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QUALEARIA: EUROPEAN AND NATIONAL SCALE AIR QUALITY FORECAST SYSTEM PERFORMANCE EVALUATION.

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Abstract: Air quality forecasts are operationally provided by some of the Italian Regional Environmental Agencies. Some of them adopted a coherent modelling framework and implemented the same boundary conditions provided by the national forecast system QualeAria. This network of regional/urban scale air quality forecast systems, represents an effective example of consistent methodology adopted to address the requirements of the European Directives, to assess, manage and forecast the state of the atmosphere.

Key words: *air quality forecast, model evaluation, bias correction, score analysis.*

INTRODUCTION

Since 2007, QualeAria (www.qualearia.eu) air quality forecast system (AQFS) provides an operational forecast over a large portion of Europe and Italy, up to 5 days in advance.

QualeAria stems from MINNI (www.minni.org), the reference Italian modelling system for air quality assessment (Mircea *et al.*, 2014), the experience gained in FUMAPEX and MEGAPOLI EU research projects and the COST Action ES0602-Chemical Weather (see Kukkonen *et al.*, 2012 for a review on European AQFS). It is based on FARM multigrid chemical-transport model (freely distributed on https://hpc-forge.cineca.it) and a suite of modelling components continuously updated and improved. QualeAria operationally provides boundary conditions to a network of regional/urban scaleAQFSs set up and operated by Regional and local Environmental Agencies to support air quality monitoring and management and to fulfil the European Directives requirement concerning the need to inform the population on air pollution conditions.

During the 2015/2016 the operational AQFS has been evaluated against the observations recorded by regional air quality networks. The role of phenomena generated at regional/global scales, along with the key role of fine-grained information available at local scale has been investigated by comparing QualeAria with the linked systems at different scales.

QUALEARIA AIR QUALITY FORECAST SYSTEM FRAMEWORK

QualeAria is based on FARM (Flexible Air Quality Regional Model), a 3D Eulerian chemical transport model simulating dispersion and chemical reactions of atmospheric pollutants, and is managed by F-Air (ARIANET Integrated Forecast System Manager), a software environment where the data sources and the modelling components are connected as sketched in Figure 1.

The prognostic meteorological model RAMS, provides the downscaling of synoptic weather forecast on the computational domains of interest. The meteorological interface module GAP+SURFPro processes the standard output fields produced by the meteorological driver to meet the needs of FARM (grid adaptations, diffusion parameters, deposition velocities, natural emissions from vegetation, aeolian resuspension and sea-salts). Gridded hourly emissions of all the pollutants considered by FARM starting from national and continental inventories are prepared by the EMMA processor. The system runs over two nested domains, covering a large portion of Europe and Italy, at 48 km and 12 km horizontal resolution respectively, over 16 vertical layers up to 10000m.

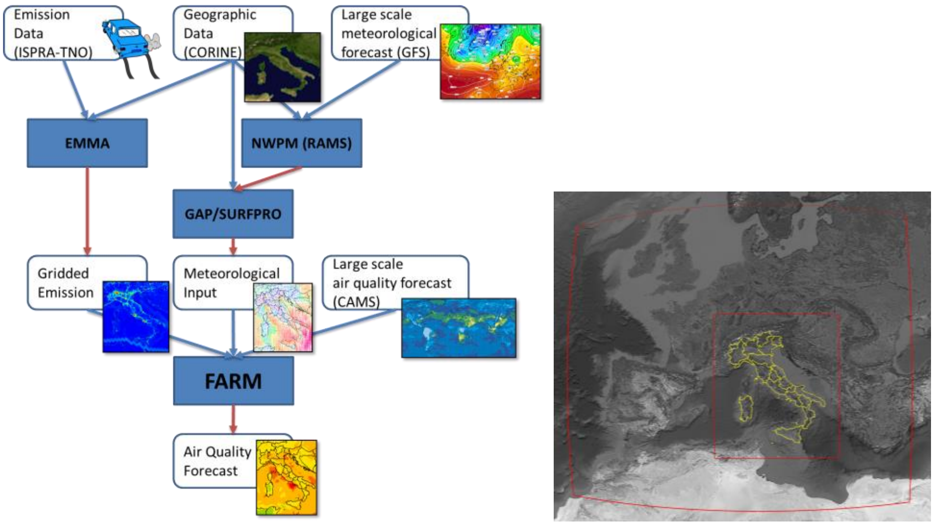

Figure 1. QualeAria framework (left) and computational nested domains (right).

