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A sensitivity study of separation distances calculated with the Austrian Odour Dispersion Model (AODM)

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Abstract

The Austrian Odour Dispersion Model (AODM) is a Gaussian model adapted for the prediction of odour sensation. It estimates the daily and seasonal variation of the odour emission, the average, ambient odour concentration and the momentary (peak) concentration for the time-interval of a single human breath (approx. 5 s). Peak concentrations, further downwind, are modified by use of an exponential attenuation function for which the ratios of the standard deviations of the wind components to the average wind speed have either to be taken from the literature or to be calculated, e.g. from ultrasonic anemometer data.

AODM calculates direction-dependent separation distances for a combination of odour threshold and exceedence probability, which are a function of the prevailing wind velocity and atmospheric stability conditions. Meteorological time series from one site in Styria in southern Austria and one site in the Austrian flatlands, North of the Alps, both rural, are used for a sensitivity study of separation distances. One aspect is, how two different schemes to determine atmospheric stability influence the separation distances. Another source of uncertainty of the calculated separation distances results from the use of measured or literature values for the ratios mentioned above. Decisions on which schemes or ratios to be used have a decisive influence on the separation distances.

Keywords: Odour; Stability class; Peak-to-mean ratio; Separation distance; Gauss model

1. Introduction

To run a dispersion model successfully, the kind and quality of meteorological input data are of primary concern. Simple dispersion models like the still wide-spread Gauss models need essentially wind and stability information on an hourly or half-hourly basis. These data can, in principle, be provided by models (meteorological pre-processors or numerical weather prediction models) or by observations. For air pollution studies in Austria, usually observations from the next meteorological station considered representative for the area of investigation are used.

Whereas the measurement of wind direction and wind velocity and its use in dispersion models is quite straightforward, atmospheric stability is not so easily representatively measured. Due to a lack of

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systematic long-term ultrasonic measurements at routine meteorological stations, discrete stability classification schemes are still in use. For the Austrian regulatory model, two different methods, depending on the available data, are often used (see Section 2.2).

As odour nuisance from livestock farms is of increasing concern in Austria, an increasing number of meteorological data sets is now available, each representing specific agricultural regions like flatlands, valleys or Alpine basins. Odour dispersion models like the German AUSTAL-G (Janicke et al., 2004) can calculate ambient odour concentrations and thus the separation distance between livestock buildings and residential areas defined by a pre-selected odour threshold and an exceedance probability (Section 2.3). Here, the Austrian Odour Dispersion Model AODM (Section 2.1), which is described in detail in Schauberger et al. (2000a), will be used to calculate direction-dependent separation distances for two selected sites. Two odour impact criteria will be used: 1 OU/m^3 and 3% exceedence probability, representative for pure residential areas (high odour protection), 1 OU/m^3 and 8% exceedence probability, representative for residential areas mixed with commercial/industrial activity (low odour protection). One site in Styria in southern Austria, Frauental, and the surroundings of Wels in Upper Austria in the North-Alpine forelands (Section 2.4, Fig. 1) are used for a sensitivity study of separation distances. At both sites, direction-dependent separation distances are calculated for a 1000 head pig-fattening unit. One aspect of the study is to demonstrate the influence of the scheme to determine atmospheric stability on the separation distances. Depending not only on the location, but also on the kind of meteorological data used to calculate dispersion categories (cloud data or net radiation), differences in separation distances will occur. Another source of uncertainty of the calculated separation distances results from how the postulated exponential decrease of the peak-to-mean ratios is determined (Section 2.3).

The investigation aims at highlighting and judging how these factors influence the direction-dependent separation distances calculated by the Austrian Odour Dispersion Model. Section 2 explains materials and methods, touching briefly the model and the data (Sections 2.1 and 2.4) and focussing on stability classes and the peak-to-mean ratio (Sections 2.2 and 2.3). Results and discussion follow in Section 3, and conclusions and recommendations are given in Section 4.

Fig. 1. Topographic map of central Austria (*source*: Austrian Map). Light grey: flatlands; dark grey: mountains; scale: approx. 130 × 160 km; Black dots: sites considered in this study.

2. Material and methods

2.1. The Austrian Odour Dispersion Model

The Austrian odour dispersion model (AODM) consists of three modules: the first calculates the odour emission of the livestock building, the second estimates mean ambient concentrations by a regulatory dispersion model, and the last transforms the mean odour concentration of the dispersion model to instantaneous values depending on wind velocity and stability of the atmosphere (Section 2.3).

The emission module is based on a steady-state balance of the sensible heat flux to calculate the indoor temperature and the related volume flow of the ventilation system (Schauberger et al., 2000b). The corresponding odour flow is assessed by a simple model of the odour release. The consideration of the diurnal variation of the odour emission is the most important feature of this module. Since odour is mainly released by the animals, by polluted surfaces and by the feed, the diurnal variation of the emission is assumed to be in phase with animal activity. Outdoor odour sources such as slurry tanks or feed storage facilities are not taken into account.

