Odour dispersion modelling with Lagrangian and Gaussian models

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The Lagrange particle diffusion model LASAT and the Gaussian Austrian Odour Dispersion Model AODM are used to calculate direction-dependent separation distances around livestock farms. As the method has been published already in several papers, the focus is here on the differences of the results due to model physics. With both models, the same peak-to-mean algorithm is used to calculate short-term peak concentrations relevant for odour dispersion. For both models, the same emission and meteorological data, but model-specific atmospheric stability classes have been used. The estimate of atmospheric stability is obtained from three-axis ultrasonic anemometers using the standard deviations of the three wind components and the Obukhov stability parameter. Separation distances are determined for two odour impact criteria, namely exceedence probabilities of 3 and 8 %, each in combination with the odour threshold of 1 ou_E/m^3. The results will be presented and discussed for two sites with very different topographical surroundings.

1. Introduction

The calculation of separation distances between odour sources and residential areas is an appropriate method to reduce annoyance. Separation distances can be obtained from dispersion models. We use a Lagrangian and a Gaussian model to calculate direction-dependent separation distances. As dispersion models usually calculate concentrations over some integration time (half an hour or an hour), the authors developed a mechanism to account for short-term concentrations relevant for the perception of the human nose. This so-called peak-to-mean algorithm is explained in detail in (Piringer et al., 2015; Piringer et al., 2016) and applied with the Lagrangian dispersion model LASAT (Janicke Consulting, 2013) as well as the Gaussian Austrian Odour Dispersion Model AODM (Schauberger et al., 2002).
LASAT and AODM calculations have been conducted at two Austrian sites of very different surroundings, namely Kittsee east of Vienna and Weißbach in the Saalach valley in the county of Salzburg. At both sites, meteorological input data are provided by three-axis ultrasonic anemometers operated over the period of at least one year. Separation distances at both sites are determined for Austrian odour impact criteria allowing an exceedence of the odour threshold by 3 % (high level of protection) or 8 % (lower level of protection). Material and methods are outlined in Section 2, the results and a brief discussion are presented in Section 3. Section 4 contains a summary of the findings.

Citation: Piringer M., Knauder W. , Petz E., Schauberger G. (2017): Odour dispersion modelling with Lagrangian and Gaussian models. Austrian Contributions to Veterinary Epidemiology. Vol. 9, 63-71.

2. Material and methods

A description of the dispersion models and the peak-to-mean approach is in the latest version given in Piringer et al. (2016), so only a brief summary is given here to maintain the status of a stand-alone paper. The dispersion model LASAT (Janicke Consulting, 2013) simulates the dispersion and the transport of a representative sample of tracer particles utilizing a random walk process (Lagrangian simulation). It computes the transport of passive trace substances in the lower atmosphere (up to heights of about 2000 m) on a local and regional scale (up to distances of about 150 km). LASAT is usually run with the Klug-Manier stability scheme (TA Luft, 2002). The Austrian odour dispersion model (AODM, Piringer et al., 2007; Piringer et al., 2013; Schauberger et al., 2000; Schauberger et al., 2013; Schauberger et al., 2002) estimates mean ambient concentrations by the Austrian regulatory dispersion model (Österreichisches Normeninstitut, 1996; Kolb, 1981) and transforms these to instantaneous values depending on the stability of the atmosphere. The model uses a traditional discrete stability classification scheme with dispersion parameters developed by Reuter (1970).
The peak-to-mean approach used to transform the half-hourly model concentrations into short-term peak values as well as the scheme to transform the Obukhov stability parameter OSP [m^{-1}] to atmospheric stability classes depending on the local roughness length z_0 [m] are described in full detail in Piringer et al. (2016).

Figure 1: Map of Austria indicating the sites of investigation.

The Obukhov stability parameter and the standard deviations of the three wind components are derived from at least a one-year time series of ultrasonic anemometer measurements. Sonic anemometers measure the along-path velocity components from the travel time of acoustic waves between transducers separated about 10-20 cm. In addition to the three-dimensional wind vector, the sound velocity is derived, from which the so-called “sonic temperature” is calculated. The measurement of sonic temperature fluctuations is necessary to calculate the sensible heat flux. Other quantities which are derived from sonic measurements are the means, standard deviations, and co-variances of the wind components and the momentum flux, the Obukhov stability parameter, and the friction velocity. Sonic anemometers usually sample at 10 Hz, and the data are usually stored as averages over 10 minutes or half an hour.