QualeAria is fed by boundary conditions from the global scale chemical weather forecast produced by the CAMS/Copernicus service and from the Global Forecast System (GFS) provided by the United States National Centers for Environmental Prediction (NCEP). Anthropogenic emissions over the two computational domains are assigned as a combination of Italian and European (ISPRA and TNO) inventories.

QUALEARIA SCORES

The validated data provided by the Italian Regional Environmental Agencies, through the EEA air pollution data center service, are used to periodically evaluate the QualeAria performance, and to ensure the quality of new improvements implemented in the modelling tools as well as in the input data set.

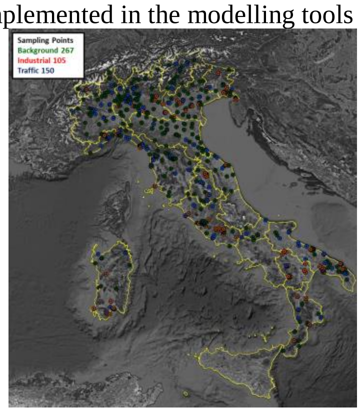

Figure 2. Sampling point provided by Italian Environmental Agencies, reference year 2015.

Figure 2 shows the spatial distributions of the sampling points. The year 2015 is taken as reference year since most of the Italian Environmental Agencies make information available on primary validated assessment data, according with the reporting obligation laid down by the Air Quality Directive IPR.

Stations with less than 85% available data for each species were excluded from the analysis and the following pollutants were considered: PM10, Nitrogen dioxide and Ozone. Data from Campania, Sicilia and Abruzzo regions not yet available in this data set, are analyzed independently and not shown here.

The first forecast day (+24h) concentrations fields provided by QualeAria are compared with the observed levels without a preliminary clustering of sampling points based on their spatial representativeness. A set of common used statistical metrics are evaluated such as: root mean square error (RMSE), mean fractional bias (MFB), mean fractional error (MFE). As an example, Figure 3 reports the QualeAria spatial distribution of these indicators referred to PM10 daily averages. Following Figure 4 shows the scatter plot and the map of observed and predicted PM10 yearly average. Despite the low 12 km resolution, a reasonable agreement can be observed even with a clear underestimation of the measured values in several sites. However, good agreement can be found in large cities, where emission sources are more evenly distributed in the model grid cells, and in background sites, where the model resolution matches the spatial representativeness of the monitoring stations.

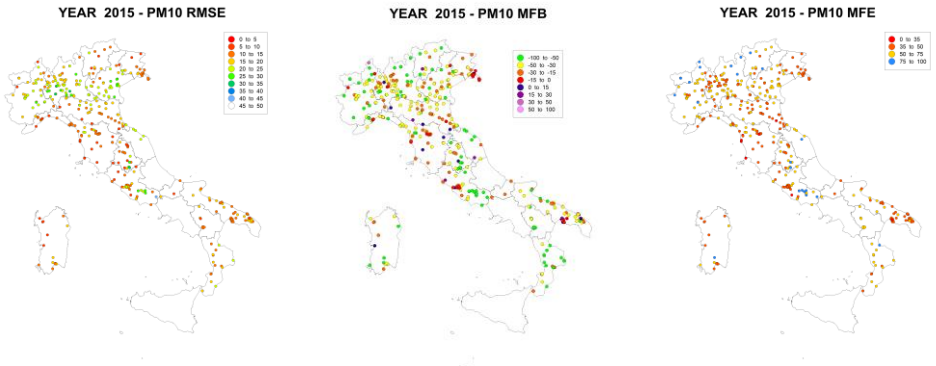

Figure 3. QualeAria RMSE, MFB and MFE computed over all sampling points for PM10 daily average.

