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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 which was adapted for the prediction of odour sensation. It consists of three modules to estimate the daily and seasonal variation of the odour emission, the average odour concentration and the momentary (peak) concentration for the time interval of a single human breath (approx. 5 seconds). Peak concentrations further downwind are modified by use of an exponential attenuation function for which the proportion 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. Two sites in Styria in southern Austria with large pig farms are used for a sensitivity study of separation distances. One aspect is the influence of the local meteorology on the separation distances. Another source of uncertainty of the calculated separation distances results from the use of measured or literature values for the attenuation function mentioned above. The article aims at highlighting and judging the meteorological factors influencing the direction-dependent separation distances calculated by the Austrian Odour Dispersion Model.

1. Introduction

Odour is one of the major nuisances in the environment mainly caused by livestock units and industry. In the USA, about 70% of all complaints on air quality concern odour [1]. For the UK [2], there were 3700 complaints about odour from farms in the years 1989 and 1990. This is about 25% of all complaints received by the Environmental Health Officers. More than half are caused by livestock buildings (building, slurry storage, feeding), the other half by slurry spreading. For Thüringen, Germany, it is reported [3] that 16% of all complaints in the year 1996 were odour related, 34% of these stem from agricultural sources. The complaints due to farms dominated with 89% over slurry spreading (1%).
To overcome such problems, a separation distance between the odour source and residential areas is used to reduce the odour annoyance to a certain level. With livestock farming, two regulatory approaches are used: a guide line approach or a modelling approach. In guide lines, the separation distance between residential houses and livestock buildings is empirically assessed (e. g. [4]). Using a dispersion model to calculate ambient odour concentrations, the separation distance between livestock buildings and residential areas is defined by a pre-selected odour threshold and an exceeding probability. Here, the Austrian Odour Dispersion Model AODM which is described in detail in [5] will be used to calculate direction-dependent separation distances for combinations of odour threshold and exceedence probability which are a function of the prevailing wind velocity and atmospheric stability conditions. Two sites in Styria in southern Austria with large pig farms are used for a sensitivity study of separation distances. One aspect is the influence of the local meteorology 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 the use of measured or literature values for the attenuation function described above.
The investigation aims at highlighting and judging the meteorological factors influencing the direction-dependent separation distances calculated by the Austrian Odour Dispersion Model.

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.

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 [6]. 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 [7,8] by making use of a statistics of stability classes representative for the Austrian flatlands north of the Alps. The model has been validated internationally with generally good results (e.g. [9]). The regulatory model is a Gaussian plume model applied for single stack emissions and distances up to 15 km. Plume rise formulae used in the model are a combination of formulae suggested by [10, 11]. The model uses a traditional discrete stability classification scheme with dispersion parameters developed by [12].

The regulatory model calculates half hour mean concentrations. The sensation of odour, however, depends on the momentary odour concentration and not on a mean value over a long time of integration. The peak value is derived from the half our mean value using the relationship in [13] depending on the stability of the atmosphere. These values are only valid close to the odour source. Due to turbulent mixing, the peak-to-mean ratio is assumed to be reduced with increasing distance from the source using the wind velocity and the stability of the atmosphere. It is modified by an exponential attenuation function [14] using the time of travel with the distance x and the mean wind velocity u, and the Lagrangian time scale as a measure of the stability of the atmosphere [15]. The approach is described in detail in [5]. Both the stability classification scheme as well as the derivation of the peak-to-mean ratio are described in more detail in the following, as the investigation of separation distances presented here depends on these parameters.

2.2 Stability classification scheme and peak-to-mean ratio

Stability classes 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 is used in combination with the mean wind speed. A three-dimensional statistics of stability classes contains the percentage frequency of each combination of wind direction (36 categories), wind speed (12 categories), and stability class (6 categories) e.g. over the whole year. The calculation of stability classes is necessary to determine the vertical dispersion parameters σ_y and σ_z as discussed in [16]. Within the Reuter scheme [12], stability classes 2 to 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 day and night. Classes 5 to 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 to 7 only during night-time. Here, the results based on schemes with cloudiness data and radiation data are compared.

The coefficients for the attenuation function of the peak-to-mean ratio are derived by two different methods: first values from the literature are used (table 1); secondly, these were derived from one-year ultrasonic anemometer measurements in different locations in Austria

(table 2). For stability classes 6 and 7 no change of the peak-to-mean ratio is assumed. In table 1, values of σ_u / u and σ_v / u are taken from [17], and no change with stability is assumed. Values of σ_w / u are stability dependent, using our long-term Sodar experience which suggests an increasing importance of σ_w compared to *u* in unstable conditions.
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 (table 2). The dependence of σ_w / u from stability is in the range of that proposed from the sodar evaluation, but generally a bit weaker.

