

# **Spatial assessment at local/hot spot scale**

*and its application for*

**compliance with EU directives and population exposure to ambient air**

## **Summary**

This document has been compiled within the FP6 project Air4EU as a guidance document for the spatial assessment of particulate matter (PM) and nitrogen dioxide (NO<sub>2</sub>) at local and hot spot scale. It provides recommendations on three levels, i.e. basic requirements, best practices and further scientific research. Two main application areas are addressed, assessment for compliance with EU directives and population exposure. Recommendations on different assessment methodologies are given, including monitoring, modelling and methods for combining modelling and monitoring. A number of particular issues are also dealt with such as emissions and uncertainty analysis. The intended main result of the spatial assessment and uncertainty analysis described here is the production of spatial distribution maps. The recommendations are intended as guidance for authorities involved in the air quality assessment at city, national and European level. They are intended to aid good assessment practice and to highlight areas that require further development.

# Contents

<b>1. Introduction</b>	<b>3</b>
1.1 Aim	3
1.2 Applications and scales	3
1.3 Structure of this document	3
<b>2. Monitoring</b>	<b>4</b>
2.1 Network design	4
2.2 Monitoring methods	7
2.3 Data quality and assurance (QAQC)	7
<b>3. Modelling</b>	<b>8</b>
3.1 General model types and requirements	8
3.2 Meteorology	10
3.3 Chemistry	10
3.5 Background contributions	11
3.6 Interactions between modelling scales	12
3.7 Population exposure	13
<b>4. Combining modelling and monitoring</b>	<b>14</b>
4.1 Model evaluation/validation	14
4.2 Data assimilation	14
4.3 Optimisation of monitoring networks using models and data assimilation	17
<b>5. Emissions</b>	<b>18</b>
5.1 General recommendations for the generation of emission data	18
5.2 Recommendations for the generation of PM, NO <sub>x</sub> and NO <sub>2</sub> emission data on local/hotspot scale	19
<b>6. Uncertainty analysis</b>	<b>22</b>
6.1 Uncertainties in monitoring data	22
6.2 Uncertainties related to representativeness	23
6.3 Uncertainties in modelling	24
6.4 Assessment of uncertainties when combining monitoring and modelling	25
6.5 Spatial mapping of uncertainties	26
<b>7. Concluding remarks</b>	<b>27</b>
<b>References</b>	<b>29</b>

# 1. Introduction

## 1.1 Aim

The main aim of this document is to give recommendations on methodologies that will lead to improved assessment of particulate matter (expressed as PM<sub>10</sub>) and nitrogen dioxide (NO<sub>2</sub>) at local/hot spots scale. The document deals with methods and issues relevant to this topic. Suggestions on use of combined monitoring and modelling method are also given.

## 1.2 Applications and scales

Assessment of pollutants, such as PM and NO<sub>2</sub>, can be for a variety of applications and purposes. This document focuses on assessment for compliance with EU directives. These directives require information on annual, daily and hourly mean concentration values. Spatial assessment can also be used to assess potential population exposure.

The required spatial resolution of assessment may vary but, in principle, both compliance and exposure calculations on local/hot spot scale require spatial resolutions ranging from few meters up to about 1 km.

## 1.3 Structure of this document

As outlined in the 'Overview and structure' section of the final recommendations document, each topic report has been structured to provide access to the individual recommendations.

The recommendations within this document are relevant to the topic:

### ***Spatial assessment of PM and NO<sub>2</sub> at local/hot spots scale***

Within this topic a number of methods and issues for carrying out this assessment are addressed, which include:

- *Monitoring*
- *Modelling*
- *Combining modelling and monitoring*
- *Emissions*
- *Uncertainty analysis*

In each of these chapters, recommendations are given at 3 levels of complexity, i.e.,

- a) Basic requirements*
- b) Best practice recommendations*
- c) Scientific recommendations*

The two main application areas of compliance with directives and calculation of population exposure are both addressed in this report. Where appropriate, the two areas are considered separately but in general cover similar methodologies.

Throughout the document recommendations are given in *italics* and **blue colour** and supporting text in normal font. Where recommendations are specific for one of the compounds PM<sub>10</sub> or NO<sub>2</sub>, this is clearly indicated. If not, the recommendations are general for both compounds.

In addition to the recommendations presented, a number of case studies designed to test and demonstrate some of the recommendations have been carried out. Results from the case studies are included in the relevant methodology chapter.

## 2. Monitoring

The monitoring data from local/hotspot stations provide a basis for assessing high levels of exposure to pollutants. The objective of monitoring for AQ assessment in relation to the EU air quality limit values for PM<sub>10</sub> and NO<sub>2</sub> is to provide the following:

- A set of time series of concentration levels over a year of basic averaging time corresponding to the requirements of the directives:
  - for PM<sub>10</sub> (and in the near future PM<sub>2.5</sub>) 24 hourly and annual averages
  - for NO<sub>2</sub> hourly and annual averages
- Estimation of the spatial extent of exceedances
- Estimation of the population exposure in ambient air (not including indoor exposure).

In connection with modelling, the objective of monitoring is to provide input data for local/hotspot scale models, the evaluation and validation of models and in many cases for the improvement of empirical models and/or parameterisations approaches.

The recommendations regarding 'monitoring' are structured in three sections:

- Monitoring network design
- Monitoring methods
- Data quality control and assurance (QA/QC)

In the *basic requirement* level of 'monitoring', it is understood that the assessment is made mainly from monitored data, and modelling is not carried out in any significant detail. Even at this level, however, one should consider the requirements for the location of stations that may be used for model evaluation purposes.

In the *best practice recommendations* level, it is understood that although assessment can be based solely on the monitoring part, the approach can be improved beyond the *basic* level by using monitoring more actively for model evaluation, validation or improvement/development. Monitoring is also used in combination with modelling to provide more informative assessment outcomes.

In the *scientific recommendations* level, it is understood that there are a number of aspects of monitoring that require further research to improve both the methods and the practices.

### 2.1 Network design

#### a) Basic requirements

The air quality (AQ) Directives set out specific requirements on the location of stations, especially those near streets. The requirements also deal with the differences between compounds when considering averaging times and health effects related to air pollution exposure.

*The design of the network should comply with the basic requirement in the AQ Directives. These include requirements regarding:*

- *The number of stations according to the size (population) of the city*
- *The types of stations, and an indication of number of each type.*

*On definition of types of stations, see the Exchange of Information (EoI) decision (97/101/EC).*

*The Directive especially specifies requirements regarding micro-location of hot spot stations:*

- *Location of shelter and inlet relative to nearby sources and nearby obstacles*
  - *height of sampler inlet: 1.5-4 meters.*
  - *distance of inlet from junctions: at least 25 meters.*
  - *distance of inlet from centre of nearest lane*

- for NO<sub>2</sub>: 4-5 meters.
- for PM<sub>10</sub>: 4-10 meters.

- Follow the reference monitoring method.

### **The locating of monitoring sites**

The air pollution concentration gradients can be very sharp near streets and industrial sources. Thus, the assessment by monitoring of local/hotspot air pollution is very dependent upon the detailed location of the stations. 'Traffic' and 'industrial' stations are defined in the Exchange of Information Decision (Council Decision 97/101/EC) and its amendment (Commission Decision 2001/752/EC), and described in the EoI Guidance Report (Guidance report on the Annexes to Decision 97/101/EC). The AQ Directives base themselves on these definitions and give general guidelines.

*In regard to the design of AQ monitoring network for local/hotspots assessment, it is recommended to consult the following references:*

- *Guidance to preliminary assessment of air quality under the EU AQ Directives (van Aalst et al. 1998)*
- *The report 'Guidance to assessment under the EU AQ Directives', (<http://ec.europa.eu/environment/air/pdf/guidanceunderairquality.pdf>) where the process are described for selecting the locations of the number of stations which are available or needed according to the Directive.*

The determination of the larger scale related contributions to the air pollutant concentrations at a local/hotspot station is also important in air quality assessment. The most important scale interactions for local/hotspot assessment are between the urban and local scales. Measurements of the urban concentrations provide boundary conditions for assessments of the local/hotspot part of the air quality problem. This is equally important for assessment methods based on monitoring as well as on modelling.

*It is recommended to establish urban-local station pairs as part of the typical urban AQ monitoring network. Locating an urban background station and a hot-spot station (traffic or industrial) in the same area can improve definition of roadside increments (see under Best practice recommendations, regarding the need also for triple stations by including a rural background station).*

### **Monitoring a combination of pollutant compounds at stations**

Monitoring of pollutant compounds other than PM and NO<sub>2</sub> is also necessary. For example, usually it is necessary and required to monitor CO and benzene near road locations and SO<sub>2</sub> for industrial site as they can provide vital information about these specific source emissions.

