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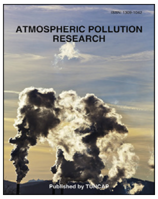

Original article

# Spatial representativeness of air quality monitoring stations: A grid model based approach

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ABSTRACT

A methodology for quantifying areas of spatial representativeness of air quality monitoring station is here proposed, exploiting the wide spatial and temporal coverage of chemical transport models results. The method is based on the analysis of time series of model concentrations, extracted at monitoring sites and around, by means of a Concentration Similarity Function (CSF). The method was tested on AMS-MINNI model results, covering Italy and three reference years (2003, 2005, 2007), for assessing the spatial representativeness of PM2.5 and $O_3$ rural background monitoring stations. The CSF methodology shows good performances in describing both the extension and the shape of representativeness areas, taking into account the difference between pollutants and the dependence on averaging time and temporal interval of concentration data. Results show a large variability in the size and shape of the selected stations in Italy, ranging from 220 to 4500 $km^2$. This confirms the importance of carrying out ad-hoc analyses on monitoring stations, as general a priori classifications and qualitative assessments of spatial representativeness are not able to fully capture the complexity of different territorial contexts.

## 1. Introduction

One of the most relevant parameters when interpreting measured concentrations of atmospheric pollutants is the spatial representativeness of monitoring stations, allowing to associate values recorded at a specific point to an area around that point. Indeed, spatial representativeness plays a key role in monitoring networks design and optimization, for maximizing spatial coverage and avoiding redundant stations. It is also important for correct data assimilation of observations in air quality models, in assigning an area of influence to each station and consequent weights to measured and modelled values. The concept of an area of representativeness associated to monitoring stations could also help to validate remote sensing measurements, such as satellite DOAS observations, with a defined areal resolution. Moreover, spatial representativeness is useful in human health and ecosystems risk assessment, in order to quantify population and vegetation exposure to the atmospheric pollution measured in one or more sites. For this reason, the proper knowledge of the spatial representativeness of a monitoring site could allow a consistent and better understanding of long term effects of air pollutants, in order to contribute to policy on environment and health, updating and supporting EC legislation in this field, to plan mitigation actions and to implement efficient practical measures.

The issue of spatial representativeness is currently addressed in the context of the European debate. The JRC and AQUILA working group siting criteria, classification and representativeness of air quality monitoring stations (SCREAM) has drafted a position paper on this issue in 2013 (JRC and AQUILA, 2013). Moreover, the Forum for air quality modelling in Europe (FAIRMODE) is promoting the discussion concerning spatial representativeness in order to provide a common European basis for a better use of monitoring data for data assimilation and validation studies. Currently, one of the FAIRMODE cross-cutting activities is devoted to spatial representativeness issue (Cross Cutting Activity 1 – Spatial Representativeness).

According to scientific literature, the spatial representativeness of a monitoring site is related to the variability of concentrations around the site (Blanchard et al., 1999; EEA, 1999; Spangl et al., 2007). In the last decade, some different approaches have been investigated to assess the spatial representativeness (Vardoulakis

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et al., 2005; Parra et al., 2009; Henne et al., 2010; Venegas and Mazzeo, 2010; Janssen et al., 2012; Martin et al., 2013; Santiago et al., 2013; Martin et al., 2014; Righini et al., 2014), but a well-established reference procedure for its quantitative assessment, suitable for different monitoring networks in different regions, is not identified at international level so far.

Measurement campaigns investigating the surroundings of one study site (Vardoulakis et al., 2005; Parra et al., 2009) are the most straightforward approach, but can be expensive, since cost-effective passive samplers are not available for all pollutants. In addition, results depend on allocation and density of available samplers and a comprehensive evaluation can be obtained only if many well placed samplers are used. Some approaches use surrogate data to describe concentration variability such as land cover characteristics (Janssen et al., 2012) or gridded emission data (Righini et al., 2014): they are useful when concentration data around sites are not available, but are affected by approximation hypotheses. Using air quality simulations results can be a more cost-effective approach because models are fully capable to take both emission and meteorological parameters variability into account. Some recent studies present spatial representativeness assessment based on air quality model results: in particular, in Martin et al. (2014) a multi-annual analysis based on Chemical Transport Model (CTM) concentrations fields is discussed, while in Santiago et al. (2013) Computational Fluid Dynamics (CFD) simulations results are used for urban traffic stations spatial representativeness assessment.

In this work we propose a plain method to assess spatial representativeness of air quality monitoring sites, based on model concentrations time series. The assessment of spatial representativeness area is obtained by calculating the area where concentrations differ by less than a threshold from the station values, for more than a certain percentage of time instants. Combining this approach and a comprehensive and validated model dataset, the spatial representativeness of monitoring sites can be quickly calculated for different pollutants, on a desired time period.

The selected model database is AMS-MINNI (Mircea et al., 2014), currently in use in Italy for national policy and regulatory purposes. We present here an application of the methodology for detecting the spatial representativeness of rural background monitoring stations, focussing on PM2.5 and $O_3$ pollutants. The choice of type of stations and pollutants is explained in Chapter 2.2.

