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Using a UAV to Assess Air Pollution and Identify Dominant Emission Sources

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ABSTRACT

Central Europe is the region with the highest concentration of particulate matter with aerodynamic diameter less than 10 micrometers (PM10) in outdoor air. Weather conditions combined with a high industrialization of regions laying along the Czech Republic and Poland border influence the formation of long smog episodes with PM10 concentrations in the atmosphere at the value of several hundred micrograms in a cubic meter. However, it has been observed that the main source of particulates pollution in the area of the Polish-Czech border between the most populated areas of Ostrava and Katowice is the residential heating fired with solid fuels, participating at the level of not less than 21% in overall air contamination with dusts. It particularly concerns PM10, which is one of the major harmful air pollutants produced by the combustion of solid fuels such as biomass and coal. The measures leading to decrease the dust emission from coal burned individual heat sources include methods to eliminate old-type boilers not permitted by the law, as well as illegal incineration of fuels of bad quality or including admixture of wastes. It requires a new approach for effective identification of such sources, as well as for recognition of pollutants leaving household emitters and evaluation of their share in overall effect on human health. Unmanned aerial vehicles (UAVs) equipped with miniaturized sensors detecting gaseous and dust particles at the outlet of an individual emitter can compensate the lack of information unable to be obtain using traditional measurements. The use of UAVs to identify specific sources of air pollution is still at an early stage of development and there are not too many scientific publications on this topic so far. Despite it, this technology seems to be usable to create undemanding, low-cost and effective method of air pollution sources assessment. In the current article, some aspects of using UAVs for identification of especially troublesome emission sources located on residential areas are presented, including finding the dominant emission source, determining the optimal distance between a UAV and the emission source or the influence of the UAV altitude, movement and sampling time on measurement result.

Keywords: air pollution, UAV, drone, emission measurement, pm10, residential emission.

INTRODUCTION

Central Europe is the region with the highest concentration of particulate matter with aerodynamic diameter less than 10 micrometers (PM10) in outdoor air. Air pollution, especially airborne particulate matter, causes adverse effects on human health, including respiratory diseases, cardiovascular diseases, and carcinogenic effects [Fanizza et al., 2018]; it is also classified by the International Agency for Research on Cancer (IARC) as carcinogenic to humans (Group 1) [IARC, 2013]. Due to high hazard for health, particulate matter is currently considered as the best indicator of the health effects of ambient air pollution [Vicente et al., 2018].

Weather conditions, combined with a high industrialization of regions lying along the border of Czech Republic and Poland, influence the formation of long smog episodes with PM10 concentrations in the atmosphere at the value of several hundred micrograms in a cubic meter (Moravian-Silesian Region, 2019). However, it has been observed that the main source of dust pollution in the area of the Polish-Czech border between most populated areas of Ostrava and Katowice (Silesian Province) is the residential heating fired with solid fuels [Bitta et al., 2018], participating at the level of not less than 21% in overall air contamination with dusts. It particularly concerns PM10, which is one of the major air pollutants produced by the combustion of solid fuels, such as biomass and coal [Chafe et al., 2015].

The measures leading to decrease the dust emission from coal burned individual heat sources include the methods to eliminate the old-type boilers not permitted by the law, as well as illegal combustion of fuels of bad quality or including admixture of wastes. It requires elaborating a new approach for effective identification of such sources as well as for recognition of pollutants leaving emitters of the low-height type and evaluation of their share in overall effect on human health [Markowicz and Chiliński, 2020].

Unmanned aerial vehicles (UAVs) equipped with miniaturized sensors detecting gaseous and dust particles concentrations can compensate the lack of information about the behavior of particular emitters that cannot be obtained using traditional measurements. The use of UAVs to identify specific sources of air pollution is still at an early stage of development and there are not too many scientific publications on this topic so far. Nevertheless, this technology seems to be possible to create undemanding, low-cost and very effective method of air pollution assessment, compared to the expensive conventional air pollution monitoring. Due to unique approach to acquire spatial information on air pollution ensuring vital advances in air quality monitoring through huge increases in spatial and temporal resolution of data, using UAVs may be an interesting option. It surely represents the future of air pollution monitoring, taking into account the intensive technological advances observed both in improvements of the flying platforms themselves and the air pollution sensors possibilities [Cárdenas et al., 2018; Rossi et al., 2017; Ren et al., 2019].

In the current article, some aspects of using UAVs for identification of especially troublesome residential emission sources are presented.

