Developing a Global Platform on Air Quality and Health

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1. Introduction: background and rationale

Air pollution is an important determinant of health. There is convincing, and growing, evidence linking the risk of disease and premature death with exposure to fine particulate matter (PM\textsubscript{2.5}) and ozone (O\textsubscript{3}). The current public health burden of exposure is substantial. WHO estimates that approximately 3.7 million premature deaths per year, or 6.7% of all deaths in 2012 could be attributed to ambient PM pollution, placing it among the top health risk factors globally\textsuperscript{1}. Ozone and several components of PM\textsubscript{2.5}, such as black carbon, are short-lived climate pollutants affecting the health of ecosystems. Other common air pollutants, such as nitrogen dioxide (NO\textsubscript{2}) or carbon monoxide (CO) are damaging to health as well, although quantification of the health burden related to such pollutants in the global population remains a challenge.

Knowledge about the health and environmental risks of air pollutants and their trends is an important stimulus for developing pollution reduction, environmental and public health policy. Demonstration of the improvement of air quality achieved by effective air pollution abatement strategies and policies, as well as their efficient implementation, support further progress towards population health and sustainable development. Therefore the data on air pollution levels and their spatial and temporal trends are essential policy indicators.

WHO, in collaboration with other international organizations, plans to strengthen the global tracking capacity for air quality and health by establishing a Global Platform on Air Quality and Health, containing data and information accessible to everyone through the Internet. Its purpose will be to facilitate access to evidence on human exposures to outdoor (ambient) air pollution, on the health impacts of the pollutants and on effective interventions for their reduction. In the future, the Global Platform’s link with information on household air pollution resulting from solid cooking fuels, which contributes significantly to outdoor air pollution and causes a significant burden to health in its own right in many regions of the world,\textsuperscript{2} will be considered.

To review current activities that could provide an input to the Global Platform and to discuss methodological and organizational aspects of the project, WHO convened this Consultation in Geneva from 30 to 31 January 2014. It gathered experts in air quality monitoring, modelling and remote sensing from various WHO regions, representatives of several international programmes and organizations that could contribute to the development of the Platform as well as WHO staff (for the list of participants see Annex 1).

2. Organization of the Consultation

During the preparations for the Consultation, WHO staff was supported by an external scientific steering group (SSG), which advised on the scope, objectives and programme of the Consultation. Selected members of the SSG prepared a concise background document which was distributed to all Consultation participants before the meeting. This document provided basic information on the state of the art in assessing exposure of the global population to PM using surface monitoring, atmospheric transport models and satellite remote sensing (Annex 2). Such a summary was considered to be an important introduction to the Consultation since

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\textsuperscript{1} http://www.who.int/gho/phe/outdoor_air_pollution/burden/en/

it was assumed that many of the experts would not be familiar with the progress achieved in all the three methods of air quality assessment. The document discussed the strengths and limitations of each of the approaches as well as the next steps necessary to improve global assessment of population exposure to air pollution.

The opening session of the Consultation adopted the following agenda:

1. Opening
2. Current methods of global assessment of outdoor air quality and integration of information from various sources to estimate population exposure to air pollutants
3. International activities contributing to the global assessment of outdoor air quality
4. Methodological aspects of the Global Platform: data and methods availability, and needs for further development
5. Organizational aspects of the Global Platform
6. Follow-up actions
7. Closure

The programme (see Annex 3) was approved as a series of plenary sessions, and one session split into three working groups focusing on approaches to strengthening each of the data sources for estimation of population exposure to air pollution. Dr K. Balakrishnan and Dr A. Cohen were appointed as the Consultation co-chairs, and Dr M. Krzyzanowski as the Consultation rapporteur. The appointed chairs and rapporteurs of the working groups were Dr M.F. Andrade and Dr G. Carmichael for the working group on modelling, Dr L. Morawska and Dr D. Schwela for the working group on surface monitoring and Dr R. Martin and Dr A. Lau for the working group on remote sensing.

3. Summary of the discussion

Scope of the Global Platform on Air Quality and Health

Evidence on the risks related to air pollution is a fundamental part of the assistance provided by WHO to enable its Member States to address environmental determinants of health. Such evidence is also relevant in WHO’s support to implementation of the Global Plan of Action on noncommunicable diseases, in addressing childhood pneumonia, and in guiding sustainable development and climate change policies to promote and protect public health. The magnitude of exposure to air pollution and the health burden attributed to it are being considered as possible indicators for monitoring achievement of some of the post-2015 sustainable development objectives. An important aspect of the evidence needed to support the above-mentioned work is the identification of the main sources and economic sectors contributing to human exposure to pollution. Identification of sources would in turn facilitate engagement of specific sectors, such as transport, energy production or agriculture, in developing policies that promote and protect health.

In light of the needs described above, the primary objective of the Global Platform will be to provide relevant air quality and health information to stimulate policy development, facilitate monitoring and evaluation, and assist in capacity building in all countries of the world to prevent diseases associated with air pollution. The focus will be on the countries where air pollution levels are highest and that have few resources available. Primary users of the Global Platform will be national health and environment sectors, addressing, in collaboration with other sectors, health aspects of air pollution.

The data collected by the Global Platform on Air Quality and Health will include estimates of population exposure to air pollution and estimates of the burden of disease associated with it as well as information on uncertainties. It will also contain assessments of interventions and
policies with regard to their effect on air quality and on health. An updated methodology for estimating health risks of air pollution together with updated WHO air quality guidelines and tools for supporting decision-making will also be part of the Global Platform. The Platform will contain information related to the pollutants that cause the greatest health burden globally, with PM$_{2.5}$ being the first of the pollutants to be considered. The Platform’s range of information will be expanded gradually to include data on population exposure to O$_3$, NO$_2$ and other air pollutants relevant to health. Information on the contribution of various economic sectors to population exposure will also be provided.

Data from surface monitoring of air quality, from atmospheric transport models and from satellite remote sensing will be used as inputs to integrated estimates of population exposure to air pollution.

The design and development of the Global Platform will be the result of intensive collaboration between WHO and other international agencies as well as with leading research institutes engaged in the sustainable development agenda. The links, trade-offs and synergies with the climate change policies will be explored and used to maximize health gains from the policies and actions. The Platform will create a forum for collaboration of experts with various specialities, aiming at the improvement of information, its transparency, timeliness, relevance and usefulness to policy debate, as well as its global scope. While the primary objective of WHO in using the Platform is to support the health sector’s engagement in clean air policy debate, the Platform should also be considered as an essential resource for representatives of other sectors facilitating consideration of health aspects in sectoral policies addressing air pollution.

**Surface monitoring of air quality**

The WHO database on air pollution, a precursor of the Global Platform, gathers surface monitoring data. As of 2013, these data currently comprise ground-level measurements from 1600 cities. Currently, the database is limited to PM$_{10}$ and PM$_{2.5}$, with PM$_{2.5}$ data for over half of the cities covered. Most of the available data are for middle- and high-income countries. Data from Africa, South America and the Eastern Mediterranean region are scarce either because only limited air quality monitoring is being performed, or because of poor availability of the data from such monitoring. The primary sources of data on annual mean PM$_{10}$ and PM$_{2.5}$ concentrations gathered in the WHO database are official national and subnational reports and national and subnational websites.

Furthermore, measurements reported by the following regional networks were included: Clean Air Asia, and AirBase – the European Air quality database. In the absence of data from the above-listed sources, data are collected from:

- United Nations agencies;
- development agencies; and
- articles from peer reviewed journals.

Wherever the primary information allows, the city averages are based on data from monitors located in urban residential, urban background, commercial or mixed locations. However, such information is not always available or reliable and it is possible that measurements conducted near specific sources of air pollution (e.g. transport or industry) are included in calculation of city means. Also, the information on the monitoring methods (equipment and its calibration, data completeness and processing, quality assurance and control procedures) as well as on the monitoring network objectives and design are often missing. These deficiencies affect the inter-country comparability of the data. Another important deficiency is the use of
different equipment for measuring PM and the lack of a generally applied protocol for inter comparison of the data.

It has been noted that, in many countries, more data are produced than are made available on the World Wide Web or in printed, internationally available reports. Also the formats, levels of aggregation and timeliness differ among countries. Often it is not clear which of the available data can be considered as verified and officially recognized, and which might be a result of an ad hoc data collection project. For many cities, only data on PM$_{10}$ are available and PM$_{2.5}$ concentrations, necessary for assessment of burden of disease caused by long-term exposure to PM, are estimated by application of national or regional conversion factors. This affects the precision of the PM$_{2.5}$ estimates since the real PM$_{2.5}$/PM$_{10}$ ratio may strongly depend on the local conditions and thus may be different from the national or regional conversion factor. The current database is limited to cities and virtually no data are available for rural areas. Some data from air quality monitoring in rural areas, however, are available in the WHO household air pollution database.

Atmospheric chemistry transport models of air quality

Atmospheric chemistry transport models link emissions of pollutants with their surface concentrations on various temporal (hours, days, years) and spatial scales (local, regional, global) using the knowledge on pollution emission and dispersion, deposition, chemical reactions and aerosol dynamics in the atmosphere. Particular strengths of models in general are that they can directly relate sources and their underlying sectoral contributions to present (or past) concentrations, as well as their very good spatial and temporal coverage. Furthermore, models are the only way to extrapolate the current situation to the future, using emission scenarios that describe various assumed developments of technological and structural changes in the sources of air pollution, and policy options to address air pollution in various world regions.

