1 **A software application for mapping livestock waste odour dispersion**

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10 **Abstract**

11 In developed Countries, coexistence of livestock production and urban settlements is a source of

12 problematic interactions that are regulated by specific legislation, often requiring the evaluation of

13 the potential environmental impact of livestock odour emissions. For this purpose, dispersion

14 models are powerful tools that can be classified as dynamic (Eulerian and Lagrangian) or static

15 (Gaussian). The latter, while presenting some limitations in condition of wind calm and complex

16 orography, are widely adopted for their ease of use.

17 *OdiGauss* is a free multilingual software application allowing to estimate odour dispersion from

18 multiple point sources and to generate the related maps. Dispersion is calculated according to a

19 Gaussian approach, as a function of wind speed and direction, precipitation, temperature, and solar

20 radiation. *OdiGauss* incorporates a model of odour emissions from poultry farms (*EmiFarm*) which

21 makes predictions based on manure production and management. Two case studies of software

22 application on real poultry and swine farms are presented.

23 **Keywords**

24 odor dispersion, livestock, odor emission, manure, exposure assessment, Gaussian model

25 **Software availability**

26 Name of software: *OdiGauss* (version 3.1.0, about 6.6 MB)

27 Main Developers: Francesco Danuso, Alvaro Rocca and Fabrizio Ginaldi (University of Udine)

28 First available year: 2012

29 Software requirements: Windows$^{®}$ XP or newer versions

30 Program languages: PowerBasic (Pbwin v. 10.04 and Pbcc v. 6.04), SEMoLa

31 Availability: freely downloadable on

32 http://www.dpvta.uniud.it/Danuso/docs/OdiGauss/OdiGauss_home.htm

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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 *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

1 at the height of the anemometer is corrected in order to take into account the actual speed at the

2 height of release as a function of surface roughness and Pasquill stability class (Briganti *et al.*,

3 2001). The Pasquill atmospheric stability class is obtained as a function of air temperature (°C),

4 global radiation (kJ·m^{-2}·h^{-1}), wind speed (m·s^{-1}) and wind direction (degrees) during daytime. In

5 addition, a method to estimate turbulence during night-time has been developed; it relies on air

6 temperature and wind direction changes (described hereinafter in sub-section 2.2). The model also

7 considers an odour reduction factor due to rainfall.

8 *OdiGauss* allows only short-term simulations; nonetheless, due to the computational efficiency of

9 the software, a climatological perspective can be easily generated by integrating simulations based

10 on hourly series of meteorological data over a period of several years.

11 The *OdiGauss* model represents the odour concentration at equilibrium, in the three spatial

12 dimensions (*x*, *y*, *z*), following the Gaussian equation (Hanna *et al.*, 1982):

13
$$\frac{C}{Q} = \frac{1}{2\pi\sigma_y\sigma_z u_h} \cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \cdot \left[\exp\left(-\frac{(z-h)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+h)^2}{2\sigma_z^2}\right)\right] \quad (1)$$

14 where:

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

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

17 σ_y and σ_z : horizontal (*y*) and vertical (*z*) dispersion coefficients. Dispersion coefficients σ_y and σ_z are

18 calculated according to Briggs (1973), following the atmospheric stability classes of Pasquill (1961)

19 indicated with capital letters from A to F in Table 1.

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

21 u_h : wind speed at the odour emission height (m·s^{-1}) calculated from the wind speed at the

22 measurement height as in equation:

23
$$u_h = u_{ref} \cdot \left(\frac{h-z_0}{z_{ref}}\right)^P \quad (2)$$

24 where:

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

26 z_0 : terrain roughness coefficient (m);

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

28 The odour removal due to precipitation is estimated correcting the hourly odour concentration (*C*)

29 with the hourly rainfall, according to a concept of "scavenging" (Zhang *et al.*, 2006). The washout

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[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 meter 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)

process leads to an effective concentration (C_{eff}) computed by an exponential model (modified from Perin, 2004):

$$C_{eff} = C \cdot \exp(-Sc \cdot Rain) \quad (3)$$

where:

C_{eff}: air odour concentration after rainfall washout (ou·m^{-3});

C: air odour concentration calculated by the Gaussian dispersion model (ou·m^{-3}) using eq. 1;

Sc: washout coefficient (mm^{-1} of rainfall);

$Rain$: rainfall (mm·h^{-1}).

Table 1. Atmospheric stability classes according Pasquill (1961) and expressions adopted to calculate dispersion coefficients σ_y and σ_z (Briggs, 1973). Variable x is the downwind distance from plume source (m). Values of P coefficients used in eq. 2 for wind speed corrections for height are also reported.

Stability class	Code	σ_y	σ_z	P
Very unstable	A	$0.22 \cdot x \cdot (1+0.0001 \cdot x)^{-1/2}$	$0.20 \cdot x$	0.1
Unstable	B	$0.26 \cdot x \cdot (1+0.0001 \cdot x)^{-1/2}$	$0.12 \cdot x$	0.1
Slightly unstable	C	$0.11 \cdot x \cdot (1+0.0001 \cdot x)^{-1/2}$	$0.08 \cdot x \cdot (1+0.0002 \cdot x)^{-1/2}$	0.16
Neutral	D	$0.08 \cdot x \cdot (1+0.0001 \cdot x)^{-1/2}$	$0.06 \cdot x \cdot (1+0.0015 \cdot x)^{-1/2}$	0.16
Slightly stable	E	$0.06 \cdot x \cdot (1+0.0001 \cdot x)^{-1/2}$	$0.03 \cdot x \cdot (1+0.0003 \cdot x)^{-1}$	0.3
Stable	F	$0.04 \cdot x \cdot (1+0.0001 \cdot x)^{-1/2}$	$0.016 \cdot x \cdot (1+0.0003 \cdot x)^{-1}$	0.3

2.2 Atmospheric stability classes

The classification proposed by Pasquill (1961), which is widely accepted and quite easy to apply, has been adopted. The degree of atmospheric instability (or turbulence) is usually high; it depends on meteorological conditions and it must be available for each simulation time step. When not available, the turbulence class is calculated and included into the file containing meteorological data. The calculation requires the calendar date and hour of day, air temperature (°C), solar radiation (kJ·m^{-2}·h^{-1}), wind speed (m·s^{-1}) and wind direction (degrees). The algorithm is different for day- and night-time. The identification of the hourly status (day/night) arises from the calculation of sunrise and sunset time. Following Gifford (1976), during light hours the Pasquill stability class is determined as a function of solar radiation and wind speed, as reported in Table 2. For night-time, the method proposed by Gifford is difficult to apply because it relies on cloud cover percentage,

only barely available. Therefore, for night hours the stability class is defined by a two-steps approach, considering first the absolute difference in wind direction ($\Delta wdir$, degrees) and air temperature ($\Delta temp$, °C) between the current and the previous hour, and then the wind speed, as reported in Table 3. If $\Delta wdir$>180, atmosphere is considered neutral, if $\Delta wdir$<180 and $\Delta temp$<1 (night temperature is increasing) atmosphere is slightly stable (E) or neutral (D), depending on wind speed; if $\Delta wdir$<180 and $\Delta temp$>1 (night temperature is decreasing), then atmosphere could be stable (F), slightly stable (E) or neutral (D), according to wind speed.

Table 2. Pasquill stability class for daytime, as a function of wind speed and solar radiation.

Hourly global radiation (kJ·m^{-2}·h^{-1})	Wind speed (m·s^{-1})					
	<2	2-3	3-4	4-5	5-6	>6
>2500	A	A	B	B	C	C
2000-2500	A	B	B	B	C	C
1500-2000	B	B	B	C	C	D
1000-1500	B	B	C	C	C	D
500-1000	C	C	C	D	D	D
<500	D	D	D	D	D	D

Table 3. Stability class of Pasquill for night-time. $\Delta wdir$ is the absolute difference of wind direction with respect to the previous hour; $\Delta temp$ is the absolute difference of air temperature with respect to the previous hour.