USING UAVS FOR RESIDENTIAL EMISSION ASSESSMENT

As it has been stated, effective identification using the measurements performed "from the outside" of the old-type boilers prohibited by the law, as well as illegal incineration of fuels of bad quality or including admixture of wastes, is vital in the fight for clean air. This goal could be achieved by using UAVs to ensure the contact of measurement equipment with exhaust gases from the combustion of solid fuels at the chimney outlet in order to assess emission. Unfortunately, evaluation of the pollutants emission with the use of UAV – in view of the impossibility to measure the actual stream of gases containing emitted pollutants – is not possible. Instead, measurement of gases and dust concentrations with the option of pointing the dominant sources of their emission can be performed. In addition, analysis of flue gases composition for the presence of substances confirming the co-incineration of substances prohibited by law (i.e. waste), can be also executed.

There are known practical implementations of the UAV usage in various areas related to fuel combustion. With regard to single sources, various applications can be pointed out – concerning, for example, fuel combustion in car engines [Weber et al., 2017], open flame combustion [Aurell et al., 2017], estimating the impact of explosions conducted in the exploration of open pit coal mines in Australia [Alvarado et al., 2015] or exhaust gas emissions from ships [Knudsen, 2016]. In order to use UAVs for measurement purposes, they need to be equipped with appropriate measuring equipment, which – in view of the UAV's limited lifting capacity and the required short time for taking measurements – requires careful, considered selection [Yungaicela-Naula et al., 2017]. In the case of the measurement using flying platforms with measurement systems, due to the regulations in force, but also – and perhaps above all – due to the real risks involved, much attention must be paid to the issue of flight safety. It is a key element of measurement methods of this kind [Armstrong, 2010]. Due to significant distortions of measurement conditions related to the influence of air streams generated by the UAV's propellers and its movement in relation to the turbulent air around the inlet to the measurement systems, extensive work is also required to properly calibrate the measurement devices, as well as to determine corrections making the obtained results more realistic [Alvarado et al., 2017]. An interesting extension of the measurement methodology using UAV may be the automatization of flights, allowing on the one hand less human involvement in the measurement procedure, thus reducing the cost and increasing the availability of measurement, as well as improving the repeatability and thus the quality of measurements on the other hand [Yungaicela-Naula et al., 2019]. It is also important to interpret the results obtained solely on the basis of pollutant concentrations together with meteorological conditions taken under consideration [Køcks, 2016].

The presented work describes the basis for conducting UAV measurements aimed at assessing particular PM10 emission sources in order to point the ones with above average harmful influence.

KEY ASPECTS OF PM10 MEASUREMENTS USING UAVS

There are significant differences between the measurement of dust concentrations in the air performed with a UAV equipped with good quality measuring equipment and stationary measurement. Both positives and negatives can be pointed out. The positives include:

- the ability to quick and rough assess the location of the dominant emission source in a group of sources,
- the possibility of covering with measurements the impact of single sources or their groups regardless of wind direction,
- ability to perform measurements at many points in a short period of time, i.e. with quasi-steady meteorological parameters,
- ability to perform measurements in the places inaccessible for the stationary equipment,
- use of a single set of apparatus for measurements in various, distant locations,
- low unit cost of the measurement.

Among the negatives, one can indicate:

- inability to directly perform long-term measurements (hourly, daily, yearly), which are pointed in the European legislation as the basic parameters of air quality assessment,
- unrepresentative heights of measurements above the ground, not corresponding to human habitation levels,
- influence of the UAV's velocity on the measurement,
- inability to perform measurements in certain types of weather,
- unfavorable regulations limiting the measurement capabilities of UAVs,
- lack of possibility of flights in some areas (proximity of airports, military units, industrial facilities, government offices, etc.).

The most valuable advantage among the ones mentioned above, is the ability to roughly assess the location of the dominant emission source within a group of sources by UAV.

Localising the dominant emission source

The location of the dominant emission source can be found by flying both on the windward and leeward side of the emitters group, along the measurement path perpendicular to the mean wind speed vector (Fig. 1). On the basis of the location of the maximum of the sum of concentrations measured by the UAV, after subtracting windward concentrations and knowing wind direction, the location of the source with increased emissions can be indicated. The analysis of the obtained concentrations distributions allows determining the rough location of the area where the dominant source is present as a rectangle with the longitudinal symmetry axis perpendicular to the mean wind vector, which crosses the concentration distribution line at the maximum point. Its precision is usually high enough to locate the actual dominant source. The idea of the measurement is shown in Figure 1.

Determining the wind direction, which is an important element of the measurement, requires on-line access to local meteorological data or the use of the own portable meteorological station. The task to be solved is the distance from the emission sources enabling effective measurement, as well as the velocity of the UAV during the flight, determining the time of its stay inside each particular dust plume and thus the spatial "resolution" of the measurement.

