

Odour episodes in the vicinity of livestock buildings: A qualitative comparison of odour complaint statistics with model calculations

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Abstract

In this paper we compare odour complaint statistics of various sites in Europe, South Africa and North America with calculated odour sensation at a site in Austria, which can be used as a typical example of a well-ventilated area with prevailing west wind and a superimposed weak influence of a mountain wind system. A major goal of this work is the discussion of the general time pattern of complaint statistics and the discrepancy with the occurrence of odour sensation calculated by a dispersion model.

The Austrian odour dispersion model (AODM) is a Gaussian model suitable for the prediction of ambient odour concentrations. Based on cumulative frequency distributions of calculated odour concentrations at receptor points, separation distances are obtained defined by odour impact criteria chosen as a combination of odour threshold and probability of threshold exceedance. At these separation distances, depending on the wind direction, the occurrence of odour sensation is analysed and compared with the well-known time pattern of the complaint statistics for odour.

Here, the AODM is used to calculate separation distances for an odour threshold of 1 odour unit (OU) per cubic metre exceeded in 3% of the year. At a site in the Austrian North-alpine foreland, direction-dependent separation distances for a 1000 head pig unit (calculated on the basis of a 2-year time series of meteorological data) lie between 99 m for northerly winds and 362 m for westerly winds. For these direction-dependent separation distances we analysed when odour sensation can be expected in relation to meteorological parameters as well time of the day and year. For the main wind directions, West and East and odour sensation can be expected more often for higher wind velocities and a neutrally or stably stratified atmosphere around sunset. North and South winds show the typical diurnal variation of a local valley wind system with predominantly northerly daytime up-valley and southerly night-time down-valley winds. Odour sensation is therefore most likely around noon for North wind and during night-time for South wind. This time pattern of the calculated odour sensation does not fit to the time pattern of the complaint statistics, which shows complaints to occur predominantly in the afternoon and evening hours of the warm season when residents are outside. The presented comparison of odour complaint statistics with the calculated odour episodes is a helpful tool to find out when odour is perceived as most annoying. As a result, the evaluation of these values by the odour impact criteria should not only be based on statistical limits as it is done today but also by considering the annoying potential of odour due to the behaviour of the neighbours. Therefore the odour episode should be weighted by the time of the day and time of the year, as it is done with the limit values for noise.

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1. Introduction

Odour is one of the major nuisances from livestock husbandry especially in the swine industry causing an

increasing need for odour related research (Thu, 2002). The final report of the Iowa State University and The University of Iowa Study Group (2002) defines odour, besides hydrogen sulphide and ammonia, as emission, which has been of major concern by residents in the vicinity of livestock. Environmental agencies are confronted by complaints of people living in the vicinity of animal producing farms.

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Reports about these complaints show similar time patterns concentrated during the warm season and in the afternoon and evening hours.

In this paper, the time pattern of the complaints is compared to the time pattern of odour episodes calculated by the Austrian Odour Dispersion Model AODM described recently (Schaubberger et al., 2001, 2002). The AODM consists of three modules: the first calculates the odour emission of the livestock building, the second estimates mean ambient concentrations using the Austrian Gaussian regulatory dispersion model and the last transforms the mean odour concentration of the dispersion model to instantaneous values that depend on wind velocity and atmospheric stability. The direction-dependent separation distance is defined as the distance from the source where a sensation level dependent on a pre-selected odour impact criterion occurs.

The odour impact criteria are defined by an odour threshold and an exceeding probability of this threshold. The threshold defines a physiological reaction to a certain odour concentration (e.g. 1 OU m^{-3} for the perception threshold, $3\text{--}5 \text{ OU m}^{-3}$ for the recognition level and 8 OU m^{-3} for the annoying level). The exceeding probability gives the percentage of time, when the pre-selected threshold will be exceeded. Many countries have different combinations of these two values. We selected a conservative criterion with the perception threshold of 1 OU m^{-3} and only 3% of the time that this odour concentration will be exceeded (Schaubberger et al., 2001).

2. Materials and methods

Only a brief summary is given here; details can be found in Schaubberger et al. (2002).

2.1. Short description of the AODM

The odour release is calculated by a steady-state balance of the sensible heat flux of the livestock building (sensible energy release of the animals, the energy flow through the building and due to the ventilation system) described by Schaubberger et al. (1999, 2000b). The odour release inside the building is modified by the calculated indoor temperature and the ventilation rate of the livestock unit (Schaubberger et al., 2000b). The corresponding odour flow in OU s^{-1} is assessed by a simple model for the odour release. The chosen system parameters are typical for a livestock building in middle Europe (Schaubberger et al., 1993). The following parameters were calculated every half-hour over the 2-year period for a mechanically ventilated pig fattening unit with 1000 pigs: outlet air temperature, outlet air velocity, volume flow of the ventilation system, odour concentration of the outlet air. The odour flow in OU s^{-1} is obtained by the product of the volume flow of the building in $\text{m}^3 \text{ s}^{-1}$ and odour concentration of the outlet air in OU m^{-3} .

The mean ambient odour concentrations are calculated using the Austrian Gaussian regulatory dispersion model (ÖNorm M 9440, 1992/1996), a Gaussian plume model for single stack emissions. The model has been validated internationally (e.g. Pechinger and Petz, 1999). The mean odour concentrations of the dispersion model are transformed to instantaneous values depending on wind velocity and atmospheric stability. The meteorological background to calculate the instantaneous values using a peak-to-mean parameterisation is described in detail by Schaubberger et al. (2000a).

