



UNIVERSITÀ
DEGLI STUDI
DI UDINE

Università degli studi di Udine

A software application for mapping livestock waste odour dispersion

Original

Availability:

This version is available <http://hdl.handle.net/11390/1088924> since 2021-03-13T18:48:03Z

Publisher:

Published

DOI:10.1016/j.envsoft.2015.03.016

Terms of use:

The institutional repository of the University of Udine (<http://air.uniud.it>) is provided by ARIC services. The aim is to enable open access to all the world.

Publisher copyright

(Article begins on next page)

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

2

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

4

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

7

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

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

33 Contact: Francesco Danuso, Department of Agricultural and Environmental Sciences (DISA),
34 University of Udine, Via delle Scienze, 206, 33100 Udine IT, francesco.danuso@uniud.it

1 **1. Introduction**

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

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

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

18 Lagrangian models (also known as puff models or particle models) describe the motion in space of
19 individual, non-interacting elementary odour particles. They are stochastic models which take into
20 account the randomness with which odour particles move toward different directions. As these
21 models require the simulation of several trajectories of elementary particles to achieve an adequate
22 accuracy level, they need high computing power (Flesh *et al.*, 1995). A well-known example of a
23 Lagrangian model is CALPUFF (Scire *et al.*, 2001), developed by the Atmospheric Studies Group
24 of Earth Tech Inc. (California), which simulates odour or pollutant puff movements in atmosphere.

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

30 Gaussian models are based on sets of equations describing the three-dimensional space
31 concentration generated from a point source, considering current meteorological conditions as
32 drivers. Emissions are considered time invariant and, for this reason, calculations refer to periods of
33 one hour or less. The rationale of Gaussian models is the following: even if instantaneous
34 concentration of a plume derived from a point source is irregular, over a sufficiently long time

1 period (e.g., one hour) the concentration distribution can be approximated by a Gaussian
2 distribution, both in horizontal and vertical direction. Although the basic formulation of these
3 models is obtained theoretically, empirical relationships are used to derive many of the parameters
4 required by the calculation.

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

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

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

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

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

23

24 **2. *OdiGauss* model**

25 **2.1 General procedure**

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

33 Gaussian models provide sound results only in presence of wind. In *OdiGauss*, when wind speed is
34 lower than $1 \text{ m}\cdot\text{s}^{-1}$, 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 ($\text{kJ}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$), wind speed ($\text{m}\cdot\text{s}^{-1}$) 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):

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

14 where:

15 C : odour concentration in surrounding space ($\text{ou}\cdot\text{m}^{-3}$)¹;

16 Q : odour emission rate ($\text{ou}\cdot\text{s}^{-1}$);

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 ($\text{m}\cdot\text{s}^{-1}$) calculated from the wind speed at the
 22 measurement height as in equation:

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

24 where:

25 u_{ref} : wind speed ($\text{m}\cdot\text{s}^{-1}$) 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

¹ Odour unit ($\text{ou}\cdot\text{m}^{-3}$) 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 $3000 \text{ ou}\cdot\text{m}^{-3}$ 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)

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

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

4 where:

5 C_{eff} : air odour concentration after rainfall washout ($ou \cdot m^{-3}$);

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

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

8 $Rain$: rainfall ($mm \cdot h^{-1}$).

9

10 Table 1. Atmospheric stability classes according Pasquill (1961) and expressions adopted to
 11 calculate dispersion coefficients σ_y and σ_z (Briggs, 1973). Variable x is the downwind distance from
 12 plume source (m). Values of P coefficients used in eq. 2 for wind speed corrections for height are
 13 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

14

15 2.2 Atmospheric stability classes

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

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

8

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

Hourly global radiation ($\text{kJ}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$)	Wind speed ($\text{m}\cdot\text{s}^{-1}$)					
	<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

10

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

$\Delta wdir$ (deg)	$\Delta temp$ (°C)	Wind speed ($\text{m}\cdot\text{s}^{-1}$)					
		<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

