STACK CONFIGURATION AND METEOROLOGICAL INFLUENCES ON THE SIMULATION OF A LARGE POWER PLANT PLUME

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Abstract: The application of CALMET/CALPUFF modelling system is well known, and several validation tests were performed until now. However, most of them were based in specific experiments with a large compilation of surface and aloft meteorological measurements, not always available. In addition, the use of an operational large smokestack as tracer source is not so usual. In this work, CALPUFF model is applied to simulate the local dispersion of SO_2 (as tracer) from the smokestack (356.5 m height) of a large coal-fired power plant in NW of the Iberian Peninsula, considering, both different stack configurations and meteorological inputs: as the stack includes four independent liners in the same structure, both a single point source and four point sources at the same location were tested. In addition, the use of surface and aloft meteorological measurements vs. WRF model outputs as CALMET inputs were compared.
This methodology was applied in three different periods (in 2005 and 2006 years), when SO_2 glc was detected over air quality sites less than 30 km far from this stack; as this source was the most significant SO_2 source in this region, this can be considered as a tracer of its plume. Then, comparison of CALPUFF results against glc measurements show that the best results were obtained by using WRF model output. In addition, better results are obtained considering four different point sources, although differences are not so significant.

Key words: *Plume dispersion, CALPUFF, stack configuration, PBL meteorological modelling, glc model validation.*

INTRODUCTION

It is well known that dispersion of air pollutants calculation from the smokestack of industrial sources is an engineering problem conditioned by both the emissions source and the meteorological conditions. In the first case, the smokestack is often seen as a point source that emits all of gaseous and particulate pollutants. In the second one, an accurate estimation of the meteorological conditions around the source usually requires the application of 3D Eulerian grid models, with high spatial resolution, which are able to provide both spatial and time variations affecting the dispersion of contaminants. Another possibility is the application of a diagnostic model fed by meteorological observations, both surface and aloft data. In addition, for a better estimation of single plume dispersion, Lagrangian models can provide feasible solutions if good meteorological input is provided, with less computational effort than Eulerian air quality grid models.
As a well established Lagrangian modelling system, the application of CALMET/CALPUFF modelling system is well known, and several validation tests were published (Cohen et al., 2005; Dresser et al., 2011; Fishwick et al., 2011; Ghannam et al., 2013; Levy et al., 2003; O'Neill et al., 2001; Protonotariou et al., 2004; Yau et al., 2004). Most of them were based in specific experiments with passive tracers and a large compilation of surface and aloft meteorological measurements during the experiments, in order to achieve the best model performance evaluation. However, with actual pollutants sources and limited meteorological datasets, uncertainties arise (both in measurements and models results) and worse models performance is expected.
In this work, CALPUFF model is applied to simulate the local dispersion of SO_2 (as tracer) from a large smokestack, considering both different stack configurations and meteorological inputs. Because of the limited availability of air quality data around the smokestack, a new approach for the plume model validation is applied.

CASE STUDY: AS PONTES POWER PLANT

As Pontes Power Plant is a 1400 MWe coal-fired power plant located in the northwest of the Iberian Peninsula, southwest of Europe. Until year 2005, this facility burnt a mix of local lignite (2% in S) and foreign subbituminous coal (0.1% in S) (Dios et al., 2013) in four boilers, with a typical 70:30 weight ratio. This ratio could change to an SO_2 emission reduction, if high SO_2 glc levels were expected in the surrounding area (Souto et al., 2009). Nowaday, 100% of subbituminous coal was burnt, so SO_2 emissions are 20 times lower.
This power plant includes a smokestack (356.5-m height), which actually is composed by four independent liners (one per boiler) in the same concrete shaft (Figure 1). Therefore, it should be considered as four different point sources practically located in the same point; alternatively, it could be considered as a single point source, with an emission and stack section as the sum of the four liners.
Because of the large SO_2 emissions from this facility, respect to other local contributions, this pollutant can be considered as a tracer of the power plant emissions in a radio of 30 km. In fact, an air quality network in this area (Figure 2) allowed the control of these power plant emissions, with 17 glc monitoring sites located in the sectors with more SO_2 impacts.