2.2. Calculating sensation and separation distance

The separation distance is calculated for eight wind direction classes (sectors of 45°) in two steps. First, sensation distances, defined as distances from the source where a certain momentary odour concentration can be expected, are calculated. We used an odour concentration threshold T of 1 OU m^{-3} . Over all eight wind direction sectors, we get a sample of 17,520 sensation distances (2 years of half-hour values). The second step is the calculation of the separation distance. Based on the selected threshold exceedance p_T of 3% the corresponding 97-percentile of this sample is taken. At the separation distance 525 out of 17,520 half-hour values (3%) of the sensation distances will be higher. This means that at the separation distance 525 half-hour values of the ambient odour concentrations will exceed the odour threshold T of 1 OU m^{-3} . The corresponding separation distance points to the opposite side of the wind direction (Schaubberger et al., 2001, 2002). An example: for a neighbour in the East the relevant wind direction is West with a frequency of $p_i = 34.1\%$ which gives also the expected odour sensation. For an exceeding probability of $p_T = 3\%$ of the year this means that at the separation distance of 362 m, in $p_{T,i} = 8.8\%$ ($p_{T,i} = p_T/p_i$) of all West wind situations, the odour dispersion model predicts an odour sensation. These cases were called observed odour sensation (Schaubberger et al., 2002).

2.3. Meteorological conditions

The selected site in Austria can be used as a typical example of a well-ventilated area with prevailing west wind and a superimposed weak influence of a mountain wind system.

The meteorological data for January 30, 1992 to January 31, 1994 were collected at Wels, a site representative of the Austrian flatlands north of the Alps (Fig. 1). The sample interval was 30 min. The city of Wels in Upper Austria is a regional shopping and business centre with a population of about 50,000. The surrounding area is rather flat and consists mainly of farmland. The mean wind velocity 10 m above the mean roof top level of 15 m is 2.2 ms^{-1} with a maximum velocity of about 13 ms^{-1} . The distribution of wind directions is shown in Fig. 1, centred at Wels.

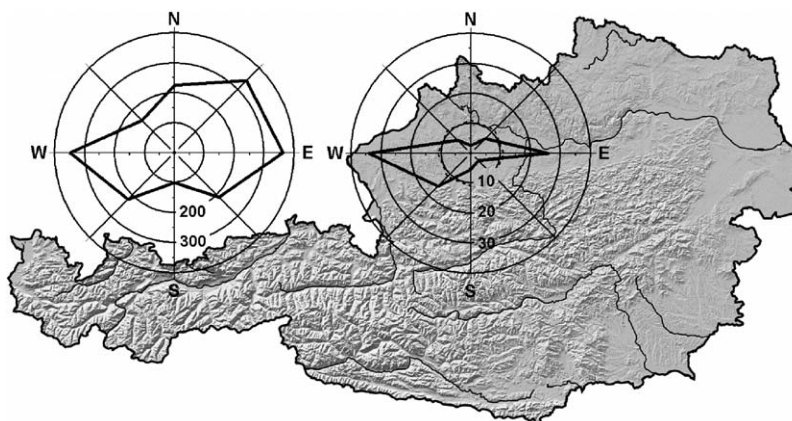


Fig. 1. Map of Austria with a polar diagram of the relative frequency distribution (in %) of the wind direction (for eight sectors with 45°), centred at Wels (site of the livestock) (calm conditions (less than 0.7 m/s) as dotted line) and a polar diagram of the separation distances (m) in the upper left corner (for eight sectors with 45°), outside of the Austrian map.

Discrete stability classes have been determined based on sun elevation angle; cloud cover and low cloud base height; wind speed (Reuter, 1970). The cloud data are measured at the Linz-Hörsching airport, about 13 km from Wels. Within the Reuter scheme, classes 2–7 can occur in Austria. Stability classes 2 (unstable) and 3 (slightly unstable), which by definition occur only during daylight hours in a well-mixed boundary layer, class 3 allowing also for cases of high wind velocity and moderate cloud cover, occur in 26% of all cases. Stability class 4 (neutral), representing cloudy and/or windy conditions including precipitation or fog, is by far the most common dispersion category because it occurs day and night (43%). Class 5 (slightly stable) occurs with higher wind velocity during nights with low cloud cover, a situation, which is not observed frequently at Wels (6%). Classes 6 (stable) and 7 (very stable) are relevant for clear nights, when a surface inversion, caused by radiative cooling, traps pollutants near the ground. Such situations occur in 25% of all cases.

3. Results

First of all the separation distances for the eight wind direction sectors were calculated (Table 1). In Fig. 1 (upper left corner), the separation distances can be compared with the frequency distribution of the wind direction, centred at Wels. For northerly winds (for a southward separation distance), the separation distance is lowest, caused by low average wind speeds and predominantly unstable conditions associated with this wind direction sector (see Figs. 4 and 5). The highest of the direction-dependent separation distances are found for the prevailing wind directions West and East with 362 and 348 m, respectively.