14

15 2.3 Procedures for wind calm and weak wind conditions

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

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

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

11 **2.4 Peak-to-mean correction**

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

28

29 **3. *OdiGauss* application**

30 **3.1 Software characteristics and use**

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

1 The software can be launched in three ways :

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

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

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

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

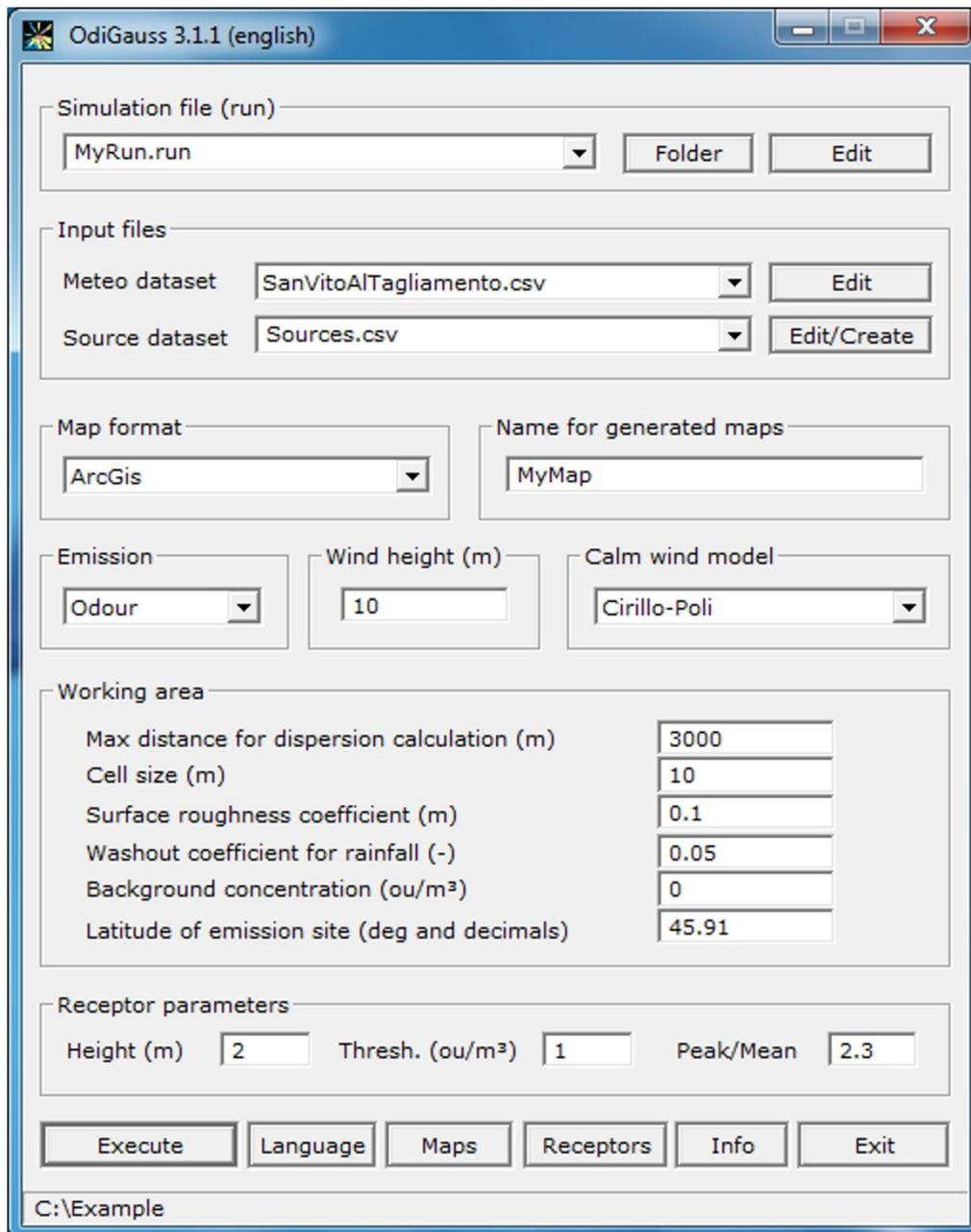
10 The software needs information about atmospheric stability class (Table 1), which can be provided
11 as an input variable in the "meteo" file (*Pasc* variable, Table A.1) or automatically calculated using
12 entered meteorological variables. If the meteorological variables required for the stability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

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

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

22 The results of spatial estimated concentration are cumulated over all simulation hours and for each
23 spatial cell of the territory, at the receptor height, producing maps of i) mean and maximum peak
24 concentration, ii) 98th percentile of peak concentration and iii) time of exposure over acceptable
25 concentration threshold (percentage of hours per year).

26



1
2 Fig. 1. *OdiGauss* main dialog window.

3
4 Values of mean peak concentration, maximum peak concentration, 98th percentile of maximum
5 concentration and time over threshold for single receptors located in the working area can be
6 extracted from the result maps, listed and saved as a `csv` file through a dialog window openable
7 from the main dialog.

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

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

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

5 **3.2 Simulation results**

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

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

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

31 Commands are highlighted in bold: **import** imports maps in ArcGis format, **class** classifies map
32 values, **legend** defines map legend items, **map** creates and displays map. The procedure loads
33 `Med_OdiGauss.txt` map, previously generated by *OdiGauss*, in ArcGis format. Moreover, the
34 script reclassifies categories, modifies the legend defining labels and colours, and finally displays
35 the map joining the classified mean odour concentration with vector elements of RTM. The
36 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
<i>Med_name.est</i>	Map of odour mean concentration	Mean hourly values of odour peak concentration	$\text{ou}\cdot\text{m}^{-3}$
<i>MedC_name.est</i>	Map of odour mean concentration (classified)	As the previous map, but with classified values	classes
<i>Max_name.est</i>	Map of odour maximum peak concentration	Maximum hourly values of odour peak concentration	$\text{ou}\cdot\text{m}^{-3}$
<i>MaxC_name.est</i>	Map of odour maximum peak conc. (classified)	As the previous map, but with classified values	classes
<i>Pct98_name.est</i>	Map of 98 th percentile of peak concentration	Peak odour concentration not exceeded by 2% of simulation hours	$\text{ou}\cdot\text{m}^{-3}$
<i>Pct98C_name.est</i>	Map of 98 th percentile of peak conc. (classified)	As the previous map, but with classified values	classes
<i>Tss_name.est</i>	Map of time-over-threshold for peak concentration	Percentages of simulation hours in which peak concentration exceed the established threshold critical value	%
<i>TssC_name.est</i>	Map of time-over-threshold (classified)	As the previous map, but with classified values	classes