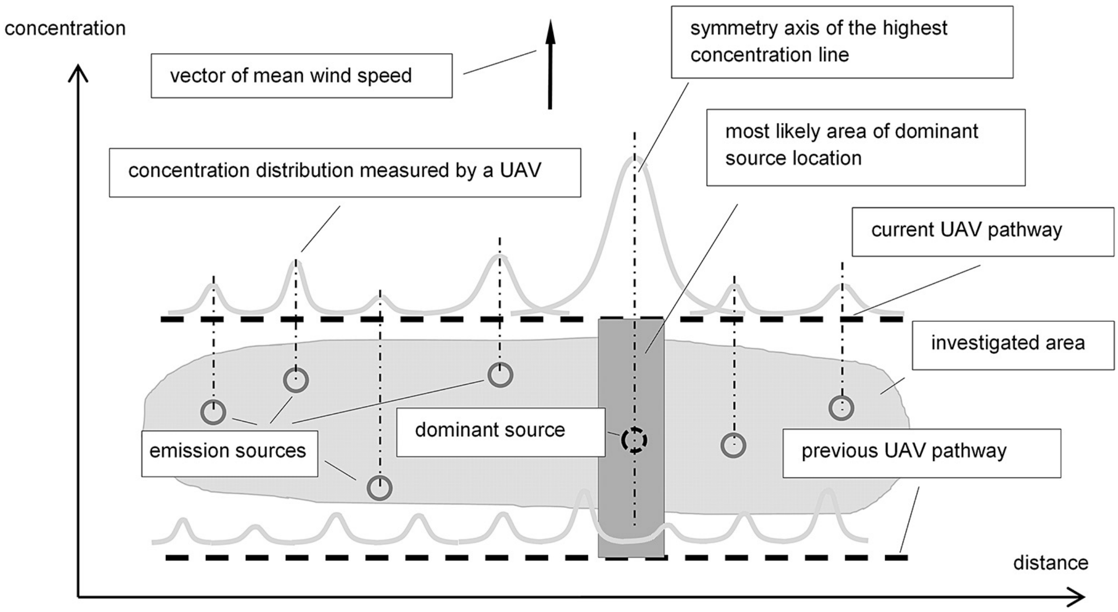

Figure 1. Graphical presentation of the idea of searching for the dominant source of emissions using a UAV (view from above)

Optimal distance between a UAV and the source during the measurement

The key issue to be resolved before proceeding with the measurements is to determine the appropriate distance of the UAV from the emitter outlet, ensuring the optimal measurement conditions. The exhaust gases flowing out from the emitter undergo intensive, turbulent mixing with air, resulting in a rapid decrease of concentration together with a distance rise from emitter. Figure 2 shows a graph revealing the percentage of pollutant concentration in the air related to the initial value (at the emitter outlet), estimated by a simple Gaussian advection-diffusion model. These numbers were calculated along the axis of the exhaust gas path at a distance of up to 25 meters from the emitter for an atmosphere with low turbulence (temperature inversion) and a wind speed of 2 m/s.

It should be noted that wind speed higher than those taken into account in the calculations means even lower final concentration values. Such a rapid drop of concentrations with the distance, even at high initial concentrations, can lead to exceeding the low measuring thresholds of the sensors used, especially while measurements are made not precisely in the plume axis. To address this issue, it is necessary to confront the limits of the measuring thresholds of devices used in UAVs with the concentration values. Table 1 presents examples of measurement thresholds of

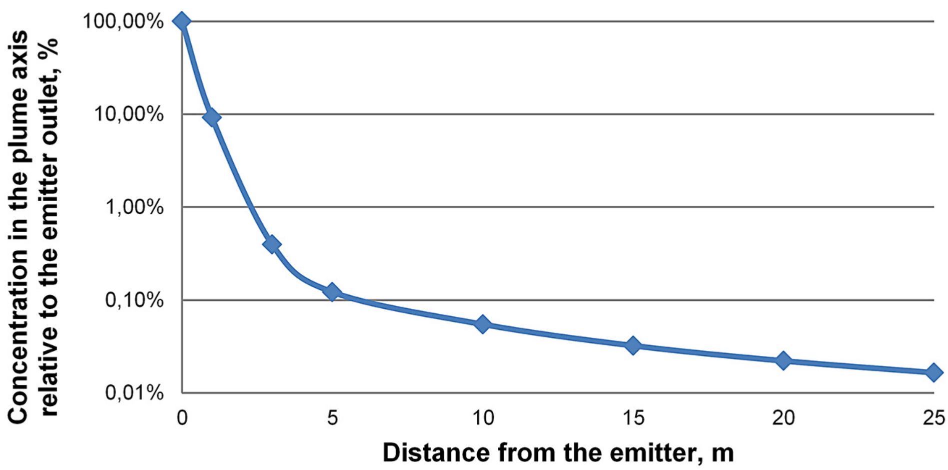

Figure 2. Calculated concentration in the plume axis in relation to the emitter outlet

