A sensitivity analysis for determining optimum WRF and CALPUFF configuration for operational air quality forecast

Application to a case study in the Port of Huelva (Southern Spain)

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Abstract

Meteorological inputs are of great importance when implementing an air quality modelling system. The aim of this study is to define a standardized methodology to determine the best meteorological configuration to reduce the uncertainty of the model predictions. To do this, a detailed sensitivity analysis to different parameterizations and schemes of the Weather Research and Forecast (WRF-ARW) model has been realized. A sensitive analysis was done in order to evaluate some simulated meteorological variables (temperature, relative humidity, wind velocity and wind direction) and achieve the optimum WRF configuration. Since the better options for WRF simulations were chosen, a new sensitivity analysis was done to determine the optimum CALPUFF-CALMET configuration for air quality forecasting.

Introduction

The goal of this study is to achieve the optimum configuration of meteorological model WRF and dispersion model CALPUFF in order to obtain better results in air quality forecasts. A region in Southern Spain, Huelva, was selected for the development of this work. Industrial and port activities, especially aggregate handling and storage piles, are responsible of major of atmospheric pollution existing in this area. An operating prediction system will be used as early warning system and will allow improving the air pollution and risk management associated to the Port of Huelva. Meteorological forecasting system developed increases the resolution and the accuracy, not only for meteorological results, but also for air quality and risk management in the zone.

Methodology

The Port of Huelva is one of the most important industrial sources in the South of Spain. Moreover, this area coexists with the city of Huelva, greenhouse zones and some nature reserves like Doana Park. Meteorology can greatly affect the atmospheric pollution generated by the Port, because the activities here carried out (loading and unloading operations and material handling) are mainly an important source of particles; meteorological parameters, such as wind speed and wind direction, are highly significant in dispersion of these particles.

Meteorological model

The meteorological model used has been WRF-ARW v3.7 (Skamarock et al., 2008). Accurate results in meteorological modelling will lead better results in air quality modelling. Here is defined the methodology to obtain the optimum WRF configuration, and then it was applied over the Port of Huelva and surroundings. In Figure 1 modeling domains used in simulations are shown.

