AQ-Watch's Air Quality Source Attribution and Mitigation Service

R. M. A. Timmermans, G. Pfister, M. Guevara, N. Huneeus, R. Kranenburg, R. Janssen, J. Ge, R. Kumar, Y. Boose, G. Adler, M. Dan, G. Brasseur, C. W. Y. Li, C. Granier, T. Liu, and M. Schaap

Abstract Outdoor air pollution was estimated by the World Health Organization to be responsible for 4.2 million premature deaths in 2019. Improving the air quality will bring major health benefits. However, air pollution can only be tackled cost-effectively if authorities have accurate information on its origin and on the potential impact of envisaged emission mitigation policies. Within the European Union Horizon 2020 AQ-WATCH project, a user driven operational source apportionment and mitigation service has been developed. It provides information on the main sources (both sectors and source regions) contributing to concentrations of NO_2, SO_2, PM and CO, and it enables policy makers to estimate the efficiency of planned mitigation measures in different anthropogenic source sectors on the air pollutants

R. M. A. Timmermans (✉) · R. Kranenburg · R. Janssen · J. Ge · M. Schaap
Department On Air Quality and Emissions Research, TNO, PO Box 80015, 3508TA Utrecht, The Netherlands
e-mail: renske.timmermans@tno.nl

G. Pfister · R. Kumar
National Center for Atmospheric Research (NCAR), Boulder, CO, USA

M. Guevara
Barcelona Supercomputing Centre (BSC), Barcelona, Spain

N. Huneeus
University de Chile, Santiago de Chile, Chile

Y. Boose · G. Adler
BreezoMeter, Haifa, Israel

M. Dan
Institute of Urban Safety and Environmental Science (IUSE), BJAST, Beijing, China

G. Brasseur · C. W. Y. Li
Max Planck Institute for Meteorology, Hamburg, Germany

C. Granier
CNRS, Paris, France

T. Liu
Beijing Computing Center, Beijing, China

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levels (Timmermans et al. in Report with description of mitigation service, deliverable from Horizon 2020 AQ-Watch project, 2022). The services are demonstrated for three different regions of the world (the Northern Colorado Front Range, Santiago de Chile and the Chinese city of Cangzhou) and are set-up in a generalised way that allows easy transfer to other regions in the world beyond the lifetime of the project. The services are based on a set of different air quality models, source attribution and mitigation methods. For source attribution these include the LOTOS-EUROS model for NO_2 and PM, including its tagging method, and the WRF-CHEM model including CO specific tracers for source attribution. The mitigation service is based on sets of model runs (with the LOTOS-EUROS model and CHIMERE-SIRANE model chains) with different emission reduction scenarios, and the establishment of relationships between emission changes and concentrations. Evaluation of modelled concentrations showed that the performance of the model depends on the quality of the available input information, e.g., emissions and their temporal and spatial distribution, meteorological data, and land use information. The use of regional emission inventories showed an improved performance. For areas with complex topography, high resolution meteorological input is desired to correctly represent the meteorological conditions.

Keywords Air quality · Air pollution · Source attribution · Mitigation · Chemistry transport model · Particulate matter · Chile · Northern Colorado · China

1 Introduction

Air pollution is one of the largest threats to human health around the world with a wide range of associated health impacts such as lung cancer and cardiovascular diseases. Worldwide outdoor air pollution was estimated by the World Health Organisation to cause 4.2 million premature deaths in 2019 (WHO 2022). Improving the air quality is therefore subject to many global, regional, and local policies. To be able to design (cost-) effective policy measures, policy makers require information on the economic activities that contribute to high pollution levels. In addition, information on the effectiveness of potential emission mitigation policies is crucial.

Within the Horizon 2020 Air Quality: Worldwide Analysis and Forecasting of Atmospheric Composition for Health (AQ-WATCH) project, several services have been set up that provide information on the past, current, and future (next 2–3 days) air quality situation in the world. Prototypes are provided for three target regions: Santiago de Chile, Colorado's Northern Front Range and the Xinhua district of Cangzhou.

One of the developed services is the source attribution and mitigation service. The aim of this service is to go a step further by providing insight into the main source regions and sectors contributing to the pollution levels and the potential impact of emission reductions within specific sources on air pollution levels. This information is vital to support the design of effective mitigation strategies for improving air quality, and hence public health in the target regions.

Here, we present the set-up of both components in this service, demonstrate the service, and provide some evaluation of results and outlook to the future. More details can be found in Timmermans et al. (2022).

2 Service Description

The service is demonstrated for several pollutants and regions. Table 1 provides an overview of the application domain of the prototype as it has been developed within AQ-WATCH.