For all cardinal directions the occurrence of odour episodes were analysed in a distance from the source, which is the calculated separation distance. For each direction the expected and the observed odour episodes were analysed according to time of the day, time of the year, wind velocity and the stability of the atmosphere. The “expected” episodes relay to the frequency of the wind direction p_i

Table 1
Direction-dependent odour separation distances

Wind direction ^a , i	Relative frequency (p_i , %)	Direction-dependent exceeding probability ($p_{T,i}$, %)	Direction for the separation distance	Direction-dependent separation distance ^b (S_i , m)
N	2.6	100.0	S	99.4
NE	6.8	44.2	SW	218.9
E	25.9	11.6	W	347.7
SE	3.4	87.7	NW	152.5
S	5.5	55.0	N	224.6
SW	15.6	19.2	NE	339.9
W	34.1	8.8	E	362.1
NW	6.2	48.7	SE	208.9

The direction-dependent exceeding probability $p_{T,i}$ for an odour threshold T and a certain wind direction i is given by:

$$p_{T,i} = \begin{cases} \frac{p_T}{p_i} & \text{for } p_T < p_i \\ 1 & \text{for } p_T \geq p_i \end{cases}$$

^a Wind direction for eight classes (45°).

^b The separation distances were calculated on the basis of an odour threshold T of 1 OU m⁻³ and a probability of threshold exceedance of $p_T = 3\%$. The maximum and the minimum distances are marked in bold.

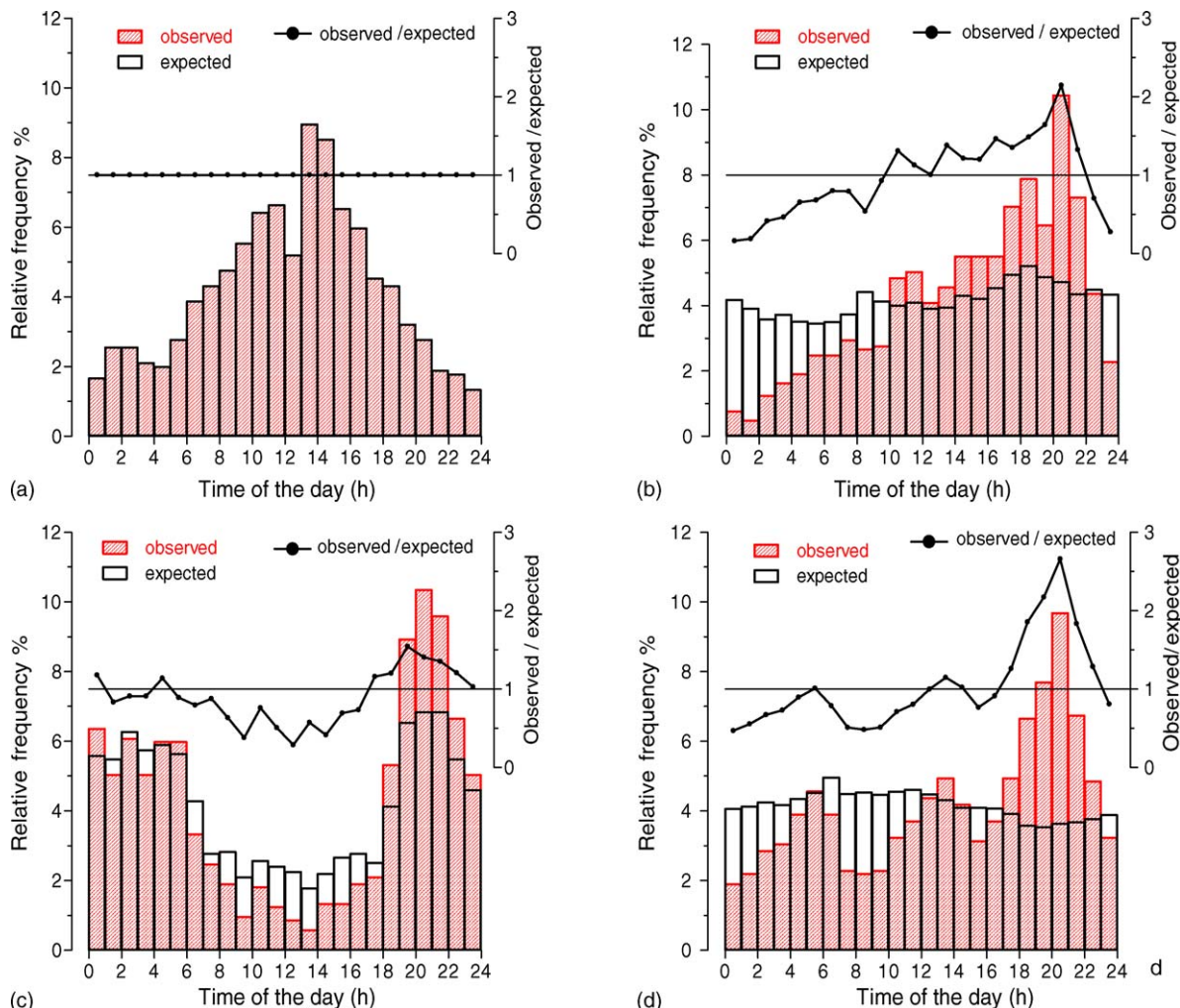


Fig. 2. Comparison of the relative frequency of expected (empty bars) and observed (filled bars) odour episodes for the time of the day. Proportion of observed to expected events (dotted line). (a) North wind, (b) East wind, (c) South wind and (d) West wind (all 45° sectors).

(Table 1), the “observed” episodes with a frequency of p_{Ti} are the cases when the ambient odour concentration exceeds 1 OU m^{-3} . The quotient of the observed cases versus expected cases (Figs. 2–5) is used to highlight those meteorological situations where the probability is higher that odour will be perceived (like the relative risk). A quotient greater than 1 gives the bias under which meteorological circumstances odour episodes can be expected with a higher probability.