*It is recommended to measure both PM<sub>10</sub> and PM<sub>2.5</sub> at the same location.*

*It is also recommended to measure NO<sub>x</sub>, NO<sub>2</sub> and PM at the same location and, in some cases SO<sub>2</sub> as well when industrial sources are prominent in the area. This type of data on multiple pollutants is important when identifying which sources are contributing to the air pollution.*

## **b) Best practice recommendations**

### **Monitoring of meteorological parameters**

Meteorological processes determine the transport and mixing of pollution in the atmosphere. In order to interpret pollution behaviour correctly, therefore, meteorological data, which is representative of the surrounding of the streets/roads or industrial sites, is needed. For example, data on parameters, such as wind speed and direction, temperature and precipitation is necessary to help explain temporal variations of the pollutants (hourly, daily, annually), and to indicate source areas influencing a station.

*It is recommended to have at least one meteorological monitoring station as near as possible to the air pollutant monitoring site. Key parameters should include wind speed and direction data and preferably also temperature and solar radiation to estimate the vertical stability.*

*Ideally, the meteorological parameters should also be monitored at the same monitoring interval as the pollutant data. The meteorological measurements should be conducted at or near roof top height if the location is near a built up area. This is to reduce the effects of the building itself on measured parameters (Oke, 2006). Existing meteorological stations operated by meteorological services and/or airport authorities should be evaluated regarding their suitability and representativeness for the pollution site being assessed (eg. street/road or the industrial site)..*

These meteorological datasets are also needed for input to local scale air quality models.

### **Enhanced networks**

It is recommended to **enhance the above network** with more stations, in order to improve the assessment. An addition of a regional station, giving a station triplet of street, urban background and regional, will add important information on the extra-urban contribution.

*When locating the additional stations, the following should be considered:*

- *At least one regional background station should be sited in the surrounding area of the city where local assessment is to be conducted, to represent the concentrations in the air entering the city from outside. The difference between the regional and urban background represents the contribution of city sources to the urban background. This is relevant to city authorities to develop action plans and programmes as well as to identify the control measures that can be implemented effectively locally and those which require regional cooperation. Consideration should be given to setting up more than one station for complex situations where one station location will not be representative of the incoming pollution for all the important wind directions.*
- *The monitoring station(s) within cities should be sited to give as good a basis as possible for calculating the population exposure distribution, which is needed as a basis for health effects assessments. This implies that the location of the site should be representative of the main areas where the population is exposed to high air pollution levels (e.g. street with pavement cafes and the facade of a residential building near road).*
- *Stations should be suitable for evaluating, validating and improving dispersion models. For a local scale model, such as a line source model which calculates the concentrations near streets/roads, the station location must reflect the situation which is represented by the model. Typically, a model will give concentrations for an idealised type of street/building configuration (e.g. a street canyon with continuous building facades of similar height on both sides). Although advanced models, such as CFD models, can calculate concentrations for more complex configurations, it is more common to employ simpler methods which do not treat the impacts of features such as junctions and intersections. Generally, if monitoring data is to be used for model evaluation purposes then the station should be located away from intersections and other features that are normally are not described in the models.*

### **PM**

*In order to enhance the monitoring data,  $PM_1$  and/or ultra fine particles (UFP) (preferably with size distribution) should be monitored in addition to  $PM_{10}$  and  $PM_{2.5}$ , at least at one station, providing an urban representation. Although, this type of information is not required by the EU air quality framework directives, it can be useful for health effect studies.*

*The contribution from non-exhaust particles should be estimated at least at one station pair (urban background and traffic station), using hourly monitoring data of  $PM_{10}$  and  $PM_{2.5}$ . A simple methodology has been described by Keuken (2006).*

*To support the first assessment of source contributions to PM mass, it is recommended to undertake chemical speciation of PM for road side and urban*

*samples. This type of data can be analysed with receptor models to provide information of the major sources and their contributions to the urban air. Useful guidance can be found in the Air4EU report D6.2 part II: Spatial assessment in urban areas.*

### **c) Scientific recommendations**

*Source apportionment and size distribution analysis should be carried out to allow a more detailed understanding of the main pollution source contributions from the street itself, the city (eg urban background) and those responsible for long range transport of pollutants into the city environment. More details about source apportionment can be found in the Air4EU report D6.2 part II: Spatial assessment in urban areas.*

## **2.2 Monitoring methods**

### **a) Basic requirements**

*It is recommended to use the reference methods, as specified in the Directive (see its Annex IX).*

*If these are not used, the equivalence of the methods used must be proven, using standard procedures (see EU's [Guidance on equivalence demonstration](#) and [Equivalence test format for general guidance on equivalence testing](#)).*

#### **PM**

*Specifically for PM<sub>10</sub>, the following reference can be consulted to test for method equivalence.*

*- CEN standard EN 12341:1998 – “Determination of the PM<sub>10</sub> fraction of suspended particulate matter – Reference method and field test procedure to demonstrate reference equivalence of measurement methods”.*

*There are several examples of reports from equivalence testing of PM<sub>10</sub> monitors, (see for example*

*[http://www.airquality.co.uk/archive/reports/cat05/0606130952\\_UKPMEquivalence](http://www.airquality.co.uk/archive/reports/cat05/0606130952_UKPMEquivalence), and [http://www.fmi.fi/kuvat/FINAL\\_PM\\_report\\_30\\_1\\_2004.pdf](http://www.fmi.fi/kuvat/FINAL_PM_report_30_1_2004.pdf)).*

*It is recommended to use methods with as short time averaging as possible, preferably hourly, to enhance the usefulness of the monitored data (e.g., when used in combination with hourly meteorological data, source areas can be detected by looking at wind conditions during high concentrations). If the method is proven to be equivalent to the reference method, it is recommended to use methods giving hourly data in preference to the reference gravimetric method, which typically gives 24-hour averages. Hourly data enables the diurnal variations of the pollutants to be identified and compared to traffic levels for air quality and traffic management strategies.*

### **b) Best practice recommendations**

#### **PM**

*It is recommended, if possible, to measure PM both with a monitor giving hourly averages and with a sampler giving PM samples on a filter for later chemical analysis. This should be performed at least at 2 stations (eg street and urban background to allow the source contributions to be estimated using Source Apportionment techniques.*

## **2.3 Data quality and assurance (QA/QC)**

Quality assurance and control (QA/QC) procedures ensures that measurements meet defined standards of quality with a stated level of confidence. The QA programme covers pre-measurement activities such as the required Data Quality Objectives (DQO), site selection and equipment and operation procedures. QC covers directly the measurement-related activities, such as calibration and data handling. QA/QC process should also ensure that data are representative of ambient air concentrations in the area under investigation both in spatial and temporal resolution and data have a level of accuracy and precision as specified in the DQO.

Basic requirements, best practice and scientific recommendations on QA/QC on urban scale assessment is applicable here and can be found in Air4EU report D6.2 Part II: Spatial assessment in urban areas”.

### 3. Modelling

The following section considers a number of modelling aspects, in regard to the assessment of PM and NO<sub>2</sub> near roadside or point sources. The objective of modelling for spatial assessment and population exposure is to provide a spatially and temporally resolved representation of air quality in the area of study. In addition, modelling is usually required for scenario calculations.

Important aspects of modelling addressed in the following subsections include meteorological input, chemical processes, background contribution and scale interactions.

#### 3.1 General model types and requirements

A great number of models exist for investigating different air quality problems. These tend to focus on specific applications (complex buildup of pollution in a given area or a road) or specific street geometries (e.g open road, street canyon). Models available for calculating concentrations in local/hotspots scale include the following model types:

- Empirical/Semi-empirical
- Gaussian
- Lagrangian
- CFD (Eulerian)

Local scale models can be Eulerian, in the case of CFD models, but are more often empirical/semi-empirical models based on observations and Gaussian or near Gaussian models. These are generally applied to traffic or point source emissions where local gradients in concentrations are high.

Empirical/semi-empirical models are not process or deterministic models but create a statistical link between observed concentrations and other factors, e.g. meteorology, emissions or observations. As these models rely largely on the use of monitoring data, the performance of these models depends critically on the availability of good data coverage and are usually only applicable at the site from which the statistics were developed. Some relationships developed in this way may be more universal and applicable to other sites but such models, and maps that may be produced using the relationships developed, must be used with care.

The following sets of recommendations address general model requirements including temporal resolution of these models.