Table 1: 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
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

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 based on ultrasonic anemometer data from Linz and Graz

Stability class	σ_u / u	σ_v / u	σ_w / u
2	0,54	0,54	0,31
3	0,51	0,49	0,27
4	0,43	0,40	0,21
5	0,41	0,36	0,23

2.3 Data

Two sites in Styria in southern Austria with large pig farms are used for the sensitivity study of separation distances: one farm with up to 1150 fattening pigs in the village Frauental (15,28° E und 46,82° N, 322 m asl.) and four smaller adjacent farms in the village Gersdorf (15,851° E und 47,154° N, 396 m asl.). Dispersion conditions for Frauental have been determined based on an almost three years half-hourly time series of net radiation, wind direction and wind speed; alternatively to the net radiation data, cloudiness from the nearby airport of Graz have been used. For Gersdorf, only wind data are available (also about three years); cloudiness to determine stability classes is from Graz airport. Frauental is situated in the more than one kilometer broad, west – east oriented Lassnitz river valley with low hills on either side; Gersdorf is centered in the upper part of the narrower Feistritz river valley which runs down to south-east.
For all the farms, knowledge of the number of animals and how they are kept, is available, and this information has been used to calculate the time series of odour emission rates according to [6] necessary to run the AODM dispersion and peak-to-mean modules.

3 Results and discussion

The frequency distributions of wind directions for Frauental and Gersdorf are shown in figs. 1 and 2, respectively. Both locations are subject to a valley wind system with daytime up-valley and night-time down-valley flow. Up-valley winds in Frauental are from North-east, down-valley winds from South-west, in Gersdorf, the respective directions are South to South-east and North. In both locations, daytime up-valley winds are associated with higher wind speeds than night-time down-valley winds. Average wind speed in Frauental is 1,2 m/s, in Gersdorf it is 1,3 m/s. Conditions with weak winds are very frequent at both locations, especially at night.

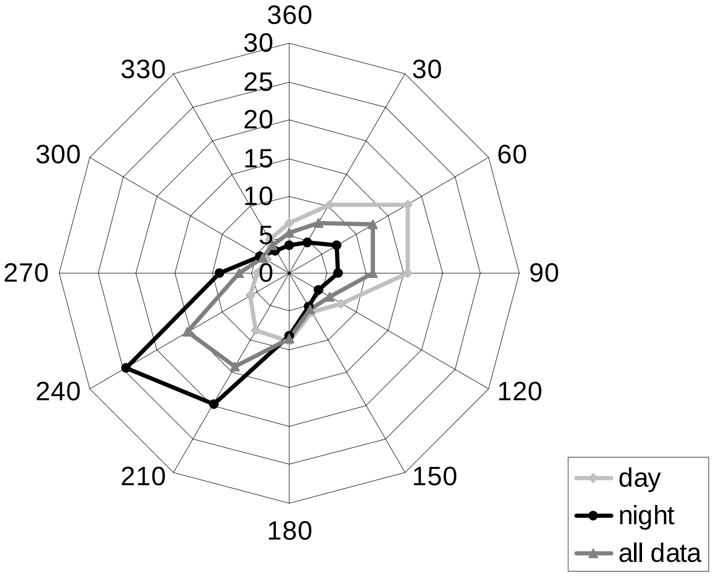

Figure 1: Frequency distribution of wind directions in Frauental

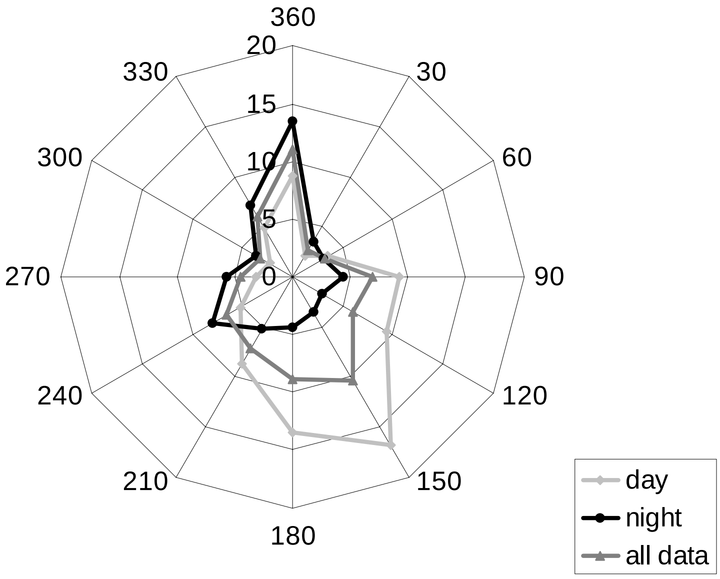

Figure 2: Frequency distribution of wind directions in Gersdorf

In the following figures, concentration iso-lines are in odour units per cubic metre. As a first example, in fig. 3 and table 3, direction-dependent separation distances for the farm in Frauental derived by use of the variance ratios in table 1 are compared to those in table 2.

