Model Calculation of Odour Sensation in the Vicinity of a Livestock Building: a Meteorological Analyses when Odour Occur

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ABSTRACT

By the dynamic Austrian odour dispersion model (AODM), a Gaussian model, which was adapted for the prediction of odour sensation the separation distance was calculated for an odour threshold of 1 odour units (OU) per cubic metre which does exceed 3% of the year. The calculated direction-dependent separation distances are a function of the prevailing wind velocity and atmospheric stability conditions. At a site in the Austrian North-alpine foreland, the direction-dependent separation distance for a 1000 head pig unit (calculated on the basis of a two-year time series of meteorological data) lies between 99 m (for northerly winds with a probability of less than 3% per year) and 362 m (for westerly winds with a probability of 34%). For the main wind directions, West and East, odour sensation can be expected more often for higher wind velocities and a neutral or stable 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.

INTRODUCTION

Public concern over air pollution from swine production and growing environmental regulations have created a great need for odour related research in the swine industry. One way to reduce odour nuisance is to use a separation distance between the odour source and residential areas. Apart from empirical guidelines used to estimate the separation distance (Piringer & Schauberger, 1999), it can also be calculated by dispersion models. These models have to be adapted to the special needs of odour to mimic the human odour sensation. We used the Austrian odour dispersion model which was described recently (Schauberger.et al., 2001 and 2002). Direction-dependent separation distances are calculated defined as the distance from the source where a sensation level dependent on a pre-selected odour impact criterion occurs. At these direction depending distances we analysed when odour sensation can be expected. These situations were investigated according to intensity, frequency and duration of odour sensation.

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MATERIALS AND METHODS

The dynamic Austrian odour dispersion model (AODM) is described in detail in (Schauberger et al., 1999, 2000, and 2001). By this model the separation distance is calculated for each wind direction (8 classes) (Schauberger et al., 2002)

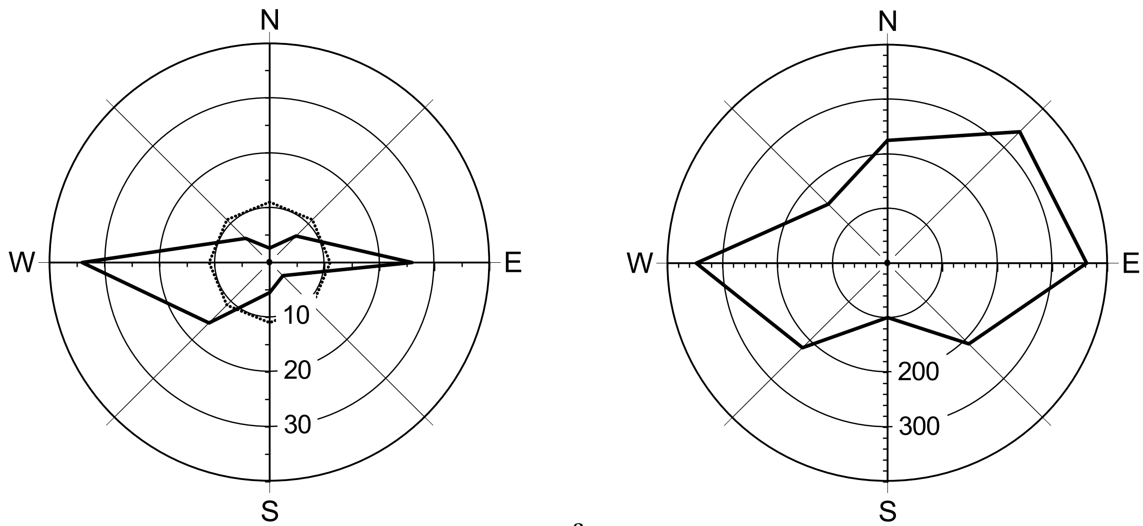
The meteorological data for January 30, 1992 to January 31, 1994 were collected at Wels, a site representative of the Austrian flatlands north of the Alps. The mean wind velocity 10 m above the mean roof top level of 15 m is 2.2 m/s with a maximum velocity of about 13 m/s. The distribution of wind directions is shown in Fig. 1a. The description of the relevant meteorological parameters can be found in Schauberger et al. (2002).

