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Case Study: a Comparison of Predicted Odour Exposure Levels in Barcelona using CALPUFF Lite, CALPUFF NoObs and CALPUFF Hybrid Model

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The use of general purpose steady state Gaussian models (e.g. AERMOD) for predicting Odour exposure levels around the vicinity of an industrial site has been considered an accepted practice for many countries around the world for more than a decade now.
This tendency has been reduced lately in Southern Europe due the widely known shortcomings of steady-state plume models to accurately assess dispersion under a range of ‘complex’ conditions (e.g. topography; coastal flows, calm and stable conditions; cold flows; heterogeneous land usage). In such circumstances, there is a real danger that odour impact risk can be either under or overestimated, which has a substantial influence on the development of pragmatic, cost efficient odour mitigation management.
Environmental consultancies in Spain have started using CALPUFF, a US EPA guideline model as an alternative means to provide a more effective way of simulating these complex conditions.
The main difference in the applications of the model among Environmental professionals in Spain seems to be the types of meteorological data inputs to the CALPUFF model. In the experience of the authors three types of met data are commonly used to drive CALPUFF in Spain: single station AERMOD observational met data, CALMET gridded windfields produced with TAPM derived surface and upper air files, and CALMET gridded windfields produced with a combination of observational data and TAPM derived surface and upper air files.
These configurations are commonly named as: CALPUFF ‘Lite’ (AERMOD surface and upper air met data), CALPUFF ‘NoObs’ (3D windfields produced with prognostic met data only), and CALPUFF ‘Hybrid’ (3D windfields produced by CALMET with blended prognostic and observational met data).
This paper evaluates how predictions with each met data type compare for odour assessment purposes for a complex study site, and whether the use of any of the met data sets offers any advantage in gaining a better understanding of odour exposure and impact risk. The modelled odour impact was validated by means of “Odour ambient measurements” using German standard VDI 3940.
According to the German standard VDI 3940 Part 1, a group of trained Olfactory panellists, selected in compliance to Olfactometry standard EN13725, observes the odour impression at a given measurement grid surrounding an emitting site. This statistical approach gives a reasonable impression of the odour impact in the vicinity of an emitting site and can be correlated to the Odour plume extent.
The results of this case study provide a compelling case to use a mix of TAPM met data, and surface observational met data to define odour management requirements and assess regulatory compliance.

1. Introduction

The following case study was conducted at a waste treatment centre managed by the Entitat del Medi Ambient of Barcelona (AMB). The installation commissioned in 2004 is designed to treat 240,000 tonnes of

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municipal solid waste by composting and anaerobic digestion. The installation has extensive containment and is fitted with mechanical extraction. The extraction gases are treated in a large scale odour treatment plant (2 stages Scrubbing followed by biofiltration, and dilution by dispersion enhancement).
As part of its commitment to the community, the facility has carried out numerous Odour studies with different standardized methodologies. One of the most widespread studies was commissioned in 2006 by the AMB to establish the actual exposure to odour in the relevant area surrounding the site. The chosen methodology was direct field measurement with olfactory assessors in compliance with German standard VDI 3940 Part 1.
According to the German standard VDI 3940 Part 1, a group of trained Olfactory panellists, selected in compliance to Olfactometry standard EN13725, observes the odour impression at a given measurement grid surrounding an emitting site. This statistical approach gives a reasonable impression of the odour impact in the vicinity of an emitting site and can be correlated to the Odour plume extent.
The conclusions of the study led to consider CALPUFF as an alternative tool for Odour dispersion purposes at Spain. The findings of the AMB 2006 study are available in the public domain and were used as a basis to evaluate the predictions of CALPUFF Lite, CALPUFF NoObs and CALPUFF Hybrid (Feliubadaló, 2008).