Table 1. Measurement thresholds of SCENTROID sensors designed to be used with a UAV for a few exemplary substances. The LDT and MDL symbols denote the Lowest Detection Threshold and Maximum Detection Limit, respectively

Substance	Sensor symbol by *SCENTROID*	Threshold	
		LDT	MDL
		µg/m³	µg/m³
PM10	PM1-10	1	2000
SO_2	SD2	85	57000
NO_2	ND1	60	40000
NO_2	ND2	4000	2000000

SCENTROID concentration sensors dedicated to be used as UAV accessory.

Table 2 shows the concentrations of PM10, SO_2 and NO_2 estimated in some distances from the emitter using the same Gaussian model. Low atmospheric turbulence corresponding to the atmosphere stability class F has been assumed and emissions corresponding to the operation of ordinal boiler fired with coal fuel of the worst quality, heating a building with an area of 150 m^2 at the assumed temperatures: internal 22 °C and external -5 °C. Moreover, the most frequent wind speed of 2 m/s (wind speed class 1.5–2.5 m/s) was taken for the estimation.

The concentrations obtained as a result of simulation were confronted with the measurement capabilities of sensors, as shown in Table 2. As it can be seen, during the measurements it is easy to exceed the MDL of the PM10 meter at a distance from the emitter of less than approx. 2.5 m, in which other substances are well measurable. At further distances, up to approx. 30 m, the concentrations of particulate matter in the air should be within the measuring range of the PM10 sensor. At the same time, the concentrations obtained for other air pollutants at a distance of more than 5 m from the emitter quickly drop to LDT – in particular NO_2. Therefore, it becomes important to maintain the appropriate distance between the UAV and the emitter during the measurements. It should be as small as possible – it can be seen that in this case the probability of exceeding the MDL is much lower than not achieving LDT. Therefore, while the flight path should approach the emission sources as close as possible, at the same time it should not be closer than 3 m from emitters (for the considered sensors) – both for obtaining relevant level of PM10 concentration and maintaining flight safety.

Sampling time

Another factor that should be taken into account when carrying out the measurement is the time that elapses from the introduction of the sample into the sensor, through the performance of the concentration analysis ending with the storing of the measurement result. In the nomenclature of apparatus manufacturers, it is referred to as response time (*RT*). Its value depends on the type of substance to be measured. The shortest *RT* applies to dusts, due to the laser measurement method used in their case. For other substances *RT* is longer – in the extreme case (e.g. measurement of CO_2 concentrations) it takes even 2 minutes. The response times of concentration sensors

Table 2. Theoretical concentrations of PM10, SO_2 and NO_2 as the function of the distance from emitter (under assumptions: F stability of atmosphere, wind speed 2 m/s, emissions assigned to ordinal boiler fired with worst quality coal, working for a 150 m^2 building with the assumed temperatures: internal 22 °C, external -5 °C) in compare with LDT and MDL sensor thresholds

Distance from source	Theoretical concentration, µg/m³						
	PM10	LDT<Conc.<MDL	SO_2	LDT<Conc.<MDL	NO_2	LDT<Conc.<MDL	
symbol	PM1-10		SD2			ND1	ND2
m	µg/m³		µg/m³		µg/m³		
1	66129	>MDL	39521		9782		
3	1896		1133		280		<LDT
5	972		581		144		<LDT
10	393		235		58	<LDT	<LDT
15	231		138		34	<LDT	<LDT
20	159		95		23	<LDT	<LDT
25	119		71	<LDT	18	<LDT	<LDT

Note: MDL - maximum detection limit, LDT - lowest detection threshold.

Table 3. Response times of typical SCENTROID sensors intended for concentration measurements of solid fuel combustion products in the air, applicable for UAV measurements

Substance	Sensor symbol by *SCENTROID*	*RT*, s
PM10	PM1-10	<1
SO_2	SD2	20
NO_2	ND1	60
CO2	CD1	120

for typical solid fuel combustion products are shown in Table 3.

The response time should be closely correlated with the velocity of the UAV in the transverse direction to the wind vector. A measurement aimed at identifying an above-average emitting source in the group must be characterized by sufficient selectivity to enable capturing, during the flight, increased concentrations corresponding to higher emissions. Table 4 shows the estimated approximate width D of the cross-section of the pollutant plume (in theory containing 68% of the mass of the pollutant) as a function of the distance L from the emission source and the maximum cruising velocity, ensuring that a single concentration measurement is made "inside the plume" and thus covers the full width of the section without going beyond its limits.