The operational source attribution service is currently based on the LOTOS-EUROS model (Manders et al. 2017) using a tagging approach (Kranenburg et al. 2013) for Particulate Matter with size < 2.5 μm ($PM_{2.5}$), Nitrogen dioxide (NO_2) and Sulphur dioxide (SO_2), and the WRF-CHEM model (Powers et al. 2017) using source tracers for CO (Kumar et al. 2021). The LOTOS-EUROS and WRF-CHEM models are driven by the most recent year of the CAMS global emission inventory and the US NEI emission inventory, respectively. Both models use a nested approach to reach spatial resolutions of 3–9 km.

The set-up of the tagging (which sectors and regions are tracked in LOTOS-EUROS) for $PM_{2.5}$, NO_2, and SO_2 is adaptable and can be altered based on user consultation. The current set-up includes the following sources: residential combustion, agriculture, road-traffic, non-road traffic, shipping, industry, power plants, sea salt, windblown dust, wildfires, any other sources, and sources entering the domain through the lateral domain boundaries. For the Northern Colorado Front Range it includes the contributions from Colorado, Wyoming, Nebraska, Kansas, Utah, Arizona, Texas, New Mexico, Oklahoma, other parts of the US and from intercontinental transport. For the Santiago de Chile region it includes the contributions from Chile, all South American countries separately, and intercontinental transport. The contributions are provided for the period of 6 weeks prior to the moment of accessing the service, and example of the provided information for a few days is shown in Fig. 1.

Similarly, the source tracers used for CO in the WRF-CHEM model can be easily adapted based on user requests. The service currently provides 2-day forecasts for the contributions of continental US anthropogenic sources, sources outside

Table 1 Overview of pollutants and regions included in the prototype service

	Northern Colorado front range	Santiago de Chile	Xinhua district Cangzhou
Attribute service	CO, NO_2, SO_2, $PM_{2.5}$, PM_{10}	NO_2, SO_2, $PM_{2.5}$, PM_{10}	
Mitigation service	CO, $PM_{2.5}$	$PM_{2.5}$	NO, NO_2, O_3, $PM_{2.5}$, PM_{10}

