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Air pollution and emission reductions over the Po-valley: Air quality modelling and integrated assessment

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Abstract: The Po-valley located in northern Italy at the footstep of the Alps is characterized by a high density of anthropogenic emissions and by the frequent occurrence of stagnant meteorological conditions. The area has been identified as one hot spot place where pollution levels will remain problematic in spite of the application of the current European legislation devoted to air pollution control. By 2020, health impact on population and effects on ecosystems by ozone and eutrophication are indeed calculated to be amongst the highest in Europe and anthropogenic fine particulate matter levels are expected to be responsible for a loss of ten months of life expectancy. In general, long-range transported air pollution in the Po-Valley represents only a fraction of 30-40%, stressing the importance of local control measures in the area to efficiently reduce the impact of air pollution.

This paper presents an overview of two connected projects focusing on air-quality modeling and integrated assessment. The POMI (PO-valley Model Inter-comparison) exercise aims at exploring the changes in urban air-quality predicted by different Air Quality Models (AQM) in response to changes in emissions. The first phase of the project has concentrated on the elaboration of the required input data for the AQM, i.e. meteorology, monitoring, and emissions. The latter have been elaborated based on the combination of various types of data originating from different Authorities and characterized by different spatial scales and levels of detail. During this process, priority has been given to the bottom-up approach believed to be more suitable to capture local information than a pure top-down disaggregation from the national emission inventory. The available POMI results at this stage indicate model performances in line with those obtained in the frame of previous model evaluation exercise but with a marked underestimation of the fine particulate matter (in particular of its organic fraction) and a significant model variability in the modeling of ozone concentrations. Work to investigate the sensitivity of the AQM to various parameters (e.g. meteorology and emission) is on-going with the aim to better understand the air quality processes in the Po-Valley region and better represent them in the AQM

In parallel to POMI, an integrated assessment tool is being developed to design and assess the effectiveness of regional abatement policies. This tool is planned to make use of information available at the local/regional scale (technological changes, emission factors…) to allow investigating the efficiency of both technical and non-technical abatement measures and to find the optimal cost allocation. POMI provides useful information for the development of sectoral local/regional source-receptor relationships and for better accounting for the different sources of model-related uncertainties (emissions, meteorology…) in the efficacy assessment of abatement strategies.

It is believed that such an approach which combines (1) collecting high quality emission inventories, (2) running extensive AQM exercises and (3) optimizing the choice of emission abatement strategies via a specific integrated assessment tool will support the local/regional Authorities in designing effective AQP in the frame of the current European air quality directive.

Keywords: *Air Quality Modelling, Regional Integrated Assessment, Decision Support System*

1 INTRODUCTION

The Po-valley located in northern Italy at the footstep of the Alps is characterized by a high density of anthropogenic emissions and by the frequent occurrence of stagnant meteorological conditions. The area has been identified as one hot spot place where pollutant levels will remain problematic in spite of the application of the current European legislation devoted to air pollution control. By 2020, health impact on population and effects on ecosystems by ozone and eutrophication as projected by the RAINS model (Amann et al. 2007) are indeed calculated to be amongst the highest in Europe and anthropogenic fine particulate matter levels are expected to be responsible for a loss of ten months of life expectancy. In general, long-range transported air pollution in the Po-Valley as calculated by the regional scale EMEP model represents only a fraction of 30-40%, stressing the importance of local control measures in the area to efficiently reduce the impact of air pollution.
A Model inter-comparison exercise over the Po-valley (POMI) has been set-up to explore the changes in urban air-quality predicted by different air quality models in response to changes in emissions in the Po-Valley. Emission scenarios corresponding to the application of regional air-quality plans over the Po-Valley and over the Lombardy region are analyzed at different spatial scales.
In parallel to POMI, an integrated assessment tool is being developed to design and assess the effectiveness of regional abatement policies. This tool is planned to make use of information available at the local/regional scale (technological change, emission factors…) and to allow investigating the efficiency of both technical and non-technical abatement measures. POMI provides useful information for the development of sectoral local/regional source-receptor relationships and for better accounting for the different sources of model-related uncertainties (emissions, meteorology…) in the efficacy assessment of strategies.
In this paper, the general set-up and objectives of POMI are first detailed whereas an overview of the structure of the local/regional integrated assessment tool is provided in the second part, emphasizing its links with POMI.