It should be noted that the measurement result appears (or in most cases is stored in internal memory) with a time shift depending not only on the RT of the measuring device used, but also on the time of the air sample transportation to the device, counted from the moment it is sucked into the sampling line. Due to the suction tubes of rather great length, which makes it possible to move the point of suction outside the area of the diluting impact of the UAV propellers, this time cannot be skipped. In the case of a measuring device used during the conducted measurements, this time is 28 seconds. The intersection of the highest concentration axis with UAV pathway (Fig. 1) should be sought right on this path, at a point that has been reached by a UAV appropriately earlier than spotting the highest concentration by UAV sensors. The difference between these two time points is reflected by the sum: the sensor RT and the time of transporting the air sample to sensor via the suction line.

Influence of a UAV movement on the measurement result

The measurement of ambient air concentrations, whether conducted in a stationary manner or using a moving platform (e.g., a UAV), always involves – to a greater or lesser extent – the measurement of time-varying temporary concentrations, which are next averaged over some period of time. These variations are related to:

- changeability of emissions,
- variability of wind direction, wind speed and other parameters of the atmosphere,
- stochastic nature of phenomena influencing concentrations distribution in the air,
- interactions between individual pollutants.

On the basis of the mathematical definition of the average value, a general equation can be written to describe the average concentration C_{me} obtained during continuous, uninterrupted measurement over the time τ_{me}:

$$C_{me} = \frac{1}{\tau_{me}} \cdot \int^{\tau_{me}} C(\tau) d\tau \quad (1)$$

where: $C(\tau)$ – temporary, non-zero, time-varying concentration.

Table 4. Maximum UAV velocity for performing full measurement "inside" of the cross-section of a plume with dimension D

RT, s		120	60	30	10
L	*D*	Maximum UAV velocity			
m	m	m/s	m/s	m/s	m/s
5	4	0.03	0.06	0.13	0.40
10	7.5	0.06	0.12	0.25	0.75
15	10.5	0.09	0.18	0.33	1.05
20	13.6	0.11	0.22	0.45	1.36
25	16.6	0.14	0.28	0.55	1.66
50	30.7	0.25	0.5	1.02	3.07

In the formula above, the effective measurement time τ_{me} has been introduced – as the time with entirely measureable concentrations (in practice, the concentrations lying only above the lowest measurement limit (*LDT*)). For actual conditions, concerning also the time in which $C(\tau)$ was not measurable, Eq. 1 can be decomposed into a form that includes both mentioned time segments, where the τ^t_{me} mean the total measurement time:

$$C^t{}_{me} = \frac{1}{\tau^t{}_{me}} \cdot \int^{\tau^t{}_{me}} C(\tau)d\tau = \\ = \frac{1}{\tau^t{}_{me}} \cdot \left\{ \begin{array}{c} \int^{\tau_{me}} C(\tau)d\tau + \\ + \int^{(\tau^t{}_{me}-\tau_{me})} C(\tau)d\tau \end{array} \right\} \tag{2}$$

The second integral appearing on the right hand of Eq. 2, corresponding to the concentrations lying below the *LTD* of the applied measuring device, takes the zero value in the interval (τ^t_{me} - τ_{me}). It means that Eq. 2 becomes:

$$C^t{}_{me} = \frac{1}{\tau^t{}_{me}} \cdot \int^{\tau_{me}} C(\tau)d\tau \tag{3}$$

After division Eq. 3 by 1, Eq. 4 is obtained:

$$\frac{C^t{}_{me}}{C_{me}} = \frac{\frac{1}{\tau^t{}_{me}} \cdot \int^{\tau_{me}} C(\tau)d\tau}{\frac{1}{\tau_{me}} \cdot \int^{\tau_{me}} C(\tau)d\tau} \tag{4}$$

Simplifying the equal integrals in the numerator and denominator of Eq. 4, changes it into the form:

$$\frac{C^t{}_{me}}{C_{me}} = \frac{\tau_{me}}{\tau^t{}_{me}} \tag{5}$$

where: C_{me} – the average concentration obtained over the time τ_{me}, when the concentrations are greater than zero (in practice: measurable).