##### a) Basic requirements

The temporal resolution of models varies from application to application. For compliance with most EU directives hourly means are the maximum temporal resolution that is required. For population exposure (short or long term) the required temporal resolution will vary from minutes to years.

*The temporal resolution of the model should be appropriate to the application. When only annual means are required, for long term exposure estimates or comparing with objective values, then empirical or semi-empirical models can be suitable. For compliance with high temporal resolution concentrations (hourly), Gaussian models should be used.*

*Some Lagrangian dispersion models with special treatment to account for enhanced horizontal dispersion in low wind speed conditions (e.g. GRAL model) perform better under low wind speed conditions where most Gaussian models 'break down' (Öttl et al. 2001) and should be used before trying new or more complex developments.*

Eulerian grid model generally require large amounts of input data and computer time and also produce large volumes of output data. Consequently, it may not be practical to calculate long term averages with these types of models for routine applications.

*Some basic principles apply when using models:*

- *A model should only be used when they are appropriate for the intended application, and their use should be justified. Thus it is very important to understand the model's limitations and apply it only to the situations that match its capabilities. Information on most models being used in Europe can be found on the [ETC/ACC Model Documentation System](http://pandora.meng.auth.gr/mds/qstart.php) (<http://pandora.meng.auth.gr/mds/qstart.php>)*
- *Models must always, whenever possible, be validated against observational data for the site of application.*
- *Model calculations should be carefully examined to determine how realistic the output concentrations are at critical times, given the known geography and meteorology.*
- *Parameters used in empirical/semi-empirical models should be recalibrated against a small number of field measurements (as a minimum requirement), if the models are to be applied to an area or a situation other than that it is developed for.*

## **b) Best practice recommendations**

*Under low-wind conditions, the traffic-induced turbulence is of a great importance (e.g. Berkowicz et al. 1997); models considering the effect of traffic-induced turbulence are recommended*

*Under convective conditions, new generation Gaussian models incorporating non-Gaussian or skew profiles are recommended (Hanna et al., 2002).*

*Lagrangian or Eulerian models should be used when meteorological conditions vary across the modelling domain and, therefore, are not compatible with the steady-state assumption made in empirical or Gaussian models.*

*All models have limitations to the scope of its application and to the accuracy of its predictions. It is recommended that the uncertainty of model results should be determined, and should form an integral part of the assessment process. Also the uncertainty of the separate modules and input data should be determined (see chapter 5 on uncertainty analysis)*

*When showing maps of air quality, uncertainty associated with the assessment should also be presented.*

## **c) Scientific recommendations**

Traditionally Empirical or Gaussian type models have been applied due to their simplicity and low computer requirements. If computing resources allow, more advanced models may be applied when meteorological conditions vary across the modelling domain. In these cases the steady-state assumption is not valid as required for Gaussian models. Frequent periods of low wind speed or calms will invalidate the use of Gaussian models. CFD models are being used increasingly for higher resolutions and for covering larger areas.

*Before new and advanced models are operationally implemented their improved value above current simpler methods, must be evaluated and documented.*

*In general, there is a need for independent, quantitative review and intercomparison of the various models used.*

*There is a need for the development of a mathematical treatment for low wind conditions for use in simple models.*

*Refinement of guidance on QA/QC for modelling should be established. A clear statement of model uncertainties is indispensable in any air quality assessment study.*

## 3.2 Meteorology

Meteorological input data are an essential part of any air quality model. Meteorological fields for local scale models can be determined using local observations or can be calculated using local scale meteorological models coupled to mesoscale models.

### a) Basic requirements

*Statistical meteorological fields are often sufficient for annual mean concentration calculations when applied to steady state empirical or Gaussian models.*

*Meteorological fields, which are sequential and have a temporal resolution of 1 hour are needed for assessments of peak conditions and daily mean concentrations.*

### b) Best practice recommendations

*For modelling areas with complex terrain, e.g. built up areas and with varying meteorological conditions, full 3-D meteorological data from diagnostic or prognostic models should be used in combination with a 3-D Eulerian dispersion model.*

*Stability should be assessed using similarity theory when data are available rather than P-G stability classes for a more realistic representation of the boundary layer (e.g. McHugh et al 1999, Hanna et al., 2002).*

### c) Scientific recommendations

*The use of data assimilation on local scale should be developed (see case study Oslo II).*

## 3.3 Chemistry

### a) Basic requirements

On the local scale the influence of chemistry, secondary particle formation and aerosol dynamics on the total mass of the particles is limited. As such a model may neglect these processes as first approximation.

#### NO<sub>2</sub>

*For screening purposes and longer-term averages, empirical relationships between different pollutants can be used to estimate levels of NO<sub>2</sub>.*

*For hourly or peak values, models with simple chemical reaction schemes, e.g. GRS, O<sub>3</sub> limiting method, can be used (LAQM, 2003).*

*Photostationary state relationship assumes there is sufficient time for steady state to be established, which is less likely at sites closer to source and cannot generally be achieved at night. Thus models that rely on this assumption are **not** suitable for near source and nighttime conditions (AQEG, 2004)*

#### PM

*Formation of secondary PM is quite limited in the time scales of local scale processes. It can be assumed that PM can be treated as an inert pollutant and that the formation of secondary PM is limited and mainly comes from background.*

### b) Best practice recommendations

#### NO<sub>2</sub>

*Photochemical reactions involving ozone and NO<sub>x</sub> should be considered. More sophisticated chemical reaction schemes should be examined although further research is required in how and under which circumstance these schemes should be used.*

#### PM

*Model that considers deposition processes should be used for industrial complexes that usually face large dust problems.*

### c) Scientific recommendations

*A detailed comparison of different chemistry schemes relevant to local scales has not been found in the literature. Such a comparative study would help to identify the merits and limitations as well as the applications of the various approaches.*

## 3.5 Background contributions

Local scale practical dispersion models will only predict the pollutant concentrations contributed by the modelled source, such as street traffic or an industrial stack. To assess the potential exceedences of the air quality objective or to compare modelled values with measurements, one must take into account of the contributions resulting from nearby roads or stacks as well as distant sources (urban, regional or even transboundary). This additional contribution is commonly referred to as 'background' contributions. This contribution can only be estimated using measurements far from the road or point source studied or by urban scale models.

When using urban scale models, or urban observations, it is important to be aware of 'double counting'. This is when the results of emissions from the local emissions, e.g. traffic or point sources, are effectively counted twice. This can also occur with observations when background concentrations are taken from stations downwind of the local traffic emissions or point sources being studied. Similarly, double counting can occur in urban scale models which include the emissions from the local source. This problem can also occur when urban and local scale models, which in principle both contain the same emissions, are not properly combined, e.g. by using different meteorological fields in the two models.

### a) Basic requirements

*The minimum requirement for obtaining background values from measurements is:*

- Hourly, daily and annual mean concentrations taken from at least 1 background station in the vicinity of the studied road or point source but not being influenced significantly by the local source.*
- If more than one station is available then wind direction should be used to determine the most appropriate upwind station.*

*The minimum requirement for obtaining background values from urban scale models is:*

- Hourly, daily and annual mean concentrations taken from the grid position upwind of the studied road or point source.*
- PM bias is common in urban models as most models currently underestimate PM levels. The model should be either validated or adjusted to account for this bias and, where possible, the physical basis of the bias should be identified.*

### b) Best practice recommendations

When using observational data from background stations the following best practices apply:

- The recommended number of background stations required for calculating local background concentrations is 3 surrounding the studied point source and 2 for a road (on each side of the road). These stations should be selected based on the most appropriate upwind direction.*
- Hourly average values are always preferred, including meteorological data, to help in the understanding of the transport processes.*
- Hour-by-hour wind directions with respect to the relative position of the modelled source and the monitoring station should be examined (as downwind monitoring stations will also record a signal from the source being modelled).*

When using urban scale models as boundary conditions for local scale models the following best practices apply:

- If possible, emissions from the local source should be excluded from the urban scale model for background calculations.*
- When meteorology is consistent between the urban and local scale model then boundary conditions can be spatially interpolated directly from the urban scale*

*model. When this is not the case then the local scale model domain should be expanded to be significantly larger than the area studied so that no 'double counting' takes place.*

- *As an alternative, when meteorology is not consistent between urban and local scale models, the boundary conditions can be taken from the upwind side of the urban model;*
- *The use of data assimilation, to improve upon the bias of current urban scale models, is recommended to improve background concentrations used for assessment.*

Recommendations on using data assimilation in urban scale models can be found in Air4EU report D6.2 Part II: Spatial assessment in urban areas.