The investigation has been carried out at two very different sites (Fig. 1) where a one year continuous data set of half-hour ultrasonic anemometer measurements is available. One is Kittsee, east of Vienna near Bratislava. The site is located at 17.070° E and 48.109 N at 136 m asl. It is within flat terrain, mainly farmland. Weissbach near Lofer (12.789 E, 47.498 N, at 678 m asl.) is situated in the Saalach valley in the county of Salzburg which at the site stretches from SE to NW. The valley with approx. only 1 km in width is relatively narrow, flanked by steep slopes with heights of several hundred meters.

Table 1: Source data for dispersion calculations.

Stack height	[m]	8.0
Stack diameter	[m]	2.7
Outlet air velocity	[ms^{-1}]	3.0
Volume flow rate	[m^3h^{-1}]	60,000
Temperature	[°C]	20
Odour emission rate	[ou_Es^{-1}]	5,200

For all model runs, the same source data are used (Table 1 and Piringer et al., 2016). These data are typical for a pig fattening unit with about 750 animals with a mean life mass of 70 kg. For the model runs, the source data are assumed constant over the year.

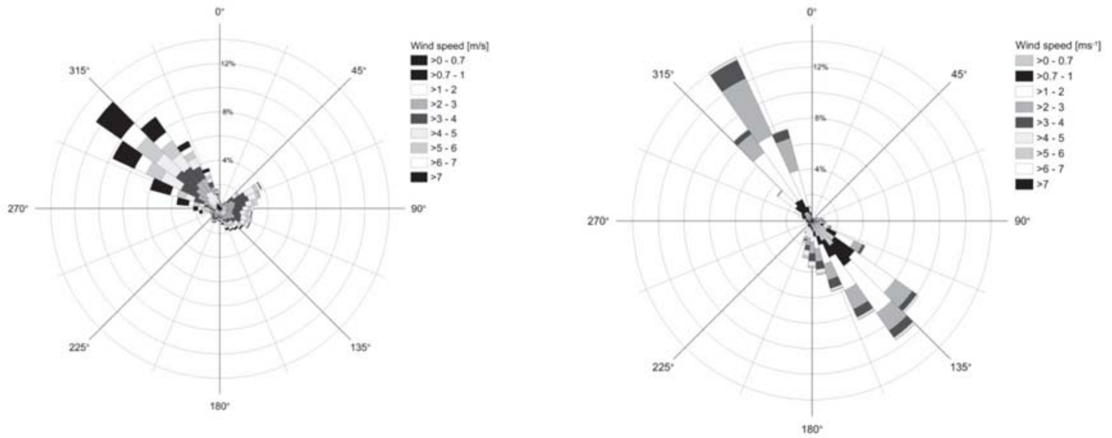

Figure 2: Wind roses at (left) Kittsee (03.03.2006 – 31.05.2007) and (right) Weissbach (01.09.2010 – 31.08.2011); black-white coding denotes wind speed.

3. Results and discussion

Kittsee can experience high wind speeds, mainly from northwesterly directions, often associated with frontal of systems and storms (Fig. 2). The secondary maximum of wind directions is from Northeast, in contrast to a lot of other meteorological stations in the area. This is explained by a topographical deflection of the regional flow in the area caused by the southernmost tip of the Carpathian mountains in the region of Bratislava North of the site. These wind directions show on average lower wind speeds as they are mainly observed in anti-cyclonic conditions.

Due to the topographical situation at Weissbach, the wind is channelled along the valley axis. Up-valley flow is from NW, down-valley flow from SE (Fig. 2b). The down-valley flow from SE shows a larger fraction of weaker winds, but also slightly more stronger winds than the up-valley flow. The strong southerly winds might also be associated with Foehn events.
The frequency of stability classes is at both sites determined from the OSP with a roughness length of 0.02 m at Kittsee and 0.5 m at Weissbach derived from on-site wind measurements. Neutral conditions are most abundant at Kittsee (Fig. 3, left panel), with 40 % for class 4 (AODM) and over 50 % for class III/1 (LASAT). This is due to the high wind speeds and/or cloudy conditions. The large differences for classes 4 and 5 compared to III/2 and III/1 is due to the different stability concepts of the Reuter and Klug-Manier schemes. Reuter's class 5 has no appropriate counterpart in the LASAT scheme.
From Fig. 3 (right panel), the frequency distribution is roughly 30:30:40 for unstable-neutral-stable conditions at Weissbach, especially for the AODM scheme. The LASAT scheme calculates slightly more stable and less unstable conditions.