The odour concentration of the centre line of the plume is calculated by the Austrian regulatory dispersion model (Kolb, 1981; Ö Norm M 9440, 1992/96). The model has been validated internationally with generally good results (e.g. Pechinger and Petz, 1995). The regulatory model is a Gaussian plume model applied for single stack emissions and distances from 100 m up to 15 km. Plume rise formulae used in the model are a combination of formulae suggested by Carson and Moses (1969) and Briggs (1975). The model uses a traditional discrete stability classification scheme with dispersion parameters developed by Reuter (1970).

2.2. Atmospheric stability

As the separation distances are calculated for fixed emission data (Table 3), they depend, apart from the meteorological time series and the odour impact criterion, on the methodologies to determine atmospheric stability and the peak-to-mean ratio. These are therefore explained here in more detail to facilitate the interpretation of the results.

For the purposes of dispersion modelling, discrete stability classes are still widely used. They are usually determined on the basis of routine meteorological observations representing rural conditions. Gauss models work in stationary meteorological conditions only, assuming that they do not change over the dispersion distance or averaging time; the limits in Austria are 15 km or 30 min (Ö Norm M 9440, 1992/96). The assumption of stationarity, especially over the averaging time, is fulfilled not in all, but in a lot of cases, especially in rather flat terrain or a broad valley as used here. Both at Frauental and Wels, discrete stability classes (Reuter, 1970) are determined as a function of half-hourly mean wind speed and a combination of sun elevation angle, cloud base height and cloud cover; at Frauental, in addition, the radiation balance in combination with the mean wind speed has been used. The details of the two schemes are given in Section 4.6 of Piringer and Joffre (2005). Three-dimensional distributions of stability classes contain the percentage frequency of each combination of wind direction (36 categories), wind speed (12 categories), and stability class (6 categories) for a chosen period, e.g. over the whole year. The calculation of stability classes is necessary to determine the dispersion parameters σ_y and σ_z as discussed in Hanna and Chang (1992).

Within the Reuter scheme, stability classes 2–7 can occur in Austria. Stability classes 2 and 3 occur predominantly during daytime in a well-mixed boundary layer, class 3 allowing also for cases of high wind velocity and moderate cloud cover. Class 4 is representative for cloudy and/or windy conditions including precipitation or fog and can occur during day and night. Classes 5–7 occur primarily at night, static stability increasing with class number. With the scheme based on cloudiness data, classes 2 and 3 can occur only during daytime, classes 5–7 only during nighttime.

The statistics of stability classes differs with methodology and site (Fig. 2). At Frauental, a comparison between the net radiation-based and cloudiness-based statistics is possible. With in situ net radiation, class 6 representative for stable situations dominates, comprising more than 35% of all cases year-round (Fig. 2a). This class as well as the "fair-weather" classes, 2 and 3, show an expected seasonal variation with enhanced occurrence of classes 2 and 3 during summer, class 6 during winter, whereas classes 4, 5 and 7 show no seasonal trend. Compared to the statistics with cloudiness data where class 4 dominates (Fig. 2b), differences occur mainly for classes 3, 4, and 6, while classes 2 and 7 occur with about the same probability. Apparently, the large abundance of class 6 when using net radiation data is mainly transformed to classes 3 and 4 in the cloudiness scheme, as is also revealed by a direct statistical comparison (not shown). This deviation between net radiation and cloudiness-based statistics is systematic, i.e. occurs independent of site, and can be explained by the fact that in the cloudiness-based statistics, in contrast to net radiation, unstable situations occur during daytime, stable situations during nighttime only. In areas with orographic modifications like Frauental, a negative net radiation and therefore, stable situations can occur still after sunrise and already before sunset, while the cloudiness method can only calculate classes 2–4 by definition, which is the main cause for this difference.

The cloudiness-based statistics for Wels (Fig. 2c) shows an even more pronounced dominance of stability class 4 than for Frauental. Class 4 takes 50% of all cases year-round and even 60% during winter. Other classes occur at about 15% at most. The reason for the dominance of class 4 in the Austrian flatlands is the more frequent

