Report on the operational R-EVA service

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1 Introduction

The GMES/MACC project aims at delivering a number of services dedicated to global atmospheric composition and air quality monitoring in Europe. This later issues is covered by a set of subprojects belonging to the so-called "regional cluster", RAQ (Regional air quality). Two operational services are available by the end of the MACC project: those that are focussed on routine and near real time products (forecasts, Near Real Time analyses) and those related to detailed analysis of past situations thanks to validated material issued from observation networks and modelling. The first class of products is available through the MACC website on a daily basis: http://www.gmes-atmosphere.eu/services/raq/raq_nrt/. Up to two days forecasts of ozone, nitrogen dioxide and particulate matter concentrations throughout Europe are available every day. Daily analyses of the same variables (simulated fields are "corrected" with observations thanks to data assimilation techniques) are proposed as well.

The MACC/R-EVA service (http://www.gmes-atmosphere.eu/services/raq/raq_reanalysis/) provides a posteriori validated air quality assessments for Europe, based on re-analysed air pollutant concentration fields. Simulations of past years are performed and "corrected" thanks to the assimilation of available validated in-situ and satellite observations. By the end of the MACC project, operational production of such information will be implemented for the years 2007-2009.
The **so-called MACC regional air quality assessment reports should describe**, with a yearly frequency, the state and the evolution of background concentrations of air pollutants in European countries. Special attention is given to pollutants characterised by the influence of long range transport, correctly caught by European scale modelling: ozone, nitrogen dioxide, particulate matter (PM10 and PM2.5). Focus on specific pollution episodes that happened during the year will be considered.

The MACC assessment initiative is conceived to be an actual tool for European policy and decision makers in charge of air quality monitoring and reporting. Indeed, according to the Directive an Ambient Air quality and Cleaner Air for Europe (the CAFE Directive 2008/50/EC), the Member states have to report to the European Commission and to inform their citizens on the state of air pollution. In particular, situations (or episodes) when ozone, nitrogen dioxide and particulate matter concentrations exceed regulatory thresholds must be carefully analysed (geographical extension, duration, intensity, population exposed...) and control plans to limit their impact and to avoid their future development must be proposed. Member states usually base their investigations on observations available from the national air quality monitoring network, modelling tools and national expertise.

In its operational stage (foreseen in 2014) the GMES atmospheric services will propose complementary and comprehensive information established on the basis of state of art chemistry-transport models run operationally by modelling teams with a long experience in the field of air pollution, and extended in-situ and satellite observation sets gathered and made available. Both sources of information (modelling and measurement) are smartly mixed by the MACC scientists to elaborate the so-called "re-analyses" of past periods and support national experts in the Member states in their interpretation of air pollution trends and events that touch their country.

With the MACC project this new generation of tool and information based on spatialized indicators fields set on comprehensive maps becomes available. It combines the capacities of chemistry transport models to represent air pollutant patterns and the accuracy of observations in re-analyses. Those set the basis of the MACC/EVA assessment reports, being considered as the "best available or most realistic" representations of air pollution

patterns: more relevant than interpolation of observations and more accurate than raw simulations.

Moreover the multi-model functionalities developed in the MACC "regional cluster" will allow to derived "ensemble" model estimations. They relate to the combination of various model results to obtain an average with improved skills compared to the individual models' ones. This combination can be a simple median average or more sophisticated averages, weighted by coefficients depending on the model, the geographical location, the simulated period.... The former option has been chosen for the reports related to the first stage of MACC (2007-2009), while the later one should be considered in a future of the GMES atmosphere service implementation according to the developments realised in the sub-project dedicated to the "ensemble" production.

The present document reports on the lessons learnt from the pre-operational phase that developed during the MACC project. It was dedicated to the development of the modelling chains and their implementation for the production of the 2007, 2008, 2009 assessment reports on European air quality. A number of challenges have been overcome to provide the expected products on time. However, there are still several progress issues that should be considered to establish a more robust and reliable service in the next phase with MACC2. Those issues are reviewed and discussed in this document, to set a relevant basis for the specifications of the next generation of the EVA air quality re-analysis systems.

