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Evaluation of modelling and remote sensing tools for improving air quality in surroundings of open-pit mines

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INTRODUCTION & AIM

The nature of the activities carried out in an open-pit mine requires appropriate and efficient management of the dispersion of pollutants generated and of the local air quality levels. Blasting, excavation and transportation of minerals are one of the main mining activities that can generate the release of particles into the atmosphere. These particles may contain heavy metals and other chemical species that can affect the respiratory health of people living near mines.

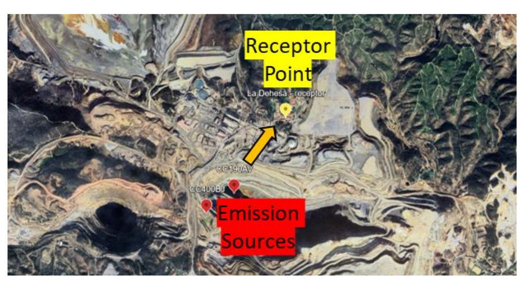
In this research innovative techniques related to air quality modelling and remote sensing have been evaluated. These three techniques aim to respond not-solved questions and sources of uncertainty identified based on the authors' experience. Firstly, we have evaluated how to calculate emissions factors of blasting activity for copper mines because there do not exist recommended values for this kind of mines in the most-used databases like AP-42 from the US Environmental Protection Agency and EMEP/EEA from the European Environment Agency. Secondly, a nowcasting tool has been created considering the direct relationship between the concentration of particulate matter and meteorological conditions like planetary boundary layer height. And finally, we have tested how to generate a heat map of the particulate matter levels over the mine and nearby populations using non-traditional data (monitoring points).

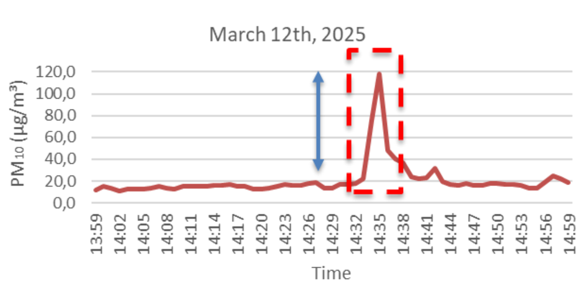
To achieve to respond these questions we have tested innovative techniques: (a) a semi empirical approach based on real data and Gaussian dispersion modeling has been used to estimate properly the emission factors of particulate matter to the atmosphere related to the blasting activity; (b) a data-science model has been prepared to generate a nowcasting of the levels of particulate matter considering, mainly, the evolution of the meteorological conditions and a high-amount of historical data; and (c) an air quality monitoring service that derives particulate matter properties from space by transforming public satellite data and other public sources has been tested. These techniques have been evaluated over one of the most relevant open-pit mines in southern Europe, the Riotinto mine, Huelva (Spain).

METHOD

Blasting Contribution

- Based on Roy et al. (2010), https://doi:10.4236/jep.2010.14041
- Using the Inverse Modelling Technique, considering the Gaussian Fit, and high-frequency data (every 10-minutes).
- Considering a blasting episode on March 12th, 2025, that meets the following criteria: A clear contribution of blasting emission over near monitoring stations (blasting emission impact directly to the receptors due to wind direction); no precipitation (dry conditions); no changes in emissions in other sources.





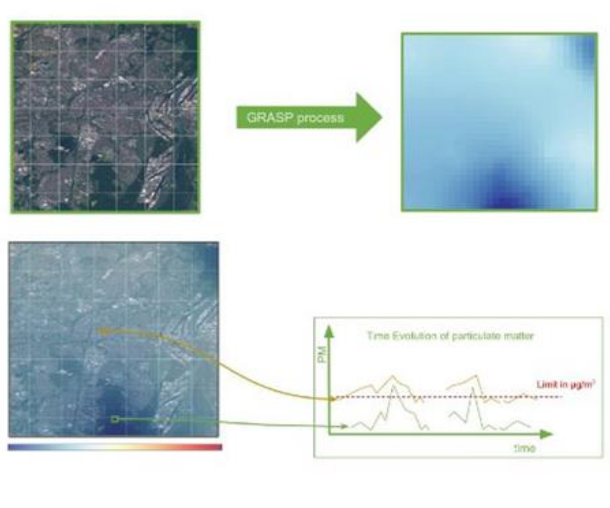
Nowcasting

- A deep learning model as Temporal Fusion Transformer has been selected.
- Variables considered:
  - Known variables: numerical model forecast parameters from WRF (planetary boundary layer height, temperature and humidity) as well as time-based features.
  - Unknown variables: particulate matter hourly data, observed meteorological data (wind, relative humidity, temperature and precipitation).
- Frequency of data: hourly.
- Training data period: 07/2021 – 12/2023.
- Performance analysis: one week of every five weeks.
- Forecast horizon: 3 hours.
- Forecast only in locations where a monitoring point exists (Nerva municipality around 1km from the mine).