5

6

7

8

9

10

11

12

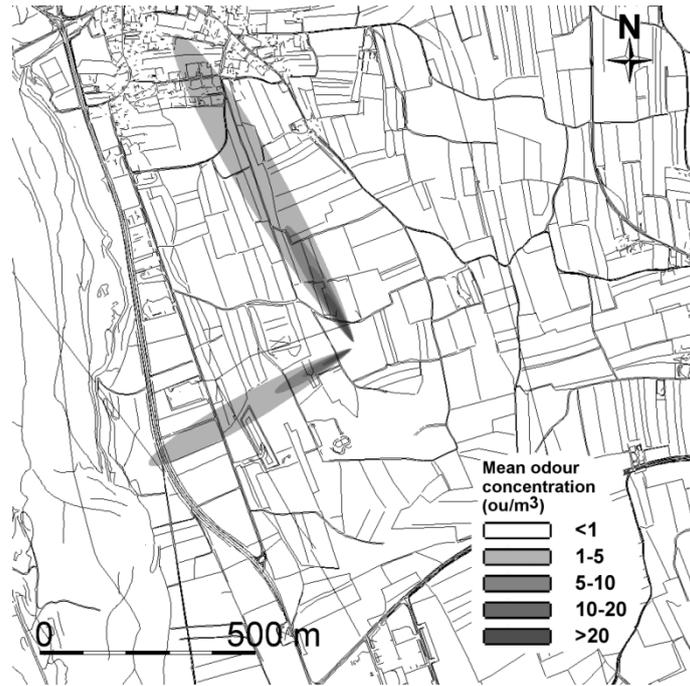
13

14

15

16

17



1

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

4

5 **4. Finding required parameters**

6 **4.1 Working area**

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

10 The maximum distance (m) is limited by the number of cells that have to be calculated (depending
 11 on cell size) and by the total number of simulation time steps. Considering a single emission source,
 12 one year of hourly wind data, a maximum dispersion distance of 2000 meters, and cell size of 4 m,
 13 *OdiGauss* will perform about $4.37 \cdot 10^9$ calculation cycles, corresponding to 365 days x 24 hours x
 14 $(n \times n - 1) / 2$ cells, where $n = 2 \cdot 2000 / 4$. In the case of multiple sources, the maximum distance
 15 calculation is applied starting from the extreme values of X and Y coordinates of the different
 16 sources. *Odigauss* default value for maximum distance is set to 3000 m.

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

20 Default values for roughness coefficient (m) and precipitation washout coefficient are 0.1 m and
 21 0.05, respectively.

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

3 **4.2 Receptor**

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

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

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

10 **4.3 Emission sources**

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

20

21 **5. Odour emission rate**

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

28 **5.1 Constant emission rate**

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

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

4 **5.2 Dynamic simulation of odour emissions**

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

8 *OdiGauss* installation package includes *EmiFarm*, a model which simulates odour emissions from
9 poultry manure heaps. This model was developed on the basis of available literature (Valli *et al.*,
10 2008) using SEMoLa modelling language (Danuso, 1992; Danuso and Rocca, 2014). Valli *et al.*
11 (2008) have presented experimental results linking the specific emissions ($\text{ou}\cdot\text{s}^{-1}\cdot\text{t}^{-1}$) to key variables
12 (type of waste, moisture, period of the year, time after litter emptying). The full model code is
13 shown in Appendix B. The model is based on the following assumptions:

- 14 • the production of broilers involves 4.5 cycles per year, each lasting about 80 days, including
15 downtime; during this period the litter accumulates in the chicken coop;
- 16 • litter is completely removed at the end of the cycle and stored in the manure heap;
- 17 • odour emission rate depends on manure moisture (wet/dry), with much higher values for wet
18 manure;
- 19 • emptying of the manure heap occurs once a year, in relation to weather conditions, agronomic
20 requirements and according to disposal regulations; manure is then incorporated into the soils;
- 21 • as manure heap is made by many "doses", each one having a different stage of maturity and
22 emission rate, the model follows the emission dynamics of every dose, according to the element-
23 based approach (Danuso and Rocca, 2014). Simulation starts with the presence of 2 doses, with an
24 average age of 20 days; for every dose, the emission rate (Em_i) decays over time from its maximum
25 value when litter is added to the manure heap, following a linear or exponential functions depending
26 also on the season;
- 27 • the maximum emission rate ($Emax$) changes during the year according to a sinusoidal function,
28 assuming that it reaches its minimum the first day of the year and the minimum on day 182
29 (halfway);
- 30 • the cumulative total emission ($EmissTot$) is calculated, day by day, adding the specific emissions
31 of every individual dose, each of them multiplied by their mass;
- 32 • the simulation step is daily and therefore emissions of the different hours of the day are kept
33 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:

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

5 where:

6 Em_i is the specific emission rate per ton of manure ($ou \cdot s^{-1} \cdot t^{-1}$) of the i -th dose;

7 $Emax$ the maximum emission rate at $Age_i=0$ ($ou \cdot s^{-1} \cdot t^{-1}$, occurring when the dose is removed from
 8 litter and added to the heap);

9 $Kdec$ the emission decay coefficient (d^{-1});

10 Age_i the age of the dose (d);

11 $Kabb$ a dimensionless coefficient of odour abatement ranging from 0 (no odour reduction) to 1
 12 (totally suppressed odour emission). Table 5 reports the coefficients obtained in different
 13 conditions.

14 Total emission rate ($EmissTot$, $ou \cdot s^{-1} \cdot t^{-1}$) is obtained, day by day, with the equation:

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

15 In order to provide the maximum emission rate for all days of the year, it has been assumed that
 16 $Emax$ follows a sinusoidal function during the year, according to the equation:

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

17 where:

18 $Ewin$ is the maximum emission of the dose in winter;

19 $Esum$ is the maximum emission in the summer;

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

21 Table 5. Model regression coefficients describing odour emission rates ($Emax$) and emission decay
 22 coefficients ($Kdec$) for different poultry manure moisture conditions and seasons (from Valli *et al.*,
 23 2008).

Material	Condition	$Emax$ ($ou \cdot s^{-1} \cdot t^{-1}$)	$Kdec$ (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