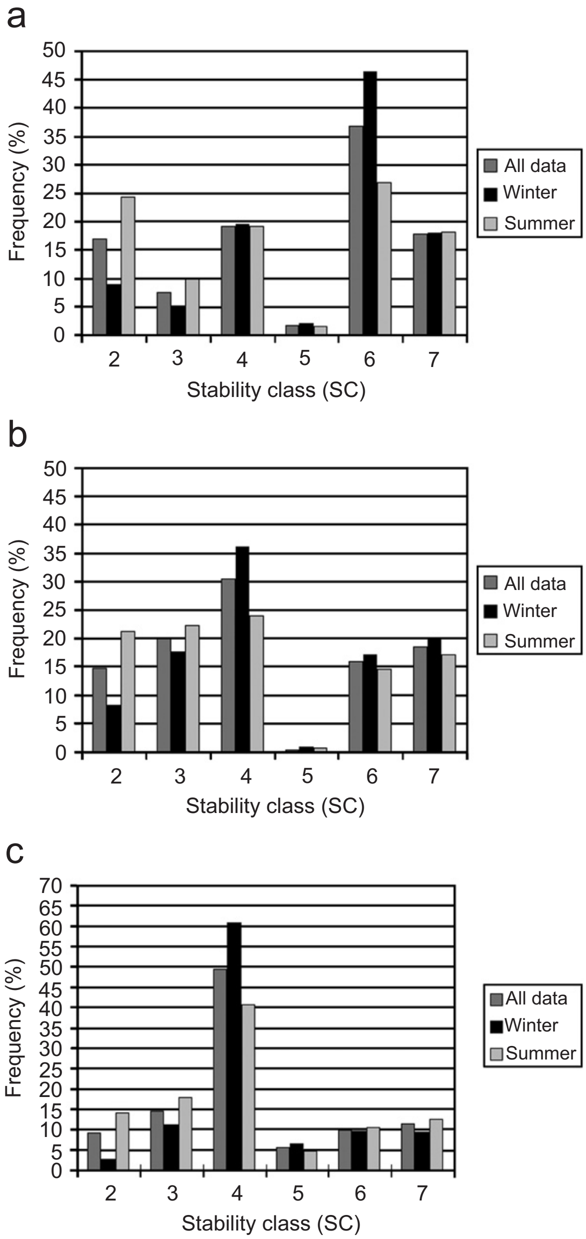

Fig. 2. Frequency distribution of stability classes (SC) 2–7. (a) Frauental: net radiation and wind speed. (b) Frauental: cloudiness and wind speed. (c) Wels: cloudiness and wind speed.

occurrence of higher wind speeds and especially wintertime cloudiness compared to Alpine sites. Both effects strengthen class 4 and weaken especially class 2 at daytime (which, in wintertime, is practically non-existent at Wels) and classes 6 and 7 at night with frequencies around 10% each only.

2.3. Peak-to-mean ratio

The regulatory model calculates half-hour mean concentrations (Section 2.1). The sensation of odour, however, depends on the momentary ("peak") odour concentration and not on a mean value over a long time of integration. The AODM scheme to calculate peak concentrations is based on the formula (Smith, 1973) $C_p/C_m = (t_m/t_p)^u$ and described in detail in Schauberger et al. (2000a). The maximum peak-to-mean factors valid near the odour source are given in Table 1 for two different approaches: the original AODM factors (Smith, 1973; "AODM" in Table 1) and one of the US—State of Texas (Trinity Consultants, 1976, "Texas" in Table 1). The schemes differ in that the Texas approach uses peak-to-mean factors also for stability classes 6 and 7 (nighttime stable static stability). All values in Table 1 are obtained by using $t_m = 1800$ s (calculated half-hour mean value) and $t_p = 5$ s (average duration of a single human breath).

The reduction of the peak-to-mean ratio with distance due to turbulent mixing is described with an exponential attenuation function (Mylne and Mason, 1991; Mylne, 1992), which involves knowledge of the standard deviations of the three wind components. These are obtained from the known average wind speed u as shown in Table 2. The approach is described in detail in Schauberger et al. (2000a). In the AODM, values for σ_u/u and σ_v/u are originally taken from Robins (1979), Table 2a, and no change with stability is assumed. σ_w/u is taken to be stability-dependant (in contrast to Robins (1979), who assigns a value of 0.1 independent of stability), using our long-term experience with sodar measurements, which suggests an increasing importance of σ_w compared to u in unstable conditions.