For North wind no comparison between observed and expected odour episodes is possible: The probability for North wind (2.6%) is less than the probability of the threshold exceedance of 3% of the selected odour impact criterion. This means that all the time with North winds, odour episodes occur and the relative frequencies of the expected and the observed odour episodes are the same.

Northerly and southerly winds show a behaviour, which suggests an influence of the North–South oriented Alm river valley running into the Alpine foreland south of Wels. Northerly up-valley winds are more frequent during daytime

(Fig. 2a), southerly down-valley winds more frequent during night (Fig. 2c). Therefore northerly winds are frequently associated with stability classes 2–4 (Fig. 5a), southerly winds with classes 4–7 (Fig. 5c). For both wind directions, the average wind velocity is rather small, with the 75%-percentile at 1.1 m s^{-1} for North (Fig. 4a) and at 1.9 m s^{-1} for South wind (Fig. 4c), respectively. In accordance with these findings, odour episodes at the separation distance for northerly winds (all half-hours) show a maximum during daytime (between 7:00 and 20:00 h) (Fig. 2a) and occur frequently more often during the spring and summer months (Fig. 3a). For southerly winds (Fig. 2c), odour episodes at the separation distance have their maximum of occurrence in the evening (after 18:00 h), are frequent throughout the night and show a local maximum in the morning (before 6:00 h). South wind is most frequent from late summer through autumn to January (Fig. 3c).

East and West winds are the dominant directions at Wels. Both directions show no strong variation over the day (Fig. 2b and d) and some but no systematic variability across

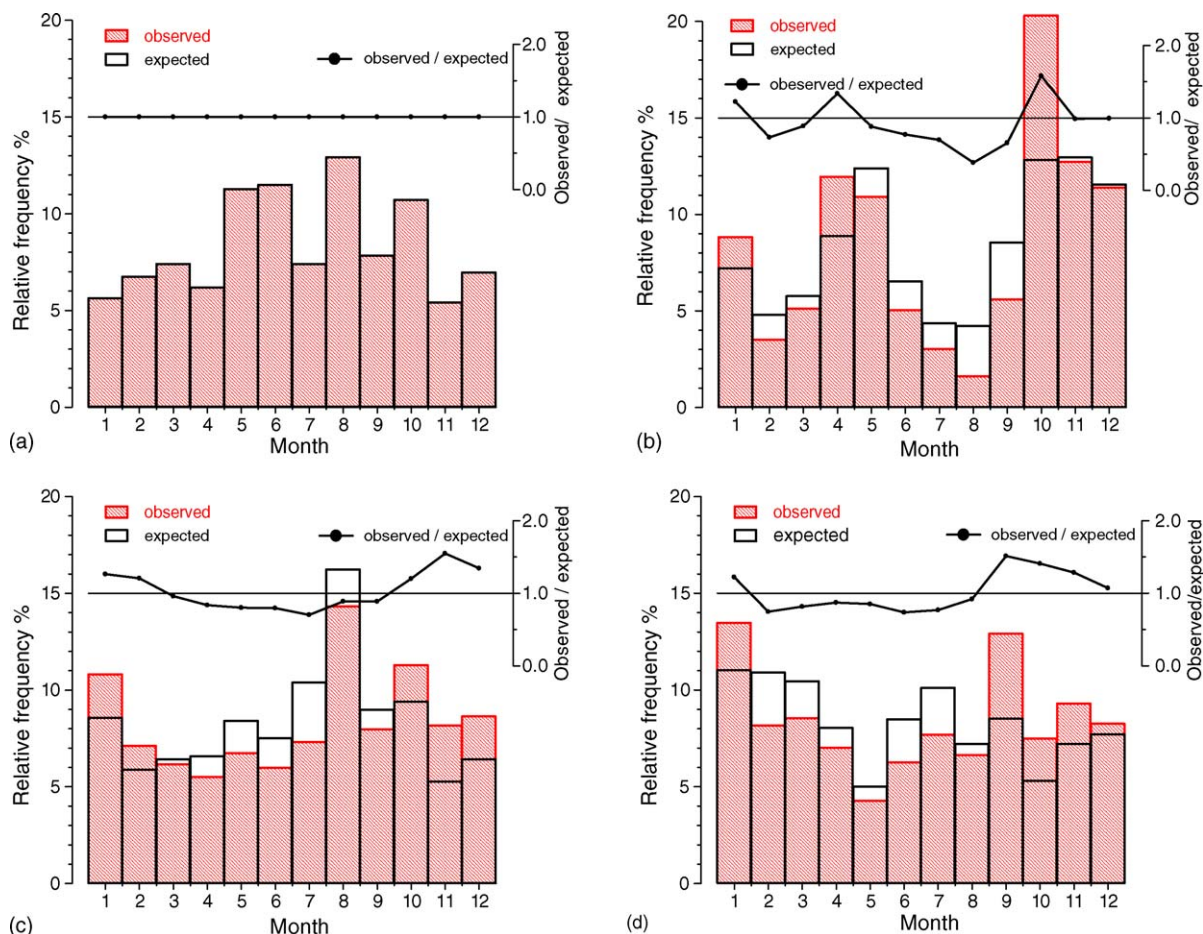


Fig. 3. Comparison of the relative frequency of expected (empty bars) and observed (filled bars) odour episodes for the time of the year. Proportion of observed to expected events (dotted line). (a) North wind, (b) East wind, (c) South wind and (d) West wind (all 45° sectors).

