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Characterization of Year-to-Year Variability of Separation Distances Between Odour Sources and Residential Areas to Avoid Annoyance

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Direction-dependent separation distances between sources of malodorous gases and residential areas play a valuable role to avoid annoyance and complaints. Atmospheric dispersion modelling is routinely used to calculate these distances, with meteorological data regarded as one of the critical inputs for the models. This study explores the temporal representativeness of using one year of meteorological data as model input to calculate reliable separation distances. The year-to-year variability of direction-dependent separation distances in the vicinity of an odour source was assessed using a sample of six years of hourly meteorological observations. The calculations relate to the odour impact criterion prescribed by the jurisdiction of Queensland (Australia). The results show that the coefficient of variation, used as a statistical measure to characterize the year-to-year variability, has a mean value of 12%. Fair agreements are thus observed for the separation distances from one year to the other at the site under investigation, which supports the utilization of one year of meteorological data as a good compromise to achieve reliable accuracy. The findings of this study have the potential to support more cost-effective odour dispersion modelling guidelines.

1. Introduction

Environmental odours emitted from industrial and livestock facilities can annoy people living nearby. Although the mechanisms of action remain unclear, epidemiological studies and community surveys have shown that exposure to environmental odour may cause adverse effects on human health (Blanes-Vidal et al., 2014; Brancher and De Melo Lisboa, 2014; Schiffman and Williams, 2005). Due to the risk of negative effects on psychosocial health and quality of life, environmental odour pollution has become a cause of growing public concern. In response, it is imperative to develop more suitable solutions to deal with odour pollution-related problems. As recently highlighted by Brancher et al. (2017), an integrated multi-tool strategy is recommended to manage environmental odours as a way to overcome the limitations of individual methods and thus increase confidence in the overall conclusion. An effective approach that is part of this integrated strategy is to establish separation distances between residents and odour sources to avoid annoyance (Schauberger et al., 2012). Separation distances are used to divide the area around odour-emitting facilities into two zones: (i) a zone beyond the separation distance where nuisance impacts are likely to be avoided and (ii) a zone closer than the separation distance where loss of public amenity can be expected (Piringer et al., 2016). The separation distance approach is somehow flexible because it should preferably be used to enforce minimum distances when new sources are planned but may also be used when reliable emission rates are available to verify compliance for existing sources. The “no-go” zone can be easily demarcated by fixed, pre-established setback distances around odour sources. However, the availability of land is vital for the development of several countries. In addition, it is known that odour impacts are more likely to occur in the prevailing wind directions (Piringer et al., 2015). By using dispersion models the distances can thus be calculated on a case-by-case basis as variable, direction-dependent separation distances. Under such circumstances, the required level of protection is given by correspondence with limit values for odours in ambient air, so-called national odour impact criteria (OIC). Therefore, direction-dependent separation separations are the final measure connecting the entire chain starting from the odour emission rate, dilution in the atmosphere, and evaluation of the ambient odour concentration by the OIC (Sommer-Quabach et al., 2014). Currently, the OIC prescribed in regulations and guidelines have great variability depending on national jurisdictions (Brancher et al., 2017; Sommer-Quabach et al., 2014; Brancher et al., 2016).

There are three main kinds of data used as input to dispersion models to calculate direction-dependent separation distances: topographical, emission and meteorological data. The last two are the most critical ones (Capelli et al., 2013). Concerning meteorology requirements, in many countries, the use of more than one year of meteorological data for odour dispersion modelling is mandated (Brancher et al., 2017). The potential of using a single year of meteorological data for odour modelling was recently shown on a scientific basis (Brancher, 2017). Initial efforts have therefore been made to reduce the length of the time series of meteorological data and concurrently maintain a good level of accuracy of the model outputs. However, more studies are needed to better understand by what means and to what extent the variability of direction-dependent separation distances are influenced by a diversity of OIC, emission scenarios, meteorological conditions, and other factors. This study aims to assess the year-to-year variability of direction-dependent separation distances in the vicinity of an odour source to avoid odour annoyance. The focus here is to investigate whether a one-year time series of meteorological data is adequate to obtain reasonable separation distances by using dispersion modelling. The results relate to the odour impact criterion presently used in Queensland (Australia), which is adopted as a reference for protection against odour annoyance.