2 Users' appreciation: feedback and how to improve the service

- **The first important point to set is that for the very first time, high resolution (20 to 25 km) re-analyses of air pollutant concentrations fields were available for the whole of Europe**. Three years are available from MACC: 2007, 2008 and 2009, and both maps and numerical data issued from several European models that run for the complete years and from an Ensemble combination of these model results were available.

- Obviously the representation of air pollution patterns with re-analysed maps, following an approach which combines modelling and measurement is **the most accurate and the most satisfactory product for decision makers**: observations are taken into account in the re-analysis process, and if the model is mature and validated enough, one can expect that the dynamical and chemical processes that drive concentration fields are well simulated. Maps of concentration fields are more comprehensive for decision making and general public information than tables of statistics or discrete information at the station sites. Moreover, they can be crossed with other indicators (statistics on population density for instance) to derive an information on exposure. Such indicators are to be reported to the European Commission, especially for locations where the limit values are exceeded. Therefore the objective of the service is definitively relevant and appreciated by the "policy" users.
- Moreover this kind of product based on the comprehensive analysis of several modelling systems **allows to build up ensemble simulations and to assess the modelling uncertainty**. It is completely new and can be of high interest for policy makers. It helps in :
    a. The identification of geographical areas where models are the most uncertain and where their results should be considered with caution;
    b. The optimisation of the regulatory monitoring network and the assessment of the station representativeness; use of modelling as an operational tool for

reporting according to the air quality Directives should require adjustment of the air quality monitoring networks that can be tackled by the re-analysis system.

- However **MACC/EVA re-analyses are appropriate to report and comment on background air pollution** (both rural and urban). The spatial resolution adopted in the current system does not allow catching local pollution situations, especially near busy roads or on industrial sites. This is a limitation of the system, because it means that exceedances of regulatory threshold values that occur at these locations cannot be reported. Only observations and local modelling (street canyon models for instance) coupled with a very high resolution emission inventory (not compatible with the European scale) can deal with this issue. We consider that such issues should be covered by local expertise or by the downstream services. However some significant improvement are expected with MACC2:
    a. **The spatial resolution of the models run in MACC2 will increase: 10 km over the whole of Europe is expected**. Such a resolution will be relevant for ozone patterns, and will highly increase accuracy of NO2 and PM concentration fields
    b. **Analysis of available approaches dedicated** to regional simulated fields' correction to better accounting for the urban and street emissions'influence will be considered. Such methods are for instance developed in the EC4MACS Life project (http://www.ec4macs.eu/home/index.html).

- **Some users from the countries where the modelling results are the most uncertain especially from the Mediterranean area and Eastern Europe required some improvements**. Complexity of meteorology and chemistry in Southern Europe is a well-known problem and all the modelling teams work on how improving air quality forecasting in these regions. However this is a long term process based on scientific research. Close link between operational and research activities will be further developed in MACC2 for an overall improvement of the process. Concerning the eastern part of Europe, some technical difficulties due to the complexity of the geographical characteristics of those areas could arise, but there are other issues. In particular the emission inventory is less accurate than in other parts of Europe, what should be improved through the official emission reporting process[1]. The regulatory monitoring network is less dense than in other countries as well. Therefore, data assimilation process is less accurate and verification is more difficult. Useful recommendations on these aspects could be provided by the MACC modelling teams.

- National authorities from various European countries pleaded for the interest of the air quality re-analysis services because **it brings a new set of tools that can complement or support their expertise on air quality issues in their countries**. Some countries (especially in the eastern part of Europe) did not develop modelling capacities and MACC/EVA can be of high interest in that perspective, especially for regulatory reporting. But country representatives need to endorse these results and to promote them. Building confidence is essential at this stage. Evaluation of the individual and ensemble model results is one of the main issues of the service. This task is processed very carefully following the same approach for all the models. A large number and representation of statistical scores of the numerical results against observations is established, analysed and provided to the users. **Help in the**

[1] According to the Convention on the Long range Transboundary Air Pollution (http://www.unece.org/env/lrtap/) of the Economic Commission for Europe from the United Nations.

interpretation of the evaluation scores should be proposed in a more "pro-active mode" in MACC2. Because it is essential that users in the countries could develop their expertise and could check that the MACC/EVA results are relevant and consistent with their own evaluation before use for reporting.

