respect to potential health impacts.

Regarding the particular contribution of airports to the concentration of ultrafine particles in the surroundings, a lot of information has emerged recently, also supported by Fraport. In this edition of the Air Quality Annual Report, we compare the first results of model calculations for ultrafine particles with current monitoring results. Even though model and measurement do not yet match to a desirable degree, the present calculations are the first steps towards a better understanding of the relationships.

Ambient Air Quality Monitoring Stations in 2018



Annual Mean Values Compared to Air Quality Standards			
		Measured Value	Air Quality Standard*
NO	S1	28	200 ¹
	S2		
	S5	10	
NO ₂	S1	43	40 ²
	S2		
	S5	29	
SO ₂	S1	2	50 ³
	S2		
CO	S1	0.3	- ⁴
	S2		
O ₃	S1	38	- ⁴
	S2		
PM10	S1	18	40 ²
	S2		
	S5	16	
PM2.5	S2		25 ²
Benzene	S1	0.6	5 ²
	S2		
Toluene	S1	1.0	30 ⁵
	S2		
m/p-Xylene	S1	0.4	30 ⁵
	S2		
Ethylbenzene	S1	0.2	20 ¹
	S2		
Benzo(a)pyrene	S1	0.2	1 ²
	S2		
Arsenic	S1	0.4	6 ²
Lead	S1	3.2	500 ²
Cadmium	S1	0.1	5 ²
Nickel	S1	1.8	20 ²

Measuring unit: µg/m³, CO: mg/m³, benzo(a)pyrene, arsenic, lead, cadmium and nickel: ng/m³

PM10 = particles passing a size selective airflow inlet with separation efficiency of 50% at aerodynamic diameter of 10 µm, PM2.5 definition corresponding

* Reference values used:

¹ Reference value according to HLNUG (Hessisches Landesamt für Naturschutz, Umwelt und Geologie, Hessian State Agency for Nature Conservation, Environment and Geology)

² Limit value 39. BImSchV (German ordinance transposing Air Quality Directive 2008/50/EC into national law); arsenic, cadmium, nickel and benzo(a)pyrene: target value

³ Limit value TA Luft 2002 (German Technical Instructions on Air Quality Control, for plants requiring licensing)

⁴ No annual mean defined for assessment by respective regulations

⁵ LAI recommendation (LAI = Länderausschuss für Immissionsschutz, Ambient Pollution Control Committee of German States)

The layout of tables and diagrams has been maintained according to the preceding years in this report, although no results are available for the S2 station, which is currently out of service. As soon as the station is in operation again, the data will be presented as usual.

In 2018, continuous monitoring was available during well above 99% of the time. Likewise, there were no failures in the passive sampling of hydrocarbons and particle constituents.

Exceedance Frequency of Short-Term Standards					
		Short-Term Standard	Reference Interval	Recorded Exceedance Number per Year	Permissible* Exceedance Number per Year
NO ₂	S1	200	1 hour	1	18
	S2				
	S5			0	
SO ₂	S1	350	1 hour	0	24
	S2				
CO	S1	10 ¹	8 hours	0	0
	S2				
O ₃	S1	180 ²	1 hour	4	0
	S2				
	S1	240 ³	1 hour	0	0
	S2				
	S1	120 ¹	8 hours	19 ⁴	25 ⁴
	S2				
PM ₁₀	S1	50	24 hours	4	35
	S2				
	S5			4	

Measuring unit: µg/m³, CO: mg/m³

* Short-term standards according to 39. BImSchV (for explanation on "permissible," refer to air quality report "Lufthygienischer Jahresbericht 2004" covering the exposure to be presumed in order to apply limit values, available in German only):

¹ Maximum permissible eight-hour running mean of the day derived from hourly means (ozone: target value)

² Threshold for the responsible authorities to inform the public in case of exceedance within their network

³ Threshold for triggering the alert in case of exceedance within the public network

⁴ Three-year average (2016, 2017, 2018)

Corresponding short-term values for the assessment of PM_{2.5}, particle constituents, NO, benzene, toluene, m/p-xylene, and ethylbenzene are not available.

The year 2018 was characterized by frequent and long-lasting northeasterly weather patterns along with an exceptional amount of sunshine, correspondingly less precipitation and higher temperature values during nearly all of the months. The total sunshine duration of 2,116 hours was 27% above the long-term mean¹, the overall precipitation sum of 401 mm barely reached two thirds of the usual amount. Only February was markedly colder than usual, and March was slightly colder than usual.

In spite of the warm and dry summer, neither the ozone alert threshold was exceeded, nor was exceedance of the information threshold unusually frequent: With only four hours in 2018, it was even an hour less than in 2017. In contrast, the reporting period contributed to an increase of the key figure for the long-term target value again (see also footnote 4 below the table). This is in accordance with the finding that peak ozone values are becoming less frequent, but the overall concentration level is hardly decreasing and increases again in case of corresponding weather situations.

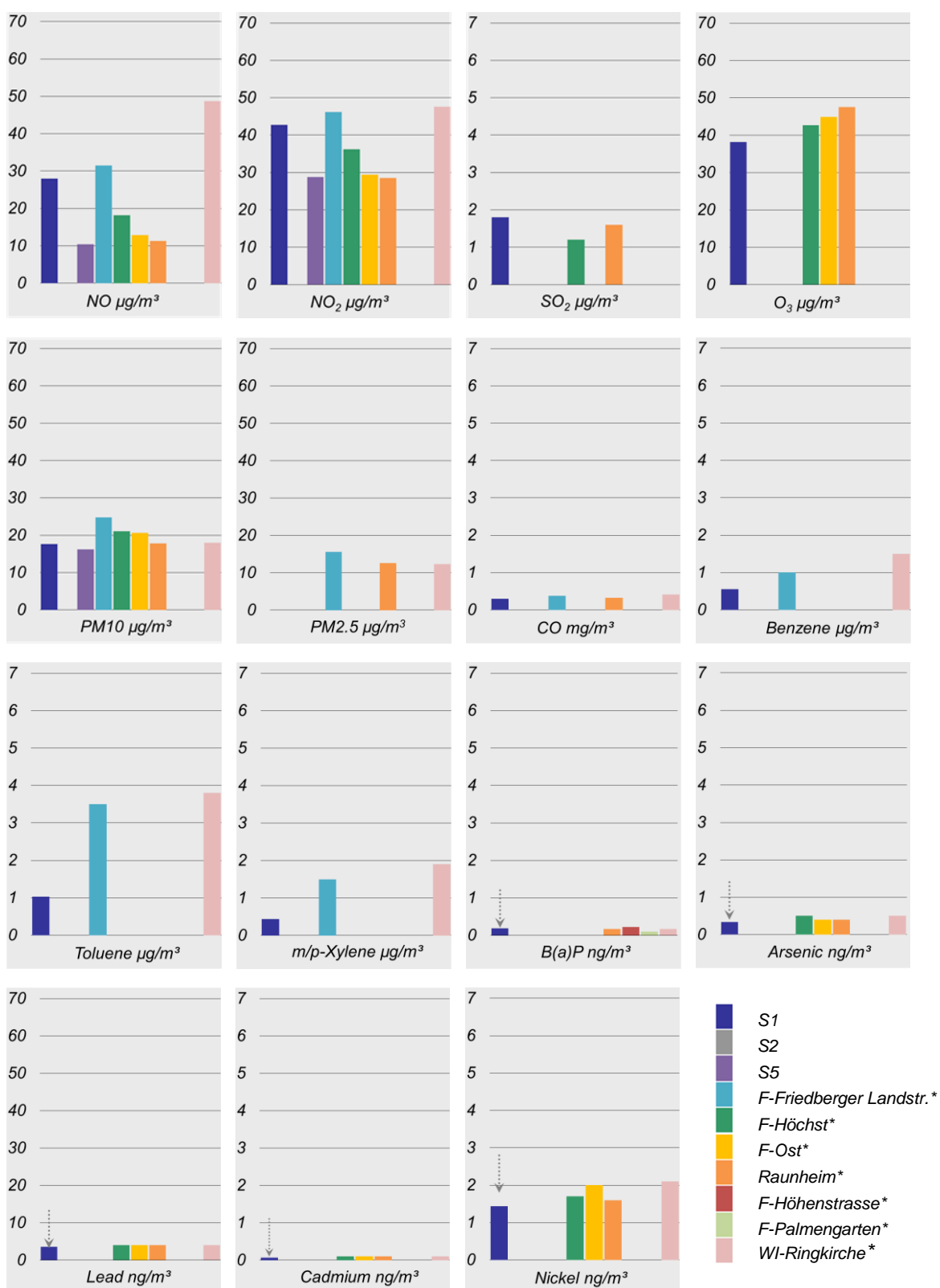
In the reporting period, the threshold for the PM₁₀ daily mean was exceeded on four days. This would have been permissible up to 35 days a year, even in the inhabited surroundings.