$\Delta wdir$ (deg)	$\Delta temp$ (°C)	Wind speed (m·s^{-1})					
		<2	2-3	3-4	4-5	5-6	>6
>180		D	D	D	D	D	D
<180	<1	E	E	D	D	D	D
<180	>1	F	F	E	E	D	D

2.3 Procedures for wind calm and weak wind conditions

Wind calm is defined as a weather condition in which measuring instruments cannot define a precise wind direction or intensity because wind speed is below the instrument detection threshold or because of anemometer flagging. Wind calm conditions do not allow the application of standard Gaussian models.

OdiGauss considers wind speeds lower than 0.5 m·s^{-1} as wind calm and wind speeds between 0.5 and 1 m·s^{-1} as weak wind. The standard Gaussian model is applied in normal wind condition (wind speed $\geq$ 1 m·s^{-1}). With weak wind, *OdiGauss* allows to choose between two options: i) procedure as in ISCST3 model (Industrial Source Complex, vers.3, EPA, 1995) or ii) the Cirillo-Poli model (Cirillo and Poli, 1992). Similarly, with wind calm conditions two alternatives are provided: i) the ISCTST3 procedure; ii) the reduced form of the Cirillo-Poli model.

In ISCST3 procedure, when the wind speed is lower than 1 m·s^{-1}, the odour spread is calculated using the wind direction of the first preceding day with wind speed higher than 1 m·s^{-1}, assuming also a wind speed of 1 m·s^{-1} (EPA, 1995). The Cirillo-Poli model is based on time integration of the Gaussian puff equation.

2.4 *Peak-to-mean* correction

The negative feeling for the smell is closely linked to the peak value. Given that an odour becomes perceivable when its concentration in the air exceeds the perception threshold just for the breathing period (3-5 seconds), it is more appropriate to determine the mean concentration on breathing time rather than on the computational step (1 hour). Since Gaussian models produce as output the odour average concentration on the hourly base, the peak concentration is to be calculated. Peak concentration is defined as the concentration exceeding the threshold with a probability of 10^{-3} in one hour, corresponding to 3.6 seconds (Högström, 1972). Studies of the NSW Environment Protection Authority (2001) show that peak concentration can be estimated by multiplying hourly mean odour concentration by a experimentally derived factor (peak-to-mean ratio), mainly dependent on source morphology. Literature reports how peak values become more similar to the odour average concentration moving away from the source and suggests a correction coefficient which reduces peak-to-mean ratio with distance from the source (Schauberger *et al*., 2001; 2012a). More recently, peak to mean ratio has been proposed as dependent on the atmospheric stability class (Schauberger *et al*., 2012b). In *OdiGauss*, a constant value of peak-to-mean ratio is adopted, which may be tuned following a precautionary criterion. The suggested default value for the peak-to-mean ratio is equal to 2.3, while a value of 1 disables the peak-to-mean correction.

3. *OdiGauss* application

3.1 Software characteristics and use

The basic information required to perform simulations with *OdiGauss* are weather data and parameters of odour emission sources. Maximum distance for dispersion calculation, reference height of the receptor, and acceptable odour threshold are also required. The application performs a validity check to the input data. For details about preparing input files see Appendix A.

The software can be launched in three ways :

1) *OdiGauss* application (Fig. 1), with manual data entry of input parameters while weather data are to be provided as a separate file. *OdiGauss* allows emission sources data management and calculation of variable emissions with the *EmiFarm* model (see section 5.2);

2) Direct use of *OdiGauss* calculation engine (*OdiGaussC.exe*) from console window;

3) Background use of *OdiGaussC.exe*, launched, as a command, from other software.

Parameters of working area, sources, and receptors can be interactively entered or saved in a file ("run" file) to run calculations autonomously. Weather data are always to be saved in a specific file ("meteo file").

The software needs information about atmospheric stability class (Table 1), which can be provided as an input variable in the "meteo" file (*Pasc* variable, Table A.1) or automatically calculated using entered meteorological variables. If the meteorological variables required for the stability class calculation are missing, stability class is set to the constant value indicated by user.

It is also possible to indicate the background odour concentration of the environment, which is added to those generated by odour sources.

The software performs as many simulation steps as the hourly record of meteorological data in the "meteo" file. Therefore, in order to get a sound climate representation, it is advisable to use at least one year of meteorological data. Considering that one simulation is carried out for each hour, in one year the model performs 24 hours x 365 days = 8760 simulations, and the results are then cumulated. In any case, it is important to use complete years of data to maintain an unbiased representation of climate conditions of the site.

The results of spatial estimated concentration are cumulated over all simulation hours and for each spatial cell of the territory, at the receptor height, producing maps of i) mean and maximum peak concentration, ii) 98th percentile of peak concentration and iii) time of exposure over acceptable concentration threshold (percentage of hours per year).
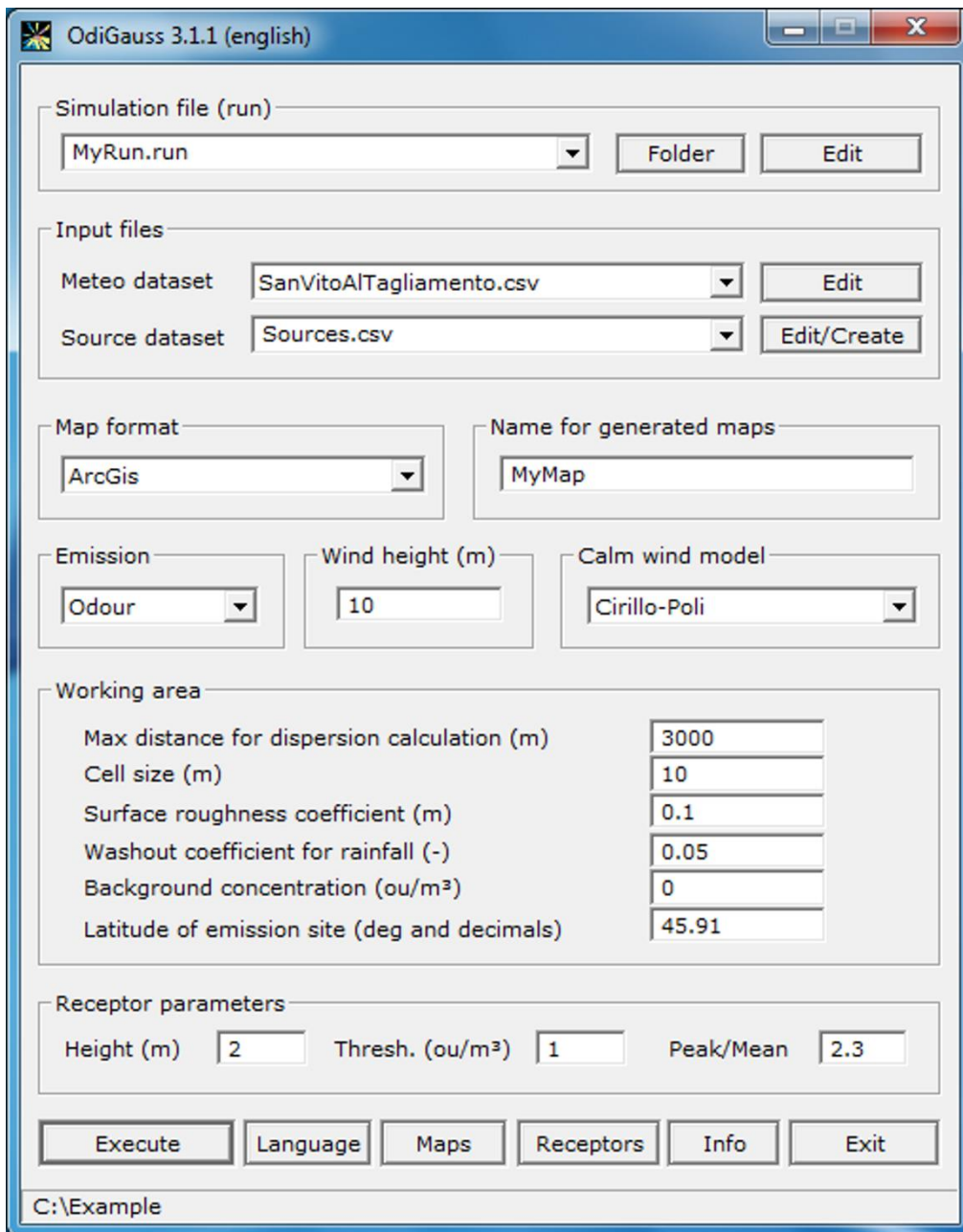
Fig. 1. *OdiGauss* main dialog window.

