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A software application for mapping livestock waste odour dispersion

Francesco Danuso*, Alvaro Rocca, Paolo Ceccon, Fabrizio Ginaldi

Department of Agricultural and Environmental Sciences (DISA), University of Udine, Via delle Scienze 206, 33100, Udine, Italy

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ABSTRACT

In developed Countries, coexistence of livestock production and urban settlements is a source of problematic interactions that are regulated by specific legislation, often requiring the evaluation of the potential environmental impact of livestock odour emissions. For this purpose, dispersion models are powerful tools that can be classified as dynamic (Eulerian and Lagrangian) or static (Gaussian). The latter, while presenting some limitations in condition of wind calm and complex orography, are widely adopted for their ease of use.

OdiGauss is a free multilingual software application allowing to estimate odour dispersion from multiple point sources and to generate the related maps. Dispersion is calculated according to a Gaussian approach, as a function of wind speed and direction, precipitation, temperature, and solar radiation. *OdiGauss* incorporates a model of odour emissions from poultry farms (*EmiFarm*) which makes predictions based on manure production and management. Two case studies of software application on real poultry and swine farms are presented.

Software availability

Name of software: OdiGauss (version 3.1.0, about 6.6 MB)
Main Developers: Francesco Danuso, Alvaro Rocca and Fabrizio Ginaldi (University of Udine)
First available year: 2012
Software requirements: Windows® XP or newer versions
Program languages: PowerBasic (Pbwin v. 10.04 and Pbcc v. 6.04), SEMoLa (v. 6.8.1)
Availability: freely downloadable on http://www.dpvta.uniud.it/Danuso/docs/OdiGauss/OdiGauss_home.htm
Contact: Francesco Danuso, Department of Agricultural and Environmental Sciences (DISA), University of Udine, Via delle Scienze, 206, 33100 Udine IT, francesco.danuso@uniud.it

1. Introduction

Odour emission from livestock is a territorial problem for agricultural areas, not only restricted to the peri-urban ones (Schauberger et al., 2001). Authorisation for the construction of new stables often requires a prior assessment of odour dispersion. Disturbance magnitude of livestock activities on surrounding settlements depends on emission source type (pig, cattle, poultry, etc.), management, topography and climate. The latter, in terms of mean values and variability, is a key factor to consider. The main weather variables involved in odour dispersion process are wind speed and direction, but air temperature, humidity, and rainfall also play a relevant role. Finally, odour nuisance is even affected by the kind of smell as well as by its frequency, intensity and duration. Odour dispersion also depends on emission rates from livestock facilities which, despite their high variability in time, are often considered as constant.

Models for pollutant dispersion from point sources come mainly from civil and industrial fields, whereas models specifically designed to predict odour dispersion for the agricultural sector are not so frequent (Navarotto et al., 2007). Therefore, odour dispersion models applied to agriculture often derive from the first ones.

Most of the models follow either the Lagrangian, Eulerian or Gaussian approaches (Collet and Oduyemi, 1997; Holmes and Morawska, 2006).

Lagrangian models (also known as puff models or particle models) describe the motion in space of individual, non-interacting elementary odour particles. They are stochastic models which take into account the randomness with which odour particles move toward different directions. As these models require the simulation of several trajectories of elementary particles to achieve an adequate accuracy level, they need high computing power (Flesh

* Corresponding author. Tel.: +39 0432 558614; fax: +39 0432 558603.
E-mail address: francesco.danuso@uniud.it (F. Danuso).

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et al., 1995). A well-known example of a Lagrangian model is CALPUFF (Scire et al., 2001), developed by the Atmospheric Studies Group of Earth Tech Inc. (California), which simulates odour or pollutant puff movements in atmosphere.

Eulerian models (grid models) calculate the average concentration of pollutant particles in different spatial cells solving the equation of advective conservation of a wind-generated turbulent flow of odour (Dupont et al., 2006). Eulerian models require more computing power than Lagrangian ones; moreover, as compared to Lagrangian models they allow a more correct spatio-temporal representation.

Gaussian models are based on sets of equations describing the three-dimensional space concentration generated from a point source, considering current meteorological conditions as drivers. Emissions are considered time invariant and, for this reason, calculations refer to periods of one hour or less. The rationale of Gaussian models is the following: even if instantaneous concentration of a plume derived from a point source is irregular, over a sufficiently long time period (e.g., one hour) the concentration distribution can be approximated by a Gaussian distribution, both in horizontal and vertical direction. Although the basic formulation of these models is obtained theoretically, empirical relationships are used to derive many of the parameters required by the calculation.