- For each year considered in MACC (2007 to 2009) an in-depth analysis of the modelling performances for both raw simulation and data assimilation results is realised. The results are presented in dedicated reports. They show that **most of the models involved in the MACC/EVA system are consistent with the state of the art and provide good quality results**. More precisely, their performances have improved along with the project.
    a. Ozone concentrations simulation is the most achieved issue. Correlation of raw simulation results with observation can exceed 0.8 and the root mean square error is lower than 20 $\mu g/m^3$, what is correct. Using data assimilation chains, these scores largely improve: 0.9 for the correlation coefficient and the RMSE ranges from 5 to 15 $\mu g/m^3$ depending on the geographical area.
    b. The largest impact of the data assimilation process relates to PM10 simulations. All the models generally underestimate PM concentrations because of uncertainties in emission and in some process parametrizations (deposition, chemistry). When observation data is assimilated in the numerical simulations, correlation coefficient of PM10 model results reaches 0.9 in some cases and the RMSE ranges between 5 and 7 $\mu g/m^3$ depending on the location. Those scores are actually very good considering the state of the art. However only three models assimilated PM10 measurements in theri modelling systems.
    c. Difficulties remain for NO2 which is definitively a local pollutant to be considered with a higher spatial resolution. This point will be carefully investigated in MACC2 and should improve in the coming years. In particular the work realised on the EURAD model (RIU, Germany) is very encouraging and the obtained results are acceptable regarding the current spatial resolution of the MACC models.

- Users and especially national and European authorities and EPAs are really interested in the EVA products and are willing to use them for operational purposes generally linked to policy reporting. **However they require some facilities that could enhance their capacity in interpreting and using MACC/EVA results** (but these remarks should hold for other services):
    a. Access with an "easy-to-use" format to the numerical values of the model results. They are actually available on request but under a GRIB format. Scripts for translating the files in excel sheets or other common formats could be provided as well.
    b. Extraction of data over a given country of interest or a given geographical area, so that users could focus on a limited zone. Access to 2D or 3D numerical fields. The former ones can be used to map concentration fields with users' graphic style or to assimilate new sets of observations using simple kriging methods. The latter can be used as boundary conditions of regional chemistry transport models or in data assimilation process with new observation datasets.
    c. Access to integrated exposure indicators for human health and ecosystems derived from hourly values of concentrations. The users should have the possibility to ask for either hourly means or averages over longer periods, or indicators related to the number of situations when some threshold values are exceeded, or aggregated indicators (SOMO35 for ozone for instance).

At this stage it is possible to fulfil such requirements case by case. Within the future operational GMES service it will be necessary to develop the functionalities that will allow providing answers to request in a more automatic way.

- Finally, beyond the modelling results, the added-value of the MACC/EVA service is **to propose interpretation and in-depth analysis of air pollution patterns that occur and develop in European countries**, taking advantage of the wealth of all available information sources. For instance if some air pollution episodes are due to global pollution events (desert dust, forest fires, volcano eruption...) the information available through the various services should be used in the MACC/EVA report for refining the description of the event. The GMES atmosphere service will gather many data on interoperable platforms (at the global and regional scales and with in-situ and satellite databases) which should support the development of a unique set of regional air quality re-analyses interpreted in terms of policy decision. Both regulatory and research data sources should be considered by the service, what does not exist so far[2].

3 Analysis of the axis of progress according to the MACC experience

It is possible to draw a set of conclusions and recommendations for future development of the EVA services at the end of the MACC project. Indeed, the MACC project aimed at building up an advanced prototype of the modelling chains dedicated to regional air quality assessment production, and to assess the interest and the feasibility of the project. In that sense those objectives have been reached and a number of issues are already identify as priorities for the next stage of the development of the EVA services within MACC2.

The following table synthesizes the main outcomes of the MACC/EVA subproject, what is still missing and how the service should improve in the near future. This analysis, together with user-oriented issues listed in the previous paragraph, will be the starting point for the revision of the service specifications that should drive developments in MACC2.

[2] Assessments and evaluations provided by the EEA or the EMEP program do not include research observational or multi-models datasets so far.

