PASODOBLE FINAL REPORT

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Executive summary

At current levels healthcare costs, associated with poor air quality in the EU27, are estimated to reach at least €189 billion per year by 2020. Considering the adverse health effects of air pollution, monitoring, assessing and forecasting of air quality are fundamental to increase the quality of life and prosperity in Europe.

Within the frame of the European Earth Observation Programme GMES/Copernicus, PASODOBLE has considerably improved information and tools on air quality in more than 30 regions and cities throughout Europe. This has been achieved by developing a portfolio of innovative and sustainable Myair services in coordination with local stakeholders and agencies (**www.myair.eu**). From 2010 to 2013 existing user requirements were analysed in order to design and implement improved air quality monitoring, assessment and forecasting services. A consortium of 21 partners joined forces to realize the portfolio by combining space-based data, in-situ measurements, modelling and information technology. In close collaboration with over 50 users from 18 countries, multiple follow-ups on service demonstration, use and assessment were successfully applied with respect to fitness-for-purpose and business planning.

PASODOBLE has been providing health community support services for hospitals, pharmacies and people at risk, public air quality forecasting services, traffic scenario assessment services for cities, compliance monitoring support for regional environmental agencies on particulate matter and finaly model evaluation support for a wide spectrum of users. PASODOBLE has augmented the supply of relevant information for policy and decision makers. Events like the Olympic Games in London in 2012 benefitted from these developments. The results and their evaluation have clearly demonstrated the necessity for services at high spatial resolution in addition to the Copernicus Atmosphere Service.

Furthermore, PASODOBLE has worked towards a harmonized European framework for air quality services. By developing a generic and modular technical infrastructure, including ready-to-use tools, modern interfaces, simple data access together with applied quality management, which takes also INSPIRE-compliance into account, the project has significantly increased interoperability and implementation efficiency. This will facilitate the service transfer into new regions and cities.PASODOBLE has worked both at local level and broader scale, resulting in advanced European harmonisation by integrating and promoting best practice tools. The technical interface to Copernicus atmosphere products will be transferred to MACC-II for operational sustainability.

An interactive online user interface has been developed offering modular tools and apps to access, visualise, analyse and validate the results of the air quality services. It further comprises a catalogue, modules for calculating human exposure, a decision-support system and an air quality management tool. By introducing Open GIS Consortium standards and implementing a coordinated interface, the access to crucial data sources has significantly been improved and will have a major impact on the next generation air quality services.

Through close collaboration with the Copernicus Atmosphere Service (MACC), PASODOBLE has linked global satellite and modelling capacities to local needs and applications. Focusing on hot spots, the service portfolio is complementary to the Copernicus Atmosphere Service. PASODOBLE has bridged important gaps between existing data, methods and end users through its developments, by supporting key players with customized solutions.

Raising awareness and delivering bespoke information, PASODOBLE contributes to reduce health costs and to improve the quality of life in Europe. Citizens will benefit, since the services provide solutions that will mitigate the harm from air pollution, directly reaching residents who are most susceptible. It allows the public to , adjust its outdoor activities, to assess its exposure or to be given necessary medical treatment reducing the impact of air pollution. This will, in the long term, reduce hospitalization, morbidity and mortality.

Summary Description of project context and objectives

If we care about our health, we pay attention to the quality of what we eat and drink. Why should it be any different with the air we breathe? It is vital to our existence and its quality affects us directly. But we cannot select the air as easily as we do fruit juice in the supermarket. We can't choose what we breathe. However, we can be informed and be aware and adapt our activity or medication. Policy makers and stakeholders can be better supported with information and tools they require.

Imagine a severe smog episode building up in several European regions. Will the hospitals be prepared? Who will tell the doctors in the right region to be prepared at the right time? Will the pharmacies have relief medications in stock?

Imagine a severe exceedance of particulate matter is detected by a regional environmental agency. How will they know and verify its source? Is it from local emissions? Advected mineral dust? Neighbouring polluted areas? How do they know the exact spatial extent? What do they report to the European Commission?

Imagine families with children, a cyclist or a hiker planning a day trip. Wouldn't it be perfect to guide them to where the air is cleanest? Wouldn't it be perfect for sportsmen or people suffering from hay fever or asthma to have information that shows highly resolved and integrated information on physical, chemical and biological weather? Wouldn't it be perfect for decision makers to be informed about the local air quality with cutting-edge forecasting methodology and information technology?

Imagine a city that wants to set up an air quality forecasting and public information system to improve quality of life for their citizens. Will they know how to proceed to get an effective and efficient solution which delivers the best objective measures and values?

Imagine ... there is PASODOBLE. In the context of the European Earth Observation Programme Copernicus/GMES, PASODOBLE aimed to improve and introduce information and tools on air quality in European regions and cities. The services were targeted to support stakeholders and the public. Combining space-based data, in-situ measurements,modeling and information technology, PASODOBLE sought to develop and demonstrate a portfolio of Myair downstream services in 4 thematic areas:

- Health community support for hospitals, pharmacies, doctors and people at risk,
- Public forecasting and assessment support for regions, cities and events,
- Compliance monitoring support on particulate matter for regional agencies,
- Forecast model evaluation support for authorities and city bodies.

To contribute to the success and credibility of the Copernicus programme, downstream services must be an essential part to ensure that its products and services reach the widest pool of end users and emerging markets. In recognition of this, PASODOBLE encompassed the following four major objectives:

1. Development and demonstration of sustainable air quality downstream services

Building on the achievements of the ESA GMES Service Element PROMOTE and being complementary to the Copernicus Atmosphere Service (MACC-II, Monitoring Atmospheric Composition and Climate), PASODOBLE aimed at developing user-driven and sustainable downstream services in European regions and cities affected by air pollution (**www.myair.eu**). This covered evolution and strengthening of existing, as well as development and demonstration of new services. From 2010 to 2013 existing user requirements were analysed to implement improved air quality monitoring, assessment and forecasting services.

2. Development and testing of a sustainable generic and modular service infrastructure
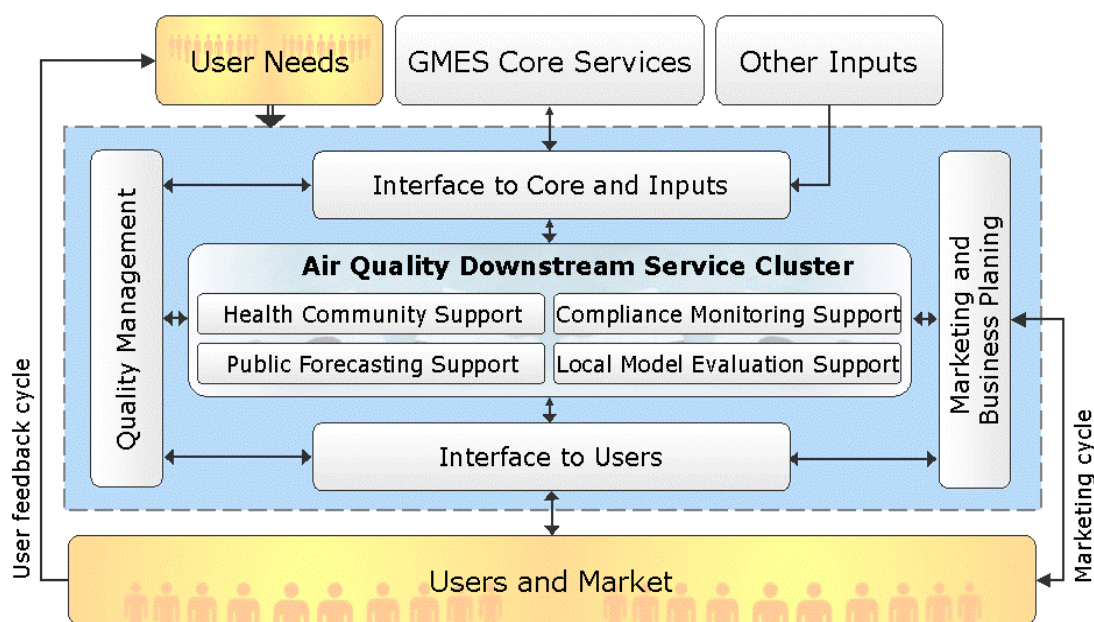
PASODOBLE worked towards a harmonized European framework for sustainable downstream air quality services. By developing a generic and modular service infrastructure, including ready-to-use tools, modern and interactive interfaces, simple data access and applied quality management, PASODOBLE envisaged to increase interoperability and implementation efficiency. In doing so PASODOBLE has been stimulating the development of quality-assured air quality services towards their application market and selected services can easier be implemented for new regions, cities and users.

3. Utilisation of multiple cycles of service delivery, use, and assessment by users

In close collaboration with a wide spectrum of users, multiple follow-ups of service demonstration, use and assessment were applied. To achieve this goal, PASODOBLE comprised an initial phase of requirement analysis, service design, development and implementation with rapid prototyping. This was followed by two full annual demonstration and evaluation cycles, in which the services and the generic technical framework were assessed, with respect to user requirements and business planning. Such an iterative evaluation allowed for a better consideration of real user needs, the implementation of refinements, a realistic preparation for fitness-for-purpose of the service and finally assure a leading role for the users and optimise chances for market penetration.

4. Promotion of best practice and harmonisation

PASODOBLE worked at local and regional level but also at a broader scale, with the objective to move towards European harmonisation by integrating and promoting best practise tools to the air quality and related communities. Harmonisation was envisaged by actively contributing to and considering ongoing initiatives and directives like INSPIRE, SEIS, OGC, FAIRMODE and GEOSS.

Figure 1 The PASODOBLE concept, the project and its relationships within the wider Copernicus/GMES community

The objectives of PASODOBLE were implemented in the project concept (Figure 1). Pasodoble means "double step" and this is the philosophy which was followed: it takes only two steps to link the users with the Copernicus Services. PASODOBLE symbolises a first generic step from the Copernicus Services to the Downstream Service Cluster; and a second generic step from the Downstream Service Cluster to the users and market).

As a dance pasodoble is also a very passionate one. Accordingly, it was the commitment of the PASODOBLE consortium to serve the user requirements, which was realized by demonstrating the value of the services and service infrastructure, assessing and developing the markets as well as stimulating the development of sustainable and self-supportive services.

The health community support service line aimed at developing new information and alerting products, taking into account short term exposure to a mixture of pollutants, different pathologies, age classes as well as thermal discomfort. The focus was on the development and evaluation of such products we in close collaboration with specialists from the health sector and the establishment of communicative platforms for experts in different European hot spots. The final goal was to enable sensitive groups to take precautionary action. In doing so European citizens and people at risk can directly benefit from the developments within PASODOBLE.

The public forecasting and assessment service line foresaw the improvement of existing information services on air quality in a variety of regions and cities. In addition it aimed at the designand implemention of new services in regions and cities lacking such services so far. Emphasis was also on the development and demonstration of new applications , like traffic management support, harbour management support and tourist information systems. There were three overarching objectives in this service line. First, the work towards integrated physical, chemical and biological weather forecasting systems. Second, the necessary increase of the spatial resolution of forecastig and assessment services, in order to enable representative and reliable results, adequate enough to address the needs of the stakeholders. Third, the regional harmonisation of the services throughout Europe with respect to INSPIRE, metadata, interoperabillity, quality management and FAIRMODE guidance.

The service line on compliance monitoring support for particulate matter was designed upon request of regional environment agencies. The objective was to facilitate the reporting for agencies with compliance monitoring duties by providing crucial information on the exceedance using complementary satellite-based data. This service line envisaged to provide useful information on the extent and origin of exceedances in various regions i.e whether the exceedance is caused by local emissions or advected dust.

The service line on local forecast model evaluation focussed on supporting local authorities, city bodies and the scientific community by developing and demonstrating a comfortable to use software toolkit. It aimed at setting standard criteria and protocols for performance evaluation, promoting good practice with respect to FAIRMODE guidance, standardizing interfaces and formats and supporting accountability studies.

The PASODOBLE concept was completed by two interfaces shared by all services: The data interface IC-DATA aimed at providing efficient and effective links from the Copernicus Services, the space component, the in-situ component and other input data to the downstream services. The user interface I-USERS foresaw the development of a shopping window for the downstream services to the users comprising cutting-edge functionalities for interactive data visualisation, analysis and online evalution from the Downstream to the end-users and the marketplace. Rounding out the PASODOBLE concept were two cross-cutting activities "Quality Management" and "Marketing and Business Planning".
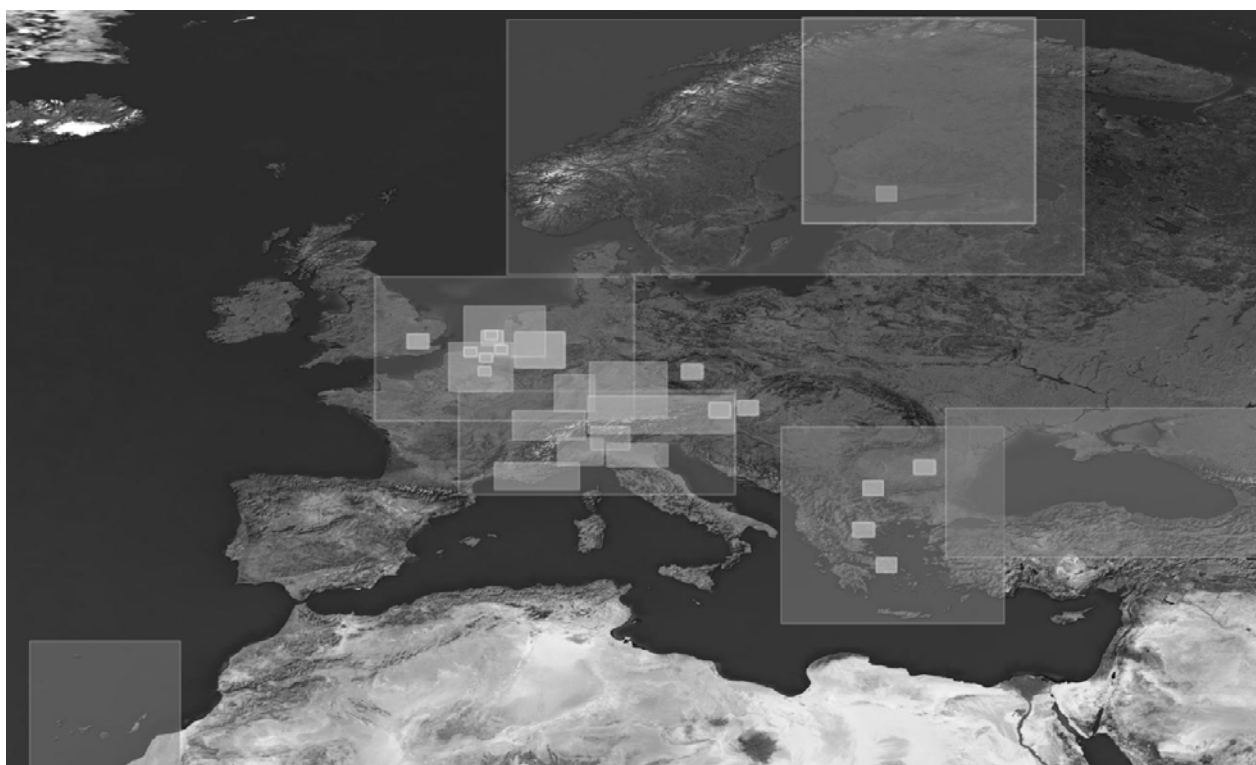
In summary, PASODOBLE sought to develop and evolve a variety of specific user-driven services in four thematic service areas as well as a generic, modular and harmonised service infrastructure. Such a well-balanced approach is the prerequisite for sustainable and self-supportive Downstream Services for the air quality sector in the future.

Description of Main Results

By close collaboration with local stakeholders and users, air quality services in 30 regions and cities throughout Europe have been developed by combining the capabilities of space-based data, in-situ measurement networks and modelling (Figure 2). In addition, an overarching modular technical infrastructure for air quality services in Europe has been developed based on latest information and communication technology.

The evaluation of the downstream services by the users regarding fitness-for-purpose was the highest priority to the project. The users provided feedback to two user evaluation reports. Three user workshops in Oberpfaffenhofen, Thessaloniki and Nice were organised as key element receiving feedback from the users and to discuss the further developments and sustainability of the services. The overall feedback from the users was positive and constructive. Many users were very satisfied with the products and services they obtain from the project. The positive evaluation was an important indication that the developments of the project adequately addressed their requirements and wishes. A continuation and collaboration beyond the project is highly desired.

In order to prepare and foster the self-supportiveness and sustainability of the downstream services, tailored procedures for business planning and market intelligence assessments have been elaborated in dedicated business plans covering the different thematic areas and services.

Figure 2 *Regions and cities covered by the PASODOBLE-Myair service portfolio*

All services have been subject of quality management, business planning and have been implemented using the generic technical infrastructure with respect to validation, interoperabaility, usage of data interfaces, metadata and INSPIRE-compliance. The evaluation of the services was harmonized and carried out using the forecast evaluation toolkit developed within the project. Due to the page limits, no detailed validation results will be presented in this report, however evaluation reports are available from the project.

Health community support services

In collaboration with the health community, services have been developed to provide appropriate, local and timely information to enable hospitals, pharmacies and doctors to mitigate the potentially harmful effects of air pollution among vulnerable groups. Together with medical specialists, new information products have been developed and are now being disseminated and used.