2 THE POMI EXERCISE

The POMI main objective is to explore the changes in urban/regional air-quality predicted by different atmospheric chemistry-transport-dispersion models in response to changes in emissions in the Po Valley. A first stage in the project foresees an evaluation of Air Quality Model (AQM) performances based on a comparison with monitoring data for the complete meteorological year 2005 which has been chosen for its representativity in terms of pollution levels and for its data availability. Six AQM are currently participating in the exercise: CHIMERE (INERIS, France), RCG (Freie Universitaet Berlin, Germany), AURORA (VITO, Belgium), EMEP (Met.no, Norway), CAMx (CESI, Italy) and TCAM (University of Brescia, Italy).

2.1 Input data

Modeling domains. In addition to simulations performed at the European scale at 50 km x 50 km resolution, AQM perform simulations over two nested domains illustrated in Figure 1 below. The first covers the whole Po-Valley (approx. 220000 km2) with a 6 km resolution whereas the smallest domain covers the Lombardy region (approx 60000 km2) with a 3km spatial horizontal resolution.

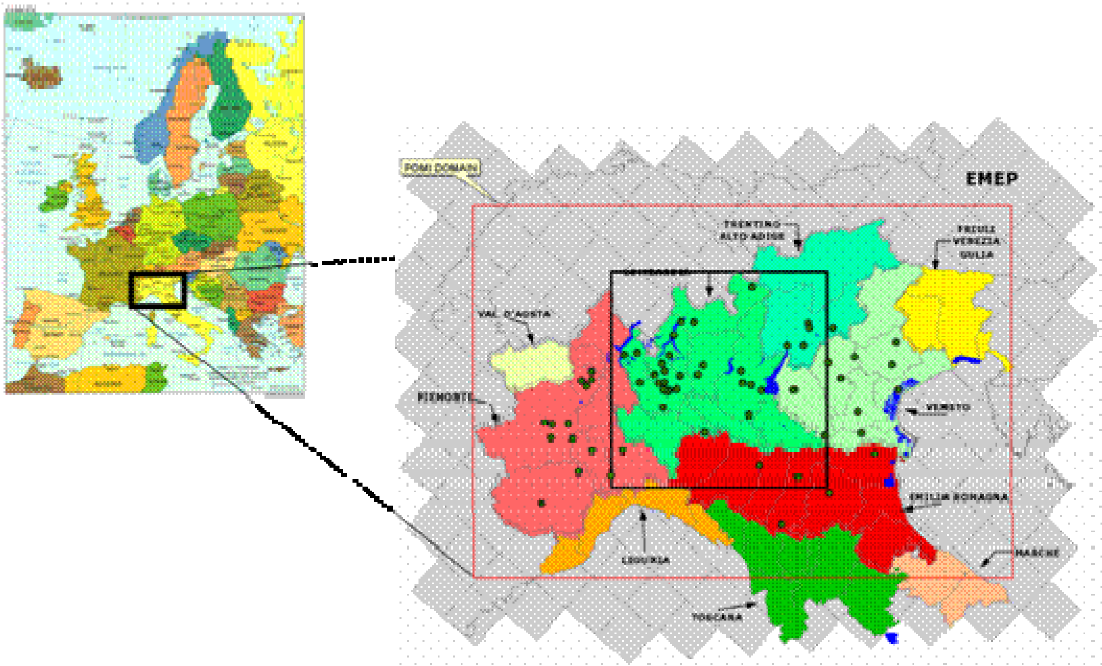

Figure 1. Modelling domain extents and resolutions: Europe (30km), Po-Valley (6km, red square) and Lombardy (3km, black square). Spatial entities to which the European scale EMEP, Italian national scale APAT and/or Lombardy regional scale INEMAR emission inventories are referred. Green dots represent the available air quality monitoring stations.

Meteorology: The nonhydrostatic meteorological mesoscale model MM5 from PSU/NCAR has been used to generate the high resolution meteorological data for 2005 (hourly data) necessary to feed the AQM at the 6 and 3 km grid resolution. In addition to the MM5 simulations, two other mesoscale meteorological models (WRF and TRAMPER) are being used at similar resolutions to analyse the AQM results sensitivity to meteorological input.

Monitoring data for ozone, nitrogen oxides, carbon monoxide, sulphur dioxide and particulate matter (PM10 and PM25) have been collected for 131 monitoring stations belonging to the different regions located in the POMI domain. Data have been analyzed and processed according to their location, type, data availability, representativeness and measurement methods.

Boundary conditions from the continental scale EMEP unified model (Fagerli et al., 2004) have been imposed to all participating models. An alternative set of boundary conditions from the CHIMERE (Bessagnet et al., 2004) model has been prepared for testing the sensitivity to this input data.