Some global models are currently run at a global 0.5º × 0.5º (ca 55 km × 55 km on the equator) resolution, and regional models are expanding their model domain, as well as improving resolutions: currently achieving resolution of the order of 5–10 km. Improvement of model resolution achieved in recent years is fostered by a continuous increase of computing capacity, and improved skills of numerical weather prediction models that often provide the meteorological input to the models. Nevertheless, inaccuracies in emission inventories and in the meteorological model predictions are still a significant challenge for modelling. Emission inventories suffer from errors of both activity data and emission factors, as well as spatial and temporal resolution of the emission data. Therefore, country totals or long-term averages might be more accurate outputs of the model than the concentrations at a grid point or at a specific time.

The Task Force on Hemispheric Transport of Air Pollution (TF HTAP) of the Convention on Long Range Transboundary Air Pollution has addressed many of the weak points of the global models. In 2010, it estimated health impacts of intercontinental transport of air pollution based on an ensemble of global chemical transport model simulations. Its current activities focus on:

- model evaluation for 2008–2010, including comparison of modelling methods and measurement-based assessments (from surface monitoring and satellites);
- coordinated global and regional simulations to understand the effects of model resolution through cooperation with AQMEII (Air Quality Modelling Evaluation International Initiative) supported by EC Joint Research Centre, Environment Canada
and US-Environmental Protection Agency (EPA) for North America and Europe, and MICS (Model Intercomparison Study) for Asia;

- future emissions scenarios for 2010–2030;
- establishing linearized emission-concentration-response functions between source and receptor regions based on emission perturbation studies with participating chemical transport models.

These functions can be incorporated in reduced-form source-receptor models (e.g., the JRC TM5-FASST model) for a quick analysis of pollutant emission scenarios, and in particular source-attribution studies, bypassing expensive full chemical transport model runs.

This ensemble of global and regional models is unprecedented in its ability to provide model estimates of human exposure, and of the relationships between emissions and concentrations. They will offer invaluable input to the Global Platform.

**Estimation of air quality through satellite remote sensing**

Satellite remote sensing of ground-level air quality has developed substantially over the past decade. Satellite remote sensing of aerosol and NO$_2$ provides valuable information about ground-level concentrations. Current satellite-derived PM$_{2.5}$ estimates rely heavily upon instruments orbiting the Earth on board the National Aeronautics and Space Administration (NASA)’s Terra and Aqua satellites, launched in 2000 and 2002, respectively. Data on aerosol optical depth (AOD) provide a column-integrated measure of light extinction due to the presence of aerosol. Satellite-based estimates of PM$_{2.5}$ rely on these data, relating AOD to PM$_{2.5}$ using either an empirical, semi-empirical or physically-derived relationship. Empirical relationships rely on statistical regression techniques between local in situ measurements and retrieved values. Semi-empirical relationships also draw on local measurements, but additionally incorporate some physically-based understanding of how these values relate.

Lastly, physically-derived relationships rely on the aerosol vertical distribution and optical properties, often simulated using a chemical transport model, to predict the AOD to PM$_{2.5}$ relationship. Currently, these methods provide PM$_{2.5}$ estimates with global coverage and 10 km $\times$ 10 km resolution. Satellite-based data have been used to estimate long-term (1998–2012) trends and time-series of PM$_{2.5}$ for various regions of the world and provided input to several studies on health impacts of PM. Satellite observations are used to estimate spatial and temporal variation of NO$_2$ in the troposphere, with methods in development to improve the spatial resolution of the NO$_2$ assessment to a 1 km $\times$ 1 km grid in selected areas.

Several ongoing projects aim at improvement of the PM$_{2.5}$ data resolution to 3 km $\times$ 3 km and at reduction of the existing uncertainties. One of these is the emerging global network to evaluate and enhance satellite-based estimates of PM$_{2.5}$ (Surface PARTICulate mAtter Network: SPARTAN), deploying PM$_{2.5}$ and PM$_{10}$ sampling stations together with AOD instrumentation in regions with little local surface monitoring of air pollution. New data analysis methods increase the accuracy of the estimates and their consistency with ground measurements. New instruments to be launched on board new satellites will further increase the quality of the data, improving also the input of remote sensing to the Global Platform.

**Integration of data from various approaches to assessment of air quality**

Estimation of exposure to PM$_{2.5}$ conducted in the framework of the Global Burden of Disease 2010 (GBD 2010) project provides an example of comprehensive integration of PM$_{2.5}$ data from remote sensing, atmospheric models and surface monitoring. It enabled estimation of the burden of disease attributed to air pollution in all (urban and rural) populations of each of 21
regions of the world, how it changed between 1990 and 2010, and a comparison of the health burden attributable to air pollution with that attributable to the remaining 66 risk factors considered by the GBD 2010 project. The intention behind integration of data from three different approaches was to borrow from the strengths of each individual estimation method. The result of data integration is:

- full global coverage with consistent methods;
- reduction of biases due to location or development status;
- high spatial resolution allowing better links to population data;
- estimates of uncertainty.

An ongoing GBD collaboration, led by the Institute for Health Metrics and Evaluation, is planning to publish in 2015 updated burden of disease estimates for 2013. GBD 2013 will estimate exposure to PM$_{2.5}$ using updated remote sensing data, new runs of the atmospheric transport model and an expanded database of surface measurements. These new developments will enable the analysis of sector-specific contributions to exposure to PM$_{2.5}$. It is planned to include systematic updates key data inputs and continuing developments and application of improved methods to estimate exposure to PM and other pollutants at the global, regional, national and subnational levels.

However, at the current level of development of the methods, the results of the GBD approach still have a number of limitations, including variable agreement with surface measurements (illustrated in the Background Paper, Annex 2) and spatial resolution is still not able to match that available for gridded population estimates. The limitations inherent to each of the contributing approaches (remote sensing, chemical transport models and surface measurements) also affect precision of the integrated estimates.

If information from all the available sources is to be utilized in the most appropriate and efficient manner, it is important that techniques for linking the data allow for the correct quantification of uncertainty at different levels of space and time.

A successful method for integration should be:

- modular;
- flexible;
- expandable;
- able to incorporate multiple levels of uncertainty;
- able to provide scope for both fast approximations and detailed computation.

A relatively simple method for data integration was successfully used in the GBD 2010 and GBD 2013 projects. The estimates from the satellite-based approach were combined with those from the chemical transport model and calibrated with available surface monitoring data using traditional regression techniques. These allowed data from the three sources to be utilized, but only provided an informal analysis of the uncertainty associated with the resulting estimates of exposure. There was also limited ability to consider changing relationships and uncertainty between the geographical regions with spatially dense monitoring networks and areas where monitoring was sparse or where there was no monitoring.

Advanced statistical techniques would provide a coherent framework for the integration of data from various sources and lead to greater precision of the estimates whilst still adequately quantifying the uncertainty of the assessment.

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3 http://www.healthmetricsandevaluation.org/gbd/2013
Recent advances in methodology for data fusion or melding in this way include Bayesian statistical downscaling models which allow for the combination of datasets which exhibit complex spatial–temporal misalignment. Within these models, differences between different data sources are treated as spatially and temporally dependent random effects, allowing pollution concentrations to be predicted at any time and location. This approach sits naturally within a Bayesian hierarchical framework, which acknowledges uncertainty at each stage of the modelling. This provides a coherent framework for combining the uncertainty that will arise from combining different data sources and will provide accurate estimates of the uncertainty that will be associated with predictions of air pollution at the required resolutions over space and time.

There may be computational challenges in implementing some of the more idealized models for this purpose and simplification of assumptions may be necessary. Examination of the effects of such simplifications is essential in order to assess possible trade-offs between accuracy and practicality. Recent advances in computational methods, e.g. integrated nested Laplace approximation (INLA), provide fast and efficient approximations for Bayesian hierarchical modelling in space and time, but will require continued assessment of performance in the GDB and Global Platform setting.

**Activities of international and national agencies contributing to the global assessment of air quality**

The current status of international activities on air quality assessment is, to a large extent, the result of collaboration under specific conventions or projects facilitated by international organizations or national agencies. The Consultation provided an opportunity to representatives of some of those organizations to present this work.

The World Meteorological Organization (WMO) coordinates the Global Atmospheric Watch (GAW) network. It is responsible for systematic, long-term global monitoring, analysis and assessment of atmospheric chemical and physical parameters, including aerosols. GAW implements a comprehensive quality assurance/quality control (QA/QC) system aiming at ensuring that the data collected are consistent, of known and adequate quality, supported by comprehensive metadata, and sufficiently complete to describe global atmospheric states with respect to spatial and temporal distribution. The system serves both developed and developing countries, and includes training of field personnel. WMO links the work on air pollution with that on climate. Recently, WMO has increased its work on megacities and large urban areas aiming at:

- development of strategies for megacities to deal with weather, climate and environmental problems, and improvement of related services;
- enhancement of environmental monitoring and modelling capabilities; and
- establishment of case studies for understanding air pollution and the connections between health and climate in different types of megacities.

The GAW Urban Research Meteorology and Environment (GURME) network is active worldwide, engaging in a wide range of collaborative projects. The results of WMO’s projects are presented in a variety of reports and bulletins addressing diverse audiences, including policy-makers and decision-makers. One recent report is the *Atlas of health and climate* published jointly with WHO in 2012.

United Nations Economic Commission for Europe (UNECE) provides a secretariat to the Convention on Long Range Transboundary Air Pollution. The European Monitoring and Evaluation Programme (EMEP) of the Convention, supplies governments with scientific
information supporting Convention implementation. Its monitoring programme includes assessment of background concentration of PM$_{10}$ and PM$_{2.5}$, ozone and a number of other pollutants. It is run in collaboration with national centres using an advanced QA/QC protocol. Annual EMEP reports document the pollution levels and trends in Europe. Data collected are also used for development and evaluation of atmospheric chemical transport models. New elements of EMEP’s monitoring strategy include extension of the monitoring to Eastern Europe, the Caucasus and Central Asia as well as combination of data from multiple platforms (e.g. in situ, satellite and remote sensing), and data assimilation. Much of the work on the global assessment of air pollution is conducted within the framework of the Task Force on Hemispheric Transport of Air Pollution (TF HTAP) of the Convention. UNECE also collaborates with WHO within the framework of the Joint Task Force on Health Aspects of Air Pollution, to which WHO European Centre for Environment and Health provides a secretariat.

