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Influence of the Variability of the Odour Emission Rate on the Separation Distance Shown for the Irish Odour Impact Criterion

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The environmental impact of odour is determined by direction dependent separation distances to avoid odour annoyance. In general, the separation distances are calculated by dispersion models using time resolved meteorological data sets of wind velocity, wind direction and the stability of the atmosphere. The calculated ambient odour concentrations are evaluated by odour impact criteria defined by an odour threshold concentration and a related exceedance probability. A relevant model prerequisite is the emission flow rate of an odour source, in most cases assumed as a constant value over time. In reality it is well known that this is not a realistic assumption. In the present study, the sensitivity of the separation distances to increased variations in the emission rates – from a constant value up to a coefficient of variation of 20% - is investigated. This is here undertaken for the national odour impact criterion of Ireland with an odour concentration threshold of 3 ou/m³ of the hourly mean value and an exceedance probability of 2% (98-percentile). The sensitivity study shows that the assumption of a constant odour emission rate will underestimate the separation distances, especially in the main wind directions. The higher the variability of the emission rate, the larger the separation distances. This means that, in the future, time resolved odour emission rates will constitute a necessary prerequisite to calculate reliable separation distances.

1. Introduction

The emission rate of odour sources is typically estimated as an constant value (e.g. Guingand, 2003; Hayes *et al.*, 2006; Nicolas *et al.*, 2008; VDI 3894 Part 1, 2011), in general given as odour emission factor. However it is well known that the emission rate of odour sources is not constant over time. Depending on the character of the odour source, various predictors causing the variation are known. For industrial sources, process based parameters like the time of the day and the differentiation between workday and weekend (Schauberger *et al.*, 2008) are relevant. Other sources like composting and waste water treatment plants show a sensitivity to meteorological parameters like wind velocity (Schauberger *et al.*, 2008; Capelli *et al.*, 2009) and temperature (Schauberger *et al.*, 2008). For fattening pigs, an emission model is used with the indoor temperature, the ventilation rate calculated by a simulation model (Schauberger *et al.*, 2000) and the animal activity as predictors (Schauberger *et al.*, 2013a).

Even if no predictors can be identified, the emission rate shows as distinct variation. In most cases, the appropriate distribution function for the odour emission rate is a log-normal distribution (Lim *et al.*, 2001; Miller *et al.*, 2004; Schauberger *et al.*, 2008; Valli *et al.*, 2008; Akdeniz *et al.*, 2012; Schauberger *et al.*, 2013a; Schauberger *et al.*, 2013b; Schauberger *et al.*, 2014b; Schauberger *et al.*, 2014a).

In this paper we compare the conventional approach with a constant emission rate (annual mean value) with three time resolved emission scenarios with identical mean value, but increasing variability. The coefficient of variation *CV* is increased from *CV* = 0% for the constant emission flow rate to *CV* = 5%, *CV* = 10%, and *CV* = 20%. The sensitivity study was done exemplarily for the odour impact criterion used in Ireland.

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2. Methods

2.1 Odour emission

For the emission rate *E* (ou/s), four different scenarios are selected: a constant emission rate E_0 = 20 000 ou s^{-1} and three scenarios with the identical mean value of 20 000 ou s^{-1} and a coefficient of variation *CV* = 5%, *CV* = 10%, and *CV* = 20%. For these three scenarios, a log-normal distribution of emissions is assumed. The logarithmically transformed emission rates e_i = log E_i are then normally distributed according to $e \sim N(\overline{e}, s)$ with the mean value $\overline{e}$ and the standard deviation $s = CV\ \overline{e}$.

There are many techniques for generating a random sample which is distributed according to a pre-selected cumulative distribution function (CDF) *F*, in our case the log-normal distribution $F = LN(\overline{e}, s)$. Here we used the inverse sampling technique, a useful tool for environmental sciences (Wilks, 2011; Schauberger *et al.*, 2013b; Schauberger *et al.*, 2014). Using this method, a pseudo-random number *RN* from a uniform distribution in the interval [0;1] *RN ~ U(0;1)* is transformed to the percentile $e = F^{-1}(RN)$. Then the emission rate e is a random variable, distributed according to $e \sim LN(\overline{e}, s)$. For each half hour mean value of a two year time series (~ 35 000 values half-hour mean values), a value for the odour emission rate is calculated using this Monte-Carlo approach.