In a typical urban environment, the population is exposed to about 200 air pollutants or classes of air pollutants. Extensive research (World Health Organisation, 2000; Sunyer et al, 2003; Brauer et al, 2006; Cairncross et al., 2007; Katsouyanni et al., 1997; Kassomenos et al., 2008; Goodman et al, 2009; Hernandez et al, 2010) has demonstrated the associations between exposure to the classical pollutants (SO_2, NO_2, Particulate Matter PM and O_3) and ill-health endpoints of respiratory and cardiovascular diseases and mortality. Furthermore, time-series and epidemiological studies focused on the health effects, increases in hospital admissions or deaths, at the population level and may be used to calculate the short-term health impacts (Dominici et al., 2006; Liang et al., 2009; Stieb, 2009 and Strickland et al., 2010). Acute exposure to high ozone levels can induce changes in lung function, airway inflammation and increased airway responsiveness to broncho-constrictors. A range of chronic and acute health impacts may result from human exposure to SO_2 or related species. In its gaseous form, SO_2 can irritate the respiratory system, in case of short-term high exposure, a reversible effect on lung functioning may occur, according to individual sensitivity (WHO, 2000a,b,c; Maynard, 2004). At very high concentrations, NO_2 exposure can result in rapid and severe lung damage (WHO, 1999; Maynard, 2004). The available evidence suggests that ambient exposure may result in both acute and chronic effects, especially in susceptible population subgroups such as people with asthma. Various studies (WHO, 1999; Berktas and Bircan, 2003; Maynard, 2004) have demonstrated that the effects of particulate matter (PM_{10}, $PM_{2.5}$) are generally consistent. The available information does not allow a judgement to be made of concentrations below which no effects are expected (WHO, 1999). Effects on mortality, respiratory and cardiovascular hospital admissions and other health variables have been observed at levels well below $100 \mu g/m^3$, expressed as a daily average PM_{10} concentration. A report of the Committee on the Medical Effects of Air Pollutants focused on $PM_{2.5}$ as the air pollutant most strongly associated with increased risks of mortality (COMEAP, 2010). Fine particles can aggravate lung diseases such as asthma and bronchitis, causing increased medication use and doctor visits. If a person has a heart disease, and is exposed to particles, they may not be able to breathe as deeply or vigorously as normal. Air pollution is associated convincingly with many signs of asthma exacerbation, e.g. increased bronchial hyper-responsiveness, visits to emergency departments, hospital admissions and increased medication use (Sunyer et al., 1993; Atkinson et al., 1999).

Besides poor air quality, urban areas are also characterized by the well-documented urban heat island (UHI) effect. Overheating in urban areas can significantly deteriorate the thermal bioclimate and, thus, adversely influence human health and well-being (e.g. Nastos and Matzarakis, 2006). According to epidemiologic studies, people living in urban areas are exposed to an elevated risk of death compared to those living in suburban or rural areas, as a result of the deteriorated thermal comfort conditions (e.g. Conti et al., 2005; Matzarakis et al., 2009). Poor thermal bioclimatic conditions may significantly increase death rates in cities, especially during heat waves (e.g. Buechley et al., 1972; Clarke, 1972; Jones et al., 1982; Smoyer, 1998).

Why develop a new sanitary index?

Currently, the use of a single index to reflect air pollution levels creates several difficulties because different pollutants may have different health endpoints. This information may be lost, with a single index per pollutant, which is currently used in many countries (e.g. Australia, Canada, France, Germany, UK and USA). These indices are not able to take into account effects of a mixture of pollutants (potential

additive effects) but interactions have been proved difficult to disentangle (COMEAP, 2011). Moreover, none of the current indices considers health data in the risk calculation. A better scientific link was therefore needed to correlate the effect of air pollutant exposure and risk for human health to obtain an intuitive and easy to use communication tool. In the general population, and amongst vulnerable people, there is a lack of awareness regarding the links between air pollution and its adverse effects. The development of an adequate tool, the Aggregate Risk Index (ARI), based on health observations, is of utmost importance and allows obtaining a more appropriate description of the general population's exposure to air pollution and linking these events with effects on their health. The new sanitary index ARI is associated with the corresponding daily risk increase, easy to understand and intuitive for the general public. The information is accompanied by a situation-specific health advice to avoid or reduce exposure and actions to control their symptoms.

Methodology for computing the Aggregate Risk Index

The Aggregate Risk Index (ARI) is calculated from the Relative Risk (RR) values, for a given health endpoint, associated with a 10µg/m³ increase of each pollutant concentration. These RR values are obtained from the published exposure-response relative risk functions (InVS, 2002, 2006, 2007, 2008; WHO, 2001, 2004, 2008). For further information, the ARI methodology has been implemented and published by Sicard et al. (2011, 2012). The ARI enables an assessment of additive effects of short-term exposure to the main air pollutants. To account for the simultaneous short-term exposure to air pollutants, the final index is the sum of the normalised values of the individual RR_i values (Equation 1). It thus provides a ready method of comparing the relative contribution of each pollutant to total risk.

$$\text{ARI} = \sum_i (RR_i - 1) = \sum_i Index_i = \sum_i a_i \cdot C_i$$

Equation 1

C_i is the corresponding time-averaged concentrations (in µg/m³) and the risk index coefficient a_i is proportional to the incremental risk values $(RR_i - 1)$. For each pollutant and pathology the risk index coefficients, calculated from the RR_i values, allows deriving an arbitrary numerical scale specific for the study area. The averaging times for each pollutant are based on the recommendations published by the WHO (2006). Research has shown that variations in day-to-day concentrations of air pollutants can have delayed effects. Assessing these delayed effects is very difficult. A high concentration on a specific day could produce effects not only on that day or in the following few days but also for a month or more afterwards (Zanobetti et al, 2003; COMEAP, 2011). Moreover, the accumulated exposure during some days could produce a larger effect. In the index, days are treated as discrete events and not as a cumulative series. An arbitrary index scale, with a colour coding system, is used to facilitate risk communication (Figure 3). The index has four bands indicating "Low, Moderate, High and Very High" the increase of risk (Table 1). Using the spatio-temporal correlations between environmental (air quality forecasts) and health data (pharmacy network data and cohorts data implemented by Nice hospital, i.e. CHU-Nice), we have elaborated and refined the scale.

CHU-Nice has provided health data necessary for improving the risk index. For that, CHU-Nice created different workbooks adapted to several cohorts: asthmatic young children (4-11 years old), asthmatic children (11-15 years old), asthmatic children (15-18 years old) and asthmatic adults. The patients provided personal information (regular activities, means of transport, etc.), information on health status (symptoms, doctor visit, hospitalization, etc.) and feeling on air quality. All data have been anonymised and collected on a specified database on the website: **www.sante2air.eu**.

Index	Information level	Excess relative risk	Health messages	
			At risk population	**General population**
0	Low	Low risk of increase: 0 to 11.9%	Enjoy your usual outdoor activities. Follow your doctor's advice for exercise.	Ideal conditions for outdoor activities.
1				
2				
3				
4	Moderate	Moderate risk of increase: 12.0 to 20.9%	If you have heart or lung problems, consider reducing strenuous physical outdoors activities, or reschedule to times when the index is lower. Follow your doctor's advice for exercise.	No need to modify your usual outdoor activities unless you experience symptoms.
5				
6				
7	High	High risk of increase: 21.0 to 29.9%	Children, the elderly and people with heart or respiratory illnesses should **reduce/restrict** physical exertion outdoors, reduce/restrict the time of their stay outdoors and particularly if they experience symptoms or reschedule to periods when the index is lower.	Anyone experiencing discomfort such as coughing or throat irritation should consider reducing or rescheduling strenuous outdoor activities to periods when the index is lower.
8				
9			Follow your doctor's usual advice. People with asthma may find they need to use their reliever inhaler more often. If symptoms persist seek medical advice.	For outdoor workers, employers are advised to assess the risk of outdoor work, and take appropriate preventive measures to protect the health of their employees.
			They should also seek advice from a doctor before participating in sport activities.	
10	Very high	Very high risk of increase: more than 30.0%	**Health warnings** of emergency conditions.	**Health alert**: everyone may experience more serious health effects.
			Children, the elderly and people with heart or breathing problems should **avoid** physical activities and to avoid staying outdoors.	Everyone should reduce or rescheduling physical exertion, particularly outdoor activities to times when the index is lower.
			People with asthma may find they need to use their reliever inhaler more often.	

Table 1: *Scale for the Aggregate Risk Index, associated risk increase, health advice and information on the short-term effects for information and communication in the European regions.*

A thermo-physiological index

The thermal bioclimate comprises the meteorological parameters of air temperature and humidity, wind and radiation, which thermo-physiologically influence humans both outdoors and indoors. From the human health point of view, monitoring of the thermal bioclimate is significant due to the close relationship between the thermoregulatory and the circulatory system of the human body. Therefore, the assessment of thermal comfort conditions should be conducted using appropriate indices, which are derived from the human energy balance for the assessment of the thermal environment. The concept of thermo-physiologically significant indices is that the factors that influence human response to the thermal environment are properly integrated to provide a single index value.
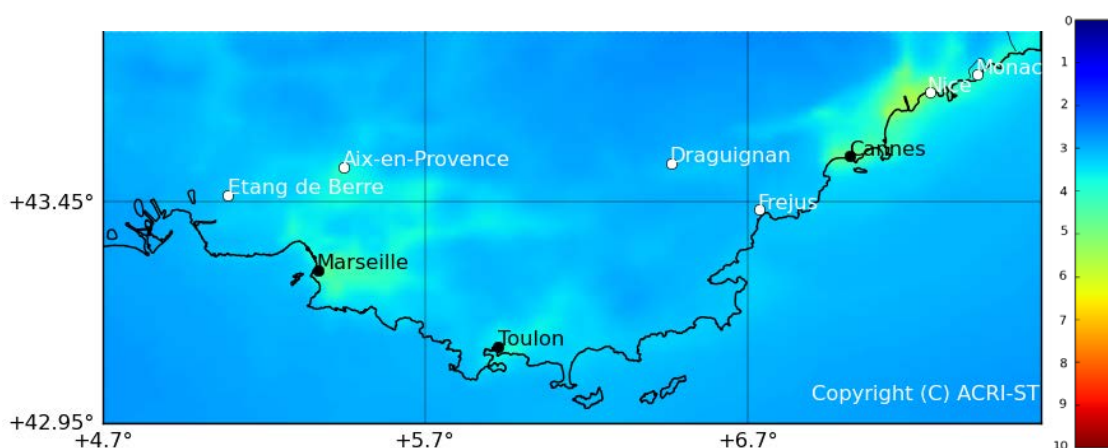
The universal thermal climate index (UTCI) was developed in the frame of COST Action 730. It follows the concept of the equivalent temperature. UTCI is calculated from a non-linear, analytical equation that relates this index to air temperature, mean radiant temperature, relative humidity and wind velocity. The interpretation of UTCI is carried out using a 10-class scheme ranging from extreme cold stress to extreme heat stress. No thermal stress is resulting from an UTCI between 9 and 26°C.

Regional health applications in Europe

In the framework of the PASODOBLE project, the Aggregate Risk Index and the Universal Thermal Climate Index were implemented at 3 European sites: Greece (Athens and Thessaloniki), the Netherlands and "Provence Alpes Côte d'Azur" (South East of France). The selected regions and cities are among the most affected by atmospheric pollution in Europe. The forecasting system has been implemented operationally and on a daily basis 72h forecasts of the Aggregate Risk Index are being provided for the three European sites. The systems have been built on the results of the air pollutant forecasting services reported later (The Airsheds – bridging the gap, page 11).

For the South-eastern France, we used the published exposure-response functions and a particular set of RR_i values published by the French Institute of Sanitary Wakefulness InVS (PSAS-9 project, 2002,

2006 and 2008). For the application in the two other European regions, we used the published exposure-response relative risk functions and a particular set of RR_i values. These functions and values have been published by the WHO (2001, 2004, 2008), APHEA-2 (Air Pollution and Health – a European Approach) under a procedure for health impact assessment for the study area (Katsouyanni et al., 1995, 1997, 2001). The exposure-response functions for the mortality (total, respiratory and cardiovascular causes) and the daily hospital admissions for respiratory diseases (15-64 and more than 65 years old), for asthma exacerbation (less and more than 15 years old) and for Chronic Obstructive Pulmonary Disease (COPD) were used.

Figure 3 *Daily risk index map of the cardiovascular daily mortality in April 2012 in South of France*

The daily UTCI maps have been implemented operationally, on a 3 or 6-hours basis depending on the site, providing forecasting data for 72 hours ahead of the initialization time. Air temperature, relative humidity and wind speed data are directly provided by the meteorological model, while the mean radiant temperature is indirectly derived following the methodology of Matzarakis et al. (2010).

Smoke Plume and Gas Cloud simulations for Emergency Services

During incidents with large fires or gas leaks the public needs to be adequaltely informed, alerted or evacuated to avoid severe health effects. However, fire departments and emergency workers face a severe lack of information about the concentrations and movements of the resulting smoke plume gas cloud. An incident in a chemical storage in the Netherlands in February 2011 illustrated this need. The fire was so large that it required participation of fire fighters from different regions. The smoke plume extended well into neighboring regions. Since the smoke was heavier than air the smoke plume descended as it cooled downwind and touched the ground at considerable distance from the fire. The smoke potentially contained several chemical species from the storage facility, as well as the products of the chemical reactions in the fire. As the species and concentration levels were not well-known, estimating the risk for affected regions was difficult or impossible.

The aim of this service is to provide emergency workers access to real time, sophisticated information about the weather and the movement of smoke and chemical species. To achieve this, a meteorological model is coupled to a chemistry-transport model (Skamarock et al., 2005). The models are integrated

with a state-of-the-art crisis management system: Eagle (Neuvel et al., 2010). A user interface is developed which conforms to existing procedures in crisis management. Network communication is used to give all the parties involved in an incident access to the same information (Scholten et al., 2008). This also allows the fire brigade's chemical specialist to share relevant information about a smoke plume with the other parties involved, in an understandable form.

The coupled modeling system was validated against the available observations from incidents in the Netherlands in the past years. Results are good, they match observations well (within expected uncertainty margins). The strength of the service is in the combination of several existing technologies (numerical models, GIS systems, the web and open map standards such as WMS, WCS and WFS). The combined service offers clear added value to the fire departments, and has been received very well by the users.
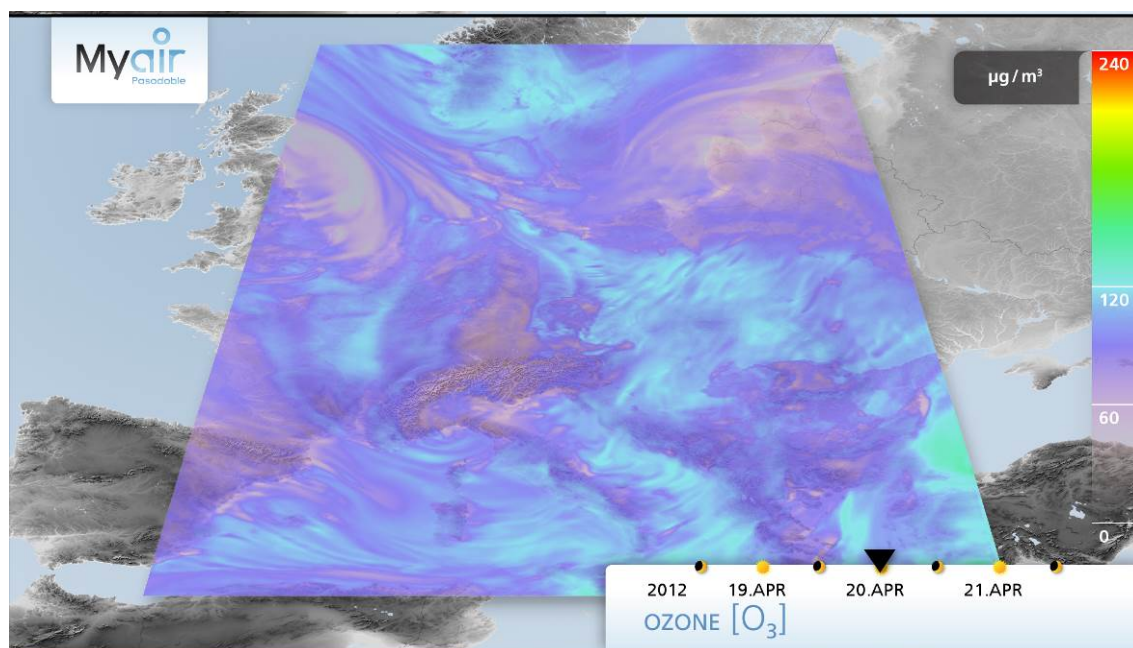
The Airsheds – bridging the gap

To bridge the gap between the high-resolution local/urban PASODOBLE forecasting services and the lower resolution services on the European scale provided by the Copernicus Atmosphere Service (MACC-II), five operational systems have been set up. These provide air quality forecasts of a.o. PM, O_3 and NO_2 at an intermediate resolution of approximately 6 km for different regions over Europe, the so-called airsheds. The systems have been developed by five different teams using different models driven by the boundary conditions from the European scale MACC core service air quality forecasts. The airsheds forecasts have been subsequently used as boundary conditions and initialization for the local/urban scale services defined within PASODOBLE linking the Core Service with the downstream services. But also new services will be able to use the airsheds forecasts. This is one of the important advantages of PASODOBLE: a generic and harmonized infrastructure allowing easy application of new services.

The location of the five airsheds have been defined in such a way that they cover most of the downstream services developed within the PASODOBLE:

1. **Central, Western and Southern Europe** (~3W-20E; 41-59N). Delivered by the Rheinisches Institut für Umweltforschung an der Universität zu Köln (FRIUUK) with EURAD-IM model.
2. **Central and Southern Europe** (4-18E; 41-51N). Delivered by ACRI-ST with the CHIMERE model.
3. **Northern Europe** (4-33E; 54-71N). Delivered by the Finnish Meteorological Institute (FMI) with the SILAM model.
4. **South-East Europe** (~13E-30E; 35N-48N). Delivered by the Aristotle University of Thessaloniki (AUTH) with the CAMx model.
5. **Joint airshed** (2W-30E; 35-62N). Delivered jointly by KNMI, RIVM and TNO with the LOTOS-EUROS model.