Emission inventory: An up-to-date emission inventory covering the whole Po-valley domain, spatialized on a regular 3 km x3 km grid has been elaborated in the frame of the project. Priority has been given to the regional emission inventories (e.g. Lombardy, Piedmont…) to obtain the highest possible accuracy assuming that for a given sector/ activity a bottom-up approach would be more suitable to capture local information than a pure top-down disaggregation from the national emission inventory. Since all regions within the POMI domain do not yet have complete databases the final POMI inventory has been built from a combination of data to provide the best compromise between completeness and accuracy. Depending on spatial scale and data availability, emissions have been retrieved from: (1) the regional inventory (INEMAR) detailed at the municipal level, (2) the National inventory (ISPRA) detailed at the provincial level or (3) the European inventory (EMEP) detailed at country level.

Emission scenarios: On the basis of the 2005 base case emission inventory two emission scenarios have been focused on the 2012 horizon when EU member states have to report on the efficacy of their abatement measures:

1. A current legislation scenario (CLE) has been defined for the whole POMI domain with: (a) emission variations for the transport and residential heating sectors in Lombardy being calculated from locally available information, (b) regional emission trends for other sectors/regions obtained from the national RAINS Italy model (Zanini et al. 2005) and (c) national emission trends for outside Italy portions of the domain calculated by the RAINS Europe model.
2. A scenario based on the Regional Air Quality Plans (AQP) has been built for the Italian portion of the POMI domain: local information related to the transport sector (substitution of circulating fleet, improvement of public transport networks, use of alternative fuels…) and energy production (increased use of renewable energy, building efficiency…) has been elaborated with reference to Lombardy while in the rest of the POMI domain emission projection/reduction rates are based on the RAINS Italy (ENEA) output introducing, region by region, local information which have been quantitatively translated into emission reduction with respect to CLE.

2.2 Preliminary results

Since not all models have yet delivered their final results, only a few outlines are provided hereafter. For the 2005 base case, Figure 2 below illustrates the model performances for the 24h-average concentrations of O3 in summer and PM10 in winter according to the type of stations and spatial resolution. Figure 3 shows in a single graphic the centered root mean square error (CRMSE), the correlation coefficient and the standard deviation (of the simulated values, not of the error) as proposed by Taylor (2001) and explained in (Fig 3a). In this figure each point represents a single model performance with respect to observations. Some preliminary observations may be drawn:

- For PM10, only slight differences are seen between urban, suburban and rural background station types both for observations and model results indicating a spread of the air pollution at the scale of the whole Po-Valley basin (Fig. 2).
- A larger variability among fine resolution model results is observed for O3 than for PM10.
- While the improvement in the PM10 modelled concentrations with respect to observations is important when the spatial resolution is refined from 50 to 6 km a further refinement to 3km does not lead to significant changes. Regarding O3 the 50 km resolution models clearly overestimate the mean values, especially in urban and suburban areas due to an underestimation of the NOx titration effects (Thunis, 2001) while the passage to 6 and 3 km resolution leads to a net improvement.
- The correlations obtained for O3 and PM10, ranging between 0.5 and 0.6 and slightly better for O3 than for PM are in line with results obtained in the frame of previous exercises (e.g. CityDelta, Vautard et al., 2004)
- PM levels are systematically underestimated (25 to 30 ug/m3). The first investigations seem to point out to a strong underestimation of the organic part, especially during winter time, but detailed PM measurements including details about the different PM components are scarce.
- For PM10 (Fig 3c) all model results are clustered indicating similar correlations and CRMSE but they generally exhibit less variability than observations which is mainly caused by the strong underestimation of the average levels. Regarding O3 concentrations (Fig 3b), model results show a much larger variability which is strongly related to the way models simulate their NOx levels especially during nighttime (not shown).