2. Background

CALPUFF is an advanced non-steady-state meteorological and air quality modelling system developed by ASG scientists. It is maintained by the model developers and distributed by TRC. The model has been adopted by the U.S. Environmental Protection Agency (USEPA) in its Guideline on Air Quality Models as the preferred model for assessing long range transport of pollutants and for those complex near-field applications where the steady state assumption does not apply (TRC, 2014)
The model includes algorithms to consider effects in the short range (e.g. terrain) and to evaluate long-range phenomena such as the removal of contaminants caused by deposition, chemical transformation, and visibility effects of particulate matter concentration (SCIRE, 2000).
In September 2008, the U.S. EPA issued a memorandum providing clarification of the regulatory status of the CALPUF modelling system in the near field. This document states that the purpose of choosing a modelling system like CALPUFF is to fully treat the time and space variations of meteorology effects on transport and dispersion (BRODE, 2008).
Unlike steady-state Gaussian models such as AERMOD, CALPUFF allows variable/curve plume trajectories, variable meteorological conditions, accurate treatment of calm hours and low wind speed conditions, while retaining information of previous hours emissions (TRC, 2014). These types of features are particularly useful when assessing complex flow situations frequently present in Southern European countries such as Spain. Some of the near field applications involving complex flow situations include: Complex terrain (terrain channelling, slope flows), Coastal effects, inhomegeinty in surface conditions/dispersion rate, land use variations, Plume fumigation, inversion breakup, Pollutants build up in valleys, stagnation, and recirculation.
The main components of the modelling system are CALMET (a three-dimensional meteorological model), CALPUFF (a non-steady state puff dispersion model) and CALPOST (post processing software data).
In the simplest terms CALMET is a diagnostic meteorological model that develops hourly wind and temperature fields on a three-dimensional gridded modelling domain (SCIRE, 2000).
Associated two dimensional fields such as mixing height, surface characteristics, and dispersion properties are also included in the met files produced by CALMET. CALPUFF is a transport and dispersion model that advects puffs of material emitted from modelled sources simulating dispersion and transformation processes along the way. In doing so, it typically uses the three-dimensional wind fields generated by CALMET with either prognostic meteorological data, or with blended observational and prognostic data. The previous two configurations are known as CALPUFF NoObs and CALPUFF Hybrid respectively. As an option there is also the possibility to use simpler non gridded meteorological data from Gaussian plume dispersion models such as AERMOD. This model configuration is commonly known as CALPUFF Lite (CARPER, 2003).
An important effect of the non-steady-state dispersion is that puffs can change direction with changing winds, allowing a curved trajectory. These mechanisms are the same when conducting CALPUFF Lite, CALPUFF NoObs or CALPUFF Hybrid. For CALPUFF NoObs and CALPUFF Hybrid, the puff responds to space-varying surface characteristics, such as surface roughness and soil moisture, as it moves through the domain. The gridded meteorological and terrain data used in CALPUFF NoObs & Hybrid meteorology are not incorporated when using CALPUFF Lite. Instead, a single value for the land use category, surface

roughness, and leaf area index is specified for the entire modelling domain. Therefore, the ability to vary dispersion spatially according to local surface characteristics is lost (CARPER, 2003).

3. Methodology

A comparative study of 3 models (CALPUFF Lite, CALPUFF NoObs and CALPUFF Hybrid) was performed to predict the extent of odour impact from the waste treatment centre. The most recent versions of AERMET, CALMET and CALPUFF were used.

One of the main differences between the met data used in CALPUFF Lite, CALPUFF NoObs and CALPUFF Hybrid corresponds to the treatment of time and space variations of meteorology effects on transport and dispersion.

The meteorological data of CALPUFF Lite is the one used in AERMOD model. In abstract terms it corresponds to a compilation of hourly surface met data and upper air soundings including temperature, turbulence, and micrometeorological parameters base on very coarse resolution landuse.

Aermod surface and upper air data was produced with AERMET using observational surface met data obtained from an onsite met station. Single point TAPM surface data was used to replace missing observational data. AERMET upper air estimator was used to derive upper air profile.

The 3 dimensional windfields for CALPUFF NoObs and CALPUFF Hybrid were calculated in a nested modelling domain. The outer domain was configured at 100km x 100km with a grid resolution of 1km. The inner domain was set at 10km x 10km with a grid resolution of 100m. 7 vertical levels were set for both domains: 0, 20, 80, 120, 280, and 520, 1480 and 2520 m. Geophysical properties of each modelling domain were extracted from SRTM, 90m terrain data and USGS CLC data.

In very rough terms, CALMET was configured to make a first estimate of the met conditions in the outer domain taking into consideration the meteorological data and geophysical properties of the entire region. This first estimate, also known as Initial Guess Field was then used to determine the wind fields on the inner nest. The inner nest of wind field determines the dispersion in CALPUFF.