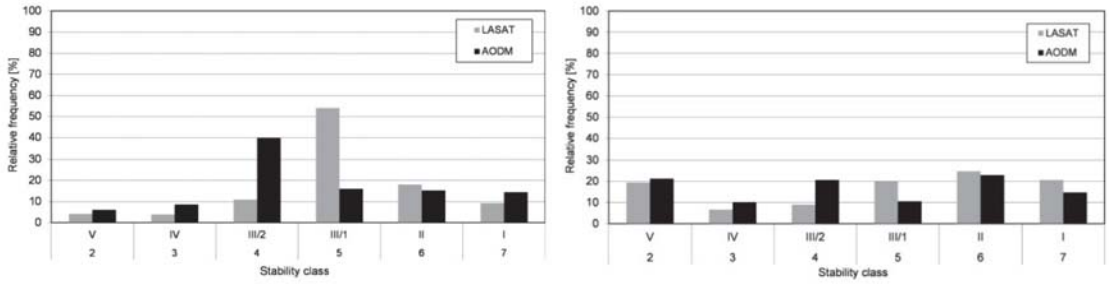

Figure 3: Relative frequency [%] of stability classes at (left) Kittsee and (right) Weissbach.

The different meteorological conditions displayed in Figs. 2 and 3 lead to remarkable differences in the dependence of the peak-to-mean factors with distance between the two sites (Figs. 4 and 5). The peak-to-mean ratios, however, start at similar values near the source. Their decrease with distance is much more pronounced at Weissbach, compared to Kittsee. In unstable conditions at Kittsee, peak-to-mean ratios at 100 m are between 5 and 8 for AODM (Fig. 4, left panel) or 4 and 5 for LASAT (Fig. 4, right panel). At Weissbach, they show a value of about 2 (Fig. 5, both panels). At Kittsee (Fig. 4), the attenuation curves in unstable conditions deliver values above 1 several 100 m downwind. At Weissbach (Fig. 5), all peak-to-mean curves reach the value of 1 about 200 m downwind, unstable conditions being most relevant here. For neutral and stable conditions at Kittsee, the peak-to-mean ratios reach the value of 1 even further downwind than in unstable conditions, so that stable conditions are most important at large distances.
The differences in the attenuation curves between Kittsee and Weissbach are due to the fact that Kittsee shows much higher wind speeds, but far less turbulence than Weissbach. The increased turbulence due to topography at Weissbach leads to a quicker decrease of peak-to-mean ratios with distance. This is explained in detail in Piringer et al. (2016) comparing the conditions at Weissbach to another flatland site in Austria.

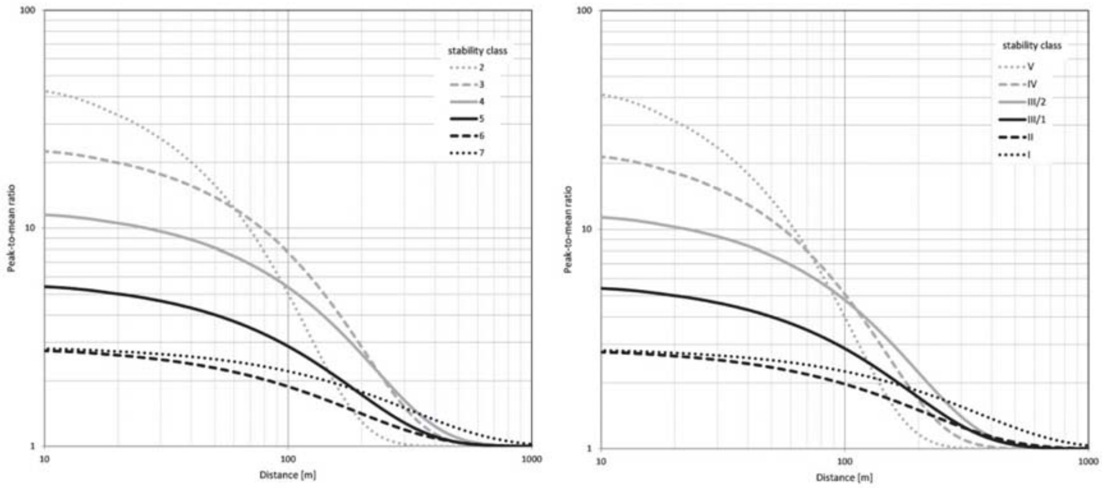

Figure 4: Peak-to-mean factors at Kittsee derived from ultrasonic anemometer data (OSP) for AODM (left) and for LASAT (right).