This realisation of the emission rate by the inverse sampling technique was done only for the scenario E_{05}. For the other two scenarios with a *CV* of 10% and 20%, scenario E_{05} was transformed by increasing the difference of each half-hour value $e_{05,i}$ from the mean value $\overline{e}$. E.g., for *CV* = 10% the corresponding half-hour value $e_{10,i}$ is calculated by doubling the distance from the mean according to $e_{10,i} = \overline{e} + 2\,(e_{05,i} - \overline{e})$. By this method the allocation of an emission rate e_i to a certain meteorological situation will be retained, only the standard deviation is adapted to the selected coefficient of variation.

2.2 Dispersion model and meteorological data

The ambient odour concentration is calculated with the Austrian regulatory dispersion model (ÖNorm M 9440 (1996); Kolb (1981)). The regulatory model is a Gaussian plume model applied for single-stack emissions and distances up to 15 km. The model uses a traditional discrete stability classification scheme with dispersion parameters developed by Reuter (1970). The meteorological parameters used as input to the model are half-hourly values of the wind direction, wind velocity, and stability class. Model results are calculated on a polar grid with a minimum distance from the source of 50 m and an angle resolution of 1°.

The meteorological data were collected at Wels, a site representative of the Austrian flatlands north of the Alps. The sample interval was 30 minutes for the year 1993. The city of Wels in Upper Austria is a regional shopping and business centre of about 50,000 inhabitants. The surroundings are rather flat and consist mainly of farmland. The mean wind velocity in the undisturbed environment is 2.2 m/s, maximum velocity amounting to about 13 m/s. The prevailing wind directions at Wels are west and WSW, as well as east and ENE. Calm conditions according to the Austrian regulatory dispersion model with wind velocity of less than 0.7 m/s amount to 18.2%; weak winds (wind velocity less than 1 m/s) comprise 26.5% of all cases. Less than 10% of all wind velocities are larger than 5 m/s. The annual mean temperature at Wels is 9.7 °C, the temperature range (two-year period) is from –14.9 °C to 35.3 °C. The annual precipitation amounts to 838 mm (mean over the period 1961 – 1990).

Stability classes SC are determined as a function of half-hourly mean wind velocity and a combination of sun elevation angle and cloud cover. The cloud cover was monitored by the meteorological station at the airport Linz-Hörsching, in a distance of about 13 km. Within the Reuter (1970) scheme, classes 2 to 7 can occur in Austria. Stability class 4, representative of cloudy and/or windy conditions including precipitation or fog, is by far the most common dispersion category because it occurs day and night (42%). Its occurrence peaks at wind velocity of 2 and 3 m/s. Wind velocity larger than 6 m/s are almost entirely connected with class 4. Stability classes *SC* = 2 (10%) and *SC* = 3 (16%), 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, peak slightly below or around the average wind velocity. They cover 26% of all cases. Class 5 (6%) occurs with higher wind velocity during nights with low cloud cover, a situation which is not observed frequently at Wels. Classes 6 (12%) and 7 (14%) are relevant for clear nights, when a surface inversion, caused by radiative cooling, traps pollutants near the ground. Such situations occur in 26% of all cases.

2.3 Odour impact criterion OIC

The time series of the ambient concentrations at a certain site is evaluated by a preselected odour impact criterion which is defined by an odour threshold concentration C_T and the exceedance probability p_T of this threshold. This odour concentration threshold is related to a one hour mean value. For this sensitivity study the direction-dependent separation distances are calculated for the national OIC of Ireland (EPA Ireland, 2001) with C_T = 3 ou m^{-3} and p_T = 2%.

3. Results and Discussion

The three emission scenarios with $CV \neq 0$ were selected to describe the emission rate of odour sources in a more realistic way as it is done by an annual mean value constant over the entire year. The cumulative frequency distribution of the four odour emission scenarios are shown in Fig. 1. All scenarios have the identical mean value of $\overline{E}$ = 20 000 ou m^{-3}, but the values of CV increase. The higher the CV, the flatter the cumulative frequency distribution.