Table 1
Maximum peak-to-mean (P/M) ratio depending on atmospheric stability

Stability class	AODM		Texas	
	Exp. u	P/M	Exp. u	P/M
2	0,64	43,25	0,68	54,74
3	0,51	20,12	0,55	25,47
4	0,38	9,36	0,43	12,57
5	0,25	4,36	0,30	5,85
6	0	1,00	0,18	2,88
7	0	1,00	0,18	2,88

Table 2
Ratio of the variances of the three-wind components u, v and w to the horizontal wind velocity u depending on the stability of the atmosphere (details see text)

Stability class	σ_u/u	σ_v/u	σ_w/u
(a) Standard (based on Robins, 1979)			
2	0,2	0,2	0,3
3	0,2	0,2	0,2
4	0,2	0,2	0,1
5	0,2	0,2	0,1
6	0,2	0,2	0,1
7	0,2	0,2	0,1
(b) Derived from sonic data			
2	0,52	0,51	0,28
3	0,50	0,47	0,24
4	0,37	0,32	0,17
5	0,32	0,26	0,15
6	0,51	0,47	0,20
7	0,52	0,49	0,19

These ratios can also be derived from 3D ultrasonic anemometer measurements. The values in Table 2b were obtained by 1-year measurements at a grass- and sand-covered site far away from buildings or trees on the edge of a large industrial complex in Linz, Austria. Similar ground conditions can also be found on large livestock farms. The measurements took place 10 m above ground. The sampling rate was 10 Hz, and the sigmas were obtained by averaging over 10 min. Compared to other sites with similar ambient conditions, where measurements are available, differences in ratios are not large. The evaluation of the ultrasonic anemometer data shows a strong dependence also of σ_u/u and σ_v/u from stability and generally larger values than suggested in the literature. The dependence of σ_w/u from stability is in the range of that proposed from the sodar evaluation, but generally a bit weaker. In both cases (Tables 2a and b), peak-to-mean ratios given for stability classes 6 and 7 can be used only with the Texas approach. In the original version of the AODM, the half-hour mean value and the short-term peak concentration are then identical.

A comparison of the peak-to-mean ratios derived from Tables 1 and 2 is shown in Fig. 3. Wind speed is set to 1 m s^{-1}; for larger wind speeds, lower peak-to-mean ratios Ψ are obtained. Peak-to-mean ratios for distances larger than 100 m are relevant here. 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. The peak-to-mean ratios depend strongly on the stability class. For classes 2 and 3, Ψ, starting at rather high values near the source, rapidly approaches 1 with increasing wind speed and within 100 m. This is in agreement with ideas that vertical turbulent mixing in weak winds then locally can lead to short periods of high ground-level concentrations, whereas the ambient mean concentrations are low. For class 4, the decrease of the peak-to-mean ratio is more gradual with increasing distance, because vertical mixing is reduced and horizontal diffusion is dominating the dispersion process. Using the values of Table 2a in the attenuation function, maximum peak-to-mean ratios in 100 m are about 10 for the Texas and about 7 for the standard AODM method for stability class 4 and a wind speed of 1 m s^{-1} (Fig. 3a and c). For classes 5–7, the peak-to-mean ratio exceeds 2 only near the source. Applying the Texas regulation in combination with the Robins' values should result in the largest separation distances, if neutral and stable conditions are statistically important. With the Robins approach, stability class 4 ("neutral") gives the largest peak-to-mean factors for all distances between 100 and 1000 m.

Using the original AODM approach results in generally lower peak-to-mean factors than applying the Texas values; using sonic data (Table 2b) instead of the Robins' values (Table 2a) for the attenuation function again gives lower peak-to-mean factors. At 100 m, the peak-to-mean ratios are about 7 for the Texas and about 6 for the standard AODM method, equally for stability classes 2–4 and a wind speed of 1 m s^{-1} (Fig. 3b, d). Using the coefficients in Table 2a,b more rapid decrease of the peak-to-mean ratio with distance is obtained. For distances of 100 m and more, for which the Gauss model calculations are valid, the importance of the peak-to-mean approach is reduced using the measured coefficients. Peak-to-mean ratios in unstable and neutral conditions in the first few 100 m are slightly larger than in stable conditions (Fig. 3b and d). After 500 m at most, peak-to-mean factors approach 1 in all stability conditions when using sonic data.

2.4. Data

Frauental in Styria in southern Austria and Wels in the Austrian North-Alpine Foreland (Fig. 1), typical for agricultural areas, where over 3 years