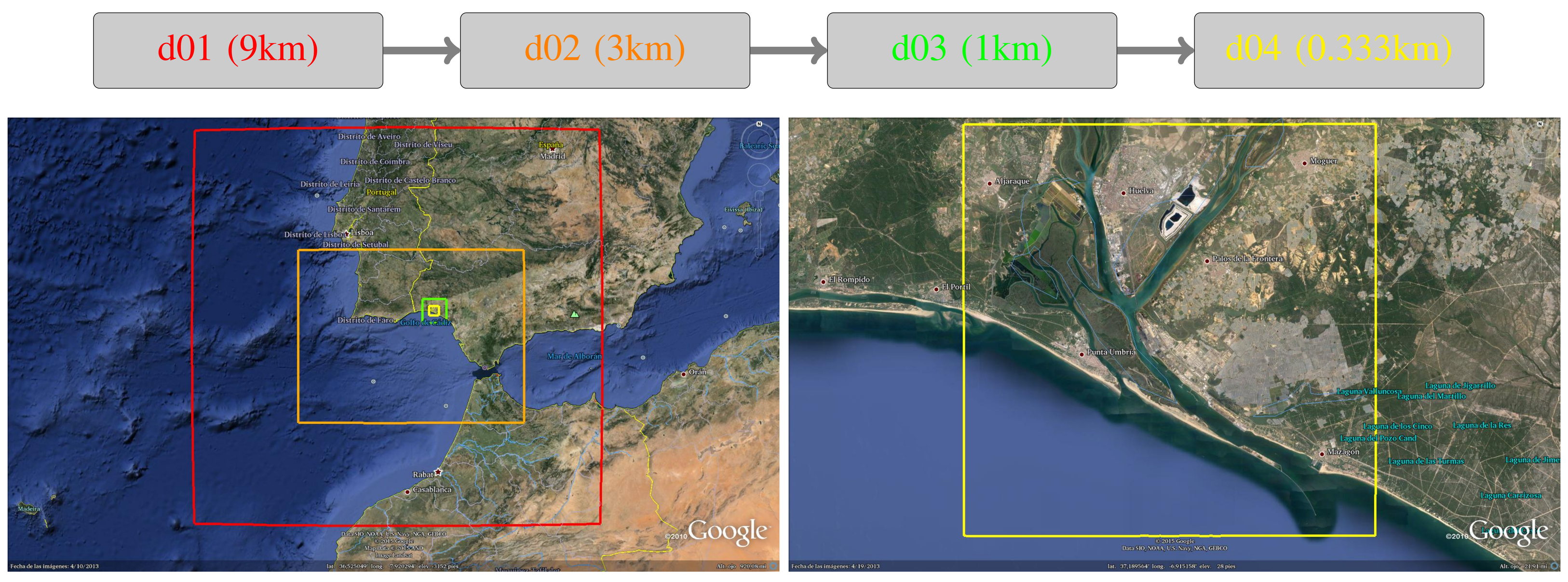

Figure 1: Modeling domains for simulations (Images generated using Google Earth)

In order to know the optimum configuration for modelling, some experiments were done:

- 18 experiments modifying physical options
- 4 experiments modifying dynamical options
- 2 experiments modifying vertical levels
- 2 experiments modifying land use and topography databases
- 5 experiments applying grid and observational nudging

Air quality dispersion model

CALPUFF model (Scire et al., 2000) was considered for air quality and risk management in here since this model is appropriated for areas with complex topography and coastal zones like the Port of Huelva. Domain used in CALPUFF simulation is similar to d04 WRF domain, covering the Port of Huelva and surroundings. Horizontal resolution was set in 100 m. WRF meteorological fields were adapted by CALWRF model, and then processed by CALMET, taking into account topography information and land use cover. 10 experiments were developed for identifying the better CALMET configuration: changes in number of vertical levels and physical options, such kinematic effects, the OBrien vertical velocity adjustment, or the diagnostic wind module. Better configuration for the model was selected according to best statistics (MB, MAGE, RMSE, and IOA).