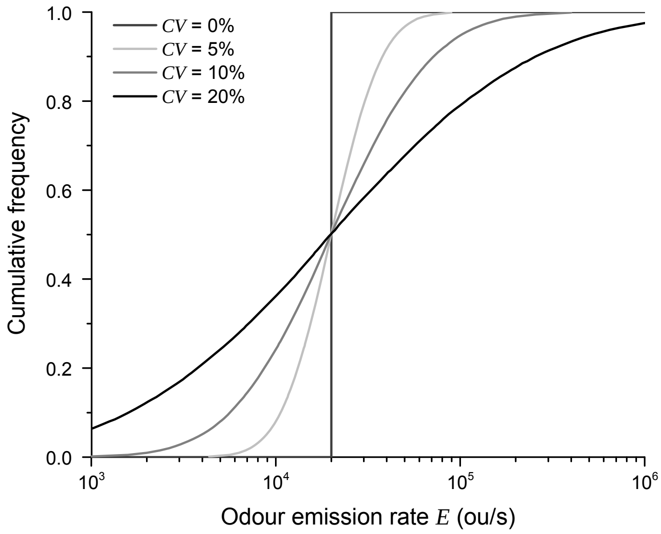

Fig. 1 Cumulative frequency distribution of the four log-normal distributed emission rates E with CV = 0%, CV = 5%, CV = 10%, and CV = 20% and a mean value $\overline{E}$ *= 20 000 ou m*$^{-3}$.

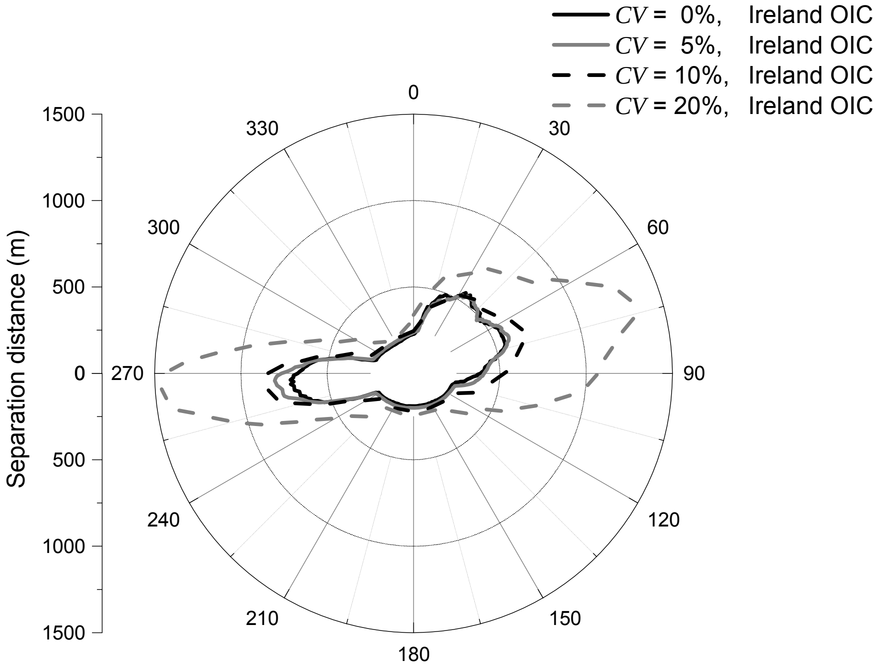

Fig. 2 Separation distances for the Irish OIC (CT = 3 ou m^{-3} *and pT = 2%) for the four log-normally distributed odour emission scenarios with CV = 0% (constant emission) and CV = 5%, CV = 10%, and CV = 20% with a mean value of* $\overline{E}$ *= 20 000 ou m*$^{-3}$.