2. Methodology

2.1 Study site and source of odour emission

The study site is located in Groß-Enzersdorf (48.203°N, 16.564°E, 151 m ASL), east of Vienna (Austria), where meteorological observations are available. It is basically within flat terrain, typically farmland. Surrounding residential dwellings and a few industries (mainly in the southwesterly and southeasterly directions) are present about 350–500 m from the source. The study site is representative of the odour sources found in the neighboring areas. Intensive animal feeding operations are a significant source of offensive odours in numerous countries including Austria. Hence, the source configuration replicates the emission from a mechanically ventilated livestock building. A single-point source with vertical release is assumed for dispersion calculations. The odour emission rate is given by an annual mean value of 7,000 ou_E s^{-1}. Emission factors reported in the VDI 3894 Part 1 (2011) can translate this odour emission rate into a typical livestock building. The geometry of the source is assumed circular, with a height of 10 m from the ground, inner diameter of 1.2 m, exit velocity of 2.5 m s^{-1}, and gas exit temperature of 30.0 °C.

2.2 Atmospheric dispersion modelling

The AERMOD Modelling System, version 16216r, was used to estimate the time series of ambient odour concentrations. Several studies have focused on the validation of the model, usually showing good agreement between modelled and observed pollutant concentrations. These studies, along with a comprehensive model description can be found elsewhere (U.S. EPA, 2016a; Cimorelli et al., 2005; Perry et al., 2005). AERMOD is a steady-state Gaussian plume model with algorithms based on planetary boundary layer turbulence structure and scaling concepts. It is the U.S. Environmental Protection Agency regulatory air quality model. The simulations performed in this study mostly follow the default regulatory options set out in the Guideline on Air Quality Models (U.S. EPA, 2017). Only the main points of the modelling protocol are shown here. The ambient odour concentrations are calculated on a polar grid with a minimum distance from the source of 50 m. The last ring is 750 m from the source. The spatial resolution was accurate enough to capture hot spots of odour concentrations. Receptors are positioned 1.5 m above the ground at the average height of the human nose. Terrain elevation data are obtained in SRTM1 format (~ 30 m resolution). Accordingly, the digital elevation model is built using the AERMAP terrain processor, version 11103 (U.S. EPA, 2016b). Elevations from near 147 to 153 m ASL can be found within the modelling domain. Elevations/hill heights are assigned to receptors and the odour source by AERMAP. Land surface characteristics (albedo, Bowen ratio, and surface roughness length) around the meteorological tower were determined by the procedures of AERSURFACE (U.S. EPA, 2008) and AERMET User´s Guides (U.S. EPA, 2016c) using the AERSURFACE utility (version 13016). Surface characteristics were first extracted from the CORINE CLC2006 database with 0.1 km resolution and then refined. The surface roughness was determined by sectoring (12 angular sectors of 30°) with a default upwind distance of 1 km radius relative to the meteorological tower location. Albedo and the Bowen ratio values were determined based on a default area of 10 x 10 km also centered on the meteorological tower. Monthly values were assigned to account for a temporal change of surface characteristics.