The nesting within the MACC ensemble, which provides forecasts for 6 species on a limited number of levels, has been tested. Results show that the set of required boundary species depends on airshed location, airshed size, the used model and it's chemistry scheme, the species that is computed, and possibly also the time of the year (de Ruyter de Wildt et al., 2012). Two airsheds are using the MACC ensemble data (in combination with one of the ensemble models for missing species). The other three airsheds use data from one of the ensemble models or from the global MACC product (Mozart) as the MACC European forecasts coverage was not sufficient.

Figure 4 *Forecast of O₃ concentrations for central Europe with intermediate resolution by the joint airshed - snapshot of a high definition animation that is produced daily for various regions. The joint airshed is the largest domain served by PASODOBLE.*

In addition to forecasts, an operational air quality analysis for the Central, Western, and Southern European airshed is delivered. For this analysis surface in situ measurements of O_3, NO_2, NO, SO_2, CO, and PM_{10}, and NO_2 column retrievals from OMI and GOME-2 are hourly assimilated.

A harmonized evaluation of the airsheds has taken place using the Myair model evaluation toolkit (The Myair Model Evaluation Toolkit, page 26) over the period of July-August 2010 and background stations from the Airbase network (Katragkou et al., 2013). Conclusions from this evaluation exercise are: Ozone is reproduced successfully by all models, with low bias and overall errors, occasionally missing the O3 peaks. All models underestimate PM (with a factor of 2-3), probably due to missing components, sources and/or emissions. NO and NO_2 are underestimated in some of the airsheds, this needs some further investigation. In most cases the modeled variability is lower than in observations. All data of the airsheds is available online via an easy to use web service (A common data interface, page 27).

Public forecasting and assessment services

The 2008 Olympic Games in Beijing demonstrated how air pollution can impact on large sporting events and the regional economy. In Europe, legislation demands that the public is informed about air pollution levels. Therefore the service line on air quality forecasting and assessment support aims at providing cutting-edge information at a high spatial resolution (Figure 5). The services have been developed together with stakeholders and are also provided to the public via public bodies and their websites or other dissemination channels. The service developments can be sorted into three groups: improvement of existing services, design and implemention of new services in regions and cities lacking such services and finally, the development and demonstration of new applications like traffic management support, traffic scenario assessments in cities and tourist information systems and. Furthermore, the forecasting services are the prerequisite for the health community support services.
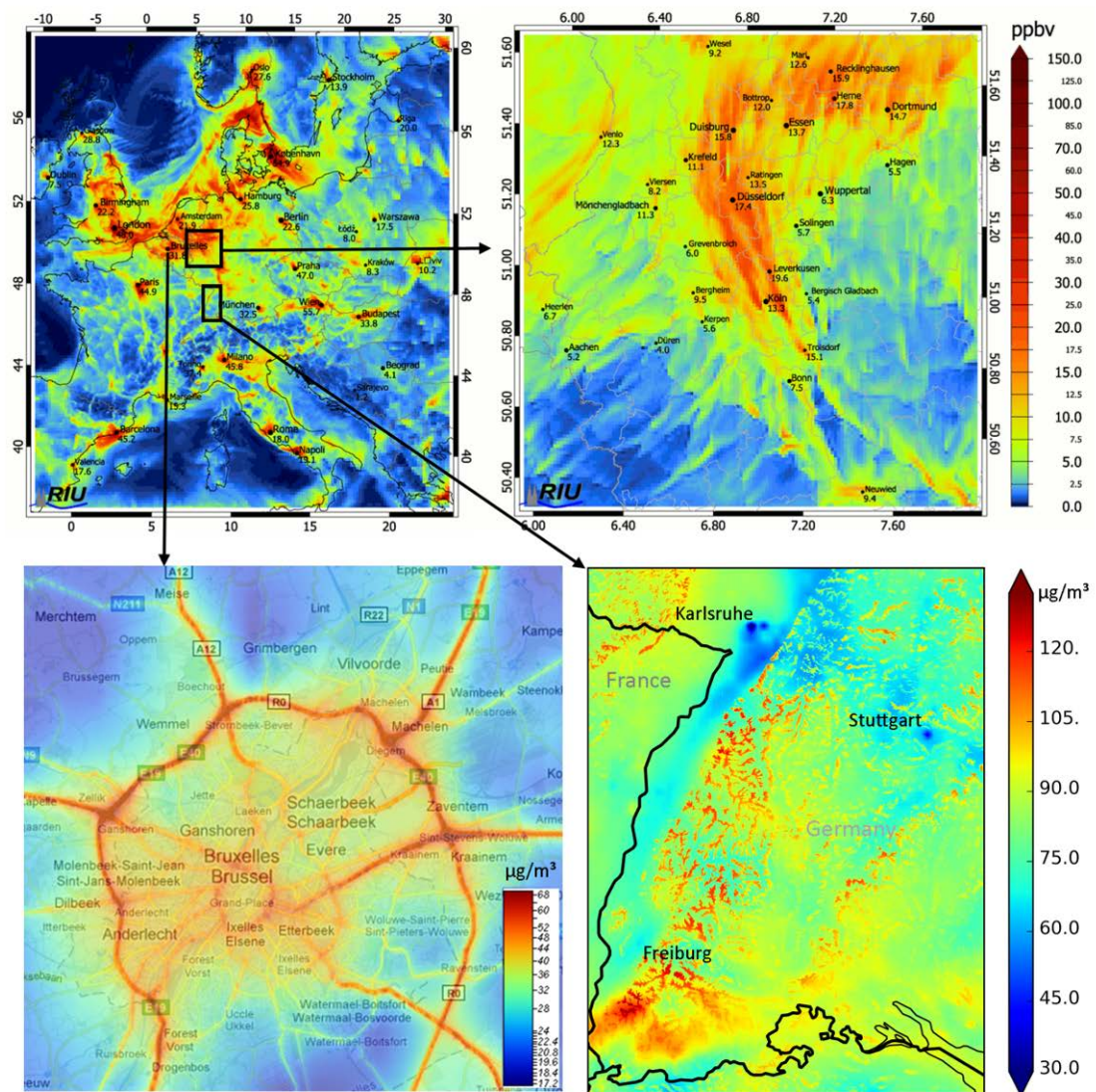
From a methodological point of view, this service area has developed thematically integrated services combining information on air quality, pollen concentration, UV radiation and meteorology. Therefore it has been contributing to developments in integrated physical, chemical and biological weather

forecasting and turning it into intuitive information. One overarching goal, which has been achieved is the regional harmonisation of the services throughout Europe with respect to INSPIRE, metadata, interoperabillity, quality management and evaluation following FAIRMODE guidance.

The PASODOBLE forecasting and assessment services were able to demonstrate the need for high resolution modelling in addition to that undertaken in MACC at European scales not only for urban hot spots. The regional forecasting service for North Rhine-Westphalia clearly demonstrated that high resolution modelling (1x1km²) and taking into account in-situ traffic stations in the data assimilation procedure significantly reduces the root mean square error of the forecasts. For the Black Forest in Germany it could be shown that the complex orography needs to be considered by high resolution three-dimensional air quality modelling to get reliable forecasts; i.e. accounting for possible high ozone values at the mountain tops.

An air quality assessment study on human exposure for Brussels shows that more than 342.000 citizens were exposed to annual mean nitrogen dioxide concentrations exceeding the European threshold of 40μg/m³ in 2005 compared to none when large scale modelling is applied. To capture the strong concentration gradients of air pollutants, high spatial and temporal resolution air quality modelling combined with state-of-the-art satellite and in-situ observation is needed to accurately estimate human exposure and to properly alert on air pollutant levels.

Figure 5 *Selection of air quality services covering different scales, features and application areas (clockwise, starting top left): Forecast of the daily NO₂ maximum for Central Europe (5x5km²) for April 12, 2012. Same forecast at high resolution (1x1km²) for a densely populated and industrialized area in North Rhine Westphalia. Ozone forecast (2x2km²) in complex orography for the Black Forest, a mountainous tourism region in Germany for April 12, 2012. Yearly NO₂ assessment for Brussels at street level resolution for 2005.*

Forecasting and alerting service for London

The London *air*TEXT forecasting and alerting service has been operational across Greater London since March 2007. It predicts nitrogen dioxide (NO_2), ozone, PM_{10} and $PM_{2.5}$ ($PM_{2.5}$ added in July 2012) in terms of a health index banding (the UK "Daily Air Quality Index", or "DAQI", defined by the UK Department for the Environment, Food & Rural Affairs (Defra)). The forecasts are presented on a user-friendly web site (**www.airtext.info**) as maps as well as "pins" representing the forecast per borough. The forecast was extended from 48 hours to 72 hours from July 2012. When pollution is moderate, high or very high alerts are issued to over 7.000 users who have self-subscribed to the service. Alerts are issued via SMS, voice mail, email and Twitter (Twitter since July 2012).

Under PASODOBLE the *air*TEXT service was developed to include forecasts of maximum temperature, grass pollen and ultra violet radiation. This was trialled in the London Borough of Islington as a "Daily Health Bulletin" PDF document, emailed daily to subscribers in the summer of 2011. It was designed to be printed out and pinned up in public spaces such as libraries, leisure centres, health centres and schools. In July 2012, grant funding from Defra enabled this service to be rolled out for all London Boroughs and extended from a 24-hour forecast to a 72-hour forecast, in response to user feedback. This service is now an integral part of the operational *air*TEXT service.

Feedback from the Islington trial also highlighted the desire amongst users to have the air quality, temperature, pollen and UV forecasts available in a smartphone application (app). In July 2012 the free *air*TEXT app for iPhone and Android phones was launched together with the new *air*TEXT website.

In the frame of the PASODOBLE project the air quality information service for the Olympic Games 2012 in London was provided. The *air*TEXT service was launched at a large event at the London Town Hall. The service became part of Secretary of State's plan in providing Olympic air quality info. The Mayor of London has given advice to Olympic athletes on using *air*TEXT alert services to keep them informed of possible health risks caused by air pollution.

Figure 6 *PASODOBLE user Paul Clift at the town hall presentation of the airTEXT service for the Olympic games in London 2012.*

Tourism information systems in Southern Germany

Air pollution does not stop at city borders. In fact, pollution from cities, roads and industries is transported to remote locations and complemented by local biogenic and anthropogenic sources. On the other hand, mountain regions and nature parks such as the Black Forest are popular touristic hideouts. The Black Forest, situated in the south-west of Germany, is one of the most popular outdoor sports and recreation destinations in Europe with approximately 30.000 km of signposted hiking and 10.000 km of signposted cycling and mountain bike trails. On average, around 22 Mio guests use these trails every year.

Tourist information and navigation systems have become increasingly popular throughout the outdoor recreation world in the last 10 years. The Naturpark-Scout GPS Navigation System was designed to guide these outdoor oriented target groups through this network of trails. Each guest can choose to download pre-designed round tours on his GPS navigation system or let the system work out an individual route which matches certain characteristics the user can define upon his individual needs and interests.

The air quality forecasts provided by PASODOBLE are an additional information layer the user can add to the map and consider in the activity planning. The objective was to provide air quality information at a resolution, which is accurate enough to be usable by the target group. This goal was achieved using the air quality model POLYPHEMUS/DLR, based on the POLYPHEMUS model system developed by (Mallet, et al., 2007). Over the Black Forest a horizontal resolution of about 2km and provision for the complex terrain has been achieved. The nesting chain starts with boundary conditions at European level, while an intermediate domain covering the Alpine area, southern Germany and northern Italy at a resolution of $^1/_8$ x $^1/_{16}$ degree links the target domain for the Black Forest.

To consider the complex orography of mountain areas a downscaling method was developed taking into account the three-dimenstional model fields of the pollutant forecasts and a Digital Elevation Model from the Shuttle Radar Topography Mission. The results of this correction procedure reflect e.g. the fact that ozone concentrations are increased at larger heights. An evaluation with the Myair model evaluation toolkit showed significant improvements in particular in inversion situations. As such the information is deemed to be relevant to tourism information. Currently, the Naturpark Scout is the only navigation system which provides environmental information and service. Using these tailored forecasts the system can now also be exploited for the health and wellness tourism which has a long tradition in the Black Forest.

Dynamical road traffic management service

The Dutch Directorate-General for Public Works and Water Management (Rijkswaterstaat) has conducted a series of pilot projects related to dynamical management of road traffic. In one of the experiments it was studied whether local exceedances of the boundary value of the PM_{10} concentration can be prevented by lowering the speed limit on the motorway near Tilburg, in the south of The Netherlands. For the pilot the KNMI has delivered 6-day forecasts of the local PM_{10} concentrations. Whenever a daily mean PM_{10} concentration above a certain threshold was forecast, the speed limit at the test site was lowered. In particular, the KNMI has studied the reliability of the PM_{10} forecasts up to 6 days ahead as required by Rijkswaterstaat (De Ruyter de Wildt et al., 2011). After the pilot project ended, the cooperation with the user ceased, due to a change of priorities. As a result, no further air quality based road traffic management system has been established in The Netherlands so far.

Emissions from shipping

The emissions from shipping have been studied by KNMI, based on available satellite observations (GOME, SCIAMACHY, OMI) of NO_2. By studying the major shipping lanes worldwide (De Ruijter de Wildt, 2012) trends could be established. Overall there is a significant positive trend in shipping emissions, but the impact of the economical crisis at around 2008-2009 led to a clearly observed emission reduction for a couple of years. Such observed relative trends may be used in multi-year modelling studies.

Traffic Scenarios and Air Quality Assessment Services for Cities

In the period 2001-2010, 18-41% of the urban population in EU-27 was potentially exposed to ambient concentrations of particulate matter (PM_{10}) in excess of the EU limit value set for the protection of human health (50 microgram/m^3 daily mean not to be exceeded more than 35 days a calendar year, EU directive 2008/50/EC) whilst 6-27 % was potentially exposed to ambient nitrogen dioxide (NO_2)

concentrations above the EU limit value (40 microgram NO_2/m^3 annual mean). Traffic is a key contributor to these exceedances, and so it is important for city authorities to assess the contribution, and investigate and implement mitigating traffic management plans.

Demonstrating some of the modelling tools required for the different spatial scales and the challenges involved to provide detailed accurate information at the local scale, VITO carried out an assessment of the Air Quality situation in Brussels to evaluate the "current" impact of air quality on the residents. This is for determining the impact of an air quality traffic management scenario i.e. to assess the impact of reducing the traffic flow on the 'Brussels Small Ring' (R20). Concentration maps for NO_2, PM_{10}, $PM_{2.5}$, EC, and O_3 were produced.

Case study: Air quality action plan city for Antwerp

The Antwerp area (city and harbour) is known as an air quality hot spot region in Europe. This is mainly due to the large volumes of transport associated with the Ports of Antwerp and Rotterdam and the high population density of Flanders. Despite ongoing actions towards a more sustainable environment, air quality levels in Antwerp still exceed European limits, especially along the main roads and heavy traffic congestion points (Figure 1)

Figure 1 – Annual mean NO_2 concentration map of Antwerp ($\mu g/m^3$)

VITO has worked with the Antwerp city authorities to assess a series of different mitigation measures using its traffic scenario assessment service. Measures investigated include a **low emission zone** (LEZ), and a **congestion charge** in combination with local **traffic management plans**. This results in different 'Impact Maps' of the Antwerp area, which give a high-resolution view, up to the street level, of the potential impact of different measures on air quality. Figure 2 illustrates an example of the impact of an ambitious package of mitigation measures on NO_2 emissions, which results in a projected 15% decrease in NO_2 concentrations in the city centre of Antwerp. The city of Antwerp is now implementing an air quality action plan, which incorporates the most cost-effective measures to improve the air quality in the city. Tools used in this service include: a traffic emissions model and a street canyon level air dispersion modelling tool.

Figure 2 – Annual mean NO_2 concentration difference map (in %) between a mitigation scenario and the base year

Figure 7 *Assessment service demonstaration for city of Antwerp.*

For modeling a region as Brussels, it is insufficient to rely only on a 3-4km scale interpolation model such as RIO, as its results are not detailed enough. RIO is a geospatial interpolation model, using land cover information as a proxy parameter to drive the interpolation (**http://rma.vito.be/demo**) (Janssen et al, 2008, Hooyberghs et al., 2006). On the other hand, a bi-Gaussian plume model such as IFDM does not account for regional air pollution patterns. In order to combine the best of both worlds, the two models are coupled to cover both the regional aspects of the air pollution phenomenon and the large gradients along the major line and point sources. A coupling procedure, eliminating the double counting of emission sources, is used (Lefebvre et al., 2011).

In conclusion, the added value of the high resolution RIO-IFDM model over RIO relies on the provision of good traffic emissions data and traffic stations for the validation. This is almost always lacking in many EU cities. In discussions with other interested users, it emphasized, that a generic traffic modelling platform would be beneficial for many cities, which do not have their own modelling tools.

Forecasting services for New Regions and Cities - Athens and Thessaloniki

The Aristotle Universtiy Thessaloniki has developed an operational system to provide air quality forecasts of PM_{10}, O_3, NO_2, SO, and CO at high resolution of 2 km over the Greater Athens and Thessaloniki regions. These domains are nested within the South Eastern European airsheds (Figure 2). which is in turn nested within the parent European grid (30 km) forced by the global scale MACC air quality forecasts. New services will be able to use the airsheds forecasts easily. The system runs operationally and provides 72h forecasts. The results serve as basis for the health community support services in Greece. The forecasts are presented at **http://lap.physics.auth.gr/pasodoble.asp.**

Air quality forecasts have been evaluated with the My**air** model evaluation toolkit. Results indicate an satisfactory model performance for ozone with error < 20% over rural areas, a strong underestimation of NO_x and PM_{10} and a location-dependent behavior for SO_2 and CO.