The United Nations Environmental Programme (UNEP) described its input to the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC). The Coalition’s objective is to reduce the pollutants that are affecting both climate and health. It has proposed a set of key actions leading to the most effective reduction of methane, black carbon and hydrofluorocarbons (HFCs), and using currently available technologies. National assessments and plans of action to reduce short-lived climate pollutants (SLCP) have already been launched in several countries. Many of these assessments and actions are based on very approximate data. Therefore more precise and relevant data are important to support the CCAC’s actions both at the planning and the evaluation stages, and both the national and regional scales. The long-term goal is to incorporate the SLCP actions into national planning. The newly created Health Task Force, in collaboration with WHO, aims at targeting the health sector in scaling up its actions and in launching the Urban Health Initiative. UNEP programmes are, to a large extent, implemented by networks of the national collaborating centres. UNEP facilitates intergovernmental processes related to air pollution in all regions outside Europe and North America, runs a joint secretariat with WHO for the Regional Ministerial Forum on Environment and Health in Asia and hosts the secretariat of the Partnership for Clean Fuels and Vehicles. It also provides guidelines, equipment, and training for monitoring and impact assessment.

The mission of the United Nations Office for Outer Space Affairs (UNOOSA) is to promote international cooperation on the use of outer space to achieve development goals for the benefit of humankind. Among other responsibilities, the Office implements the UN Programme on Space Application which assists Member States in the use of satellite remote sensing, global positioning, geographical information systems (GIS) and satellite communications in various application areas, including spatial epidemiology, telemedicine and telehealth. The Programme runs conferences, workshops and training courses on various topics, including environmental monitoring, climate change and application of space technologies for global health and disaster management, as well as disseminating information on the use of space tools in various disciplines. UNOOSA also coordinates space-related activities within the United Nations system through the Inter-Agency Meeting on Outer Space Activities, which is organized on an annual basis for harmonization of future plans and programmes of common interest for cooperation and exchange of views on current activities in the practical application of space technology. Outcomes of the Inter-Agency Meetings are presented in the Secretary-General’s report on coordination of space-related activities within the United Nations system.

Japan Aerospace Exploration Agency (JAXA) operates, or plans to launch in the next few years, a number of satellites carrying instruments able to contribute to the assessment of aerosols in the atmosphere. The “IBUKI” or Greenhouse Gases Observing Satellite
(GOSAT), established in 2009, is observing aerosol scattering to minimize uncertainty for CO₂ and CH₄ retrieval. It is providing data that allow estimation of their amount, particle size distribution, height and distribution as well as particle type and absorption and scattering characteristics. Its follow-on GOSAT-2 adds PM₂.₅ monitoring as one of its main objectives, by improving aerosol measurements over land with additional UV and visible channels to its cloud and aerosol imager (TANSO-CAI-2). In 2016, JAXA is planning to launch GCOM-C1 to observe both land and ocean aerosols using UV and polarization imagers. JAXA and the European Space Agency (ESA) will jointly launch EarthCARE designed to provide 3D distributions of clouds and aerosols and to assess chemical properties of aerosols. In addition to its work on aerosol, JAXA has started the feasibility study on a new imaging spectrometer to improve the resolution of NO₂ assessment to 1 km × 1 km.

National Aeronautics and Space Administration (NASA) operates the satellites providing most of the information used in current assessments of population exposure to air pollution based on remote sensing. NASA promotes uses of Earth Observing Data and models regarding implementation of air quality standards, policy, and regulations for economic and human welfare. It also addresses effects of climate change on public health and air quality to support managers and policy-makers in their planning and response preparations. The Air Quality Applied Sciences Team converts the research results to air quality management applications, including pollution monitoring, forecasting, and source attribution. The results of its work include evaluation of exceptional pollution events, changes in emission in selected regions of the globe and their attribution to specific economic activities (e.g. changes in activities of power plants in India and China or in oil sand recovery in Canada). NASA’s Applied Remote SEnsing Training (ARSET) provides online and hands-on training on access, interpretation and use of NASA satellite images for decision support.

4. Recommendations by thematic area: improving data coverage and quality, making data policy-relevant and building capacity for global assessments

The discussions, both in plenary and in the smaller working groups, resulted in the set of recommendations specific to each of the three exposure assessment approaches as well as data integration contributing to the development of the Global Platform on Air Quality and Health. These recommendations are presented in the sections that follow.

Surface monitoring of air quality

The following approaches are recommended to strengthen surface monitoring of air pollution contributing to the Global Platform:

A. To establish a minimum common protocol for air quality monitoring by countries, with reference to existing good practice examples and basic standard operating procedures (SOPs) for:
   - definition of monitoring objectives, one of which should be provision of data for health risk assessment, and data quality objectives with uncertainty estimate;
   - pollutants to be monitored (e.g. PM₂.₅, black carbon, NO₂, O₃); however, PM₂.₅ should have the highest priority, followed by O₃;
   - PM₂.₅ speciation monitoring in support of atmospheric transport models and satellite remote sensing development and data validation;
   - minimum time resolution of monitoring;
• spatial monitoring issues (including density, urban and rural monitoring, pollution hotspots, and urban micro-scale monitoring);
• choice of positioning, maintenance, and calibration of monitoring equipment;
• the QA/QC system to be used;
• appropriate training of staff necessary for monitoring implementation;
• integration of PM$_{2.5}$ monitoring data into the WHO database.

B. In establishing new monitoring, adopt a stepwise approach prioritizing:
• longer term population-oriented monitoring in fixed locations to reflect trends in pollution and support source characterization;
• maximal use of existing data from models and remote sensing in designing monitoring networks;
• improved spatial coverage (also with low-cost equipment) over sophistication of measurements – while still working to continuously improve data quality;
• exposure indicators useful for burden of disease calculations;
• expansion of monitoring network in developing countries and emerging economies, with sub-Saharan Africa as a top priority, using, if necessary, affordable monitoring devices of proven quality.

**Atmospheric transport models**

The contribution of atmospheric transport models to population exposure estimates can be improved by implementation of the following recommendations:

• Improve spatial and temporal resolution for PM$_{2.5}$ and ozone estimates, e.g. by better description of urban areas and emissions.
• Consider the use of regional emission inventories (e.g. Model for Simulating Aerosol Interactions and Chemistry (MOSAIC)) in global models, and the use of emission inventories by source sector. This would facilitate assessment of the regional and sector-specific contributions and provide better information for policy-makers.
• Consider the development of an “ensemble” of models to improve the simulated concentration data, including exploration of the use of the regional or local modelling that is being conducted by countries.
• Explore the use of top-down constraints by satellite and in situ observations for assessment of pollution trends, spatial and temporal variation and emission ratios such as NO$_2$/reactive hydrocarbons ratios.
• Advance understanding and description of parameterization of the sub-grid physical processes occurring in the atmosphere and their impact on the concentration estimates, e.g. secondary organic particle formation.
• Explore feasibility of global models for other health and climate-related air pollutants and of models describing pollution in cities (or megacities).
• Conduct retrospective analysis and source apportionment (integrating the air quality modelling and monitoring data) in order to provide information on the main sources and sectors contributing to human exposure.

**Satellite remote sensing**

To strengthen satellite-derived PM$_{2.5}$ estimates used by the Global Platform, the following steps are recommended:
• Proceed towards higher spatial resolution of estimates (e.g. using satellites (moderate resolution imaging spectroradiometer (MODIS)) with 1–3 km resolution, (mult-angle imaging spectroradiometer (MISR)) with 4 km resolution, and eventually visible infrared imaging radiometer suite (VIIRS) with 750 m resolution).
• Use more accurate and precise retrievals (e.g. through MODIS Collection 6).
• Incorporate active measurements more fully (e.g. through (CALIOP) space-borne lidar).
• Use measurements with higher temporal resolution to estimate the annual mean more accurately (e.g. from geostationary satellites).
• Endorse and foster the collocation of AOD and surface PM$_{2.5}$ measurements (e.g. through the SPARTAN project and other networks).
• Develop related information on NO$_2$ and other pollution species (e.g. using the TROPOspheric monitoring instrument (TROPOMI) on board the Sentinel-5 precursor satellite with 7 km resolution after launch expected in 2015).
• Build on expertise from space agencies to increase data continuity.
• Consider modifications of the estimating procedures to account for urban increment.
• Consider using ground-based and airborne measurements that offer valuable resources to calibrate and validate satellite data.
• Consider exploring information on road networks to inform the ground-level monitoring stations’ proximity to roads.
• Make formal statements to space agencies to encourage relevant measurements.
• Nurture groups and communities that will contribute to the exposure dataset.

**Data integration**

The work in this area necessary for the Global Platform should include:

• further documentation on the available statistical techniques;
• an examination of the practicalities of their implementation in the assessment of population exposure to air pollution based on various approaches;
• possible feasibility analyses based on existing datasets.

**5. Conclusions – A way forward**

Providing truly global estimates of exposure to outdoor air pollution requires the integration of information provided by different approaches. Each of the three approaches to the assessment of air quality discussed at the Consultation: surface monitoring, atmospheric modelling and satellite remote sensing must provide information to the Global Platform on Air Quality and Health, each contributing its strengths and advantages. Combining the three approaches merges those strengths leading to more robust and reliable exposure assessment with a global coverage, and a capacity for assessment of sector-specific contributions to the exposure and policy scenario analysis. Gradual improvement of each of the data sources recommended in the methods-specific section, and profiting from the developments in each of the methodologies, will further strengthen the integrated approach. This will allow regular
enhancement and expansion through the consecutive updates of the database in the Global Platform.