These models consider weather conditions as homogeneous and stationary and, in their basic formulation, cannot be applied if wind is weak or absent. Gaussian models give results at equilibrium (steady-state); however, when applied to time series of weather conditions, they provide integrated quasi-dynamic representations. These models suit flat and homogeneous areas but do not with complex terrain (McCartney and Fitt, 1985). Conversely, they can be useful because they give reasonably accurate assessment of pollutant concentration and deposition released from various sources. They are also appreciated as they are easy to apply and require low computing power.

The complexity of the developed models makes difficult to put them in a practical use, to the extent that even more empirical approaches have been attempted (Schauberger et al., 2012a).

The aim of this paper is to present an easy-to-use computer tool for predictive and spatial representation of odour dispersion from livestock to the surrounding areas, with relation to climate characteristics. For this purpose, a mathematical model, implemented in the multilingual *OdiGauss* software, which estimates the territorial dispersion of odours from multiple point sources and creates their maps, has been developed.

Furthermore, the application allows the appraisal of dynamic emission rates using a simulation model developed for poultry farms (*EmiFarm*), also included in the installation package.

The software has been tested to assess odour dispersion on the surrounding areas, hypothesizing the construction of buildings for pig and poultry housing in North-Eastern Italy locations.

2. *OdiGauss* model

2.1. General procedure

OdiGauss simulates odour dispersion according to the steady–state statistical approach of Gaussian models. Inputs are hourly values of wind speed and direction, rainfall, temperature, and solar radiation. The model is made “dynamic” by repeating hourly dispersion calculation, at least for one year. Results of estimated concentration for each spatial cell are cumulated over the simulation period producing maps of peak concentration and exposure time above a threshold, as generally required by regulations (Schauberger et al., 2001; Schauberger and Piringer, 2012). The model considers the *peak-to-mean* correction for the estimation of the odour peak values.

Gaussian models provide sound results only in presence of wind. In *OdiGauss*, when wind speed is lower than 1 m s^{-1}, specific procedures are applied (see sub-section 2.3). The wind speed measured at the height of the anemometer is corrected in order to take into account the actual speed at the height of release as a function of surface roughness and Pasquill stability class (Briganti et al., 2001). The Pasquill atmospheric stability class is obtained as a function of air temperature (°C), global radiation (kJ m^{-2} h^{-1}), wind speed (m s^{-1}) and wind direction (degrees) during day-time. In addition, a method to estimate turbulence during night-time has been developed; it relies on air temperature and wind direction changes (described hereinafter in sub-section 2.2). The model also considers an odour reduction factor due to rainfall.

OdiGauss allows only short-term simulations; nonetheless, due to the computational efficiency of the software, a climatological perspective can be easily generated by integrating simulations based on hourly series of meteorological data over a period of several years.

The *OdiGauss* model represents the odour concentration at equilibrium, in the three spatial dimensions (x, y, z), following the Gaussian equation (Hanna et al., 1982):

$$\frac{C}{Q} = \frac{1}{2\pi\sigma_y\sigma_z u_h} \cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \cdot \left[\exp\left(-\frac{(z-h)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+h)^2}{2\sigma_z^2}\right)\right] \quad (1)$$

where:

C: odour concentration in surrounding space (ou m^{-3})[1];

Q: odour emission rate (ou s^{-1});

σ_y and σ_z: horizontal (y) and vertical (z) dispersion coefficients. Dispersion coefficients σ_y and σ_z are calculated according to Briggs (1973), following the atmospheric stability classes of Pasquill (1961) indicated with capital letters from A to F in Table 1.

h: height at the odour emission point (m);

u_h: wind speed at the odour emission height (m s^{-1}) calculated from the wind speed at the measurement height as in equation:

$$u_h = u_{ref} \cdot \left(\frac{h - z_0}{z_{ref}}\right)^P \quad (2)$$

where:

u_{ref}: wind speed (m s^{-1}) measured at z_{ref} height;

z_0: terrain roughness coefficient (m);

P: coefficient associated to Pasquill stability class (Table 1).

The odour removal due to precipitation is estimated correcting the hourly odour concentration (C) with the hourly rainfall, according to a concept of “scavenging” (Zhang et al., 2006). The washout process leads to an effective concentration (*Ceff*) computed by an exponential model (modified from Perin, 2004):

[1] Odour unit (ou m^{-3}) is the unit adopted to express odour concentration. It corresponds to the amount of odorigenous substance which, dispersed in a cubic metre of air, produces a concentration of odorous substance equal to the olfactory threshold. For example, an odour concentration of 3000 ou m^{-3} means that it is necessary to dilute the odorous air sample to 3000 times with fresh air in order to reach the olfactory threshold of 50% of individuals (perceived by 50% of individuals).