Only the annual mean of the NO₂ concentration at S1 remained above the reference value, at a level of 43 µg/m³. A slight exceedance of the NO₂ short-term threshold (201 µg/m³) occurred in the evening of August 3, again with northeasterly wind directions – and therefore not related to the airport.

The key figures of the reporting period would largely comply with human health protection standards again if they were applicable to airports (see note* below table). Once more, the only exception is the slightly elevated annual NO₂ mean at S1 being increased by vehicle emissions. It is similar to the concentration level at those urban sites that are also exposed to road traffic and does not represent a particular feature related to the airport.

¹ 1981–2010 at the airport station of the German Meteorological Service (DWD)

Annual Means at Airport Sites Compared to Values from Nearby Sites of Public Network (HLNUG*)



No bar = species not available at site, F = Frankfurt/Main, WI = Wiesbaden, particle constituents: bars = preceding year's data 2017, arrows = current FRA data 2018

* Reference: Lufthygienischer Monatsbericht Dezember 2018 (running annual means), HLNUG and Lufthygienischer Jahresbericht 2017 (particle constituents), 2018 not available by editorial deadline of this report.

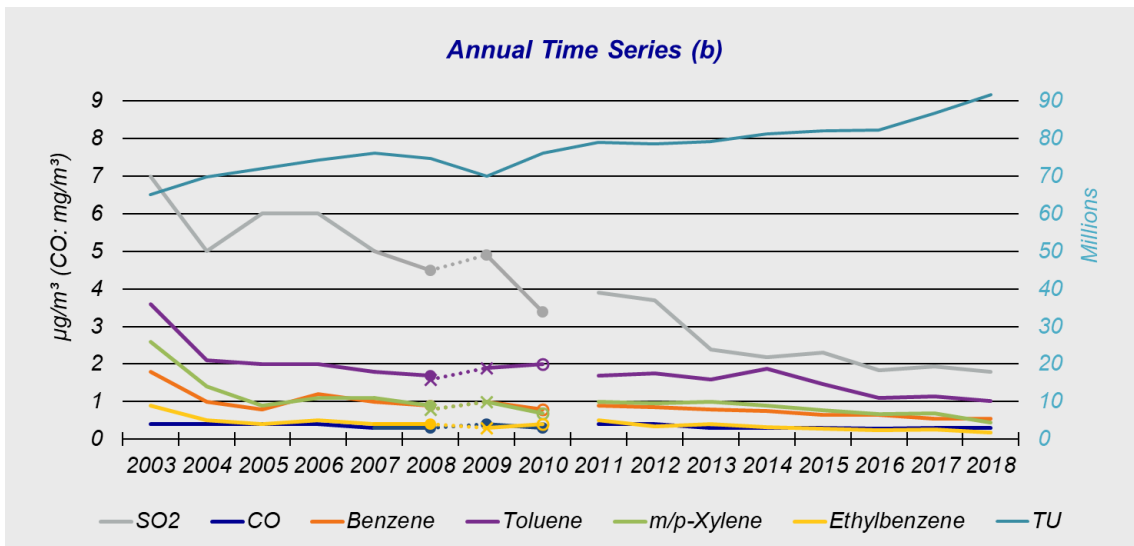
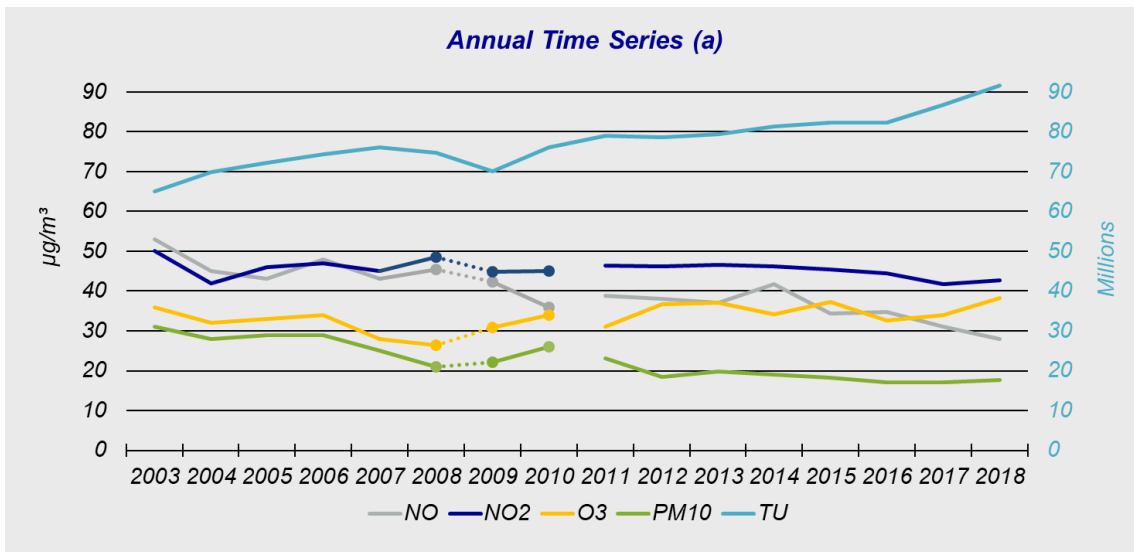
Comparison between Fraport Sites and Nearby HLNUG Sites

The comparison with monitoring results at the HLNUG stations for 2018 is similar to the preceding years due to site characteristics. At those sites that are exposed to road traffic, Frankfurt Friedberger Landstraße and Wiesbaden Ringkirche, the NO₂ limit value for the annual mean was also exceeded. As is the case at the airport site, the 2018 ozone values were higher than in the preceding year at comparative sites as well.