Values of mean peak concentration, maximum peak concentration, 98th percentile of maximum concentration and time over threshold for single receptors located in the working area can be extracted from the result maps, listed and saved as a `csv` file through a dialog window openable from the main dialog.

Some model limitations restrict its use in order to avoid unreliable results. In particular: i) the model does not consider inversion processes of the plume; ii) only the mean hourly odour concentration is considered, though it estimates a peak value; iii) the model does not take into account the effect of other meteorological factors (e.g., air humidity) and odours abatement due to UV solar radiation; iv) the model does not consider topography, nor the presence of natural or artificial obstacles and

therefore it is not suitable for complex orographic conditions; v) for all the odour sources, the weather conditions are considered to be the same.

A multilingual on-line help is available both for the GUI application and for the console version. Further documentation and examples are available on the software website.

3.2 Simulation results

After each run *OdiGauss* produces: i) the compass rose of wind distribution (see later as example Fig. 5); ii) six maps with their documentation files; iii) a "report" file. Maps (Table 4) are generated in ASCII grid raster format and can be saved for some of the most common GIS software (ArcGIS, GeoMedia, Idrisi and Surfer). The "report" file contains the parameters used for the simulation and the names of the generated files. Map documentation file has the same name as the map but `.inf` extension name. Maps are also saved as XY table, in `csv` file format, containing values of the calculated points with their coordinates, only for those values exceeding the critical odour threshold.

Maps generated by *OdiGauss* can be imported into commercial GIS but also edited with *SemGrid* (Danuso and Sandra, 2006a; 2006b), a freeware raster GIS developed at the Department of Agricultural and Environmental Sciences of University of Udine and included in *OdiGauss* installation, freely available from the web. *SemGrid* allows to reclassify maps and create images by overlapping themes (as roads, houses, rivers, etc.) obtained from ESRI shapefiles of regional technical maps (RTM). In *SemGrid*, data processing can be automated creating scripts of commands. The following script loads maps generated by *OdiGauss* into *SemGrid* environment, reclassifies and displays them adding themes from RTM:

```
import Med_OdiGauss.txt as(ArcGis) gen(Mymap) type(float)
class Mymap 1 50 100 500 gen(MymapC)
legend def MymapC 1 11711154 "<1"
legend def MymapC 2 13421772 "1-5"
legend def MymapC 3 8553090  "5-10"
legend def MymapC 4 6842472  "10-20"
legend def MymapC 5 5131854  ">20"
map MymapC labels vect(LINE_066080.shp,1,1) vect(LINE_066120.shp,1,1).._
    compass(90,8) ruler(4,95) saving(MyMap.bmp)
```

Commands are highlighted in bold: **import** imports maps in ArcGis format, **class** classifies map values, **legend** defines map legend items, **map** creates and displays map. The procedure loads `Med_OdiGauss.txt` map, previously generated by *OdiGauss*, in ArcGis format. Moreover, the script reclassifies categories, modifies the legend defining labels and colours, and finally displays the map joining the classified mean odour concentration with vector elements of RTM. The obtained map is saved in the `MyMap.bmp` bitmap, and the result is shown in Fig. 2.

1 Table 4. Maps generated by *OdiGauss*. The name indicated by the user for maps (*name*) is inserted

2 into the name of every map produced. Extension name (*est*) for generated ASCII grid files is `txt`

3 for ArcGis, `asc` for GeoMedia, `grd` for Surfer and `rdc` for Idrisi.

4

| Map name	Description	Content	Unit
Med_*name.est*	Map of odour mean concentration	Mean hourly values of odour peak concentration	$ou·m^{-3}$
MedC_*name.est*	Map of odour mean concentration (classified)	As the previous map, but with classified values	classes
Max_*name.est*	Map of odour maximum peak concentration	Maximum hourly values of odour peak concentration	$ou·m^{-3}$
MaxC_*name.est*	Map of odour maximum peak conc. (classified)	As the previous map, but with classified values	classes
Pct98_*name.est*	Map of 98th percentile of peak concentration	Peak odour concentration not exceeded by 2% of simulation hours	$ou·m^{-3}$
Pct98C_*name.est*	Map of 98th percentile of peak conc. (classified)	As the previous map, but with classified values	classes
Tss_*name.est*	Map of time-over-threshold for peak concentration	Percentages of simulation hours in which peak concentration exceed the established threshold critical value	%
TssC_*name.est*	Map of time-over-threshold (classified)	As the previous map, but with classified values	classes

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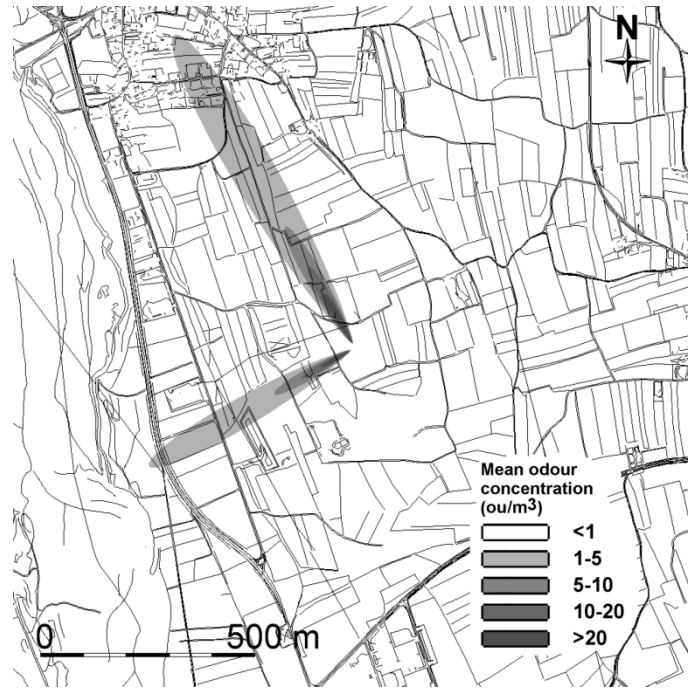
Fig. 2. Map created by *SemGrid* importing a map generated by *OdiGauss*. The graph represents the distribution of odour concentration in two hours with different wind conditions.

4. Finding required parameters

4.1 Working area

The squared-shaped working area is defined by the maximum distance for dispersion calculation, the cell size, the surface roughness coefficient, the washout coefficient of rain, and the average geographical latitude of emission sites.

The maximum distance (m) is limited by the number of cells that have to be calculated (depending on cell size) and by the total number of simulation time steps. Considering a single emission source, one year of hourly wind data, a maximum dispersion distance of 2000 meters, and cell size of 4 m, *OdiGauss* will perform about $4.37 \cdot 10^9$ calculation cycles, corresponding to 365 days x 24 hours x (n x n-1)/2 cells, where $n=2 \cdot 2000/4$. In the case of multiple sources, the maximum distance calculation is applied starting from the extreme values of X and Y coordinates of the different sources. *Odigauss* default value for maximum distance is set to 3000 m.