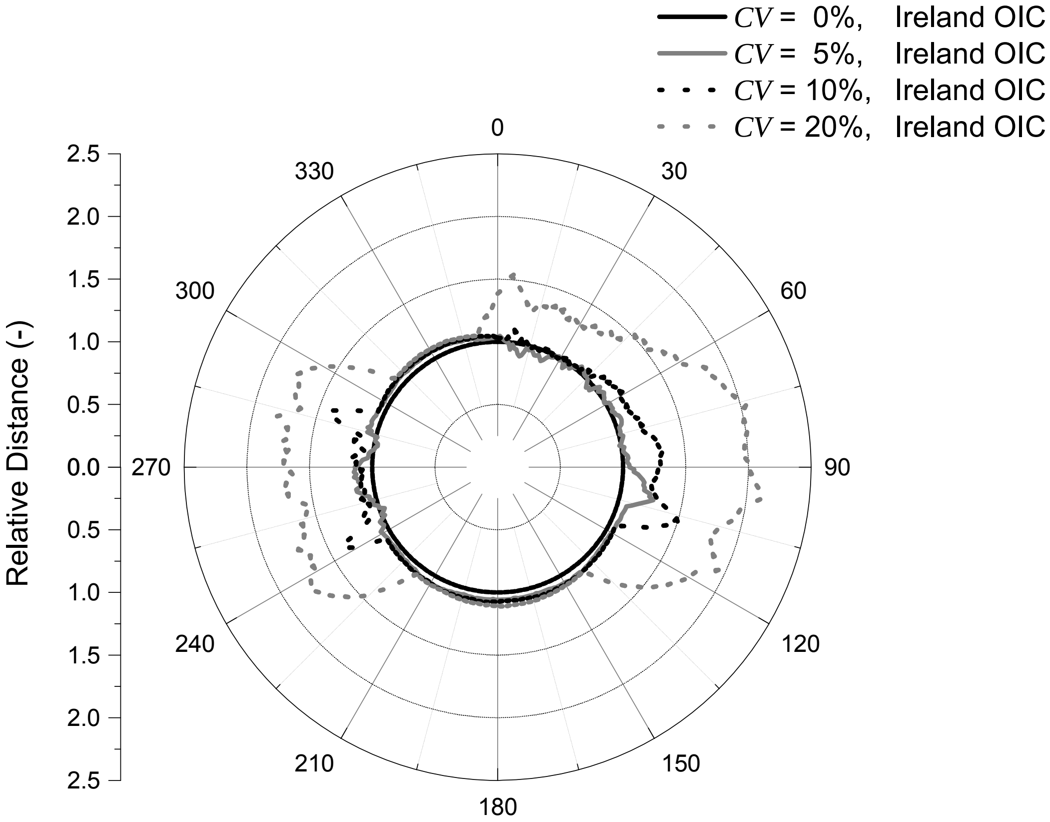

Fig. 3 Relative distances for the Irish OIC normalised by the constant emission CV = 0% for the odour emission scenarios with coefficients of variation from CV = 5% , CV = 10%, to CV = 20%.

Due to the high number of data points (*N* ~ 35 000), a good agreement between the theoretical log-normal cumulative distribution function CDF and the Monte-Carlo realisation is achieved. The goodness of the fit has been calculated by the probability plot correlation test (Loucks *et al.*, 2005), which is a powerful test of whether a sample has been drawn from a postulated distribution, in our case the theoretical log-normal CDF for the odour emission rate. The level of significance of the probability plot correlation coefficient is below $p < 0.001$ for all emission scenarios.

The direction-dependent separation distances for the Irish OIC are depicted in Fig. 2 showing the mirrored pattern of the wind direction. For an increasing variability of the emissions, the separation distances become larger, especially in the main wind directions W and E. To quantify this effect, the direction-dependent separation distances of the three scenarios with *CV* = 5% , *CV* = 10%, and *CV* = 20% were normalised by the separation distances for *CV* = 0% (Fig. 3). The relative distances are distinctly influenced by the frequency of the wind directions. Only for the two prevailing wind directions from West and East, the relative distance is considerably greater than 1. This means that for these directions, the assumption of a constant odour emission rate (CV = 0%) will underestimate the separation distances . For a small variability (CV = 5%), the separation distances increase by about 5% with a maximum of 26% in the ESE direction. For CV = 10%, they increase by 11%, with a maximum of 50%. For the highest variability with CV = 20%, the separation distances are increased by 44% with a maximum of more than 100% to the East and about 60 to 80% to the West.

For this sensitivity study we calculated the emission rate on an hourly basis by a Monte-Carlo approach. By using a time resolved emission model, which is synchronised with meteorological data (e.g. by the use of the ambient temperature as a predictor for the emission rate), the sensibility of the separation distances to the variability of the emission rate can be modified.

The cumulative frequency distributions of the ambient concentrations at the separation distance for the East direction are exemplarily presented in Fig. 4. All emission scenarios show a log-normal distribution. The course of the cumulative frequency distribution for CV=0% is exclusively caused by the variation of the meteorological parameters.