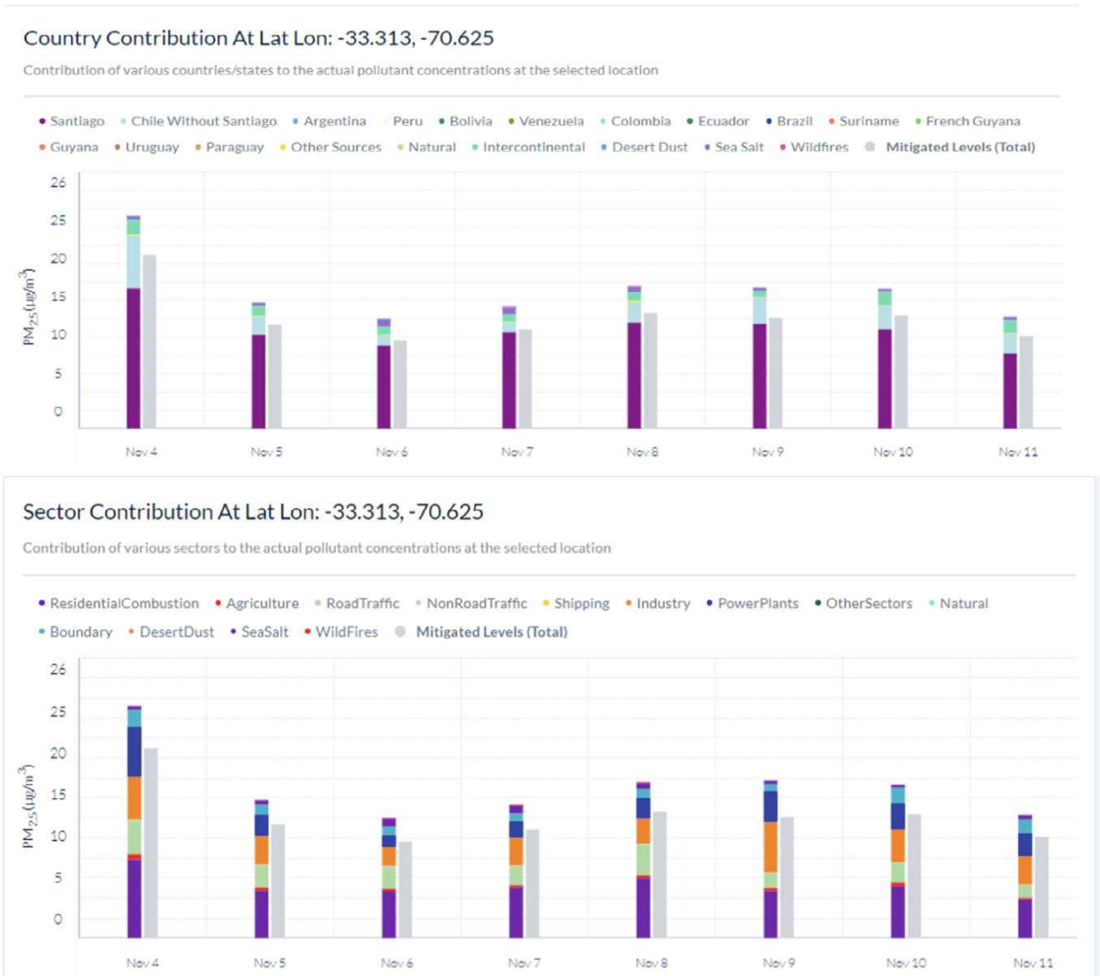

Fig. 1 Example of source attribution results for $PM_{2.5}$ in Santiago de Chile

the continental US, fires within the continental US, fires outside the continental US, all Asian sources (per user request), and photochemical production from oxidation of hydrocarbons to the modelled CO concentrations (Fig. 2).

The mitigation service allows the user to reduce the emissions from pre-defined emission sources and provides the resulting expected impact on air pollutant concentrations (NO_2, PM, O_3 (Ozone) or CO), an example is provided in Fig. 3. The service is based on 3 different models and methods:

1. The LOTOS-EUROS model (targeting $PM_{2.5}$, for Colorado and Santiago), using a surrogate model based on a set of 12 emission reduction runs and polynomial fits, operates in a way similar to the CAMS Air Control tool (Colette et al. 2022). The mitigation service based on this set-up is available for the traffic, industry, residential, and agriculture emission sectors.
2. The WRF-Chem model (targeting CO for Colorado), using the tracer contributions from the source attribution and the assumption of linearity, is available for the sources which are also included in the source attribution of CO (continental US anthropogenic sources, sources outside the continental US, fires within the

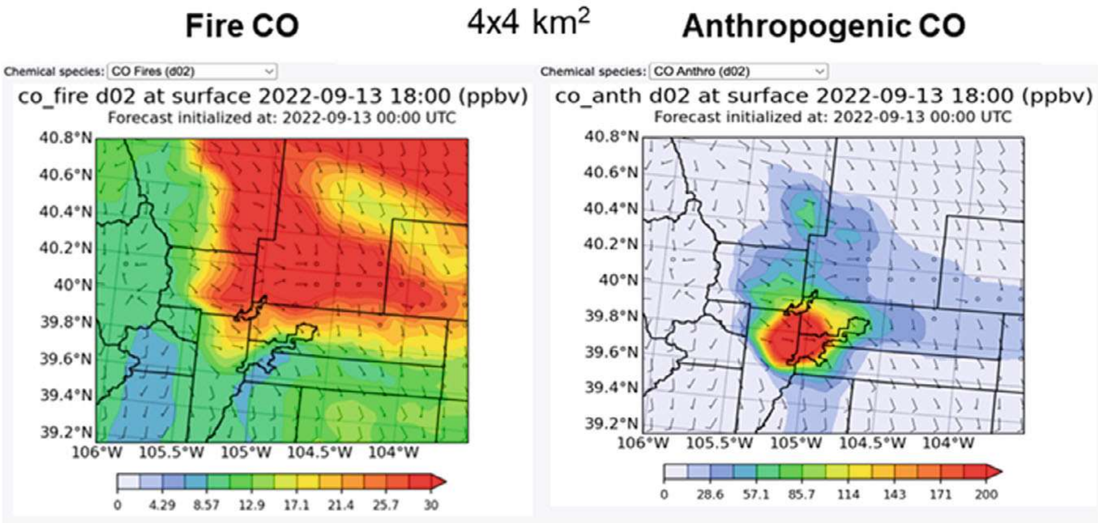

Fig. 2 Example of CO contributions from fire emissions within the US (left) and anthropogenic sources (right) over the Northern Colorado Front range

continental US, fires outside the continental US, all Asian sources, and photochemical production). Evaluation of this linearity assumption from a study in India showed only small non-linear effects (Kumar et al. 2013).