Approaches to data presentation

The following recommendations aim at assuring transparency and reliability of the exposure estimates presented by the Global Platform, as well as their usability for various groups and communities. A hierarchical approach, with increasing complexity, would facilitate data use. The Platform, managed by WHO, should enable open, read-only access to the data and information. The access should be facilitated by shared and automatic data management platforms.

A. The basic dataset, aiming primarily at the decision-makers would include:
   - separate databases for all three data streams – surface monitoring, atmospheric transport models and satellite remote sensing – with methods for integration of the three streams to be explored as a separate endeavour;
   - minimal output of each of the air pollution datasets (surface monitoring, modelling, remote sensing, separately) should use a common format that is easily understandable, (e.g. country/urban annual means or population-based distribution of concentrations). For each of the datasets, a consistent error metric should be included.
   - integrated national exposure indicators (e.g. annual mean PM$_{2.5}$ concentration for a country, possibly with additional estimates for urban and rural areas) based on a combination of the results from all three data streams with spatially explicit population data from international, verified sources. Integration of the data will be based on methods of statistical fusion and, in the future, assimilation.

B. Additional information, aimed primarily at national and international experts using the Platform for research and comparative assessment of risks to health from air pollution would include:
   - high-resolution estimates of pollution concentration that can, if necessary, be aggregated up to national level or to urban or rural scale;
   - pointers or links to external databases that contain higher time resolution data (seasonal or daily) from countries with capacity to provide such data;
   - links to higher spatial resolution air quality data, particularly for urban areas; an option for a real-time update of the Platform’s data linked to the local data sources should be explored;
   - PM$_{2.5}$ speciation and other data on air pollutants (in particular, information relevant to climate change, such as on black carbon and other SLCPs);
   - minimum information on physical data (metadata) that goes along with surface measurements (or links to such information);
   - links to other exposure databases, e.g. for household fuel combustion and indoor air pollution;
   - links to databases that facilitate attribution of exposure to key pollution sources;
   - GIS-ready graphs (maps) with gridded estimates of pollution on a regional and country level, accessible through widely used GIS software packages;
   - database with gridded estimates with information allowing their use in mapping programmes.
Role of WHO

The Global Platform will be instrumental for WHO to support strengthening of countries’ capacity to address air pollution-related health risks, at the global, regional and country levels. WHO headquarters will focus on the development of the knowledge base, monitoring and evaluation. The WHO regional offices will use the Platform to strengthen their direct support to the Member States, and in particular the support to their health and environment sectors, in design of their engagement with other sectors to address health aspects of air pollution.

Development of the Global Platform can be achieved only through active collaboration of the experts from the relevant disciplines, supported by their professional networks, national institutions and international organizations, including space agencies. However, there is a special role for WHO to play in order to harness relevant data and use it to support the development of policies and to build capacity in the Member States necessary to address air pollution as an important determinant of health. The Consultation recommended that WHO:

- provides leadership and coordination for activities leading to the establishment and maintenance of the Global Platform, defining the framework for all activities. Specific objectives could be pursued by task groups involving relevant external experts and facilitated by WHO;
- provides the institutional framework for all activities of the Global Platform;
- provides information technology (IT) infrastructure support for the Global Platform, potentially using advice and technical support from the external experts and institutions;
- continues technical guidance through updating of WHO air quality guidelines and actively communicating its findings in the Member States;
- uses the data from the Global Platform to widely communicate about the status of air quality and its health impacts in the world, particularly in developing countries;
- organizes communication and training activities to strengthen the capacity of countries to contribute to, interpret and use the data gathered by the Platform;
- articulates the key messages that establish the link between air quality and health in global policy platforms around the world, e.g. through the post-2015 Sustainable Development Process or the CCAC;
- engages developing countries and emerging economies including in sub-Saharan Africa, in a discussion about air quality and health, exploring existing barriers (financial, policy, awareness, and capacity) to air quality monitoring and encouraging development or improvement of their pollution emission inventories;
- supports capacity building, particularly in countries with high estimated exposure to air pollution but that so far have undertaken little or no air quality monitoring or assessment of related impacts on health;
- actively looks for support among Member States, international organizations and space agencies for the groups and communities that will inform the exposure dataset and for activities (surface monitoring, modelling, and satellite remote sensing) contributing to the exposure data, including promotion of these activities through such frameworks as the annual United Nations Inter-Agency Meeting on Outer Space Activities;
- enhances networking with relevant organizations and groups, such as Group on Earth Observations (GEO) and its Secretariat and the Committee on Earth Observation Satellites (CEOS), Institute for Health Metrics and Evaluation (IHME), Health Effects Institute, and the Task Force on Hemispheric Transport of Air Pollution of the Convention on Long-range Transboundary Air Pollution (LRTAP) to coordinate the
work on the exposure dataset and lend confidence in the assessment results to policy-makers;

- facilitates Member States’ access to the existing air quality and health assessment expertise so as to strengthen policy-making and to encourage national initiatives, such as new measurement networks, new emission inventories, better regional resolution of databases and air quality modelling that supports policy and decision-making;

- use the information gathered by the Global Platform for periodic assessments of the burden of disease due to air pollutants, and for developing scenario analysis that can support policy-making (including regional and sector-specific assessments).

**Follow-up actions**

Participants at the Consultation recommended the following activities on exposure assessment as an essential input to the Global Platform on Air Quality and Heath:

1. Preparing the estimates of national mean concentration of PM$_{2.5}$ demonstrating the proposed approach, to be completed by the end of 2014. The estimates will be based on the most recent update of air quality data collected by WHO and others (e.g. for the GBD 2013), the updated ensemble atmospheric transport model outputs, including source-sector contributions, developed for TF HTAP and updated estimates from satellite remote sensing. WHO should appoint a small Data Integration Task Group for managing this development and involving experts currently working on each of the approaches as well as on the methods of data fusion.

2. Besides the Data Integration Task Group, WHO will establish three thematic Task Groups following up the topic-specific recommendations and facilitating the link with the national experts. Each of the groups cooperating with WHO should identify its “core” team and be open for external contributions. WHO will propose the organizational structure and way of working of the task groups.

3. WHO will organize web-based communication channels facilitating online discussion of each group, exchange of information and documents.

4. Regular consultative meetings (roughly every two years), gathering representatives of the task groups and of the Global Platform users should be convened to review the status of the Platform, assess its utility for the burden of disease assessment and policy support and agree on the further steps to increase its use to policy-making, concerning not only public health, but also environment, climate and other sectors.
## Annex 1. List of participants

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<th>Name</th>
<th>Institution/Location</th>
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<tbody>
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1Co-chair of the Consultation.
2Member of the Scientific Steering Group.
3Rapporteur of the Consultation.
4Participated remotely through videoconference.
Annex 2. Background paper

Updating WHO database on population exposure to air pollution: background document for a WHO consultative meeting


Michael Brauer, Aaron Cohen, Frank Dentener, Michal Krzyzanowski, Randall Martin, Annette Prüss-Ustün, Rita van Dingenen, and Aaron van Donkelaar

1. Background

Air pollution is an important determinant of health (WHO, 2006). There is convincing evidence linking the risk of disease and premature death, with exposure to fine particulate matter (PM$_{2.5}$) and ozone (O$_3$), even at relatively low concentrations of the pollutants. And the public health burden is substantial. The recently published Global Burden of Disease 2010 assessment indicated that approximately 3.2 million premature deaths and 3.1% of the global disease burden could be attributed to outdoor air pollution in 2010 (Lim et al., 2012). Ambient PM pollution is the fourth highest-ranking risk factor in East Asia, the sixth in South Asia and the seventh in North, Western and sub-Saharan Africa as well as in the Middle East, where annual average levels of particulate air pollution are several-fold higher than in North America or Western Europe (Brauer et al., 2012). International efforts to combat epidemics of the noncommunicable diseases, including cardiovascular and respiratory diseases, and lung cancer, for which air pollution is recognized as a risk factor, would profit from contributions from sound environmental policies aiming at reduction of air pollution. Components of PM$_{2.5}$, such as black carbon, as well as ozone, are short-lived climate-related pollutants, and other PM components such as sulfur and nitrogen components affect ecosystems’ health. Benefits of efforts to reduce concentrations of these components could be seen relatively quickly, resulting in economic gains far exceeding the costs of pollution reduction programmes (Holland et al., 2011). Knowledge about the health risks and their trends is an important stimulus for developing disease prevention programmes and relevant public health policy. Therefore the data on air pollution levels and their temporal trends are important health policy-relevant indicators.

Ground-level measurements of concentration of major health-damaging air pollutants suitable for use in health effects research and assessment of the attributable burden of disease are limited. Despite the recent growth of monitoring networks in South-East Asia, most of the measurements are conducted in high-income countries of Europe and North America. Very few measurements are available in some highly-polluted regions, including Africa and the Middle East. Moreover, measurements for the most part are available only for urban areas, despite the fact that approximately 50% of the global population resides in rural areas. Besides the insufficient coverage of the global population by the monitoring networks, the data quality, their harmonization and standardization, and accessibility, remain unresolved problems hindering the reliable assessment of population exposure to air pollution in many regions of the world.

Recent progress in methods based on remote sensing and global chemical transport models, combined with existing surface monitoring, promises an increase in availability of global information on key air pollutants, also for the most highly-polluted and data-poor regions. This creates a new opportunity for significant improvement of the assessment of the burden of disease due to the pollution and for supporting global and regional policies with reliable information.