The calculation of CALPUFF NoObs windfields was carried out using a single point surface and upper air met data derived using TAPM model at the site coordinates. An adjustment of winds to account for fine scale terrain effects was done at the inner nest with a 100m resolution. A reintroduction of single point TAPM surface and upper air met data was done at the inner nest.

The calculations of CALPUFF Hybrid windfields was calculated using observational surface met data obtained from an onsite met station, and single point TAPM upper air data extracted at the site coordinates. Single point TAPM surface data was used to replace missing observational surface data.

CALMET windfield step 1 calculation was done to determine Initial Guess Field @ 1km scale. Step 2 Diagnostic adjustment of winds to account for fine scale terrain effects as resolved by CALMET grid spacing @100m. A reintroduction of Observations in Step 2 wind calculations.

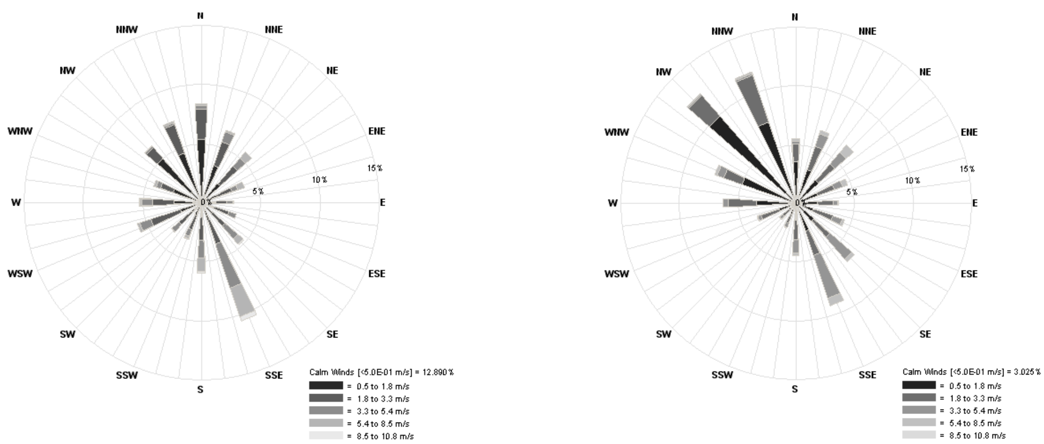

Figure 1: Windrose at 10m height. CALPUFF Lite/ CALPUFF Hybrid (left), CALPUFF NoObs(right).

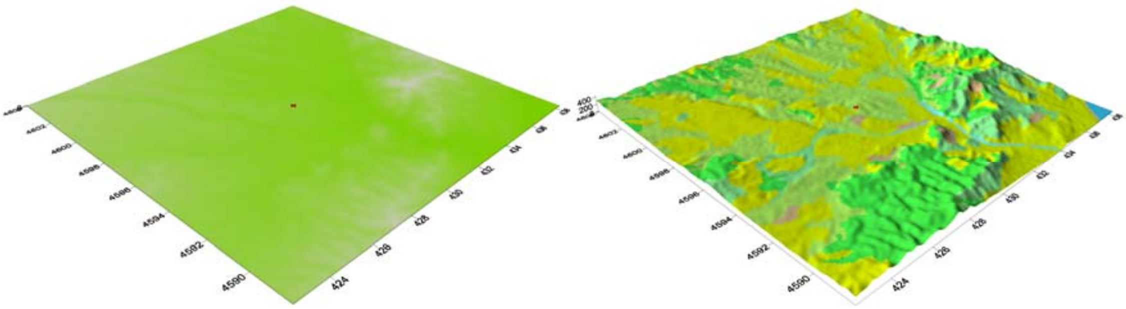

Figure 2: Geophysical properties of the Modelling Domain. CALPUFF Lite (left), CALPUFF NoObs/Hybrid (right).

4. Results

The white contours presented in figure 3 to 5, represent the area where the maximum hourly average ground level concentration will be greater than 3 ou_E/m^3 for more than 2% of the hours in the year. The predicted ground level concentrations are above background concentrations and only relate to odour from the site. The 3 ou_E/m^3 98 percentile contour is the applicable odour impact criteria stated in the draft Odour law for Catalonia, Spain. The shape of the isopleths is determined by the emission rate, height and location of odour source, topography of the locality and the prevalent meteorological conditions.
The results of the field measurement campaign in accordance with standard VDI3940 are presented in the background in Figures 3 to 5. Squares presented in light gray with an Odour frequency greater than 15% are considered to exceed the acceptable odour exposure both for residential and industrial zones in Germany. The black point within the light grey squares corresponds to the site location.