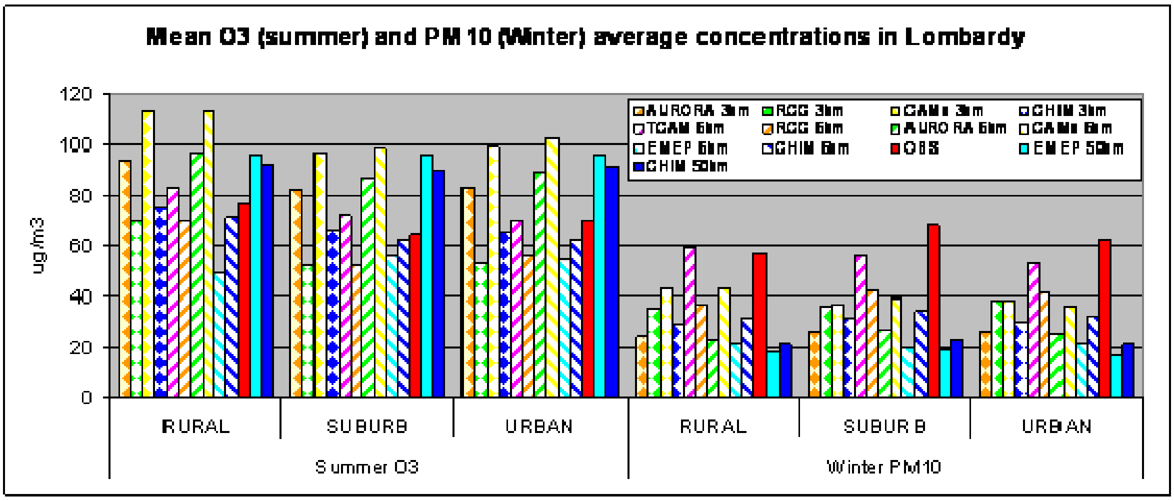

Figure 2. Comparison of model results and observations for summer O3 mean and winter PM10 levels for the Lombardy region background stations classified in types. Models are identified by a given colour whereas resolution is characterized by a specific filling.

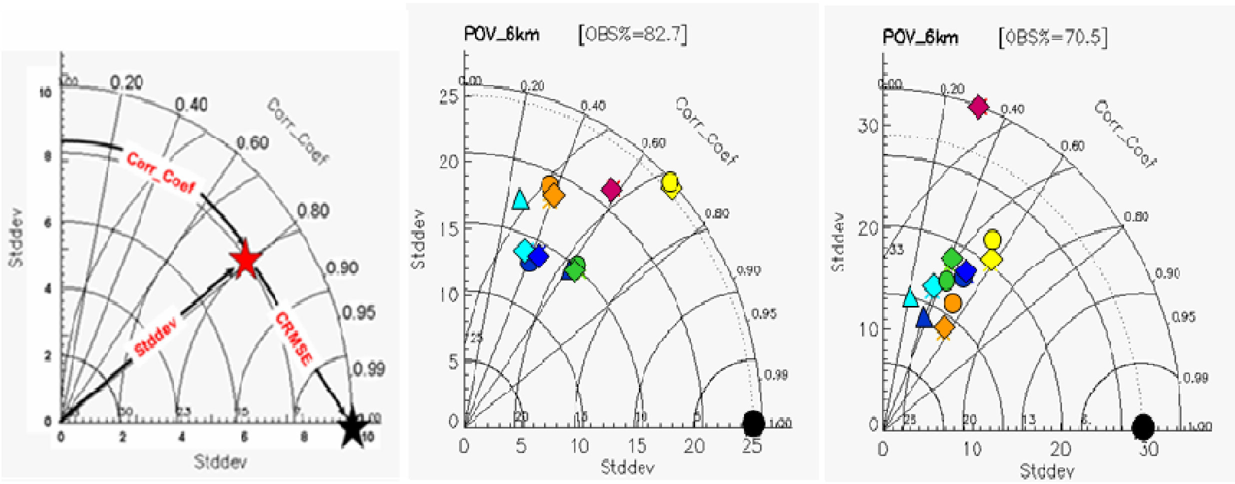

Figure 3. (a) Describes the diagrams proposed by Taylor for the simultaneous visualization of three different statistical indicators, i.e., the correlation coefficient, the centered root mean squared error (CRMSE) and the standard deviation (Stddev). The red and black stars identify the model result and the observation, respectively. (b) Shows the model results for 24h mean summer ozone values for different models for all Lombardy region background stations (c) same as (b) but for 24h mean annual PM10 levels. Simulations with 50, 6 and 3 km are represented with triangles, squares and circles respectively. Models are indicated with the following colour codes: Dark blue: CHIMERE, light blue: EMEP, yellow: CAMx, green: RCG, orange: AURORA and violet: TCAM.

Considering available results and the preliminary conclusions mentioned above, further checks are now being made to identify possible causes for the strong underestimation of the modelled PM levels (both the coarse and the fine fractions) and the large model variability obtained in the O3 simulations. A series of sensitivity simulations to investigate the relevance of different parameters is being currently carried out. In particular the treatment of traffic and residential heating emissions in the model (e.g. speciation between organic and elemental carbon in PM emissions) as well as the sensitivity to meteorological data are considered.