2. Creating a global database on population exposure to air pollution

The WHO database on air pollution currently comprises ground-level measurements from 1100 cities worldwide, reaching 1500 cities in its 2013 update (http://www.who.int/phe/health_topics/outdoorair/databases/en/index.html ). However, it is limited to PM$_{10}$ and PM$_{2.5}$, and most of the available data are for the high-income countries. In some regions of the world, and especially in Africa and the Eastern Mediterranean region, either very limited air quality monitoring is performed, or the data from such monitoring are not available. The sparse information that is available indicates that air pollution is often high in such areas, and programmes to reduce the potential health risks are urgently needed.
To provide truly global data it will be necessary to add to the data from the monitoring information generated by other methods with global coverage, including satellite-based remote sensing and chemical transport models. The final product would consist of high-resolution maps of the outdoor air pollutants of greatest relevance to health, including PM$_{2.5}$, PM$_{10}$, NO$_2$ and O$_3$, covering all inhabited areas of the globe. It should also combine air quality estimates with data on the resident population to provide first estimates of human exposure. This expanded database should be designed for long-term sustainability and reliability, with periodically updated estimates of population exposure to health-relevant outdoor air pollutants covering all regions of the world published on a WHO web site. As such, it should become a standard component of WHO Global Health Observatory (http://www.who.int/gho/en/), which is a widely-used global reference. The exposure information included in the data will be a basic resource for estimating health impacts of pollution at country and regional levels, for evaluating trends in pollution levels and exposures, for raising awareness on the importance of ambient air pollution as a determinant of population health at country level, and for evaluating effectiveness of health protective measures. The database would provide estimates of exposure for urban and rural populations, with the spatial resolution sufficient to assess accurately average exposure in urban areas.

The primary users of the database would be national and international authorities and scientists monitoring spatial and temporal patterns in environmental determinants of health, designing national and regional policies to address air pollution and evaluating the effects of interventions and policies. This will include WHO, United Nations Environment Programme (UNEP), World Meteorological Organization (WMO), United Nations Development Programme (UNDP), United Nations Economic Commission for Europe (UNECE), Organisation for Economic Co-operation and Development (OECD), Institute for Health Metrics and Evaluation (IHME), Climate and Clean Air Coalition (CCAC), and the World Bank. National authorities would be able to compare their national situation with regional and global trends and patterns. Nongovernmental organizations (NGOs) and the media will receive a reliable and scientifically sound basis for their activities. The research community will be able to use the database both as input to their studies and as a stimulus for new initiatives, such as analysis of specific local patterns of pollution or effectiveness of various pollution reduction programmes. The design of the database should aim at responding to the needs of the widest possible range of users.

Since the calibration of the models will require surface monitoring data, creation of the global database will provide additional incentives for international actions to develop air quality monitoring in regions where the air quality (AQ) data are scarce. The attention raised with regard to air pollution levels may also be an incentive for national authorities to improve monitoring, and stimulate pollution abatement programmes.

National authorities and experts need to be included in the process of database development and its long-term maintenance by providing regular updates of their own data following a standardized format. This will increase their confidence in the estimates, create a network of data providers and users and contribute to maintaining high data quality including standardization and quality control.

3. Use of surface data on air quality for global exposure estimates

While ambient air quality monitoring data derived from ground-based (regulatory) monitoring networks have been the basis for most of the epidemiological research on the effects of air pollution on health, the availability of these data varies greatly around the globe. For the recent Global Burden of Disease 2010 project, an attempt was made to gather available monitoring data on global annual average PM$_{2.5}$, mainly from readily available official monitoring networks for 2005 (and where data for 2005 were unavailable, for 2004–2006) (Brauer et al., 2012), an approach that has been updated for 2010–2012 measurements as part of GBD 2013 (http://www.healthmetricsandevaluation.org/gbd/2013). Literature sources and personal communications were also used, especially in locations without regional or national monitoring networks. Where PM$_{10}$ but not PM$_{2.5}$ data were available, PM$_{2.5}$ were estimated from PM$_{10}$ measurements. Where available, local (or country-specific, to reflect differences that may relate to the regional contributions of coarse PM) PM$_{2.5}$/PM$_{10}$ ratios were used for all locations within a particular country. Elsewhere, a ratio of 0.5 was used, which was the default in the previous global burden estimates (Cohen et al., 2004) and which approximates mean ratios for regions with large numbers of coincident measurements. Given the uncertainties inherent in estimating PM$_{2.5}$ from PM$_{10}$ by this simple ratio method, the estimated PM$_{2.5}$ concentrations should be used cautiously, especially in areas with high levels of dust. Where multiple measurements were available for a metropolitan area, all urban background values (roadside and industrial monitoring sites having been excluded) were averaged to provide a single value for each metropolitan area. All measurements were geo-referenced and compiled into a consolidated database representing urban background concentrations.

Figure A2.1 presents the ground-based monitoring data used for the GBD 2010. No observations of either PM$_{10}$ or PM$_{2.5}$ were available for the Asia Central, Caribbean, Latin American Andean, Oceania, sub-Saharan Africa Central, and sub-Saharan Africa East regions.
Of the 475 locations for which measurements of PM$_{2.5}$ were retrieved up to 2006, the vast majority (90%) were from high-income countries. In low- and middle-income countries, PM$_{10}$ measurements were more common. Subsequently, WHO compiled updated monitoring data from accessible sources (mostly national governments) for the year 2010 (later updated for 2012), or the latest available year. While most of the measurements are still restricted to high-income countries, there has been an increase in surface monitoring, especially of PM$_{10}$ suggesting a slow trend towards increasing availability of monitoring data.

**Figure A2.1:** PM$_{2.5}$ estimated from PM$_{10}$ and directly measured used for GBD 2010

![Annual average PM2.5 (μg/m3)](image)

*Source:* Brauer et al., 2012.

### 3.1 WHO database on urban air quality

The primary sources of data on annual mean PM$_{10}$ and PM$_{2.5}$ concentrations gathered in the WHO database on air quality are official national and subnational reports and national and subnational websites (WHO, 2011). Furthermore, measurements reported by the following regional networks were used: the Asian Clean Air Initiative (Clean Air Initiative, 2011) for Asia, and AirBase (European Environment Agency, 2011) for Europe. In the absence of data from the above-listed sources, data from UN agencies, development agencies and articles from peer-reviewed journals were used. In 2013, an annual mean for PM$_{10}$ or PM$_{2.5}$ could be compiled for 1500 cities, 67% of which are located in high-income countries and 33% in low- and middle-income countries, respectively (Figure A2.2a, Table A2.1). In contrast, annual mean PM$_{2.5}$ measurements were publicly available for 883 cities, but only 8% of them are located in low- and middle-income countries. Accessible monitoring data are relatively scarce in developing regions, particularly in Africa and parts of Asia and the Middle East, Latin America and Eastern Europe, but also in the high-income regions of the Eastern Mediterranean (Figure A2.2b).

**Figure A2.2a:** Number of cities with accessible PM$_{10}$ and PM$_{2.5}$ data in 2013 per million urban inhabitants
AMR, America; AFR, Africa; EMR, Eastern Mediterranean; SEAR, South-East Asia; WPR, Western Pacific; LMI: low- and middle-income; HI, high-income.


**Figure A2.2b**: WHO database on urban outdoor air quality: available annual average ambient PM$_{10}$ concentrations in 1081 cities, 2003–2010


In developed countries, the network of monitoring stations is generally sufficiently dense to respond to local legal requirements. In some countries this has been the case for two decades or more (Air Parif, 2011). In developing countries, however, the situation varies widely. While in some countries the network for monitoring PM$_{2.5}$ has recently been extended into numerous cities, it is still at the planning stage in others. Many developing
countries, however, are currently expanding their monitoring systems (Clean Air Initiative, 2009; Department of Environmental Affairs, 2012; Ministry of Environmental Protection, 2012).

### Table A2.1: Number of cities with accessible PM$_{10}$ and PM$_{2.5}$ data

<table>
<thead>
<tr>
<th>Region</th>
<th>PM$_{2.5}$</th>
<th>PM$_{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>America, LMI</td>
<td>18</td>
<td>87</td>
</tr>
<tr>
<td>Africa (sub-Saharan)</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>Eastern Mediterranean, LMI</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>Europe, LMI</td>
<td>20</td>
<td>99</td>
</tr>
<tr>
<td>South-East Asia</td>
<td>11</td>
<td>166</td>
</tr>
<tr>
<td>Western Pacific, LMI</td>
<td>0</td>
<td>133</td>
</tr>
<tr>
<td>High income</td>
<td>816</td>
<td>1001</td>
</tr>
<tr>
<td>Total</td>
<td>883</td>
<td>1515</td>
</tr>
</tbody>
</table>

LMI: low- and middle-income.


Most countries provide public access to air quality data on PM$_{2.5}$, and only a few limit access to the data collected. Some countries make only an air quality index available to the public, rather than the actual PM values, although retro-analysis can sometimes retrieve PM data from these indices. Air quality monitoring data may be used for public information, to guide policy decisions in areas such as transportation or energy, and to estimate the related disease burden in the population (Brauer et al., 2012).

Unfortunately, measured PM data have limited comparability across countries. Measurements and techniques are not standardized globally, are subject to different quality control programmes, protocols and sampling frequencies, and may not use the same calibrations, or may differ in the types of sampling locations (e.g. roadside, background, or industrial) (Brauer et al., 2012). Nevertheless, surface measurements are a key component of an integrated approach, combined with modelling results and satellite data. Therefore, additional PM$_{2.5}$ measurements that are standardized across countries would be valuable.