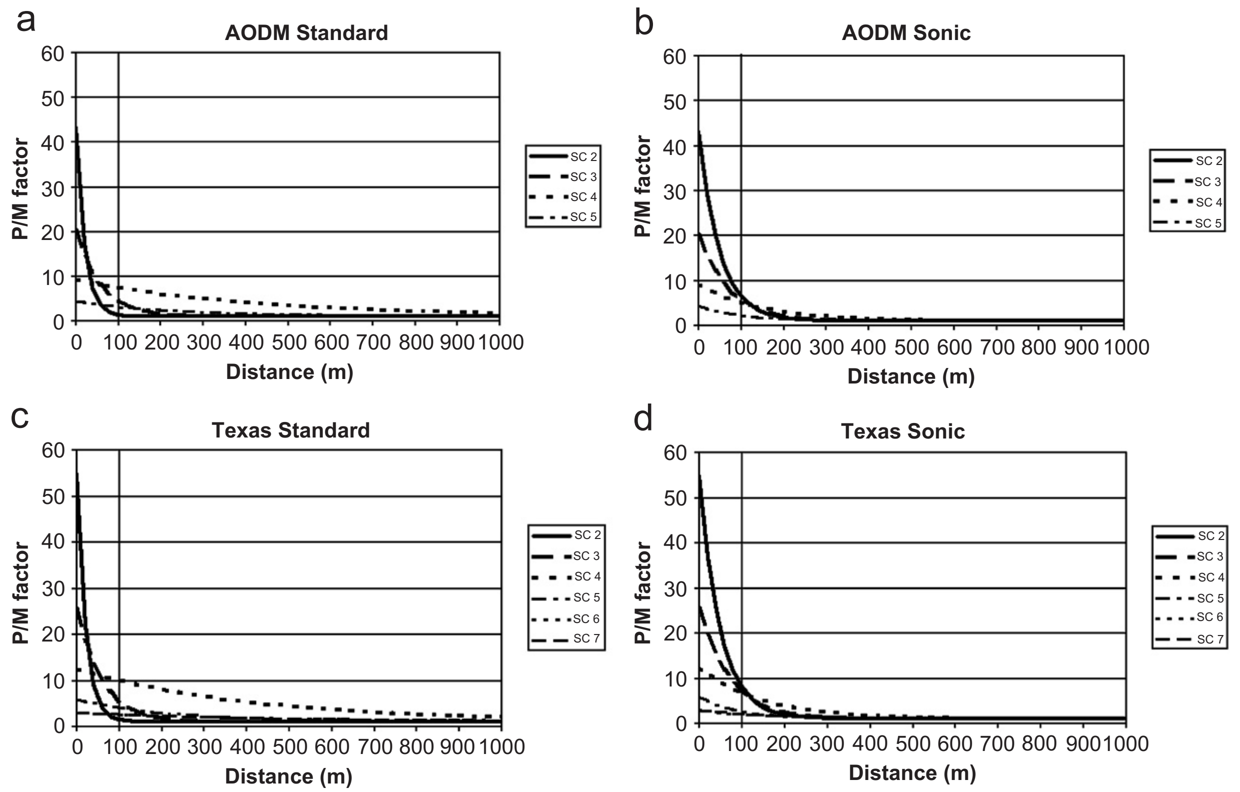

Fig. 3. Peak-to-mean ratios depending on stability class (SC) and distance (wind speed $1\,m\,s^{-1}$). (a) Maximum P/M ratios according to AODM, attenuation function according to Table 2a. (b) Maximum P/M ratios according to AODM, attenuation function according to Table 2b. (c) Maximum P/M ratios according to Texas regulation, attenuation function according to Table 2a. (d) Maximum P/M ratios according to Texas regulation, attenuation function according to Table 2b.

Table 3
Source data of the mechanically ventilated pig fattening unit (1000 head)

Pig odour number acc. to Schauberger et al. (19xx)	0,13 AU
Specific emission factor	$40\,OU\,s^{-1}\,AU^{-1}$
Odour flow	$5200\,OU\,s^{-1}$
Exit velocity	$3\,m\,s^{-1}$
Emission height	8 m
Outlet air temperature	20 °C
Specific volume flow	$60\,m^3\,h^{-1}$
Volume flow	$60\,000\,m^3\,h^{-1}$ or $16{,}7\,m^3\,s^{-1}$

time series of meteorological data are available, are used for the sensitivity study of separation distances. At both sites, odour concentrations are calculated for a 1000 head pig-fattening unit (source data see Table 3). Frauental (15, 28° E and 46, 82° N, 322 m asl.) is situated in the more than 1 km broad, west–east-oriented Lassnitz river valley with low hills on either side. The distance from Graz airport is about 20 km. Dispersion conditions for Frauental have been determined based on net radiation, wind direction and wind speed; alternatively to the in situ net radiation data, cloudiness from the airport of Graz has been used. Frauental is subject to a valley wind system with daytime up-valley and nighttime down-valley flows. Up-valley winds in Frauental are from North-east, down-valley winds from South-west. Daytime up-valley winds are associated with higher near-ground wind speeds than nighttime down-valley winds. Average wind speed in Frauental is only $1.2\,m\,s^{-1}$.