2.3 Meteorological data

The Austrian Meteorological Service ZAMG (Zentralanstalt für Meteorologie und Geodynamik) provided hourly surface meteorological data for a weather station located ~ 0.6 km from the odour source (Groß-Enzersdorf, 48.199°N 16.559°E). The meteorological variables used as input to the model are wind direction, wind speed, air temperature, and atmospheric pressure. This weather station does not measure cloud cover which is a necessary input for the meteorological pre-processor AERMET. This variable was thus also provided by ZAMG for the Vienna International Airport (48.110°N, 16.569°E) which is situated ~ 10 km from the source. Upper air data were obtained from the NOAA/ESRL Radiosonde Database for Wien-Hohe Warte (48.248°N, 16.356°E) located ~ 16 km from the source. The meteorological years selected to perform the modelling were 2004, 2008, 2013, 2014, 2015, and 2016. Both surface and upper air data were processed using AERMET (version 16216). Representativeness regarding the spatial and temporal resolution of the meteorological data is attained. Atmospheric pressure is used within the model basically to calculate dry air density, and cloud cover is a necessary input to AERMET to derive the micrometeorological parameters. The model uses the Monin-Obukhov similarity theory to estimate the atmospheric stability. This theory is grounded on the Obukhov stability length. Groß-Enzersdorf in Austria can be subject to high wind speeds, mainly from prevailing northwesterly (NW) directions. The secondary prevailing wind direction is from Southeast (SE), which also can be subject to stronger winds. Whereas the southeasterly wind is regularly observed with anticyclonic conditions, the northwesterly wind is mainly associated with cloudy or rainy periods. The average wind speed is 3.2 m s^{-1} and the highest speed of the period is 13.2 m s^{-1}. A minor percentage of calm winds recorded in the surface meteorological dataset (~ 0.3%) are not excluded for dispersion calculations. The calms are adjusted into a minimum speed threshold of 0.5 m s^{-1} and uniformly redistributed around the compass to maintain the wind profile. Fig. 1 shows the wind rose with distributions of wind direction for 10° sectors at the Austrian site for the selected meteorological period (i.e., six years).

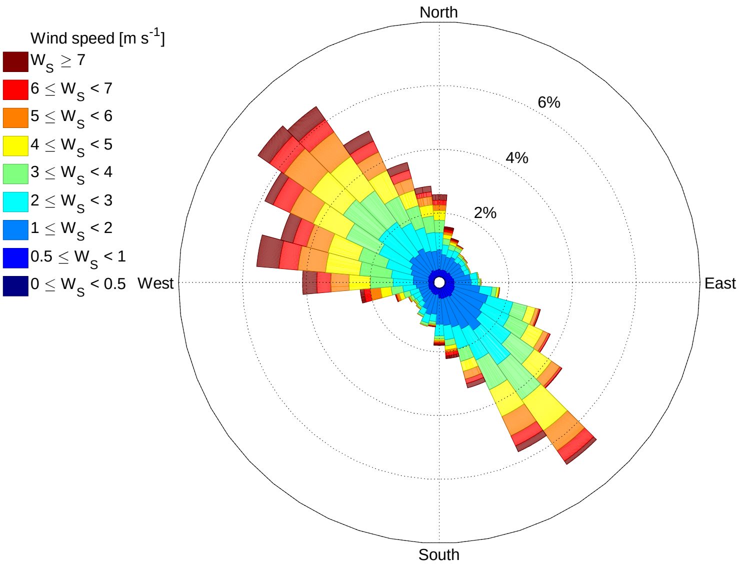

Figure 1: Wind rose at Groß-Enzersdorf (2004, 2008, 2013, 2014, 2015, and 2016): Legend denotes wind speed categories and their associated colors.

2.4 Odour impact criterion

An odour impact criterion evaluates the time series of ambient odour concentrations at a particular site to calculate the necessary direction-dependent separation distances to avoid annoyance. This criterion is defined by an odour threshold concentration (C_T) and the exceedance probability (p_T) of this threshold, in addition to the averaging time (A_T) based on a specific period over which odour exposure is assumed to cause adverse effects. The separation distances are herein calculated for the national odour impact criterion currently used in Queensland (Australia), with C_T = 0.5 ou_E m^{-3}, p_T = 0.5% and A_T = 1 h. In this jurisdiction, the concentration limit value is based on the default annoyance threshold of 5 ou_E m^{-3} (as a peak value), and a conservative default peak-to-mean ratio of 10:1 for wake-free stacks. It is presumed that the height of the stack (10 m) is

2.5 times higher than any nearby building, and therefore building downwash effects are unlikely to occur (i.e., wake-free stacks) (EHP, 2013). This criterion belongs to a conservative group of OIC, defined by low odour concentration thresholds and low exceedance probabilities of this threshold.

2.5 Statistical analysis

The direction-dependent separation distances, in full meters, are given in increments of 10° using the stack position as the reference point for determining the distance. Separation distances are typically drawn to the opposite side of the wind direction (W_d) because this is the direction to which emissions spread. This direction is called transport direction (T_d) and is given by $T_d = W_d + 180°$ (Schauberger et al., 2006; VDI 3894 Part 2, 2012). The coefficient of variation (CV), given by the standard deviation divided by the mean, is used to quantify the extent of variability in relation to the mean separation distance values over the individual meteorological years.