Forecasting Services for New Regions and Cities – Bulgaria and Sofia

Several versions of the Bulgarian Chemical Weather Forecast and Information System (BGCWIFS) have been developed during the PASODOBLE project. The final version of the system (BgCWFIS v.3) is based on CMAQ v.4.6 (Community Multi-scale Air Quality model, Denis et al.,1996, Byun and Ching, 1999, Byun and Schere, 2006), WRF v.3.2.1 (Weather Research and Forecasting Model, Skamarock et al., 2005, Skamarock and Klemp, 2008) and finally SMOKE (Sparse Matrix Operator Kernel Emissions Modelling System, Coats and Houyoux, 1996, Houyoux and Vukovich, 1999, CEP, 2003). The simulations are carried out in nested domains with the following horizontal resolutions: Bulgaria - 9km, Sofia district - 3km and Sofia city - 1km.

The Bulgarian national emission inventory is used for the territory of the country. GIS based emission pre-processing procedures have been developed for gridding the emissions, performing speciation and introducing temporal profiles. The chemical boundary conditions for the Bulgaria domain are taken from the PASODOBLE airsheds. Particularly, results from the SILAM model are exploited (Sofiev et al., 2006, 2008, Vira and Sofiev, 2012, Kukkonen et al., 2012).

In order to make the forecasts public, a specialized web-site was created **http://www.niggg.bas.bg/cw3/**. 5 main pollutants (Ozone, NO_2, SO_2, CO, and PM_{10}) as well as AQI and the dominant pollutant in AQI (dpAQI) are presented there. Several AQI are exploited within working groups over Europe (Leeuw and Wim, 2005). The Bulgarian Chemical Weather Forecast and Information System use the UK index (p.25 of the just cited report) for its forecasts.

Forecasting Services for New Regions and Cities – Prague and Bratislava

For both Prague & Bratislava, a high resolution (1km x 1km) air quality forecasting service (up to 72 hours) was established, providing daily pollutant concentration maps (in µg/m³) of O_3, PM_{10}, $PM_{2.5}$ and NO_2. Subscribed users are currently receiving daily emails which contain a link to the My**air** OGC compliant web application where their service can be viewed and analysed. This mail also provides a visual overview of the forecast maps for the next 3 days for each of the pollutants.

All in all, the model evaluation showed that the AURORA model chain is currently able to accurately model the observed O_3 concentrations. For both PM_{10} and NO_2, the model tends to underestimate the observed values. In general, the differences between the model results for the different forecast horizons (current day, 24 and 48 hours) were found to be negligible.

Regional forecast for the Netherlands and the Dutch provinces

This service delivers analyses and forecasts of the main AQ parameters to the Dutch Institute for Public Health and the Environment (RIVM) and the Dutch provinces. These parameters include concentrations of NO_x, O_3, SO_x, NH_x, $PM_{2.5}$ and PM_{10} and an AQ index, with a focus on ozone, nitrogen oxides and PM. The official forecasts are presented by RIVM to the public through several media: teletext, internet (**http://www.lml.rivm.nl/**) and, more recently, the smartphone app "Luchtkwaliteit". The service includes The Netherlands and neighbouring countries, as well as the PASODOBLE airshed domain. The system is nested within the MACC-II system and produces, once per day, an analysis and a three-day forecast. Service providers are TNO (maintaining the LOTOS-EUROS model code) and KNMI (operational service provision).

The air quality model LOTOS-EUROS has been upgraded from version 1.6 to version 1.8 in 2012. For total PM the addition of mineral dust, changes in the deposition scheme, and a new treatment of sea salt, have reduced the bias of total PM in the model. New model developments are included in yearly major upgrades of the system. This includes data assimilation improvements (e.g. Curier et al.,2012).

Verification is performed by user and co-developer RIVM. Before a new model version becomes operational, the expected performance is documented based on a 4-year integration. Model versions with degrading performance may then be rejected. At the end of each year the analysis and forecasts of the past year (and summer season) are evaluated to document the overall performance and success in predicting exceedances.

Forecasting services for Northrhine-Westphalia and the Black Sea

The major goal of the public forecasting and assessment services from the Rhenish Institute for Environmental Research (RIUUK) is to satisfy the user needs for specific information on air quality: the Landesamt für Natur, Umwelt und Verbraucherschutz (LANUV) of the German federal state Northrhine-Westfalia and the Black Sea Commission. Within PASODOBLE this information is provided by combining air quality modeling and observational data like satellite retrievals and in situ data by data assimilation techniques. Three operational services have been set up, which provide daily 72h air quality forecasts and analyses of the previous 24 hours for different regions with specific horizontal resolutions: Northrhine-Westfalia (~5W-10W, 50N-53N) with a horizontal resolution of 5km, Ruhr-Rur Area (~6.4W-7.7W, 51N-51.8N) with 1 km horizontal resolution, Black Sea Area (~27W- 42W, 40W-47N) with 15 km horizontal resolution.

AQ forecasts and analyses are produced with the comprehensive Eulerian Chemistry Transport Model EURAD-IM (Ackermann et al., 1998, Memmesheimer et al., 2004, Elbern et al., 2007, Friese and Ebel, 2010). To provide the AQ analysis, MACC NRT surface in situ observations and NO_2 column retrievals from OMI and GOME-2 are assimilated each hour using intermittent 3d-var. The services are accessible through the website **http://db.eurad.uni-koeln.de/en/forecast/eurad-im.php**. They will be sustained beyond the end of the PASODOBLE project.

Forecasting and assessment services – Fennoscandia and Helsinki

Within the project, an operational air quality forecasting and analysis system based on the SILAM chemical transport model has been established. The forecasting suite for air quality consists of 3 nested domains. The largest one is the MACC domain, which covers Europe. The Fennoscandia (Northern European) airshed has been set up and extensively verified within PASODOBLE. The high-resolution domain covers Gulf of Finland, Southern Finland and Estonia. The spatial resolution of that forecast is 3 km, with the forecast horizon being 36 hours. For all three domains, SILAM v.5.1 is currently used as the computational engine. The suite provides all main AQ characteristics for the respective domains: sulphur and nitrogen oxides, ammonia, ozone, primary and secondary particulate matter, sea salt, several other

inorganic and organic species. Primary user of the AQ forecasts was: Helsinki Regional Environmental Service Authority HSY, a governmental agency that provides water supply, sewerage and waste management services for over one million inhabitants in the Helsinki region. HSY also provides regional and environmental information, for example, on air quality and housing.

Fire plume forecasting service

Apart from the above "classical" AQ information, FMI PASODOBLE AQ services included the European-scale fire plume forecasting system. Near-real-time fire information from satellite observations (MODIS) is being assimilated to the operational AQ forecasts. European fires vary strongly in different regions; their spatial pattern is extremely patchy. Thus air pollution due to fire emissions requires very high spatial resolution for treatment. The Fire Assimilation System based on NRT satellite fire monitoring products, such as Temperature Anomaly and Fire Radiative Power, has been linked with the dispersion modelling system SILAM. The emission fluxes have been made available for the other PASODOBLE service providers, so as for the core users. At present, historical fire emission starting from 2000 is open at **http://is4fires.fmi.fi** and at GEIA data portal (**http://geiacenter.org**).

The tailored fire information products are used by the Helsinki Regional Environmental Service Authority, the public, and several research and application projects. Particular interest was attracted by the historical fire emission data in combination with the assessments of the injection height of the fire smoke, which were used in several research projects.
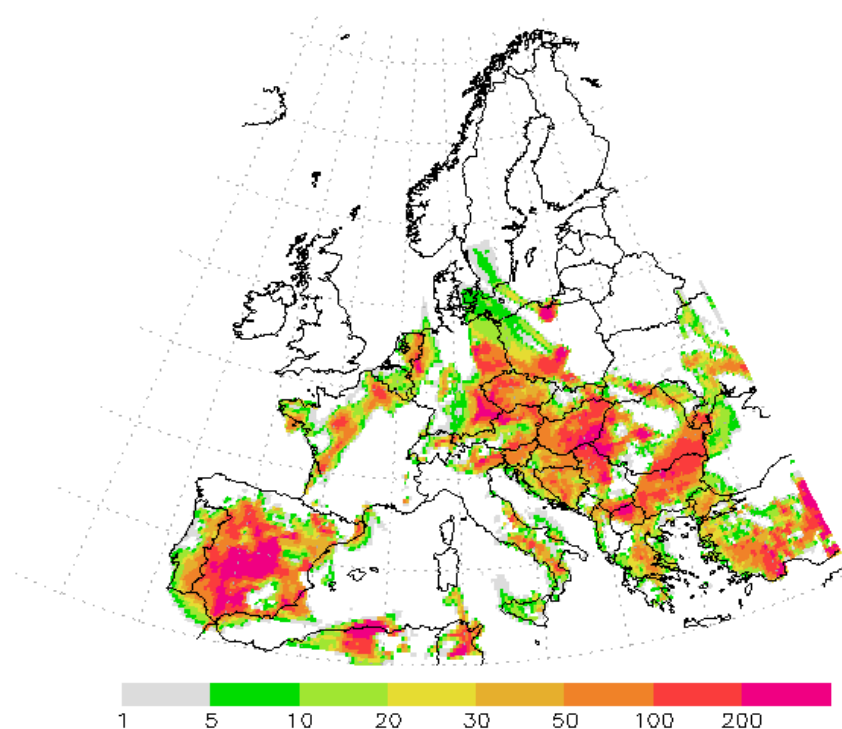
Pollen forecasting and near-real-time provision of aeroallergens

The PASODOBLE pollen forecasting service has been developed as a joint action of the Finnish Meteorological Institute and the Medical University Vienna (MUW), which represents the Europe-wide pollen observational network (European Aeroallergen Network EAN). The service provides tailored information on the allergenic pollen content of the atmosphere, which has a direct impact on human allergy. The service covers whole Europe (Figure 8) and is provided for birch, grass, olive, and ragweed pollen.

Since spring 2013, birch forecast has been introduced in MACC, which therefore took over the PASODOBLE birch line. In this connection, FMI has developed the birch forecasts (and also included other taxa) for the same three nested domains as the main AQ forecasting: added domains included Northern airshed and high-resolution Gulf of Finland area (see **http://silam.fmi.fi**). Possibilities for other regions can be considered as well in the future.

The service content: Concentrations of natural allergens in air, integrated allergenic indices developed in co-operation with core users. The services are provided on a daily basis and constitute of 96-hours-long forecasts. Resolution of the European-scale forecast is 20km, whereas for nested domains it is 7 and 3km, respectively.

Primary users of the service are the partners of EAN, with MUW playing the role as a system integrator and developer of the dissemination activity via Web portal **http://www.polleninfo.org**. The service is primarily used for health-related applications, including development of professional aeroallergen users throughout Europe. Comparative analysis of the 4 species available from the forecast also allows regionalization of the information for the species characteristic for main European regions: boreal and central (birch, grass), southern (grass, olive), south-east-to-rest-of-Europe invasive species (ragweed).

Figure 8 *Grass pollen (Poaceae) concentrations over Europe [in grains/m³]. SILAM forecast for 16.5.2013.*

The operational maps of near-surface pollen concentrations and supplementary phenological and meteorological parameters are publicly available at the above Web resources. The numerical data are subject to restrictions but can be requested via the European Aeroallergen Network. Possibility of the service evaluation in near-real-time is very limited due to essential absence of NRT pollen information. Options of actualization of the forecasts and their evaluation are discussed in a separate PASODOBLE report.

Compliance monitoring support services for particulate matter

The Directive 2008/50/EC on Ambient Air and Clean Air For Europe (CAFÉ) lays down requirements for compliance monitoring of regulatory pollutants and reporting of exceedances of their respective thresholds. The service line for compliance monitoring support for particulate matter has collaborated with agencies with air quality directive compliance duties with the aim to facilitate their reporting. In recent years, the use of satellite observations for air quality assessment has significantly enlarged, although there are still improvements needed for operational use in air quality (Hoff and Christopher, 2009). The increasing capabilities of Earth observation satellites in the retrieval of anthropogenic and natural aerosols and their strength of synoptic views enables a complete and homogeneous monitoring of the spatial distribution of particulate matter (PM) concentrations over large areas, whilst also complying with the EC (Gupta and Christopher, 2008).

The achievements of PASODOBLE include the provision of services for the explanation of exceedances whether they are caused by local emissions or advected dust. This service line has introduced satellite data, complementary to ground-based data, to better cover the spatial extent of pollution and to quantify mineral dust loadings and $PM_{2.5}$ levels. Moreover, it could be demonstrated that natural contributions can be separated from anthropogenic ones by satellite-based retrievals, which is not

possible by the standard in-situ instrumentation for particulate matter. The downstream services have been demonstrated and evaluated in close cooperation with legally mandated organisations in North Rhine-Westphalia (Germany), the Canary Islands (Spain), the Netherlands, Emilia Romagna and Lombardy (both in Italy).

Separating Natural from Anthropogenic Particulate Matter

LANUV, as regional authority of North Rhine-Westphalia in Germany, has among others the duty to monitor air quality. With a network measuring particulate matter up to 2.5 and 10µm size ($PM_{2.5}$ and PM_{10}) LANUV monitors the compliance with EU directive 2008/50/EC, which permits only 35 exceedances of daily mean PM_{10} above 50µg/m^3 per station per year - to safeguard the population from adverse health effects. The directive allows the subtraction of exceedances caused by natural origin. It was the goal of this service to demonstrate compliance monitoring by satellite with its comprehensive view on a region as complementary tool to the point measurements at the ground stations.

Individual satellite-based $PM_{2.5}$ observations typically show errors of 30% and reach correlations up to 0.6 with RMSE up to 10 µg/m^3. This uncertainty is inherent to all methods, which convert aerosol optical depth (AOD) into PM with the most critical unknowns being vertical profile shape, varying aerosol properties and horizontal smoothing in large satellite pixels vs. station observations. SYNAER developed at DLR-DFD for a radiometer spectrometer combination onboard polar orbiting satellites such as ENVISAT (T. Holzer-Popp, 2008) and MetOp allows retrieval of AOD and aerosol composition which serves as basis for deriving PM (T. Holzer-Popp, 2002; F. Baier, 2011). The aerosol type information in SYNAER tackles one of the critical issues lined out above, so that the method can be applied all over Europe without any need for local tuning. To overcome the other aspects, the product of choice is mapping annual mean PM values under assumption of a well-mixed boundary layer. Furthermore, the aerosol type offers the possibility to produce maps of so-called "local PM", after subtracting coarse mode aerosols like sea salt and mineral dust. Satellite-based PM results are dependent on the underlying AOD retrieval within the core service MACC-II: Limited temporal coverage and individual pixel AOD uncertainties determine the quality of the annual mean PM maps. The transition of SYNAER from ENVISAT to MetOp (with much better temporal coverage) and their radiometer/spectrometer instruments AATSR/SCIAMACHY to AVHRR/GOME-2 led to the need for extra efforts to adapt the parameterization of surface brightness to broader radiometer channels.

Annual mean maps of $PM_{2.5}$ and PM_{10} together with "local PM_{10}" were produced from ENVISAT for 2007–2009 and with METOP for 2008 covering entire Europe and selected regions (North Rhine-Westphalia, Po basin). Products were validated against annual mean PM concentrations calculated from station measurements operated by LANUV and EMEP. This satellite product is unique for air quality monitoring according to the core user LANUV and could become valuable subsidiary information for regional authorities all over Europe depending on the evolution of the European air quality directives. With an RMSE of 5 µg/m^3 against rural LANUV stations the annual METOP product shows a better performance than individual satellite PM pixels.

SYNAER will become operational using MetOp's AVHRR/GOME-2 within MACC-II after consolidating the necessary optimization of the MetOp AOD retrieval. Using the operational MetOp platform will then enable a cheap post-processing of the SYNAER product into annual mean PM maps for the next decade.

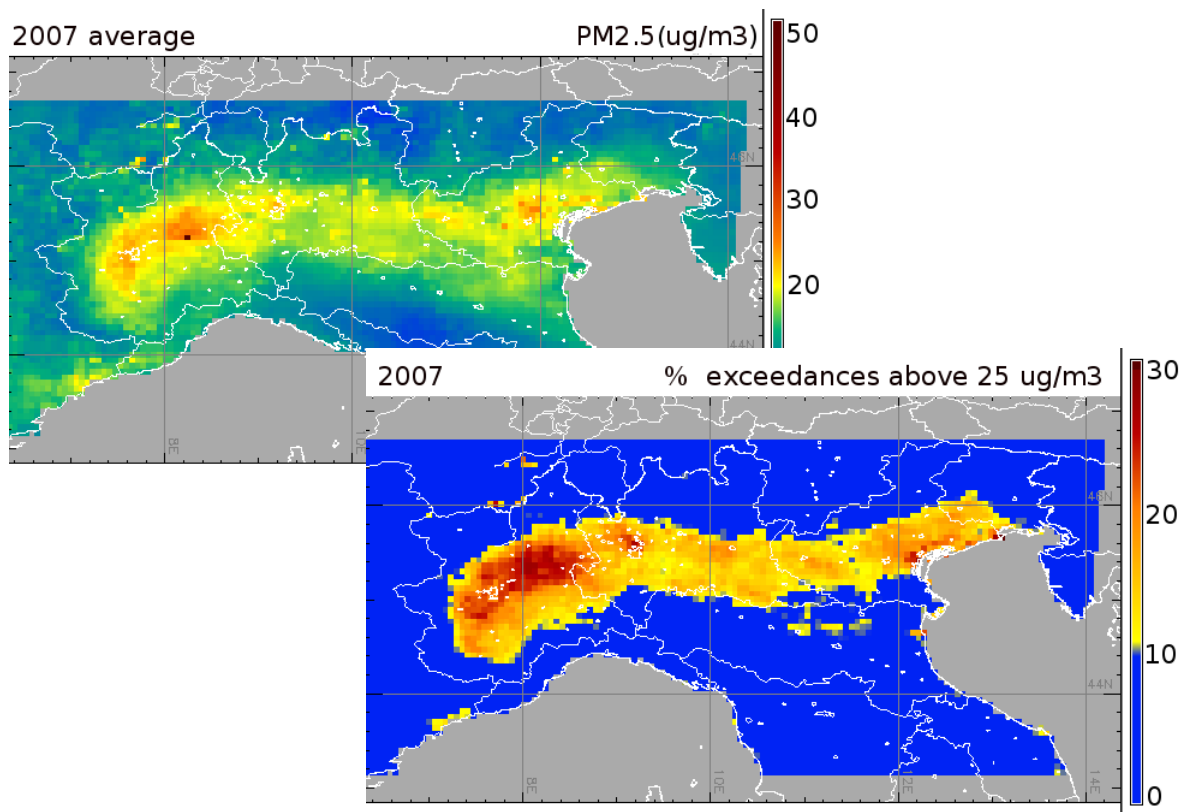### Annual compliance monitoring for Northern Italy

As introduced above, satellite data is increasingly used to map Aerosol Optical Depth (AOD) - a measure of the columnar aerosol extinction in the visible spectral range – and is then related to ground-level concentration of PM (Di Nicolantonio et al., 2007; Gupta and Christopher, 2008; Di Nicolantonio et al., 2009a). In this service, MODIS (Terra and Aqua) aerosol observations, ECMWF meteorological initial and

boundary conditions, and in situ samplings of PM concentrations have been used to estimate daily MODIS-based PM_{10} and $PM_{2.5}$ concentrations over Northern Italy (Di Nicolantonio et al., 2009b; Di Nicolantonio and Cacciari, 2011). Furthermore, annual means of satellite-based PM concentrations are calculated over the whole domain together with evaluations of the corresponding yearly percentage of days exceeding the legal limit of PM daily concentration, as stated by the above mentioned EC directive. In Figure 9 the 2007 yearly averaged map of MODIS-based $PM_{2.5}$ concentration is presented with the corresponding annual percentage of days exceeding the daily limit of 25 $\mu g/m^3$, highlighting areas affected by high levels of pollution and correspondingly exceeding legislation limit. Areas characterized by significant particulate matter concentration can be easily recognized over the domain, also where no sampling sites are available. This information could be profitably exploited by policy makers in managing air quality and also directly by citizens due also to the easy reading of the maps.