The nickel value at the airport was slightly higher in 2018 (arrow) than it had been in the preceding year (bar). Whether this was also the case at the HLNUG stations remains to be seen, as the corresponding monitoring results of particle constituents are not yet published. At all sites, the available concentrations of hydrocarbons and the particle constituents of benzo(a)pyrene, arsenic, lead, cadmium and nickel were very small in relation to the corresponding standards as they have been before.

Time Series of Annual Means (Station S1) and Traffic Units (TU)

Along with increased ozone concentration, the concentration of nitric monoxide continued to decrease and the NO₂ concentration slightly increased again as well as the PM10 concentration. This is caused by meteorological conditions and is independent of the development of traffic units, which had notably grown in 2018 once more. The hydrocarbon values range at the limit of the quantitation level.



1 TU = 1 passenger including luggage or 100 kg of airfreight or airmail
 Solid lines: measurement results at site, dotted lines: minor change of site 2008 / 2009, 2010 relocation approx. 1000 m to the north-northeast
 Large dots: correction for gaps in data at site, crosses: low data volume at site without correction
 Circles: data derived from two sites without possibility for correction

Ultrafine Particles (UFP) by Measurement and Model Calculation

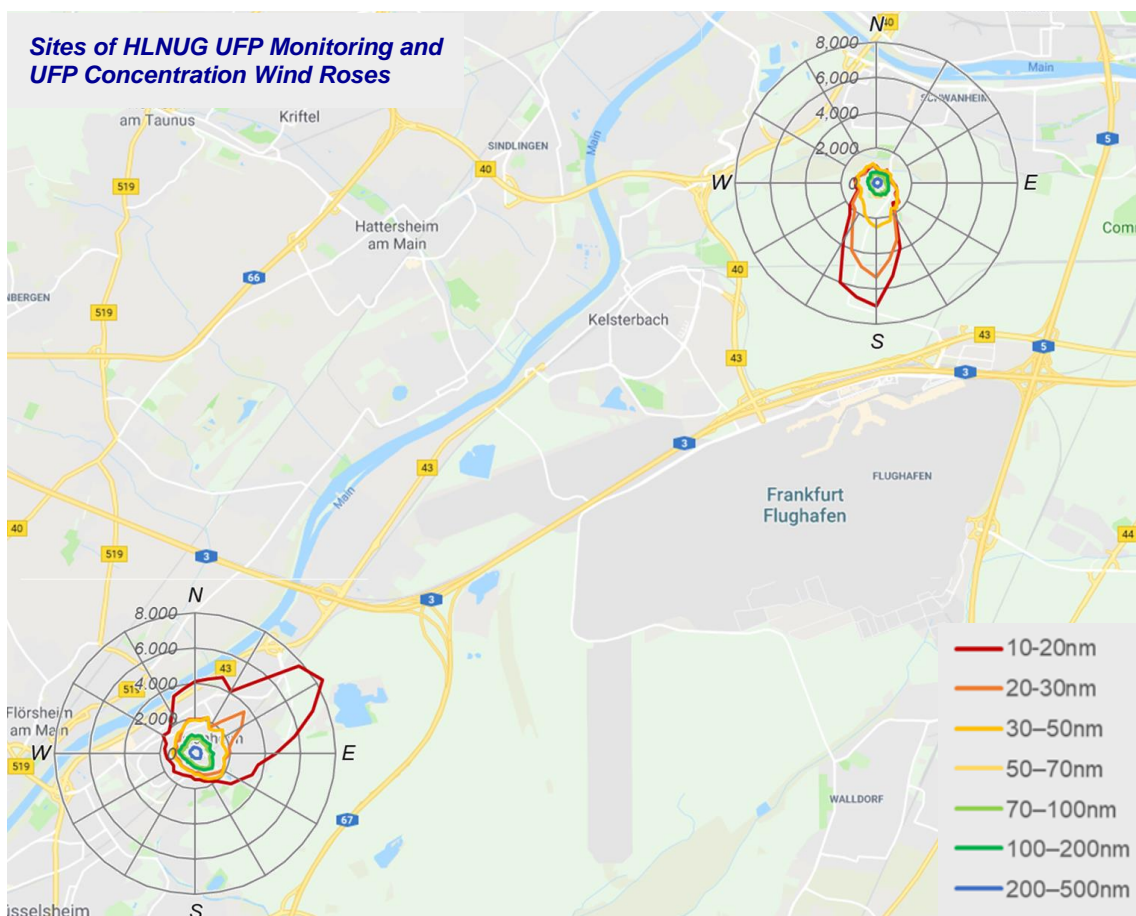
In the previous Annual Report, we already described monitoring results of the particle number at the HLNUG station of Raunheim. Modelling this figure correspondingly was not yet possible, but a relation to aircraft emissions was indicated by model calculation results for other constituents of the aircraft engine exhaust. Further detailed UFP monitoring results are now available, and particle number can be simulated by the Lasport calculation model. Coincidence between monitoring and calculation results, however, is not to be expected for now. Aircraft UFP modelling is just at the beginning, and it only covers the stable, primarily emitted proportion. In contrast, with the available measurements, all particles from all sources are sampled, which means the volatile ones as well, which are formed secondarily during transport but may also decay again.

HLNUG Measurement in Raunheim and Schwanheim

For the year 2018, not only measured particle numbers are available but also their distribution among size classes. To this end, particular measuring equipment is required, which has just been in use since autumn 2017. Until then, only the total particle number was counted. Both monitoring systems cover particles beyond the maximum diameter of 100 nm defined for UFP, however, larger particles contribute little to the total number. The lower size classes are particularly meaningful for the following evaluation. In addition to the information on size distribution, another HLNUG monitoring station, situated close to the airport, has been available in the Schwanheim district of Frankfurt since October 2017.