Discrete stability classes are still a wide-spread approach how ambient weather conditions can be considered in dispersion calculations. Stability classes 2 and 3, 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 more frequently below or around the average wind velocity. They occur in 26% of all cases. Stability class 4, 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 %). Its occurrence peaks at wind velocity of 2 to 3 m/s. Wind velocities greater than 6 m/s are almost entirely connected with class 4. Class 5 occurs with higher wind velocity during nights with low cloud cover, a situation which is not observed frequently at Wels (6 %). Classes 6 and 7 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.

RESULTS

In Fig. 1b, the calculated direction-dependent separation distance is shown. For northerly winds (for a southward separation distance), the separation distance is lowest, caused by the low probability for this wind direction of 2.6 %. The highest of the direction-dependent separation distances are found for the prevailing wind directions Wets and East with 362m and 348 m, respectively.

At the separation distance, the episodes when odour sensation can be assumed were analysed according to the FIDO factors, frequency, intensity, duration and offensiveness. For the frequency it was investigated, if odour sensation is evenly distributed over the time of the day, months, air velocity and stability of the atmosphere. Therefore we compared the relative frequency of the entire data set of the 2 year period and with the episodes when odour was predicted by the model. The intensity is represented by the odour concentration which can be expected during the sensation episodes. The duration was analysed by the relative frequency of consecutive odour sensation.



a b

Fig. 1. Polar diagram of (a) relative frequency distribution of the wind direction at Wels for eight 45° sectors. Calm conditions according to the ÖNorm M 9440 (1992/1996) with wind velocity less than 0.7 m/s evenly distributed over all directions (dotted line) and (b) separation distances (in m) calculated by the model for eight wind directions based on an odour concentration threshold of 1 OU/m³ and the probability of the threshold exceedance of 3 %.

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, southerly down-valley winds more frequent during night (Fig. 2). Therefore northerly winds are frequently associated with stability classes 2 to 4, southerly winds with classes 4 to 7 (Fig. 3). For both wind directions, the wind velocity is rather small, with the 75 %-percentile at 1.1 m/s for North and at 1.9 m/s for South wind , respectively. In accordance with these findings, odour sensation at the separation distance for northerly winds (all half-hours) shows a maximum during daytime (between 7:00 and 20:00) and occurs frequently more often during the spring and summer months. For southerly winds, the odour sensation at the separation distance has its maximum in the evening (after 18:00), is large throughout the night, and shows a local maximum in the morning (before 6:00).

East and West winds are the dominant directions at Wels. Both directions show no strong variation over the day and some but no systematic variability across the year. Both directions are associated with much stronger wind velocities than North and South wind: the most frequent velocities for East wind are around 3 m/s, for West wind around 4 m/s. Maximum velocities are around 9 m/s for East wind and around 13 m/s for West wind. The distribution of stability classes with East and West winds is relatively similar to the overall distribution, due to the large frequency of these directions. Stability class 4 dominates, especially for West wind 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. For East and West winds, odour sensation at the separation distance takes place more often in the second half of the day, with peaks around 22 CET (Fig. 2), and from October to January. For both directions, the dependence of odour sensation on wind velocity shows several peaks, mostly at 1, 3, and 6 m/s. For East wind, odour sensation occurs only with stability classes 4 to 7 (Fig. 3); for West wind, it occurs with classes 4 to 6; classes 2 and 3 are free from odour sensation for the selected odour impact criterion, which is an effect of the large separation distances for these directions.

The next FIDO factor is the odour intensity. For each cardinal direction the expected odour concentration which is directly correlated to the perception of the odour intensity was analysed. The main difference can be seen between the two wind directions which are predominantly influenced by the valley-wind system (North and South) and the East and West wind influenced by the large-scale atmospheric flow. For the easterly and westerly wind very little variation was found. Most of the expected odour concentration is close to the used odour threshold of 1 OU/m³ of the odour impact criteria. For northerly winds we found concentrations, which go up to 17 OU/m³.