The satellite-based daily PM maps, for both $PM_{2.5}$ and PM_{10}, have been averaged on a monthly and yearly basis and then compared with corresponding in-situ measurements collected throughout the whole year 2009 in the Emilia Romagna region at 23 and 48 sampling sites, respectively. The mean bias between yearly averaged values of $PM_{2.5}$ (PM_{10}) measured in situ and yearly averaged values of $PM_{2.5}$ (PM_{10}) measured in situ only when MODIS observations were present was found to be equal to $\approx$ 2.5 (4) $\mu g/m^3$. At the same time, the RMSD between yearly averaged values of $PM_{2.5}$ (PM_{10}) measured in situ and the yearly average of the satellite-based values was found to be equal to $\approx$ 3 (5) $\mu g/m^3$. These findings confirm that satellite-based monitoring can be adopted to detect and describe the spatial distribution of the particle pollutant concentration in the Po valley area.

Products generated by this service pertain to the Northern Italy domain and are relative to the 2004-2009 time period. The users have been provided with daily satellite-based PM concentration data together with compliance monitoring support data consisting in $PM_{2.5}$ and PM_{10} yearly averaged maps and corresponding standard deviations and exceeding maps of the percentage of days exceeding the daily limit value of concentration for the year in analysis.
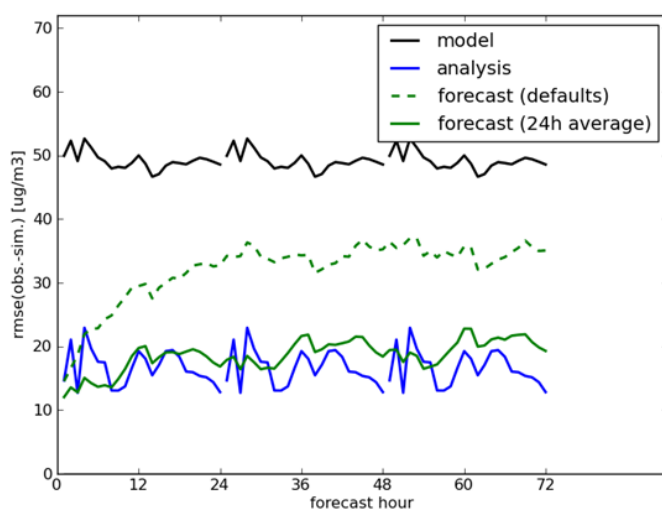
Figure 9 *Yearly averaged map of MODIS-based PM$_{2.5}$ concentration (above), corresponding annual percentage of days exceeding the daily limit of 25 $\mu g/m^3$ (below) for year 2007.*

Daily PM exceedance forecasting in the Netherlands

In Manders et al. (2009) it was demonstrated that a particulate matter (PM) forecasting service in the Netherlands based on the LOTOS-EUROS chemistry transport model (CTM) performed better regarding timing of events than the statistical model which was used up to then by the user Dutch Institute for Public Health and the Environment (RIVM). As is the case for many other CTMs, the PM$_{10}$ concentrations are underestimated by LOTOS-EUROS. Within this project we have addressed this shortcoming with the goal to improve particulate matter forecasts to satisfy the information needs in the Netherlands. On the one hand improvements have been obtained by improved model descriptions. Due to a change in the deposition scheme (Wichink Kruit et al., 2012) and improved sea salt calculations (Hoogerbrugge et al., 2012, Schaap et al. 2013) the model bias has been substantially decreased in comparison with in-situ observations of secondary organic aerosols in the Netherlands and PM$_{10}$ from the EMEP network over Europe.

On the other hand improvements through assimilation of satellite and ground-based measurements in LOTOS-EUROS have been pursued. Timmermans et al. (2008) and Denby et al. (2008) have shown that assimilation of AOD and daily PM$_{10}$ data yields a significant improvement in the correlation in time and RMS error. The assimilation of AOD observations provides many challenges, one of them being the treatment of water uptake by aerosol, and consequent optical effects, correctly. Due to the non-linearity of aerosol-water uptake, the use of a single relative humidity (RH) value to represent the boundary layer as is standard in the LOTOS-EUROS model may lead to serious underestimations in modeled AOD, especially when RH reaches high values. To overcome this, an updated routine has been produced taking the RH values at the ECMWF layers into account.

In addition to the updated AOD assimilation system, a new approach for assimilation of hourly in-situ PM observations has been developed where the bias correction normally applied to the modeled PM concentrations is replaced by an unspecified PM (UPM) source which can be adjusted through the assimilation of the PM observations. The new approach leads to simulated PM_{10} concentrations that are in good agreement with observations. Next a strategy was implemented to inherit model parameters obtained through the assimilation to improve the forecasts. The daily mean values of the UPM source for the day before are progressed into the 3-day forecasts. The results show a strong improvement in the exceedance forecasts even for forecast day 3. Without the inheritance, the forecast performance quickly deteriorates when going to 1, 2 and 3 day forecasts (Figure 10).

Figure 10 Improved forecasts due to PM assimilation. RMSE between simulated and observed PM_{10} concentrations from the LOTOS-EUROS model (before (black), after assimilation of PM observations (blue) and for the forecasts with (solid green) and without the inheritance (dashed green).

Quanfication of mineral dust from desert outbreaks over the Canary Islands

The purpose of this service is to utilise infrared satellite data to estimate dust loadings in order to provide estimates of exceedances specifically for the Canary Islands. The service has been developed in close collaboration with AEMET, the meteorological service of Spain based in Tenerife, Canary Islands.

The achievements comprise the development of a fast algorithm for using MSG/SEVIRI infrared imagery to estimate effective particle size and infrared optical depths at roughly 3 x 3 km² spatial resolution. These parameters can be used to determine the total column mass loadings (g/m²). The SEVIRI data are received locally at NILU in near real-time every 15 minutes continuously $^{24}/_7$. Several dust events for further analysis, comparison and validation have been selected. As a further service component, the particle dispersion model (FLEXPART) has been used to provide vertically resolved dust concentrations and to "fill in" regions where clouds or other masking effects (high water vapour) obscures the dust in the SEVIRI data. The model estimates and the satellite estimates are combined using a simplified version of a Kalman filter. Analysis, no forecasting is provided in the service, which is provided via **http://www.nilu.no/pasodoble/**. To validate the dust loading estimates an infrared camera system at the Izana observatory has been established. During November 2012 and March 2013 the infrared camera (nicAIR) was taken to the Izana observatory to make measurements for validation. Finally the satellite-based dust loadings have been compared to MACC forecasts (in hind cast mode) and other independent dust estimates.

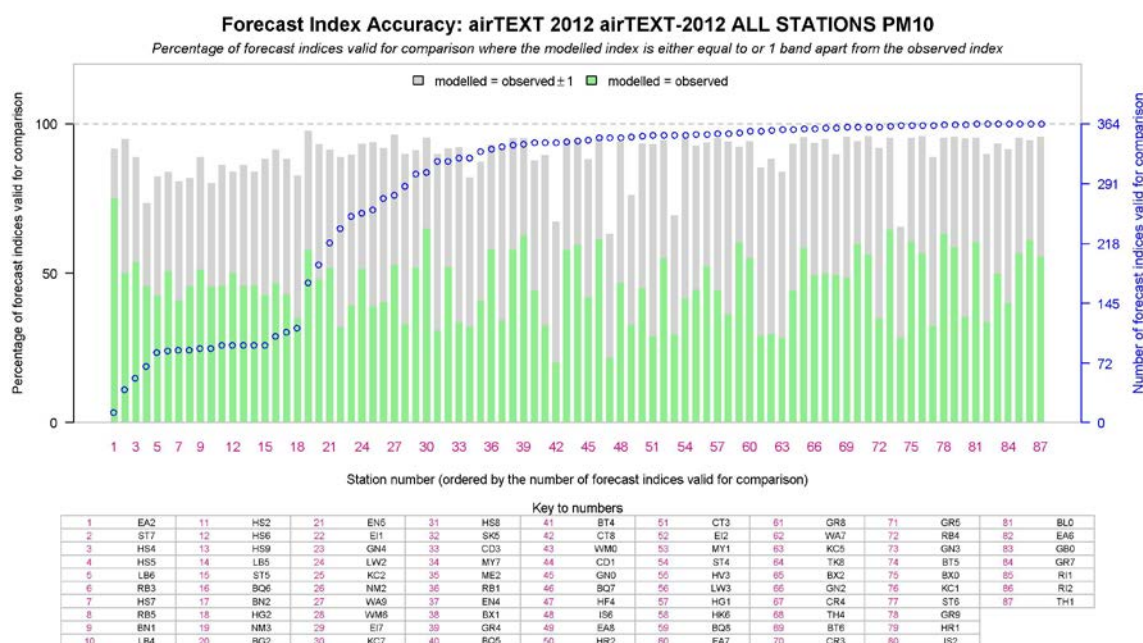# Local forecast model evaluation support service

Regional and municipal governments are increasingly interested in providing services to rate and forecast local- and city-level air quality. Local air quality forecasting is crucial in assessing air quality against the EC air quality directive. Its strength is that it can provide high resolution maps of concentration where the population density is high. Additionally it allows the investigation of proposed mitigation measures on short or long time scales. Understanding of the benefits, limitations and performance of individual models is often lacking. Setting standard evaluation criteria and comparing model capabilities in a structured way is therefore a essential task.

The Myair Model Evaluation Toolkit

The local forecast model evaluation support work package of PASODOBLE has developed, demonstrated and evaluated a toolkit for evaluating local air quality forecasts: the Myair Toolkit for Model Evaluation. A key aim in design of the toolkit was to build on existing tools and methods wherever possible. A state-of-the-art review carried out in 2010 and updated in 2011 identified two key initiatives upon which the toolkit was later built: firstly the work of the FAIRMODE community in developing the DELTA tool (Thunis *et al.*, 2011) and secondly the openair suite of tools (Carslaw and Ropkins, 2012). The methods used for the analysis of the performance of meteorological forecasting models are also highly relevant to a tool for evaluating local air quality forecasts, in part because forecast meteorological data are an essential input to air quality forecasting models. The indicators used at the European Centre for Medium-Range Weather Forecasting (ECMWF) for assessing meteorological forecasts were reviewed as part of this work and event-based methods were identified, which could be applied to pollution forecasting.

The resulting toolkit consists of four tools: a questionnaire tool offering structured advice on the advisability of the proposed evaluation; a data input tool able to import a wide range of modelled and in-situ monitored data formats; a model evaluation tool that analyses the performance of the model at predicting concentrations and pollution episodes; and a model diagnostics tool that compares modelled and monitored data at individual stations in more detail. A key feature of the Myair Toolkit is its ability to analyse model skill at predicting pollution indices (for example a scale from 1 to 10) and pollution bandings (for example 'low', 'moderate', 'high' and 'very high'), since these are commonly used to communicate air quality forecasts to the public.

The Myair Toolkit is easy to use and produces statistical data and attractive graphs. It is coded in the widely used statistical language R with an interface for user inputs; it has additionally a command-line mode giving scope for automating its use, for example in batch files. The Toolkit has been evaluated during the PASODOBLE project by a panel of air quality forecasting users. Within PASODOBLE it has been applied to evaluate the performance of the Airsheds forecast products and to evaluate the performance of many of the downstream services, including the *air*TEXT pollution forecasts for Greater London (**http://www.airtext.info/**). Not only with its local forecasting assessment capability, the Toolkit has the potential to be exploited more generally in the field of air pollution model evaluation and has therefore been used in the validation of the ADMS suite of air pollution dispersion models.

Figure 11 *Forecast index accuracy graph, showing the percentage of forecasts that are equal to or within one of the observed index value. The stations are sorted in order of the number of indices valid for comparison, shown by the blue circles.*

A common data interface

The Data Interface work package has aimed at negotiating agreements and mechanisms for the timely and appropriate delivery of Copernicus Core Service products, space-based observations, in-situ measurements, meteorological forecasts and emission inventories to the Downstream Service providers. The other objective was providing feedback to the Core Services and all other data providers on their products. Since all these inputs and products are prerequisites for the Downstream Services, harmonised processes and guidelines have been established to access and understand them. As the main result a common data interface has been implemented in PASODOBLE.

Coordinated Data Access

There are several good reasons to realize coordindated data access. In general, a wealth of data is available but it is scattered all over the community, different projects and providers. Data usage requires understanding and managing different datasets, formats and locations. Moreover, keeping track of changes is quite an effort. Consequently a distributed interface for harmonized access to all input data has been defined and implemented. It is a component of the PASOODBLE developments for a sustainable generic service infrastructure for efficient data access and implementation of services now and in the future. Promoting the use of good practise and harmonization, INSPIRE-compliant web services have been developed. Two examples will be briefly described in the following.

All forecast and analyses data from the 5 PASODOBLE Airsheds, as well as the results from the MACC European Forecasting Ensemble, can be downloaded via a Web Coverage Service (**wdc.dlr.de/cgi-bin/airsheds_new** and **wdc.dlr.de/cgi-bin/macc_ens**). Using a simple URL, query data can be selected by region, species, service provider, forecast day. The resulting netCDF file can be downloaded and opened in most viewers. The data can be used as a service itself, back-up, data for comparisons or lateral boundary conditions as it is done for most of the PASODOBLE downstream services. The URLs above will return all avalailable options (get capabilities). These kind of HTTP-requests can easily be integrated in operational scripts.

In-situ data from EEA can be retrieved in near-real time via a comfortable Web Feature Service. Via one URL one can simply query and download all in-situ measurements in a specific country, domain, time period, station or species. Various formats can be selected.

Concerning sustainability of the common data interface, all important functionalities will be continued partly in MACC-II and partly the World Data Center for Remote Sensing of the Atmosphere (**wdc.dlr.de**).

Core Service Evalution

The products of the Copernicus Core Services i.e. MACC-II have been evaluated in two evaluation cycles resulting within two reports. The derivation of requirements towards MACC is based on analysing technical requirements of the PASODOBLE services as well as on conducting several experiments to assess potentially critical scientific issues (e.g. number of species). The output of the MACC European Model Ensemble for Air Quality Forecasting has been the main input for PASODOBLE. It has been used for nesting by giving the boundary conditions for the regional air quality forecasts.

It can be reported now that MACC partly addressed and implemented these requirements, which is highly appreciated. Especially the extension of the forecast range helps to keep the timeline for the downstream services. However, it can be concluded that the current set up of the MACC ensemble is still not sufficient for nesting. In particular the lumped aerosols (PM_{10}, $PM_{2.5}$) are not suitable for proper nesting.

In addition, MACC products have been compared to the relevant developments in PASODOBLE. Therefore the Core Service Evaluation Report comprises a first intercomparison of the MACC dust forecasting products with the PASODOBLE mineral dust loading service for the Canary Islands and a comparison of the improved LOTOS-EUROS version to the related MACC version and a comparison of the MACC and PASODOBLE wildfire services.

Finally, we are pleased to emphasise that the working relation to MACC has been excellent.

The User Interface

A prototype of an online user interface has been developed, offering modular tools to access, visualize, analyse and validate the results of the air quality services. It comprises of a catalogue, a state-of-the-art visualisation tool, automatic online validation, modules for calculating human exposure, a decision-support system and finally an air quality management tool optimized for the use with tablet PCs.

To maximize usability and interoperability the following are implemented: web coverage, web feature and web map services compliant with the Open GIS Consortium (OGC) standards, as well as Google Earth and export functionalities for data and metadata. The user interface, the decision-support tool and the air quality management system can be accessed via **www.myair.eu**.