3. Results

3.1 Direction-dependent separation distances

The direction-dependent separation distances determined in increments of 10° are presented in Fig. 2. At the site under investigation, two main separation distance peaks are observed around the odour source because of the prevailing winds heading in these directions. It is found a maximum separation distance of 520 m for $T_d = 320°$ in 2014 and 404 m for $T_d = 140°$ in 2013. The minimum separation distance in the prevailing winds is 322 m for a $T_d = 340°$ in 2016 and 299 m for a $T_d = 120°$ in 2004. All in all, separation distances vary in transport directions between ~ 85 and 520 m.

As seen in Fig. 2, there is some inter-annual variability, particularly in the prevailing wind directions, both concerning the frequency of occurrence and to the wind speed. This year-to-year variability of the separation distances is most likely related to the frequency of wind direction and atmospheric stability in a certain sector.

The spreading of the separation distance is driven by the distribution of wind directions. In response, the largest distances are observed in the prevailing wind directions. A priori one can expect that the higher the frequency of a certain wind direction sector, the greater the elongation of the separation distance will be in that direction. Piringer et al. (2016) showed that the combination of atmospheric stability with frequent wind directions can be crucial for large separation distances.

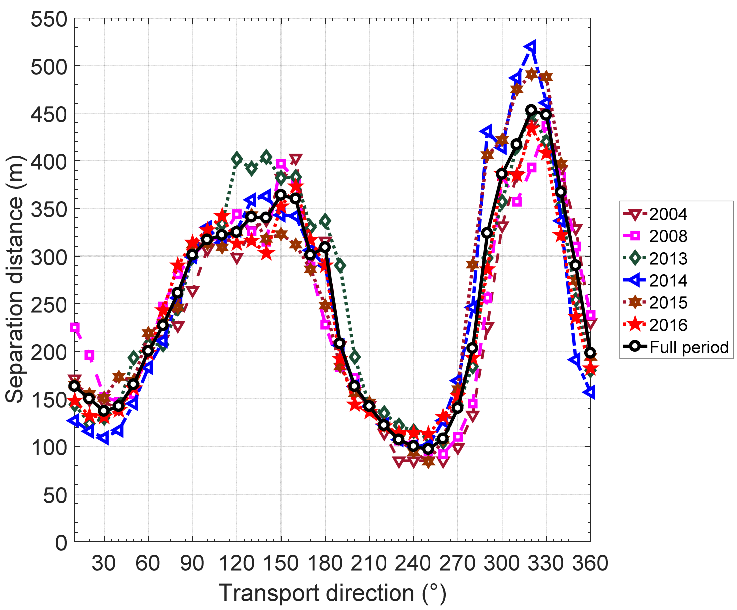

Figure 2: Direction-dependent separation distances at the site under investigation: Legend denotes the meteorological years used for dispersion calculations and their associated colors and markers.

3.2 Characterization of year-to-year variability

The amount of year-to-year variability of the direction-dependent separation distances is shown in Fig 3. The mean direction-dependent separation distances over the individual meteorological years are mostly in agreement with the distances calculated using the six years of meteorological data. This can be observed in

Fig. 3 through the substantial overlapping of the lines “mean over single years” and “full period”. Besides, the separation distances determined for the six years of meteorology, assumed as the “true value” herein, are continuously inside the confidence interval of the mean direction-dependent separation distance values determined for the individual years of meteorology data.
The maximum CV is about 30% for a T_d = 280°. It is also observed a CV of about 19% for a T_d = 190° and a T_d = 350°. The mean CV taking into account all direction-dependent distances corresponds to 12%. Considerable divergence within the separation distance results from one year to the next is not seen at the site under investigation.