While the global coverage of surface monitoring for PM$_{10}$ and to a lesser extent PM$_{2.5}$ is growing, most of the world still lags far behind the density of monitoring sites that is available in North America and Western Europe. Although such monitoring networks have been the basis of numerous epidemiological studies and analyses of temporal and spatial trends in ambient concentrations, additional approaches are needed to estimate exposures for disease burden or for epidemiological studies in areas where surface monitoring networks are now, and may well remain, non-existent or inadequate. Even in high-income countries with dense monitoring networks, recent studies have indicated that satellite-based estimates and high-resolution air quality models can complement surface monitoring data and be used to fill temporal and spatial gaps (Atkinson et al., 2013; Lee et al., 2012). Existing national and regional monitoring programmes, complemented with the newly emerging networks such as SPARTAN could provide measurements to test the database and a framework upon which to build.  

#### 4. Atmospheric transport models for exposure estimates

Increasingly, atmospheric chemistry transport models are being used for calculation of the concentrations and exposures to air pollution. Brauer et al. (2012) merged the TM5 atmospheric model output with satellite data, and calibrated them with PM data from surface monitoring. In this study the two-way nested TM5 model was run at a 1×1 degree resolution$^5$ over four major world regions, fed with emissions from the Greenhouse Gas and

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$^4$ An emerging global PM$_{2.5}$ network SPARTAN http://www.spartan-network.org

$^5$ Corresponding to approximately 111 × 70 km on the Berlin/Paris latitude.
Air Pollution Interactions and Synergies (GAINS) emissions database, as used in the Global Energy Assessment (http://www.globalenergyassessment.org/). The output was consequently refined to a 0.1 × 0.1 degree resolution using spatial information on the location of the emissions. As discussed by Brauer et al. (2012), both atmospheric model and satellite data have specific strengths and limitations. A particular strength of models in general is that they can directly relate sources and their underlying sectoral contributions to concentrations. Furthermore, models are the only way to extrapolate the current situation into the future, using emission scenarios that describe various assumed developments of technological and structural changes in the sources of air pollution, and policy options to address air pollution in various world regions.

There is a tendency for global models to go to finer resolutions: in 2012 some models were run at a global 0.5 × 0.5 degree resolution, and regional models are expanding their model domain, as well as improving resolutions – currently of the order of 5–10 km resolution.

This development is fostered by a continuous increase of computing capacity, and improved skills with numerical weather prediction models that often provide the meteorological input to the models, from the global to the regional scale. Nevertheless, errors in emission inventories and in the meteorological model predictions are still a significant issue for modelling (Dentener et al., 2010; Granier et al., 2011; Zhao et al., 2011). Emission inventories suffer from errors of both activity data and emission factors, as well as in the spatial and temporal resolution of the emission data. Therefore, country totals or long-term averages might be more accurate than the emissions at a grid point or at a specific time.

The models increasingly make use of data-assimilation and the most widely used data come from satellites. Numerical weather forecast models have been collecting information on temperature, humidity and winds from satellites for several decades. Now they are also starting to use information on aerosol (PM) – with the prime objective of improving weather forecasting, but also increasingly to provide services to the public on aerosol air pollution (e.g. http://www.ecmwf.int/research/EU_projects/MACC/). The crucial aspect of data assimilation is that it makes objective use of the information on errors in both data and models, and provides a solution that combining the best of both worlds. Nevertheless, by definition, it is not possible to use such systems for studies of future scenarios. The same applies to understanding the past – for which good measurements on aerosols are only available for two decades and from satellites for about one decade.

While Brauer et al. (2012), relied on one particular global chemical transport model, future developments involve the creation of ensembles of model outputs, where best practice has shown that, compared to measurements, model performances are significantly better. The Convention on Long-Range Transboundary Air Pollution Task Force will, in the next years, focus on the consistent coupling of ensembles of global models with regional scale models, computing coherent air pollution estimates at a resolution so far unprecedented. Nevertheless exposures of people to air pollution happen on scales that are still not covered by these regional–global models, and consistent parameterizations are still needed to cover the scales below that.

In the coming years the challenge will be to make optimal use of the information available from measurements and models. A variety of techniques are available for these purposes, but in essence all techniques will rely on the availability of reliable observations.

5. Exposure estimates based on satellite remote sensing

Satellite remote sensing of ground-level air quality has developed substantially over the past decade as reviewed by Martin (2008) and Hoff and Christopher (2009). Most of the satellite observations that are relevant to air quality are in polar orbits that yield global coverage on a timescale of days. Satellite remote sensing of aerosol and nitrogen dioxide (NO₂) offers substantial information about ground-level concentrations.

Satellite retrievals of AOD provide a column-integrated measure of light extinction due to the presence of aerosol. Satellite-based estimates of PM₂.₅ rely on these retrievals, relating AOD to PM₂.₅ using either an empirical, semi-empirical or physically-derived relationship. Empirical relationships rely on statistical regression techniques between local in situ measurements and retrieved AOD (e.g. Liu et al., 2009; Kloog et al., 2011). Semi-empirical relationships draw on local measurements, but additionally incorporate some understanding of how these values relate (e.g. Di Nicolantonio et al., 2009; Schaap et al., 2009) physically. Lastly, physically-derived relationships rely on the aerosol’s vertical distribution and optical properties, often simulated using a chemical transport model to predict the AOD to PM₂.₅ relationship (e.g. Drury et al., 2010; van Donkelaar et al., 2010).

Current satellite-derived PM₂.₅ estimates rely heavily upon instruments orbiting the Earth on board NASA’s Terra and Aqua satellites, launched in 2000 and 2002, respectively. MODIS instruments (Levy et al., 2007) on board each of these platforms provide a near-daily snapshot of global AOD at approximately 10 km × 10 km resolution; a 3 km product is expected to be released for the MODIS data record in the near future (Remer et al., 2008).
2013). In addition, the Collection 6 MODIS aerosol data product will include AOD retrieved by the Deep Blue algorithm (Hsu et al., 2013). The Deep Blue AOD has been shown to have better coverage over bright surfaces such as deserts and urban areas, which could potentially alleviate the MODIS sampling bias. Further research is needed to evaluate the ability of Deep Blue AOD to estimate ground-level PM_{2.5} concentrations. The MISR instrument (Kahn et al., 2010), on board Terra, has reduced retrieval uncertainties compared to MODIS over some regions, but its more limited swath width requires between six and nine days for global coverage. Cloud and snow cover inhibit AOD retrieval from both instruments and can produce seasonal sampling effects that should be taken into account during compilation into long-term mean values.

Chemical transport models (CTMs), which describe the atmospheric composition using meteorological datasets, emissions inventories and equations of the physics and chemistry of atmospheric constituents, can be used globally to estimate local variation in AOD to PM_{2.5} relationships. For example, van Donkelaar et al. (2010) used the GEOS-Chem CTM (http://geos-chem.org) to demonstrate that this approach is globally effective for long-term mean satellite-derived PM_{2.5} estimates, with a population-weighted mean global uncertainty of 1 μg/m^3 ± 25%. Regional uncertainties varied predominantly with the level of accuracy for their local simulated aerosol vertical profile and satellite AOD retrieval. The effects of sampling bias due to snow and cloud cover were accounted for using the CTM-calculated seasonal variation.

Ageing of the MODIS and MISR instruments can influence the accuracy of AOD retrieval from these platforms. The recently launched VIIRS instrument, however, will help to ensure a continuous satellite-derived PM_{2.5} record although VIIRS AOD has not yet been evaluated in the context of estimating ground-level PM_{2.5} concentrations. Satellite retrievals of NO_2 offer additional information on the spatial structure of combustion-related air pollutants (Cooper et al., 2012). The development of geostationary missions will extend satellite-based PM_{2.5} coverage towards regionally continuous aerosol observation under cloud and snow-free conditions. Algorithmic improvements, including tighter CTM-retrieval integration, will permit PM_{2.5} estimates with higher accuracy and spatial resolution, possibly up to 1 km × 1 km, over the entire MODIS/MISR record. Global ground-level measurements of AOD and PM_{2.5} would be useful to evaluate and improve CTM calculations of that relationship.

6. Combination of methods – data fusion

In the estimation of global exposure for GBD 2010 (Brauer et al., 2012), estimates from the satellite-based approach were combined with those from TM5 and calibrated with available surface monitoring data, including estimated PM_{2.5} concentrations derived from PM_{10} measurements. This approach borrows from the strengths of each individual estimation approach. Although it was innovative for air pollution burden estimation, the approach was ad hoc and more formal statistical data fusion could be achieved in the future. For example, use of all available air pollution measurement data (including other pollutants besides PM_{2.5}), satellite-based estimates, simulations from multiple CTMs and even land use data could be combined and used to estimate missing PM_{2.5} observations. A rigorous combination of data from these different approaches could involve a Bayesian approach that weights the data according to uncertainty. This emphasizes the need for uncertainty information to accompany each PM_{2.5} data source, and for that uncertainty to be consistent for each PM_{2.5} data source.

Alternatively, estimations of PM_{2.5} from satellite-based approaches, CTMs and available surface measurements could be combined with a data assimilation approach. As discussed in the modelling section, state-of-the-art approaches increasingly combine multiple models. However, to date, there has been no successful demonstration of the ability of global data assimilation to improve predictions of ground-level PM_{2.5}. This is a large, active research area and developments should continue to be watched over the coming years for their ability to benefit this project.

7. Uncertainty estimates

7.1 Previous approach used in the Global Burden of Disease Project

In the estimation of exposures for GBD 2010 a relatively simple approach was taken for practical reasons (Brauer et al., 2012). Specifically, for each grid cell (with resolution of 0.1° × 0.1°, equivalent to approximately 11 km × 11 km at the equator) estimates were provided by the satellite-based approach and from the TM5 chemical transport model. The range of these values provides a crude estimate of uncertainty in the overall estimate of exposure.

