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Use of Ultrasonic Anemometer Data to Derive Local Odour-related Peak-to-mean Concentration Ratios

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In Austria, a peak-to-mean approach is used to transform half-hourly mean concentrations calculated by the Austrian Odour Dispersion Model AODM to instantaneous values depending on the stability of the atmosphere describing the stimulus concentration of the odour perception. The reduction of the peak-to-mean ratio with distance due to turbulent mixing is described with an exponential attenuation function which involves knowledge of the standard deviations of the three wind components. Apart from obtaining these values via prescribed relations from the known average wind speed (approach by Robins), they can be derived directly from 3D ultrasonic anemometer measurements. Therefore, a measure of atmospheric stability has to be used. In this work, it has been determined by the Austrian Reuter-Turner scheme (based on cloudiness and wind speed) and the Obukhov Stability Parameter (OSP) derived directly from the ultrasonic anemometer measurements. The latter delivers site-specific attenuation curves. Results for two sites are presented and compared to general attenuation curves obtained from the Robins' approach.

1. Introduction

Odour is perceived by humans in the time scale of a single breath (i.e. 4 seconds on average; Kleemann et al., 2009). The so called peak-to-mean concept is a way used in some countries (for an overview, see Piringer and Schauberger, 2013) to adopt dispersion models which usually calculate half-hourly or hourly averages of concentrations to the relevant short-term odour concentrations. The Austrian peak-to-mean approach is used in the Austrian Odour Dispersion Model (AODM) described by Piringer et al. (2007) and Piringer et al. (2013). In the latter the possibility to take the necessary meteorological information from three-dimensional ultrasonic anemometers to arrive at site-specific attenuation curves for the peak-to-mean factor was already discussed. The importance of the peak-to-mean approach for odour impact criteria is discussed in Schauberger et al. (2012), Sommer-Quabach et al. (2014a) and Sommer-Quabach et al. (2014b). This approach is described here in detail (Section 2), and results are demonstrated for two Austrian sites with different meteorological conditions (Section 3). In the Conclusions, some practical implications are discussed.

2. Methodology

The peak-to-mean concept in the AODM is based on a relationship by Smith (1973), where the peak-to-mean factor $\psi_0 = C_p / C_m$ is given by:

$$\frac{C_p}{C_m} = \left(\frac{t_m}{t_p} \right)^a \qquad (1)$$

with the mean concentration C_m calculated for an integration time of t_m (1800 s) and the peak concentration C_p for an integration time of t_p (5 s). The exponent a depends on atmospheric stability (Table 1). The maximum peak-to-mean factors ψ_0 valid near the odour source are given in Table 1 for an approach used in a Texas regulation (Beychock, 1994).

Table 1: Exponent a and maximum peak-to-mean ratio (ψ_0) depending on atmospheric stability (Beychock, 1994)

Stability class		a [-]	ψ_0 [-]
2	very unstable	0.68	54.74
3	unstable	0.55	25.47
4	neutral	0.43	12.57
5	slight stable	0.30	5.85
6	stable	0.18	2.88
7	very stable	0.18	2.88

Due to turbulent mixing, the peak-to-mean ratio is reduced with increasing distance from the source. Mylne and Mason (1991) analysed the fluctuation of the plume concentration and developed a relationship where the peak-to-mean ratio is modified by an exponential attenuation function of T / t_L by

$$\Psi = 1 + (\Psi_0 - 1)\exp\left(-0.7317\frac{T}{t_L}\right) \tag{2}$$

where $T = x/u$ is the time of travel with the distance x and the mean wind speed u, t_L is a measure of the Lagrangian time scale (Mylne, 1992), and Ψ_0 is the peak-to-mean factor given in Table 1.

The time scale t_L is taken to be equal to σ^2/ε where $\sigma^2 = \frac{1}{3}\left(\sigma_u^2 + \sigma_v^2 + \sigma_w^2\right)$ is the variance of the wind speed taken as the mean of the variance of the three wind components u, v, and w, respectively, and ε is the rate of dissipation of the turbulent energy using the following approximation:

$$\varepsilon = \frac{1}{k\,z}\left(\frac{\sigma_w}{1.3}\right)^3 \tag{3}$$

where k = 0.4 is the von Karman constant and z = 2 m is the height of the receptor, the human nose.