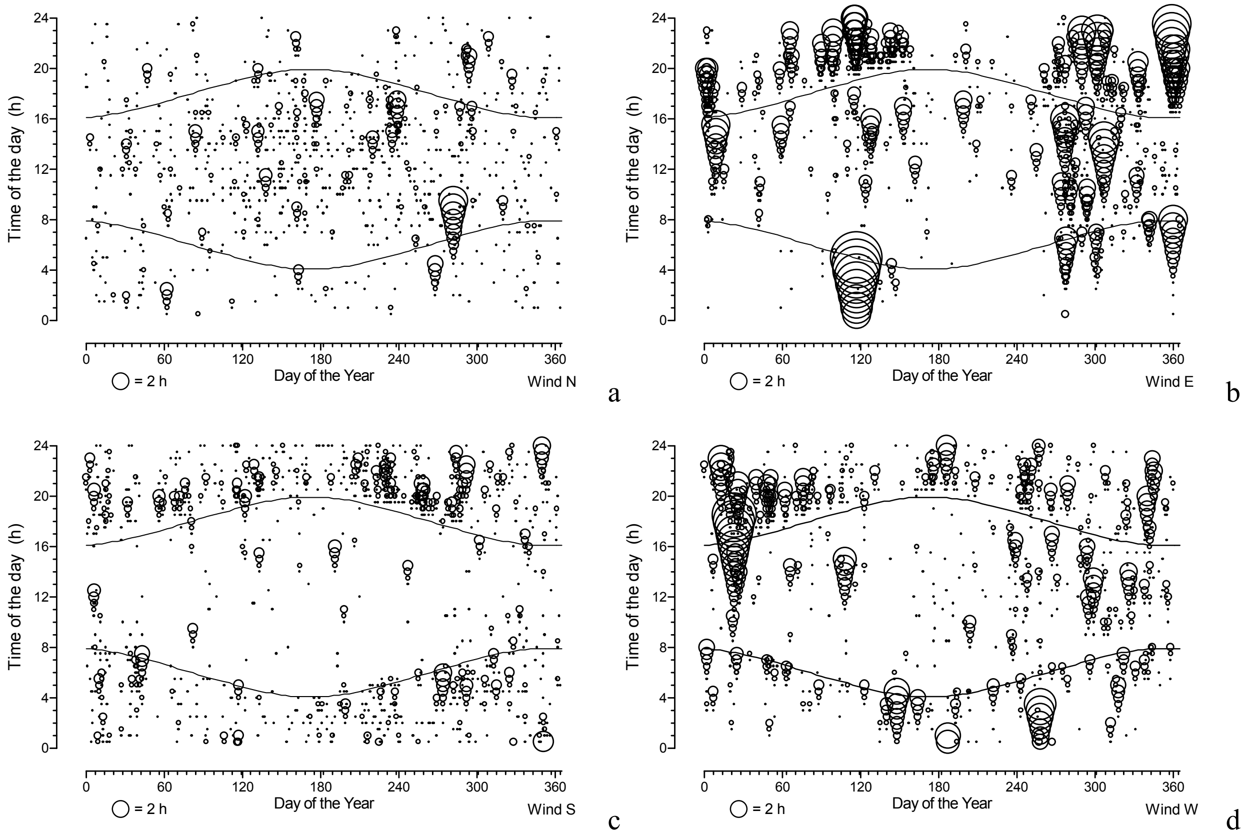


Fig. 2. Duration of odour episodes (consecutive half-hourly odour sensation) for the four cardinal direction as a function the day of the year and the time of the day. The diameter goes proportional with the duration of odour sensation (a) wind North - separation distance South, (b) wind East- separation distance West, (c) wind South- separation distance North, and (d) wind West- separation distance East.
The lines mark sunrise and sunset for the Wels (geographic latitude: 47.17°N)

The duration is the next characteristic which is related to the annoying potential of odour sensation. First of all the duration of odour is limited by the odour impact criteria which reduces the duration to 3%. Secondly we used the duration of consecutive half-hourly odour episodes to describe the persistency of odour sensation (Fig. 2 and 3). The main difference is between the prevailing wind directions (East and West) and the two directions which are influenced by the valley wind system. By the fact that the prevailing wind directions have a more constant character as the other two directions, the relative frequency of long lasting episodes gets higher. For northerly and southerly winds the episodes last only one half hour in 76% and 64%, respectively. The duration of odour sensation episodes were also investigated in relation to the time of the day and the day of the year (Fig. 2). The duration was depicted by the diameters of circles. For all four wind directions a distinct pattern can be seen. The lines, marking the time of the day of sunset and sunrise delimit daytime and night-time, which changes the character of the dispersion process in the atmosphere. For the two wind directions, influenced by the valley wind system, show a distinct diurnal pattern. 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.