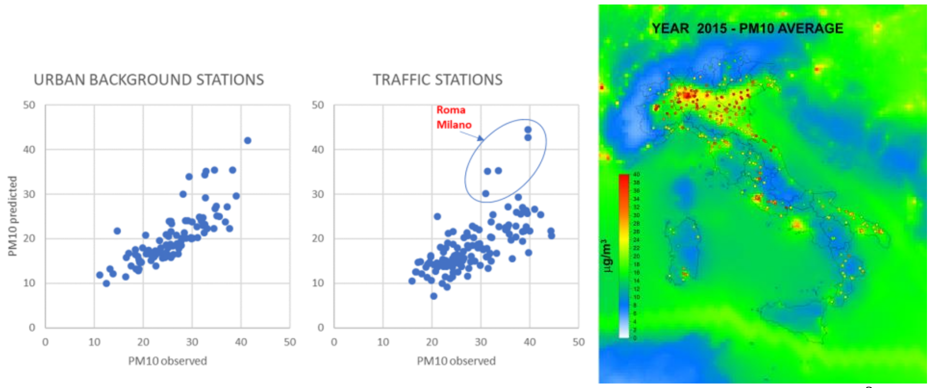

Figure 4. Scatter plot and map of observed and predicted PM10 yearly average (µg m^{-3})

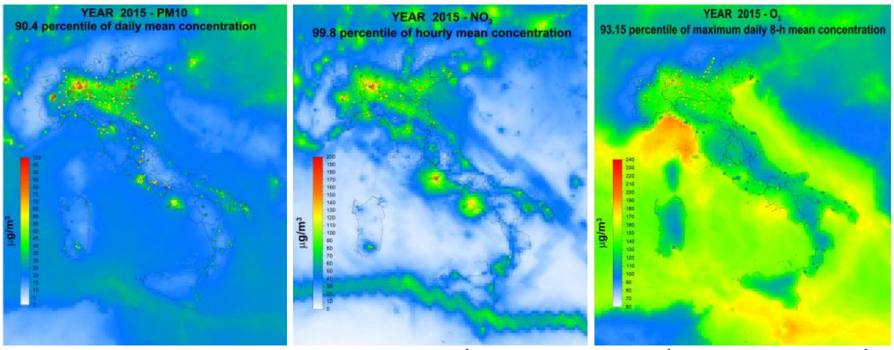

Figure 5. Maps of observed and predicted: PM10 90.4^{th} (µg m^{-3}), NO_2 99.8^{th} (µg m^{-3}), O_3 93.15^{th} (µg m^{-3})

To estimate the capability of QualeAria to predicts pollution events both a discrete and a categorical evaluation method are used. Figure 5 shows the capability of QualeAria to describe over the national territory, the incidence of yearly exceedances of air quality limits as set by legislation for the considered species. The categorical approach used is based on the so-called "Contingency table". Table 1 reports the number of occurrences in which observed data and model output are both above the selected threshold (hits, a), the number of occurrences in which they were both below (correct-negative, d), the number of alarms missed by the model (misses, c) and the number of false alarms (b). Four indices, described in Table 2 are used to quantify QualeAria predictability skill scores. Table 3 shows the values of these indices computed for PM10 considering a threshold value of 33 µg m^{-3} that represents, according to Pay *et al.* (2014), the 75th percentile of the observed concentrations. The analysis of this table evidences the capability of QualeAria to capture such events.

Table 1. Contingency table

	Observed yes	**Observed no**
Predicted yes	a=9208	b=2310
Predicted no	c=24583	d=103197

Table 2. Categorical indices

Index name	**Formula**	**Range**	**Ideal value**
Accuracy [ACC]	A=(a+d)/n*100	0 to 100	100
Bias [BIAS]	BIAS=(a+b)/(a+c)*100	0 to 100	100
Probability of Detection [POD]	POD=a/(a+c)*100	0 to 100	100
False Alarm Ratio [FAR]	FAR=b/(a+b)*100	0 to 100	0

Table 3. PM10 scores considering a threshold value of 33 ($\mu g\ m^{-3}$)

BIAS	**POD**	**FAR**	**ACC**
34.09	27.25	20.06	80.69

LINK WITH LOCAL SCALE FORECAST SYSTEMS

A coherent modelling approach (GAP/SURFPRO/FARM) and emissions treatment (EMMA), provides a shared framework from European to local scale AQFSs. Boundary conditions from QualeAria allow a correct reproduction of ozone maxima and a proper PM background deriving from larger scales phenomena, while the increase in resolution and a more accurate description of emissions from the local inventories lead to better forecast performances, especially for NO_2 and PM maxima as shown in Figure 6 for Arpa Puglia, and further analyzed in Schipa I. *et al.*, 2017.