Heat Map / Hindcast

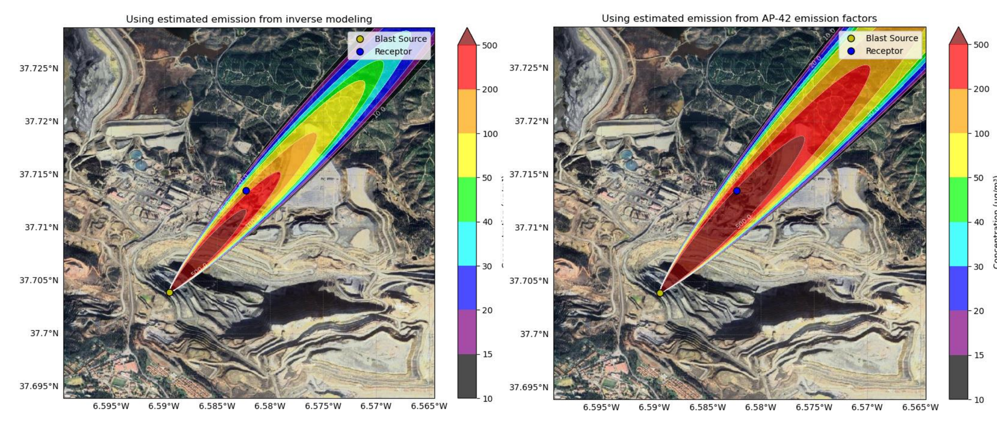
- Based on satellite public data.
- To create an air quality monitoring service that utilizes public data based on GRASP algorithm https://www.grasp-open.com/

	POLDER/PARASOL	SENTINEL-2	SENTINEL-3	SENTINEL-5p
Launching Date	2004	2015	2016	2017
End Date	2013	--	--	--
Ground Resolution	6km	10m	300m	7 km x 3.5km
Revisit time	2 days	5 days	2-3 days	1 day
Passing time	13:30 Local time	10:30 Local time	10 Local time	13:30 Local time



RESULTS & DISCUSSION

Comparative of PM_{10} emission	
Estimated using inverse modelling	Using standard emission factor (US EPA AP-42)
1.40 kg	6.63 kg