The cell size (m) is the size of the square cell with which territory is tasselled. Small cells improve map resolution but considerably increase computation time, while values greater than 50 m make maps too coarse; therefore, acceptable values usually range from 4 to 20 m.

Default values for roughness coefficient (m) and precipitation washout coefficient are 0.1 m and 0.05, respectively.

The geographical site latitude is required to calculate the astronomical day length by which solar radiation and atmospheric stability class can be estimated when measured data are lacking.

4.2 Receptor

The receptor (schools, settlements, other production sites, etc.) characteristics to be considered are: height at which odour is perceived, odour threshold and peak-to-mean ratio.

The reference height for the odour detection (m) indicates the height where the odour receptor is located (suggested value, 2 m).

The odour concentration threshold ($ou \cdot m^{-3}$) is the value below which odour is not perceived by 50% of population; this value is often set by local regulations (the default value is set to 1 $ou \cdot m^{-3}$).

4.3 Emission sources

Emission sources can be animal buildings, manure heaps, lagoons, etc. In the "source" file each source is characterized by name, description and emission rate. The odour emission rate ($ou \cdot s^{-1}$) indicates how many units per second are emitted from the source; it can be considered constant or variable over time. In the latter case, hourly emission values must be estimated by a specific model (e.g., *EmiFarm*, implemented in *OdiGauss* application and described in detail in 5.2 sub-section) and included in the meteorological data file ("meteo" file). These variables assume the same name their sources have in "source" file. The model allows to create variables for different emission sources; if a source is not present as emission variable in the "meteo" file, the constant value specified in the "source" file is adopted.

5. Odour emission rate

The estimation of odour emission rate significantly affects odour spatial distribution. Odour emission is expressed in emitted ou per second ($ou \cdot s^{-1}$), usually called "emission factor". In literature, to facilitate calculations and allow easy comparisons, odour emission rate is also described in terms of odour emitted per unit area of livestock building floor ($ou \cdot s^{-1} \cdot m^{-2}$), in relation to the live mass of the animals ($ou \cdot s^{-1} \cdot LU^{-1}$, with a Livestock Unit $\cong$ 500 kg, VDI 3894 Part 1, 2011) or to the number of animals ($ou \cdot s^{-1} \cdot head^{-1}$).

5.1 Constant emission rate

The odour emission rate depends on several factors such as species and age of animals (newborn, weaning, etc.), productive purposes (fattening or lactation, etc.), livestock and waste management, and also on the building structure and ventilation system. Many studies indicate that odour emissions change during the day and during the year (Zhu *et al*., 2000; Schauberger *et al*., 1999; Schauberger *et al*., 2014; Guo *et al*., 2006). Outdoor and indoor temperatures seem to have, at the same time, some influence (Heber *et al*., 1998). Emission factors to use as input parameters for

OdiGauss can be found in literature; Jacobson *et al.* (2003) report emission rates from different types of animal husbandry and Navarotto *et al.* (2007) show odour emission factors from pig slurry storage structures and for the various stages of the production process.

5.2 Dynamic simulation of odour emissions

As an alternative to the constant emission rate, *OdiGauss* can process hourly emission rates, for one or more sources, saved in the meteorological data file. The emission rates can be obtained through field measurements or generated by simulation models.

OdiGauss installation package includes *EmiFarm*, a model which simulates odour emissions from poultry manure heaps. This model was developed on the basis of available literature (Valli *et al.*, 2008) using SEMoLa modelling language (Danuso, 1992; Danuso and Rocca, 2014). Valli *et al.* (2008) have presented experimental results linking the specific emissions ($ou \cdot s^{-1} \cdot t^{-1}$) to key variables (type of waste, moisture, period of the year, time after litter emptying). The full model code is shown in Appendix B. The model is based on the following assumptions:

• the production of broilers involves 4.5 cycles per year, each lasting about 80 days, including downtime; during this period the litter accumulates in the chicken coop;

• litter is completely removed at the end of the cycle and stored in the manure heap;

• odour emission rate depends on manure moisture (wet/dry), with much higher values for wet manure;

• emptying of the manure heap occurs once a year, in relation to weather conditions, agronomic requirements and according to disposal regulations; manure is then incorporated into the soils;

• as manure heap is made by many "doses", each one having a different stage of maturity and emission rate, the model follows the emission dynamics of every dose, according to the element-based approach (Danuso and Rocca, 2014). Simulation starts with the presence of 2 doses, with an average age of 20 days; for every dose, the emission rate (Em_i) decays over time from its maximum value when litter is added to the manure heap, following a linear or exponential functions depending also on the season;

• the maximum emission rate (*Emax*) changes during the year according to a sinusoidal function, assuming that it reaches its minimum the first day of the year and the minimum on day 182 (halfway);

• the cumulative total emission (*EmissTot*) is calculated, day by day, adding the specific emissions of every individual dose, each of them multiplied by their mass;

• the simulation step is daily and therefore emissions of the different hours of the day are kept constant;

1 • an odour abatement coefficient (*Kabb*), which can take into account any device implemented to

2 reduce emission, is also considered.

3 Values of unitary emissions, graphically reported in Valli *et al.* (2008), have been converted into

4 numerical values by the negative exponential regression model in equation:

5
$$Em_i = Emax \cdot \exp(-Kdec \cdot Age_i) \cdot (1 - Kabb) \quad (4)$$

6 where:

7 *Em_i* is the specific emission rate per ton of manure (ou·s^{-1}·t^{-1}) of the *i*-th dose;

8 *Emax* the maximum emission rate at *Age_i*=0 (ou·s^{-1}·t^{-1}, occurring when the dose is removed from

9 litter and added to the heap);

10 *Kdec* the emission decay coefficient (d^{-1});

11 *Age_i* the age of the dose (d);

12 *Kabb* a dimensionless coefficient of odour abatement ranging from 0 (no odour reduction) to 1

13 (totally suppressed odour emission). Table 5 reports the coefficients obtained in different

14 conditions.

15 Total emission rate (*EmissTot*, ou·s^{-1}·t^{-1}) is obtained, day by day, with the equation:

16
$$EmissTot = \sum_i Em_i \quad (5)$$

17 In order to provide the maximum emission rate for all days of the year, it has been assumed that

18 *Emax* follows a sinusoidal function during the year, according to the equation:

19
$$Emax = Ewin + (1 - \sin(Doy \cdot 2 \cdot \frac{\pi}{365} + \pi/2)) \cdot \frac{Esum - Ewin}{2} \quad (6)$$

20 where:

21 *Ewin* is the maximum emission of the dose in winter;

22 *Esum* is the maximum emission in the summer;

23 *Doy* is the day of the year (from 1 to 365).

24

25 Table 5. Model regression coefficients describing odour emission rates (*Emax*) and emission decay

26 coefficients (*Kdec*) for different poultry manure moisture conditions and seasons (from Valli *et al.*,

27 2008).

Material	Condition	*Emax* (ou·s^{-1}·t^{-1})	*Kdec* (d^{-1})
Dry manure	Summer	253.52	0.03189
	Winter	33.66	0.02742
Wet manure	Summer	518.01	0.02637
	Winter	51.78	0.02488

28

1   This function leads to a yearly fluctuation of *Emax* that, for the dry manure, ranges between 34 and

2   254 ou·s^{-1}·t^{-1}.

3   The input parameters required by the model and their default values are: manure conditions

4   (dry/wet), daily production of manure (2.0 t·d^{-1}), date of the manure heap discharge (75th day of the

5   year), litter box cleaning frequency (number of days between two consecutive cleaning events, 80

6   days), odour abatement coefficient (0.4 for sheltered heaps).

7   Fig. 3 shows the trend of odour emission, as simulated by *EmiFarm*, from a poultry manure heap,

8   considering the litter cleaned every 80 days, and a dry manure production of 2 t·d^{-1}.

9   *EmiFarm* model is run by *OdiGauss* but can also be run independently (from DOS window),

10   launched from another program or from the SEMoLa framework.