Equation (5) can be used to analyze the concentration measurements performed by a UAV, characterized by relatively low values – often falling below the *LDT*. For the most common scheme, the actual total time of a single measurement τ^t_{me} corresponds to the time constant T_c of the measurement device used, which means that the highest accuracy of the C^t_{me} concentration estimate ($C^t_{me} \approx C_{me}$) can be achieved at $\tau_{me} \rightarrow T_c$. It implies that in the most common case, where the UAV flies transverse to the motion of a pre-identified pollution plume (Fig. 1), the flight velocity which ensures that the entire width of a single exhaust plume is traveled in a time not shorter than T_c, can be identified as optimal.

The stationary concentration measurement (i.e. without taking into account the UAV's motion)which is described by Eqs. 2–5, undergoes the scheme as the one presented at Figure 3. The stream of air containing varying amounts of the measured substance arrives to the reception point *Rec* (inlet to the measuring device), due to advection generated by the wind.

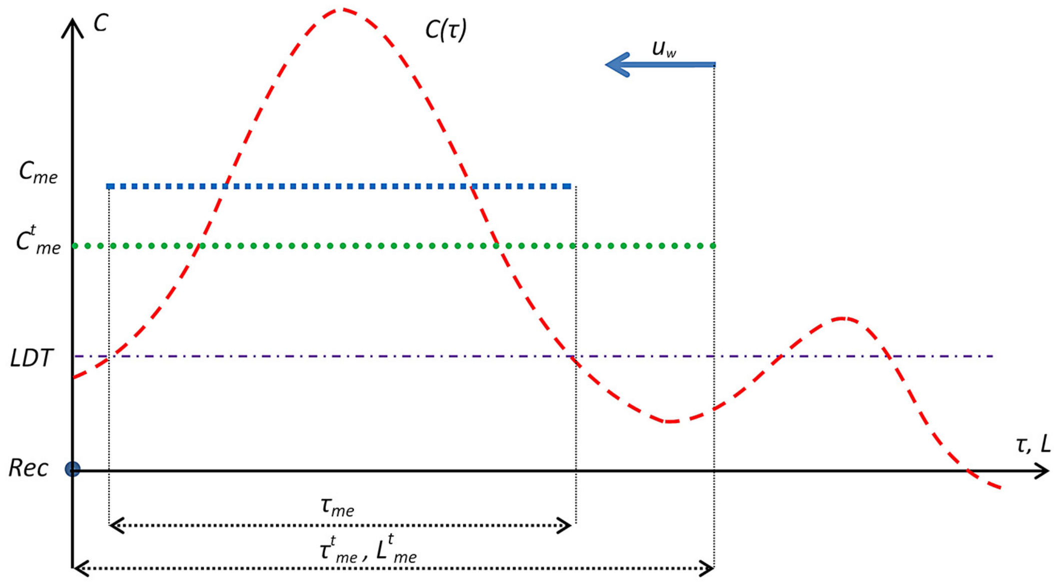

Figure 3. The instance of concentrations distribution in the incoming air, with the measurement path Ltme visible. LDT – lowest detection threshold

In the case of stationary sensors, the measured concentration corresponds to the instantaneous values recorded in the incoming air stream, averaged in time τ^{t}_{me}. These concentrations are shaped along the path of length L^{t}_{me}, which the stream travels before reaching the measurement point (Fig. 2). Assuming that the air stream moves with the average wind speed u_W, the length of the path section undergoing to concentration averaging (which results in appearing of a single, mean concentration value) can be estimated as:

$$L^{t}_{me} = u_W \cdot \tau^{t}_{me} \tag{6}$$

When performing concentration measurements with non-stationary devices (as with the use of a UAV), their velocity, relative to the earth, has influence on the final result. In the most special case, the *Rec* measurement point (the apparatus on the UAV) moves in the direction opposite to the u_W vector with a velocity u_{dr}. Since these velocities add up, there is an apparent increase in the length of the stream segment influencing the measuring device to L'^{t}_{me}, with the measurement time τ^{t}_{pom} unchanged (Fig. 4):

$$\begin{aligned} L'^{t}_{me} &= u_W \cdot \tau^{t}_{me} + u_{dr} \cdot \tau^{t}_{me} = \\ &= (u_W + u_{dr}) \cdot \tau^{t}_{me} \end{aligned} \tag{7}$$

The length L'^{t}_{me} can also be represented as the product of the wind speed itself and a hypothetical, correspondingly extended measurement time τ'^{t}_{me} taken at a stationary measurement point (Fig. 3):

$$L'^{t}_{me} = u_W \cdot \tau'^{t}_{me} \tag{8}$$

From the equality of the left-hand sides of Eqs. 7 and 8, the formula for the apparent measurement time associated with the movement of the sensors is obtained:

$$\tau'^{t}_{me} = \tau^{t}_{me} \frac{u_{dr} + u_W}{u_W} \tag{9}$$

After applying Eq. (4), the formula for the concentration C'^{t}_{me} considering the velocity of the UAV is obtained:

$$C'^{t}_{me} = C^{t}_{me} \frac{u_W}{u_{dr} + u_W} \tag{10}$$

Equation (10) has limited applicability - e.g. to situations, where a UAV moves towards an emission source and flies over it, continuing the measurement on the windward side of the emitter with zero concentrations. This leads to obtaining the concentrations that are lower than the actual ones.

