HARMO22
22nd International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
10-14 June 2024, Pärnu, Estonia

MESOSCALE SIMULATIONS OF FUGITIVE PM10 EMISSION FROM HARBOUR ACTIVITIES IN COMPLEX TERRAIN

Andrés Simón-Moral[1,2], Ales Padró[2], María Aróstegui[1], Sergio Gil-López[1], Andoni Aranguren-Ubierna[1], Adrián Zafra-Pérez[1]

[1]TECNALIA, Basque Research and Technology Alliance (BRTA), Derio, Spain
[2]Cantabria Physics Institute, Santander, Spain

Abstract: A modelling system consisting of the Weather Research and Forecasting model to simulate the meteorology and CALPUFF for pollutants dispersion is used in this study to simulate the impact of fugitive PM10 emissions related to harbour activities in nearby populated areas. Results for wind speed and direction show that the model performs well in the area, although some differences exist. PM10 concentrations show high differences respect to observations. Binarizing the PM10 signal points to the high uncertainty in emission factors as the main source of error.

Key words: *Mesoscale modelling, fugitive emissions, dispersion modelling, harbour activities, PM10.*

INTRODUCTION

Ports act as economic engines in regional dynamics, driving the growth and development of European cities. Those located near urban areas with high population density often find themselves balancing the development and management of port activities with the preservation of natural habitats and the quality of urban life. This is primarily because their activities lead to significant impacts in terms of emissions, noise, water pollution, soil degradation, and habitat fragmentation (Ducruet et al. 2024, Schenone et al. 2016, Trozzi and Vaccaro 2000). This situation underscores the need for port authorities to promote a commitment to sustainable development and continuous improvement of their environmental behaviour. This commitment will enable the sustainable growth and operation of the port, without losing sight of the various challenges that port authorities face, such as financial and regulatory challenges.

The European Commission, in its various Communications (COM/2007/0616 and COM/2013/295), and the European Sea Ports Organization (ESPO) urge Port Authorities to establish an effective relationship between environmental management and port management. The latest ESPO Environmental Report (ESPO, 2023) highlights the environmental priorities of European ports, identifying air quality as the second priority action. In this context, the handling of solid bulk materials is one of the main sources of emissions to the air, specifically, the emission of fugitive or diffuse particles. The issue related to the control of emissions and impacts associated with diffuse emissions can be reflected in the effect on the nearby population and businesses, leading to complaints and lawsuits.

Historically, air quality assessment has been based on the analysis of data from fixed stations. However, over the last few decades, the use of numerical models to control atmospheric pollution has become a common practice as they offer several advantages. They also have a lot of uncertainty in their calculations. Especially the uncertainties associated with the use of emission factors from different sources, which are based on formulas that depend on certain parameters of each material. This is the case of diffusive emissions, where high uncertainties exist. In the scenario presented here, the modelling of fugitive emissions is compared with low-cost sensors observation, with special focus on the source of error analysis.

METODOLOGY

Study area

This study is carried out in the Port of Bilbao, located in the northern coast of the Iberian Peninsula (43°20'53"N, 3°3'40" W, Figure 1). The flow in the area is characterized by land-sea breezes, channelled through the valley where the port is located. The area is also characterized by relatively dense urban areas, belonging to the so-called Great Bilbao conurbation. The presence of small cities in the surroundings would potentially interact with the land – sea breeze system (Freitas et al. 2007).

Modelling system

A modelling system consisting of the Weather Research and Forecasting (WRF, Skamarock et al. 2019) to compute the meteorology and CALPUFF (California Puff model, developed by Sigma Research Corporation) for the dispersion of pollutants is used in this study.

WRF is applied in this study, using 5 nested domains to increase the resolution from 27 km to 0.250 km, with the inner domain covering the port and its surroundings. The 5 domains, with a grid resolution (number of points in east-west and south-north directions) of 27 km (101 x 101), 9 km (103 x 103), 3 km (103 x 103), 1 km (101 x 101) and 0.25 km (101 x 101) are shown in Figure 1. Although an even number is not recommended for the grid resolution ratio, tests have been done with 0.333 km and 0.25 km for the inner domain (not shown), with only slight differences.