### **c) Scientific recommendations**

#### **PM**

*Many urban scale models currently underestimate PM concentrations and so their value as background is questionable. There is a need for improved emission inventories and process descriptions in these models.*

### **3.6 Interactions between modelling scales**

Despite the multi-scale character of the atmosphere, considerations of computational cost and availability of data has led to the development of scale-specific models. However it is often necessary to calculate concentrations on a variety of scales. Urban background contributions to local scale modelling, see section 3.5 above, is an example of scale interaction from larger to smaller scales.

When calculating exceedances or human exposure in areas affected by road traffic or industrial sources it is necessary to include the urban scale effect in the model calculations. One method is 'nesting' where particular local regions, within the urban area, are selected and Eulerian type models (eg CFD models) are coupled to an urban scale model. The use of coherent time dependent boundary conditions for local scale models allows the refined description of interactions between larger scale meteorological phenomena and local scale processes. A simple example of nesting or coupled models is when urban scale models are used to calculate hourly, daily and annual mean background concentrations for local scale models. Further examples of air quality modelling can be found in the review of local scale air quality assessment conducted by Sokhi and Yu (2005).

More detailed information on scale interactions can be found in the Air4EU report M4: Scale interactions.

#### **a) Basic requirements**

*When performing one-way or two-way coupling of different scale models, the chemistry and various physical processes across the scales have to be consistent in terms of the specific spatial and temporal characteristics of the interaction.*

#### **b) Best practice recommendations**

*When carrying out assessment in local/hotspot areas, a larger scale model can be employed to estimate the background contributions if suitable observations are not available.*

*Modelling systems that avoid double counting and have the same temporal resolution as the local scale model should be employed where possible.*

#### **c) Scientific recommendations**

*Integrated models can be used (eg Eulerian Models) instead of coupling different models to account for scale effects (eg using an urban model for estimating background for a another local model). This type of approach can, in principle, take into account urban as well as regional (eg long range transport) contributions in a consistent manner.*

### 3.7 Population exposure

Depending on the methodology employed and the needs of the calculation, population exposure can be carried out at a variety of levels. In general, population exposure is an average quantity representing a 'potential' exposure as there are very few measurements of actual individual exposures. The following should be treated as indicative guidance:

#### a) Basic requirements

*The most straightforward methodology for assessing population exposure is to combine spatially distributed population density maps with concentration maps. For example, if a map showing the spatial extent of exceedance and the population density is available then a similar map can be constructed by taking the intersection of these maps. The spatial resolution of both model and population density determine the final spatial resolution of the combined maps.*

#### b) Best practice recommendations

Usually, studies involving population exposure assessment are based on measurements of ambient air pollutant concentrations at outdoor fixed sites or sometimes in different micro-environments. These ambient pollutant concentrations are assumed to be related to the average population exposure. However, the measurement data from fixed stations do not necessarily represent areas beyond their immediate vicinity, as the concentrations of pollutants near traffic road or industrial complexes may vary by orders of magnitude on spatial scales of a few to hundreds of metres.

*It is recommended that spatial concentration distributions should be evaluated first by atmospheric dispersion models or a set of onsite measurements before evaluating the exposure of the population to air pollution.*

*It is recommended that the time-activity patterns of the population should be taken into account when fixed air monitoring data are to be used as a proxy for assessing population exposure.*

Ideally, personal exposure measurements, i.e. measurements collected from an individual's immediate environment, should be carried out to assess population exposure. But the use of this type of measurements is labour intensive, and requires extensive co-operation of the study participants.

*Exposure models can be used to simulate and predict population exposure and dose distributions, and to identify the most important factors and their variability and uncertainties.*

#### c) Scientific recommendations

There are a number of more advanced methods for assessing the total population exposure based on the mobility of populations, indoor exposure calculations and activity data. These methods are more complex and require a large and varied dataset of concentration data as well as statistically significant activity data.

*Studies with emphasise on establishing the link between personal exposures and ambient air concentrations measured by air quality networks should be conducted to assist the use of ambient air pollutant concentration measurement for population exposure assessment. For this kind of study both personal exposure data and ambient pollution levels should be available for the same time period.*

## 4. Combining modelling and monitoring

Measurements provide the most direct information on pollution conditions (at least at the measurement sites). Measurements in themselves cannot explain spatial variations without interpolation or extrapolation techniques. Also they cannot predict the impact of future scenarios except when coupled to modelling approaches. With the use of receptor modelling techniques they can be used to identify and attribute the main sources contributing to the concentrations measured at the station. This type of application, however, requires extensive measurements along with chemical analysis to identify markers for the main sources. Usually for air quality management purposes, measurements are used as part of surveillance programmes for reporting the present conditions and for archiving historical trends. Proper interpretation of the measurements in terms of aspects such as source-receptor relationships, meteorological conditions, emissions and urban conditions, can only be performed using local dispersion models. It should be stressed, however, that neither measurements nor models on their own can provide all the information needed in conducting a good air quality assessment at the local scale. In fact, both measured and modelled concentrations contain relevant information about the air quality patterns and their behaviour. Consequently, only using measurements or modelling and not both, for air quality assessment, should be avoided.

*Combining model results with measurements reduces uncertainties inherent in both, and is strongly recommended in order to achieve a better depiction of the real situation in the area of interest.*

### 4.1 Model evaluation/validation

The most common method for combining modelling and monitoring on local scale problems is to use monitoring data to evaluate or validate the model and to improve empirical relationships. Improvement of the process description in the model based on the comparison with observations is an essential part of any model development activity. However, there is always a danger that models become 'tuned' to their validation data if data is limited and become less applicable to other areas or conditions.

#### a) Basic requirements

*The model used in AQ assessment should have undergone published evaluation or validation assessment, and/or should be recognised to be fit for the purpose of application.*

*When measurements are not available in the assessment region then the model should have been validated at a number of other, but similar, sites.*

#### b) Best practice recommendations

*The models used for assessment should be validated at a number of different locations within the assessment area.*

#### c) Scientific recommendations

Understanding the relationship between a given model and a set of observations is generally a complex issue. Although much work has been done in this area resulting in different recommended statistical evaluation parameters, and evaluation kits and procedures, more research on how to evaluate models properly is still needed.

*It is advisable to interact with the experts in statistics and modelling to employ more sophisticated approaches to model evaluation. These can include a combination of statistical measures of performance, sensitivity analysis, dynamic evaluation and diagnostic evaluations.*

### 4.2 Data assimilation

Combining modelling and monitoring can also be done using different techniques of data assimilation. The purpose of such techniques is to adjust the values of some or all of a set of uncertain variables or parameters of the model in order to better fit with the measured concentrations.

Data assimilation methods have been successfully applied for regional and urban scale AQ models (see examples of this in the Air4EU report M5: Data assimilation), but as far as we know there exists no applications of such methods for the local scale, except for an application in the Air4EU case study D7.1.4 (see description of this case study below). However, several data assimilation methods exist which

may also be used for the local scale such as, 3D-Var, Kalman filters, and the more recent class of Sequential Monte Carlo methods or particle filters such as, the Sequential Importance Re-sampling (SIR) method used in the Oslo II case study.

The following set of recommendations on data assimilation reflects some of the more basic and general considerations for applying data assimilation. More detailed information on data assimilation can be found in the Air4EU report M5: Data assimilation.

#### **a) Basic requirements**

*The use of data assimilation for combining local scale AQ model output with local measurements is an advanced approach, and have still not been well developed, so no specific recommendations on basic requirements can be given.*

*Before attempting to use such techniques, however, one should first perform a proper evaluation or validation of the model, using local input data and local measurements. This part of the work should not be underestimated, as it often forms the key to success in combining monitoring and modelling. If the model evaluation shows that the model performs poorly (e.g. having low correlation or strong bias. as compared with measurements), one should try to improve the model first, rather than using methods of data assimilation.*

#### **b) Best practice recommendations**

*Ideally, model sensitivity analysis should also be conducted before performing data assimilation. When selecting variables to be used in the data assimilation procedure, one should focus on variables which are most uncertain, and for which measurements will be most useful. Variables which may be uncertain, but for which model output concentrations will not be very sensitive, should not be included in the data assimilation procedure.*

*It is generally recommended to use input variables or parameters to the local scale model as variables in the data assimilation procedure, rather than directly manipulating or adjusting the model output concentrations. Examples of input variables that could be selected are emissions, wind speed and direction, stability conditions and background concentrations.*

#### **c) Scientific recommendations**

*It is recommended that further research be carried out to investigate the usefulness of applying data assimilation methods for local scale models. Currently, routine methodologies do not exist for the local scale applications but some possibilities have been suggested:*

##### **NO<sub>2</sub>**

*It is perhaps easiest to apply data assimilation first on inert or nearly inert species such as NO<sub>x</sub> (NO + NO<sub>2</sub>) or O<sub>x</sub> (NO<sub>2</sub> + O<sub>3</sub>), before working with more reactive species such as NO<sub>2</sub> and O<sub>3</sub>, since the latter two requires in addition a model for the photochemical reactions between NO, NO<sub>2</sub> and O<sub>3</sub>.*

##### **PM**

*PM<sub>2.5</sub> may also be easier to start with than PM<sub>10</sub>, since there are generally more sources to PM<sub>10</sub>, and thus more difficult to model.*

## Case study Oslo II

### Use of data assimilation in open road line source modelling

In this case study we have investigated how an open road line source model can be improved by using local (roadside) air quality (AQ) observations.