In Austria, discrete stability classes (Reuter, 1970; ÖNorm M 9440, 1992), abbreviated “ON” to indicate their origin from the cited Austrian Standard, are determined as a function of half-hourly mean wind speed and a combination of sun elevation angle, cloud base height and cloud cover; alternatively, the radiation balance or the vertical temperature gradient, each in combination with the mean wind speed, can be used. The details of the two schemes are given in section 4.6 of Piringer *et al.* (2005).

Atmospheric stability can also be deduced from three-dimensional (3D) ultrasonic anemometer measurements. The scheme of Golder (1972) is used here and shown in Table 2. The table shows the Obukhov Stability Parameter OSP (m^{-1}) depending on the roughness length z_0 (m) and the stability class. In this way, stability classes are obtained without additional sensors or data.

Table 2: Dependence of Obukhov stability parameter (m^{-1}) from the roughness length (z_0) and the Reuter (1970) stability class (adapted from Golder, 1972)

Stability class		Roughness length z_0 [m]					
Reuter/ON		0.01	0.02	0.05	0.1	0.2	0.5
2	very unstable	-0.085	-0.080	-0.070	-0.060	-0.050	-0.040
	Class limit	-0.066	-0.060	-0.050	-0.040	-0.030	-0.015
3	unstable	-0.045	-0.040	-0.030	-0.025	-0.020	-0.010
	Class limit	-0.025	-0.020	-0.016	-0.012	-0.010	-0.005
4	neutral	0.000	0.000	0,000	0.000	0,000	0,000
	Class limit	0.006	0.005	0.005	0.004	0.003	0.002
5	slightly stable	0.012	0.010	0.008	0.007	0.006	0.005
	Class limit	0.020	0.015	0.012	0.010	0.008	0.006
6	stable	0.040	0.030	0.025	0.020	0.017	0.015
	Class limit	0.059	0.050	0.039	0.033	0.028	0.025
7	very stable	0.080	0.070	0.055	0.050	0.045	0.040

Before the widespread use of 3D ultrasonic anemometers, assumptions of the relationship between the standard deviations of the three wind components and the mean wind speed u were used; we followed those proposed by Robins (1979) and given in Tables 3 and 4. For σ_u/u and σ_v/u, no change with stability is assumed. Deviating from Robins (1979), σ_w/u is taken in the AODM to be stability-dependant, assuming an increasing importance of σ_w compared to u in unstable conditions.
The ratios in Tables 3 and 4 can also be directly determined from ultrasonic anemometer data via the OSP. This is demonstrated for the two Austrian sites Weißbach (Table 3) and Limmersdorf (Table 4). Weißbach is situated in the narrow Saalach valley in the county of Salzburg which at the site stretches from SE to NW. A valley wind system is dominant here, with night-time downvalley winds from SE, daytime upvalley winds from NW. Limmersdorf is a very calm site in a broad south-alpine basin near Klagenfurt. Wind speeds below 1 ms^{-1} occur predominantly in autumn and winter. At both sites, the ratios derived from ultrasonic anemometer measurements show a strong dependence also of σ_u/u and σ_v/u from stability and often larger values than suggested by Robins (1979), especially at Weißbach. The dependence of σ_w/u from stability is more in the range of Robins, but generally lower values are obtained, especially at Limmersdorf.

Table 3: Ratios of the standard deviations of the three wind components (σ_u, σ_v and σ_w) to the horizontal wind velocity u depending on the stability of the atmosphere for Weißbach. Values proposed by Robins (1979) are compared to site-specific ratios derived from 3D ultrasonic anemometer measurements (OSP).

Stability class		σ_u/u		σ_v/u		σ_w/u	
		Robins	OSP	Robins	OSP	Robins	OSP
2	very unstable	0.2	0.54	0.2	0.53	0.3	0.27
3	unstable	0.2	0.53	0.2	0.49	0.2	0.24
4	neutral	0.2	0.51	0.2	0.48	0.1	0.24
5	slight stable	0.2	0.47	0.2	0.47	0.1	0.24
6	stable	0.2	0.53	0.2	0.49	0.1	0.25
7	very stable	0.2	0.52	0.2	0.49	0.1	0.24

Table 4: Ratios of the standard deviations of the three wind components (σ_u, σ_v and σ_w) to the horizontal wind velocity u depending on the stability of the atmosphere for Limmersdorf. Values proposed by Robins (1979) are compared to site-specific ratios derived from 3D ultrasonic anemometer measurements (OSP).