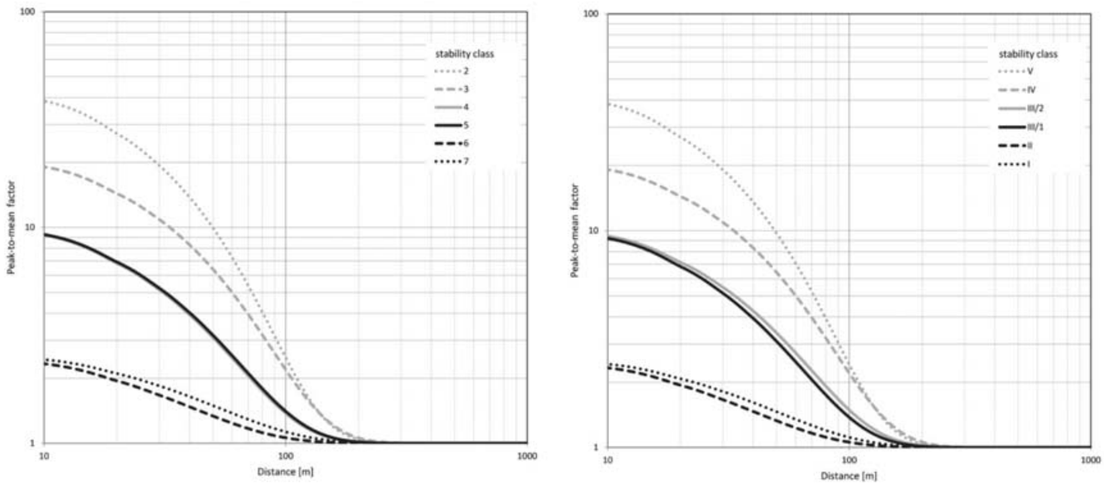

Figure 5: Peak-to-mean factors at Weissbach derived from ultrasonic anemometer data (OSP) for AODM (left) and for LASAT (right).

Direction-dependent separation distances are calculated for two odour impact criteria used in Austria: 1 ou_E/m^3 and 3 % exceedence probability, representative for recreation areas (high odour protection), 1 ou_E/m^3 and 8 % exceedence probability, representative for residential areas mixed with commercial activity (lower odour protection). Following Piringer et al. (2016), the separation distances are shown as isolines in the coming figures, encompassing the area of exceedence of the given thresholds. The larger the area, the more unfavourable is the odour impact criterion. In each of the figures showing the separation distances, AODM results (left) are compared to LASAT results (right) for the same scenario.

At Kittsee, using AODM, maximum separation distances for an exceedence probability of 3 % are about 350 m towards SE and about 250 m towards W; with 8 %, these distances are about 250 and 150 m, respectively (Fig. 6, left). The calculation with LASAT leads to a further increase of separation distances for an exceedence probability of 3 % by about 100 m (Fig. 6, right) compared to AODM. For 8 %, however, there is only a slight increase towards SE to about 320 m, whereas a decrease to about 100 m is observed towards W, compared to the AODM results.