the year (Fig. 3b and d). Both directions are associated with much stronger wind velocities than North and South wind (Fig. 4b and d); the most frequent velocities for East wind are around 3 m s^{-1} , for West wind around 4 m s^{-1} . Maximum velocities are around 9 m s^{-1} for East wind and around 13 m s^{-1} for West wind. The distribution of stability classes with East and West winds is relatively similar to the overall distribution (Section 2.3), due to the large frequency of these directions. Stability class 4 dominates, especially for West wind (Fig. 5d) frequently in conjunction with high wind velocities, cloudiness and rain. Classes 2 and 3 as well as 6 and 7 are more common with East wind associated with anticyclonic conditions (Fig. 5b). For East and West winds, odour episodes at the separation distance take place more often in the second half of the day, with peaks around 22 CET (Fig. 2b and d) and from October to January (Fig. 3b and d). For both directions, the dependence of odour episodes on wind velocity shows several peaks, mostly at 1 and from 3 to 5 m s^{-1} (Fig. 4b and d). For East wind, odour episodes occur only with stability classes 4–7 (Fig. 5b); for West wind, they occur with classes 4–6; classes 2 and 3 are free from odour episodes for the selected odour impact criterion, which is an effect of the

large separation distance for these directions (Table 1 and Fig. 1).

The daily frequency distribution of observed odour episodes shows a distinct maximum for all direction sectors (Fig. 2). For northerly winds, a maximum occurs in the afternoon, for the three other direction sectors in the evening hours which is also expressed by a maximum of the ratio between the frequency of the observed and expected episodes. For the annual variation (Fig. 3) no such clear time pattern could be found; however, apart from North wind, there is a tendency of more observed than expected episodes in the winter months.

An important parameter describing the nuisance potential of odour is the duration of consecutive odour episodes (Fig. 6). The duration of odour episodes was investigated in relation to the hour of the day and the day of the year. It is expressed by the size of the circles in the graph. The lines, marking the time of sunset and sunrise, separate daytime from night-time, which changes the character of the dispersion process in the atmosphere, expressed by the stability class. For all four wind directions, a distinct pattern can be seen. The two wind directions (N and S) influenced by the valley wind system show a distinct diurnal pattern: For

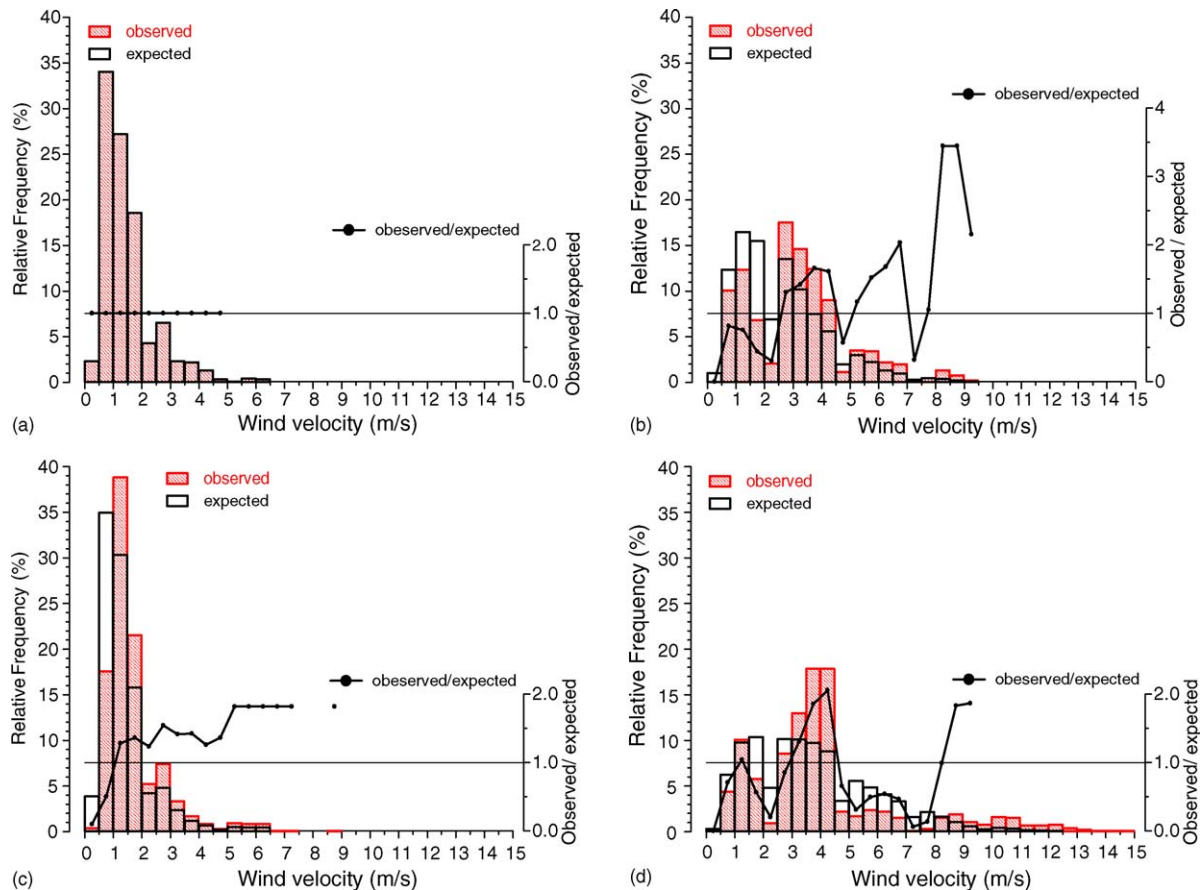


Fig. 4. Comparison of the relative frequency of expected (empty bars) and observed (filled bars) odour episodes for wind velocity. Proportion of observed to expected events (dotted line). (a) North wind, (b) East wind, (c) South wind and (d) West wind (all 45° sectors).

