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Comparison of CALPUFF and AERMOD Models for Odour Dispersion Simulation

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Different types of models can be used to simulate the odour dispersion into the atmosphere. This work aims to compare two dispersion models that are widely used for regulatory purposes (Dresser and Huizer, 2011): the steady-state, U.S. Environmental Protection Agency (EPA) model AERMOD, and the non-steady-state puff model CALPUFF. The comparison focuses on how meteorological conditions (i.e., stable vs. instable conditions) and source type (i.e., point vs. area source) affect the modelling results, thereby allowing to analyse the differences based on the characteristic dispersion equations of the two above mentioned models.

1. Introduction

Nowadays odours are subject to control and regulation in many countries (Nicell, 2009), thus entailing the need for specific methods for exposure assessment. Odour dispersion modelling is commonly applied to simulate how odour disperses into the atmosphere, and therefore to calculate ground odour concentration values in space-time domain (Sironi et al., 2010); recent odour regulation in many countries has been based on this approach. In most cases, regulations based on odour dispersion modelling fix acceptability standards in terms of the exceedence frequency of a given odour concentration (JORF, 2008; Regione Lombardia, 2012; UK Environmental Agency, 2002). In general, different types of models can be used to simulate the dispersion of pollutants into the atmosphere, for instance, to predict downwind pollutant concentrations or to back-calculate average pollutant emission rates from downwind concentration measurements. This work aims to compare two dispersion models that are widely used for regulatory purposes (Dresser and Huizer, 2011): the steady-state, U.S. Environmental Protection Agency (EPA) guideline model AERMOD, and the non-steady-state puff model CALPUFF. The comparison focuses on how meteorological conditions (i.e., stable vs. instable conditions) and source type (i.e., point vs. area source) affect the modelling results, thereby allowing to analyse the differences based on the characteristic dispersion equations of the two above mentioned models.

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2. Materials and Methods

2.1 Dispersion models

2.1.1. AERMOD

The AERMOD Gaussian model is a steady-state plume model. In the stable boundary layer, it assumes the concentration distribution to be Gaussian in both the vertical and horizontal. In the convective boundary layer, the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function. The AERMOD incorporates current concepts about flow and dispersion in complex terrain.

There are several research studies describing the model effectiveness for odour dispersion simulation (Drew et al., 2007; Latos et al., 2011).

Gaussian plume models for predicting downwind odour concentrations from point and are sources can be described by the following equations (Wang et al., 2006).

For point source:

$$C = \frac{Q_P}{\pi \sigma_y \sigma_z u} \exp\left(-\frac{y^2}{2\sigma_y^2} \right) \exp\left(-\frac{H^2}{2\sigma_z^2} \right) \tag{1}$$

For area source:

$$C = \frac{Q_A}{2\pi u} \int_X \frac{V}{\sigma_y \sigma_z} \left(\int_Y \exp\left[-\frac{1}{2} \left(\frac{y}{\sigma_y} \right)^2 \right] dy \right) dx \tag{2}$$

Where C is the downwind odour concentration (ou m^{-3}), Q_P the point source odour emission rate (ou s^{-1}), Q_A the area source odour emission rate (ou m^{-2} s^{-1}), σ_y, σ_z the Pasquill-Gifford plume spread parameters based on stability class, u the average wind speed at pollutant release height (m s^{-1}), H the effective height above ground of emission source m), V the vertical term used to describe vertical distribution of the plume, x the upwind direction (m), and y the cross wind direction (m).

2.1.2. CALPUFF

CALPUFF dispersion model was developed by Sigma Research Corporation as a generalized non-steady-state air emission modelling system for regulatory use (Earth Tech and Inc., 2000). Also in this case, there are several scientific studies proving the possibility of applying CALPUFF for modelling the dispersion of odours and odorous compounds (Abdul-Wahab et al., 2011; Capelli et al. 2011). Puff models represent a continuous plume as a number of discrete packets of pollutant (Earth Tech and Inc., 2000) and evaluate the contribution of a puff to the concentration at a receptor by a “snapshot” approach. Each puff is “frozen” at particular time intervals (sampling steps). The puff is then allowed to move, evolving in size and strength until the next sampling step. The total concentration at a receptor is the sum of the contributions of all nearby puffs averaged for all sampling steps within the basic time step. The sampling step and time step may both be 1 h, indicating only one “snapshot” of the puff is taken each hour.