3 RIAT – A REGIONAL INTEGRATED ASSESSMENT TOOL

In order to support the implementation of cost-effective regional/local policies aiming at reducing the burden of adverse effects of air quality on human health, Regulatory Agencies (e.g. Lombardy Region Authorities) require tools to evaluate outcomes and costs associated to different emission reduction strategies. These tools are even more useful if they are able to consider secondary pollutant concentrations, due to the complex nonlinear processes that affect their production and accumulation. To achieve this task, the RIAT (Regional Integrated Assessment Tool) decision support system (DSS) needs to bring together data on pollutant sources (emission inventories), their respective contribution to atmospheric concentrations and human exposure, together with information on potential technological abatement and other measures that may be used to reduce pollutant concentrations and their emission abatement costs. It aims at answering the following questions:

- How can a given set of environmental targets in a given region be achieved most cost-effectively, and how much does it cost?

- How efficient is a given emission reduction strategy in terms of cost and environmental impacts?

Although tools exist at the European scale, e.g. RAINS/GAINS (Amann et al. 2004) or at the national scale e.g. RAINS-Italy to assess in a cost-effective way the impacts on environment and human heath, one of the project aims is to provide the Regional Authorities with a tool able to assess the efficiency of AQP with respect to compliance issues (e.g. number of exceedance days above a given threshold to be fulfilled) with the possibility of accounting for non-technical measures while taking advantage of the locally available information (i.e. detailed emission inventory, or implementation rate of technologies),for instance differentiating policy respect to air quality zoning. The methodology is based on implementing and solving a multi-objective problem (Pisoni et al. in press). An optimization algorithm finds the optimum of an objective function defining the set of the effective emission abatement measures. The set of the efficient abatement measures is represented by the Pareto boundary (non-dominated scenarios). Each effective solution is described in terms of prioritizing abatement measure sectors, spatial implementation of reduction technologies, internal (due to abatement measures implementation) and external (due to population exposure) costs, air quality improvements. Below a general overview of the RIAT structure is presented

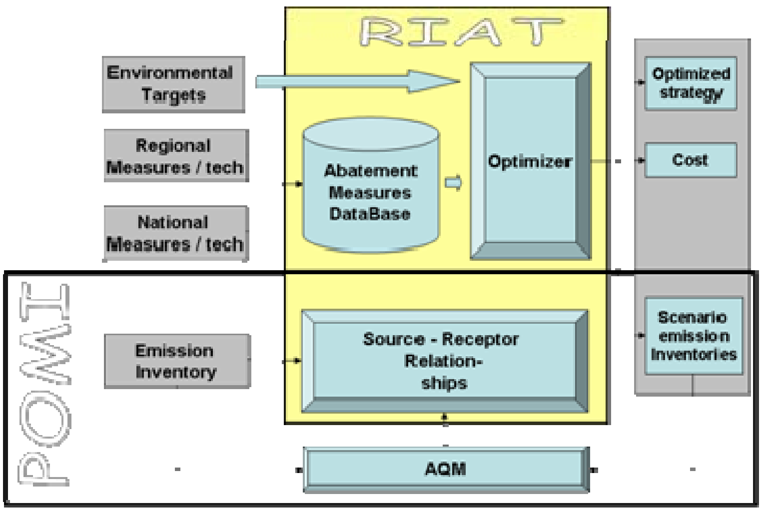

Figure 4. Overview of the RIAT DSS modules and links with the POMI exercise

4 CONCLUSIONS

In this paper a brief overview of two connected projects focussing on air quality modelling and integrated assessment at the local/regional scales has been provided. The main function of POMI is to develop a consistent set of data on which the integrated assessment RIAT tool can be based to assess future emission abatement strategies. One important component of this dataset is the set of emissions which must be defined and quantified in a consistent way within the domain of interest. One task related to the elaboration of the emission inventory consisted in merging different sources of data at European, national and regional scales, each obtained through different estimation methodologies, into a unique and consistent database at the scale of the Po-Valley basin. Simulations with different air quality models are performed, evaluated and inter-compared to build confidence in our representation of the atmospheric and chemical processes in the area as well as to quantify the uncertainty characterizing these results. An accurate representation of the governing processes is indeed required before using AQM for the task of generating the source-receptor relationships, task in which AQM are used in an intensive way to perform emission reduction scenario simulations to relate emission to concentration changes in terms of geographical area, emission sectors and pollutants.

Once the RIAT tool is set-up, it will provide optimized emission scenarios which will be used as input in the frame of the POMI exercise as one further evaluation step of the RIAT approach.

It is believed that such an approach which combines (1) collecting high quality emission inventories, (2) running extensive AQM exercises and (3) optimizing the choice of emission abatement strategies via a specific integrated assessment tool will support the local/regional Authorities in designing effective AQP in the frame of the current European air quality directive.

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