Product characteristics	Achieved	Missing	Potential improvements and decisions for MACC2
Operational production of yearly reanalyses by 7 individual CTMs (Chemistry Transport model)	5 models over 7 were able to provide re-analyses by the end of MACC. For the first year (2007) only 2 models run their data assimilation chains: CHIMERE for O3 and PM (CNRS/INERIS, France) and EURAD (RIU, Germany) for all pollutants. For the 2008 assessment LOTOS-EUROS (KNMI/TNO, the Netherlands), SILAM (FMI, Finland) and MOCAGE (Météo France, F), proposed respectively NO2 and ozone re-analyses. CHIMERE sent NO2 re-analyses. For the 2009 assessment, LOTOS-EUROS extended its capacities to PM and ozone, and MOCAGE to PM.	Only EMEP (met.no, Norway) did not provide any data assimilated fields because of problems in the development of the system and its implementation for simulation long periods (annual). Raw simulations results were provided for the three years. MATCH (SMHI, Sweden) provided incomplete datasets because of problems in the computing chain. The system was not fully operational to run yearly re-analyses.	A review of the status of the re-analysis chains for air quality developed in MACC will be realised in the first month of MACC2. The cases of EMEP and MATCH will be carefully considered to assess their actual capacities for providing the expected EVA products. The ability of the other models to produce high quality re-analyses will be assessed and discussed furthermore (see below) to enhance EVA services robustness and accuracy.
Production of re-analyses compliant with a certain level of accuracy	The quality of the modelling results was assessed by comparison with observations from the AIRBASE database. EURAD, CHIMERE, MOCAGE and SILAM showed very significant improvement of their results thanks to the data assimilation process. They provided results of high accuracy. The conclusion is more disappointing for LOTO-EUROS, especially for PM concentrations fields that remain uncertain.	Investigation and further validation of the LOTOS-EUROS data assimilation process is still needed... Some results for the years 2008 and 2009 are deceiving compared to those provided by the other DA chains.	Improvement of the robustness of the individual DA chains in compliance with the objectives of the MACC2/EDA subproject.
Production of Ensemble model results	The ensemble approach aims at combining individual model results to obtain better quality simulations taking advantage of the strengths of each model. It is commonly used in climate and meteorological sciences and usually gives better results than those from the individual models.	When the project started the possibility to implement other "ensemble strategies" than the median was foreseen. Few studies started, especially in the ENS sub-project but none of them gave better results than the median.	Further investigations on possible ensemble approaches that could be more accurate than the median approach, will be realised in MACC2.

	In the MACC/EVA service (as in MACC/ENS) the ensemble was built up as the median of the individual model results		
Use of various types of observation data in the data assimilation and in the evaluation processes	The AIRBASE database is the reference source of in-situ for air quality issues. It is maintained by the EEA and results from regulatory reporting of air pollutant concentrations measured in the member states. In-situ data from research networks (for instance those provided by the EUSAAR[3], EUCAARI[4] or EARLINET[5], MOZAIC[6]/IAGOS[7] projects) could give relevant information as well. Generally the parameters measured are not the same as the regulatory ones (PM speciation). The counterpart is that the measurement techniques are not standardized what can be a problem for data comparability. Earth Observations have not been used in an extended way in MACC/EVA. Only two teams (RIU and KNMI/TNO) used operationally satellite information in their data assimilation chain. Other teams developed a research activity on the topic which is still under validation.	A limited number of observation data is currently used to produce the assessment and validation reports. It is mainly focused on AIRBASE, what was very important for users like the EEA or national EPAs. Research data have been only partly used and this is the same for satellite information. Beyond comparison with model results or data assimilation, complementary observational datasets can be used for interpreting and analyzing air pollution episodes as expected in the yearly assessment reports. This opportunity has not been used very extensively in the 2007, 2008 and 2009 reports.	In MACC2 an "observations" (OBS) subproject will ensure the interface between the service providers and the data providers (inc. Research data). This organization should help in getting more data along with a routine and robust process. MACC2/EVA teams should spend significant effort on how to integrate this information in the modelling process as well. And it will be used more systematically in the assessment reports.
Provision of re-analyses accounting for all types of pollutant sources	MACC simulations and forecasts are generated on the basis of input data which characterizes: - Meteorological conditions - Emissions - Boundary conditions Meteorological re-analyses were issued from	The material available from the subprojects of MACC (EMIS and GLOBAL especially) had been only partly used by the modelling teams because time missed for building up relevant interfaces and validating	In MACC2, the available input data for the regional models will be carefully reviewed especially for emissions and boundary conditions. More homogeneity between the choices of the seven regional