Available data from the site Nordbysletta close to Oslo, Norway was used. The site is ideal for this study since it is a relatively flat area containing a single 800 m long 4-lane roadway with traffic. Air quality observations at the site consist of measured hourly average concentrations of  $\text{NO}_x$ ,  $\text{NO}_2$  and  $\text{PM}_{10}$ , at three stations in different distances from the road, during a 4 months period (January-April 2002). During the same period, hourly average background concentrations of the same species, together with  $\text{O}_3$ , were measured at a station on the opposite side of the road. Hourly data for local meteorology and traffic counting were also available.

It was decided to focus on  $\text{NO}_x$  in this case study since this is simpler to model than  $\text{NO}_2$  and  $\text{PM}_{10}$ . Local traffic counting data of light and heavy duty vehicles were used to estimate emissions of  $\text{NO}_x$  from the road traffic accurately on an hourly basis. In addition observed background concentrations of  $\text{NO}_x$  were subtracted from the measured concentrations at the three roadside stations, in order to produce net observations that could be compared directly with the modelled concentrations at the stations. Further improvement of the model could then focus on the meteorological input parameters.

After careful investigation of the importance and uncertainty of different meteorological parameters it was decided to use horizontal diffusion and initial size of plume as two of the most important parameters to be included in the data assimilation procedure.

Data assimilation using the Sequential Importance Resampling (SIR) method was then used on an hourly basis in order to estimate these parameters using the available AQ observations. It was decided to use one station and leave the other two stations for checking for any model improvement. In the SIR-method, model ensembles of 2500  $\text{NO}_x$  concentrations values were calculated at each station and for each hour during the period, based on randomly perturbing the above meteorological parameters according to a given Bayesian prior probability density function (PDF). Corresponding posterior PDFs were calculated by multiplying the prior PDFs with Gaussian likelihood functions assuming that observations of  $\text{NO}_x$  have a relative measurement error standard deviation equal to 5%. The parameters were finally estimated as the mean values of the posterior PDFs.

**The results from this case study show that using AQ observations at one station reduces the meteorological uncertainty and improves the model concentration results significantly at the other two independent stations, especially regarding the high percentile concentrations.**

### 4.3 Optimisation of monitoring networks using models and data assimilation

Data assimilation can also be used to evaluate different monitoring networks with the aim of optimizing the network with respect to a given set of criteria. This should first start by addressing the purpose of the monitoring network, and for what reasons one wants to combine monitoring and modelling. One example could be to check compliance with the limit values, e.g., that all concentrations in an area are below a certain threshold. Another example could be to estimate the degree of pollution exposure and health hazard for the population living in the area. At the start it is critical to be clear of the purpose of the monitoring network and how monitoring and modelling data are to be combined. After this, an evaluation can be performed of the fitness for purpose of combining results from a local scale AQ model, data from given monitoring network, and a given data assimilation technique. Such an exercise may guide us in selecting an optimal monitoring network to best solve a specific problem.

#### a) Basic requirements

The use of data assimilation for network design is an advanced methodology and so no basic requirements are recommended. The recommendations on network design given in chapter 2.2 above will in practice form a general set of constraints on the number and possible placements of monitoring stations.

*The optimization of the network design discussed in chapter 2.2 should be performed as the basic requirement.*

#### b) Best practice recommendations

In order to evaluate a given monitoring network, simulated (or pseudo) measurements may be more advantageous to use than real measurements. Simulated measurements are synthetic measurements produced by first running the local scale AQ model to produce a conceived set of 'true' concentrations for the area, and then for each measurement point to use Monte Carlo random draw procedures to simulate measurement errors. Systematic or random errors in the model input data and/or model physics etc. can then be introduced, and assimilated concentrations produced, based on using the set of simulated measurements.

*If the 'true' concentrations are assumed to be known one may easily check how accurate the assimilated concentrations are, and thus check the applicability of the data assimilation methodology and fitness of the current monitoring network with respect to the given set of criteria. This may be repeated and compared for different configurations of the monitoring network and thus form part of an iterative procedure for optimizing the network.*

#### c) Scientific recommendations

More research is needed to understand better the role of different monitoring network configurations on the statistical inferences drawn from the results of combining air quality models with measurements using methods of data assimilation.

## 5. Emissions

Calculating emission data for road traffic and large industrial sources are of special importance for local/hotspot scale air quality assessment. Emission data generation requires source specific input data for emission calculations (activity rates, emission factors) as well as for spatial allocation and the analysis of temporal variation. This chapter outlines several recommendations of good practice for emission data generation in general as well as specific recommendations for the local scale with the main focus on PM, NO<sub>x</sub> and NO<sub>2</sub> from road traffic/line sources and large point sources. More detailed information is contained in the Air4EU Report M1.

### 5.1 General recommendations for the generation of emission data

Compiling emission data usually requires a multitude of input parameters in order to model reality as accurate as possible. Data collection, data analysis and data choice are important procedures for this compilation. Quality criteria for generated emission data include accuracy, completeness, consistency and comparability (see for example IPCC 2000 which is generally relevant to all scales). The following general recommendations mainly refer to these requirements.

#### a) Basic requirements

QA/QC procedures play an increasingly important role in environmental studies, especially when those studies are conducted to support decision in environmental problems. It is good practice to document all information, assumptions and methodologies used to generate emission data. A systematic documentation is an important precondition for an uncertainty analysis.

*It is recommended to document and archive information used for emission inventories in a systematic and transparent way. Documentation should consist of records that are unambiguous. This is an important precondition for constant improvement and update as well as for uncertainty analysis. Examples of specific documentation and reporting can be found in (IPCC, 2000).*

A validation of emission data as well as of specific emission factors is desirable but often not possible because it requires extensive project capacities. Several validation studies were carried out on local/hotspot scale in the past (e.g. Mensink 2000, Mellios et al. 2006, Schatzmann et al. 2005, Corsmeier et al. 2005, Ketzler et al. 2005, Gehrig et al. 2003, Colberg et al. 2005, Hausberger et al. 2003).

*It is recommended to compare calculated emissions with available other independently compiled emission datasets as an option to internally evaluate completeness and to approximate emission levels. It helps to check key sources and plausibility of source contributions. If direct validation of emission data is not possible, results of other validation studies as well as source apportionment for comparable locations can be used to further assess used emission factors e.g. to verify ratio of exhaust and non-exhaust PM<sub>10</sub> emissions from road traffic.*

The assessment of uncertainties within the emission inventory is usually complicated and cannot be performed with statistical methods because of possible systematic errors due to the choice of methodologies and emission factors. Nevertheless, it is always necessary to give an answer to questions about uncertainties and plausibility.

*It is recommended to always carry out an uncertainty assessment and analysis for calculated emissions at least qualitatively. The EMEP/CORINAIR Guidebook (EEA; 2003) presents a default table for quality ratings that can be used for uncertainty discussion and assessment.*

#### b) Best practice recommendations

*Emission inventories should include all anthropogenic sources that may contribute significantly to the concentration in the area under investigation. Coarse estimations – if transparent – are better than to omit relevant sources because there seems to be no established methodology and data for an emission calculation.*

An independent review by external experts is recommended as well. A real expert peer review calls for a systematic approach to calculate emission data.

*Although harmonised methodologies do not often exist, it is recommended to discuss data choice, e.g. for emission factors, with external experts in order to avoid the choice of inappropriate and incorrect values.*

## **PM**

*Particle emissions should be estimated especially for fugitive fine particulate matter emissions like e.g. road dust suspension. Milestone Report M6.4 provides some references for the quantification of these emissions.*

### **c) Scientific recommendations**

Emission inventories have several uncertainties and knowledge gaps that significantly affect accuracy and validity of this information.

*Further harmonised methodologies for emission calculation, documentation and validation are needed.*

There is a lack of uncertainty analysis of generated emission data as a systematic methodology for uncertainty assessment does not exist.