24

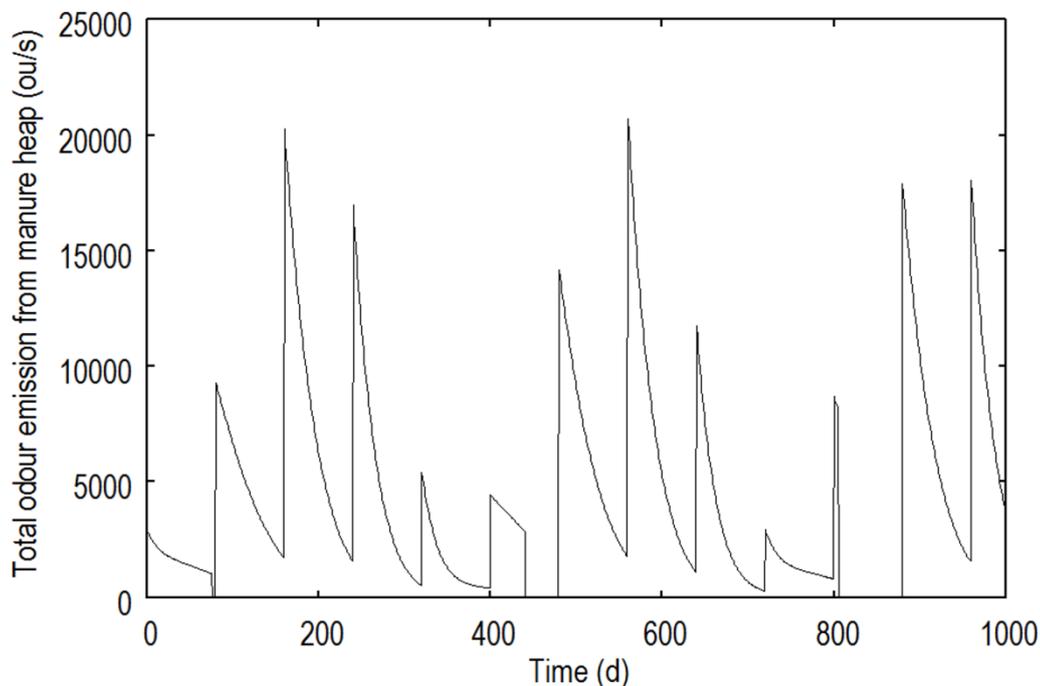
1 This function leads to a yearly fluctuation of E_{max} that, for the dry manure, ranges between 34 and
2 254 $ou \cdot s^{-1} \cdot t^{-1}$.

3 The input parameters required by the model and their default values are: manure conditions
4 (dry/wet), daily production of manure ($2.0 t \cdot d^{-1}$), 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).

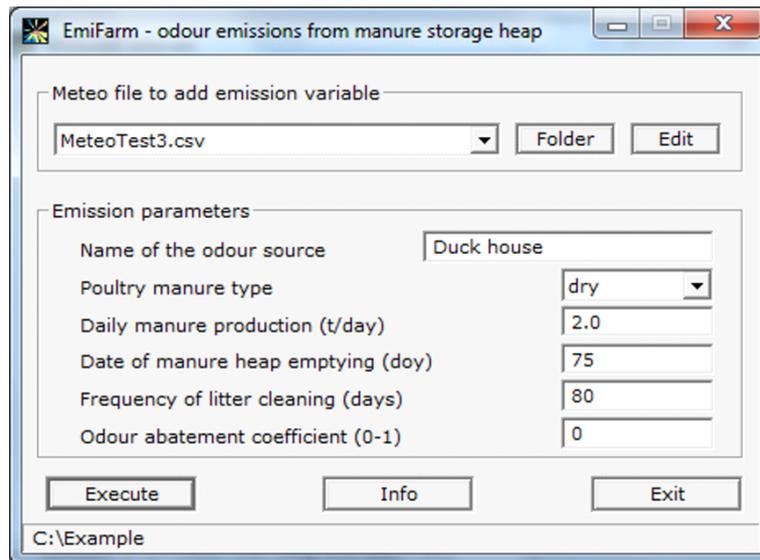
7 Fig. 3 shows the trend of odour emission, as simulated by *EmiFarm*, from a poultry manure heap,
8 considering the litter cleaned every 80 days, and a dry manure production of $2 t \cdot d^{-1}$.

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 *OdiGauss* 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 ($ou \cdot s^{-1}$) 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 $2 t \cdot d^{-1}$.



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

3
4 It is possible to create several emission variables, but it is not necessary to do this for all sources in
5 the “source” file because some of them can be declared with a constant emission value.
6 The “meteo” file updated in such a way is used by *OdiGauss* to calculate the dispersion maps.

7
8 **6. Case studies**

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

11 Case study A simulates odour dispersion from a swine stable located in Udine province. The farm
12 adopts a fully slatted floor, with fast slurry removal system, called “Vacuum System” and a forced
13 ventilation plant. Stable hosts on average 3018 pigs: 1008 in the first fattening stage and the other
14 2010 in the following fattening phases. Slurry is stored in a concrete tank covered with a PVC tent.
15 The emission point height is 5 m.

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

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

1 Table 6. Description of livestock production systems and odour emission rates calculation in the
2 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·s ⁻¹)
A (Udine province)	Fattening pigs – first stage (25-50 kg lw)	1008 heads	fully slatted floor with Vacuum system	4 ou·s ⁻¹ ·head ^{-1a}	-	1.00 ^a	4032
	Fattening pigs – second stage (50-160 kg lw)	2010 heads	fully slatted floor with Vacuum system	59 ou·s ⁻¹ ·head ^{-1a}	Vegetable oil sprinkling for swine production facilities	0.50 ^a	59295
	Concrete slurry tank	1165 m ²	-	76 ou·s ⁻¹ ·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·s ⁻¹ ·t _w ⁻¹	-	1.00	23310
						Total	23310