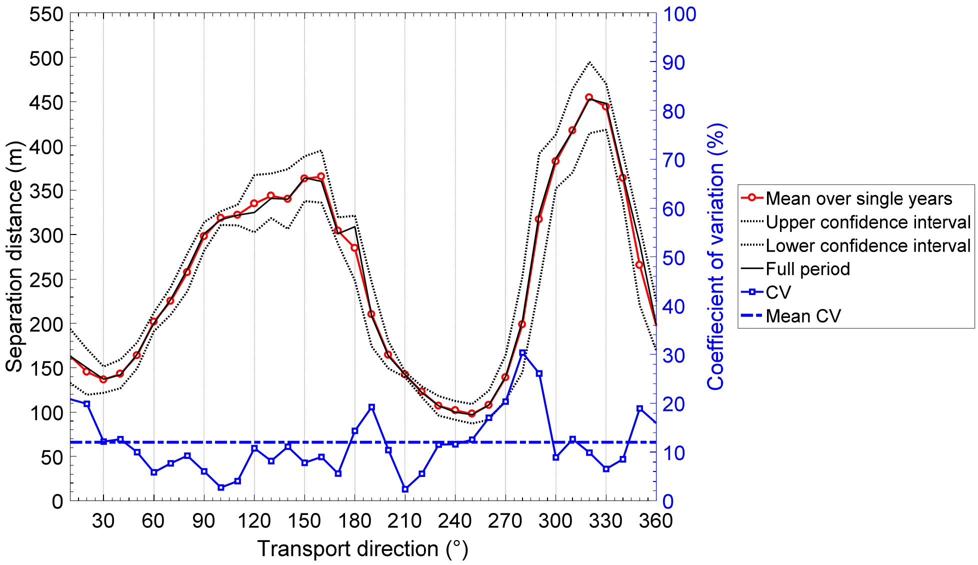

Figure 3: Characterization of year-to-year variability of the direction-dependent separation distances at the site under investigation: Legend denotes the metrics used for the evaluation.

3.3 Discussion remarks

This study demonstrates that the reduction of the meteorological data for a year has temporal representativeness in the calculation of separation distances. It was shown that long time series of meteorological data have the ability to provide an understanding of the "average" conditions of how direction-dependent separation distances are calculated in the vicinity of odour-emitting sources. However, it has to be pointed out that long time-series of meteorological data are not always available, and it can be expensive and time-consuming to collect, process and validate a large data file to input into a dispersion model.
In this regard, the statistical analysis reveals a relatively low yearly variability, which is evidence supporting the use of one single meteorological year to calculate separation distances using dispersion modelling (Fig. 3). Moreover, visual interpretation of the separation distance results also indicates the representativeness of the single meteorological years against the full period of meteorology (Fig. 2). Therefore, the results show, for the scenario here tested, that one single year of hourly meteorological observations can reasonably calculate direction-dependent separation distances.
In a comparison of separation distances at other sites across Austria, Piringer et al. (2016) found that separation distances are a result of a complex interaction of stability classes, wind conditions, and attenuation curves due to peak-to-mean factors. Consequently, it can be anticipated that these factors also will affect the year-to-year variability of separation distances. It is added that the year-to-year variability can be influenced by the use of a particular odour impact criterion.
Emission-related uncertainty is problematic for odour studies. Odour sources may show variation in emissions, and there may be diffuse sources in a facility where odour emissions are difficult to quantify accurately, based on current methods. In a modest comparison, it may be more important to obtain reliable emission data than spending time and resources using numerous years of meteorological data. For those cases that many years of meteorological data are available, more data should be preferred for use in dispersion calculations, which is logical. A limitation of this study lies in the use of a constant odour emission rate, given by an annual mean value. It is well-known that livestock odour emissions fluctuate over time. Most odour modelling studies are still performed with constant emission rates due to the difficulties in obtaining variable emission rates. Thus, future research is needed to broaden the results emerged from this study.

4. Conclusions

This study showed that a complete and validated one-year time series of hourly meteorological data is sufficient to calculate reliable direction-dependent separation distances near an odour source to avoid annoyance. Based on international guidelines for dispersion modelling, the most recent meteorological year should be preferred. The results relate to a conservative odour impact criterion currently prescribed by the jurisdiction of Queensland (Australia). The year-to-year variability of the calculated direction-dependent separation distances was characterized by the coefficient of variation and had a mean value of 12%. Additional studies are encouraged to confirm and generalize the outcomes across different settings. Finally, the findings of the present study have practical implications for the development of a more cost-effective methodological step for odour dispersion modelling.

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