Dependence of Measured Particle Number on Wind Direction

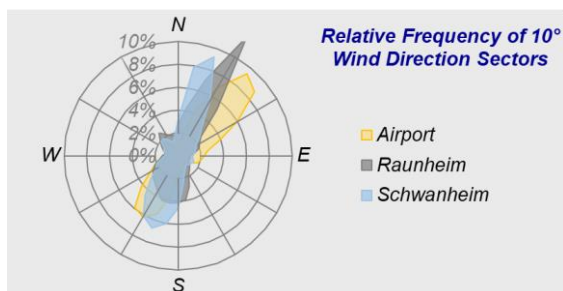
The directional concentration distributions displayed in the map below denote the two sites of Raunheim to the south-west and Schwanheim to the north of the airport. While the site of Raunheim is characteristic for urban background, the Schwanheim station is located on a sports ground surrounded by woodland



Average number of particles per 10° wind direction sector at HLNUG stations Raunheim (lower left) and Schwanheim (upper right) in 2018. The outer circle represents a mean number of 8,000 particles per ccm in the corresponding sector. The various size classes are represented by lines of different colors. Reddish to yellow colors are selected to highlight the notably small particles. Map background: Google Maps

At both of the sites, maximum values arise from wind coming from the direction of the airport, namely in the smallest size class from 10 to 20 nm (red line). While the next larger class of 20 to 30 nm (orange) contributes only a small number from the corresponding sector in Raunheim, the directional dependency is clearly evident in this class and also still present in the class of 30 to 50 nm (yellow) in Schwanheim. The number of even larger particles is smaller and distributed more regularly between the wind directions at both sites.

In Raunheim, elevated concentrations of very small particles are also found with northerly wind directions, which is not discernable for larger ones. The predominance of these smallest particles at least contradicts primary road traffic emissions as a main source with wind from corresponding directions. The latter range above 40 nm. Thus, particles below 23 nm are not even considered by vehicle certification measurement.



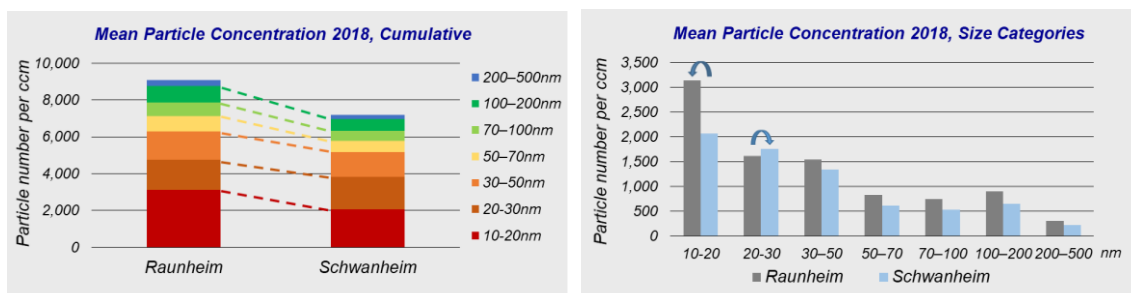
The diagram to the left shows relative frequency distributions of the wind direction in 2018 at the sites of the airport, Raunheim and Schwanheim for additional information. While the DWD monitoring series at the airport is complete, approximately 3% of the wind values are missing in Raunheim and 20% in Schwanheim. Failures, however, were distributed throughout the year in each case, so the relative distributions will barely be affected.

A maximum from the northeasterly sector is common to all three of the sites, being more pronounced than usual this year and corresponding to the dry and warm weather conditions. The secondary maximum from the south-southwesterly direction, however, turned out less, particularly in Raunheim. In the preceding year, too, such wind directions did not occur as frequently as at the airport there. Likewise, a very narrow distribution peak from the northeast was already discernible in 2017.

In Raunheim and also in Schwanheim, other wind directions are more frequent than those related to maximum UFP concentrations, a fact being naturally reflected by the annual means.

Comparison between Measured Size Distributions in Raunheim and Schwanheim

Different particle size distributions in Raunheim and Schwanheim are already apparent in the UFP wind roses. The following diagrams indicate even more distinctly that this refers to the two lower size classes in particular.

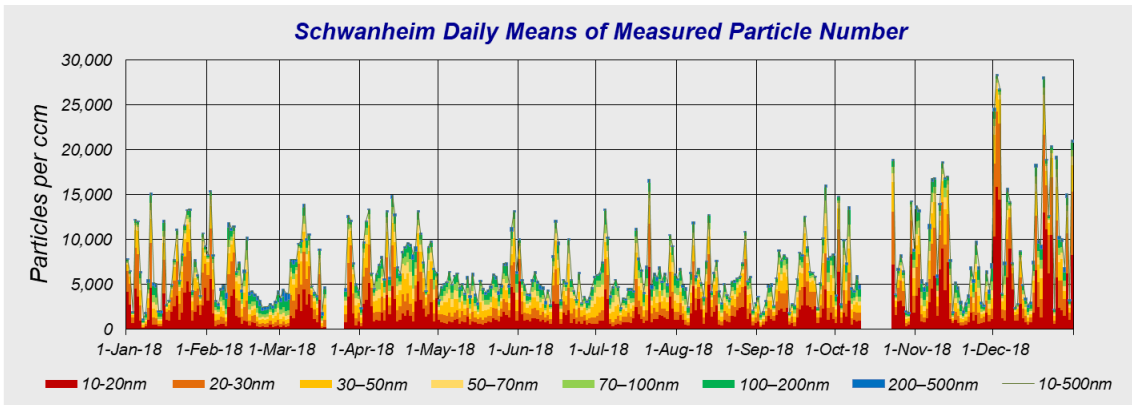
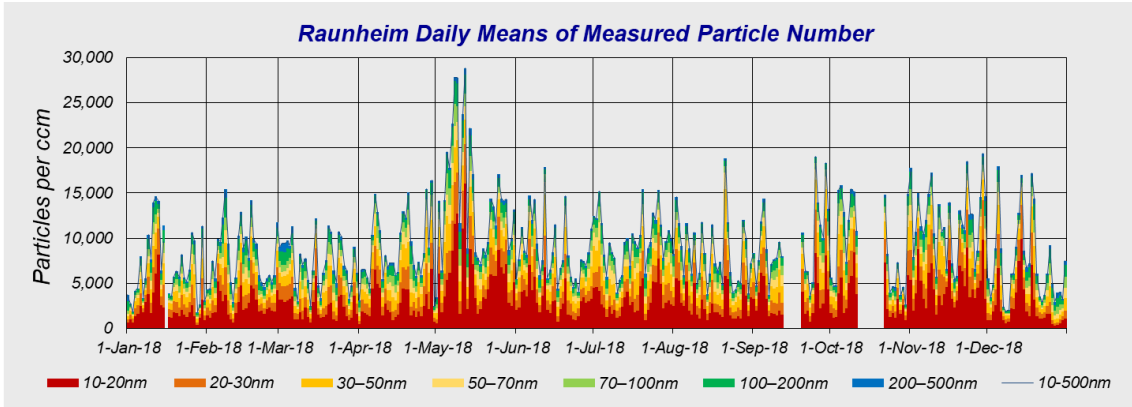


Particle size distribution in Raunheim and Schwanheim 2018. Left: total of all size classes, right: size classes separately

While the number of larger particles is uniformly just a little higher in Raunheim, a considerable difference exists with the lowest class. For the second lowest class – and only for this one – the relation between Raunheim and Schwanheim is reversed. So, in Raunheim, the smallest particles represent the maximum category, the particles that are just a little larger are less numerous than in Schwanheim there. At both sites, the two lower classes account for approximately half of the total particle number in the annual mean.