3 ^a Navarotto *et al.*, 2007

4 ^b Guarino *et al.*, 2006

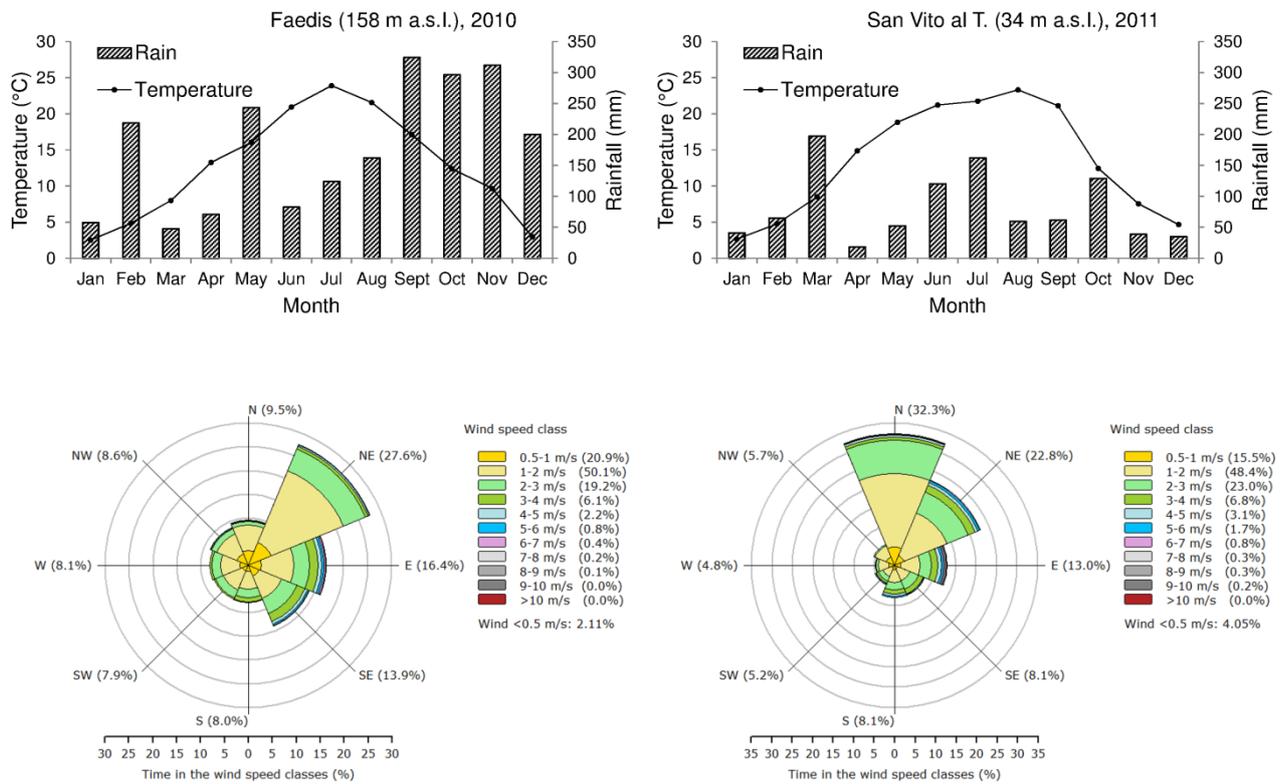
5

6 implementation of odour mitigating techniques. VDI 3894 also indicates that the odour emission
7 factor from broiler fattening in floor husbandry conditions is 60 ou·s⁻¹·LU⁻¹. Thus, the resulting
8 odour emission rate from the broiler house in case study B is 22000 ou·s⁻¹.

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

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

1 odour emission rate is $81035 \text{ ou}\cdot\text{s}^{-1}$, 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 $23310 \text{ ou}\cdot\text{s}^{-1}$, calculated considering an average
 4 live weight (lw) of 1 kg per head and an odour emission factor of $126 \text{ ou}\cdot\text{s}^{-1}\cdot\text{t}_{\text{lw}}^{-1}$ (Valli *et al.*, 2008).
 5 This value is similar to that one calculated using VDI 3894 emission factors ($22000 \text{ ou}\cdot\text{s}^{-1}$).
 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 $5 \text{ ou}\cdot\text{m}^{-3}$. These values have been suggested by Nicell (1994)
 14 which discusses the whole chain of odour sensation: unspecific detection ($1 \text{ ou}\cdot\text{m}^{-3}$), 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.

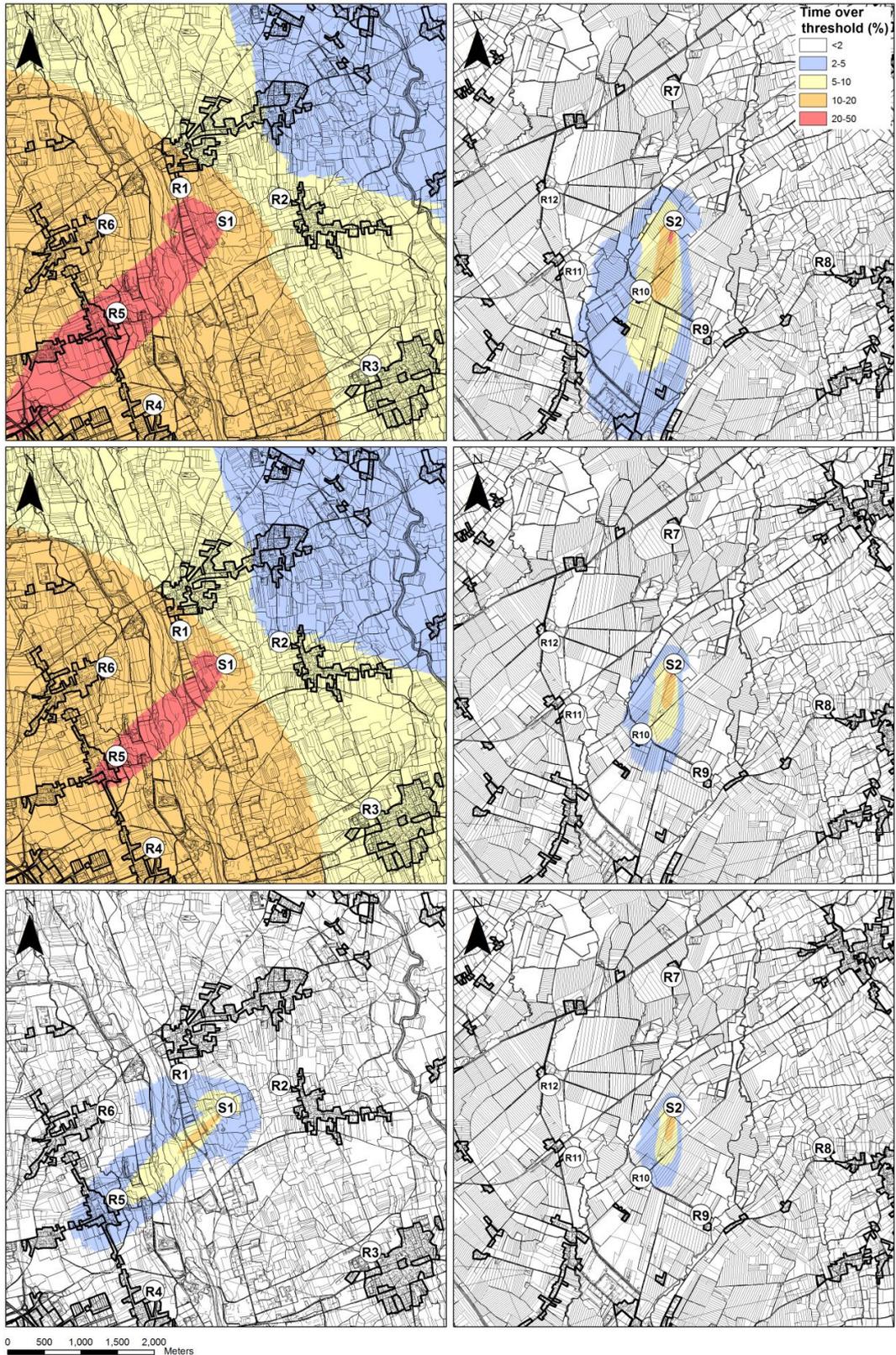
1 (3-5 $\text{ou}\cdot\text{m}^{-3}$), unmistakable perception (5 $\text{ou}\cdot\text{m}^{-3}$, complaint level), and as last step the degree of
 2 annoyance.