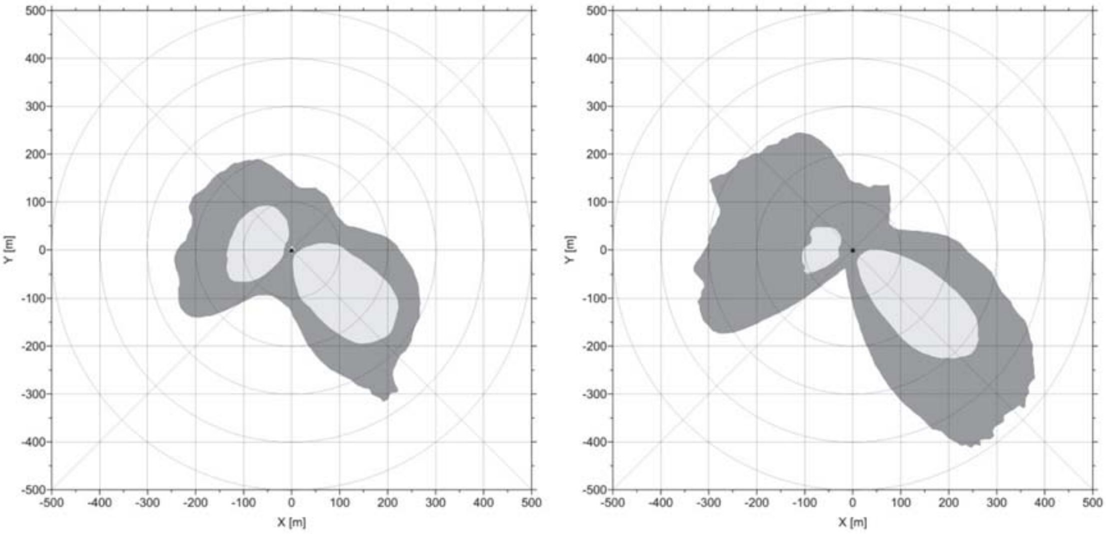

Figure 6: Direction-dependent separation distances [m] with (left) AODM and (right) LASAT for 1 ouE/m3 and 3 % (dark grey) and 8 % (light grey) exceedence probability with peak-to-mean factors derived from ultrasonic anemometer measurements at Kittsee.

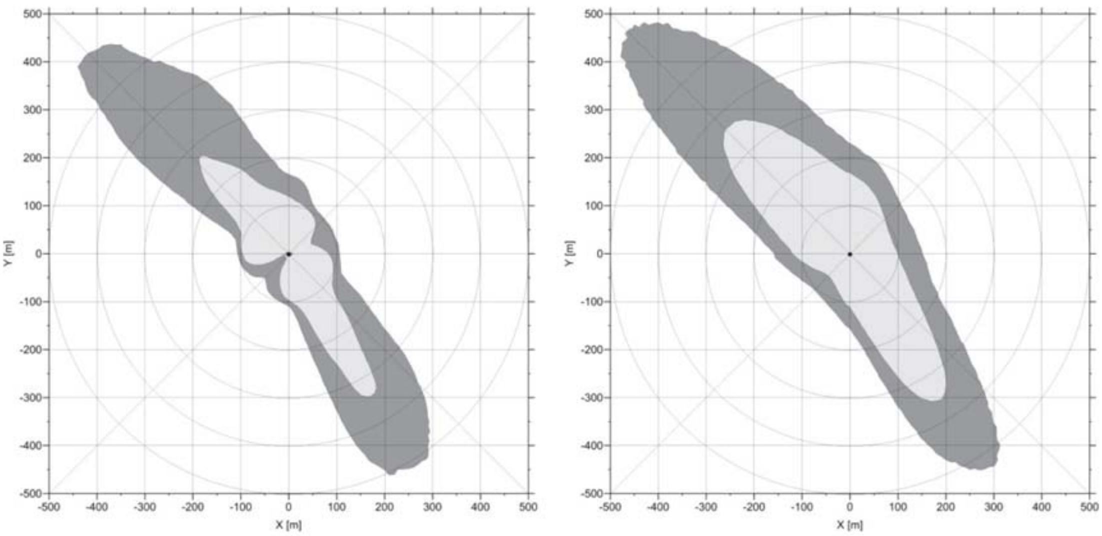

Figure 7: Direction-dependent separation distances [m] with (left) AODM and (right) LASAT for 1 ouE/m3 and 3 % (dark grey) and 8 % (light grey) exceedence probability with peak-to-mean factors derived from ultrasonic anemometer measurements at Weissbach.

At Weissbach, using AODM, maximum separation distances for an exceedance probability of 3 % are about 600 m towards NW and about 500 m towards SE; with 8 %, these distances are about 300 m in both directions (Fig. 7, left). The calculation with LASAT leads again to an increase of separation distances for an exceedance probability of 3 % (Fig. 7, right) compared to AODM. For 8 %, however, maximum separation distances calculated with LASAT only slightly increase to about 400 m in both directions, compared to the AODM results. The area of exceedances is generally larger for LASAT than for AODM.

Looking at Figs. 6 and 7, considerable differences in separation distances between the chosen sites and also systematic differences between the two models used are observed. Looking first on the differences caused by the sites, these are certainly due to the different meteorological conditions, in the first place. We selected two topographically very different sites, a flatland and a narrow valley site, for the calculation of separation distances (Fig. 1). Kittsee can experience high wind speeds, especially with winds from NW (Fig. 2a); half-hour average wind speeds up to 14 ms^{-1} are observed. In contrast, wind speeds of up to only 7 ms^{-1} occur at Weissbach in the Saalach valley, where the flow is strongly channelled along the valley axis (Fig. 2b). The near-surface atmosphere, apparently due to the topographical conditions, is much more turbulent at Weissbach than at Kittsee (Piringer et al., 2016; Piringer et al., 2015). The overall effect on the peak-to-mean factors is a more rapid decrease with distance at Weissbach compared to Kittsee (compare Figs. 4 and 5).