CALPUFF is a non-steady-state Lagrangian puff model. The basic equation for the contribution of a puff at a receptor is:

$$C = \frac{Q}{2\pi \sigma_y \sigma_z} g \exp\left(-\frac{d_a^2}{2\sigma_x^2} \right) \exp\left(-\frac{d_c^2}{2\sigma_y^2} \right) \tag{3}$$

$$g = \frac{2}{(2\pi)^{1/2} \sigma_z} \sum_{n=-\infty}^{\infty} \exp\left[-(H_c + 2nh)^2 / \left(2\sigma_z^2 \right) \right] \tag{4}$$

Where C is the ground-level odour concentration (ou m^{-3}), Q the product of the odour concentration in the puff and the puff volume (ou), σ_x the standard deviation of the Gaussian distribution in the along-wind direction (m), σ_y the standard deviation of the Gaussian distribution in the cross-wind direction (m), σ_z the standard deviation of the Gaussian distribution in the vertical direction (m), d_a the distance from the puff centre to the receptor along the wind direction (m), g the vertical term of Gaussian equation (m^{-1}), H the effective height above ground of the puff centre (m), and h the mixing height (m).

2.2 Modelling conditions

For model comparison purposes, it was decided to run a set of simulations considering an "ideal" case, with the purpose of limiting the differences due to the meteorological pre-processors of the two models, which work with different logics.

More in detail, the meteorological input data (especially the solar radiation) were directly set as to represent standard conditions of a geographical zone with temperate continental climate, e.g., Northern Italy.

The wind direction was fixed considering a wind blowing from East to West (wind provenance 90°).

Also the wind speed was set constant for every hour of the year. Different simulations were run considering three different wind speed values: 0.5, 2 and 6 m s^{-1}, with the aim of investigating model performances in conditions of low, medium and high wind speed, respectively.

As far as orography is concerned he terrain was considered as flat and at sea level.

Two different simplified emission scenarios were considered: the first, including one point source, the second, one area source. The characteristics of the sources are resumed in Table 1. In both cases, the emissions were considered as constant with time.

Therefore, 6 simulations were run in total for each model: 2 different emission scenarios (point source vs. area source) x 3 different wind speed values (0.5, 2 and 6 m s^{-1}).

Table 1: Characteristics of the odour sources

Characteristic	Unit	Scenario 1 (point source)	Scenario 2 (area source)
UTM East	km	485.124	485.124
UTM North	km	5,034.533	5,034.533
Height	m	6	0
Equiv. diameter	m	1	0.785
Surface	m^2	35.7	1,000
Temperature	K	313	293
Velocity	m s^{-1}	5	0.035
OER	ou s^{-1}	50,000	5,000

3. Results and discussion

3.1 Point source

During the day, i.e., with unstable conditions, the results of the two models are in agreement, turning out in plumes with a radius of a few hundred meters located near the source, with maximum concentrations of few odour units (Figure 1).

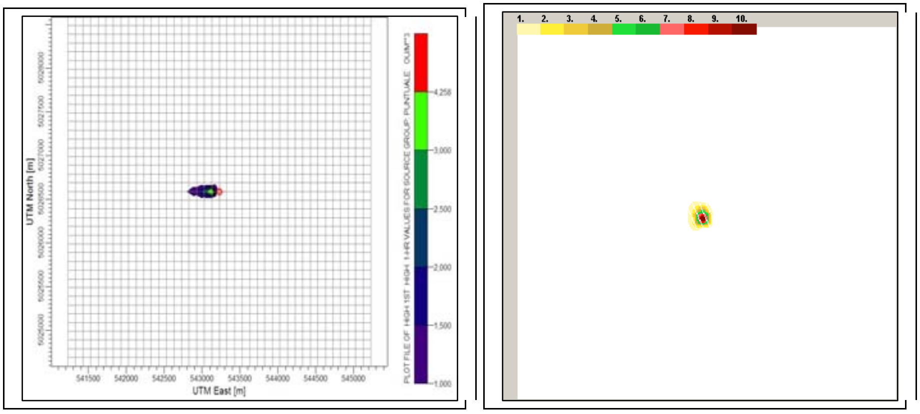

Figure 1: Maps of odour concentrations obtained for a point source, with a wind speed of 0.5 m s^{-1} and unstable conditions, using Aermod (left) and Calpuff (right)

During the night, with stable atmospheric conditions, odour concentrations simulated both by Aermod and Calpuff are close to zero.