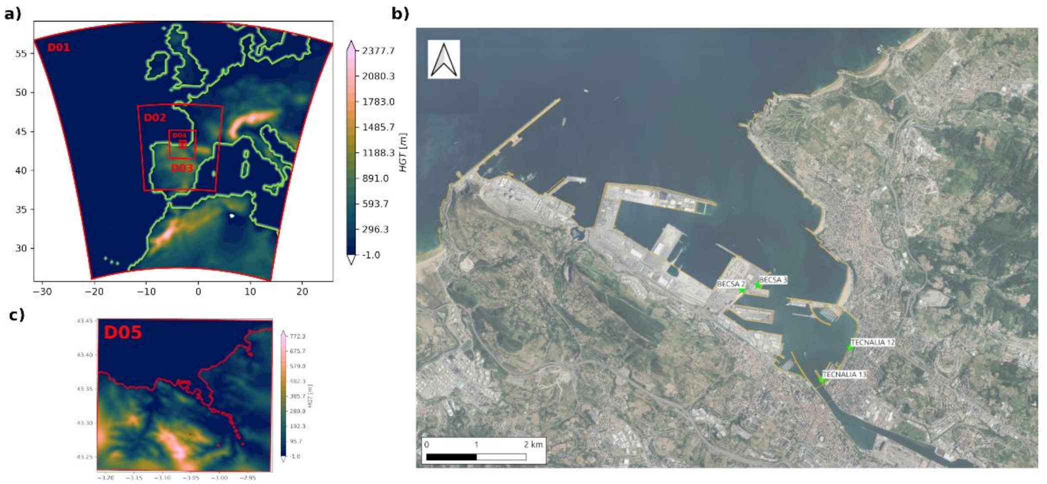

Figure 2: a) Domains used for WRF simulations, b) area where the Port of Bilbao is located and c) highest resolution WRF domain (D05).

A total of 56 vertical levels, ranging between the surface and 50 hPa are used, with the first layer located at 5 m height and 17 levels below the first 1,000 km. This allows for high resolution close to the ground, where the emissions occur, to properly capture the wind.

BEP-BEM urban canopy parameterization is used (Martilli et al 2002, Salamanca et al 2010), to account for the nearby urban areas impact on the flow, which were considered following the Local Climate Zones classification (Stewart and Oke, 2012). The rest of physical parameterizations considered in this study are the same as in Simón-Moral et al. 2022)

WRF outputs are used to provide 3-dimensional information to drive CALMET, the meteorological preprocessor of CALPUFF. 8 Vertical profiles of the required variables are built from the meteorological simulations, whose locations are selected to represent different orography characteristics found in the study area. From these profiles, a 3-dimensional grid is computed to force the dispersion model.

PM10 emissions

PM10 emissions are calculated from the Emission Factors produced in the HADA LIFE project (LIFE02 ENV/E/000274). In the project, emissions for three different activities performed in ports are calculated: ship load (1.75 g s^{-1}) and discharge (2.3 g s^{-1}) and truck load (1.6 g s^{-1}). In this study, information of the operations performed in the port provided by the port authority are used to define hourly emissions in each dock.

A high uncertainty exists in the emission factors: First, the ones used in this study are calculated for alfalfa, without considering the specific material manipulated. Second, the impact of wind speed on the emissions is not consider here and, third, fugitive emissions related to port activities are highly dependent on the worker performance. For example, the emissions from releasing a bulk of material from a shovel will depend on the height from which the release is performed.