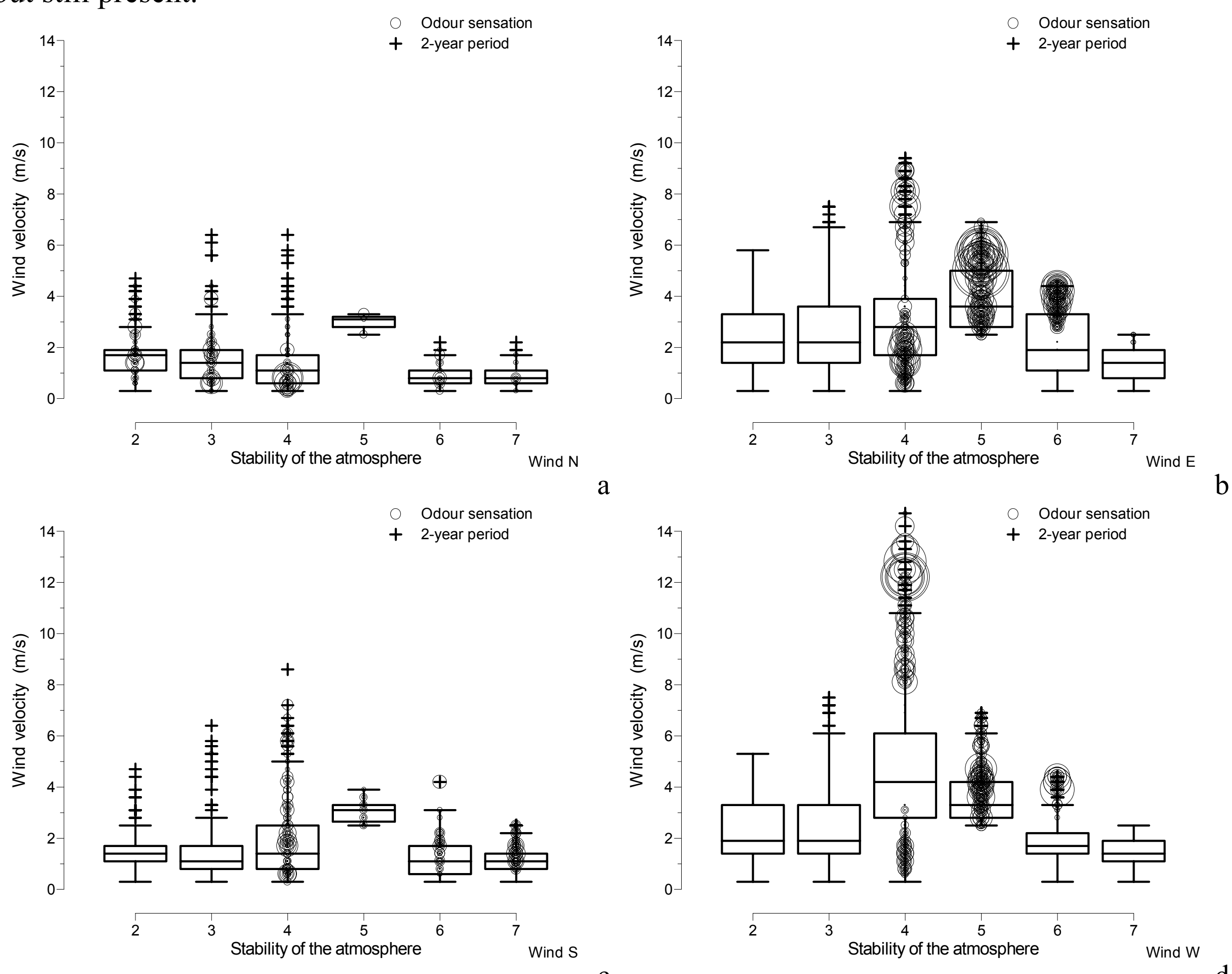


Fig. 3 Duration of odour episodes (consecutive half-hourly odour sensation) for the four cardinal direction as a function of the stability of the atmosphere and the wind velocity. The diameter goes proportional with the duration of odour episodes. The boxes describe the entire data set for the 2-year period by the median, upper and lower quartiles (box). The whiskers extend to the outermost data on each end that lies inside the corresponding inner fence (±1.5 inter quartile range; data values outside the inner fences are plotted as individual points).