Temporal Course of Particle number

As would be expected due to the very pronounced and different UFP wind roses at both sites, there is no coincidence between the corresponding time series. When wind direction favors a high UFP concentration at one site, this cannot also be the case for the other one simultaneously due to the spatial positioning.

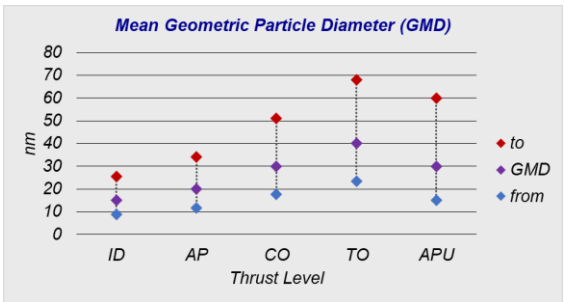


Time series of particles measured in Raunheim (top) and Schwanheim (bottom) 2018

In the time series diagrams, too, different size classes are indicated by color. The variability of daily means is discernible, the temporal pattern, the peaks in particular, being mainly shaped by smaller particles. Failures occurred in Raunheim during just several days in September and October and in Schwanheim in March and October.

UFP Modelled by Lasport

As already mentioned, the current Lasport edition 2.3 allows for the simulation of non-volatile particles emission and the resulting contribution to the ambient air number concentration. The particles are assumed to be stable, i.e. neither formation nor decay take place. The software package includes thrust-dependent emission indices as a particle number per kilogram of kerosene for each engine type. This information is not readily available in detail but is rather derived from the approach for particle mass (FOA3), having already been integrated before, and from literature on particle size distribution. Thus, particle numbers are inversely related to particle size, the particle mass emission being given as a prerequisite. So, the particle number is directly linked to particle size. The following diagram shows the particle size categories applied with Lasport referring to the four thrust settings of the landing and take-off cycle and to auxiliary power units as well.



- Abbreviations:
- FOA3 First Order Approximation (see text)
 - GMD Geometric Mean Diameter
 - ID Idle, Taxi
 - AP Approach, Descent
 - CO Climb-Out
 - TO Take-Off, accelerated ground movement for departure
 - APU Auxiliary Power Unit

Characteristic diameter of non-volatile particles due to the Lasport model. Entries "from ... to" indicate the range within a thrust level.

The FOA3 approach provides three constituents contributing to the particle mass:

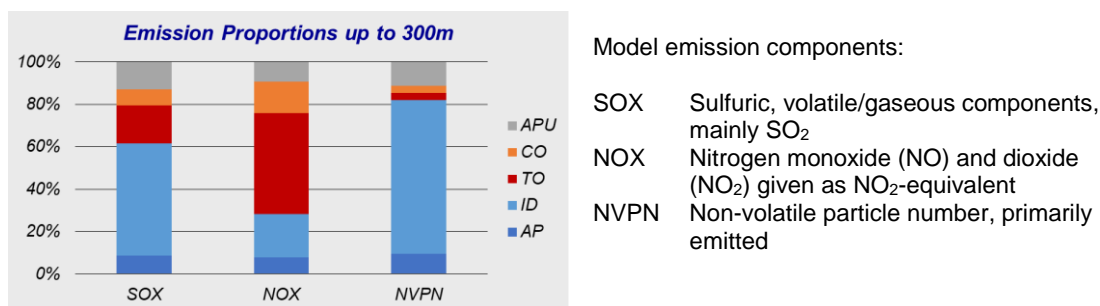
- Non-volatile (mainly soot)
- Volatile sulfuric (SO_x)
- Volatile organic (containing hydrocarbons)

The behavior of the volatile components also depends on ambient conditions. It is not (yet) possible to simulate their number by Lasport. Only the non-volatile proportion is considered in the particle number calculation as NVPN (non-volatile particle number).

Calculated Emission Proportions of Thrust Levels

For the year 2018, a Lasport calculation was performed, including only aircraft emissions from the landing and take-off cycle (LTO) and emissions from auxiliary power units. The remaining airport sources only contribute very little to the particle number, as was stated by a preliminary report on the UBA project aiming to calculate the airport's influence on the UFP concentration in the surroundings.

Depending on the component, the shares of the total emission due to each LTO mode or the APU operation are different, the emission being reported up to an altitude of 300 m here as usual. Emission shares from higher altitudes, however, are considered by the calculation, but they only contribute to a lesser extent to the ambient air concentration at surface level and thus are less relevant² in this regard. For comparison of the calculated emissions, the three components were selected that are also referred to with the ambient air comparison between calculation and measurement.



Model emission components:

- SOX Sulfuric, volatile/gaseous components, mainly SO₂
- NOX Nitrogen monoxide (NO) and dioxide (NO₂) given as NO₂-equivalent
- NVPN Non-volatile particle number, primarily emitted

Relative distribution of annual emission amounts 2018 depending on thrust levels during the landing and take-off cycle up to 300 m altitude as well as APU operation by model

The largest NVPN share results from the lowest thrust level "Idle", i.e. while aircraft is taxiing or waiting in idle mode (light blue). This is partly due to the long emission duration at that thrust. A similar effect is noticeable with SO_x. Its emission rate is proportional to the fuel consumption and thus rather small at low thrust. So in this case, too, high emission totals can only be caused by a long emission duration. Regarding NVPN, a higher emission rate in "Idle" mode has an additional effect, corresponding to the inverse relation between particle size and number.

The second largest share of the NVPN emission originates from APU operation. Here, too, a relatively long operating time is assumed. However, the basic data are not as reliable as in case of aircraft movements.