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
<i>Run file data</i>		
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 ($\text{ou}\cdot\text{m}^{-3}$)	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 ($\text{ou}\cdot\text{m}^{-3}$)	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
<i>Source file data</i>		
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 ($\text{ou}\cdot\text{s}^{-1}$)	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.



1
 2 Fig. 6. Maps of exceeding probability classes for three odour thresholds (1, 3, 5 ou·m⁻³, top to
 3 bottom) as a function of the distance from the odour emission source for case study A (left) and B
 4 (right). Residential areas boundaries are highlighted in bold. Receptors positions are enumerated
 5 from R1 to R12. S1 and S2 are the source emission points.

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

Receptor	Emission source	Longitude (m) ^a	Latitude (m) ^a	Time over threshold (%)		
				Threshold = 1 $\text{ou}\cdot\text{m}^{-3}$	Threshold = 3 $\text{ou}\cdot\text{m}^{-3}$	Threshold = 5 $\text{ou}\cdot\text{m}^{-3}$
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

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

4

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

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

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

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

23

1 **7. Conclusions**

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

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

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

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

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

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

32

1 **Acknowledgements**

2 Authors thank Mario Portolan and Giovanni Bombardella for the stimulus to explore the issue of
3 livestock odour dispersion and for their technical advice. We also thank ARPA-OSMER FVG for
4 the availability of hourly meteorological data and the Friuli Venezia Giulia regional administration
5 for the Regional Technical Map.

7 **References**

- 8 Blanes-Vidal, V., Nadimi, E.S., Ellermann, T., Andersen, H.V., Løfstrøm, P., 2012. Perceived
9 annoyance from environmental odors and association with atmospheric ammonia levels in non-
10 urban residential communities: a cross-sectional study. *Environ. Health* 11, 27
11 (<http://www.ehjournal.net/content/11/1/27>).
- 12 Briganti, G., Giarola, S., Grippa, G., Zanini, G., Monforti, F., Kolarova, M.P., 2001, WinDimula
13 model evaluation with the Model Validation Kit. 7th Inter. Conf.on Harmonisation within
14 Atmospheric Dispersion Modelling. Belgirate, Italy, May 2001.
- 15 Briggs, G.A., 1973. Diffusion estimation for small emissions. ATDL Contribution File NO. 79,
16 Atmospheric Turbulence and Diffusion Laboratory.
- 17 Cirillo, M.C., Poli, A.A., 1992. An intercomparison of semi empirical diffusion models under low
18 wind speed, stable conditions. *Atmos. Environ.* 26, 765-774.
- 19 Collet, R.S., Oduyemi, K., 1997. Air quality modelling: a technical review of mathematical
20 approaches. *Meteorol. Appl.* 4, 235-246.
- 21 Danuso, F., 1992. Continuous dynamic system simulation with Stata. *Stata Technical Bulletin*, n.8,
22 19-32, Santa Monica, California.
- 23 Danuso, F., Rocca, A., 2014. SEMoLa: A simple and easy modelling language. *Ecol. Modell.* 285,
24 54-77.
- 25 Danuso, F., Sandra, M., 2006a. SemGrid: applicazione a scala territoriale di modelli epidemiologici
26 e culturali. *Atti 9° Convegno Nazionale di Agrometeorologia - AIAM "Agrometeorologia e
27 gestione delle colture agrarie"*, Torino, 6-7-8 giugno 2006.
- 28 Danuso, F., Sandra, M., 2006b. SemGrid: Land application of epidemiological and crop
29 models. *Pros. IX ESA Congress*, 4-7 September 2006, Warszawa, Poland, 631-632. PL ISSN
30 0860-4088 (*Bibliotheca Fragmenta Agronomica*).
- 31 Dupont, S., Brunet, Y., Jarosz, N., 2006. Eulerian modelling of pollen dispersal over heterogeneous
32 vegetation canopies. *Agr. Forest. Meteorol.* 141, 82-104.
- 33 EPA, 1995. Users's guide for the industrial source complex (ISC3) dispersion models. Volume II -
34 Description of model algorithms. EPA-454/B-95-003b, U.S. Environmental Protection Agency.

1 Office of Air Quality Planning and Standards. Emissions, Monitoring, and Analysis Division.
2 Research Triangle Park, North Carolina 27711.