3. The SIRANE local model (Soulhac et al. 2011), nested within the CHIMERE model (targeting PM, NO_2 and O_3 for the Xinhua District of Cangzhou), is using convolutional Neural Networks (CNN) to perform model emulation. This local model is run at a horizontal resolution as low as 10 m and the mitigation service based on this set-up is available for the traffic, industry, and residential emission sectors through an R shiny-based interface in English and Chinese.

The attribution and mitigation service (except for the mitigation service over China) has been made available together with the other AQ-watch services through a user-friendly web interface (https://toolkit.aq-watch.eu/,not available anymore).

3 Evaluation

A first step in evaluating calculated source contributions and mitigation impacts is to evaluate whether the modelled concentrations are in line with observations. Large gaps between modelled and observed concentrations could indicate missing, under-, or overestimated sources, and therefore influence the source attributions and mitigation estimates. Such gaps then require proper analysis of potential causes to accompany the source contribution estimates.

Evaluation of modelled concentrations showed that the performance of the mode depends on the quality of the available input data, e.g., emissions and their spatial and temporal distribution, meteorological data, and land use information. The use

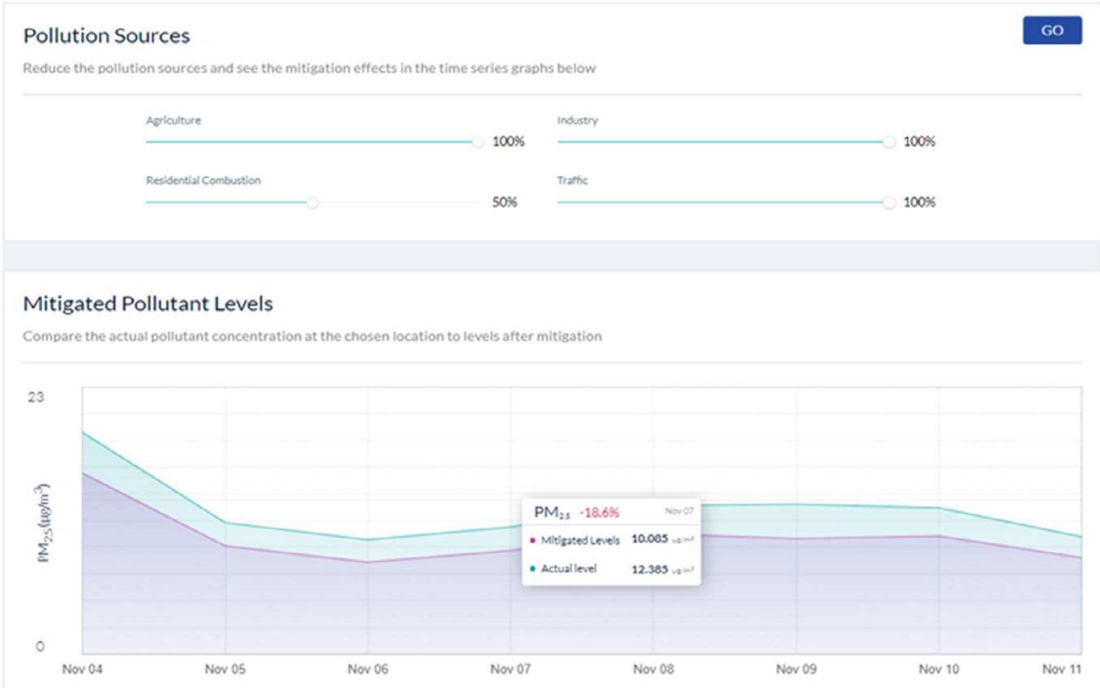

Fig. 3 Example of mitigation service for $PM_{2.5}$. With the sliders the user can select emission reductions. The bottom plot then shows the difference in modelled $PM_{2.5}$ timeseries as a result of the chosen emission reduction at the selected location

of regional emission inventories in LOTOS-EUROS showed an improved performance as can be seen in Fig. 4. For areas with complex topography, high resolution meteorological input is desired to correctly represent the meteorological conditions.

For the evaluation of the estimated mitigation impacts we have compared results from the surrogate model based on LOTOS-EUROS model runs to brute force runs. The results showed that for the majority of the locations and times the relative error in the calculated emission reduction impact is below a few percent, as can be seen in Fig. 5. Over all tested emission reduction scenarios only for a few single grid cells and days the error can exceed 10%.

4 Conclusions

Within the AQ-watch project a source attribution and mitigation service is developed and demonstrated over different populated regions of the world (the Colorado Northern Front Range, the area around Santiago de Chile and the Chinese city of Cangzhou). The services are based on state-of-the-art air quality models and methods for source attribution and mitigation and have been developed by experts in the field.