The influence of the stability of the atmosphere on the dispersion process is presented in Fig. 3, showing the occurrence of odour episodes in comparison to the entire data set for the stability of the atmosphere and the wind velocity. The boxes describe the entire data-set with median and upper and lower quartile. For the prevailing wind direction (East and Wets) the occurrence of odour episodes is limited to neutral and slightly unstable conditions. Further on this episodes are not evenly spread. There are two distinct maxima one at the low end and one at the high end of the observed wind velocity. Only for slightly unstable atmosphere (class 5) and West wind, the long lasting odour episodes can also be found close in between the both quartiles.

The offensiveness of the last FIDO factor cannot be taken into account in this analysis because there is no information if the hedonic tone and the offensiveness is changing during the dilution in the atmosphere.

DISCUSSION

In this paper we analysed the occurrence of odour sensation according to the FIDO factors which were suggest by Watts and Sweeten (1995) to assess odour nuisance.

Caused by the climatological situation of Wels, the lowest separation distances are mostly found for North wind associated with low wind velocities and stability classes 2 and 3; the largest ones are found for West wind, caused by large mean wind velocities and frequent occurrence of stability class 4.

Odour sensation at separation distances depends on the time of the day, the month of the year, the wind velocity, and the stability of the atmosphere, for a selected wind direction (Fig. 2 and 3). At the investigated site, the city of Wels, representative for the Austrian flatlands north of the Alps, two prevailing wind directions are observed with a probability of 26% for East wind and 34% for West wind. The less frequent North and South winds at this site are subject to the periodically changing wind system of the Alm river valley running from South to North and entering the flatlands south of Wels.

Most complaints (‘time of most complaint’) from swine odour were recorded early in the morning or late at night under stable conditions (Schiffman, 1994). Another time of above-average complaints could well be the transition from day- to night-time, when a stable stratification evolves in the near-surface boundary layer. The results presented in Fig. 2 show maximum odour probability 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). These results indicate that generalisations on maximum odour probability depending on the time of the day are difficult. It should to be emphasised here that the model is designed to predict odour perception of the neighbours, but not the occurrence of neighbour complaints. Therefore the assessment of the perception by the AODM may not coincide with the real time of

nuisance complaints because the behavioural response of the neighbours to the odours are not included in the model.
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. Lohr (1996) investigated the odour perception for the four seasons by the frequency of odour exposure (number of odour sensation noticed per month) and found 3.24 for summer, 1.18 for spring, 0.71 for autumn, and 0.12 for winter.

Based on the model calculations of the direction-dependent separation distance it has to be discussed if the odour impact criteria, defined solely by a probability of the threshold 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. It is obviously not the same with respect to odour reception if odour sensation of the same concentration occurs e.g. around sunset in summertime or during night-time in winter. The situation is complicated because odour sensation is not equally distributed over the time of the day and the months of the year (diurnal and annual variation Fig. 2). In addition to the odour impact criteria, the local meteorological situation has a strong impact on possible odour nuisance from livestock farming.

The comparison of odour complaint statistics with the meteorological situation could be helpful to find out when odour is perceived as most annoying. This could help to weight the odour sensation episodes, calculated by a model like the presented one to get a better fit of the model calculations to the observed complaints.

CONCLUSIONS

In this paper we could show that there is a discrepancy between the temporal odour perception pattern calculated by the AODM and the observed complaint by the neighbours. This could be explained by two reasons:

1. The evaluation of the calcualeted odur concentration by the odour impact criteria is based only on statistical limits. It doesn't consider the annoying potential of odour due to the behaviour of the neighbours. Therefore the odour sensation should be weighted by the time of the day and time of the year, as is done with the limit values for noise. This means that besides the suggested frequency, intensity, duration, and offensiveness (FIDO) factors, a diurnal and annual weighting should be introduced in the odour impact criteria which reflects the outdoor behaviour pattern of neighbours.
2. The used odour emission scenario doesn't take into account the increase of odour release by the indoor temperature, the ventilation rate, and the activity of the animals (Schauberger et al., 2003) as well as the influence of the odour perception due to temperature and humidity.

A main objective in future work should be a better fit of calculations by odour dispersion models to the observed odour perception and the resulting annoyance in the neighbourhood.

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