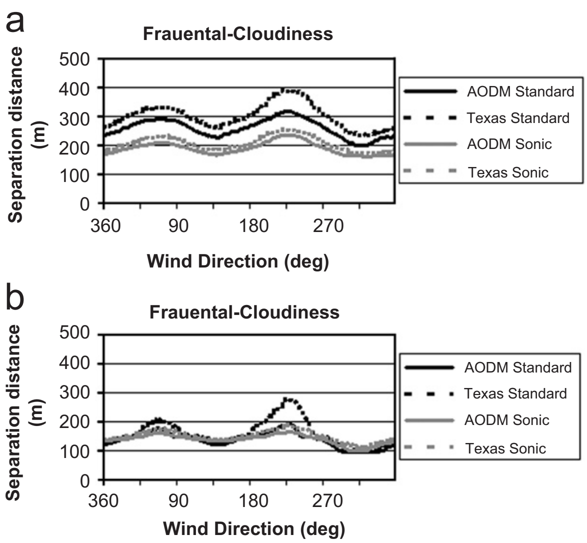

Fig. 4. Direction-dependent separation distances (m) for Frauental, stability classes determined via cloudiness data at Graz airport and wind speed at Frauental: (a) exceeding probability: 3% and (b) exceeding probability: 8%.

At Wels (14, 04 °E, 48, 17 °N, 317 m asl.), a regional shopping centre with about 50 000 inhabitants, stability classes have been determined based on in situ wind data and cloudiness data from nearby Linz airport. The agricultural area around Wels is rather flat. Wels is representative for the better-ventilated North-Alpine foreland with average wind speeds above 2 m s^{-1}. Main wind directions are from South-west to West and East to East-north-east. As no explicit valley wind system develops, day–night differences are weaker than at the valley site Frauental. The highest wind speeds on average occur for the main wind directions West (up to 3 m s^{-1} during daytime) and East (up to 2.5 m^{-1}s). Northerly and southerly wind directions are associated with average wind speeds around 1 m s^{-1}.

For both farms, based on the information given in Table 3, time series of odour emission rates according to Schauberger et al. (2000b) are calculated, necessary to run the AODM dispersion and peak-to-mean modules.

3. Results and discussion

3.1. Direction-dependent separation distances: general results

The separation distances shown in Figs. 4–6 are direction-dependent because of the use of exceedence probabilities in combination with the fixed

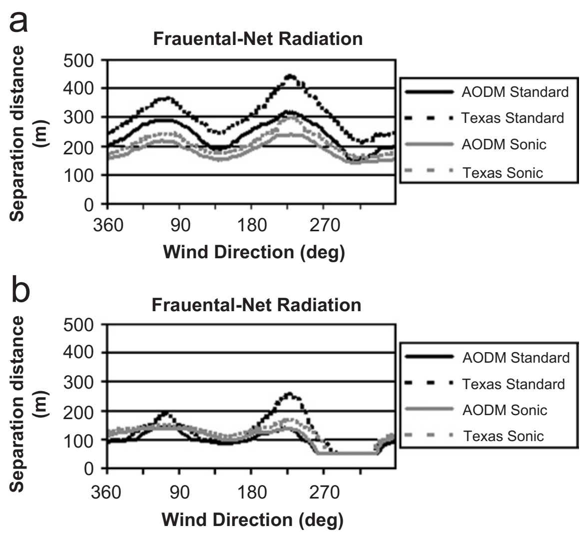

Fig. 5. Direction-dependent separation distances (m) for Frauental, stability classes determined via net radiation data and wind speed at Frauental: (a) exceeding probability: 3% and (b) exceeding probability: 8%.

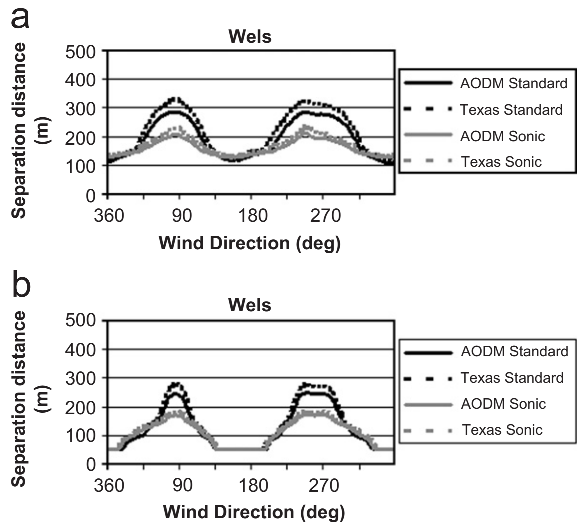

Fig. 6. Direction-dependent separation distances (m) for Wels, stability classes determined via cloudiness data at Linz airport and wind speed at Wels: (a) exceeding probability: 3% and (b) exceeding probability: 8%.