Interoparable air quality web services

It is one big achievement to develop reliable air quality services, but it is another, to ensure that these services are made available on an INSPIRE and OGC compliant central web interface for common presentation, user friendly analysis and online validation. This enables a seamless combination of air quality information from different sources across Europe, so that it can be uniformly shared with many users and other Copernicus related applications. In PASODOBLE a central web platform has been developed, with access to decentralized PASODOBLE downstream services via an open source discovery metadata service. In doing so, PASODOBLE has promoted and showcased the establishment of OGC compliant air quality services. In the following, the key functionalities offered by the central web

platform and the technical challenges in generating OGC-compliant model outputs and INSPIRE-compliant metadata for accessing the services in the web platform are discussed.

Web tools to visualize, analyse and validate air quality information

The "User Interface" web application consists of four core functionalities, which can be accessed once a service is selected from the PASODOBLE catalogue:

1. A **standardised viewer** ("Maps" page) to visualise the air quality map(s) of the selected service
2. An automatic **on-line forecast validation tool** ("Validation" page) that allows evaluation of the performance of a recent air quality forecast, using statistics based on the FAIRMODE Delta tool.
3. Links to **analysis tools** which are available on request:
   a. The data fusion tool which uses an optimal interpolation scheme to fuse specified model output with measurement results to provide data-assimilated results and
   b. an exposure tool that allows users to determine how many people are exposed to a certain pollutant value with the chosen model output domain and, finally
4. A showcase of **interactive tools** that can be customized for users to view their chosen services in a more user friendly interactive way. One of these, the interactive decision support application (Professional Services tab) is described separately in chapter "Air quality management and decision support service" on page 30. Alongside this latter application, high quality interactive Google Earth animations of a selection of the PASODOBLE services are viewable and downloadable.

The back-end of the platform was designed to be capable of collecting different types of data both from the various service providers (located at different physical locations across the EU) and the data providers (ECMWF, AirBase, airsheds) in accordance with OGC guidelines. To demonstrate an air quality service on the PASODOBLE web application, service providers must generate OGC-compliant model outputs and INSPIRE-compliant metadata for each generated product. Generation of the metadata is handled in the following chapter on Quality Management. This metadata is sent to Ricardo-AEA's ftp website where the open source catalogue, built on GeoNetwork is hosted. Using this portal users can search and discover the air quality services available.   To access the catalogue there are two options:

1. It can be accessed directly at **http://www.myair.eu/geonetwork**
2. Or via the My**air** website **http://www.myair.eu/** from the User Interface page

To facilitate integration of the services, a dedicated Integration Support website **http://rma.vito.be/pasodoble/documentationvm/** was established. This website describes the metadata generation (including working templates) and the various tools required to generate the OGC compliant maps and data. In short, to enable viewing of their service, the service provider must be capable of producing a WMS (Web Map Services) layer for each of its products, containing data for a given pollutant, a given day, and a given indicator (e.g. daily mean, daily maximum). If they wish to use the "Validate" functionality, then a Web Feature Service (WFS) must be provided.
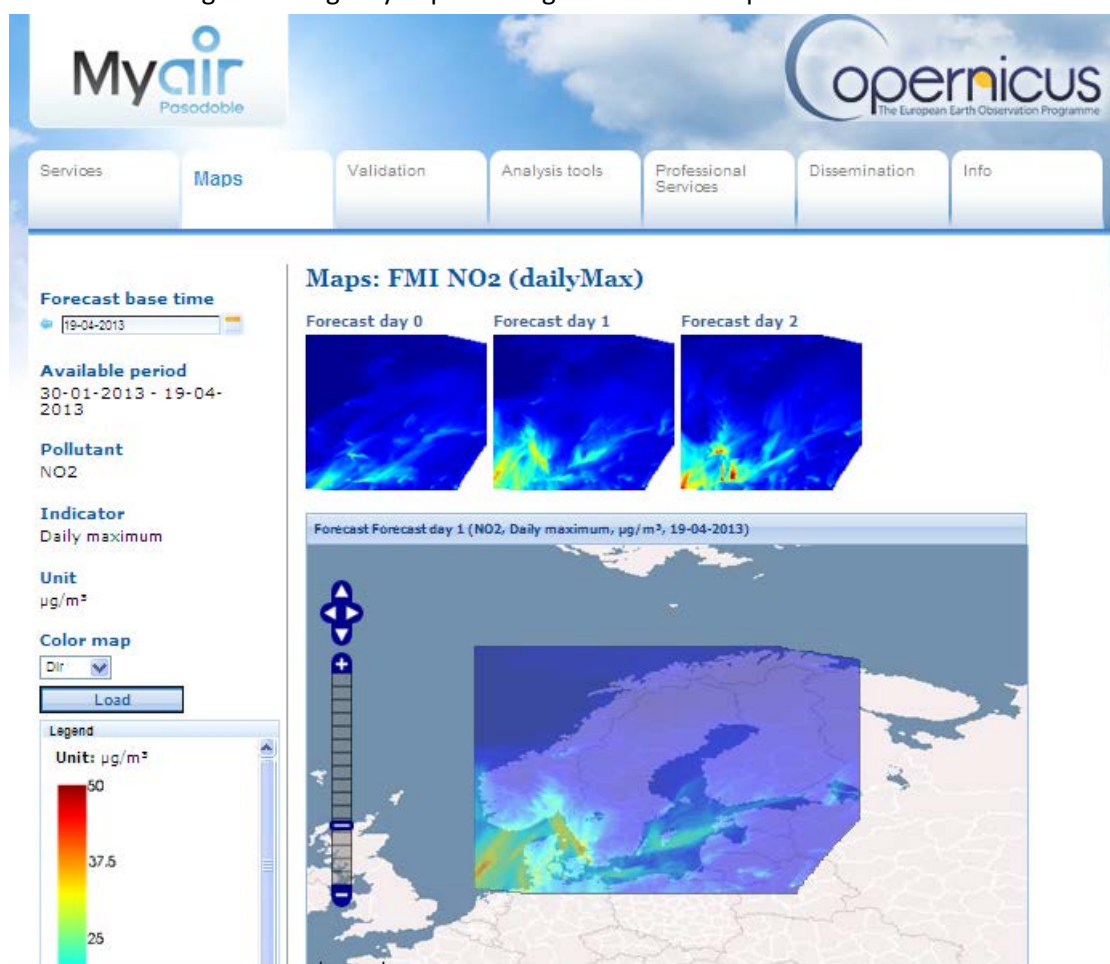
Some of the service providers either already had existing in-house solutions (GeoServer, MapServer, Thredds) or decided to opt for an alternative long term solution. Although not all of these solutions, were fully OGC compliant, it was found in terms of interoperability and sustainability of the services after PASODOBLE, that these "technical issues" were minor, when compared to the fact that the different solutions fit better into the individual technical infrastructure of the partners going forward.

For those partners who were not famimiliar with OGC web services, a *Service Integration tool* was developed. More detail on this tool (also known as the Virtual Machine) and indeed the integration can be found on the dedicated website listed above. Despite this tool and all the support and simplifications

that were developed within PASODOBLE, generating OGC compliant model output is still very challenging and requires a high technical understanding (e.g. on security aspects, firewalls etc.), which is very specific for each institution or company.

When a service provider uploads the metadata for a particular product to the catalogue, (e.g. daily NO_2 forecasts for Brussels) it also provides an unique resource locator (URL) which is parameterized, providing details of it's WMS and WFS layers. The parameters differ for each product provided. This URL directs the user to that chosen service on the central web application. The web application should only be viewed as a 'shopping window' of the key PASODOBLE services; it only demonstrates a limited aspect of the particular service shown. The full comprehensive individual tailored services are accessible via the "Products and Services" page of the Myair website (**http://www.myair.eu/products-services/**). An example is shown in Figure 12.

Thanks to the interoperable interfaces PASOODOBLE services can now be easily integrated in other Copernius information portals or indeed various other portals hosted by the service providers. Indeed working with OGC standards has positively transformed the way many of the air quality institutes share their model data and gone a long way in promoting the use of best practice tools.

Figure 12 *The Web Application Visualisation Page – The Northern Europe Airshed Service provided by FMI*

Air quality management and decision support service

Based on the air quality forecasting services from PASODOBLE and the Copernicus Atmosphere Service (MACC-II) a modern and interactive air quality management and decision support service has been developed. As such an interactive web application for dissemenation of air quality forecast data has

been developed by the Irish partner Nowcasting. The application has been designed with the consumer or non scientific professional user (decision maker) in mind. It is configured for delivery on standard PC/Laptop browsers as well as tablet devices. The consumer version of the application should be free to use for the public and will be sustained through advertising. The professional version omitts advertising and these customers are expected to pay for access to the system. Access to the application can be provided either remotely or internally on the customers own website.

Application Features

- The application is built on the familiar google maps api.
- Users can download 3 day forecasts for their chosen location.
- Available forecast data includes:
  - Air Quality. MACC - Low Resolution - hourly data. (O_3, NO_2, PM_{10} & $PM_{2.5}$)
  - Air Quality. PASODOBLE - High Resolution city forecast data (where available)
  - Weather Data. Hourly (Wind Speed and Direcion, Temperature, Precipitation)
- MACC hourly data can be viewed as both grid and map data
- MACC forecasts are used to achieve full European coverage and the broadest scope of market possible.
- Graph view of hourly time series data.
- Alerts to simplify the visualization of relative good versus bad conditions.
- Multi-factorial alerts - **Weather Window**. This shows you a summary of the forecast from the perspective of your chosen alert levels. Its function is to simplify the data and alerts into a traffic light system where you can easily spot weather windows.
  - All ok (green)   = Green.
  - One alert setting of many in alert state (red) = Amber.
  - More than one setting in alert state (red)   = Red.
- Inclusion of near-real-time air quality observation data.
- Forecast Confidence Indicator. When viewing a graph of the observation data for the previous 24 hours we also show the corresponding forecast values. The benefit of showing forecast and observation data together is so the user gets a real time confidence indicator of how the forecast is performing.
- An interactive help / tour guide is available which takes the user through applications features and how to use them.
- Tablet Support and Detection. Once detected we silently route these users to a tablet optimized version of the application.

User Experience Achievements

A number of efforts and achievements have been made to vastly improve the user experience e.g with the Irish Environment Protection Agency. The general user is identified as the non scientific consumer. They are assumed to have a short attention span and expect results and interactions to respond quickly.

The application is designed for use in all the major Browser vendors (Google Chrome, Firefox, Internet Explorer, Safari) as well as tablet browsers. It has been implemented using basic web technologies, html, css & javascript. That way we can safely say, no user will have to install any 3rd party software or plugin to run this application. This is particularly important when considering the professional user, who might be working in a secure environment where software installation is not allowed.

Quality Management

The activities led within the PASODOBLE cross-cutting *Quality Management* (CC-QUALITY) work package have resulted in the establishment of procedures and concepts applicable to the validation and documentation of Air Quality Services (AQS). These include an AQS validation protocol , an atmospheric metadata model, concepts for automated validation, a validation report template and the design of a validation report editor. Supporting tools include the metadata editor and an online archive of quality assessment and validation resources.

The PASODOBLE Validation Protocol, established in harmony with the MACC validation protocol, developed in collaboration with PASODOBLE service providers and endorsed by them, sets up the general principles of a sound service and data validation procedure, tackles air quality specific issues and refers to applicable standards.

The Atmospheric Metadata Model integrates INSPIRE high level metadata fields as described in the INSPIRE Metadata Regulation. It served as a basis for the development of a metadata editor suiting the needs of AQ product providers and able to generate a subset of metadata complying with the INSPIRE Metadata Regulation. It was also used as a reference document at the GEO AQ CoP workshop on metadata (Dublin, September 2012) and supported the feedback of the project partners' community as a registered SDIC to INSPIRE .

The technical note on automated validation is a survey of concepts potentially applicable or actually applied (including within PASODOBLE) to various pieces of an AQS entire validation chain.

The Validation Report Editor design document provides in accurate detail the description of an online tool (which has not been implemented within the project duration) to help service providers edit harmonized validation reports while offering them a checklist of items. It is based on the principles enunciated in the Validation Protocol and allows the insertion of results and graphs generated with the automated tools developed by the PASODOBLE *Local Forecast Model Evaluation Support Service* (DS-LOCAL) and *Interface to Users* (I-USERS) work packages. Its output includes a section devoted to the comparison of actual product properties with formulated user requirements.

The above conceptual and practical instruments have been applied to PASODOBLE AQ services to document the products distributed via the Myair website. The main visible output of this work includes the PASODOBLE Product Portfolio, the PASODOBLE AQ Service Validation Report, which is a compilation of all individual PASODOBLE downstream service validation reports, each of them following the common template, and the information provided through the PASODOBLE online searchable product catalogue after ingestion of the metadata editor output.

In parallel to the supporting cross-cutting activities and achievements described above, CC-QUALITY has interacted with the designers of the INSPIRE Directive Implementing Rules on metadata and data specifications at the occasion of informal meetings with the INSPIRE drafting team and of formal INSPIRE consultations (user requirement survey and consultation on the data specification for atmospheric conditions and meteorological geographical features), thus contributing to the elaboration of INSPIRE implementing rules.

Marketing and Business Planning – preparing sustainability

Website, online and metadata services

The public information website can be located at **http://www.myair.eu**. The purpose of this service is to provide a user-friendly website containing information about the project and give access to the products and services to members of the public and potential customers. To make the website more accessible to a wider audience, the core pages are available in six different languages: French, German, Italian, Spanish, Bulgarian and Greek. These languages were selected based on the languages within the consortium as well as statistics from the google analytics website as to where most visitors to the website originate. The website also contains a password protected information and document management system, accessible only to PASODOBLE consortium members. This area has been used by members to view reports or deliverables and work package leaders to manage and add deliverables.

As well as designing the website, CC-MARKET also had input into the creation of the metadata services, defining a publication process and carrying out upload checks prior to the publication of the xml files. The harvest function of the GeoNetwork was used to achieve automatic updating of the metadata layer.

Marketing and marketing collateral

Initially, the marketing effort focused on the creation of a PASODOBLE brand, which was used for the website and on all PASODOBLE material. A selection of business cards, introductory leaflets, banner stands and posters were created and shared with members of the consortium. Marketing help was offered to all project partners. During the final year of the project the effort focused on the products that were the most well developed and where there was a willingness from consortium members to engage with the marketing effort. A series of successful marketing teleconferences were held with a number of services lines, with the outcomes varying from establishing that the markets were too small to warrant marketing effort, to the production of marketing leaflets, hosting of webinars and surveys/questionnaires to assess the market potential. To help promote the project a twitter account was set up, to make important announcements.

Also a My*air* promotional film was produced. In seven minutes the film explains the benefits of PASODOBLE using various examples relevant for European administrations and the daily life of European citizens. It can be viewed via the home page of the PASODOBLE website.

Business Plan strategy and assessment

During the duration of the project, three Market Intelligence Assessments were produced. The initial report assessed the vision and potential market for PASODOBLE in each of the four service lines, providing an assessment of the external environment, a competitor analysis, industry analysis and customer needs analysis and used these to make recommendations on how to develop the products. The subsequent report built on this, updating the market research information and competitor analysis and identifying key success factors for each of the four services. The final report developed the themes from the previous reports, particularly focusing on the five services which had been identified as the most commercially viable. Data was presented to show market size or the current economic cost/risk of inaction.

A series of business plans were produced over the duration of the project. During year 2, a consortium business plan plus individual plans for each of the four service areas were produced. These suggested routes to market, lists of potential customers, high level sales strategy, financial forecasts and recommended marketing activities for each product. In the final year, the consortium business plan was updated. Further to this a series of short, high level business plans were created for the following products with main outcomes and recommendations:

1. Gas plume and smoke cloud modelling – a highly niche service which can add considerable value to emergency responders. Needs to be marketed and sold appropriately and further developed to include a range of chemical species and easy accessibility in the field. This product will be taken forward by BMT ARGOSS

2. ARI and UTCI – have a huge potential benefit in the market place improving quality of life and reducing hospital admissions. However, the route to market is difficult to establish and could be via patients, hospitals, doctors or national health services. ACRI-ST need to establish suitable routes to market.

3. Pollen service – the service is in a highly competitive environment and may not have significantly strong unique selling points to be successful.

4. Traffic modelling scenarios – VITO have produced a commercially viable consultancy service. There was a good amount of interest in the service following a successful webinar but as yet no hot leads. Further work is needed in marketing the service.

Potential Impact, Dissemination Activities and Exploitation of Results

A summary of the potential impact, the dissemination activities and the general exploitation of results will be given followed by a report on specific aspects of selected downstream services.

Potential Impact

Clean air is the focus of EU environmental policy discussions throughout 2013, the Year of Air. PASODOBLE with its latest service developments can contribute just in time to help raising the awareness in Europe's hot spots where people live, and provide reliable information to policy makers. PASODOBLE has developed sustainable air quality services in more than 30 regions and cities throughout Europe in close collaboration with 50 local actors from 18 countries. Focusing on applications on the local and regional scale it is supplementary to the Copernicus Atmosphere Service (MACC-II) and bridges important gaps to the users.

The potential impact can be substantiated by bespoke service developments addressing user needs. PASODOBLE has improved public air quality information services, the health support for people at risk and the supply of policy relevant information for decision makers. Major international events like the Olympic Games 2012 have benefited from these developments, as they delivered the official service backed by the London Town Mayor and recommended in his health advice to the athletes. Other services have already contributed to facilitate the reporting for compliance monitoring on particulate matter for regional environment agencies. According to the European Environment Agency one third of the urban population in Europe is exposed to particulate matter levels exceeding threshold levels. The satellite-based air quality assessments introduced by PASODOBLE will support the EC's goal of countering reduced life expectancy due to particulate matter in the air. Traffic is a key contributor to these exceedances and therefore it is important for city authorities to assess the contribution, and investigate and implement mitigating traffic management plans. Here, the traffic scenario and assessment services for cities will have a major impact, since most cities are lacking such capabilities.