Moreover, the flights following the wind direction can be a source of significant measurement errors. For instance, at $u_W = u_{dr}$ the UAV moves, maintaining invariable position with respect to the concentration curve from Figure 3, with the actual concentration value decreasing successively with the distance from the emission source under the influence of atmospheric diffusion mechanisms (advection has no role in it).

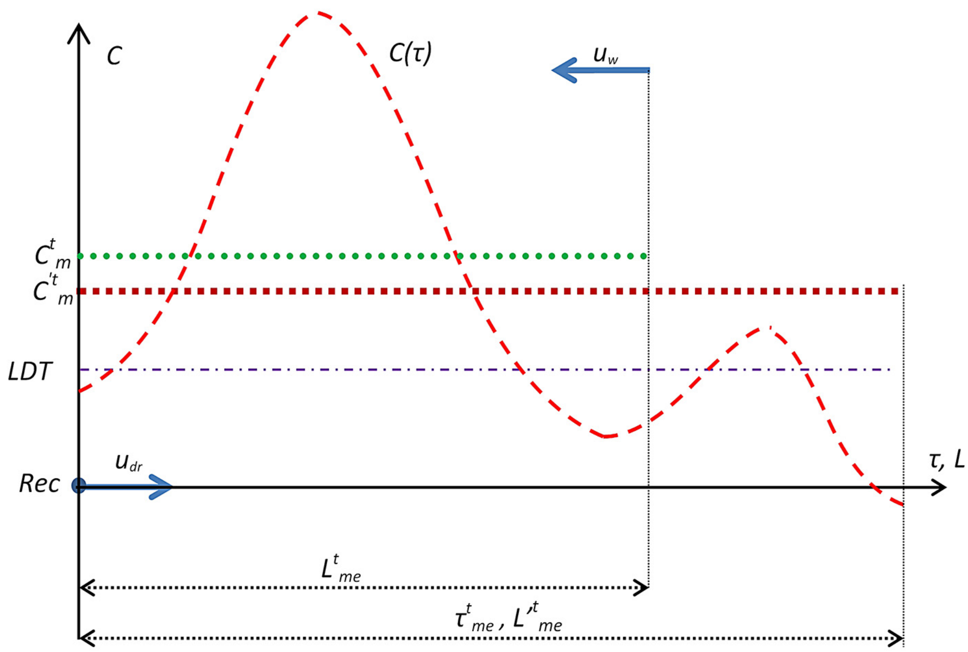

Figure 4. The instance of concentrations distribution in the incoming air, with the increased measurement path L'tme visible

During the flights carried out in accordance with the scheme from Figure 1 (the UAV's movement occurs transverse to the mean vector of wind, although usually it is not exactly perpendicular to it), the component of the wind vector u_w in the direction of the UAV's movement assumes small values, which leads to an increase in the significance of the UAV's velocity u_{dr} in Eq. (10) and, in general, to the appearance of small values of the fraction on its right side. This means that the C'^{t}_{me} concentrations obtained under such conditions may reach low values in relation to the real ones, leading to underestimation of the concentrations generated by significant emission sources and, consequently, to the lack of their identification.

Altitude of flights

The choice of flights altitude is affected by two basic factors:

- safety reasons – the flight must take place at a safe distance from the roofs of buildings,
- representativeness of the obtained concentrations.

Representativeness is associated with the existence of related, characteristic phenomena:

- the effect of the plume "reflection" from ground surface on the concentrations of pollutants,
- the real distribution of concentrations, connected with existence of inversion layer,
- strong dispersion of contaminants induced by increased mechanical turbulence introduced into the flow by buildings.

In particular, the representativeness of the measurement is affected by its height over the terrain. For safety reasons, it is usually carried out above local buildings and therefore well above the human habitation zone. In fact, the concentrations at this level comparable with the emission typical for residential sources are clearly higher than at the level of the ground surface. Therefore, the results of the measurements of this type do not reflect the degree of atmospheric pollution in the human habitation zone. In theory, and sometimes also in practice, it is possible to indicate a certain height above the roofs of houses which corresponds – in terms of concentration levels – to the values obtained at the average height of human habitation (by default 1.7 m above the ground level). The decisive phenomenon for such a distribution is the reflection of the plume from the ground, which increases the concentration value at a short distance from the emission sources. The essence of the phenomenon is illustrated in Figure 5.