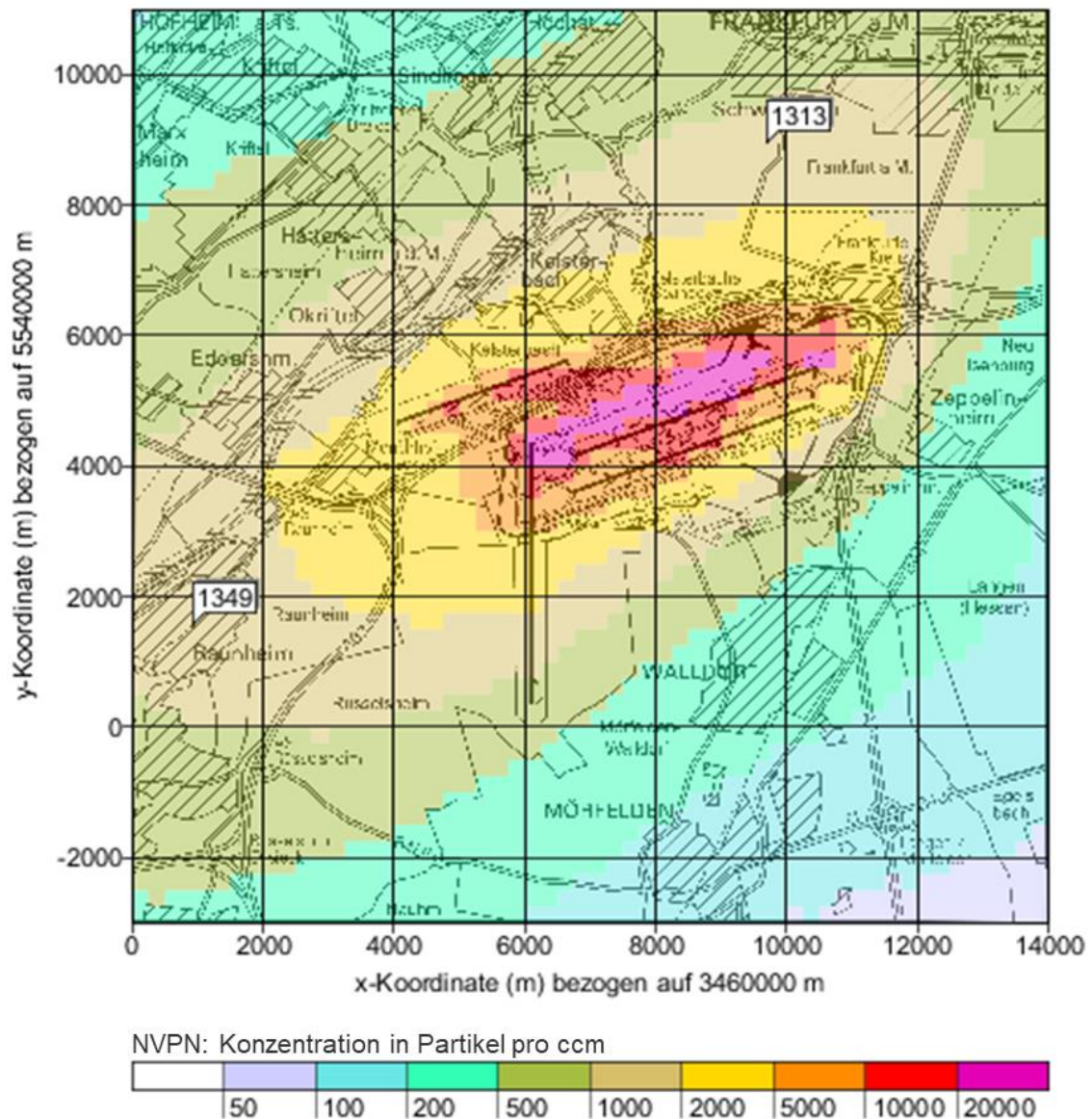
Spatial Distribution of Modelled NVPN Concentrations

The particle concentration calculated by model shows a distribution similar to other engine exhaust components. Maximum values are located in the apron area. In accordance with the distribution of frequent wind directions but also with those easterly ones being rather adverse with respect to air quality³, the concentration does not decrease as rapidly to the southwest and northeast as it does to the transversal northwest and southeast.

The annual mean arises to 1,349 particles per ccm in Raunheim and 1,313 in Schwanheim. This is considerably less than has been measured there, even if only the two lowest size classes up to 30 nm were considered, which contribute the largest share to the calculated emission. As mentioned before, coincidence of absolute monitoring and modelling results would not be expected. Below, the results are analyzed for common patterns.

² See also 5. BImSchVwV, the directive for compiling emissions inventories. The calculation of ambient air concentrations routinely covers emission up to an altitude of 3000 ft (914 m).

³ High pressure conditions along with minor atmospheric mixing

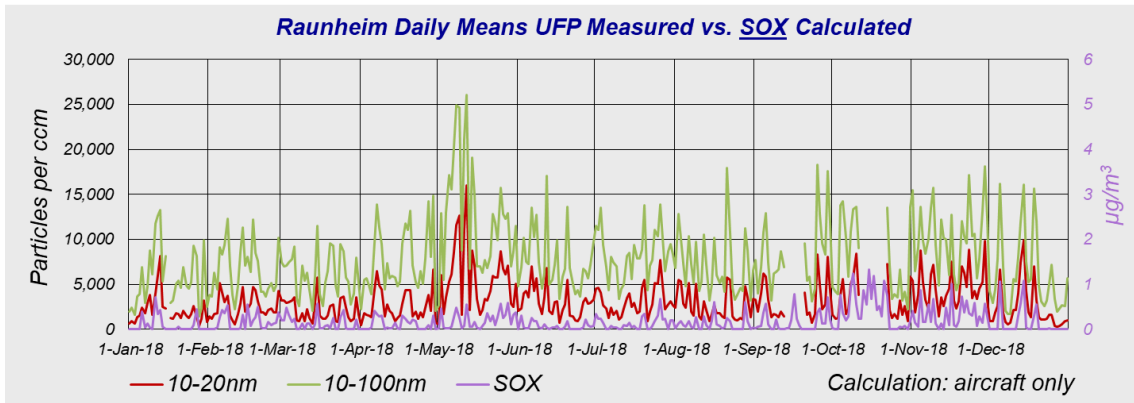
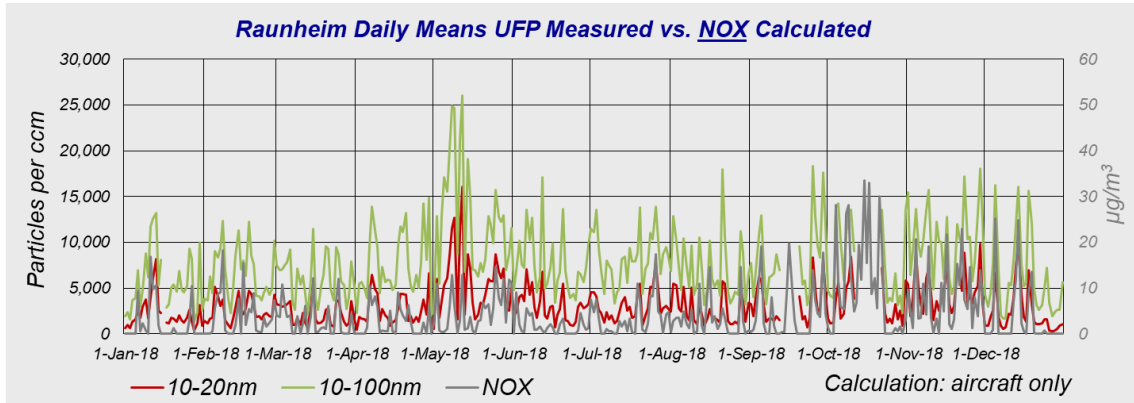
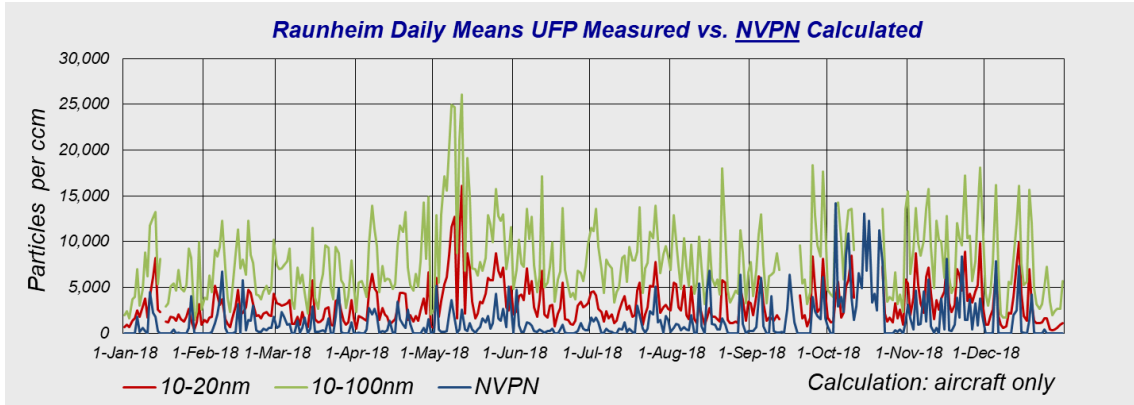