Stability class		σ_u/u		σ_v/u		σ_w/u	
		Robins	OSP	Robins	OSP	Robins	OSP
2	very unstable	0.2	0.44	0.2	0.44	0.3	0.23
3	unstable	0.2	0.32	0.2	0.32	0.2	0.13
4	neutral	0.2	0.26	0.2	0.25	0.1	0.11
5	slightly stable	0.2	0.28	0.2	0.26	0.1	0.10
6	stable	0.2	0.31	0.2	0.31	0.1	0.10
7	very stable	0.2	0.33	0.2	0.34	0.1	0,10

3. Attenuation curves

The attenuation curves for the two sites are displayed in Figs. 1 a-b (solid lines: Robins; dashed lines: OSP). Generally, all peak-to-mean curves approach the value of 1 after some distance from the source, usually within a few hundred meters or less. In unstable conditions, use of OSP from sonics gives larger peak-to-mean factors, whereas in neutral and stable conditions, the differences between Robins and OSP are not so large and not systematic. The Robins' curves are of course the same in both figures. This means that, as long as no specific meteorological data are used in the attenuation algorithm (see values of Robins in Tables 3 and 4), the attenuation curves (Fig. 1, solid lines) are independent of a specific site.

The curves are displayed from a distance of 10 m from the source onwards, up to 1000 m. A Gauss model like the AODM can be applied, strictly speaking, only from distances of 100 m from the source onwards. At shorter distances the implicit assumption in Gaussian plume models that the longitudinal diffusion is negligible compared to the lateral and vertical diffusion is no longer valid (Kolb, 1981; ÖNorm M 9440, 1992). In Fig. 1, this distance is marked by a thin vertical line.

There are sometimes remarkable differences in the peak-to-mean curves between the two sites. From Fig 1, the peak-to-mean ratios for unstable conditions (classes 2 and 3) using OSP start at much higher values near the source compared to the curves from Robins, and their decrease with distance seems to be reduced, leading to maximum peak-to-mean ratios at 100 m between about 2 (Weißbach) and 8 (Limmersdorf). From Robins, a peak-to-mean ratio of only 1 is obtained at 100 m in unstable conditions. At Limmersdorf, most OSP attenuation curves deliver values above 1 several 100 m downwind. For neutral and stable conditions, the differences between the Robins' and the OSP curves are often far less pronounced. The peak-to-mean ratios then decrease less than with Robins at Limmersdorf and more rapidly at Weißbach. Looking closer at the important distance of 100 m, atmospheric stability is less important at Weißbach as the peak-to-mean factors vary only between 1 and 4, whereas at Limmersdorf, they comprise the range of 1 to 9.

So site dependence enters with the use of ultrasonic anemometer data. They are very sensitive to the surroundings of a selected site: near-by buildings or topography increase the turbulence compared to an undisturbed site, which can be reflected in high values of the standard deviations of the wind components and in a large range of observed vertical velocities. The sites selected here are representative for a narrow Alpine valley with enhanced (Weißbach, Table 3) and for a South-Alpine basin (Limmersdorf, Table 4) with reduced turbulence. Enhanced turbulence decreases, low turbulence increases the site-specific peak-to-mean curves, compared to Robins, as seen in Figure 1.