[3] European Supersites for Atmospheric Aerosol Research www.eusaar.net
[4] European Integrated Project on Aerosol Clouds, Climate and air quality Interactions (http://www.atm.helsinki.fi/eucaari/)
[5] European Aerosol Research Lidar Network www.earlinet.org
[6] Measurements of OZone, water vapour , carbon monoxide and nitrogen oxides by in-service AIrbus aircraft http://mozaic.aero.obs-mip.fr/web/
[7] In-service Aircraft for a Global observing System http://www.iagos.org/

	ECMWF databases. Emission data were compiled in the MACC emission inventory set in the MACC project for the years 2007 and beyond. Emissions from forest fires were available too. The global subproject provided boundary conditions for gaseous compounds, aerosols including desert dust.	the final results. In particular in the 2007, 2008 and 2009 yearly assessment report no emissions from forest fires were taken into account in PM calculations. Desert dusts were not included in all models. Finally interface between the global aerosol reanalyses (from the MACC/AER sub-project) and the regional system had not been developed by all the model: this needs to solve some inconsistencies between models output/input that should be considered carefully.	modelling teams should be established to avoid artificial bias in uncertainty analysis or in the ensemble calculation. Use of common input datasets and common interfaces to implement them will be promoted. In particular, forest fire emissions will be systematically included in the 2010 and following assessment reports.

4 Conclusions

The European air quality assessment reports proposed by the MACC/EVA service are innovative products which compile high quality and high resolution modelled and data assimilated maps of air pollutant concentrations together with an with in-depth analysis of air pollution events and trends. Resulting from the combination of a large panel of in-situ and satellite measurements and modelling, maps and data reported in these reports are considered as the most relevant representation of background air pollution patterns. Moreover running several chemistry transport models and mixing their results to build up an "Ensemble" simulation should improve the quality of the service and allow uncertainty analysis (what is rather new considering available air quality modelling platform in Europe at an international level).

The service is framed to support European and national decision makers in charge of air quality management. Availability of data characterizing air pollution fields commented, regarding their origin and their evolution, by experts from the MACC teams aims at dealing with some users' expectations which are not completely fulfilled by other research or operational projects. MACC's wealth comes from the know-how developed in coupling global and regional atmospheric scales to forecast and analyse air pollution events, from the extensive sets of observation data processed and used, from operational capacities including quality assurance objectives.

The MACC/EVA service has been welcome by the targeted users. In particular, the European Commission (DG ENV) acknowledged the assessment report as potential useful tools for those countries which have to report on air pollution levels and exceedances according to the Air Quality Directives, but are not able to run appropriate tools. Their existence will be mentioned to the member States in the process of revision of these legal texts (2013).

Therefore, at the end of the MACC project, we consider that the feasibility and the relevance of this service have been demonstrated. The quality of the model results too. Actually, the obtained results are very encouraging although they did not reach the complete maturity we expected when we conceived the service.
The initial MACC/EVA road map was very ambitious. Long time has been spent on the development and the validation of simulation and data assimilation chains able to run for an entire year and to answer the quality criteria set for the model results.
Therefore there is still certain heterogeneity in the seven modelling teams'production: raw simulation and re-analyses, various set of observations assimilated in the models, different sources for input data.... This will be corrected very quickly, and a significant improvement of the model results is expected.
This report draws a list of actions identified as priorities to frame the work on the EVA service within MACC2.

Comments and requests gathered so far from the MACC users will drive the next stage as well. As set in the MACC2/EVA work plan, a large effort will be dedicated to the promotion and dissemination of the re-analyses. Tools to facilitate their use and support to the users will be proposed. Finally, as far as possible (it depends from the availability of the validated data in AIRBASE and in the research databases), we will try to reduce the time when the assessment report is released. At this stage it is not possible to get a consolidated set from AIRBASE for the year X before the mid-year X+1. Anyway, strong interaction with users will be maintained in MACC2 to fit a suitable and relevant service on air quality validated assessments, in the GMES atmosphere service.