Number concentration field of non-volatile particles due to aircraft emissions as calculated by Lasport, averaged for the year 2018. Data entries within the map refer to the sites of Raunheim and Schwanheim. Coordinates in m are relative to $x=34'60,000$ and $y=55'40,000$ in the Gauss-Krüger system. Terminal 3 in the southeasterly part of the airport is still under construction.

Comparison between Measured UFP Time Series and Calculated Model Time Series of NVPN, NOX and SOX

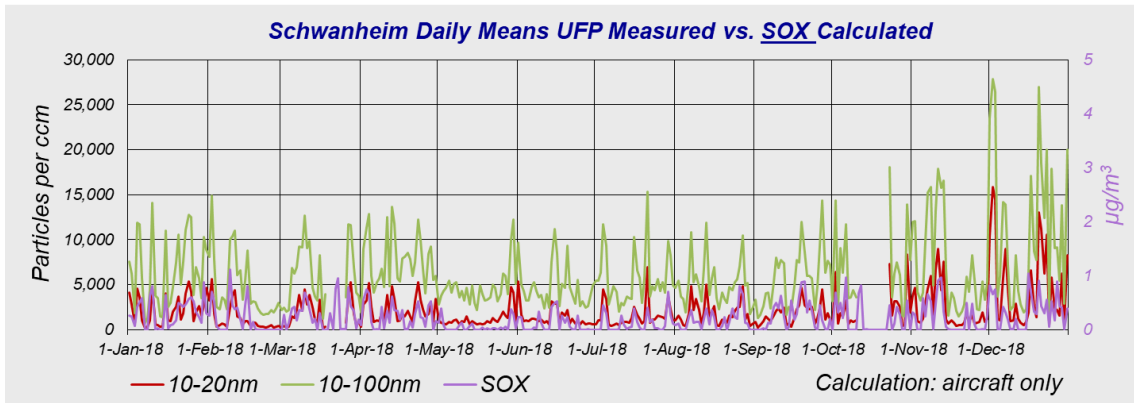
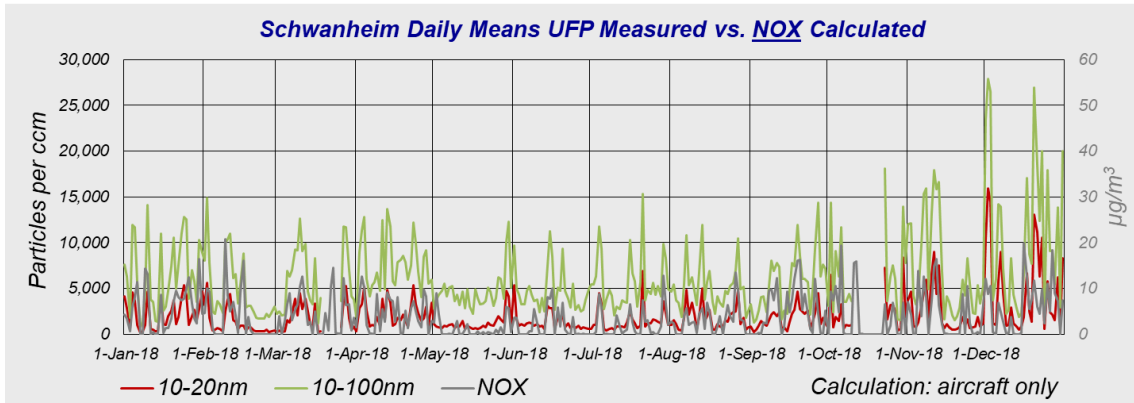
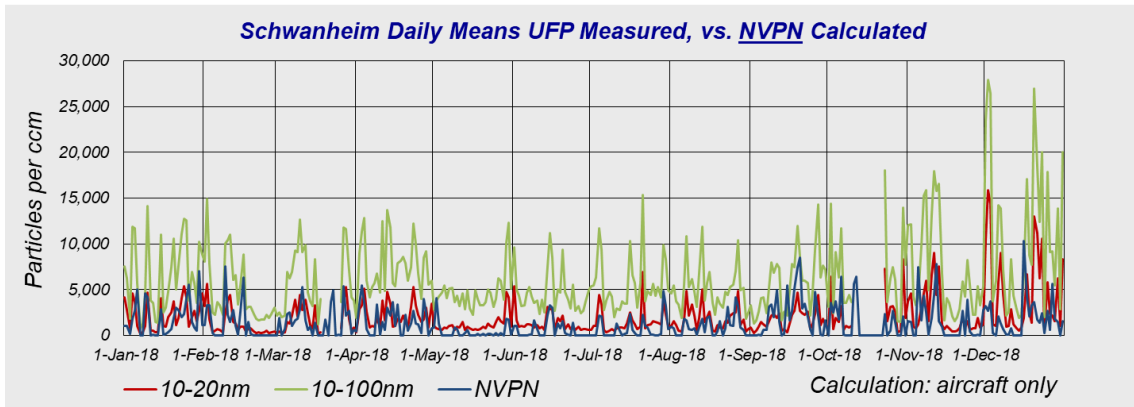
In the Air Quality Annual Report 2017, common patterns of the UFP concentration measured in Raunheim and calculated engine exhaust components were described. Although some preconditions for a reliable statistical analysis were not valid, a relation to NOX and a little less to SOX was discernable. The NVPN concentration, which is now calculable, should reveal the best match with the measured UFP concentration.

For the following comparison of time series, the class of the smallest particles from 10 to 20 nm is selected as well as the total of all UFP from 10 to 100 nm. The order of the calculated components refers to the expected degree of coincidence with the UFP measurement: NVPN, NOX, SOX.



Daily mean time series of measured UFP and model values for other components in Raunheim 2018. The right y-axis is valid for model values, optimized for the highlighted model component. Top: NVPN, center: NOX, bottom: SOX

This year's comparison of time series also yields common patterns between UFP measurement in Raunheim and all of the presented model components.