## 2. Materials and methods

For the quantitative assessment of atmospheric monitoring stations spatial representativeness, Nappo et al. (1982) give a useful and detailed definition: “a point measurement is representative of the average in a larger area (or volume) if the probability that the squared difference between point and area (volume) measurement is smaller than a certain threshold more than 90% of the time”.

On the basis of this definition, assuming the model concentrations as “measurements”, we developed a procedure for recursively comparing concentration time series. The procedure is based entirely on grid model results, exploiting the completeness of an Eulerian chemical transport model with national coverage in Italy, hourly concentrations on many reference years, calculation of all regulated pollutants, state-of-art description of atmospheric physical and chemical dynamics, solid validation.

### 2.1. Implemented procedure

The implemented procedure recursively compares, at surface level, model concentration time series at the site of interest, $C(X_{site},Y_{site},t)$, and at each grid point, $C(x,y,t)$, in the model computation domain. At each time step, $t$, the percentage difference between concentration values is computed and compared with a threshold, in order to assess the condition of “concentration similarity”: indeed, we refer to this methodology as “Concentration Similarity Frequency” (CSF).

The threshold value of 20% was set according to literature (Blanchard et al., 1999; Janssen et al., 2008; Martin et al., 2014) and to data quality objectives for most monitoring data included in the Air Quality Directive (EC, 2008) (from 15% to 25%, depending on the measured pollutant).

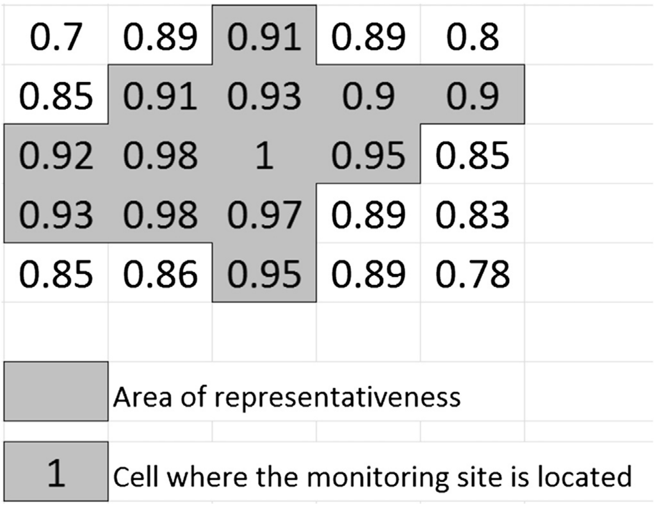
A frequency function $f_{site}(x,y)$, specific of each site of interest, counting positive occurrences of “concentration similarity” on a yearly basis, for each grid point of the model domain, was so defined in Equation (1).

$$f_{site}(x,y) = \frac{\sum_{i=1}^{N_t} flag}{N_t}, \quad where\ flag = \begin{cases} 1, & \dfrac{|C(X_{site},Y_{site},t_i) - C(x,y,t_i)|}{C(X_{site},Y_{site},t_i)} < 0.2 \\ 0, & \dfrac{|C(X_{site},Y_{site},t_i) - C(x,y,t_i)|}{C(X_{site},Y_{site},t_i)} > 0.2 \end{cases} \tag{1}$$

Equation (1) Frequency function according to the condition $\Delta C/C < 0.2$ ($C(x,y,t)$ represents surface concentration field, while $N_t$ is the number of time steps).

According to the Nappo's definition, the representativeness area of the site of interest was finally assessed as the area where the condition $f_{site}(x,y) > 0.9$ is verified, on yearly or multi-year basis, depending on the chosen time interval. In Fig. 1a schematic example of the expected results is shown.

The CSF is similar to the Martin et al. (2014) approach: in both cases spatial representativeness assessment is based on comparison of CTM gridded data. The main difference consists in the time treatment. Martin et al. (2014) deal with time as the first step: for every pollutant and averaging time, the appropriate time percentile concentration field is obtained on the basis of exceedances numbers allowed by the Air Quality Directive (EC, 2008); then spatial representativeness assessment is made by comparison of concentration values of the obtained field. Instead, in this study, 4D concentration fields (3D fields varying in time) are directly taken into account: comparison between concentration values is made as time varies, in order to obtain the time frequency, over a specific time interval, of concentration similarity conditions.



|  |  |  |  |  |
|---|---|---|---|---|
| 0.7 | 0.89 | 0.91 | 0.89 | 0.8 |
| 0.85 | 0.91 | 0.93 | 0.9 | 0.9 |
| 0.92 | 0.98 | 1 | 0.95 | 0.85 |
| 0.93 | 0.98 | 0.97 | 0.89 | 0.83 |
| 0.85 | 0.86 | 0.95 | 0.89 | 0.78 |

▨ Area of representativeness

1 Cell where the monitoring site is located

**Fig. 1.** Schematic example of $f_{site}(x,y)$ results.