3 Flesh, T.K., Wilson, J.D., Yee, E., 1995. Backward-time Lagrangian stochastic dispersion models
4 and their application to estimate gaseous emissions. *J. Appl. Meteorol.* 34, 1320-1332.

5 Gifford, F., 1976. Turbulent diffusion-typing schemes: a review. National Oceanic and Atmospheric
6 Administration, Oak Ridge, TN.

7 Guarino M., Fabbri C., Brambilla M., Valli L., Navarotto P., 2006. Evaluation of simplified
8 covering systems to reduce gaseous emissions from livestock manure storage. *Transactions-*
9 *American society of agricultural engineers* 49, 737-747.

10 Guo, H., Dehod, W., Agnew, J., Laguë, C., Feddes, J., Pang, S., 2006. Annual odor emission rate
11 from different types of swine production buildings. *Trans. ASABE* 49, 517-525.

12 Hanna, S.R., Briggs, G.A., Hosker Jr., R.P., 1982. Handbook on atmospheric diffusion. Technical
13 Information Center U.S. Department of Energy.

14 Heber, A.J., Ni, J.Q., Haymore, B.L., Duggirala, R.K., Diehl, C.A., Spence, M.L., 1998.
15 Measurements of gas emissions from commercial swine buildings. ASAE Paper No. 98-4058. St.
16 Joseph, Mich.: ASAE.

17 Högström, U., 1972. A method for predicting odour frequencies from a point source. *Atmos.*
18 *Environ.* 6, 103-121.

19 Holmes, N.S., Morawska, L., 2006. Review of Dispersion Modelling and its application to the
20 dispersion of particles: An overview of different dispersion models available. *Atmos. Environ.*
21 40, 5902-5928.

22 Jacobson, L.D., Bicudo, J.R., Schmidt, D.R., Wood-Gay, S., Gates, R.S., Hoff, S.J., 2003. Air
23 emissions from animal production buildings. *Proc. XI International Congress ISAH 2003*, 23-27
24 February 2003, Mexico City.

25 JRC Joint Research Centre – Institute for Environment and Sustainability, 2002. Final report of
26 Moland project in Friuli Venezia Giulia Region.

27 McCartney, H.A., Fitt, B.D.L., 1985. Construction of dispersal models, in: Gilligan, C.A., (Ed.),
28 *Mathematical Modelling of Crop Disease*, vol. 3, *Advances in Plant Pathology*. pp. 107-143.

29 Navarotto, P., Guarino, M., Brambilla, M., 2007. Odori emessi dagli allevamenti suinicoli: come
30 prevederne l'intensità a diverse distanze: Quaderni della ricerca. Regione Lombardia-Direzione
31 Generale Agricoltura.

32 Nicell, J.A., 1994. Development of the odour impact model as a regulatory strategy. *Int. J. Environ.*
33 *Pollut.* 4, 124-138.

1 NSW EPA, 2001. Technical notes: assessment and management of odour from stationary sources in
2 NSW. NSW EPA, Sidney. 43 pp.

3 Olesen, H.R., Løfstrøm, P., Berkowicz, R., Ketzel, M., 2005. Regulatory odour model
4 development: Survey of modelling tools and datasets with focus on building effects. National
5 Environmental Research Institute, Denmark. 62 pp. - NERI Technical Report No. 541.
6 <http://technical-reports.dmu.dk>.

7 Pasquill, F., 1961. The estimation of the dispersion of windborne material. *Meteorol. Mag.* 90, 33-
8 49.

9 Perin, 2004. *Ecotossicologia - cap.IV – Il comparto atmosfera*. [http://www.unive.it/media/allegato/
10 ecotossicologia/CapIVARIA_\(new\).pdf](http://www.unive.it/media/allegato/ecotossicologia/CapIVARIA_(new).pdf)

11 Schauburger, G., Piringer, M., 2012. Assessment of separation distances to avoid odour annoyance:
12 interaction between odour impact criteria and peak-to-mean factors. *Chemical Engineering
13 Transactions* 30, 13-18.

14 Schauburger, G., Piringer, M., Petz, E., 1999. Diurnal and annual variation of odour emission from
15 animal houses: a model calculation for fattening pigs. *J. Agr. Eng. Res.* 74, 251-259.

16 Schauburger, G., Piringer, M., Petz, E., 2001. Separation distance to avoid odour nuisance due to
17 livestock calculated by the Austrian odour dispersion model (AODM). *Agr. Ecosyst. Environ.*
18 87, 13-28.

19 Schauburger, G., Schmitzer, R., Kamp, M., Sowa, A., Koch, R., Eckhof, W., Eichler, F., Grimm, E.,
20 Kypke, J., Hartung, E., 2012a. Empirical model derived from dispersion calculations to
21 determine separation distances between livestock buildings and residential areas to avoid odour
22 nuisance. *Atmos. Environ.* 46, 508-515.

23 Schauburger, G., Piringer, M., Schmitzer, R., Kamp, M., Sowa, A., Koch, R., Eckhof, W., Grimm,
24 E., Kypke, J., Hartung, E., 2012b. Concept to assess the human perception of odour by
25 estimating short-time peak concentrations from one-hour mean values. Reply to a comment by
26 Janicke et al. *Atmos. Environ.* 54, 624–628.

27 Schauburger, G., Piringer, M., Heber, A.J., 2014. Odour emission scenarios for fattening pigs as
28 input for dispersion models: A step from an annual mean value to time series. *Agr. Ecosyst.
29 Environ.* 193, 108–116.

30 Scire, J.S., Strimaitis, D.G., Yamartino, R.J., 2001. *A user's Guide for the CALPUFF Dispersion
31 Model*, Earth Tech, Concord, MA.

32 Sommer-Quabach, E., Piringer, M., Petz, E., Schauburger, G., 2014. Comparability of separation
33 distances between odour sources and residential areas determined by various national odour
34 impact criteria. *Atmos. Environ.* 95, 20-28.