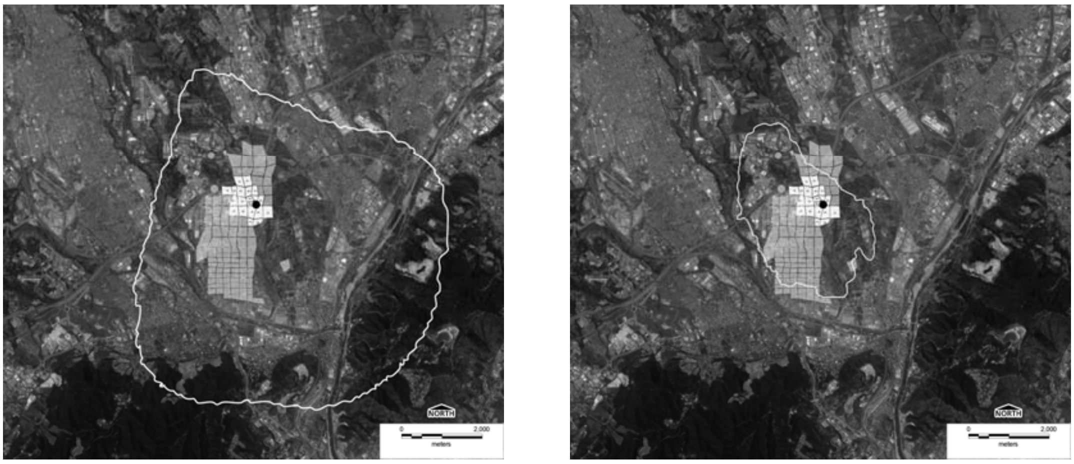

Figure 3: $C_{98,\ 1\text{-}hour}$ = 3 ou_E/m^3 contour. CALPUFF Lite (left), CALPUFF NoObs (right)

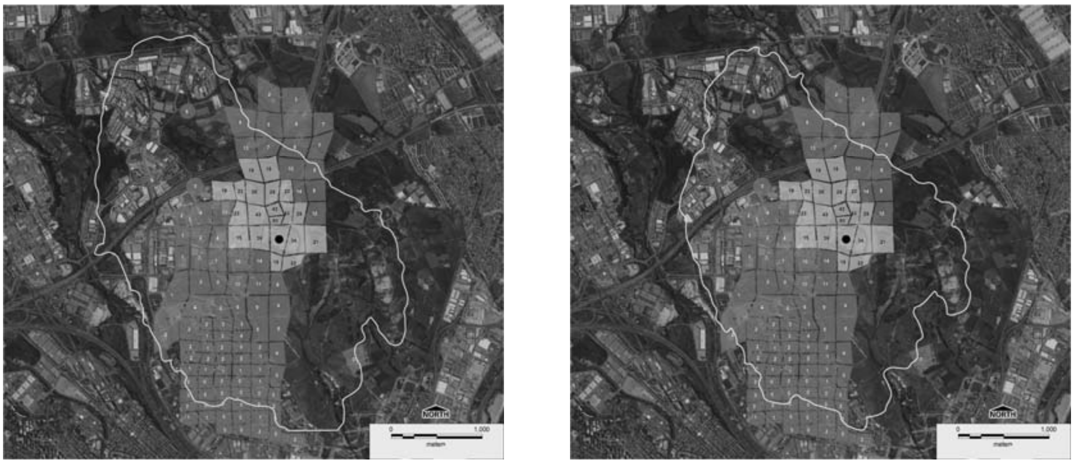

Figure 4: $C_{98,\ 1\text{-}hour}$ = 3 ou_E/m^3 contour. CALPUFF 3D Noobs (left), CALPUFF Hybrid (right)