11   *OdiGausss* asks the user for model parameter values to calculate emissions (Fig. 4), and launches

12   *EmiFarm* which generates a file containing the simulation results (`emifarm.res`). Later, the

13   application uploads the simulation result file and extracts the *EmissTot* variable (total actual

14   emission from manure heap) which contains daily emission values; from this, a variable in the

15   "meteo" file with the same name as in "source" file is created. Finally, it saves the "meteo" file with

16   updated emissions.
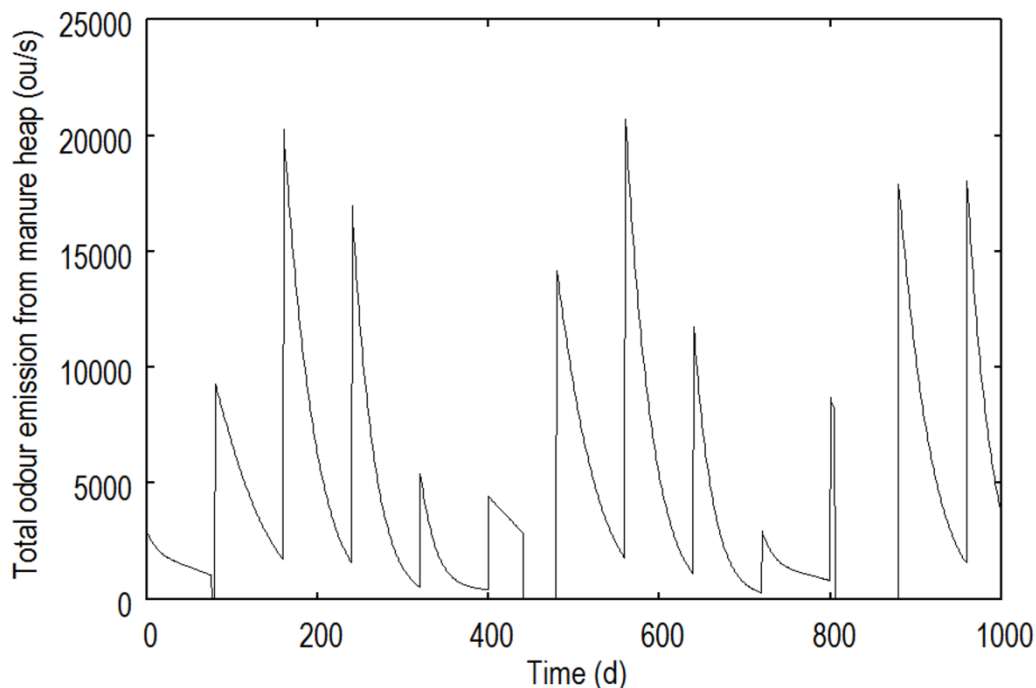
17

18   Fig. 3. Total odour emission rate (ou·s^{-1}) from poultry manure heap, for a 1000 days period, as

19   simulated by *EmiFarm* model. It has been assumed a litter cleaning every 80 days and a daily dry

20   manure production of 2 t·d^{-1}.

1
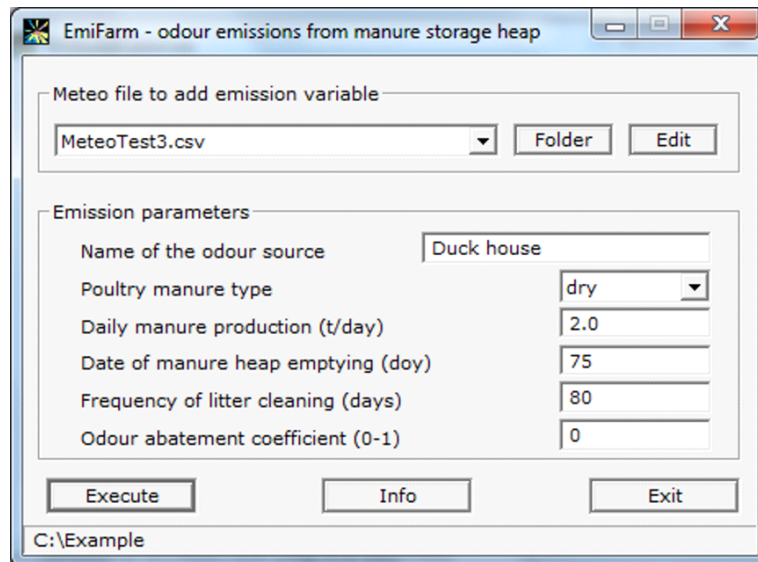
Fig. 4. Dialog window of *EmiFarm* model.

3

It is possible to create several emission variables, but it is not necessary to do this for all sources in the "source" file because some of them can be declared with a constant emission value.

The "meteo" file updated in such a way is used by *OdiGauss* to calculate the dispersion maps.

7

6. Case studies

As an example of *OdiGauss* use, simulations have been carried out on two farms (Table 6) located in the plain area of Friuli Venezia Giulia region (FVG, NE Italy).

Case study A simulates odour dispersion from a swine stable located in Udine province. The farm adopts a fully slatted floor, with fast slurry removal system, called "Vacuum System" and a forced ventilation plant. Stable hosts on average 3018 pigs: 1008 in the first fattening stage and the other 2010 in the following fattening phases. Slurry is stored in a concrete tank covered with a PVC tent. The emission point height is 5 m.

The second farm (case study B) is a poultry farm growing 185000 broilers in Pordenone district, using a fully littered housing system with chopped straw bedding. The building is equipped with modern feeding and drinking systems (nipple drinkers with drip water catch bowls) and a computerised climate control system. Manure is daily hauled away from the farm. The emission point height is 2 m.

VDI 3894 (Part 1, 2011) guidelines on emissions from animal husbandries, generally recognised as reference standard, suggest odour emission factors of 30 $ou{\cdot}s^{-1}{\cdot}LU^{-1}$ for pig fattening on deep litter and 7 $ou{\cdot}s^{-1}{\cdot}m^{-2}$ for an open surface outdoor liquid manure store. Assuming that the mass of an individual corresponds to the mean weight of the class which it belongs to, the odour emission rate in case study A is 14931 $ou{\cdot}s^{-1}$ for animals and 8155 $ou{\cdot}s^{-1}$ for slurry storage, ignoring the

Table 6. Description of livestock production systems and odour emission rates calculation in the two case studies.

| Case study	Odour source (Animal category/ Manure storage type)	Number of heads /Surface	Housing system	Emission factor	Odour mitigating techniques	Odour abatement coefficient	Total emission rate ($ou \cdot s^{-1}$)
A (Udine province)	Fattening pigs – first stage (25-50 kg lw)	1008 heads	fully slatted floor with Vacuum system	4 $ou \cdot s^{-1} \cdot head^{-1a}$	-	1.00[a]	4032
	Fattening pigs – second stage (50-160 kg lw)	2010 heads	fully slatted floor with Vacuum system	59 $ou \cdot s^{-1} \cdot head^{-1a}$	Vegetable oil sprinkling for swine production facilities	0.50[a]	59295
	Concrete slurry tank	1165 m^2	-	76 $ou \cdot s^{-1} \cdot m^{-2\ a}$	PVC cover	0.20[a,b]	17708
						Total	81035
B (Pordenone province)	Broilers (1 kg lw)	185000 heads	fully littered floor with automatic climate control	126 $ou \cdot s^{-1} \cdot t_{lw}^{-1}$	-	1.00	23310
						Total	23310

[a] Navarotto *et al.*, 2007

[b] Guarino *et al.*, 2006

implementation of odour mitigating techniques. VDI 3894 also indicates that the odour emission factor from broiler fattening in floor husbandry conditions is 60 $ou \cdot s^{-1} \cdot LU^{-1}$. Thus, the resulting odour emission rate from the broiler house in case study B is 22000 $ou \cdot s^{-1}$.