1 Valli, L., 2001, Le emissioni di odori dagli allevamenti zootecnici. L'Informatore Agrario 57, 35-
2 40.

3 Valli, L., Moscatelli, G., Labartino, N., 2008. Odour emissions from livestock production facilities.
4 Chem. Eng. Trans. 15, 239-246.

5 VDI 3894 Part 1, 2011. Emissions and immissions from animal husbandry e housing systems and
6 emissions e pigs, cattle, poultry, horses. In: Deutscher Ingenieure, Verein (Ed.). Beuth, Berlin.

7 VDI 3940 Part 1, 2006. Measurement of odour impact by field inspection - Measurement of the
8 impact frequency of recognizable odours - Grid measurement, Corrigendum concerning
9 guideline VDI 3940 Part 1:2006:02. In: Deutscher Ingenieure, Verein (Ed.). Beuth, Berlin.

10 Zhang, L., Vet, R., Michelangeli, D.V., 2006. Numerical investigation of gas scavenging by weak
11 precipitation. J. Atmos. Chem. 54, 203-231.

12 Zhu, J., Jacobson, L.D., Schmidt, D.R., Nicolai, R., 2000. Daily variations in odor and gas
13 emissions from animal facilities. Applied Eng. in Agric. 16, 153-158.

14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33

1 **Appendix A: preparing input files**

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

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

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

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

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

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

32
33
34

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·s ⁻¹	Required
Wdir	Hourly wind direction	degrees and decimals from North, clockwise	Required
Rain	Hourly rainfall	mm·h ⁻¹	Optional
Temp	Hourly mean temperature	°C	Optional
Rad	Hourly global radiation	kJ·m ⁻² ·h ⁻¹	Optional
Pasc	Atmospheric Pasquill stability class	A-F	Optional
backgOU	Background odour concentration	ou·m ⁻³	Optional
source_name	Odour emission rate of the source	ou·s ⁻¹	Optional

4

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·s ⁻¹
Hem	Height of odour release	m

6

7

8

9

10

11

12

13

14

15

16

17

```

1 Appendix B: SEMoLa code of the model EmiFarm
2 ' Model: EmiFarm.sem 11-16-2012 15:38:22
3 ' Odour emission from poultry manure storage heap
4 ' Bib.:
5 ' Valli et al., 2008 (Odour emissions from livestock production facilities)
6 ' - Dose: manure amount removed with a single cleaning event
7 ' - All doses are considered of the same amount
8 ' - Poultry manure production:710 t/year, 4.5 cycles/year of 80 days each
9 ' - Average daily manure production: 710/365 = 1.95 t/day
10 ' - 4.5 cycles of broilers per year, cycle duration=80 days
11 ' - Emptying of the heap occurs one time per year at doym=75
12
13 $ dt(1$ dt(1)
14 $ tspan(0,1000) tunit(d)
15 A doym=mod(time-1,365)+1 "Day of the year (1-365)" (d)
16 0
17 ' === Parameters =====
18 P ManType=0 "0=dry manure; 1=wet manure" (-)
19 P ProdDay=1.95 "Manure production" (t/d)
20 P DateEmpty=75 "Day of manure heap emptying" (doy)
21 P CleanCycle=80 "Cleaning cycle length" (d)
22 P Kabb=0.5 "Odour abatement coefficient" (-)
23 P Qdose=ProdDay*CleanCycle "Manure produced per cleaning cycle" (t)
24
25 ' === Manure production and litter cleaning =====
26 S ManLitter=0 "Manure in the litter" (t)
27 S ManHeap=2*Qdose "Amount of manure in the heap" (t)
28 R IncrLitt=ProdDay ?->ManLitter "Daily manure production" (t/d)
29 V Cleaning=after(CleanCycle) "Litter cleaning event" (-)
30 V Emptying=when(Doy=DateEmpty) "Emptying manure heap event" (-)
31 I CleanLitt onevt(Cleaning,ManLitter) ManLitter->ManHeap "Litter cleaning" (t)
32 I EmptyHeap onevt(Emptying,ManHeap) ManHeap->? "Manure heap emptying" (t)
33
34 ' === Manure heap loading =====
35 G Dose=2 newon(Cleaning,1) dropon(Emptying) _
36 "Fixed amount of manure removed at each cleaning event" (n)
37 S Dose.Age=20 ifnew(Cleaning,0) "Age for each dose in the heap" (d)
38 R Dose.Ageing=dt ?->Age "Ageing of each manure dose in heap" (d)
39 A Dose.EmissDose=Qdose*EmUni "Odour emission from each manure dose" (ou/s)
40 A EmissTot=gsum(EmissDose) "Total odour emission from manure heap" (ou/s)
41 A Dose.EmUni=Emax*exp(-Kdec*Age)*(1-Kabb) _
42 "Specific dose odour emission f(Age)" (ou/s/t)
43
44 ' === Odour emissions (interpolation of graphical data from Valli et al., 2008) ==
45 A EmaxDry=33.7+(1-sin(Doy*2*Pi/365+Pi/2))*(253.5-33.7)/2 _
46 "Max emission of removed dry dose at Age=0" (ou/s/t)
47 A EmaxWet=51.78+(1-sin(Doy*2*Pi/365+Pi/2))*(518.0-51.78)/2 _
48 "Max emission of removed wet dose at Age=0" (ou/s/t)
49 A Emax=cond(ManType,EmaxWet,EmaxDry) "Actual maximum emission" (ou/s)
50 ' It has been assumed a sinusoidal trend of Emax during the year
51 A Kdec=cond(ManType,0.025,0.03) "Decay coefficient of odour emission" (-)
52 ' Kdec has been obtained as averaged value of summer and winter values,
53 ' because almost identical (0.03 for Dry manure, 0.025 for Wet manure)
54
55
56
57
58
59
60
61
62
63
64

```