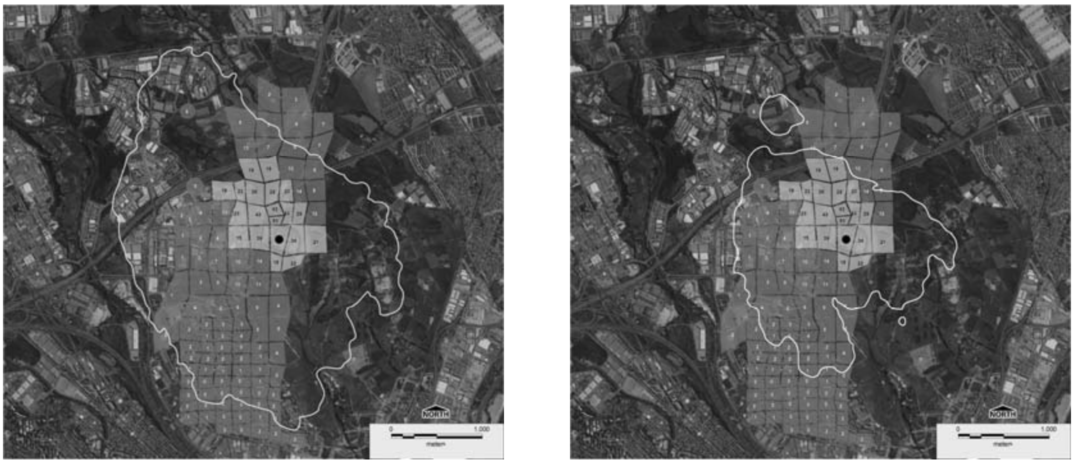

Figure 5: CALPUFF 3D Hybrid. $C_{98,\ 1\text{-}hour}$ = 3 ou_E/m^3 contour (left), $C_{98,\ 1\text{-}hour}$ = 6 ou_E/m^3 98p contour (right)

If we refer to the white contour of C 98-1hour = 3 ou_E/m^3, presented in Figures 3 to 5, which defines the maximum extent at which the CALPUFF model predicts there is reasonable cause of odour annoyance, it's clear that the type of met data input to CALPUFF is very much significant.

This behaviour is expected considering that the Meteorology defines how the plume is transported through the modelling domain and contains parameters used to define the dispersion of the plume. Considering that VDI3940 field measurement results provides a good estimate of the odour exposure level of the population, it´s clear that CALPUFF Lite is significantly overestimating the level of annoyance experienced in the area.

CALPUFF NoObs results are already a better fit to reality, having a significant improvement when compared with CALPUFF Lite.

CALPUFF Hybrid shows the best fit of all models, having up to 12% improvement against CALPUFF NoObs.

Such results suggest that it's recommendable to input to CALMET as many representative observational data as available in the area. Depending on the level of emissions, you may need to consider all representative stations within 5 to 25km from a site.

The $C_{98\text{-}1hour}$ = 3 ou_E/m^3 contour from the CALPUFF Hybrid model appears to represent more restrictive air quality criteria than the German Legislation. The $C_{98\text{-}1hour}$ = 6 ou_E/m^3 contour presented in Figure 5 seems to be a more comparable level of exposure to the German legislation. Plotting higher concentration contours would exclude some of the light grey areas located at the North of the site. The results of the study prompt to undertake a new investigation to identify the factors causing the discrepancy between the German Legislation and draft Odour law for Catalonia.

5. Conclusions

The results of this case study lead to the following conclusions:
The predictions made by CALPUFF Lite significantly overestimate the likely extent of odour impact.
The $C_{98\text{-}1hour}$ = 3 ou_E/m^3 criteria set in the Catalonian draft odour law seem to represent a more restrictive air quality criterion than one set in the German Legislation VDI3940.
For this particular case study, a $C_{98\text{-}1hour}$ = 6 ou_E/m^3 criteria seems to be a more comparable level of exposure to the air quality criterion set in the German Legislation VDI3940.
Considering the field assessment VDI3940, provide a good representation of the odour annoyance levels experienced by the population, its considered that CALPUFF NoObs and CALPUFF Hybrid have conservative but adequate performance for locations with complex flow situations.
Further investigation is required to compare the predicted odour exposure levels of a CALPUFF NoObs run using prognostic model gridded windfields (MM5, WRF, TAPM).
Considering the complexity of operating and maintaining the current Spanish met stations network, is normal and expected that from time to time, the quality and data count could be limited. On this type of situations it´s estimated that a CALPUFF NoObs will provide adequate estimations of the impact extent of a facility.

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