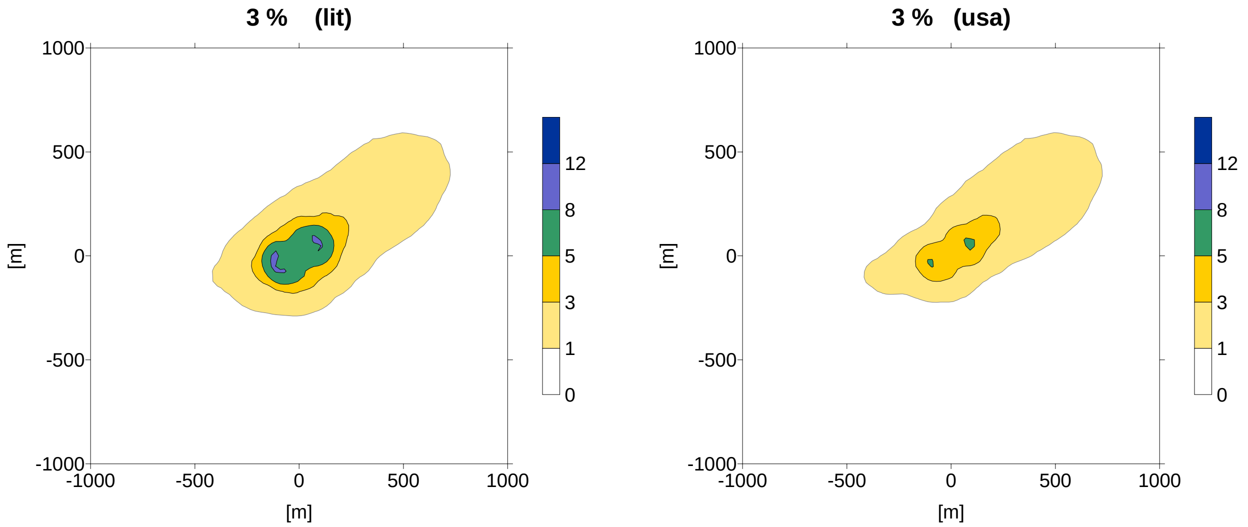

Figure 3: Direction-dependent separation distances (m) in Frauental for an exceeding probability of 3 %. Left: ratios of variances according to table 1; right: ratios of variances according to table 2.

Fig. 3 clearly shows the Robins ratios [17] to deliver higher odour concentrations than those of table 2, as expected; however, the most relevant maximum separation distances for one odour unit per cubic metre are almost the same (Table 3). Although night-time wind velocities are considerably lower than daytime ones, the down-valley elongation of the odour concentration field for one odour unit per cubic metre is about twice as large as up-valley due to the stability conditions favouring long plumes at night.

Table 3: Maximum separation distances (m) in Frauental for an exceeding probability of 3 % for up- and down-valley winds

Direction	Ratios according to table 1				Ratios according to table 2			
	1 GE	3 GE	5 GE	8 GE	1 GE	3 GE	5 GE	8 GE
Up-valley	441	235	182	144	440	173	121	--
Down-valley	867	285	184	133	867	285	144	--

Whereas the results in fig. 3 and table 3 have been derived by using net radiation data to calculate stability classes, the following comparison between Frauental and Gersdorf (Fig. 4) is based on stability classes calculated with cloudiness data and wind velocity. Comparing the left panels of figs. 3 and 4, the use of cloudiness data instead of net radiation leads to a less down-valley elongated plume because the frequency of very stable situations is less than with net radiation; on the other hand, high concentrations near the source cover a larger area as unstable situations are more frequent when using cloudiness data. Separation distances for 1 and 3 OU/m^3 are considerably lower when using cloudiness data (table 4 in comparison to table 3, left panels), but almost equal for 5 and 8 OU/m^3.
Comparing the left and right panels in fig. 4, it is evident that the farms in Gersdorf (right panel) produce less odour than the big farm in Frauental (left panel). Also in Gersdorf, a valley wind system is active, with main wind directions North and South. Down-valley winds go South, leading to a plume elongation in this direction, which is however not as prominent as in Frauental. The considerably smaller separation distances compared to Frauental are also evident from table 4. As in Frauental, the concentration maximum occurs up-valley, caused by unstable situations in connection with daytime up-valley winds.