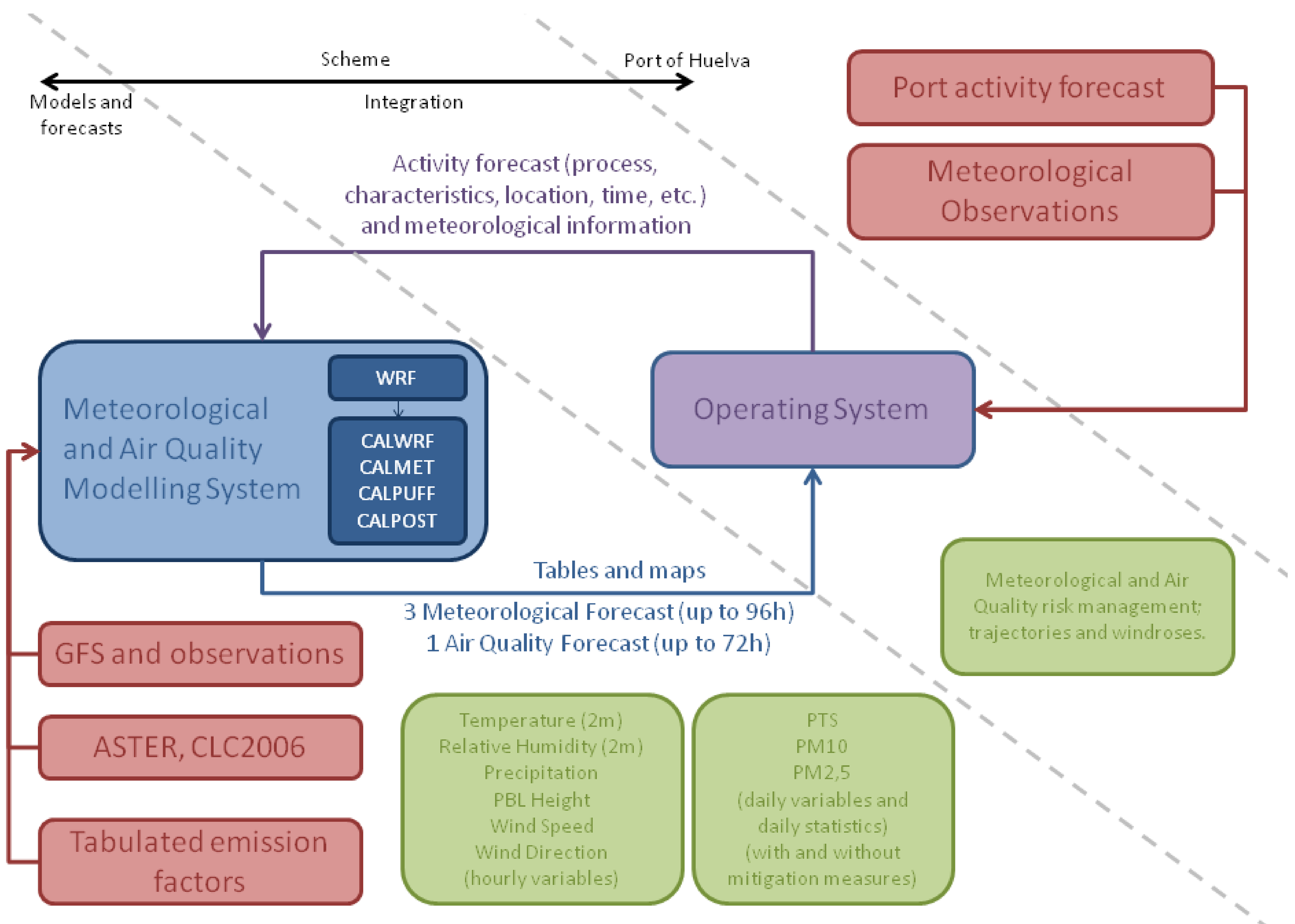

Figure 2: Operating system scheme for the Port of Huelva

Apart from meteorological information, CALPUFF model needs emissions inputs, provided by AEMM (Air Emission Model of Meteosim, Arasa et al., 2013; 2016). Emissions are calculated by the model after taking emission data of the Integration Platform Operations Authority of Port of Huelva. With this information and specific emission factors for different materials, AEMM gives emission predictions for TSP, PM10 and PM2.5. Simultaneously, emissions are also estimated considering some mitigation measures: water sprays, cleaning programs, or aestivation good practices. The last step, post-processing, is done with CALPOST module. Analysis of dispersion results id calculated by CALPOST with the purpose of compare with legislated values. Figure 2 shows the whole scheme for operating system.

Results

A sensitive analysis was done in order to determine the optimum configuration for WRF model. Temperature, wind speed, wind direction and relative humidity in high resolution domains (d03 and d04) were modelled and compared with observed values. Results obtained by each experiment were compared with WRF default configuration. A local meteorological station inside the Port of Huelva (37.20N, 6.93W) was incorporated to compare the performance obtained in these high resolution domains. Table 1 summarize all the selected options for that configuration whose statistical evaluation was the best.

Statistical evaluation is also was done for air quality forecast, taking into account some meteorological parameters, by comparing the modelled parameters to the meteorological station observations of temperature at 2 m, wind speed at 10 m, wind direction at 10 m and relative humidity at 2 m. Options that provided better results, and therefore, were selected, are listed in Table 1. Slight improvement was achieved in wind speed and wind direction when both optimum configurations were selected.

Table 1: Configuration options selected as optimum for meteorological and air quality forecast over Huelva.

Scheme or parametrization	WRF Selected option	CALMET Selected option
Initialization	GFS 0.25°	-
Microphysics	SBU-Lin	-
Longwave radiaion	RRTMG	-
Shortwave radiation	Dudhia	-
Cumulus	Kain-Fritsch	-
Surface Layer	MM5 similarity	-
Planetary Boundary Layer	YSU (d01,d02,d03) / LES (d04)	-
Vertical levels number	36	20
Diffusion 6th order option	Knievel	-
Diffusion 6th order factor	0.36 (d03)	-
Damping	Rayleigh	-
Topography	GTOPO30 (d01,d02) / ASTER (d03,d04)	ASTER
Land Uses	GLC (d01,d02) / CLC2006 (d03,d04)	CLC2006
Nudging	Grid nudging (d01) / Obs. nudging (d02,d03)	-
Kinematics effects	-	Yes (IKINE)
Vertical velocity adjustement	-	Yes (IOBR-O'Brien)
Diagnostic wind module	-	Yes (IWFCOD)

An operating prediction system was developed for the Port of Huelva. Meteorological and air quality forecasting had been integrated in a platform which allows visualize all the predictions, which are actualized 4 times a day. Dispersion of each pollutant is calculated with and without considering mitigation measures in emission estimation. This methodology lets the user to compare the differences between different air quality predictions. Hourly meteorological variables, multiple maps and tables for atmospheric pollution are included in operating prediction system, actualized each six hours. Daily statistics maps for each prediction and pollutant (TSP, PM10 and PM2.5), and time series of selected points of interest near the Port of Huelva are also displayed. As an example, Figure 3 shows some maps for meteorological and air quality predictions, calculated with WRF model and CALPUFF model, respectively.