When the variability of the odour emission rate is increased, the range of the ambient odour concentrations is increased, too, shown by the flattening of the cumulative frequency distributions. The Irish OIC, which is shown as a circle in Fig. 4, lies in the flat part of the cumulative frequency distribution. For the scenarios with variable emission rates there is no match with the Irish OIC. This means either that the separation distance drifts to higher values or that the exceedance probability at 3 ou m^{-3} increases above 2% (up to 7% for *CV* = 20%).

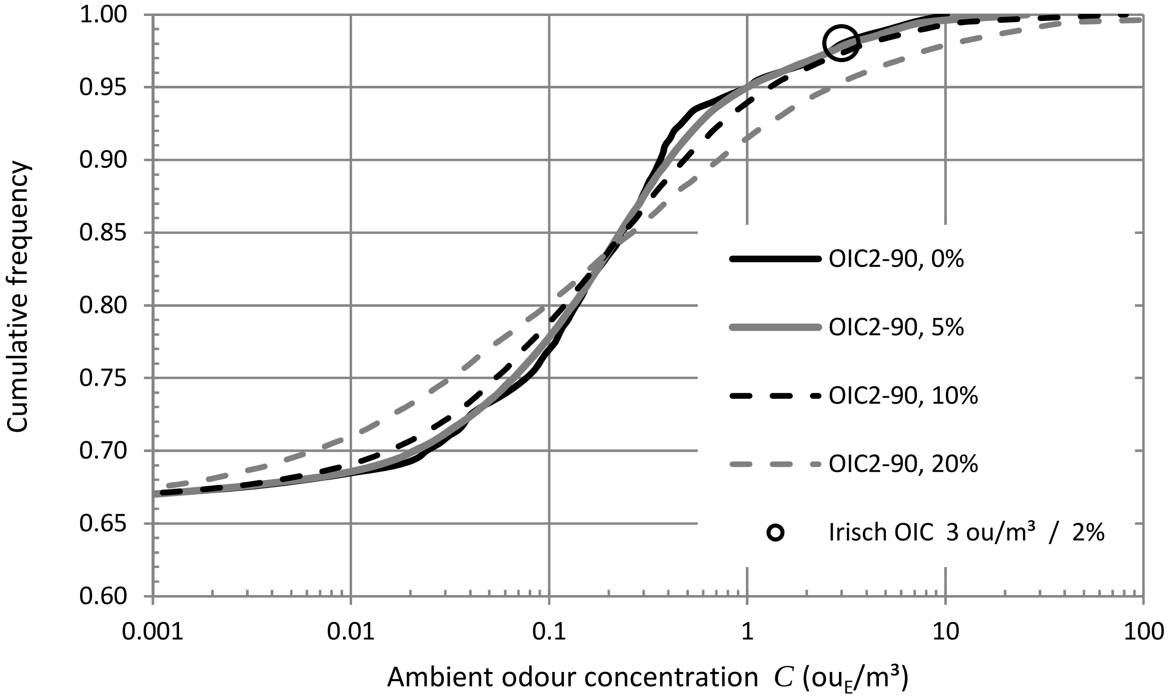

Fig. 4 Cumulative frequency distribution of the ambient concentrations at the separation distance for the East direction for CV = 0%, CV = 5% , CV = 10%, and CV = 20%.

The impact of environmental odour is evaluated by a nonlinear criterion, calculating the exceedance probability of a certain threshold of the ambient odour concentration. By this criterion, the right tail of the cumulative frequency distribution is used for the evaluation. The exceedance probability which is used for odour lies in the range between 20% for areas in Germany where agriculture dominates and less than 1% in Australia. The limit value of the exceedance probability depends on the selected odour concentration threshold (Sommer-Quabach *et al.*, 2014a; Sommer-Quabach *et al.*, 2014b).

4. Conclusions

In this paper we showed that the common assumption of an annual mean value of the odour emission rate underestimates the calculated separation distances, compared to variable emission rates. The separation distances were calculated for the Irish odour impact criterion. The model calculations show, that the separation distances increase with a growing variability of the emission rate. This is most pronounced for the prevailing wind directions. In the future, time resolved odour emission rates will constitute a necessary prerequisite to model reliable separation distances.

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