However, this paper assumes odour emission factors measured in experimental trials carried out in Northern Italy rather than VDI 3894 conventional values because it has been considered they better suit to local climate conditions (both in terms of seasonal and daily variability), housing systems and management of the two case studies.

The average odour emission rate in case study A has been computed considering an odour emission factor of 4 $ou \cdot s^{-1} \cdot head^{-1}$ for growers (25-50 kg), 59 $ou \cdot s^{-1} \cdot head^{-1}$ for fatteners (50-160 kg) and 76 $ou \cdot s^{-1} \cdot m^{-2}$ for slurry storage (Navarotto *et al.*, 2007). The presence of a sprinkling system of vegetable oil on adult animals provides an odour abatement of 50% (Navarotto *et al.*, 2007), while the cover of slurry storage reduces odour emission rate by 80% (Guarino *et al.*, 2006). The resulting

1　odour emission rate is 81035 ou·s^{-1}, much higher than the value estimated following VDI 3894

2　guidelines without considering odour mitigating systems.

3　The average odour emission rate in case study B is 23310 ou·s^{-1}, calculated considering an average

4　live weight (lw) of 1 kg per head and an odour emission factor of 126 ou·s^{-1}·t$_{lw}^{-1}$ (Valli *et al.*, 2008).

5　This value is similar to that one calculated using VDI 3894 emission factors (22000 ou·s^{-1}).

6　In both cases, simulations have been carried out for a period of one year, with hourly time step,

7　using meteorological data taken from the nearest weather station. Fig. 5 reports monthly mean air

8　temperatures and total rainfall, and frequency distributions of wind direction and velocity, retrieved

9　from hourly meteorological series of Faedis (from 1/1 to 31/12/2010) and San Vito al Tagliamento

10　(from 1/1 to 31/12/2011), which have been used for the simulations of the odour dispersion in case

11　study A and B, respectively.

12　Three odour dispersion simulations have been performed for each site, considering odour

13　concentration thresholds of 1, 3 and 5 ou·m^{-3}. These values have been suggested by Nicell (1994)

14　which discusses the whole chain of odour sensation: unspecific detection (1 ou·m^{-3}), discrimination

15
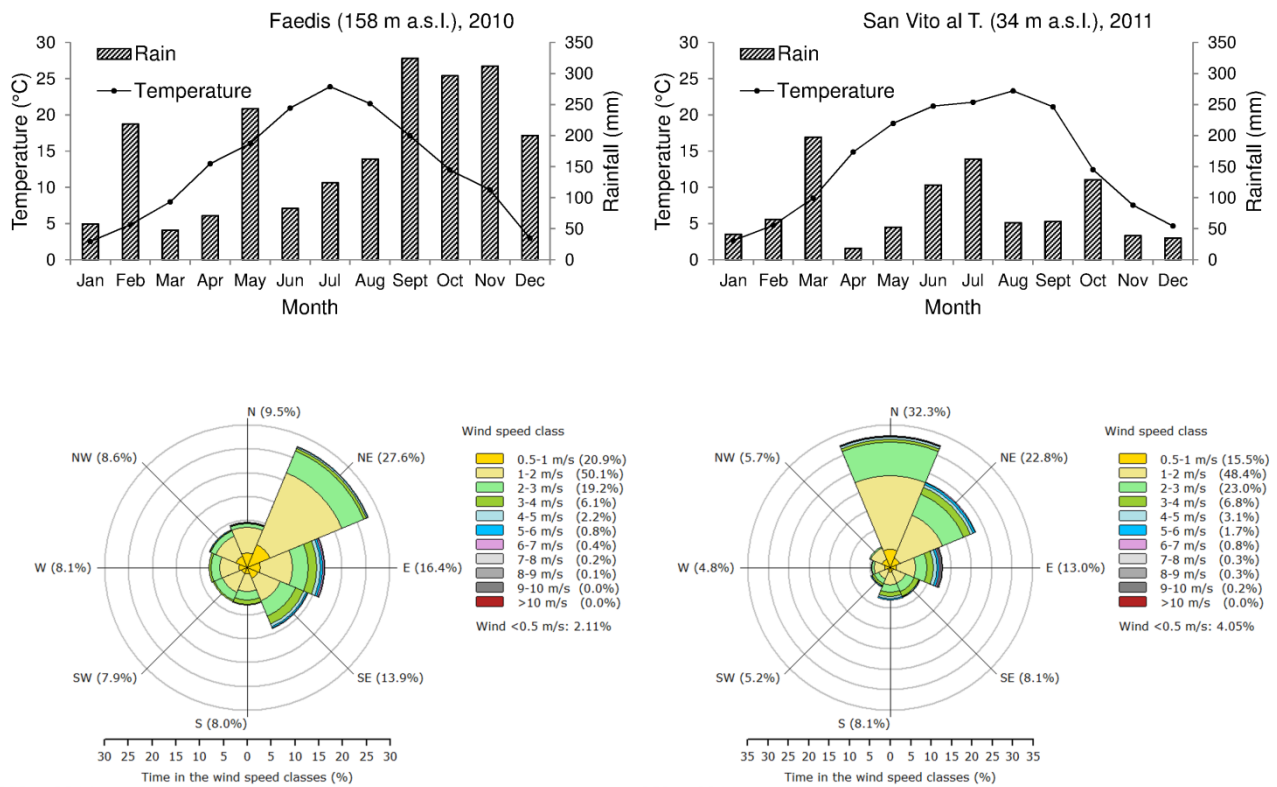
16

17　Fig. 5. Monthly mean air temperature and total rainfall, and frequency distribution of wind direction

18　and wind velocity for the meteorological time series of Faedis (2010, left) and San Vito al

19　Tagliamento (2011, right) obtained from ARPA-OSMER FVG.

20

1 (3-5 ou·m^{-3}), unmistakable perception (5 ou·m^{-3}, complaint level), and as last step the degree of

2 annoyance.

3 The complete input data sets for odour dispersion simulations are reported in Table 7.

4

5 Table 7. Input data for the two sets of simulations.

	Case study A	Case study B
Run file data		
Calculation type		
Calm wind model (ISC; CP)	CP	CP
Working area		
Max distance for dispersion calculation (m)	3000	3000
Land cell size (m)	10	10
Surface roughness coefficient (m)	0.1	0.1
Washout coefficient for rainfall (-)	0.05	0.05
Background concentration (ou·m^{-3})	0	0
Emission site latitude (deg. and decimals)	46.15	45.91
Wind measurement height (m)	10	10
Receptor		
Height for odour detection (m)	2	2
Threshold for odour intensity (ou·m^{-3})	1/3/5	1/3/5
Ratio peak-to-mean	2.3	2.3
Input data – Results		
Working folder	D:\myfolder	D:\myfolder
Name for generated maps	CaseStudyA_1/3/5	CaseStudyB_1/3/5
Format (arcgis, geomedia, surfer, idrisi)	ArcGis	ArcGis
Meteo file name	Faedis2010.csv	SanVito2011.csv
Source file name	SourceA.csv	SourceB.csv
Source file data		
Name of the odour emission source	S1	S2
Text describing the odour emission source	Fattening pigs	Fattening Broilers
Y coordinate of the source (latitude, m)[a]	5107104	5082525
X coordinate of the source (longitude, m)[a]	2387928	2350806
Odour emission rate (ou·s^{-1})	81035	23310
Height of odour release (m)	5	2