North wind, episodes occur predominantly during daytime (Fig. 6a), for South wind, during night-time (Fig. 6c). The occurrence of long lasting odour episodes is much smaller than for the prevailing wind directions (West and East). For the prevailing wind directions, the influence of solar radiation on the occurrence of odour episodes is less pronounced but still present (Fig. 6b and d). For these directions, the occurrence of odour episodes shows a minimum at midday in summer.

4. Discussion

In this paper we compare odour complaint statistics of various sites in Europe, South Africa and North America with calculated odour sensation at a site in Austria, which can be used as a typical example of a well-ventilated area with prevailing west wind and a superimposed weak influence of a mountain wind system. A major goal of this work is the discussion of the general time pattern of complaint statistics and the discrepancy with the occurrence of odour sensation calculated by a dispersion model. We discuss published complaint statistics from Austria (Strauss et al., 1986), South Africa (Stretch et al., 2001), South Michigan (Lohr, 1996), Canada (<http://freenet.edmonton.ab.ca/capilano>; 2005) and

North Carolina (Schiffman, 1994). They show a broad agreement of the observed time pattern.

We used the Austrian odour dispersion model (AODM), a Gaussian model suitable for the prediction of ambient odour concentrations (Section 2), to calculate direction-dependent separation distances, defined by odour impact criteria chosen as a combination of odour threshold and probability of threshold exceedance. The selected odour impact criterion is based on a guideline of the Austrian Academy of Sciences, discussed by Stangl et al. (1993). A discussion of impact criteria, used in several countries can be found in Schaubberger et al. (2001) and Sheridan et al. (2004).

At these direction depending separation distances the occurrence of odour episodes was analysed and compared with complaint statistics for odour via a literary survey.

Most complaints ('time of most complaint') from swine odour are recorded early in the morning or late at night under stable conditions (Schiffman, 1994). In the Canadian community Capilano (<http://freenet.edmonton.ab.ca/capilano>), the following distribution of odour episodes over time was reported for 2002. Fifty four percent of odour complaints were registered between 20:00 and 23:00 h and 78% of all complaints were registered during evening hours between 16:00 and 24:00 h. Thirteen percent of complaints only were registered during mid-day hours (08:00–16:00 h)