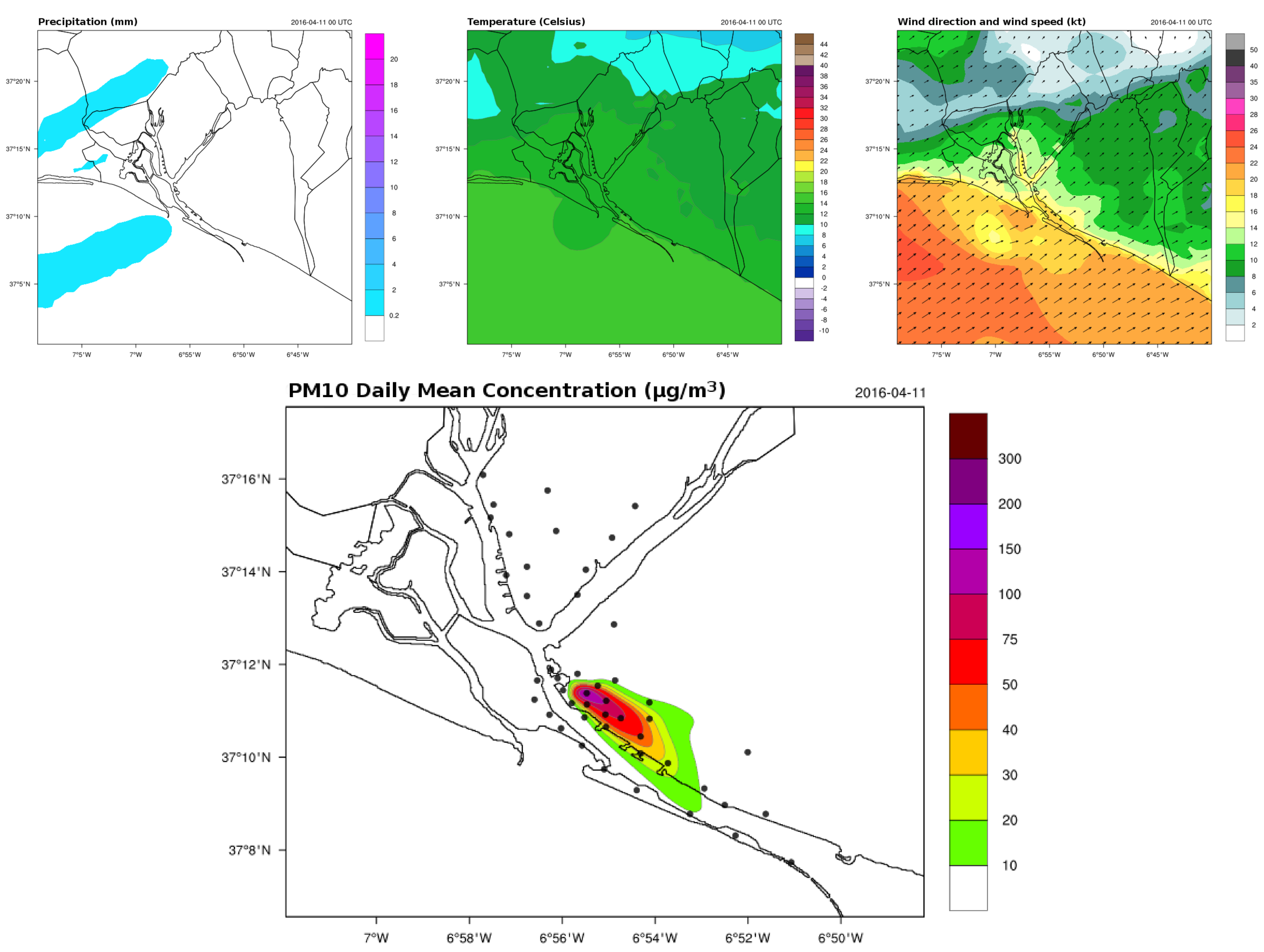

Figure 3: Some examples for meteorological forecasting (top) and air quality forecasting (bottom)

Conclusions

- An air quality modelling system has been developed in the Port of Huelva area.
- Some experiments modifying physical and dynamical configurations, vertical levels, topography or land use databases, were done in order to determine the best configuration for WRF and CALPUFF. A sensitivity analysis for each configuration was carried out for this purpose.
- This meteorological and air quality prediction system could be developed in any region of interest.

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