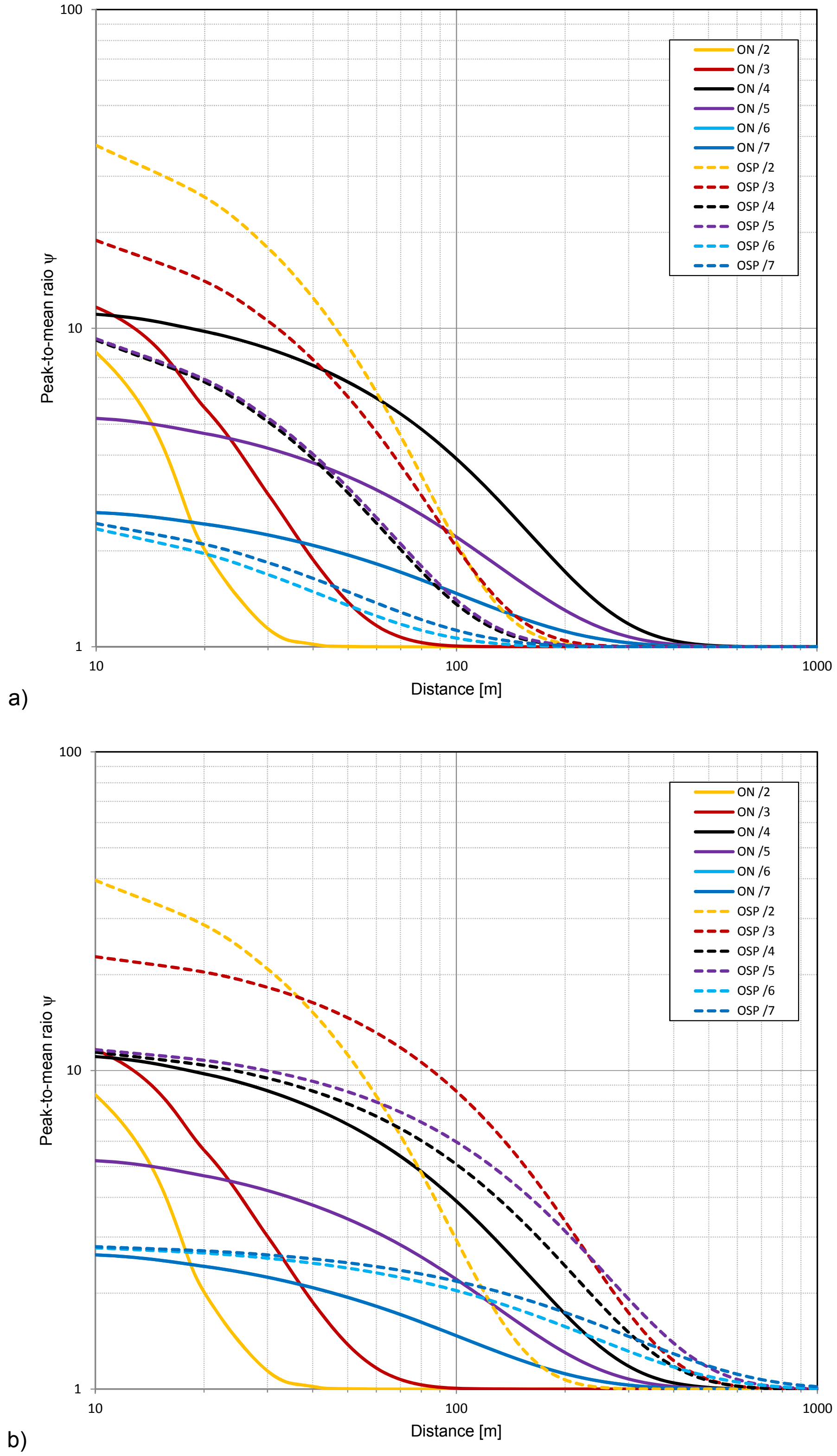

Figure 1: Peak-to-mean ratio attenuation curves dependent on atmospheric stability (classes 2 to 7) for a) Weißbach and b) Limmersdorf. The solid lines (ON) indicate the curves derived from Robins (1979) and the dashed lines (OSP) indicate those determined using the Obukhov stability parameter from the three-dimensional ultrasonic anemometer.

4. Conclusions

The implications of the described approach for local-scale odour dispersion modelling are apparent. The use of site-specific attenuation curves will increase the reliability of dispersion calculations especially when unstable conditions occur frequently, e.g. during daytime in the summer months, when also the sensibility of the population to odour perception is highest. Thus, the use of site-specific attenuation curves is recommended, whenever possible. The more such data are available, the greater the chance will be to develop a regional climatology of attenuation curves. This will have advantages for experimental expertises not only on odour pollution, but of all kinds, which often have to be carried out under financial and time constraints.

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