*Therefore a further development of methodologies and experiences of emission data validation is needed.*

Quantitative uncertainty assessment and analysis remain a problem regarding sectoral inventories as well as emission data in temporal and spatial resolution.

*Thus, it is required to do more research in order to define adequate procedures for an error quantification and sensitivity analysis.*

## **5.2 Recommendations for the generation of PM, NO<sub>x</sub> and NO<sub>2</sub> emission data on local/hotspot scale**

The first step of generating emission data is the calculation of sectoral emissions based on source specific basic data (activities, emission factors etc.). Calculation methodologies as well as data quality are mainly a function of data availability and data choice. Spatial resolution of emission modelling depends on scale of air quality assessment. Methodologies, data need and key sources to be considered depend on pollutant and on scale as well. For local/hotspot scale, exhaust and non-exhaust emissions from road traffic and emissions from significant industrial point sources are of special importance. Recommendations for the calculation of emissions on local/hotspot scale are given in the following.

### **a) Basic requirements**

Increased requirements on the accuracy of emission calculation exist on the local/hotspot scale modelling compared to regional scale. Key source groups and processes have to be analysed with high level of detail and as far as possible based on site-specific information about activities and specific emissions.

*For road traffic and large industrial point sources, bottom-up approaches are recommended for an accurate emission calculation. As far as possible site specific or local information should be used to calculate activities (traffic volume) and assign emission factors.*

*It is recommended that the calculation of vehicle emissions from road traffic should be based on detailed data on technology level. Detailed emission factor data sets such as HBEFA or COPERT III (see UBA 2004, Ntziachristos and Samaras; 2000) can be used if no national expert validated emission factor database is available. Because of the different methodologies both emission factor data sets are based on, the same assumptions for vehicle category, technology and road class will lead to different results. The user has to decide which emission factors are suitable for his scope.*

*The calculation of road traffic emissions should distinguish at least between different road classes and vehicle categories. Information about fraction of diesel and gasoline engines and EURO emission standards of the fleet should be used, e.g. from national or regional statistics, to aggregate detailed emission factors for emission calculations. Information on vehicle categories can, in principle, be derived locally as well by automatic license plate number registration using video recording and consultation of vehicle register.*

To provide a micro-scale or a local scale assessment, an inventory with high spatial resolution is needed. A typical area under investigation is 1 km x 1 km or certain streets with a spatial resolution of some meters (e.g. 15 m x 15 m). Hotspot scale modelling is mainly carried out in single street canyons or near roads where exceedances of ambient air quality limit values mostly occur.

*It is recommended that line source models based on local traffic census data should be used for road traffic emissions. The spatial allocation within a microscale emission model requires a digitised road net and linked mileage data. It is recommended that manual traffic counting with a more detailed categorisation of the vehicle fleet should be used where possible for the spatial allocation in addition to the use of automatic traffic counting. Examples of methodologies for road traffic emission calculation on local scale can be found in Air4EU report M1: Emissions and data needs (Figure 3.2, Table 3-11).*

If emissions from area sources (e.g. residential combustion) are calculated, a fine resolution is needed for micro-scale models in order to represent the location and emission behaviour as accurate as possible.

*It is recommended to use land use data (e.g. CORINE) with high spatial resolution to allocate area source emissions before intersecting with a microscale grid. Small scale data, e.g. the fuel consumption per block/square of residential area or different types of industrial or settlement area, might be available for local areas and can be used to improve emission allocation. But it has to be noted that for local scale applications a bottom up approach is necessary. A top-down approach (a disaggregation of statistical emission data) may not be sufficient.*

If relevant point sources exist in the area under consideration, information on emission, activity, source location (coordinates) and effective height of stacks (stack height plus plume rise) should be available. For plume rise calculation flue gas velocity and temperature is required.

*It is recommended that local industrial data be used if available. EPER data might be used if no other information is available but it provides information only for a small part of industrial point sources and no information on stack height, flue gas velocity and temperature are provided. If EPER data is used, additional estimations on the vertical distribution of industrial emissions will be required..*

Most of the activities, which cause air emissions, are time dependant. The distinction between high and low time resolution of emission data is important. For micro-scale or local scale estimation as well as for the simulation of air pollution episodes, high time resolution emission inventories are needed. To estimate the background concentration of primary pollutants, a lower temporal resolution is sufficient.

*It is recommended that source or process specific temporal profiles be generated and assigned to calculated annual emissions in order to generate emission data in high temporal resolution. For road traffic emissions traffic counting can be used to directly generate hourly emission data with a bottom-up approach.*

## **b) Best practice recommendations**

*It is recommended that driving conditions, such as speed, on the road/roads under investigation should be analysed. Also acceleration plays an important role for emission data generation. As acceleration is affected by slope as well as traffic signals or other traffic blocks, these conditions should be taken into account. Also a registration of congestion times is required for accurate assignment of emission factors.*

Automatic counters alone can lead to significant over- or underestimations of heavy goods vehicle traffic.

*It is recommended that manual traffic counting for selected days (working day, Saturday, Sunday) in addition to automatic traffic counters be used for the calculation of road traffic emissions in order to improve accuracy. Manual traffic counting allows distinguishing between several vehicle categories whereas automatic counting distinguishes between large and small vehicles only. Alternatively local/regional data on average fleet composition (vehicle stock per category, emission standard and fuel) can be used to split mileage*

*between different light and heavy vehicles in order to improve assignment of emission factors. Manual traffic counting should also be employed to improve the determination of travel patterns and fraction of heavy-duty vehicles.*

Emission calculations for single point sources should be performed using detailed emission factors on technology level taking into account local plant type and abatement technologies. The usage of average emission factors from literature does not usually reflect local characteristics and leads to significant under- or overestimations of single source emissions.

*Activities of and emissions from large point sources should be included on an individual plant or emission outlet. These data should be provided by plant operators and available from regulatory authorities. Emission measurements at single sources should be carried out by certified institutions with standardised methods and facilities (see e.g. ISO standards ([www.iso.org](http://www.iso.org)), US EPA Emission Measurement Center ([www.epa.gov/ttn/emc/](http://www.epa.gov/ttn/emc/)), German VDI guidelines ([www.vdi.de](http://www.vdi.de))). Specific operation conditions, e.g. holiday seasons and shift operations, should be taken into account. If source specific information for one specific plant/process or one specific region is applied to local sources, comparability should be assessed with regard to technology, operation and other significant boundary conditions (e.g. temperature/climate, industrial operation, harvest times, idle times).*

Harmonisation of emissions factors and activity data calls for a detailed analysis and assessment of basic data and data choice with regard to existing technologies and a review of the current state of knowledge.

*It is recommended that emission factors and activity data used for emission calculations be harmonised as far as possible with already existing data compilations on regional or national level including a detailed analysis and assessment of basic data and data choice with regard to existing technologies and a review of the current state of knowledge.*

Temporal profiles for some sources depend on climatic conditions (e.g. small combustions in households, gasoline evaporation and vehicle cold starts).

*It is recommended that temporal variation of local temperature data be taken into account for sources such as cold start emissions and gasoline evaporation. Temperature dependent calculation formulas can be used for generating hourly emission values for these sources (see M6.4 for examples).*

## **PM**

For road dust suspension the use of the empirical equation of the US EPA derived from measurements in the USA (EPA 2003) is not recommended as this can lead to overestimations of a factor of two or more. EPA methodology was often criticised because it lacks mechanistic background and it is based on local data sets that were partly measured under conditions (silt loads, humidity, vegetation, weight of vehicle fleet) that are far from usual driving situations especially in central and northern Europe.

*Non-exhaust emissions of particulate matter due to tyre wear, brake wear and road dust suspension should be included as they contribute significantly to the PM<sub>10</sub> concentration. Recently a new chapter within (EEA 2003) was published that provides suitable methodologies as well as emission factors for tyre and brake wear emissions. Measuring results and derived emission factors have been published for different European driving conditions that provide better estimations (e.g. Düring et al. 2005 and Gehrig et al. 2003).*

The development of **action plans and strategies** to reduce local emissions requires **trend scenarios** in addition to emission inventories for previous years.

*Trend scenario calculations on local/hotspot scale should include regional/local conditions, that may change the emission situation in the future (e.g. changes in road network, land use, industrial structure). General information on e.g. future fuel split for small combustion can be assumed from national CAFÉ baselines (IIASA, 2004).*

### **c) Scientific recommendations**

*Development of a better understanding of non-exhaust traffic emissions are needed, including:*

- *Measurement of the particle size distributions of brake wear, tyre wear and road dust resuspension;*
- *Investigation into the distinct chemical signatures of particles from brake wear, tyre wear and road dust resuspension, which may allow them to be identified and quantified; and*
- *Assessment of factors such as driving mode, vehicle weight and speed and heavy acceleration and braking, which are likely to influence emissions of non-exhaust particles from vehicles.*

For a realistic representation of traffic emissions, real world driving conditions are essential. Topography (road slopes), acceleration, ambient temperatures, traffic flow on minor and major roads and the vehicle load of heavy duty vehicles are aspects to be considered.