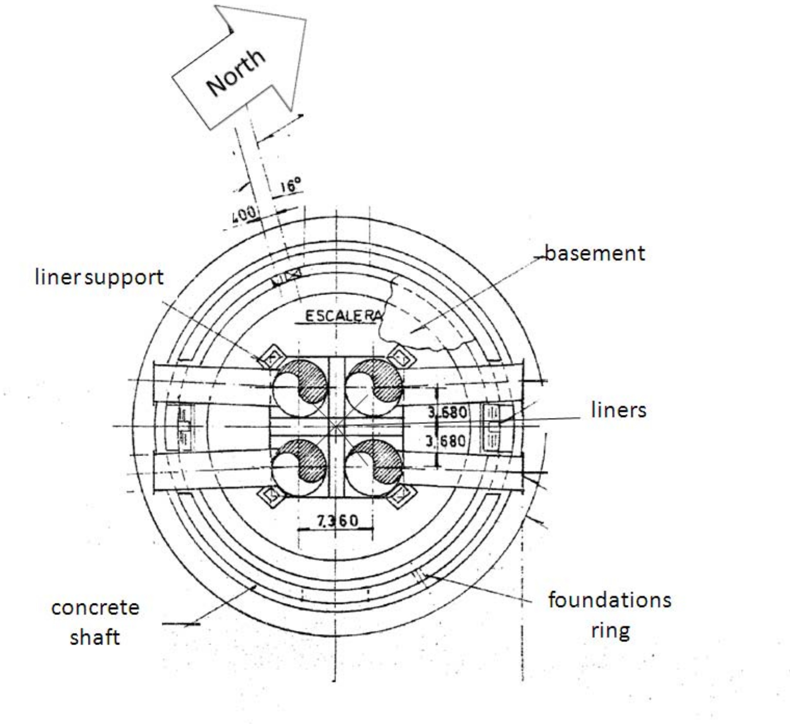


Figure 1. As Pontes Power Plant stack top view, with the four liners inside it. Measurements in mm and degrees (º).

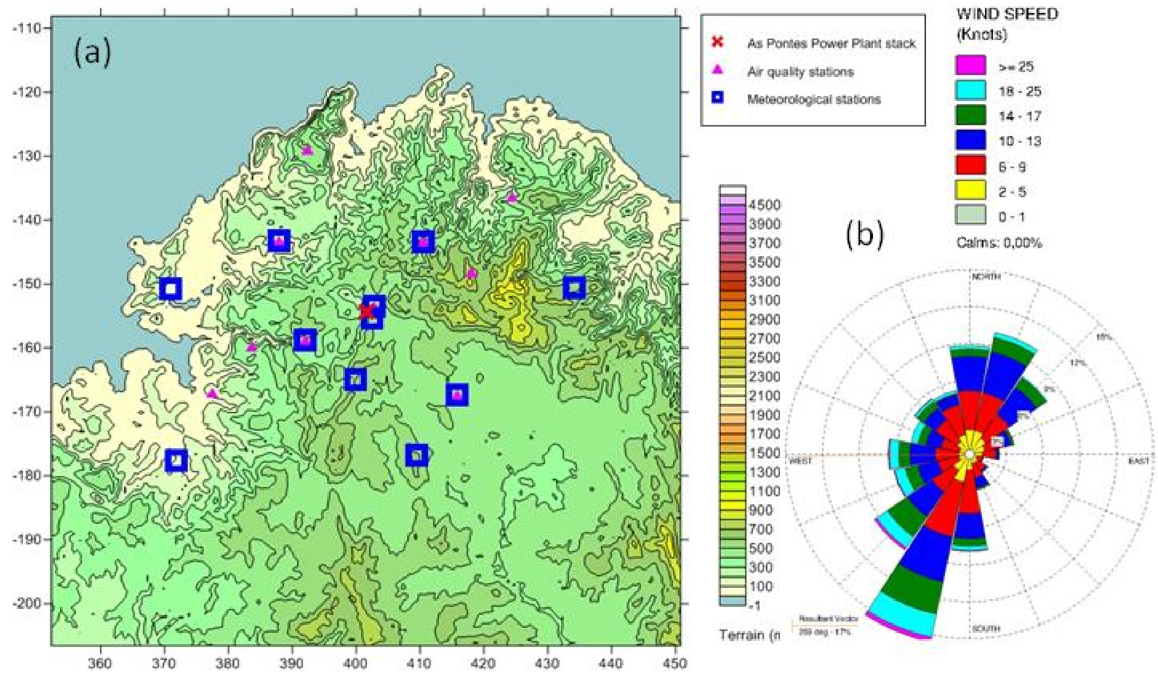


Figure 2. Surrounding area around As Pontes Power Plant stack (X), also showing: (a) meteorological and air quality sites; (b) typical annual wind rose in this region.

The surrounding area of this power plant is a complex terrain and coastal Atlantic region, with changeable weather, a lot of cliffs and different land uses, and a significant sea breeze influence. Therefore, although the annual wind pattern is mainly NE-SW (Figure 2), significant variations are observed both regional and locally along every day. These complex regional conditions and the large power plant stack are a difficult problem in terms of an accurate estimation of its plume dispersion and glc calculation (Davakis et al., 1998).