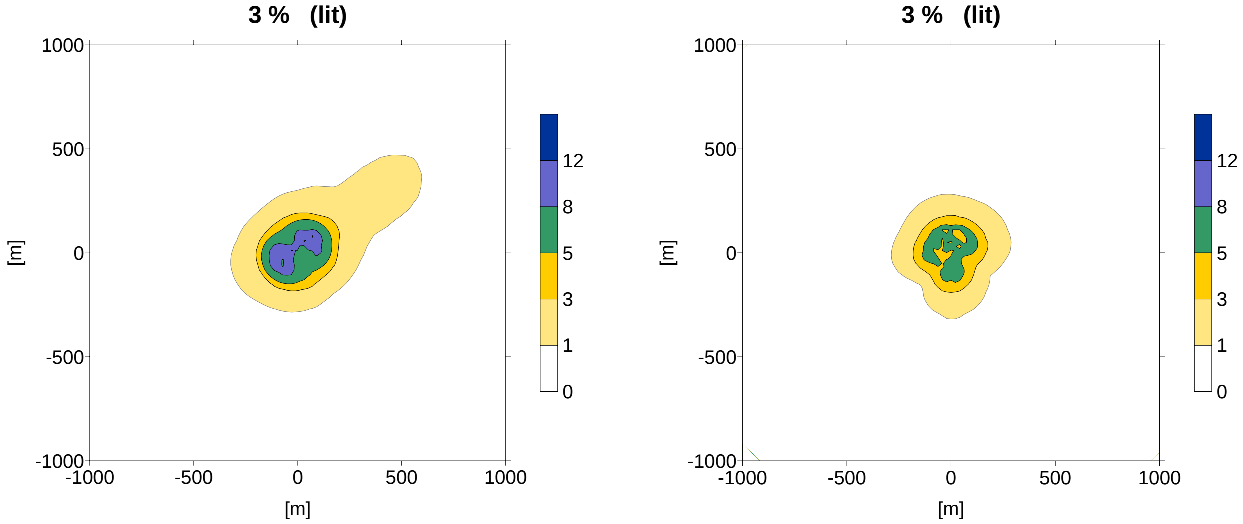

Figure 4: Direction-dependent separation distances (m) in Frauental (left) and Gersdorf (right) for an exceeding probability of 3 %. Ratios of variances according to table 1.

Table 4: Maximum separation distances (m) in Frauental and Gersdorf for an exceeding probability of 3 % for up- and down-valley winds

Direction	Frauental				Gersdorf			
	1 GE	3 GE	5 GE	8 GE	1 GE	3 GE	5 GE	8 GE
Up-valley	329	200	178	146	283	179	142	--
Down-valley	725	231	181	142	321	190	151	--

4 Conclusions

For two locations with pig farms in Southern Austria (section 2.3) a sensitivity study of the separation distances calculated with the Austrian Odour Dispersion Model AODM (section 2.1; [4], [5], [6]) has been carried out. AODM has an advanced peak-to-mean module (section 2.2). The sensitivity study shows the influence of cloudiness or net radiation data as well as different ratios of wind variances to wind speed (tables 1 and 2) on the separation distances (section 3).
At both locations investigated, a valley wind system is present (figs. 1 and 2) with predominantly day-time up-valley and night-time down-valley winds. The up-valley winds co-incide with unstable, the down-valley winds with stable stratification; the former are associated with on average larger wind speeds than the latter. The down-valley separation distances are however larger than those up-valley (figs. 3 and 4), especially for a concentration of 1 odour unit per cubic metre, indicating that the influence of stability is larger than that of wind speed. The highest concentrations occur up-valley in the vicinity of the source due to unstable conditions associated with the up-valley flow.
Whereas these are conclusions relevant for both sites investigated, the separation distances themselves are also a function of the farm parameters, esp. the number of animals and how they are kept. The different farm parameters lead to systematic differences in the separation distances of the two farms investigated (see e. g. table 4).
With respect to odour assessments, the results of model calculations have to be 'on the safe side', i. e. the largest separation distances calculated are relevant for assessing the environmental impact of a farm. For the ratios of the variances of the wind components to the mean wind speed, values of table 1 should therefore be used. With respect to the determination of dispersion categories, larger separation distances for 1 OU/m^3 are obtained by using net radiation; however, the maximum odour concentration near the source is obtained by using cloudiness data to determine atmospheric stability.

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