Modelled concentrations have been evaluated and showed improved quality of results when using regional emission inventories based on local knowledge and information. In addition, the estimated mitigation impacts have been evaluated and show a general high performance.

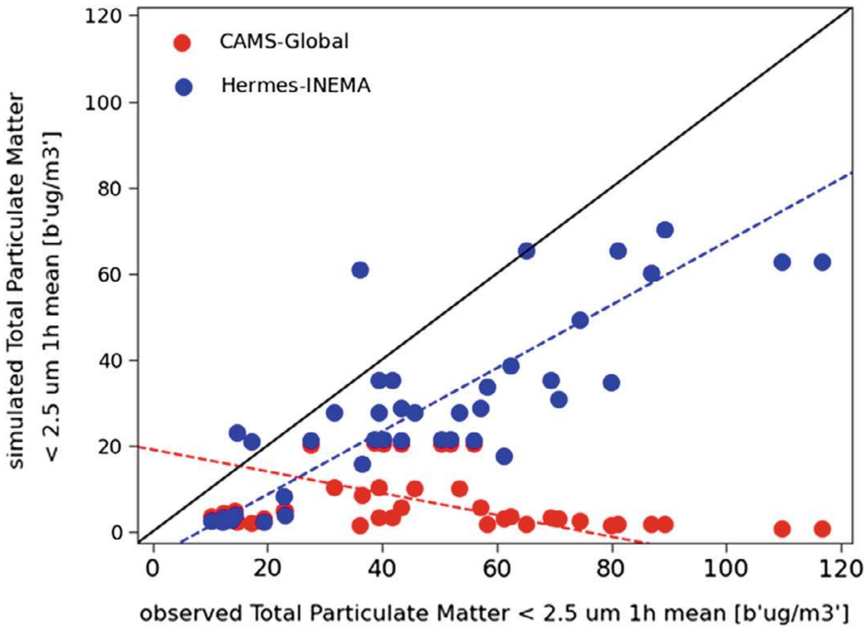

Fig. 4 Impact of updating emission input to local emission inventory for Chile. LOTOS-EUROS modelled $PM_{2.5}$ concentrations (in $\mu g/m^3$) in Chile using CAMS global emissions (red dots) or local Hermes-INEMA emission inventory (blue dots) versus observed concentrations (in $\mu g/m^3$) for winter of July 2016

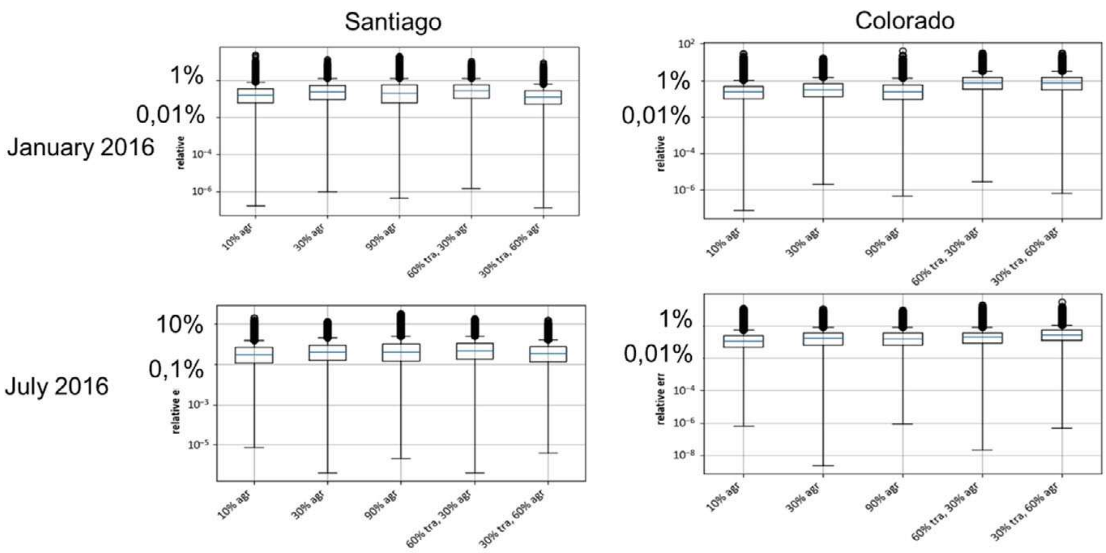

Fig. 5 Relative errors in the calculated emission reduction impact on $PM_{2.5}$ concentrations

In general, the developed services are transferable to other regions in the world. However, it should be noted that the quality of the model results depends highly on the available input information and its details and quality. Among others, this includes emissions and their temporal and spatial distribution, meteorological data, and land use information.

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