MODELS AND METHODS

CALPUFF (Scire et al., 2000) is a well known Lagrangian puff model, with releases included in the US EPA regulatory models. The model applies well established modelling solutions for the different atmospheric pollutants processes, plume rise, atmospheric diffusion, first order chemicals kinetics and dry and wet deposition. Different solutions for some of these processes are included in the model, as the user can configure it depending on the specific problem. In addition, meteorological input is provided by CALMET diagnostic meteorological model, using either measurements or other models outputs and, even, a combination of both datasets.

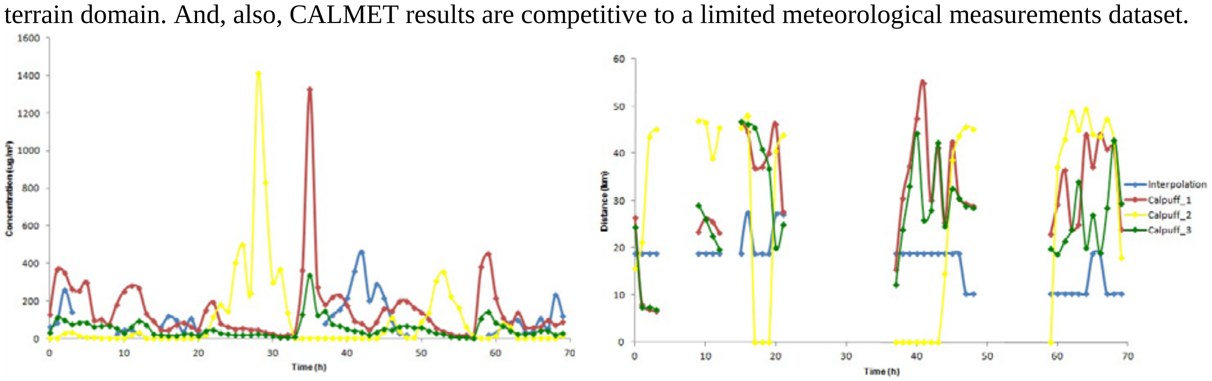
About the CALPUFF configuration, apart from the default options recommended in the regulatory release, in this work attention was put in two specific processes: entrainment and complex terrain influence. Entrainments are quite usual in large stack plumes, especially if both exit temperature and velocity are high, providing a significant plume rise. In addition, if the testing environment is a coastal region with complex terrain, both in topography and land use, it is important to select the most appropriate approach in the model.

METEOROLOGICAL MODELING

An accurate estimation of local plume dispersion depends on the meteorological input provided, particularly, wind and turbulence fields. CALMET diagnostic model can provide high resolution and accurate wind fields if input data enough are available. Although this model was originally designed to use measurements as meteorological input, the lack of them and the improvement of the numerical weather forecast models, both in accuracy and resolution, derived in the adaptation of CALMET to use these models outputs (forecasts and reanalysis).

In this work, both input datasets were tested: (a) WRF model (Skamarock et al., 2008) simulations (3 km^2 grid resolution), with GFS 1º reanalysis as initial and boundary conditions; (b) surface and aloft meteorological measurements; these dataset was provided by eleven surface meteorological sites (Figure 2) and one operational rawinsonde (twice-a-day) located in the area. In both cases, a 0.5 km^2 grid resolution was applied to CALMET model.

Results of both WRF and CALMET models in hourly basis along three different SO_2 glc episodes (July 13th-15th, 2005; June 1st-3rd, 2006 and July 9th-11th, 2006) were compared to measurements (Hernandez et al., 2012), showing that improvements in wind speed and temperature are obtained using CALMET in this complex terrain domain. And, also, CALMET results are competitive to a limited meteorological measurements dataset.



(a) (b)

Legend: Interpolation: From glc measurements; Calpuff_1: WRF data with 4 liners; Calpuff_2: Meteorological measurements with 4 liners; Calpuff_3: WRF data with 1 virtual liner

Figure 3. Hourly maximum SO_2 glc (a) and travel distance to it (b), both calculated (CALPUFF) and interpolated (from measurements) along the testing period June 1^{st}-3^{rd}, 2006.

RESULTS

CALPUFF was tested considering a single point source and CALMET results using WRF model outputs, in order to evaluate its best configuration. In this environment, the best glc results over the available sites were achieved using as CALPUFF options: CALPUFF terrain adjustment scheme and gas phase deposition.

With this CALPUFF configuration, the effect of both different stack configurations and CALMET outputs were evaluated in terms of the glc CALPUFF performance, in hourly basis simulations over the three testing periods. Because of the limited air quality monitoring sites available in the domain, the typical comparison between model results and measurements (site by site) was changed by an integrated plume impact evaluation (De Castro, 2001), based in,

- C_{max}: Maximum SO_2 glc over the whole simulation domain.