Taking it into account requires preliminary measurements of the concentrations vertical distribution and choosing the height over the level of maximum concentration, on which concentration value corresponds to the one appearing on the ground. While using this method, the new vertical measurement should be made in every change of the inspected buildings height, distance between them or the horizontal gap from the flight axis. Although this type of measuring concentration is closer to the reality, the flight level should be lowered to an emitter outlet heightened by 1–2 m due to sensitivity and safety reasons.

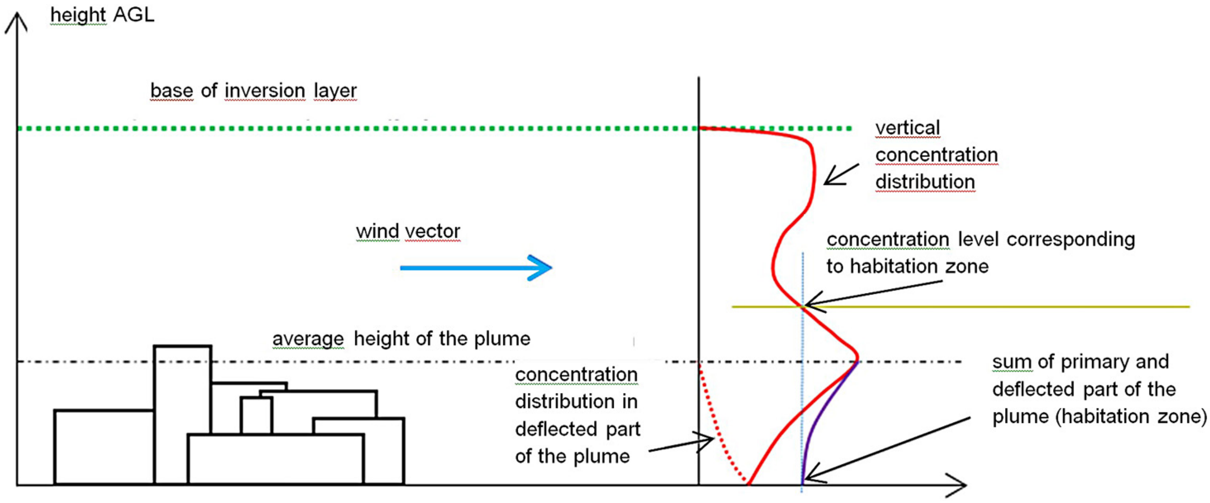

Figure 5. Effect of measurement height on obtained pollutant concentration values (AGL – above ground level)

CONCLUSIONS

The identification of dominant emission is an important field of UAV applications in air protection against the emissions from residential heating. A number of conditions must be met by the measurements to bring the expected results. Among them are those related to the distance of the UAV from the source, the measurement time, the velocity of the UAV and its impact on the measurement result, as well as the flight altitude. In order to ensure optimal conditions for searching the sources of above-average dust emission with the use of UAVs, a simple methodology for identifying such sources was developed at the ITPE, and the impact of the above-mentioned factors on its representativeness was analyzed. The conclusions steaming from the presented analyses are as follows. The presented methodology provides good opportunity to identify the dominant emission sources. During measurements, the sensors with increased sensitivity should be used (designed for measurements in ambient air, not in the exhaust gas stream). The following optimal parameters should be maintained during flight. The optimal horizontal distance of the UAV from the source during the measurement, taking into account the average sensitivity of measuring devices, should be 3–5 m. The height of a flight should be located inside the zone of concentration maxima and thus be performed at the average height of the emitter outlet. In practice, for safety reasons, this height should be raised to the level exceeding an emitter outlet by 1–2 m. In order to increase the measurement area (by accelerating velocity of the UAV), it is necessary to select the sensors with a small averaging time. In practice, devices with an averaging time of 30 s should be used with an averaging time 2 min being absolute maximum. The velocity of UAV must match to the averaging time. For the adopted configuration: distance of 5 m and averaging time of 30 s, this velocity should not exceed 0.13 m/s (i.e., about 0.5 km/h). With the actual measurement time of 20 min, this means a total length of the measurement path covered in a single flight of about 150 meters.

The influence of UAV movement on the measurement result, when the UAV is equipped with air sampling probes extended beyond the area of influence of the UAV's propellers, is not significant. When estimating the location of the emission point, the time shift between the measurement result appearance and the collection moment should be taken into account in such a case, related to the relatively significant time of sample transport to the measurement system.

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