Another important meteorological parameter for the calculation of separation distances is atmospheric stability which is also entirely different between the two sites. Atmospheric stability is here determined from three-axis ultrasonic anemometer measurements via the Obukhov stability parameter (Section 2, see Piringer et al. (2016) for details). When transformed into stability classes, the local roughness length is also considered, and the stability schemes associated with the models (the Reuter (1970) scheme with AODM, the Klug-Manier scheme (TA-Luft, 2002) with LASAT) use different class widths and limits for this transformation. The distribution of stability classes is different between the schemes as well as between the sites (Fig. 3).

Atmospheric stability exerts an influence on the separation distances. As the peak-to-mean factors are stability-dependent, a separate curve is obtained for each stability class for their decrease with distance (Figs. 4 and 5). The differences between Kittsee and Weissbach are very pronounced, for all stability classes. Kittsee, compared to Weissbach, is thus characterized by higher wind speeds, lower turbulence and larger peak-to-mean factors. Nevertheless, the separation distances along the valley axis at Weissbach are considerably larger than the maximum separation distances at Kittsee, especially with AODM (Figs. 6 and 7).

The solution to this problem is seen in the fact that the along-valley wind directions at Weissbach are often associated with stable conditions, whereas the main wind direction sector at Kittsee is mainly combined with neutral atmospheric stability. The channelling of the flow in combination with frequent stable conditions causes higher odour concentrations and leads to the enhanced separation distances at Weissbach. This enhanced frequency apparently compensates for the peak-to-mean factors which are not relevant at Weissbach for large separation distances. At Kittsee, separation distances south-east of the source, calculated with LASAT, are with almost 500 m for an exceedence probability of 3 % comparable to those at Weissbach along the valley (compare Figs. 6 and 7, right panels). The combination of a high occurrence of wind directions and frequent neutral conditions is also prone for large separation distances. A more detailed discussion is available from Piringer et al. (2016).

As already discussed in Piringer et al. (2016), a reason for generally larger separation distances with LASAT compared to AODM is probably due to the different model physics: whereas AODM, a Gaussian model, produces a stationary concentration field for a half-hour time step, LASAT calculates concentrations as long as the trajectories stay within the model domain, thus likely increasing residence times and also separation distances. Because of this more realistic assumption we conclude that, even in flat terrain, the use of a Lagrangian model is to be preferred over a Gaussian model.

4. Conclusions

In this paper, direction-dependent separation distances are discussed derived for Austrian odour impact criteria to avoid odour annoyance at two sites, calculated with two models, the Gaussian Austrian Odour Dispersion Model AODM and the Lagrangian particle diffusion model LASAT. Short-term peak odour concentrations have been calculated with a stability-dependent peak-to-mean algorithm (Section 2). The same emission (Table 1) and meteorological data have been used for both models. The estimate of atmospheric stability is obtained from three-axis ultrasonic anemometers using the standard deviations of the three wind components and the Obukhov stability parameter. The results are demonstrated at the Austrian villages Kittsee and Weissbach (Fig. 1) which are very different with respect to their topographical surroundings (Section 2) and thus the resulting on-site meteorological conditions (Section 3). The causes for the differences in separation distances between the two sites were analysed.

The shape of the contour lines of separation distances is primarily determined by the distribution of wind directions; the elongation in the main wind directions is in addition caused by wind speed (at Kittsee) and the frequency distribution of stability classes with wind direction (at Weissbach); see Figs. 6 and 7. Weissbach is a very specific site as its location in the narrow Saalach valley leads to a strong channelling of the flow and the development of a valley wind system. Both contribute to higher odour concentrations and thus extended separation distances along the valley axis despite to the lower wind speeds (Fig. 2) and the smaller peak-to-mean factors at larger distances (Figs. 4 and 5) compared to Kittsee. The combination of a channelled flow with an enhanced occurrence of stable conditions leads to larger separation distances than larger peak-to-mean factors. Atmospheric stability in combination with frequent wind directions can be very important for large separation distances, outweighing the values of the peak-to-mean factors. In the vicinity of livestock farms, even slight reductions can become important, and they will increase with higher exceedence probabilities, often valid in agricultural areas. This underlines the importance of the peak-to-mean concept and the use of on-site meteorological information for odour impact analyses.

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