*Hence, it is recommended to derive and use (real-world) emission factors that depend on traffic situations rather than just on one parameter such as average speed. This should be based on data from dynamometer measurements for different vehicle types, engine loads and driving conditions (real world driving cycles).*

*A systematic verification of vehicle emission factors used in Europe is required in order to assess their reliability and improve accuracy.*

### **PM**

The quantification of road dust suspension PM remains a problem due to insufficient information about activity rates, specific emissions and influencing parameters/mechanisms.

*Therefore, it is recommended to further examine road dust suspension PM emissions and carry out more size selective measurements at typical sites and a systematic analysis and determination of model parameters (s. e.g. Düring et al. 2005, Gehrig et al. 2003).*

### **NO<sub>2</sub>**

Average NO and NO<sub>x</sub> concentrations near roads in Europe have decreased during the last decade while NO<sub>2</sub> concentration remained stable or even increased.

*Therefore, it is recommended to further examine technology specific NO<sub>2</sub>/NO<sub>x</sub> ratios in order to accurately define emission factors and calculate fleet emissions of primary NO<sub>2</sub> (s. Milestone Report M6.4).*

## **6. Uncertainty analysis**

### **6.1 Uncertainties in monitoring data**

Measuring the concentration of atmospheric pollutants is of primary importance in order to obtain the closest value to the reality. Nevertheless, the actual measured value is always affected by a certain amount of error due to a number of sources.

Quantifying, or establishing, the uncertainty associated with a measured value, although difficult, is strongly recommended. Detailed information can be found in the Air4EU report M2: Uncertainty of models and modelling.

The first step is to clearly define the purposes of the measurements. Examples are:

- Determine compliance with air quality standards
- Determine the highest concentration in a predefined area
- Determine the representative concentration in areas of high population density
- Determine effects of particular emitters on the ambient air concentrations
- Determine background pollution levels.

The following procedure is to establish a monitoring network design that represents the continuous field of concentration pollutants over the area of interest and that is in agreement with the purpose of the measurements.

It is highly recommended that cities approve and implement a Quality Assurance/Quality Control plan for their air quality measuring networks. Prior Data Quality Objectives must be defined. QA/QC of air quality measurements is a system of procedures to ensure that measurements are of known precision and accuracy and results are comparable and representative of ambient conditions. The major elements of a QA/QC programme are the network design (number of stations and location criteria), measurement technique (sampling, analytical and calibration procedures), equipment evaluation and selection (methods validation and performance tests) and routine site operation (calibration under field conditions, maintenance, management and training).

If air quality data obtained on a monitoring site are only for air quality standards compliance assessment, then quality objectives and indicators given in the EU Daughters Directives on air quality are compulsory. For comparative purposes/mapping or trend analysis it is recommended to follow Data Quality Objectives and QA/QC plans (minimum or complete) described in EEA Technical Report n° 12: Criteria for EUROAIRNET (The EEA Air Quality Monitoring and Information Network). If the implementation of the defined QA/QC plans is achieved, it is then possible to analyse temporal, spatial, sampling and chemical data and associate this information to the measured air pollutants concentration.

There are no specific recommendations, at the moment, for the estimation of PM monitoring uncertainties. The defined requirements are valid for all pollutants.

**a) Basic requirements**

*Data and associated uncertainty should be reported for compliance assessment of the EU Daughters Directives on air quality.*

**b) Best practice recommendations**

*A QA/QC plan based on EUROAIRNET recommendations should be established.*

*Report data and associated uncertainty along with the QA/QC plan document should be openly disseminated.*

**c) Scientific recommendations**

*A clear statement of data quality objectives and an adequate documented QA/QC plan formulation and implementation should be provided.*

## **6.2 Uncertainties related to representativeness**

The representativeness issue is an important aspect in assessment methodology. Representativeness deals with the fact that in environmental assessment we cannot measure or model every area and time period as we wish. This subchapter gives recommendations on how to deal with uncertainties resulting from the limited spatial coverage of monitoring stations and uncertainties related to using monitoring data for model validation.

**a) Basic requirements**

*When basing the results of assessment on monitoring data, it should be ensured that the relevant locations in the study area are sufficiently covered. In the current air quality directives these are the hotspot locations with the highest population exposure and the areas representative for the exposure of the general population.*

*When monitoring data are used for model validations it is recommended to select adequate and representative monitoring sites for the model resolution used. The spatial and/or temporal resolution or averaging characteristics should be matched as closely as possible between the monitored and the modelled data.*

**b) Best practice recommendations**

*It is recommended to take the following steps to characterise and possibly quantify the representativeness uncertainties in an assessment based on monitoring data. This should be followed **for each pollutant and each purpose** of the measurements separately. It would be wise to do this first quickly, to acquire insight, and then to elaborate where needed.*

- 1. Decide for **which area** the assessment should be made, e.g. near a busy street, in an industrial area, or an air quality zone. If there are several areas to be assessed separately, carry out the following steps for each area.*

2. *Estimate the main spatial characteristics of the air pollution concentration patterns in the area using the results of the monitoring network, supplementing this by model results or by estimates based on knowledge of emissions in the area. In particular, estimate where peaks exist and where smooth patterns can be expected.*
3. *Characterise for each station its site by station classes and by the 'relative pollution level': the severity of pollution at this station compared with all other locations within this class: is the station at one of the most polluted locations of its class in the study area ('highest') or at a typical site for its class ('typical')*
4. *Taking the objective of the assessment into account, determine which relative pollution level should be characterised: the highest, the typical or both. Establish for each station class which stations in the network give the required information.*
5. *For each station class and relative pollution level, determine whether the available station(s) give adequate information on the relative pollution level needed. (If several stations within a class are available, estimate whether they characterise the distribution of the relative pollution levels as well.) If the information is adequate for each station class and relative pollution level, no further steps are needed. If the information is not adequate, it should be considered to either relocate or add one or more stations to improve the coverage. The shortcoming of the network and the possible concentration range missed by the network should be included in the assessment report.*

*Spatial representativeness of monitoring stations on the local scale can be assessed by the use of CFD models. Due to the complex nature of these models, expert support will be required..*

### **c) Scientific recommendations**

*In view of the severe shortcomings in comparability of European networks due to differences in coverage, further development of procedures to characterise and minimise the uncertainty ranges related to representativeness is needed.*

## **6.3 Uncertainties in modelling**

The uncertainty concept is one of the crucial points of Quality Assurance/Quality Control (QA/QC) procedures that should provide quantitative information about the modelling precision, identifying the uncertainty sources and their potential reduction. The present European legislation defines the Modelling Quality Objectives as an acceptable measure, to guarantee good model performance and reliable modelling results for decision makers. However, a practical application of these requirements and interpretation of the uncertainty analysis results based on the recommended methodology is ambiguous, and in some cases incomprehensible for non-expert users. The development of a consistent procedure for the uncertainty evaluation is still a challenge for the scientific community.

The following recommendations are proposed to estimate the total model uncertainty. The different steps should be addressed according to the end users needs. More detailed information on the application of the referred procedure can be found in the Air4EU report M2.

### **a) Basic requirements**

The first point that needs to be defined is the purpose of the uncertainty estimation process. If the goal is to estimate the quality of the model itself then data error could be omitted, but if the modelling results will be used as support for political decision, the total model uncertainty is essential, and the information about uncertainties associated with modelling results will be as important as the modelling results themselves.

*An assessment of known model error or estimated uncertainty is always required when modelling results are presented.*

Another issue refers to the effective communication of model uncertainties to decision makers, so that model outputs can be correctly interpreted.

*It is recommended to present a qualitative (e.g., graphical), as well as a quantitative (e.g., statistical) analysis of model results against measured values from the air quality network.*

*For the estimation of the Total Model Uncertainty it is recommended to use the following statistical parameters: correlation coefficient, fractional bias and normalized standard deviation.*

*For the application of the Quality Objectives of the Air Quality Framework Directive it is recommended to use the alternative model error Relative Percentile Error (RPE) when dealing with percentiles.*

For annual means, the Quality Objectives requirements of the EU Directives are unambiguous. A distinction between a paired-in-time and an unpaired-in-time intercomparison, or between the relative percentile error and the relative maximum error is not necessary. *Thus both RPE and RME (relative maximum error) are compatible for annual means and should be applied in that context.*

#### **b) Best practice recommendations**

In order to improve model performance, it is necessary to investigate the contribution of the different components of total model uncertainty. The contribution of stochastic variations in the total model uncertainty should be examined separately, since it cannot be reduced.