Observational data

Observational data from previously calibrated low-cost sensors (Kunak Air Pro) are used for wind and PM10 concentration validation purposes. Two sensors located in the emission area and two near urban areas are selected for a qualitative comparison with simulations results (Figure 1). For the calibration process, the sensors have been located next to a reference particulate matter measurement device (Fidas Palas 200E) for 3 months. A study was performed to identify the best regression model for this scenario and data. Consequently, the Random Forest method was chosen and applied to calibrate the low sensors' observations, which were particularly sensitive to temperature and humidity changes.

In addition, results from the Copernicus Atmosphere Monitoring System (CAMS, Peuch et al. 2022) are used as background concentration, to isolate the pollution not related to port activities.

Event selection

Based on the PM10 measurements, one event is selected to verify the modelling system. For the selection process, days with potentially emitting operations, wind direction favourable to an impact in the urban areas, and PM10 increase registered within the activity time window are chosen. Following this procedure, the 12[nd] of July 2023 is extracted for the methodology verification (Figure 2).

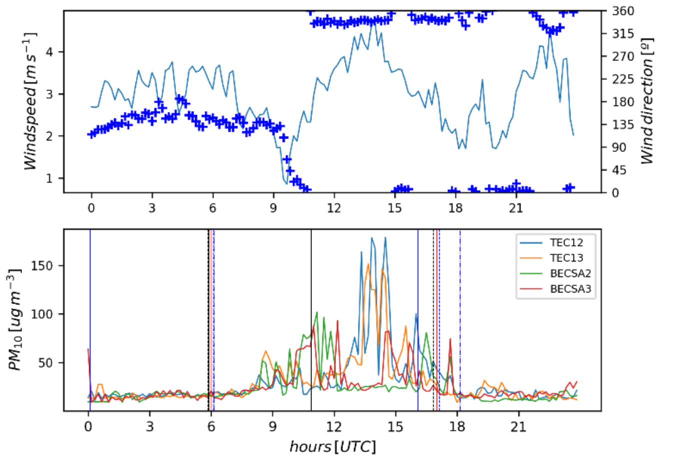

Figure 2: Wind speed (blue line) and direction (blue crosses) recorded in (top panel) and PM10 concentrations [µg m^{-3}] inTECNALIA-12 (blue), TECNALIA-13 (orange), BECSA -2 (green) and BECSA – 3 (red). Vertical lines represent the starting and ending times of port activities.

Table 1: Activities performed in the Bilbao Port

<table>
<tr><th>Day</th><th>PRINCESA</th><th>ADOSADO</th><th>NEMAR1</th></tr>
<tr><td rowspan="3">12/07/2023</td><td>Palm kernel discharge
00:00 – 01:00
06:00 – 11:00
12:00 – 16:00</td><td rowspan="3">Iron alloys discharge
06:00 – 10:00
12:00 – 17:00</td><td>Coal discharge
06:00 – 11:00</td></tr>
<tr><td>Truck load of other minerals
06:00 – 09:00
12:00 – 17:00</td><td rowspan="2">Truck load of coal
06:00 – 17:00</td></tr>
<tr><td>Cereals discharge
06:00 – 10:00
12:00 – 18:00</td></tr>
</table>

RESULTS

A qualitative comparison between PM10 concentration and wind speed and direction is shown next. The sensors located close to the emission docks (e.g. BECSA-2 and BECSA-3) are shown in Figure 3. While the model produces low wind during the morning, underestimating the observed value, it simulates higher values in the afternoon. The results are better in BECSA -2, where they are close to observations. Respect to wind direction, it is southeast until 10:00, when it rotates to northeast. The model mostly captures the direction, although a ~60º bias is produced during the afternoon.

In both cases, CALPUFF highly overestimate PM10 concentrations during the morning and underestimate them afterwards. One possible reason of the overestimation is the potential impact of low wind. In such conditions, the uncertainty in the emissions, or the uncertainty related to the simulation resolution would have high impact on the pollutant dispersion, hence producing a high overestimation.