odour threshold of 1 OU m^{-3}. For each wind direction, a cumulative frequency distribution of all separation distances is calculated. Depending on the chosen exceedence probability, 3% or 8% of the separation distances are cut off from the maximum distance. If the occurrence of the wind direction is less than the chosen exceedence probability, the smallest distance (apart from zero) is taken as the separation distance. The separation distances are thus largest for the most frequent wind directions at all sites, and they are largest in the direction of the down-valley flow at Frauental. They depend inversely on the exceedence probability: the lower the exceedence probability (i.e. the higher the level of protection), the larger are the separation distances. For an exceedence probability of 3%, separation distances can reach more than 400 m; for 8%, less than 300 m. Differences between schemes are most pronounced for an exceedence probability of 3%, when generally the Texas peak-to-mean ratios in combination with the standard values for the attenuation function (Table 2a) give the largest distances, followed by the original AODM peak-to-mean ratios with the factors of Table 2a. Using the sonic-derived factors for the attenuation function (Table 2b) results in considerably smaller separation distances, independent of the scheme for the peak-to-mean ratios. Differences in separation distances between wind directions decrease also significantly when using the sonic-derived factors.

In the following, the direction-dependent separation distances are discussed with respect to the schemes to determine atmospheric stability, to the different coefficients in the attenuation function, and to meteorological differences of the two sites.

3.2. Direction-dependent separation distances: sensitivity to the stability scheme

This comparison can be undertaken for Frauental only; results are displayed in Figs. 4 and 5. The separation distances are sensitive to the atmospheric stability scheme, as has to be expected from the discussion in Section 2.2. Looking, at first, at the exceedance probability of 3% and comparing the results for the cloudiness-based and the net radiation-based stability schemes (Figs. 4a and 5a), larger separation distances in the main wind directions are obtained for the latter when using the Texas peak-to-mean values, which are larger than 1 for stable dispersion categories also (Table 1). Application of the Texas scheme then results in longer separation distances because with the net radiation scheme, stable situations, especially of class 6, are twice as frequent as with the cloudiness scheme (cf. Figs. 2a and b). This is most relevant for nighttime down-valley flow. But also the up-valley separation distances are larger for the Texas scheme because with net radiation used to determine atmospheric stability, class 6 with long plume elongations can also occur at the beginning and the end of daytime, sometimes connected with up-valley flow. Using the standard AODM scheme, either with or without sonic data, no apparent difference in separation distances between net radiation and cloudiness schemes for the main wind direction occurs as the stable dispersion categories are then not relevant for the peak-to-mean approach (Fig. 3), and the maximum separation distances occur for class 4 when the peak-to-mean ratios are largest.

For the cross-valley wind components, slightly larger separation distances are calculated when using the cloudiness scheme to determine atmospheric stability, especially for the standard schemes. This can only be explained by the fact that, using cloudiness data, class 4 is the dominant dispersion category, whereas for the net radiation scheme, classes 2 or 3 are obtained. Thus, the directional dependence of separation distances is less pronounced using cloudiness data to determine atmospheric stability, as the separation distances for along-valley directions are lower, for cross-valley directions larger than those determined with the net radiation scheme.

Allowing for a larger exceedence probability of 8% (Figs. 4b and 5b), the differences in separation distances between the two stability schemes generally decrease, especially for the less frequent wind directions. In these cases, near-minimum separation distances are obtained, almost independent of the approach used. Especially for the down-valley component, the Texas scheme combined with the original AODM attenuation function factors, still gives the largest separation distances, because of the importance of class 6 in this scheme.

3.3. Direction-dependent separation distances: sensitivity to the attenuation function

Differences are again most distinct for an exceedence probability of 3% (Figs. 4–6, part a), which is discussed first. At Frauental (both methods to determine atmospheric stability), using the sonic-derived values of Table 2b in the attenuation function results in considerably lower separation distances for all wind directions; the differences are slightly larger for the Texas than for the standard AODM scheme, because the differences in peak-to-mean factors are larger (cf. Figs. 1c and d–1a and b). At Wels, this is true only for the more frequent wind directions (Fig. 6a); the others occur too seldom to give distinct differences between methods. Using meteorological data to determine the factors for the attenuation function, separation distances, especially for the most frequent main wind directions, are reduced by 25–30%.

The reduction is less effective when the exceedence probability is increased to 8% (Figs. 4–6, part b). Reductions in separation distances using values of Table 2b instead of Table 2a occur only for small sectors around the main wind directions. These reductions are still larger for the Texas peak-to-mean factors and for down-valley winds at Frauental, reaching up to 30% in these cases.