The results obtained at 2 m s^{-1} are similar to those obtained at 0.5 m s^{-1}. At 6 m s^{-1} , due to the high wind speed, i.e. neutral conditions, the results of the simulations are similar both for day- and nighttime, even though a slight increase of the odour impact is still observed overnight. Odour concentration calculated by Aermod is slighty higher, even though the higher values are strictly limited to the emission point (Figure 2 and Figure 3).

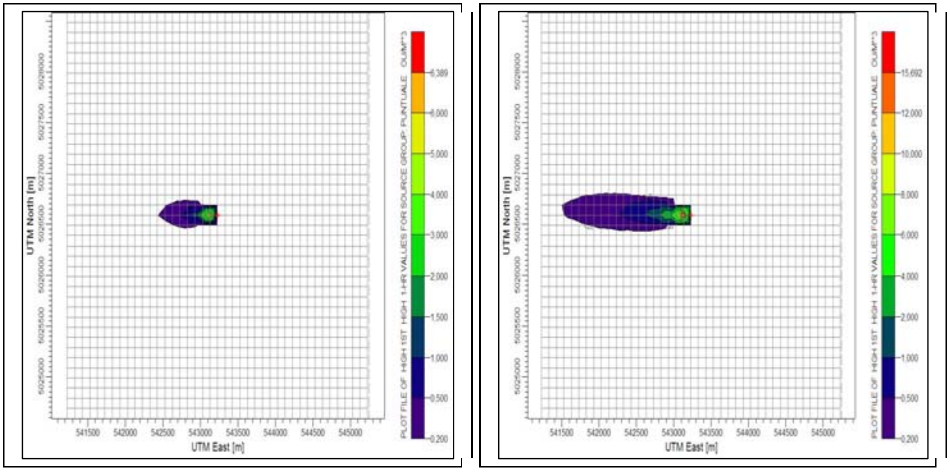

Figure 2: Maps of odour concentrations obtained using Aermod for a point source, with a wind speed of 6 m s^{-1} during day (left) and night (right)

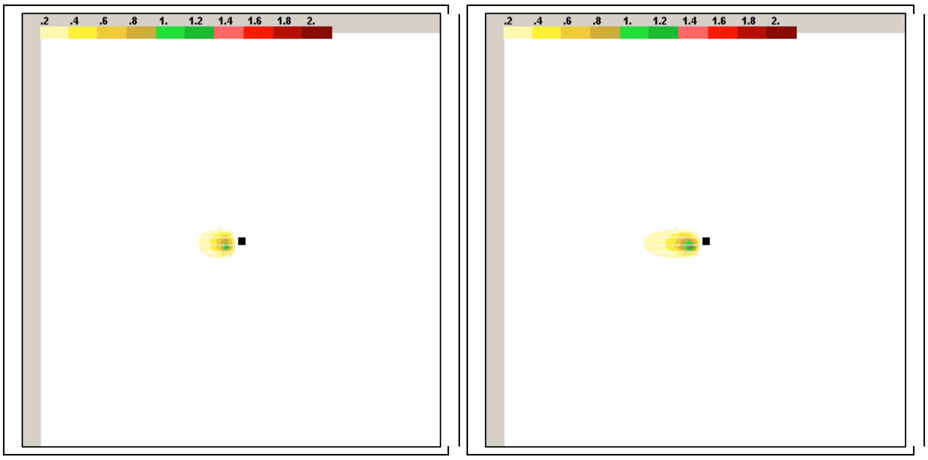

Figure 3: Maps of odour concentrations obtained using Calpuff for a point source, with a wind speed of 6 m s^{-1} during day (left) and night (right)

3.2 Area source

In the case of unstable conditions the simulation results are similar to those for a point source. The plumes modelled by Calpuff and Aermod are comparable in terms of extension, even though the maximum odour concentration calculated by Aermod is much higher (generally above 100 ou/m^3), by the way such higher values are strictly confined upon the emission source (Figure 4).

On the contrary, in stable conditions, the odour impact simulated by the two models is totally different: Aermod results show a long and narrow plume with very high odour concentrations, whereas the odour concentrations simulated by Calpuff do not reach 1 ou/m^3 (Figure 5).

This is closely related to the models implemented by two software: AERMOD considers always a Gaussian plume and then, in a stable condition, generates a long plume that under conditions of calm wind is diluted slightly and get far, while CALPUFF generates puffs that under the same conditions, stagnate over the source term.