6 [a] Coordinates of case studies are referred to East Gauss Boaga projection, Roma 40 Datum.
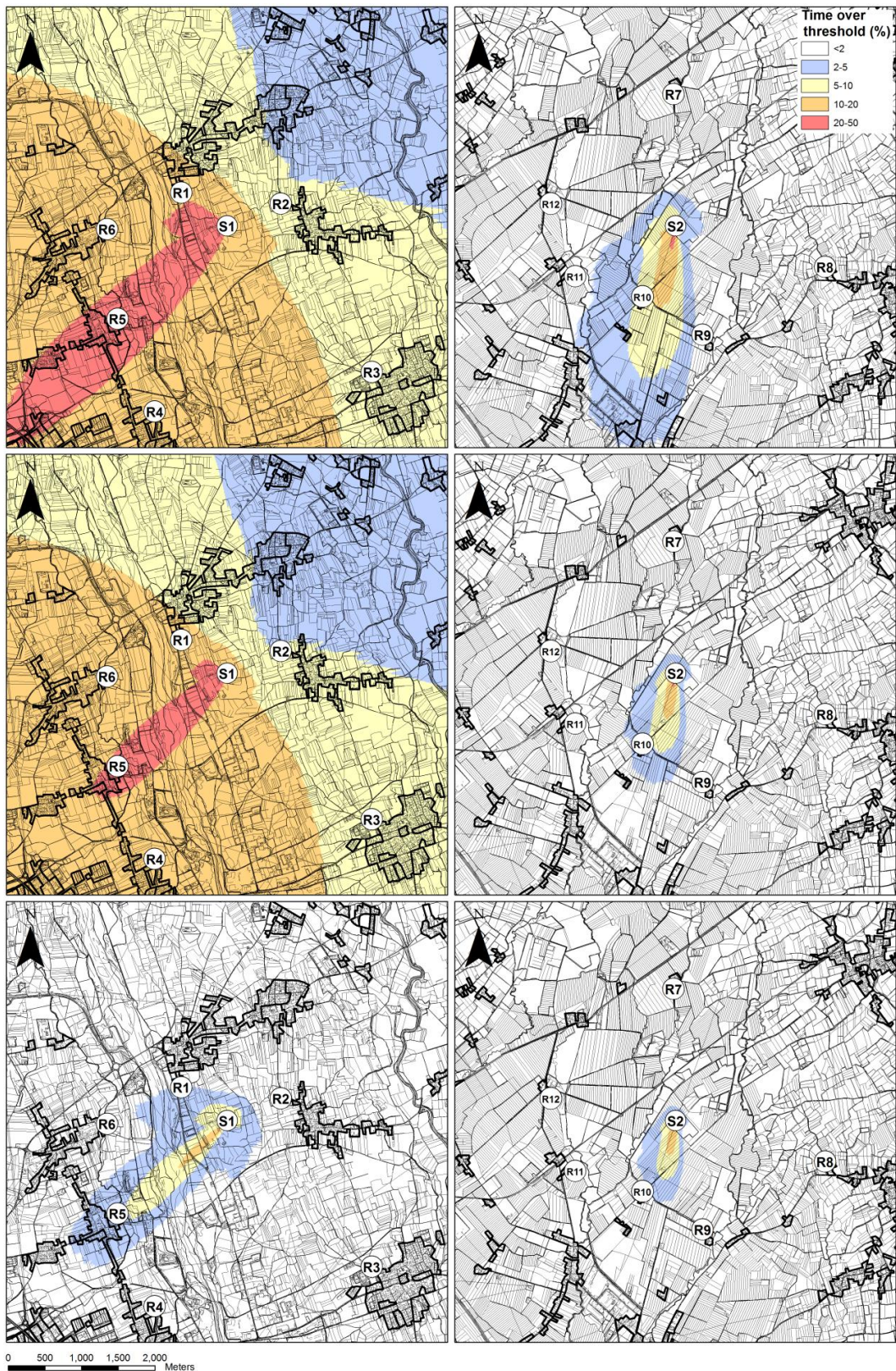
Fig. 6. Maps of exceeding probability classes for three odour thresholds (1, 3, 5 ou·m^{-3}, top to bottom) as a function of the distance from the odour emission source for case study A (left) and B (right). Residential areas boundaries are highlighted in bold. Receptors positions are enumerated from R1 to R12. S1 and S2 are the source emission points.

21

Table 8. Exceeding probability (%) for three different odour threshold (1, 3, 5 ou·m^{-3}) simulated for receptor points in residential areas identified in Fig. 6.

Receptor	Emission source	Longitude (m)[a]	Latitude (m)[a]	Time over threshold (%)		
				Threshold = 1 ou·m^{-3}	Threshold = 3 ou·m^{-3}	Threshold = 5 ou·m^{-3}
R1	S1	2387304	5107559	18.0	15.6	2.3
R2	S1	2388661	5107408	7.6	5.4	0.6
R3	S1	2389901	5105114	7.4	6.8	0.1
R4	S1	2386942	5104575	15.4	14.7	0.3
R5	S1	2386436	5105839	24.9	21.6	4.4
R6	S1	2386292	5107062	17.8	16.0	1.1
R7	S2	2350779	5084328	0.2	0.03	0.03
R8	S2	2352857	5081966	0.2	0.05	0.02
R9	S2	2351176	5081037	1.5	0.3	0.1
R10	S2	2350355	5081560	6.8	3.2	1.8
R11	S2	2349436	5081840	1.5	0.4	0.1
R12	S2	2349102	5082832	0.4	0.08	0.05

[a] Coordinates of case studies are referred to East Gauss Boaga projection, Roma 40 Datum.

Regulations of European countries protect residential areas from odour annoyance (Schauberger and Piringer, 2012; Sommer-Quabach *et al.*, 2014). Combining the time over-threshold raster layers resulting from *OdiGauss* simulations with the position of the residential areas derived from MOLAND map 1:25.000 (JRC, 2002), the six closest residential areas for each odour emission source have been identified (Fig. 6, Table 8).

In both case studies, the simulated odour dispersion follows the main wind direction (SW and S in case study A and B, respectively) (Fig. 6).

Considering odour thresholds of 1 and 3 ou·m^{-3}, in the case study A the area with an exceeding probability higher than 2% goes beyond the 36 km^2 of the simulated area. In these conditions, receptors situated downwind from the emission point have a probability higher than 14.5% to exceed the 3 ou·m^{-3} threshold. Increasing the odour threshold to 5 ou·m^{-3} the time over threshold area with an exceeding probability higher than 2% decreases dramatically, down to about 3 km^2. This area extends up to 2.8 km in the prevalent wind direction (SW) from the source emission point while in the opposite direction the impact distance is about 0.4 km.

In case study B, the time over threshold area with an exceeding probability of at least 2% decreases progressively from 4.2 km^2 to 0.6 km^2 when the odour threshold increases from 1 ou·m^{-3} to 5 ou·m^{-3}. R10 is the only receptor that exceeds the 2 % of probability to pass the odour limits of 1 ou·m^{-3} and 3 ou·m^{-3}.

7. Conclusions

Gaussian models are widely used in environmental impact assessments for their simplicity as they usually require a reduced number of input parameters. More complex models are often useless because of the lack (or the high uncertainty) of the requested parameters; moreover, high accuracy is seldom required in models used for regulative purposes when these results in an excessive difficulty of use (Olesen *et al*., 2005). In fact, assessments can be acceptable also when they give an objective and standardized reference. Furthermore Gaussian models, being able to run more easily than other approaches, allow to fully exploit climate variability, required when taking into account climate uncertainty.

OdiGauss application is user-friendly, available in several languages (at present English, Italian, and Spanish); it requires less training than software of greater complexity and is fast in performing simulations. *OdiGauss* can also be applied to simulate the dispersion of particles (for example, PM10); in addition, it could be applied to the dispersion of other materials, such as pollen, provided that appropriate emission models will be developed.

Odigauss performs odour dispersion simulations and generates time-over-threshold maps considering different odour threshold levels. These maps can be managed by the included *Semgrid* application that allows to classify them in relation to exceedance probability established by users. This integrated system permits the determination of the separation distance for different land uses in relation to their protection level established by the current regulations.

The availability of a separate executable engine performing odour dispersion simulation (*OdiGaussC*) easily allows the implementation in other software which can take advantage of using the dispersion calculation of *OdiGaussC*, launched as a background process.