*To analyse the uncertainty related to variability it is recommended to filter out stochastic processes from the monitoring data based on spectral analysis and quantify model uncertainty without the influence of stochastic variations.*

*It is recommended that the analysis of the stochastic contribution to uncertainty be taken into account when assessment is based on hourly means but this is not required for annual means.*

#### **c) Scientific recommendations**

*For a complete knowledge of the components of total model uncertainty it is recommended to perform a sensitivity analysis and/or model intercomparison to evaluate the different model modules (Chemical mechanisms, physical parameterisations and numerical algorithms) to determine intrinsic model uncertainty.*

*For the estimation of uncertainty related to input data, sensitivity analysis on input parameters (initial and boundary conditions, meteorological parameters, emissions, background concentrations) is recommended.*

*An appropriate measure for intrinsic model uncertainty and input data uncertainty is the standard deviation and normalised bias of the results of sensitivity tests.*

### **6.4 Assessment of uncertainties when combining monitoring and modelling**

The major aim of combining monitoring and modelling is to reduce the uncertainty in the final spatial assessment. There is no general guarantee that carrying out such a combination will improve the spatial assessment, however, this should always be assessed. The assessment is confounded by the fact that the 'true' value will always remain unknown since both monitoring data and model results have intrinsic uncertainties.

#### **a) Basic requirements**

*In order to obtain an estimate of the uncertainties in the assimilated results, the data assimilation method used must be capable of producing such results based on uncertainties associated with the model and with the measurement data.*

#### **b) Best practice recommendations**

*Use of ensemble based data assimilation techniques such as e.g., the Ensemble Kalman filter (EnKF) method or the class of Sequential Monte Carlo methods (particle filters) (e.g., the SIR-method), is generally recommended in order to achieve a more accurate assessment of the uncertainties in the assimilated results.*

*Use of controlled experiments and simulated measurements where the true concentration values are assumed known, and the quality of the assimilated concentrations can be checked, as described in Chapter 4.3, is also highly recommended.*

#### **c) Scientific recommendations**

*More research is generally needed to understand better how to best perturb model input data and produce ensembles of model runs in order to achieve an accurate assessment of the uncertainties*

*in the assimilated results. Here again increased interaction with the statistical communities is recommended.*

### **Case study Oslo II**

#### **Use of data assimilation in open road line source modelling**

As part of this case study a sensitivity analysis was performed in order to investigate the uncertainties associated with the Gaussian open road line source model used (see description of this case study in Chapter 4.2 above).

The results showed that the sensitivity (uncertainty) of model output concentrations at three roadside stations, to errors or uncertainties in different model input parameters such as wind speed and direction, horizontal and vertical diffusivity, initial size of plume etc. were highly dependent on the meteorological situation, and varied substantially with time. The model were e.g., more sensitive to errors in the wind speed when the wind speed was low (< 2-3 m/s), than when it was higher. It was also more sensitive to wind direction when the wind direction were along the road as compared to the cases when the wind direction were more perpendicular to the road.

After careful investigation of the uncertainty and model sensitivity of the different meteorological parameters it was decided to use horizontal diffusivity and initial size of plume as two of the most important parameters to be included in the data assimilation procedure. Data assimilation using the ensemble based Sequential Importance Resampling (SIR) method was then used on an hourly basis in order to reduce the uncertainties in these parameters using the available roadside AQ observations at one station This led to significant reduction of uncertainty and improvement of accuracy for the model output concentrations at the other two independent stations, especially for the high percentile concentrations.

**The results from this case study show that using ensemble based assimilation methods, such as the SIR-method, makes it easier to make a more accurate assessment of the resulting uncertainties associated with the selected model parameters and output concentrations.**

## **6.5 Spatial mapping of uncertainties**

There are a number of uncertainty parameters available that can be spatially represented using maps, and these could be a supplement of any assessment maps. The available parameters are dependent on the methodology used to produce the maps and on the application of the maps.

### **Interpolating model errors between monitoring sites**

When the model error for annual means and daily average percentiles are required, e.g. for directive purposes, then the most relevant parameter is RPE for daily averages and RME for annual means (as proposed in Chapter 6.3) evaluated at monitoring sites. Such point like assessments can be spatially interpolated to create maps from the given values through

- Direct spatial interpolation of the model errors through kriging or some other interpolation method
- Creating a regression model, based on model concentrations, for the error field
- Calculating the normalised RMSE of these values and apply this as a representative uncertainty

However, since model error is only known at the observational sites any interpolation of the error values between sites must be addressed with caution. For the application of the interpolation method it is necessary to guarantee a good spatial coverage of the study domain by the air quality network. In case of deficient spatial coverage, e.g. for local/hotspot scales, it is recommended to use point representation instead of spatial interpolation. The error analysis must first be interpreted as model uncertainty, e.g. by calculating the RMSE of the values or assuming the error to be representative of model variability.

### **Model uncertainty from sensitivity assessment**

When intrinsic model uncertainty is required then the results from sensitivity analysis can be directly mapped using the FB and standard deviation. No interpolation is required as these parameters can be assessed on the spatial grid.

### **Model uncertainty from data assimilation**

When data assimilation is used results from the use of cross validations should be presented. This can be dealt with in a similar fashion as the methods outlined for spatial mapping of model error.

#### **a) Basic requirements**

*When there is limited information concerning the model error, i.e. few or no observations available, then uncertainty can be represented by a 'best estimate', based on other information available. This should be applied to the assessment map as a relative uncertainty, e.g. 20%, which should be representative of the expected standard deviation.*

*When more information is available concerning the model error, e.g. more sites, then the RMSE from these sites can be used as indicative of the uncertainty and used as a constant relative, or absolute, uncertainty for the mapping.*

*When representing the model error based on point assessments, e.g. RME or RPE, then it is not recommended to spatially interpolate the error when there is not a sufficiently high density of station available.*

#### **b) Best practice recommendations**

*When using data assimilation the local scale AQ model should be set up to produce concentration results not only at the monitoring stations used in the data assimilation procedure, but generally at all spatial points of interest. Uncertainty parameters such as e.g., FB, standard deviations etc., can then be mapped without further spatial interpolation.*

#### **c) Scientific recommendations**

*Uncertainty mapping is currently not carried out for most air quality assessments. The methodologies described here still require further development and examination to establish them as operational methodologies.*

*Other methods of using uncertainty in maps, such as the probability of exceedence, should be further investigated to assess their usefulness as uncertainty indicators.*

Other recommendations related to urban scale AQ assessment can be found in Air4EU report D6.2 Part II: Spatial assessment in urban areas.

## **7. Concluding remarks**

This document has been compiled as a guidance document for the spatial assessment of particulate matter (PM) and nitrogen dioxide (NO<sub>2</sub>) at local/hotspot scales. The main aim is to recommend methodologies that will lead to improved assessment of PM and NO<sub>2</sub> at these scales. Recommendations are provided at 3 levels of complexity, i.e. basic requirements, best practices and further scientific research. These recommendations are intended as guidance for authorities involved in the assessment of air quality at city, national and European level. They are intended to aid good assessment practice and to highlight areas that require further development. It is not possible to include all details for undertaking the recommendations and hence this report should be used in conjunction with other AIR4EU documents.

This report focuses on two main application areas, i.e. assessment for compliance with EU directives and population exposure, focusing on the assessment for compliance with EU directives. Recommendations are provided for different methodologies including monitoring, modelling and methods for combining modelling and monitoring. A number of particular issues are dealt with including emissions and uncertainty analysis. The spatial assessment and uncertainty analysis described in this document is intended to produce spatial distribution maps. Information on spatial distributions of pollutants can also be used to assess potential population exposures.

Air quality assessment methods are in continuous development. Some methods identified in this document may be too complex for local authorities currently, but may become practicable in the future. Several areas where further research are needed have been identified in this document, for

example, monitoring and modelling of PM, estimating non-exhaust and resuspension emissions and developing data assimilation method for local scale models.

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M6.4 Cross-Cutting Issue 1: Emissions & Data Needs.

M6.5 Cross-Cutting Issue 2: Uncertainties of Models & Monitoring.

M6.7 Cross-Cutting Issue 4: Scale Interaction.

M6.8 Cross-Cutting Issue 5: Data Assimilation.

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