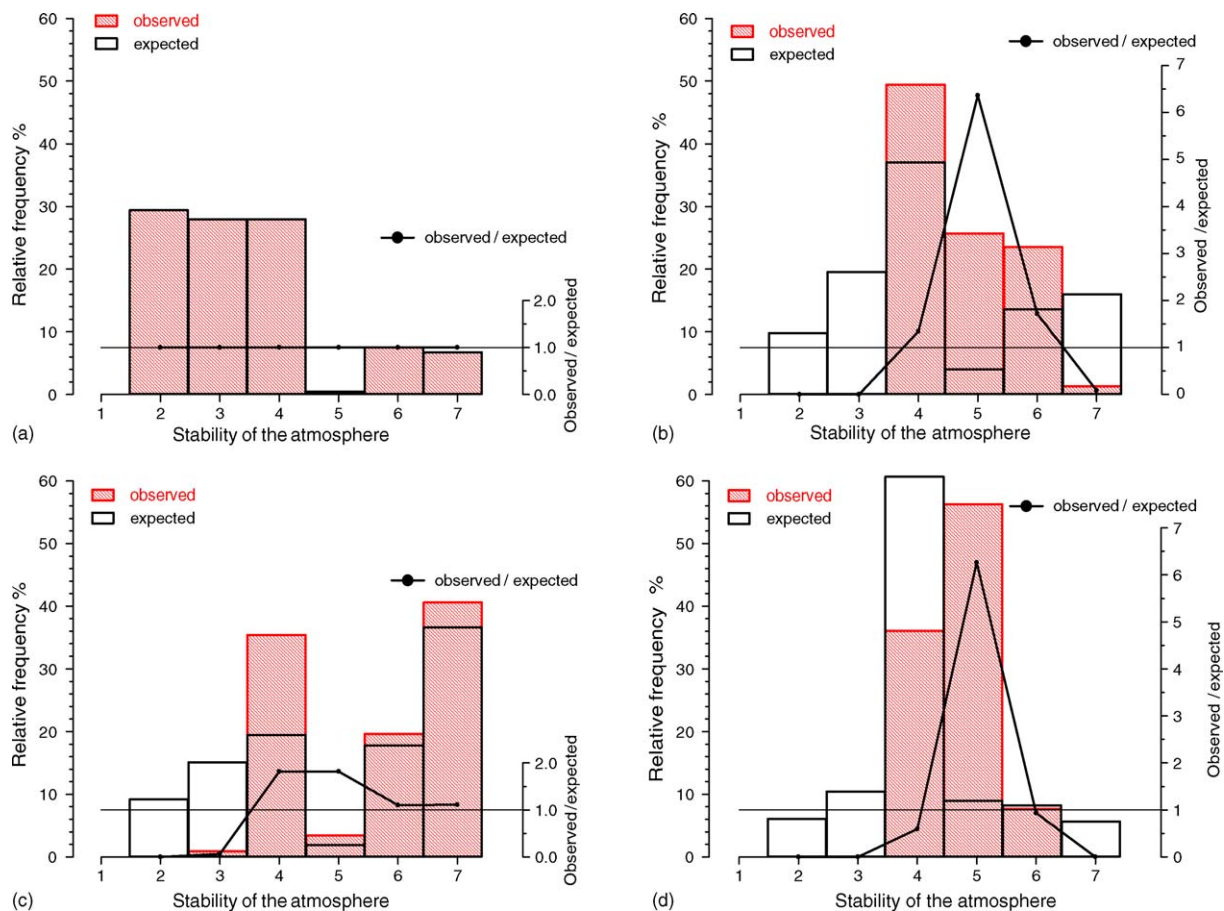


Fig. 5. Comparison of the relative frequency of expected (empty bars) and observed (filled bars) odour episodes for stability of the atmosphere. Proportion of observed to expected events (dotted line). (a) North wind, (b) East wind, (c) South wind and (d) West wind (all 45° sectors).

and 9% during early morning hours (00:00–08:00 h). Sixty seven percent of all complaints were registered during June and July. The reported duration of odour episodes (in hours per episode) in Southern Michigan, USA by Lohr (1996) shows the following pattern: 16.59 for summer, 12.00 for spring, 10.59 for autumn and 2.47 for winter. Another time of above-average complaints could well be the transition from daytime to night-time, when a stable stratification evolves in the near-surface boundary layer.

The results obtained applying the AODM to meteorological conditions typical for Austrian areas North of the Alps and presented in Fig. 2 show, however, maximum odour probability predicted to occur at different times of the day: afternoon hours for northerly winds (Fig. 2a), late evening hours for easterly winds (Fig. 2b), night-time including evening and morning transition for southerly winds (Fig. 2c) and again late evening hours for westerly winds (Fig. 2d). Thus, predicted and observed odour episodes coincide to a large extent, but also partly differ. The co-incidence is strongest for late evening hours, an indication that the AODM seems to be capable of correctly taking into account the spread of odour over longer distances in stable conditions. It should be emphasised here that the model is designed to predict odour perception at receptor

points (e.g. neighbours), but not the occurrence of complaints at the neighbours. Moreover, the “comparison” is not direct, as the model calculations are not undertaken for these sites where the complaints were reported. The assessment of odour perception by the AODM does not always coincide with the real time of nuisance complaints because the behavioural response of the neighbours to the odours cannot be included in the model.

For the annual variation the complaints statistics and the calculated odour episodes show a weaker relationship. Strauss et al. (1986), in a survey about the complaints due to livestock units in Austria, found a higher probability during summer (50%) compared to spring (34%), autumn (25%) and winter (1%). Only 26% of the persons interviewed feel constantly annoyed all year. For a landfill site in Durban, South Africa (Stretch et al., 2001) more complaints were reported during summertime. Lohr (1996) investigated the odour perception for the four seasons by the frequency of odour episodes (number of episode noticed per month) and found 3.24 for summer, 1.18 for spring, 0.71 for autumn and 0.12 for winter. The AODM calculation of the direction-dependent separation distances for Wels does not show such a clear dependence of odour episode on the season (Fig. 3). The results, however, indicate high odour levels during