Future developments will focus on the comparison of *OdiGauss* with Lagrangian dispersion models, such as CALPUFF, in order to further define its applicability limits and improve the proposed method for the atmospheric stability class estimation during night-time. Other aspects to develop will include the implementation of models of odour emissions from different animal wastes; this is particular relevant because, as compared to industrial emissions, the dynamics of odours emissions from agricultural farms are highly variable.

Odigauss calibration will be performed using filed measurements (VDI 3940 Part 1, 2006). For this purpose, the use of models of ammonia emission as indicators for odour dispersion could be an interesting opportunity (Blanes-Vidal *et al*., 2012).

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Appendix A: preparing input files

In order to run *OdiGauss*, the user has to: i) prepare a file containing meteorological data ("meteo" file); ii) insert, by a dialog window, the characteristics of the odour sources, then saved in the "source" file; iii) insert, by a dialog window, input simulation parameters, then saved in the "run" file.

Otherwise, in order to directly use *OdiGaussC.exe* calculation engine, "source" and "run" files are to be managed manually or with other software, as described below.

The "meteo" file contains hourly values of weather data, for an appropriate time period (at least one year), in `csv` file format. If the name extension of the "meteo" file is not declared, then `csv` is assumed. The "meteo" file can contain up to the variables listed in Table A.1 but only date, hour, wind speed and direction are strictly required. Variables are on the columns of the file and different hours on the rows. The order of variables is free and the case of name characters is unimportant.

When *Pasc* variable is not present, *Rad* and *Temp* variables are automatically used for the calculation of the Pasquill stability class. During day-time if both *Rad* and *Pasc* variables are missing in the "meteo" file, the Pasquill class is considered as D (neutral atmosphere). Instead, for night-time, if *Temp* variable is missing, Pasquill class is estimated considering temperature constant over time. Missing data have to be indicated by dot (.). Calculation is not performed for records of weather data with at least one missing value. Meteorological conditions are considered the same for all odour sources.

The "source" file as well has to be prepared in the `csv` format. If extension name is not declared, `csv` is assumed. The "source" file contains, in any order, the variables listed in Table A.2. Variable names must be written exactly as shown, even if case is unimportant. To enter hourly emissions generated by an external model, the simulated variables must have the same source name existing in the "source" file.

The "run" file is a text file containing all parameters and information needed to carry out an *OdiGauss* simulation. It has a specific format and allows to launch *OdiGaussC.exe* as a command or in the background by other software. To launch a simulation from command line, the word "`OdiGaussC`" has to be followed by the name of a "run" file that specifies all parameters and information to perform simulation automatically. The "run" file must contain the different options in a specific order. Blank lines and comments (prefixed by an asterisk) can be inserted at will. The simulation parameters are entered, in every line, just after the colon.

1 Table A.1. Variables of the "meteo" input file. Some variables are optional, others are required. The

2 names of variables are to be exactly those reported in the table. It is possible to add emission

3 variables for one or more sources.

Name	Description	Unit/values	Type
mdy/dmy/ymd	date in the format mm-dd-yyyy, dd-mm-yyyy or yyyy-mm-dd	-	Required
Hour	hour	1-24	Required
Wspeed	Hourly mean wind speed, measured at 10 m height	$m \cdot s^{-1}$	Required
Wdir	Hourly wind direction	degrees and decimals from North, clockwise	Required
Rain	Hourly rainfall	$mm \cdot h^{-1}$	Optional
Temp	Hourly mean temperature	°C	Optional
Rad	Hourly global radiation	$kJ \cdot m^{-2} \cdot h^{-1}$	Optional
Pasc	Atmospheric Pasquill stability class	A-F	Optional
backgOU	Background odour concentration	$ou \cdot m^{-3}$	Optional
source_name	Odour emission rate of the source	$ou \cdot s^{-1}$	Optional

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5 Table A.2. Variables of the "source" input file.

Name	Description	Unit
Name	Name of the odour emission source	-
Desc	Text describing the odour emission source	-
Ycoord	Y coordinate of the source (latitude)	m
Xcoord	X coordinate of the source (longitude)	m
Qem	Odour emission rate (not used if emission is declared as a variable in meteo file)	$ou \cdot s^{-1}$
Hem	Height of odour release	m

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Appendix B: SEMoLa code of the model *EmiFarm*

```
 ' Model: EmiFarm.sem  11-16-2012 15:38:22
 ' Odour emission from poultry manure storage heap
 ' Bib.:
 ' Valli et al., 2008 (Odour emissions from livestock production facilities)
 ' – Dose: manure amount removed with a single cleaning event
 ' – All doses are considered of the same amount
 ' – Poultry manure production:710 t/year, 4.5 cycles/year of 80 days each
 ' – Average daily manure production: 710/365 = 1.95 t/day
 ' – 4.5 cycles of broilers per year, cycle duration=80 days
 ' – Emptying of the heap occurs one time per year at doy=75

$ dt(1$ dt(1)
$ tspan(0,1000) tunit(d)
A doy=mod(time-1,365)+1            "Day of the year (1-365)"              (d)
0
 ' === Parameters ===============================================================
P ManType=0                        "0=dry manure; 1=wet manure"           (-)
P ProdDay=1.95                     "Manure production"                    (t/d)
P DateEmpty=75                     "Day of manure heap emptying"          (doy)
P CleanCycle=80                    "Cleaning cycle length"                (d)
P Kabb=0.5                         "Odour abatement coefficient"          (-)
P Qdose=ProdDay*CleanCycle         "Manure produced per cleaning cycle"   (t)

 ' === Manure production and litter cleaning ================================
S ManLitter=0                      "Manure in the litter"                 (t)
S ManHeap=2*Qdose                  "Amount of manure in the heap"         (t)
R IncrLitt=ProdDay ?->ManLitter    "Daily manure production"              (t/d)
V Cleaning=after(CleanCycle)       "Litter cleaning event"                (-)
V Emptying=when(Doy=DateEmpty)     "Emptying manure heap event"           (-)
I CleanLitt onevt(Cleaning,ManLitter) ManLitter->ManHeap "Litter cleaning" (t)
I EmptyHeap onevt(Emptying,ManHeap)  ManHeap->?    "Manure heap emptying" (t)

 ' === Manure heap loading ==================================================
G Dose=2  newon(Cleaning,1) dropon(Emptying) _
                "Fixed amount of manure removed at each cleaning event"  (n)
S Dose.Age=20  ifnew(Cleaning,0) "Age for each dose in the heap"        (d)
R Dose.Ageing=dt    ?->Age       "Ageing of each manure dose in heap"   (d)
A Dose.EmissDose=Qdose*EmUni     "Odour emission from each manure dose" (ou/s)
A EmissTot=gsum(EmissDose)       "Total odour emission from manure heap" (ou/s)
A Dose.EmUni=Emax*exp(-Kdec*Age)*(1-Kabb) _
                                 "Specific dose odour emission f(Age)"  (ou/s/t)

 ' === Odour emissions (interpolation of graphical data from Valli et al., 2008) ==
A EmaxDry=33.7+(1-sin(Doy*2*Pi/365+Pi/2))*(253.5-33.7)/2             _
                                "Max emission of removed dry dose at Age=0" (ou/s/t)
A EmaxWet=51.78+(1-sin(Doy*2*Pi/365+Pi/2))*(518.0-51.78)/2           _
                                "Max emission of removed wet dose at Age=0" (ou/s/t)
A Emax=cond(ManType,EmaxWet,EmaxDry)   "Actual maximum emission"        (ou/s)
 ' It has been assumed a sinusoidal trend of Emax during the year
A Kdec=cond(ManType,0.025,0.03) "Decay coefficient of odour emission"    (-)
 ' Kdec has been obtained as averaged value of summer and winter values,
 ' because almost identical (0.03 for Dry manure, 0.025 for Wet manure)
```