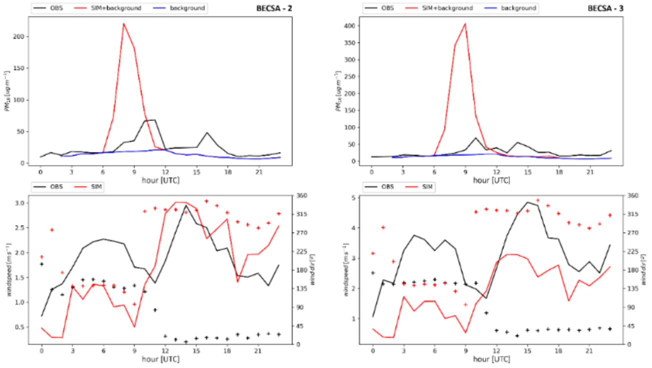

Figure 3: Observed (black line), background (blue line) and background + simulated (red line) PM10 concentration in BECSA -2 (top left) and BECSA -3 (top right), and observed (black) and simulated (red) wind speed (continuous line) and direction (crosses) in BECSA -2 (bottom left) and BECSA -3 (bottom right) during the 12nd of July 2023.

Figure 4 shows the wind speed and direction, and the PM10 concentration in TECNALIA 12 and 13. While in TECNALIA – 13 the model captures accurately the wind speed and direction, in TECNALIA – 12 the performance is not so good. This is probably related to the influence of local obstacles, not considered by WRF.

PM10 concentrations look different to what observed in the sensors located near the source. In this case, the model underestimates the contribution of port activities in both sensors. Considering the ability of WRF to reproduce wind speed and direction in TECNALIA – 13, the source of the underestimation points to the emissions considered, those being highly uncertain.

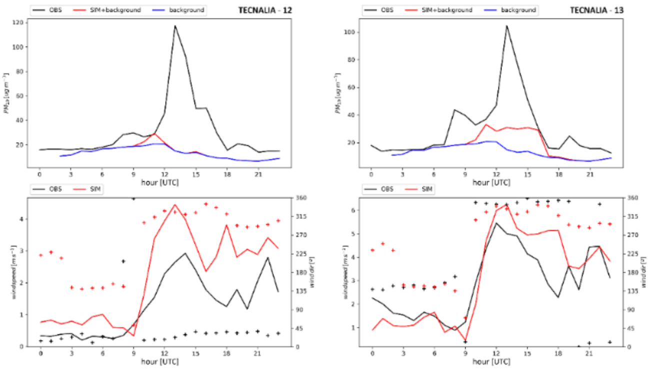

Figure 4: Same as Figure 3 for TECNALIA – 12 (left panel) and TECNALIA -13 (right panel).

‘Binarizing’ PM10 concentrations (PM10 = 1 (yes) if modelled value is higher than zero and PM10 = 0 (no) if not) shows that the model captured the event in terms of start and ending times (Figure 5). Considering that the existence of an event is highly dependent on the wind speed and direction, this again suggest the emissions as main source of error.

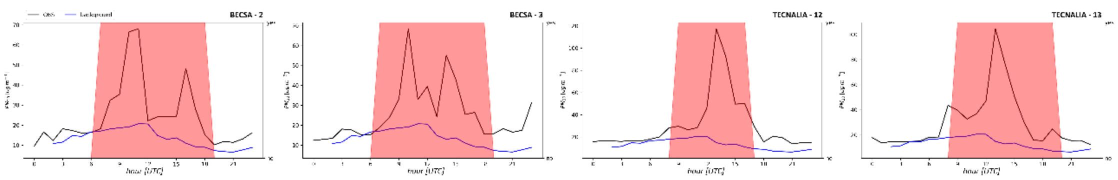

Figure 5: Observed and background PM10 concentration in BECSA -2, BECSA – 3, TECNALIA – 13 and TECNALIA – 14. Red areas correspond to the ‘binarized’ PM10 signal

CONCLUSIONS

An event where the diffusive emissions due to the port activity impact populated areas is simulated by a combination of WRF and CALPUFF models. The meteorological model shows the ability to reproduce wind field in four locations, two next to the sources and two next to the areas where people live. The pollutant dispersion model highly overestimates the impact next to the source and underestimates what observed next to the population.