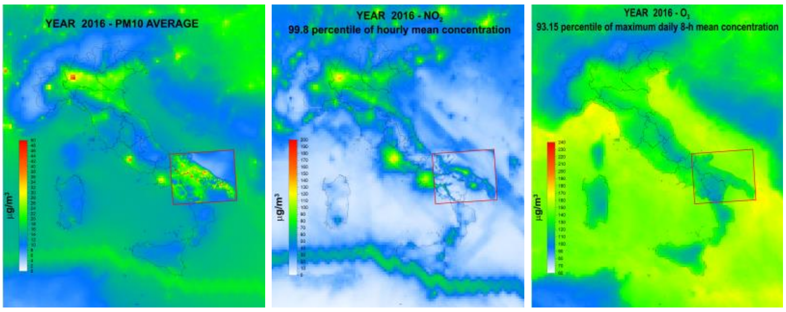

Figure 6. Maps of QualeAria (12 km) and APA Puglia system (4 km inside the red box) comparisons.

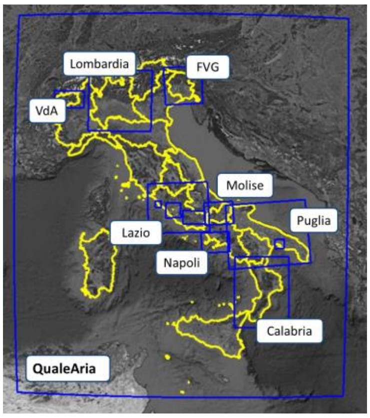

Figure 7. Regional forecast system linked with QualeAria (red boxes)

Figure 7 shows the computational domains of the local and regional forecast system that are fed by QualeAria boundary conditions. The regional forecast systems use different horizontal resolutions: 4 km (Lazio, Puglia), 2 km (Valle d'Aosta, Friuli Venezia Giulia, Calabria) and 1 km (Lombardia, Molise and Napoli). Some of the systems further add nested domains at 1 km resolution over critical areas, for example ARPA Lazio forecast system includes a 4 km domain over the region and three nested domains at 1 km horizontal resolution over the city of Rome, the port of Civitavecchia and the Valle del Sacco area. ARPA Puglia system covers the regional and a downscale over the city of Taranto at 4km and 1km of resolution.

Despite of the continuous improvement of the forecast performance, the need of accurate results may reach the intrinsic limitations of a modeling system which provides results locked to a finite computational grid resolution and affected by many sources of uncertainty in their use for operational applications (Kukkonen *et al.*, 2012). Sub-grid scale phenomena or local emissions not described by the inventories, can lead to pollutants concentrations that can hardly be estimated. Critical conditions have been encountered in reproducing pollutants concentration levels in smaller urban areas and valleys. In these areas a bias adjustment technique, the Kalman filter, has been adopted to improve the model predictions as described in Silibello *et al.*, 2015.

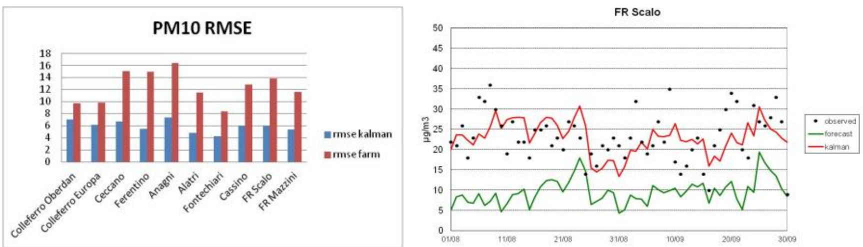

Figure 8. Air Quality system (1 km), Kalman filter RMSE reduction and observed, modelled and adjusted PM10 daily mean concentration at some sampling points of the ARPA Lazio air quality network.

CONCLUSIONS

Over a continuous improvement, QualeAria aim to provide a reliable operational prediction product over Italy. The score analysis conducted for the reference year 2015 shows good results for both discrete and categorical verification methods. As expected, better agreement is targeted for sampling points representative of a background area on the other hand, underpredictions of PM and NO_2 are more frequent for those locations affected by sub-grid phenomena. More detailed emissions inventories and higher horizontal resolutions resolve part of the uncertainty as shown by the comparison of QualeAria with the regional and local forecast systems. Nevertheless, the need to provide an operational prediction overcoming the modelling limitations is achieved by means of the Kalman filter bias adjustment technique as implemented for the Lazio and Puglia regional domains.

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