To maximise the impact of PASODOBLE, the evaluation of the downstream services by the users regarding fitness-for-purpose has been of highest priority to the project. The service uptake has been stengthened by the implementation of two full cycles of user requirement analysis, service development, demonstration and evaluation with respect to fitness-for-purpose and business planning. The feedback of the users has been meticulously analysed and documented in two User Evalution Reports. Three user workshops with over 100 attendees have been organised in Oberpfaffenhofen, Thessaloniki and Nice, as key element to gather feedback from the users and to discuss the further developments and sustainability of the services. The overall feedback was very positive and constructive. The users are very satisfied with the products and services they obtain from the project. The positive evaluation is an important indication that the developments of the projects adequately addressed their requirements and wishes. This is seminal for the impact of PASODOBLE. Moreover, a continuation and collaboration beyond the project is highly desired by the users. In order to strengthen the self-supportiveness and sustainability of the services, business planning and market intelligence assessments have been undertaken and specific business plans accomplished.

Not only has PASODOBLE developed dedicated downstream services, but also a sustainable, generic and modular technical infrastructure. PASODOBLE has considerably contributed to a harmonisation with respect to interoperability, quality management, validation, transparency, data access and INSPIRE compliance. This has been realised by combining local action and work with a European vision.

The achievements towards a consistent European framework for local and regional air quality services with a larger impact on the community comprise a metadata model for air quality services, harmonised interfaces, coordinated access to input data from space, in situ measurements, boundary conditions and emissions, simplified nesting approaches and cutting-edge web interfaces to users including a catalogue.

The available technical infrastructure will now increase the implementation efficiency for new services in new regions and cities in the future. Benefiting from these developments the project contributes to increasing the competitiveness for European service providers

Working with Open GIS Consortium (OGC) standards enabling interoperability has had a strong impact to the partners involved in this project. The PASODOBLE virtual appliance enables service providers to publish data interoperable in a simple way. Due to PASODOBLE, FMI undertook a major development by installing Thredds-server based web services. With this technological advancement, distribution of numerical data from all of SILAM model products between users, providers and researchers has dramatically improved. Similarly, other service providers have revolutionized the way they share their data and many have had a steep learning curve. Thanks to the achieved interoperability, the PASODOBLE services can now easily be integrated into other information services and portals (GEOSS, obsAIRve, ESA App Camp, World Data Centers).

Following the concept of interoperability, an online user interface has been developed offering modular tools to access, visualize, analyse and validate the results of the air quality services. One of the major objectives of this web application has been to serve as a central interactive platform connecting to all decentralised services, where users can search for PASODOBLE services and utilise the functionalities to evaluate and analyse their selected service. The web application comprises a catalogue, a visualisation tool, automatic online validation, modules for calculating human exposure, a decision-support system and an air quality management tool. The web application can also be viewed as a "distinct" platform comprising of "apps" (the functionalities), that can be customized to the user needs. This is what has been elaborated within the Life+ project ATMOSYS (**www.ATMOSYS.eu**); some aspects of the viewer, the validation and the exposure tools, developed within PASODOBLE have been optimized and customised for one single user's air quality forecasting service in Belgium. Furthermore, there are already users, like the Irish EPA and the Slovakian Hydrometrological Institute, interested in using parts of the platform to improve and disseminate their own current air quality services. The user interface web application has been demonstrated to the various users within PASODOBLE bilateraly or at the user workshops. The City Development Authority of Prague commented on the quality of their forecasting service that *"the technological quality of the supporting infrastructure (the web systems, validation tools and product delivery) is impressive".* Furthermore high-quality animations and Google Earth layers have been produced operationally since policy makers often prefer using these strong visual tools to emphasise an air quality situation to politicians.

A large impact has further resulted from the developments on enhanced data access via common interfaces. Significantly improved data access and handling of modell data, in-situ measurements and space data has been achieved. A web feature service now allows easy access to in-situ measurements in near-real time from the European Environment Agency. In-situ data can now easily be retrieved by time, country, region and species in different user friendly formats and this is very relevant for the community and environmental authorities. By means of web coverage services model data and boundary conditions for a customized region and different pollutants can now simply be retrieved via a browser or batch job for 5 airsheds in Europe and the MACC European Forecasting Ensemble. The technical developments have now been partly continued by MACC-II, partly by the World Data Center for Remote Sensing of the Atmosphere hosted by DLR, or the different service providers that offer the tools like the Myair model evaluation toolkit, the metadata editor or the airsheds data access. These have already experienced a good uptake in the wider user community and are increasingly requested and used.

The impact of validation activities in the field of air quality (AQ) directly entails from its crucial practical consequence on societal applications. A sound AQ data validation also has a potential impact on the fulfillment of member states' duties in complying with international environmental legislation. The PASODOBLE *Quality Management* work package has laid the bases of harmonized validation and

documentation of air quality products and services, which will hopefully outlive the project through continued practice. It is expected that conceptual and practical tools developed by CC-QUALITY in the course of PASODOBLE will continue to support AQ services (as references and applications), and PASODOBLE products should continue to benefit from the improved documentation on product and service quality. To improve on the European harmonisation of air quality services a validation report editor and concepts for automated evaluation have been implemented in a consistent way with the Copernicus Atmosphere Service. Impact in two areas has already taken place during the project lifetime, namely in influencing the debate, within INSPIRE, on the metadata and data specification for atmospheric conditions, and in contributing to the effort to build up some consistent metadata scheme for atmospheric datasets. The PASODOBLE metadata model has also circulated among participants to other European environmental research projects.

The impact of PASODOBLE was strengthened and increased by promotion and a strong involvement of the project partners in ongoing initiatives and projects. These include active contributions to FAIRMODE, INSPIRE, MACC-II, GENESIS, the Mission Advisory Group for the Sentinels 4 and 5, GMES-PURE, AQUILA, EIONET, HARMO, GEOSS and finally the national and European GMES User Fora. PASODOBLE has liaised with the Joint Research Center, DG_Environment, the Copernicus/GMES Bureau and the Air Quality Committee. With respect to the European Earth Observation Programme Copernicus, PASODOBLE has communicated satellite data requirements at hearings, expert meetings and conferences. Requirements for satellite data and future space missions have been elaborated in a dedicated report. PASODOBLE has also interacted with the European Environment Agency, the European Space Agency and the European Center for Medium Range Weather Forecast in order to improve the data access and data policy within the Copernicus framework. Feedback to the Copernicus Atmosphere Service (MACC and MACC-II) has been provided by two Core Service Evaluation Reports for the mutual benefit.

The innovative technical and methodological developments of PASODOBLE will impact the next generation air quality and health assistance services.

Socio-economic Impact

According to a study on the socio-economic impact of GMES services up to 2030 on behalf of the European Space Agency, air quality is the leading environmental theme on European Policy Formulation benefits as demonstrated by figure 3.1 in ESA and PWC, 2006.

Total costs of asthma in EU27 are estimated at €17.7 billion/year, with more than half of this number accounted to productivity loss due to poor asthma control (Jackson et al., 2011), which means that the situation can be improved with better information products. In addition, healthcare costs associated with poor air quality in EU27 are estimated to range from €189 billion/year up to €790 billion/year, which again can be reduced by better information, awareness and tools to facilitate mitigation strategies. The World Health Organisation estimates that by reducing illness caused by airborne particulate matter the EU could save up to €29 billion/year. Air pollution and aeroallergens are thus among the most significant environmental challenges given the big political, societal and economic impacts. This is confirmed by Environment Commissioner Janez Potocnik who has declared 2013 to be the "Year of Air". The aim is to improve especially the air quality in the cities: "Current shortcomings will require the good will of policy-makers at all levels – European, national, regional and local"

Given the relevance and impact of air pollution and the significant information gaps especially on local scales where people live, downstream services focusing on the regional and local scale must be an essential part of GMES. In this context PASODOBLE has significantly contributed to close information gaps and to ensure that GMES products and services reach the widest pool of users, citizens and emerging markets and improve the quality of life of European citizens.

Admittedly, PASODOBLE cannot solve the current problems leading to air pollution, but the project has actively contributed to developing information services, tools and products in response to local needs, so that people at risk can better help themselves with respect to timely medication. Public authorities get support in assessing pollution episodes by cutting-edge tools which is highly demanded. Having demonstrated, evaluated and assessed the fitness-for-purpose of the downstream services with involved users, detailed business assessments, economic models and solutions have been elaborated for service sustainability. The business plans contain a cost benefit analysis the according services.

Together with MACC and obsAIRve, PASODOBLE now contributes establishing the Copernicus service chain for air quality to raise public awareness. By raising awareness, reducing health costs and diminishing morbidity, the service chain will contribute to improve quality of life and sustainability of welfare. The European citizens will benefit from the services since they provide a solution to mitigating the harm from air pollution by directly reaching residents who are most vulnerable, allowing them to change their behaviour or to take relief mediation in time. This will in the long term reduce hospitalization, morbidity and mortality.

Societal Implications

PASODOBLE has focused on a major societal challenge: A recent study by the European Topic Center for Air and Climate Change attributes 492.000 premature deaths per year in Europe to fine particles in the air (De Leeuw F., 2009). This corresponds to an average reduction of life expectancy by eight months and in some areas by even 36 months. In order to evaluate the adverse health effects of air pollution cohorts of vulnerable groups have contributed to the project by documenting and reporting their well being. In addition anonymous health data from hospitals and pharmacy networks has been analysed. The Ethical Committees of France and Greece have approved the use of the data in the project.

The project has engaged with a large number of government/public bodies and policy makers, including international organisations in implementing the research agenda and in communicating, disseminating and in using the results of the project i.e. the downstream services. In doing so PASODOBLE has generated outputs as a primary objective, which has been used by policy makers in the fields of environment, information society, public health, regional policy, research and innovation as well as space. The results have been used at local, regional, national and European level.

PASODOBLE was an interdisciplinary effort embracing Earth and related environmental science, mathematics and computer science, health science and economics. With respect to employment the project has mainly safeguarded employment in environmental science and computer science in small and medium sized enterprises as well as large companies.

Dissemination Activities

This section describes the general dissemination activities of PASODBLE, led by the cross-cutting activity Marketing & Business Planing. Detailed dissemination activities are listed in Table A.2 of the final report, where 196 activities have been reported, and in the subsequent sections. Altogether 33 peer-reviewed articles have been published in the context of the project. A peer-reviewed general publication on PASODOBLE is currently under preparation.

Creating Myair - Initially, the marketing effort focused on the creation of the PASODOBLE brand Myair, which was used for the website and on all PASODOBLE material. A project logo was designed.

Website - One of the main ways used to disseminate information on the project to a wide audience was via the project website (**www.myair.eu**). The main pages are available in 8 languages. The website contains all the information on the products and services within the PASODOBLE project. The user interface, the decision-support tool and the air quality management system can also be accessed. All public deliverables are accessible from the website. It also contains copies of all the marketing material

and leaflets. The "news" section on the homepage provides a method of disseminating the latest information relating to the project. Over the duration of the project the website has had 4,383 unique visitors from 96 countries.

Twitter - A twitter account @MyairPasodoble was set up during the project in order to disseminate up to date information to a wider audience.

Leaflets - A selection of marketing collateral was produced over the course of the project. General information leaflets were distributed to consortium members and taken to workshops and disseminated. Product specific leaflets were also produced. These were used by consortium members to inform potential users of the products and their use. Product specific leaflets were produced for the ARI and UTCI, traffic scenario assessment model for city hotspots and the CERC toolkit. They are all available on the project website: **http://www.myair.eu/download/product-leaflets/**

Webinars - Two webinars were held during the latter stage of the project to help promote and disseminate information. The first was related to the traffic scenario assessment model for city hotspots, developed by VITO. This was attended by over 40 people from around Europe who were based in both government and private organisations. The second webinar was about the ARI & UTCI products developed by ACRI. This was attended by 15 people from around Europe.

Workshops - Among specific workshop, three PASODOBLE user workshops have been organised with over 100 participants in Oberpfaffenhofen (June 2010), Thessaloniki (June 2011) and Nice (March 2013) as key element to get feedback from the users and to discuss the further developments and sustainability of the services.

Market research questionnaires - During March 2012, a mass marketing email was sent to over 5000 email addresses in Europe, to contacts in the following target sectors; General hospitals and General Medical Practitioners; Private Consultants Clinics; Clubs; Exhibition Contracting and Organising; Local Authorities; Hotels; Nursing homes; Primary Education; Sports and Recreation Education; Tour Operators, Travel Agencies, Tourist Guides. The aim of the email was to raise awareness of the air quality services offered by the PASODOBLE project and to gain knowledge and insight into what would help the services deliver their maximum value. The email contained a short survey in order to achieve this. The email was delivered to 3698 email addresses and was opened by 625. This opening rate is about normal for a cold marketing email. 102 users clicked through to the survey.

Promotion Film - A PASODOBLE film was produced by DLR. In seven minutes the film explains the benefits of PASODOBLE using various examples relevant for European administrations and the daily life of European citizens. This film is available via a link on the homepage of the website (HD1, HD2, PAL, mov and wmv versions).

Exploitation of Foreground

The principal objective of PASODOBLE has been to provide its foreground in the form of services to end users or intermediate service providers. The services consist of data, products and information. The form and modalities of service provision are stipulated in Service Level Agreements (SLA). Currently over 20 SLAs are signed with institutional end users. Other services have recently been developed and implemented as pre-operational services and have become available to the general public or interested users via web services. Several business planning activities are still ongoing.

Key elements for completing the exploitation of the results have been the final user workshop in March 2013 at Nice Hospital and the comprehensive Service Demonstration and Evaluation Report activity, where each service demonstration is documented followed by a question and answer section filled in by the users. The feedback was very positive which guarantees a good uptake of the service developments.

Moreover it was clearly stated to continue the collaboration. Most services will be operated and provided on a sustainable basis after PASODOBLE has ended.

The foreground comprises also software developments of several partners, which contribute to a general technical and service infrastructure e.g. interoperable access to data and products via online user interfaces. Detailed data policy principles for the use of the foreground of each of the services have been developed in the project and summarized in a dedicated report. It is obvious from this development strategy that the use of foreground and dissemination may vary significantly depending on the nature of the particular service. While PASODOBLE services for commercial applications are restricted, other data products are publicly available, depending on services and users. The management of IPR with respect the foreground and background has been stipulated in the Consortium Agreement of PASODOBLE.

Business Plan strategy and assessment

Scientific work and user-driven service development relies more and more on an economic approach to dissemate the results in a sustainable and self-supportive way. Therefore, within PASODOBLE three Market Intelligence Assessments were elaborated. At the beginning of the project the vision and potential market for each of the four service lines was evaluated. It was analyzed how far the external environment influences prospective markets. Competitor analysis, industry analysis and customer needs analysis were herein enclosed and used to make recommendations on how to develop the products. During the second year updating the market research information and competitor analysis helped identifying key success factors for each of the four service lines. Finally, five individual services were identified as the most commercially viable ones, for which during the final year of PASODOBLE the themes from the previous general asessments were developed in detail. Data was presented to show market size or the current economic cost/risk of inaction.

During the whole project a series of business plans were produced, which includes a consortium business plan plus individual plans for each of the four service areas. Within these plans, suggestions on routes to market, lists of potential customers, high level sales strategy, financial forecasts and recommended marketing activities for each product were done. The consortium business plan was updated until the end of the project.

Further to this, a series of short, high level business plans were created for the following four products with main outcomes and recommendations:

1. Gas plume and smoke cloud modeling – a highly niche service which can add considerable value to emergency responders. Needs to be marketed and sold appropriately and further developed to include a range of chemical species and easy accessibility in the field. This product will be taken forward by BMT ARGOSS (SME)

2. ARI and UTCI – have a huge potential benefit in the market place improving quality of life and reducing hospital admissions. However, the route to market is difficult to establish and could be via patients, hospitals, doctors or national health services. ACRI-ST (SME) needs to establish suitable routes to market.

3. Pollen service – the service is in a highly competitive environment and may not have significantly strong unique selling points to be successful.

4. Traffic modeling scenarios – VITO have produced a commercially viable consultancy service. There was a good amount of interest in the service following a successful webinar but as yet no hot leads. Further work is needed in marketing the service.

Overall a number of key findings or lessons learned were drawn from the business planning exercise and these can be summarised as follows to help service providers think about the reality of commercialising technical products/ services in the future.

Consider market potential	• Market size? • Competitors? • Understand competitor offerings
Is there a market need?	• Will anyone buy the product / service? • How will you sell it? • Do you have any friendly users/partners you can develop the product/service with?
Product development	• Needs to be constantly tested with users • Continue to review competitors, competitor offerings and market needs • Start to plan marketing and selling activities
Product launch	• Marketing plan • Sales plan

Potential impact, dissemination and exploitation of results for selected services

Health community support service

The results and services have been disseminated during relevant seminars, international workshops, scientific papers, and training sessions towards pharmacists (Ph@re network) and doctors by the European Medical Association. CHU of Nice has elaborated and disseminated information to health professionals and patients by posters, flyers ("air pollution", "asthma", "allergies" or "COPD") and the website **www.sante2air.eu** containing health advices.

It has proven to be very useful having a daily and easy to use communication tool about the levels of air pollution, to communicate the health risks associated to the general public, authorities and to the health care community. The health-risk communication has the following impacts: it enables the public to understand the likely health and environmental impacts of air pollution, it encourages a reduction in activities that contribute to air pollution, it enables sensitive groups such as asthmatics to take precautionary measures, it enables the public to assess pollution trends and finally it increases awareness of the public health implications of air pollution.

The ARI and UTCI aim to inform. The health advices given to the general population, and to the high risk groups, do not replace the doctor's advice. As the health effects on individuals may vary, people should seek advice from a medical doctor if they are in doubt or feel uncomfortable. Outdoor workers should inform their employers of the medical advices. This pilot answers many emergency services expectations, for example, crisis management, by anticipating « critical » medical consultation for various pathologies in case of high level of pollutant: forecast, human resources and material management to face exceptional flow risk, specific emergency devices mobilization.