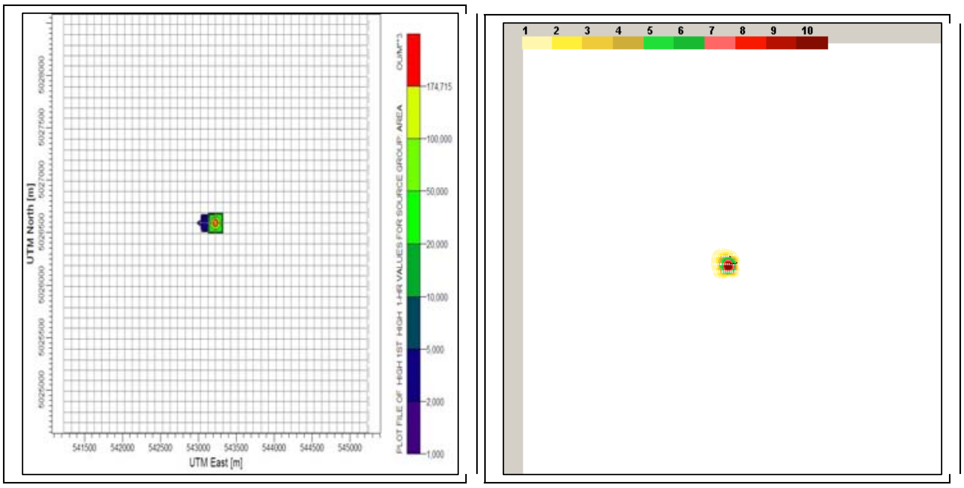

Figure 4: Maps of odour concentrations obtained for a point source, with a wind speed of 0.5 m s^{-1} and unstable conditions, using Aermod (left) and Calpuff (right)

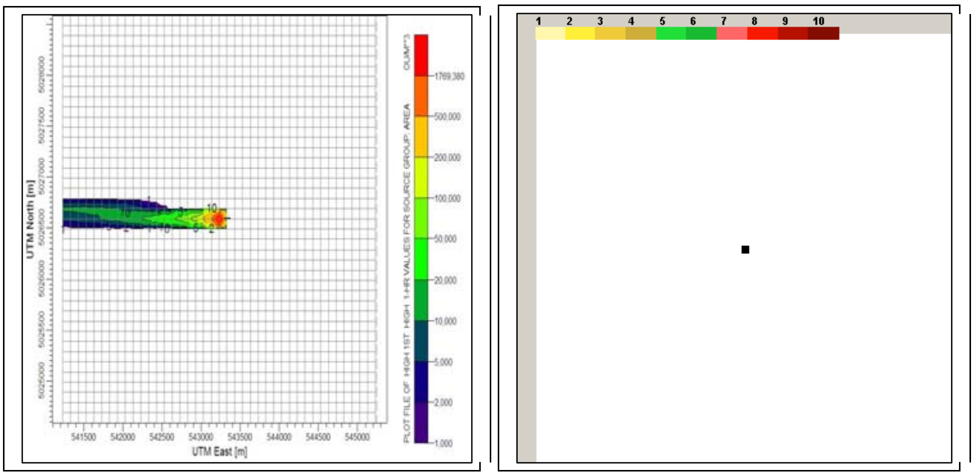

Figure 5: Maps of odour concentrations obtained for a point source, with a wind speed of 0.5 m s^{-1} and stable conditions, using Aermod (left) and Calpuff (right)

The results obtained at 2 m s^{-1} are similar to those obtained at 0.5 m s^{-1}, even though the agreement between the two models is slightly reduced in the case of unstable conditions.
In the neutral conditions determined by high wind speeds (i.e., simulation at 6 m s^{-1}), the results of the model applications tend to resemble to those obtained in stable conditions at a wind speed of 0.5 m s^{-1} (Figure 4): Calpuff results show small plumes and low odour concentrations, whereas Aermod simulates an odour impact described by prolonged plumes and odour concentrations above 100 ou/m^3, even though such high values are concentrated very close to the source and tend to decrease rapidly with the distance.

4. Conclusions

A comparison between the dispersion of odour modelled by AERMOD and CALPUFF was here presented. In order to obtain general results, an ideal case, considering both a point source and an are source, was run in different meteorological conditions belonging to a standard year.

The results show a good agreement between the two models except for stable atmospheric condition for which the AERMOD plume are longer and more concentrated, thus the only way to discriminate the best available model for odour dispersion would be a validation of simulations with experimental results or feedback from citizens of the considered area.

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