3.4. Direction-dependent separation distances: intercomparison of sites

The comparison is first undertaken for an exceedance probability of 3% with cloudiness and wind speed data to determine atmospheric stability (cf. Figs. 4 and 6, parts a). In Frauental, a valley-wind system is active, with valley-parallel main wind directions. Down-valley winds are from South-west. Separation distances for this direction are largest, ranging, depending on the method, between 250 and 400 m. The up-valley wind sector (North-east to East) is also well defined, with separation distances between 200 and 320 m. Although wind speed on average is higher for daytime up-valley flow than for nighttime down-valley flow, separation distances are larger for down-valley flow. Nighttime stable static stability thus exerts a stronger influence on separation distances than wind speed. Of the parameters wind direction, wind speed and stability category relevant for the distribution of concentrations around the source, the wind speed is the least important at the Alpine site Frauental. Whereas, up-valley winds often coincide with conditions favouring dilution, nighttime down-valley winds are often associated with stable conditions, under which especially vertical dispersion is strongly limited, leading to long plumes. In cases of near-calm conditions (wind speeds below $0.8\,m\,s^{-1}$), concentrations, according to the Austrian regulation Ö Norm M 9440 (1992/96), are multiplied by a factor of 1.5 thus further increasing predominantly the down-valley distance at which, concentrations above $1\,OU\,m^{-3}$ will occur.

At Wels, the separation distances for the two main wind-direction sectors are about the same (Fig. 6a) and range between 200 and 320 m, comparable to the up-valley wind sectors at Frauental. The cross-valley separation distances are larger in Frauental (Fig. 4a), as this site in a broad valley shows even less channelling of the flow than Wels.

Increasing the exceedence probability, the changes in separation distances are more relevant for the valley site than for Wels in the flatlands. The reduction in the separation distances at Frauental is most relevant for the cross-valley directions, when going from 3% to 8% exceedence probability, especially when using the Robins' factors in the attenuation function (Table 2a). With the Texas peak-to-mean values, the reduction in separation distances in Frauental is then more than 100 m. The down-valley separation distances at Frauental are also reduced by about 150 m for the Texas method with Robins' factors, and less especially for the sonic methods (only about 50 m). At Wels, the reduction in the main wind directions is only about 50 m for the non-sonic and even less for the sonic methods. In the cross-wind directions, the separation distances are reduced by about 50 m when going from 3% to 8%.

4. Conclusions and recommendations

For a valley location in Southern Austria and one site in the Northern Alpine Foreland (Fig. 1), a sensitivity study of the separation distances calculated with the Austrian Odour Dispersion Model AODM (Section 2.1; Schauberger et al., 2000a, b, 2001) has been carried out. AODM has an advanced peak-to-mean module (Section 2.3). At both sites, the calculations have been done for a 1000 head pig-fattening unit. The sensitivity study shows the influence of cloudiness or net radiation data to calculate atmospheric stability as well as different ratios to calculate the peak-to-mean factors (Tables 1 and 2) on the separation distances (Section 3).

At the valley location, a valley wind system is present with predominantly daytime up-valley and nighttime down-valley winds. The up-valley winds occur mainly with unstable, the down-valley winds mainly with stable stratification; the former are associated, on average, with larger wind speeds than the latter. The down-valley separation distances are however, larger than those up-valley (Figs. 4 and 5), indicating that the influence of stability is larger than that of wind speed. At Wels, in the North-Alpine foreland, no valley wind system is present, and the separation distances calculated for the neutral dispersion category are equal for the two main wind directions (Fig. 6). The choice of the stability scheme or the ratios of wind variances to wind speed, does not change these fundamental findings, but has an influence on calculated separation distances that is relevant in impact assessment studies.

With respect to odour impact assessments, two main conclusions can be drawn. If on-site data consist only in conventional wind speed and wind direction, with stability obtained from the nearest airport, and one wants the results of model calculations to be 'on the safe side', i.e., the largest separation distances calculated to be relevant for assessing the environmental impact of a farm, then the Texas peak-to-mean factors (Table 1), in combination with the attenuation factors of Table 2a, have to be used. If an ultrasonic anemometer is available and net radiation is measured on-site, separation distances are considerably reduced, especially for the most relevant main wind directions. Moreover, the use of ultrasonic anemometers enables to calculate atmospheric stability directly via boundary-layer parameters (Monin–Obukhov length), which might be more appropriate, especially if the environment is not predominantly rural (Piringer and Joffre, 2005). This could not be applied in this study as no ultrasonic anemometers were installed so far at agricultural sites in Austria. Determining stability classes in rural areas, the combination of net radiation and wind measurements can be recommended. Net radiation is preferable to cloudiness observations as the former can be measured on-site and, with complex topography, also allows for stable conditions after sunrise and before sunset. Only if cloudiness data are measured representatively in the vicinity, mostly at the nearest airport, they can be considered to determine atmospheric stability (here for the area of Wels). Statistics of stability classes based on cloudiness data are, however, still more widespread in Austria than those on net radiation data, as net radiation is not a routine meteorological parameter measured by the National Weather Service. In the majority of cases, on-site meteorological measurements as input to dispersion modelling is necessary for a proper and reliable impact assessment.

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