'Binarized' PM10 results, shows that the event is properly captured in terms of start and ending times, hence pointing to the emissions as the source of errors.

While this is a good results in terms of meteorological modelling in complex terrain, shows important bias in the emissions. In this context, more research is to be done, to better reproduce the impact of port activities. One of the possible lines of research is the application of bias correction techniques to make the binarize signal fits the observations. 'Binarizing' the signal represents a good technique for impact analysis, isolating the effect of emission factors on the results.

REFERENCES

Ducruet, C., Polo Martin, B., Sene, M.A., Lo Prete, M., Sun, L., Itoh, H., Pign´e, Y., 2024. Ports and their influence on local air pollution and public health: a global analysis. Sci. Total Environ. 915 https://doi.org/10.1016/j.scitotenv.2024.170099.

Freitas, E.D., Rozoff, C.M., Cotton, W.R. Silva Dias, P.L. (2007). Interactions of an urban heat island and sea-breeze circulations during winter over the metropolitan area of São Paulo, Brazil. *Boundary-Layer Meteorol* **122**, 43–65 https://doi.org/10.1007/s10546-006-9091-3

Martilli, A., Clappier, A., Rotach, M.W., 2002. An urban surface exchange parameterization for mesoscale models. *Bound.-Layer Meteorol*. 104 (2), 261–304

Peuch, V.-H., Engelen, R., Rixen, M., Dee, D., Flemming, J., Suttie, M., Ades, M., Agusti-Panareda, A., Ananasso, C.,…(2022) The Copernicus Atmosphere Monitoring Service: From Research to Operations, B. Am. Meteorol. Soc., 103, E2650–E2668, https://doi.org/10.1175/BAMS-D-21-0314.1, 2022. a, b

Puig, M., Wooldridge, C., Darbra, R.M. 2023 ESPO Environmental Report 2023. ESPO Secretariat, October 2023. (https://www.espo.be/media/ESPO%20Environmental%20Report%202023.pdf)

Salamanca, F., Krpo, A., Martilli, A., Clappier, A., 2010. A new building energy model coupled with an urban canopy parameterization for urban climate simulations—part I. Formulation, verification, and sensitivity analysis of the model. *Theor. Appl. Climatol*. 99 (3), 331–344

Schenone, Corrado, Pittaluga, Ilaria, Borelli, Davide, Kamali, Walid and El Moghrabi, Yara. "The impact of environmental noise generated from ports: outcome of MESP project" *Noise Mapping*, vol. 3, no. 1, 2016. https://doi.org/10.1515/noise-2016-0002

Simón-Moral, A., Martilli, A., Padró, A., Yurrebaso, L., (2022). Assessment Of The Dispersive Capacity of Neighbbourhoods Based On Local Climate Zones Classification. 21st International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes 27-30 September 2022, Aveiro, Portugal

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, Z. Liu, J. Berner, W. Wang, J. G. Powers, M. G. Duda, D. M. Barker, and X.-Y. Huang, 2019: A Description of the Advanced Research WRF Version 4. *NCAR Tech. Note NCAR/TN-556+STR*, 145 pp. doi:10.5065/1dfh-6p97

Stewart, I. D., and Oke, T. R. (2012). Local Climate Zones for Urban Temperature Studies. *Bulletin of the American Meteorological Society* 93, 12, 1879-1900, https://doi.org/10.1175/BAMS-D-11-00019.1>

Trozzi, C., and Vaccaro, R. (2000). "Environmental impact of port activities," in Maritime engineering and ports II. Eds. C. A. Brebbia and J. Olivella (Southampton: WIT Press), 151–161.