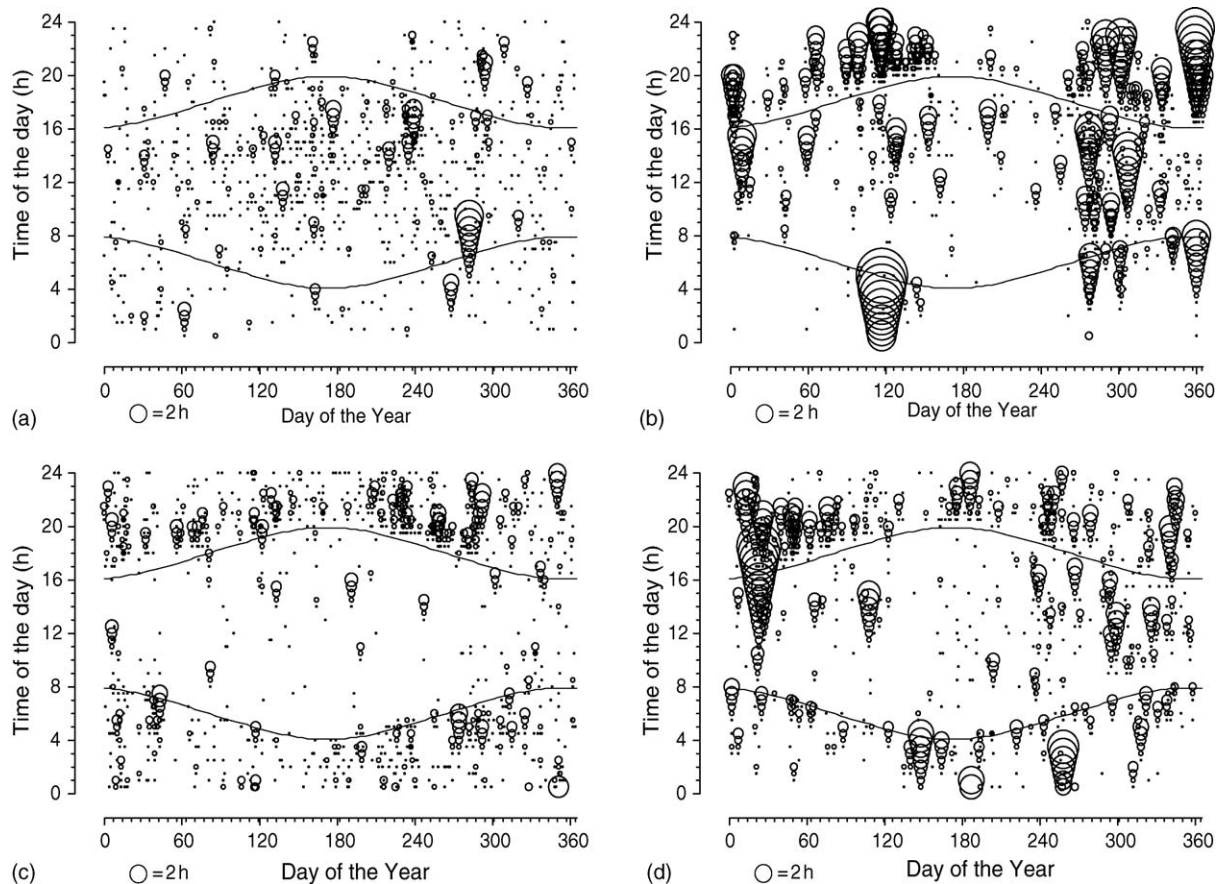


Fig. 6. Duration of odour episodes as a function of the day of the year and the time of the day. The diameter of the circles is proportional to the duration of odour episodes. (a) North wind, (b) East wind, (c) South wind and (d) West wind (all 45° sectors). The lines mark sunrise and sunset for Wels (geographic latitude: 47.17°N).

summer for North wind and South wind in August only, whereas for East and West winds, summer months show a minimum in odour episodes. Instead, AODM predicts more frequent odour episodes for the winter months.

A residents-based field observation of odour in the vicinity (4.8 km × 4.8 km) of livestock buildings was done by Jacobson et al. (2001). Odour was detected in 71% during neutral to slightly stable conditions and during light winds (<2.5 m/s). Odour episodes occurred predominantly during the warm season and either in the early morning or during evening hours. Jacobson et al. (2001) found the following reasons: increased odour emission due to higher temperatures and more outdoor activities of residents during summertime.

One reason why odour complaints are registered more often in the warm season compared to the model calculations presented could be caused by the annual variation of the outdoor temperature. The first influence might be the sensitivity of odour perception (Strauss et al., 1986). For the taste closely related to odour sensation, Cruz and Green (2000) found a sensitivity to temperature, depending on the location of the tongue and the four types of taste. Fang et al. (1998) found a weak linear correlation between the acceptability of air quality and the enthalpy of the air with

the restriction that the investigation was done for indoor air and a limited range of both air temperature (18–28 °C) and relative humidity (30–70%). Speculating that this weak influence could be extrapolated to outdoor temperatures during wintertime, this could cause a reduction of frequency of perceived odour episodes. The second influence could be the temperature dependent production of odorous substances inside the livestock building (Oldenburg, 1989; Schaubberger et al., 2003). van Langenhove and de Bruyn (2001) found a correlation coefficient between odour emission and indoor temperature of 0.35 and 0.85 for the outdoor temperature, respectively. Huegle and Andree (2001) found that temperatures strongly influenced odour emission from head space of swine and cattle slurry.

The most important reason for the discrepancy between complaint statistics and model calculations seems to be the time pattern of the behaviour of the neighbours. This influence is not included in the odour impact criteria, which are applied to calculate the separation distances. It is obviously not the same with respect to odour nuisance if odour episodes occur e.g. around sunset in summertime or during night-time in winter. It has to be discussed if the odour impact criteria, defined solely by a probability of exceedance of the selected odour threshold, are sufficient to

guarantee protection with respect to the time of the day or the season of the year. Jacobs (1994) suggested a weighting factor for the offensiveness of odour caused by manure spreading on fields in three steps from low, moderate and high for the time of the year, the time of the week, the time of the day, wind velocity and humidity.

The presented comparison of odour complaint statistics with calculated odour episodes is a helpful tool to find out when odour is perceived as most annoying. This could help to weight the modelled odour episodes to get a better fit of the model calculations to the observed complaints.

5. Conclusions

The Austrian odour dispersion model AODM is used to predict the occurrence of odour perception. The evaluation of the direction-dependent separation distances according to the daily (Fig. 2) and yearly course (Fig. 3) as well as for wind speed (Fig. 4) and atmospheric stability (Fig. 5) leads to a calculated occurrence of odour episodes which differs from various odour complaint statistics which show odour to occur predominantly during the evening hours of warm summer days. As a result, the evaluation of these values by the odour impact criteria should not only be based on statistical limits as it is done today but also by considering the annoying potential of odour due to the behaviour of the neighbours. Therefore odour episodes should be weighted by the time of the day and time of the year, as is done with the limit values for noise.

The results of this study lead to the following open questions:

- Is an odour impact criterion, defined by a threshold and an exceedance probability, an appropriate method to assess the annoying level?
- Should we weight odour sensation by time of the day and time of the year to take into account the time pattern of the behaviour of neighbours?
- Is odour perception sensitivity dependent on outside temperature and humidity?

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