Note: This section is largely excerpted from supporting information in Brauer et al., 2012.
Figures A2.3 and A2.4 show the global distribution of the individual grid cell absolute and proportional differences in the 2005 SAT and TM5 estimates of PM$_{2.5}$. As expected there was a trend towards greater absolute differences in areas of higher pollution as well as areas with high emissions of windblown mineral dust.

**Figure A2.3.** Global distribution of absolute differences (μg/m$^3$) between TM5 and SAT estimates of PM$_{2.5}$ for 2005

To provide the actual exposure estimates used in the disease burden calculations, the average of the satellite-based and TM5 estimates were calibrated to available surface monitoring data in corresponding grid cells in a prediction model:

$$\text{PM}_{2.5} = 1.32 \times \text{AVG}^{0.922}$$

where AVG = average of the satellite-based and TM5 values. The outcome was a very nearly linear prediction of AVG compared to the available surface measurements. From the above prediction model, the prediction error was calculated. This error was mainly due to residual error (as the large sample size leads to very small model error). The ratio of prediction error/predicted value ranged from 8.3% to 15.9% over the log (average) values, which was a relatively small error compared to sources of error in the overall burden estimates (Burnett et al., forthcoming).

While formal uncertainty analysis in the GBD 2010 estimates incorporates additional uncertainty (for example, in the concentration–response functions), to specifically characterize exposure uncertainty one could generate multiple replicated random values representing the mean and uncertainty in exposure estimates for each grid cell by generating a random number from a normal distribution with mean log(AVE) and variance 0.1483 (the residual error of the prediction model) and then take the exponential of this randomly generated number.
Figure A2.4. Global distribution of proportional (absolute value of difference between TM5 and SAT divided by final estimates (the average of TM5 and SAT calibrated with the prediction model)) differences in SAT and TM5 estimates of PM$_{2.5}$ for 2005

While this approach provides an indirect estimate of uncertainty, there is also inherent uncertainty and potential bias in the approaches themselves. For example, the satellite-based approach is designed to improve accuracy relative to surface measurements by incorporating the time and location-specific vertical distribution of aerosol estimated from a chemical transport model and to incorporate AOD information from two complementary sensors (MODIS/MISR). Thus, residual uncertainty in the satellite-derived PM$_{2.5}$ results from inaccuracy in both the model and satellite AOD measurements. As part of the aforementioned filtering process in which MODIS and MISR AOD retrievals are used in a complementary fashion, mean satellite AOD error was limited to 0.1 AOD units or 25%. Accuracy of the PM$_{2.5}$/AOD ratio is dominated by the relative vertical structure of the chemical transport model (van Donkelaar et al., 2006). Based on a comparison with extinction profiles from the CALIPSO satellite (Vaughan et al., 2004), it is estimated that the simulated fraction of AOD within the boundary layer is accurate to within 15%. The overall error for annual mean coincident satellite-derived PM$_{2.5}$ is estimated to be ±25%.

Incomplete ness of daily global satellite sampling, caused by cloud cover and/or instrument limitations, has the potential to introduce sampling bias into annual mean satellite-derived PM$_{2.5}$. Comparisons of continuously and coincidently-sampled simulated PM$_{2.5}$ indicate that satellite-derived PM$_{2.5}$ sampling is sufficient to represent true annual PM$_{2.5}$ to within ±20%. In a few cases, however, this bias can increase to as much as ±50%, where major seasonal cycles prevail (e.g. South American and Central African biomass burning). In all cases, however, a correction has been applied to account for these differences, which should further minimize their impact.

All of these factors can be combined into a total uncertainty estimate as described previously (van Donkelaar et al., 2010). The overall PM$_{2.5}$ uncertainty is estimated to be ±25%, which results in a mean global, population-weighted uncertainty of 6.7 μg/m$^3$ PM$_{2.5}$. Uncertainty in the satellite-based estimates is highest in regions with substantial landscape fires (the Amazon basin, Central Africa, and south-east Asia), desert regions with the potential for high emissions of windblown mineral dust, and high latitude regions of Asia and North America.

For TM5, multi-factor sensitivity analysis or error-propagation of all processes has not been performed because of the high computational cost. The performance of the model is assessed by evaluating the different modules (emission, vertical and horizontal transport, chemical and physical processes, wet and dry deposition) with
measured data and through multi-model inter-comparison exercises. For example, TM5 has participated in AeroCom (Aerosol Comparisons between Observations and Models), an international initiative, which has been running since 2003, where the performance of global and regional aerosol (PM) models and their key input parameters are evaluated with a focus on climate impacts (Schulz et al., 2006; Textor et al., 2006).

In addition, the HTAP model comparison provides summaries of model estimates and standard deviations for TM5 compared to other global CTMs included in HTAP (Dentener et al., 2010). Comparing to a subset of models (GEOS-Chem, MOZART, Lawrence Livermore National Laboratory (LLNL) and EMEP (run only for the northern hemisphere, so does not provide global estimates)) for major PM components (the HTAP model comparison did not provide PM mass) for four populated regions as examples.

On a global basis, for all constituents except particulate organic matter, TM5 estimates were within the range of estimates provided by other models. For particulate organic matter, estimates from all of the models varied substantially (relative standard deviation of 0.41) with TM5 providing the highest estimates. Globally, relative standard deviations were largest for particulate organic matter and black carbon and were substantially lower for sulfate.

For TM5 (as with other global CTMs) the following parameters or processes are believed to have the greatest influence on the resulting PM concentration estimates:

- emission strength of primary PM (black carbon, primary organic carbon, dust, sea salt);
- emission of gaseous precursors for secondary PM (sulfur dioxide (SO₂), nitrogen oxides (NOx), volatile organic compounds (VOC), and ammonia (NH₃));
- removal rate of PM (mainly wet deposition for most anthropogenically emitted components, and sedimentation or dry deposition for dust and sea salt);
- horizontal resolution of the model;
- physicochemical processes leading to the formation of secondary PM from gaseous precursors (in particular secondary organic matter);
- sub-grid urban increment parameterization; and
- the PM size distribution and derived PM₂.₅ fraction.

### 7.2 Comparison of GBD 2010 estimates with ground-level measurements available in 2013

More recent comparisons with additional ground-level data have revealed interesting discrepancies (Figure A2.5, and Figure A1A.1 (see Appendix)). While in some countries the type and exact location of ground measurements are relatively poorly documented (e.g. in China, although improvements are being made), in other countries data are geo-referenced and type of location is provided. In many countries, data are collected and reported with high temporal coverage (e.g. Eastern Europe and Turkey, source: AirBase). Wherever the type of location was available, only air quality data from background stations (as opposed to near traffic or industrial locations) were used for the comparison in Figure A1A.1. This does not mean that the ground measurements are more accurate than the modelled estimates. However those differences will need to be explored to reduce them in the future.
Figure A2.5. Comparison of country mean PM$_{2.5}$ based on model outputs and available ground measurements for background locations (or other locations if not available)

A. Only PM$_{2.5}$ measurements

B. Based on converted PM$_{10}$ and PM$_{2.5}$

*Data from “database” represent urban means from the database, combined with lowest modelled rural data.
Based on these preliminary comparisons, the model reflects the real situation well in high-income countries, but shows systematically less reliable results for many low- and middle-income countries (except for China, where results are higher than officially reported measurements). Also, the resolution of the modelling may not be high enough to assess medium-sized cities. A succinct summary of the strengths and limitations of the current approaches to global assessment of air quality for evaluation of population exposure and its health effects is provided in Table A2.2.

8. **Potential developments of the method of uncertainty characterization**

In the future, it would be desirable to assess global uncertainty with *in situ* observations in a more rigorous manner. Such a comparison would provide the most direct means to assess uncertainty. One challenge is that at present few consistent observations are made around the world, as discussed in the future needs section. To be informative, the ability of *in situ* observations to provide metrics that are representative of mean concentrations at the resolution and conditions of comparison datasets must be considered. For example, differences in PM$_{2.5}$ measurements may occur as a result of positive or negative sampling artefacts and the contribution of residual water (during sampling, transport, storage, equilibration and analysis) to PM$_{2.5}$ mass measurements.

Table A2.2. Strengths and limitations of various approaches to global AQ assessment

<table>
<thead>
<tr>
<th>Satellite-based estimates</th>
<th>Chemical transport models</th>
<th>Ground-based monitors</th>
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</thead>
<tbody>
<tr>
<td><strong>Strengths</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Based on comprehensive, global observations</td>
<td>• Allow past and future estimates</td>
<td>• Precise measurements of a range of parameters</td>
</tr>
<tr>
<td>• Relatively high spatial resolution (0.1° × 0.1°)</td>
<td>• Valuable for emissions scenario assessment and evaluation of contribution of sources</td>
<td>• Widely accepted</td>
</tr>
<tr>
<td>• Quantified uncertainty</td>
<td>• Specifically designed to simulate the (global) distribution of quantity of interest (e.g. PM$_{2.5}$, O$_3$, PM chemical speciation)</td>
<td>• Growing networks</td>
</tr>
<tr>
<td><strong>Limitations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Potential for sampling biases</td>
<td>• Rely on emissions, parameterizations and available meteorology</td>
<td>• Sparse</td>
</tr>
<tr>
<td>• Rely on modelled relationship between observed column and ground-level concentration</td>
<td>• Limited spatial resolution and ability to incorporate sharp spatial gradients in concentrations related to urban areas</td>
<td>• Data can be inaccessible</td>
</tr>
<tr>
<td>• Quality depends on retrieval accuracy</td>
<td>• Some processes remain poorly represented (e.g. secondary organic aerosols)</td>
<td>• Measurement characteristics (e.g. proximity to local sources) can be ambiguous</td>
</tr>
</tbody>
</table>

As indicated above, the level of understanding of the factors affecting simulated and satellite-derived PM$_{2.5}$ error plays a pivotal role in the extension of local *in situ*-based error estimates to a global scale. Satellite-derived PM$_{2.5}$ estimates rely on the accuracy of both AOD retrievals and AOD–PM$_{2.5}$ relationships, often supplied by a CTM. Satellite retrievals of AOD are, in turn, impacted by assumptions related to surface reflectance, which is a function of land cover type. The relative aerosol extinction profile is one of the most significant factors affecting the AOD–PM$_{2.5}$ relationship. One possible approach to extend satellite-derived PM$_{2.5}$ is to weight *in situ*-based uncertainties according to the land types they best represent, combined with a metric of CTM relative aerosol profile accuracy. Co-location of PM$_{2.5}$ monitors with AOD measurements provides a more direct method to evaluate the CTM AOD–PM$_{2.5}$ relationship. The CALIOP space-borne lidar and EARLINET surface-based lidar measurements may be effective tools with which to assess relative profile accuracy.