Daily mean time series of measured UFP and model values for other components in Schwanheim 2018. The right y-axis is valid for model values, optimized for the highlighted model component. Top: NVPN, center: NOX, bottom: SOX

In Schwanheim, too, common features between monitoring and model time series are discernible.

Correlations

The subjective impression of common patterns with the time series for monitoring and the model is to be confirmed quantitatively. As was done in the preceding year, the daily means of both time series are evaluated by linear regression. At this point, presenting the regression graphs is omitted. Only the correlation key figures are reported here.

The regression coefficients of determination (R^2), initially being determined just computationally, are compiled in the table below, one for each relation between a monitoring interval and the model component. Only the three lowest size classes are presented here. The weakest correlation is shaded in yellow, and the strongest one in green, along with corresponding intermediate hues.

Raunheim		Measurement 10–20 nm	Measurement 20–30 nm	Measurement 30–50 nm
Calculation	NVPN	0.24	0.29	0.17
Calculation	NOX	0.39	0.39	0.18
Calculation	SOX	0.43	0.40	0.17

Schwanheim		Measurement 10–20 nm	Measurement 20–30 nm	Measurement 30–50 nm
Calculation	NVPN	0.17	0.32	0.37
Calculation	NOX	0.28	0.46	0.46
Calculation	SOX	0.40	0.58	0.47

“Correlation” (coefficients of determination R^2) of daily means between measurement and model calculation for Raunheim (top) and Schwanheim (bottom) 2018. Three different monitoring size classes are each compared to three different model components (only aircraft)

This evaluation, too, is under the caveat of the statistical preconditions being only valid to a limited degree. Some noticeable features, however, could hint at causal relations:

- At both sites, the calculated particle number unexpectedly correlates least of all three calculation components with the measured one, and this is basically the case over all three size classes.
- The calculated SOX correlates best with the measured UFP at both sites and basically over all three size classes as well.
- In Raunheim, all three calculated components correlate particularly weak with measured particles beyond 30 nm, but with the smallest ones, however, stronger than in Schwanheim.
- In Schwanheim, all calculated components correlate even more clearly with particles beyond 20 nm than with the smallest ones.

The simplest explanation for the weak NVPN correlation with measured particle numbers would be shortcomings of the calculation model. In opposition to this, the model represents scientific knowledge with respect to the conventional components (which have already been calculable before), and it has been correspondingly validated. The newly added NVPN emission parameters have also been derived from scientific studies. Possibly, model results could be optimized by selecting a higher statistical accuracy. This would require considerably more calculation time, while it is questionable whether the tendencies that are described here and are in part rather distinct would change.

To a greater degree, the strong influence of non-calculable, volatile, secondarily formed particles on the monitoring results seems to be apparent here, which at first should naturally belong to the lower size range.

This could explain why, especially in Raunheim, the smallest particles measured correlate relatively well with the gaseous model components NOX and particularly SOX which are known to be precursors. Particle formation is enforced by a warm and sunny summer, where photochemistry also plays a role. In the course of corresponding weather situations, northeasterly wind directions prevail, as they lead to the highest concentration of smallest particles in Raunheim. Airport-independent precursor sources also contribute to the secondary particle formation here. With respect to the larger, rather non-volatile particles, such airport-independent impact seems to be decisive in Raunheim, thus not being calculable here. Correlation with model results is not expectable then and has turned out to be correspondingly weak.

In Schwanheim in contrast, model components are related more strongly to larger measured particles than to the smallest ones. This is also valid for the NVPN. Airport-independent impacts obviously contribute to a lesser extent here. In Schwanheim, too, a certain amount of secondary particles is to be assumed, even though possibly a smaller one than in Raunheim. This is indicated by the overall smaller particle counts in the lowest size class and the slightly larger number in the next higher class, which is the bottom of the diameter range for particles due to aircraft primary emissions.

For the reasons already noted, the described correlation results must not be over-interpreted. They suggest, however, that a considerable proportion of ultrafine particles measured in Raunheim and Schwanheim is admittedly related to airport and aircraft operations, but this proportion does not consist of primary engine emissions, i.e. soot. This would also have implications for the assessment of their impact. While the health impact of soot is undoubted, this may not be the case, or may not be to the same extent, for other, secondarily formed particles, in particular with regard to soluble secondary species formed from gaseous precursors like sulfur dioxide and nitric oxides. Also for this reason, assessing the presently available model and monitoring results is not yet possible.

Prospect

By now, numerous findings about the influence of airports on the UFP concentration in their surroundings are available. The Airport Council International (ACI) published a contemporary report on that in 2018. With regard to Frankfurt Airport, the HLNUG monitoring is being continued and extended in order to obtain information on the structure of the concentration field and to delimit influences of various emission sources against each other.

The research project initiated by the German Environment Agency (Umweltbundesamt, UBA), which aims at investigating the influence of Frankfurt Airport on the UFP concentration in its vicinity by use of model calculations, is about to be finalized. Here, the methods of calculating non-volatile particles due to aircraft engine emissions have been applied for the first time, which have now been integrated into the Lasport model, which was also used for this Annual Report.

Questions still remain open as to the share of volatile particles in the model calculation and the distinction between volatile and non-volatile particles in the measurement and to their chemical composition. Likewise, it is still unresolved whether, or to which extent, a health impact due to ultrafine particles has to be assumed and which of their properties are material in that regard.

In order to make progress in answering these questions, the UNH⁴ in Kelsterbach has formed a working group, designated to determine and to document the areas that still require research. Members of the competent authority HLNUG are among those who cooperate here. Fraport, too, is committed in this working group and will report on new developments in terms of knowledge.

⁴ Umwelt- und Nachbarschaftshaus, institution of the Hessian State

Further Information:

Fraport AG
www.fraport.de

HLNUG Hessisches Landesamt für Naturschutz, Umwelt und Geologie
(Hessian State Agency for Nature Conservation, Environment and Geology)
<http://www.hlnug.de>

Lasport Model Calculation
<https://www.janicke.de/de/lasport.html>

Determination of Particle Mass Emitted by Aircraft Engines according to FOA3 (ICAO Doc 9889)
https://www.icao.int/publications/Documents/9889_cons_en.pdf

ACI EUROPE: Ultrafine Particles at Airports. 2018
<https://www.aci-europe.org/component/downloads/downloads/5566.html>

UFP Monitoring in Raunheim (Jacobi et al. 2016)
<https://www.hlnug.de/themen/luft/sonstige-berichte/ultrafeine-partikel.html>

UFP Monitoring in Schwanheim (Rose, Jacobi 2018)
https://www.hlnug.de/fileadmin/dokumente/luft/sonstige_berichte/ufp/1_Zwischenbericht_HLNUG_Ultrafeinstaub_final_Korrigendum_20180619.pdf

UBA-UFP-Project UFOPLAN 3716 52 200 0

DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
of 21 May 2008
on ambient air quality and cleaner air for Europe
http://ec.europa.eu/environment/air/quality/legislation/existing_leg.htm

DWD data CDC
<https://cdc.dwd.de/portal/>