Smoke Plume and Gas Cloud Service

The service has been received very well by the fire departments partaking in the project. We have received excellent cooperation from the fire departments, with good feedback and enthusiastic use of the demonstration service. This shows that the system has real added value to the users and the potential impact can be rated high. No such information is currently available. Open standards allow coupling to different user interfaces. Although government agencies have proven to be a difficult customer in times of financial cutbacks, we aim to see the service in operational use as soon as possible. The system is now entering the market introduction phase. It is planned that the interested fire departments will be offered a trial contract within 2013, to be followed up by a definitive service contract once the service has reached full maturity. Other market sectors are being explored: notably the chemical industry and the oil and gas industry are very big potential markets, with a well-established awareness that safety systems are important for their business. The service will be introduced into these markets as a next step following the fire departments in the Netherlands. Fire departments in other European countries will of course be approached as an additional market as well.

Forecasting Services for London

The service provider CERC have met regularly with the *air*TEXT consortium, which includes representatives from each of the 33 London authorities plus Slough Borough Council (from outside Greater London), the Greater London Authority (GLA), the Environment Agency and the Health Protection Agency (HPA). On 9th July 2012, CERC hosted a launch of new *air*TEXT services at the offices of the GLA in Central Londonwith speeches made by Dr Reinhard Schulte-Braucks, Head of Unit of the GMES Bureau at the European Commission, Sean O'Byrne from the Atmosphere and Local Environment division at Defra and Dr Deborah Turbitt, HPA's regional director for London. The Mayor of London, Boris Johnson, said: "I have introduced a range of effective measures to cut pollution, including the first ever age limit for taxis, tougher standards for the London Low Emission Zone and more, cleaner buses. It is also important that we improve information to help those whose health can be affected when pollution levels are higher. We've been delighted to help *air*TEXT develop their brand new and enhanced information service for Londoners and visitors." To promote the new *air*TEXT app, hundreds of business cards were printed and distributed by "Games Ambassadors" at major transport hubs in London over the period of the Olympic and Paralympic games.

Tourism Information Systems

Currently the Naturpark-Scout is the only navigation system which provides this spectrum of information and service including air quality. The system is run and disseminated by a network of SMEs and the air quality forecasts are operationally provided by DLR. With 22 Mio tourists each year the Black Forest can now serve as an excellent test bed for the tourism information service. Together with pollen information as an additional information layer the system has a good potential for various tourism projects not only in the outdoor sector but even more in the health and wellness sector. This part is even more interesting for exploitation of results since the target group in this tourism segment is much more willing to pay for high quality services. The idea is to use the data together with a special training and rehabilitation programs for patients with heart and circulation problems. The air quality forecasting services for the Black Forest and Bavaria will be continued in the frame of the World Data Center for Remote Sensing of the Atmosphere where they have been implemented at the end of PASODOBLE in an operational environment (**http://wdc.dlr.de/data_products/SERVICES/**). The forecasts are available to the public via web services, Google Earth layers and animations.

Traffic Scenario and Assessment Service for Cities

During a webinar conducted in February 2013, VITO demonstrated to an audience of about 50, comprising of a mix of scientists and city representatives, two traffic scenario assessment methodologies that are available to city authorities to evaluate local traffic pollution and assess the effectiveness of some mitigation measures in their city. The first was based on a high resolution air quality assessment study that was carried out for the city of Antwerp to assess a series of impact measures using its traffic scenario assessment service. The latter, was based on the IFDM (Immision Frequency Dispersion Model) -Traffic assessment tool (**http://ifdmtraffic.rma.vito.be/IFDMTraffic/**), which was developed and tailored for the Flemish administration and is now frequently used by consultants for impact assessments. It was clear from the questions and feedback received that many cities do not have access to a transport emission model and/or atmospheric dispersion tools to evaluate the impact of a traffic management plan. In this regard, there is a clear need for provision of these tools. It was also recently highlighted by DG Environment that many of these cities, especially in Eastern Europe, do not have the capability to carry out these assessments.

Forecasting Services for Athens and Thessaloniki

High resolution air quality information for Athens and Thessaloniki is being disseminated through web-pages available for public awareness and further exploitation from selected end-users like the Hellenic Ministry of Environment, Physical Planning and Public Works. The air quality information produced is additionally used for calculation of bioclimatic indices, which are related to human health and protection, and have serious impacts especially in view of climate change already underway. The air quality services provided by PASODOBLE have been established as a result of ongoing work that has built a collaborative production infrastructure of uniform services through the federation of national resource providers.

Forecasting Services for Bulgaria and Sofia

The core user of this service in Bulgaria is the Executive Environmental Agency (EEA). They have been closely involved in the progress of service development of the forecasting system BgCWIS, v.3. Forecast results are regularly sent so the performance of the system is permanently monitored by the core user. The Bulgarian PASODOBLE team prepares monthly reports on the performance of BgCWIS for EEA. The service user EEA of Bulgaria is acknowledged for taking a decision for funding the current operation and maintenance of the system (contract № 2334/15.06.2012 with NIGGG-BAS). The system, now operating with the highest (1 km) resolution for the city of Sofia can be deployed for other cities/highly polluted regions in Bulgaria with the same resolution. Contacts were made with the municipality of Sofia, who will probably grant some additional support for the BgCWIS sustainable operation.

Forecasting Services for Prague and Bratislava

The newly established city forecasting services for Prague & Bratislava have enabled the relevant authorities to comply with the AQ directive in supplying AQ forecast information. This is a major step for these cities. For instance, before 2012, the city of Bratislava did not have any AQ forecasting services. The fact that the service is viewable with an interface where the user can apply the Myair validations tools provide important support to these users for not only validation of these services but also validation of their own modeling assessments and air quality forecasting initiatives. Although both users are very satisfied with the products, in order for these services to be fully accepted by the relevant authorities, the big challenge is to obtain better emission and measurement (for validation) data at local level. This will require an investment of resources by the local users/national authorities to ensure

these forecasting services continue to be a valuable service. From an EU level, continued supply of reliable boundary conditions from MACC is essential.

Forecasting Services for Northrhine-Westphalia and the Black Sea

The high-resolution air quality services from RIUUK can support regional environmental protection agencies in the implementation of air quality directives. Further possible exploitations include consulting for in depth interpretation of observations, or provision of data from the air quality forecast and analysis archive. In addition to the regular delivery of service products to the service webpage (**http://db.eurad.uni-koeln.de/en/forecast/eurad-im.php**), there are further dissemination paths of the AQ services provided by RIUUK. Firstly, high-resolution AQ forecasts, which have supported the PEGASOS Zeppelin NT measurement campaigns. Secondly, the results from the AQ service for the Ruhr-Rur Area supports the German science foundation project Transregio 32 *Patterns in Soil-Vegetation-Atmosphere-Systems.* Thirdly, graphical products are shown on web-based displays at Research Centre Jülich and LANUV.

Forecasting services for Fennoscandia, Wildfires and Pollen

The inclusion of near-real-time emissions from wild-land fires into the operational air-quality forecasts provides reliable information to local authorities for operational decision making. Northern Europe is a comparatively clean area that is largely polluted from the southern and eastern sides. Thus, harmonized multi-scale simulations starting from European level (with global background anticipated within MACC) provide an important source of information for all users. The near-real-time data on fire emissions and air-quality forecasts are publicly available in various formats on operational basis (**http://silam.fmi.fi** and **http://silam.fmi.fi/thredds)**. Pollen forecasts are available in graphical form at **http://www.polleninfo.org**, the primary European dissemination portal for aeroallergen information. The services are used by user Helsinki Metropolitan Area Council, NIMH Bulgaria, University of Tartu, City of Vilnus, Lithuanian Environment Protection Agency and the public.

Forecasting Services for The Netherlands and the Dutch Provinces

The forecasts produced by KNMI and TNO are presented on the website of RIVM (National Institute for Health and the Environment) in the Netherlands, who have the task to inform the public in case of exceedances of air quality limit values, mainly through internet (**http://www.lml.rivm.nl/**). The forecasts are currently being included in an air quality application for smart phones (app "Luchtkwaliteit"). For policy makers the improved ozone and PM exceedance forecasts can help them in their reporting and to find solutions for possible exceedances of limit values and defining policy. With some additional research the sources of air pollution can be identified. A market exploration within the Netherlands focusing on insurance companies and health associated industry is currently taking place to investigate the potential further exploitation of results.

Satellite-based compliance monitoring for Particulate Matter in Europe

Particulate matter as one major air pollutant has received large public attention in recent years. Satellite-based data can provide crucial complementary information on exceedance episodes and has thus a large potential for raising public awareness as well as complementing the measurements at stations. The Joint Research Center and FAIRMODE have raised their interest to assess further the potential of satellite PM information as supporting tool in implementing European air quality directives. This interest will be followed up. On the other hand, the added value for national/regional environmental agencies in using such complementary information depends strongly on the compliance

pressure put forward by the European legislation, which seems lately rather tending to relax this pressure towards thresholds, which can be achieved more easily.

Satellite-based compliance monitoring in Northern Italy

Dissemination activities have been conducted to convey the results achieved to the scientific community and to communicate progress on the service design and operational set up to the users ARPA Emilia Romagna and Arpa Lombardia environmental agencies. Even if ARPA users - up to now - do not make operational use of these satellite-based products, these were assessed as robust enough to make realistic long-term analysis. As a consequence, a contract has been assigned from ARPA Emilia Romagna to CGS to customize and setup the satellite-based PM software package core of this sub-service. This fosters a possible and profitable use of the satellite-based information by environmental agencies, policy makers in managing air quality and in future directly by citizens due also to the easy reading of the maps.

Local forecast model evaluation support service

The Myair Toolkit for Model Evaluation is unique because it comprises a set of tools that are tailored to the requirements of the air quality forecasting community. The Toolkit combines a novel capability to assess the skill of an air quality forecast service at predicting pollution episodes with the state-of-the-art in concentration evaluation techniques (e.g. DELTA-style target plot, openair graphs) and more traditional model evaluation graphs and statistics such as scatter plots and time series. This makes it a comprehensive system for the evaluation of air quality forecast models. The Myair Toolkit for Model Evaluation is available to download free from **http://www.cerc.co.uk/environmental-software/myair-toolkit.html**.

The PASODOBLE Airsheds

Airsheds have been heavily used by the PASODOBLE partners for nesting their high-resolution applications. In some cases, airshed data are used directly by authorities, which need an integrated view over substantial parts of Europe, still with the highest possible resolution and level of details. Advantages of the airsheds are that they reflect the main features of the region with regard to air quality. The delivery of airsheds data through an OCG compliant web coverage service (WCS) at DLR for use by the downstream services has been realized in the frame of the coordinated data access. Different studies using airsheds material have been published in several peer reviewed journals.The airsheds services will continue their delivery of air quality forecasts for the downstream services, which has shown to be an added-value to the operational systems.

ANNEX

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Glossary

(A)ATSR	(Advanced) Along-Track Scanning Radiometer (**http://www.lmd.polytechnique.fr/chimere/**)
AirBase	European Air quality dataBase
AIRS	Advanced InfraRed Sounder
Airshed	geographical area with all parts of the area being subject to similar conditions of air pollution
*air*TEXT	PROMOTE service for air pollution alerts by CERC
AOD	Aerosol Optical Depth
AQ	Air Quality
AQS	Air Quality Services
ARI	Aggregate Risk Index
ASCII	American Standard Code for Information Interchange
AURORA	Air quality modelling in urban regions
AUTH	Aristotle University of Thessaloniki
AVHRR	Advanced Very High Resolution Radiometer
BMT ARGOSS	BMT ARGOSS Marknesse, the Netherlands
CAFE	Clean Air For Europe
CAMx	Comprehensive Air-quality Model with eXtensions
CC	Cross-Cutting activity
CCI	Climate Change Initiative (ESA)
CC-MARKET	CC activity: Marketing and Business planning
CC-QUALITY	CC activity: Quality Management
CEOS	Committee on Earth Observation Satellites
CERC	Cambridge Environmental Research Consultants
CGS	Compagnia Generale per lo Spazio
CHU-Nice	Centre Hospitalier Universitaire Nice
CIPE	association of 10 hospitals and 3 private clinics
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CO	Confidential, only members of the consortium (including the Commission Services)
CORINE	Coordinated Information on the European Environment
COST	European COoperation in the field of Scientific and Technical research
CSV	Comaa Separated Values
CTM	Chemistry Transport Model
DEMO	Demonstration
DG Environment	DG for Environment
DG Health	DG for Health and Consumers
DG	Directorate General
DLR	German Aerospace Center
DLR-DFD	German Aerospace Center, German Remote Sensing Data Center

DoW	Description of Work
DS	Downstream Service
DS-HEALTH	DS Health community support services for people at risk, hospitals, pharmacies and doctors
EAN	European Aeroallergen Network
EC	European Commission
ECMWF	European Center for Medium-range Weather Forecast
ECSS	European Cooperation for Space Standardization
EEA	European Environment Agency
EIONET	European Environment Information and Observation Network
EMA	European Medical Association
EMEP	European Monitoring and Evaluation Programme
ENVISAT	European polar-orbiting environmental satellite
EO	Earth Observation
EPS	European Polar System
ESA	European Space Agency
EU	European Union
EU27	European Union (27 member countries)
EUMETSAT	EUropean organisation for the exploitation of METeorological SATellites
FAIRMODE	Forum for Air Quality Modelling in Europe
FLEXPART	an atmospheric trajectory and a particle dispersion model
FMI	Finnish Meteorological Institute (Ilmatieteen laitos)
FP7	seventh Framework Programme
FP7	seventh Framework Programme
(F)RIUUK	Rheinisches Institut für Umweltforschung an der Universität zu Köln
FUMAPEX	integrated systems for Forecasting Urban Meteorology, Air pollution and Population EXposure
GAS	GMES Atmosphere Service
GEMS	Global and regional Earth-system (Atmosphere) Monitoring using Satellite and in-situ data
GENESIS	GENeric European Sustainable Information Space for environment
GENESIS	GENeric European Sustainable Information Space for environment
GEO	Group on Earth Observations
GeoServer	Open source software server that allows users to share geospatial data
GEOSS	Global Earth Observation System of Systems
GIS	Geo-Information System
GMES	Global Monitoring for Environment and Security
GMES	Global Monitoring for Environment and Security
GOME	Global Ozone Monitoring Experiment
GSE	GMES Service Element
GUI	Graphical User Interface

HARMO	Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
HDF	Hierarchical Data Format
IASI	Infrared Atmospheric Sounding Interferometer
IC-AIRSHEDS	IC Providing emissions, intermediate air quality forecasts and analyses for selected European airsheds
ICT	Information and Communication Technologies
INSPIRE	Infrastructure for Spatial Information in Europe
IPR	Intellectual Property Rights
IR	Infrared
IRCEL	Intergewestelijke Cel voor het Leefmilieu
IT	Information technology
JRC	Joint Research Center
KNMI	Koninklijk Nederlands Meteorologisch Instituut
LANUV	Landesamt für Natur, Umwelt und Verbraucherschutz of North-Rhine-Westphalia
LOTOS-EUROS	an atmospheric chemistry transport model
LRTAP	Long Range Transboundary Air Pollution
MACC	Monitoring Atmospheric Composition and Climate
METOP	European polar-orbiting weather satellite, part of EPS
MODIS	MODerate resolution Imaging Spectro-radiometer
MSG	Meteosat Second Generation
MUW	Medical University of Vienna
Nowcasting	NowCasting International
NDACC	Network for Detection of Atmospheric Composition Change
NE	North-East
NetCDF	Network Common Data Format
NILU	Norsk Institutt for Luftforskning
NL	the Netherlands
NRT	Near Real-Time
NRT	Near Real-Time
NRW	North-Rhine-Westphalia
obAIRve	Observe the air and provide the service, GMES preparatory action
ODC	OutDoor Concepts GmbH
OGC	Open Geospatial Consortium
OGC	Open Geospatial Consortium
OI	Optimal Interpolation
OMI	Ozone Monitoring Instrument
PACA	région Provence-Alpes-Côte d'Azur
PASODOBLE	Promote Air quality Services integrating Observations – Development Of Basic Localised information for Europe
PC	Personal Computer

PDF	Portable Document Format
PM_{10}	Particulate Matter with diameter smaller than 10μm
$PM_{2.5}$	Particulate Matter with diameter smaller than 2.5μm
PROMOTE	Protocol Monitoring for the GMES Service Element
PROPART	statistical model for PM_{10} forecast
QA	Quality Assessment
QA4EO	Quality Assurance framework for Earth Observation
R&D	Research and Development
RE	restricted to a group specified by the consortium (including the Commission Services)
RIUUK	Rheinisches Institut für Umweltforschung an der Universität zu Köln
RIVM	National Institute for Public Health and Environment (the Netherlands)
RMS	Root-Mean-Square
RMSE	Root-Mean-Square Error
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SDIC	Spatial Data Interest Community
SEIS	Shared Environmental Information System
SEVIRI	Spinning Enhanced Visible and InfraRed Imager
SHMU	Slovenky Hydrometeorologicky Ustav
SLA	Service Level Agreement
SME	Small and Medium-sized Enterprises
SMOGPROG	air quality monitoring and forecasting system
SMS	Short Message Service
SYNAER	SYNergetic AERosol retrieval
TNO	Nederlandse organisatie voor toegepast Natuurwetenschappelijk Onderzoek
US	United States
UTCI	Universal Thermal Climate Index
UV	Ultraviolet
VITO	Vlaamse Instelling voor Technologisch Onderzoek
WDC/RSAT	World Data Center for Remote Sensing of the Atmosphere
WFS	Web Feature Service
WG	Working Group
WGCV	Working Group on Calibration / Validation
WIS	WMO Information System
WMO	World Meteorological Organisation
WMO	World Meteorological Organisation
WMS	Web Map Service
XML	Extensible Markup Language