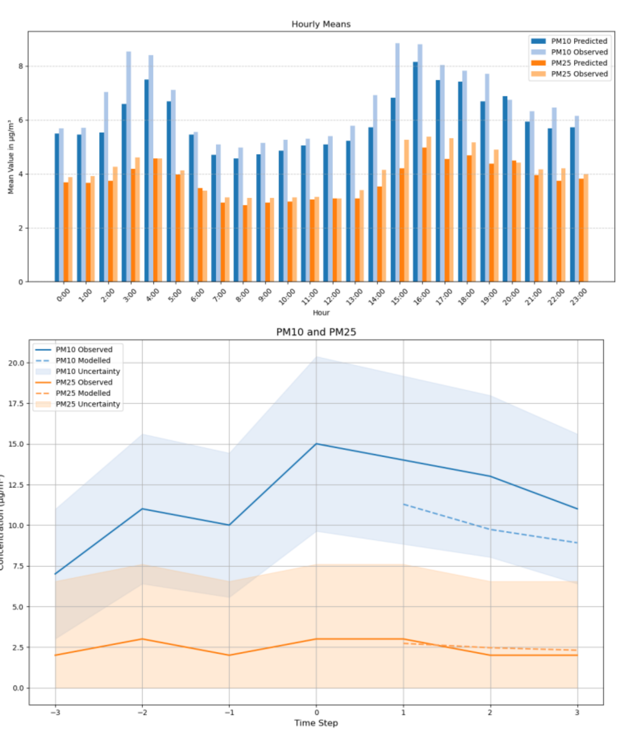


Blasting Contribution

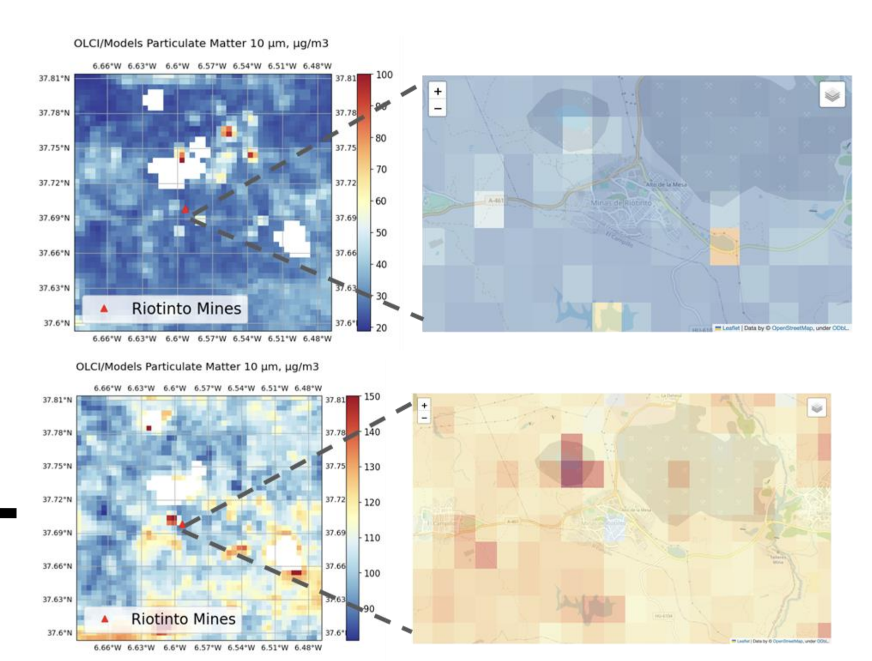
For the episode selected and analyzed, the developed method reduces emissions by a factor of 4.7 compared to those we would obtain if we used a standard emission factor such as US EPA AP-42, thereby considerably reducing the estimated contribution of blasting to PM_{10} levels. This reduces the overestimation that was considered when using standardized emission factors.

Nowcasting

The nowcasting methodology developed offers good results when comparing observation and modeling results for both PM10 and PM2.5, as well as their corresponding daily profiles. It is also observed that the Model Quality Objective defined by FAIRMODE (https://fairmode.jrc.ec.europa.eu/document/fairmode/WG1/Guidance_MQO_Bench_vs3.3_20220519.pdf) is met in both cases, being 0.84 and 0.89 for PM_{10} and $PM_{2.5}$, respectively. The fit is observed to be better for $PM_{2.5}$ than for PM_{10}, presumably due to more emission sources contribution and higher uncertainty of measurements. Also, we have identified difficulties to represent exceedances of the legislated limit values



Heat Map / Hindcast



The image shows PM_{10} levels estimated from satellite data using SENTINEL-3/OLCI observations on July 06th (above) and July 20th (below), 2019. OLCI provides data at a 300-meter resolution with a revisit time of 2–3 days. The GRASP/OLCI retrieval used to estimate PM_{10} incorporates certain a-priori constraints based on information from VIIRS and POLDER. Satellite-derived PM_{10} measurements allow us to observe the impact of mining activities. This type of tool can help to identify hotspots and generate hindcast maps. However, the current revisit frequency limits the temporal resolution, making it difficult to compare directly with regulatory levels.

CONCLUSION

(1) The blasting emission factor analysis allows us to diagnose the effects of blasting activity on particulate matter levels more precisely than standard emission factors;
(2) Nowcasting technique enables us to determine, with a high-degree of accuracy, the evolution of this pollutant over the next few hours;
(3) Satellite data allow us to determine the past levels of particulate matter at any point in the mine by generating heat maps, identifying previously unknown hot spots and helping to better understand mining activities in relation to their surrounding context, enabling the distinction between local sources and potential external contributions.

FUTURE WORK

- To use CFD techniques to improve blasting modelling.
- To extend the inverse modelling estimation considering the type of material (mineral or sterile), $PM_{2.5}$ and heavy metals and considering a long-period analysis.
- To use a more representative period to validate nowcasting results and focusing on exceedances forecasts.
- To increase satellite data information with higher resolution enhancing the capacity to monitor pollutant distribution at finer spatial scales, and considering satellite data with lower revisiting time. Future instruments, such as the multiangular, multi polarimeter 3MI, will be very helpful in addressing this limitation.