- $X_{\max}$: Travel distance of the plume, from the stack to the maximum SO_2 glc.

Estimations of both parameters can be obtained from the CALPUFF model results, over its 0.5 km^2 resolution grid. However, in order to estimate both parameters from the glc measurements, an interpolated glc grid was obtained, hour by hour, using the equation (1) (De Arellano, 1993),

$$c(i,j) = \frac{\sum_{1}^{ns} c_n \times \exp\left[\frac{1}{r_n(i,j)}\right]}{\sum_{1}^{ns} \exp\left[\frac{1}{r_n(i,j)}\right]} \tag{1}$$

where c_n is the measured glc in site n, ns is the number of glc sites, and $r_n(i,j)$ is the distance between the site n and the (i,j) grid point where glc is calculated.

Results of both parameters, C_{max} and X_{max}, along the June 1^{st}-3^{rd}, 2006 period are shown in Figure 3, considering different stack and CALMET configurations. It is apparent that CALMET results using WRF output provide some improvements in glc, taking into account that glc measurements are not always able to catch the maximum plume impact; so glc peaks with CALPUFF are usually higher than interpolated peaks. At the same time, considering a more realistic four stacks configuration, CALPUFF glc time series are higher than using just one virtual liner (chimney), and higher glc is more in agreement to measurements. Results are similar in the other two simulation periods (not shown).

On the other hand, travel distance to the maximum glc is usually overestimated by CALPUFF, in comparison to the interpolated glc. However, this difference is also affected by the limited air quality network area, which covers up to 30 km from the chimney. In fact, Figure 4 shows the maximum hourly glc locations both calculated and interpolated from measurements in the June 1^{st}-3^{rd} 2006 period, using the best configuration: simulation provides a quite good approach to the most frequent locations, detected in the WSW sector around the power plant; but most of the modelled impacts are farer from the interpolated impacts.

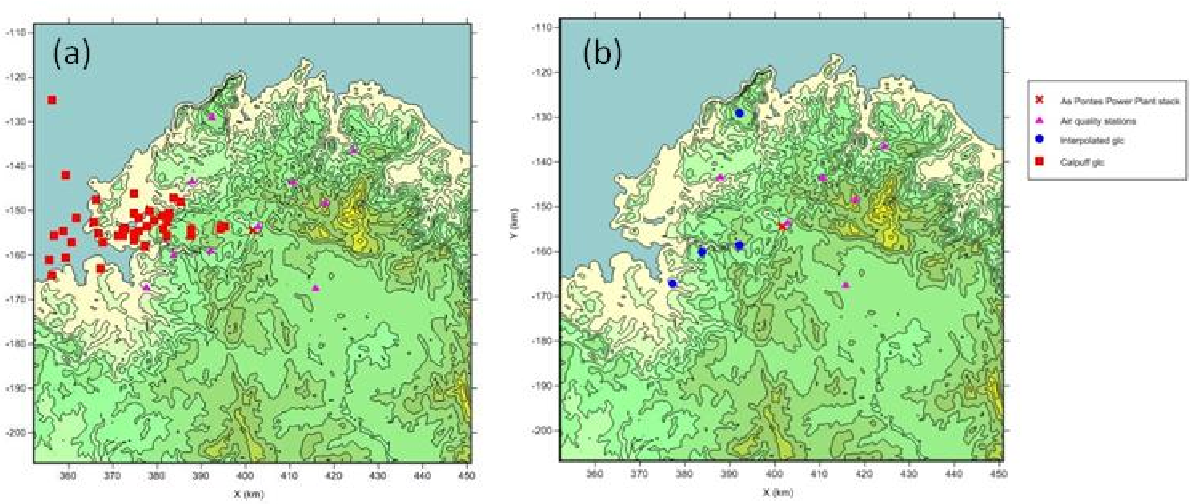


Figure 4. Maximum hourly glc locations along the June 1^{st}-3^{rd} 2013 period: (a) calculated with the best CALMET/CALPUFF configuration, (b) interpolated, from measurements.

CONCLUSIONS

Results of CALPUFF model using different configurations for the simulation of a large smokestack emission show that CALMET meteorological output based in a regional numerical meteorological simulation, using WRF, provides better glc results against a limited meteorological measurements dataset; especially, due to the limited aloft measurements available. In addition, a more realistic smokestack (which is divided in four independent liners) provides higher and more realistic glc than a virtual one liner-chimney. Although some glc simulated peaks cannot be detected, due to the limited air quality network area; this is more apparent comparing the travel distance to the maximum glc, which is usually higher using CALPUFF results that applying glc measurements interpolation.

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