If simulated values are used in future exposure estimates, they should be thoroughly evaluated in comparison to *in situ* observations. This is a challenging task, but that challenge need not be prohibitive. The accuracy of simulated PM$_{2.5}$ depends on the accuracy of emissions, atmospheric chemistry and physics, and meteorological...
conditions. Extension of simulated in situ-based error should, therefore, include a representation of these factors. Emissions, chemistry and physics can be typically considered as species-specific. An understanding of species relevant to the in situ locations can be used to extend their local error estimate to similar regions. Where speciation is not directly measured, simulated values may possibly be used to provide some insight. Prevailing meteorology can also be used to predict how errors observed at one location carry over to other locations.

As discussed in the following section, data-assimilation approaches (e.g. in the ECMWF-MACC project) may be an effective mechanism both to characterize and to reduce uncertainty. The TF HTAP phase 2 modelling (www.htap.org ), will start linking regional and global models in terms of source–receptor relationships, which hold a large potential to produce surface PM$_{2.5}$ and O$_3$ (and other components) on the relationships with emissions on multiple scales.

9. Data needs

While the use of currently available information from all sources combined enables global estimates of population exposure to PM$_{2.5}$, the uncertainty of the estimated concentration of the pollution in each location depends on availability of each type of information for a given region. The following key information is needed:

- Surface measurement of PM$_{2.5}$ at sites representative for population exposure, both in urban and rural areas. The most urgent need is for measurement in regions in which air quality monitoring is currently very sparse and population is dense, including sub-Saharan Africa, parts of Asia, and the big cities of Latin America. Standardized data collection methods are needed, covering the whole year and enabling reliable estimation of annual mean concentrations. PM$_{2.5}$ measurements would be useful to evaluate PM$_{2.5}$ inferred from the satellite and CTM methods, and to assess their relative uncertainty. Initiatives such as the emerging SPARTAN surface monitoring network and the WHO air quality database will be helpful in this regard. Further, new developments in relatively inexpensive (but probably less accurate) wireless sensor-based monitoring networks (e.g. http://www.myairbase.com/, http://cps-vo.org/node/1752, http://citi-sense.nilu.no/ ) may provide a source of high spatial resolution measurements that could be useful to reduce uncertainty. A comprehensive, easily-accessible, central repository of global, geocoded, quality assured PM$_{2.5}$ data would be a valuable resource for development of exposure estimates.

- Reliable pollution emission data, providing input to chemistry transport models and used for estimation of surface PM concentrations from the remote measured AOD (already in progress).

- Uncertainty estimates for each PM$_{2.5}$ data source to inform efforts to combine the sources. Reliable estimates of population density with a resolution comparable to that provided by the PM concentration estimates are required.

- Estimates of source-sector contributions to ambient concentrations to inform policy options.

- Estimates of contributions from natural sources (i.e. mineral dust and sea salt).

An emerging network (SPARTAN) has the potential to contribute to meeting the pressing need for PM$_{2.5}$ measurements. The network is designed to provide standardized long-term speciated PM$_{2.5}$ measurements in populated regions. These PM$_{2.5}$ data can be used to directly inform exposure estimates, and to evaluate the quality of data from other sources, such as from the satellite and CTM methods. The network is collocated with AERONET AOD measurements, and thus will allow evaluation of simulated AOD–PM$_{2.5}$ relationships that are used to relate satellite AOD to ground-level PM$_{2.5}$ concentrations. Links should be explored between SPARTAN and the plans to update the WHO database.

10. Research needs

The global estimation of population exposure to air pollution requires effective collaboration of scientists from various disciplines, using innovative and diverse data sources, and state-of-the-art computing technologies. Continued progress in atmospheric measurements and modelling, coupled with improved coverage of surface measurements, is needed to enable more precise and accurate estimates of PM mass concentration. Future work should also aim at increased spatial and temporal resolution and the estimation of distribution of key components of PM. Indeed some of this work has already started through atmospheric modelling activities, and through coordinated in situ monitoring as discussed above. It would be valuable to coordinate these needs with ongoing and emerging activities.

The approach to data fusion is a research area that warrants further consideration. Data fusion techniques ultimately rely on a consistent metric of uncertainty between datasets. Development of a detailed evaluation framework that produces global uncertainties of existing and future datasets is therefore key to their fusion. It is worth noting that the satellite-based datasets described by van Donkelaar et al. (2010) are a form of data fusion.
that combines information from a CTM and satellite observations. With sufficient in situ observations it would be possible to develop three-way data fusion between the satellite, CTM, and in situ observations, following van Donkelaar et al. (2012).

Downscaling the CTM model resolution to the resolution relevant for human exposure remains an important challenge. Currently, simple parametrization techniques are being applied, but there is ample space for improved methods. Also here, high-resolution, satellite-based results could be used to reconstruct sub-grid PM gradients from grid-averaged modelled PM.

In situ monitors remain an important component of global PM$_{2.5}$ monitoring, whether in direct application or in their role in evaluation of other datasets. Proper placement of monitors ensures their applicability in this role. An important research need is to identify the locations that best characterize exposure of populations in various regions for future development of in situ monitoring.

A further research task is to evaluate the relevance of the air quality estimates, based on the combination of various methods, for population exposure in different regions of the world. Various activity patterns, types of housing or other factors may influence the relation between ambient air pollution and exposure differently in different regions.

While the focus of air quality assessment on PM is well justified by the recognized health impacts of PM$_{2.5}$, development of the methods for the estimation of global population exposure to other health-relevant pollutants, such as O$_3$ or NO$_2$, should also be included in future research.

References


Lee HJ, Coull BA, Bell ML, Koutrakis P. Use of satellite-based aerosol optical depth and spatial clustering to predict ambient PM2.5 concentrations. Environ Res. 2012;118:8–15.


Appendix

Figure A1A.1: Comparison of model outputs and available ground measurements for background locations (or other locations if not available); each bar represents the percentage of the population at the specified exposure level.

Legend:
Light grey: model output for total population
Dark grey: model output for urban population only
Green: ground measurements for background stations
NB: Based on values converted to PM2.5 where PM10 data were not available; Figures in title correspond to total urban population (in percent), and percent of urban population of cities assessed by ground measurements.
India, Sear, 32, 15

Poland, EurHI, 61, 31
Annex 3. Programme

WHO Consultation

Developing a Global Platform on Air Quality and Health

Thursday, 30 January 2014

9:00 Opening: welcome, objectives of the meeting, introduction of participants, appointment of the chair and rapporteur (C. Dora)

9:20 Adoption of agenda and programme

9:30 Assessment of exposure to air pollution in the Global Burden of Disease project (M. Brauer)

10:00 Current status of WHO database on outdoor air quality (A. Pruess-Ustun)

10:30 Coffee break

11:00 Current status of methods for estimation of PM using atmospheric transport models (R. van Dingenen)

11:30 Current status of methods for estimation of PM using remote sensing from satellites (R. Martin & A. van Donkelaar)

12:00 Discussion on the scope, purpose and products of the Global Platform

12:30 Lunch break
<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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<tr>
<td>13:30</td>
<td>Presentation of international activities contributing to the global assessment of outdoor air quality by partner organizations, agencies and programmes</td>
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<tr>
<td></td>
<td>- World Meteorological Office (WMO) (L. Jalkanen)</td>
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<td></td>
<td>- United Nations Economic Commission for Europe (UNECE) (F. Ilg)</td>
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<td></td>
<td>- United Nations Environment Programme (UNEP) (H. Molin Vades)</td>
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<td></td>
<td>- United Nations Office for Outer Space Affairs (UNOOSA) (S. Chernikov)</td>
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<td>- Japan Aerospace Exploration Agency (JAXA) (T. Igarashi)</td>
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<td></td>
<td>- National Aeronautics and Space Administration (NASA) (J. Haynes – via remote connection)</td>
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<tr>
<td>15:00</td>
<td>Challenges of integration of PM estimates produced by various methods and data sources (L. Waller, G. Shaddick)</td>
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<td>15:30</td>
<td>Coffee break</td>
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<tr>
<td>16:00</td>
<td>Approaches to strengthening each of the data sources for estimation of global population exposure to PM (in 3 small groups: monitoring, modelling, remote sensing)</td>
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<tr>
<td>17:30</td>
<td>Closure of day 1</td>
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<td>18:00</td>
<td>Social event</td>
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**Friday, 31 January 2014**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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<tbody>
<tr>
<td>9:00</td>
<td>Approaches to strengthen surface monitoring data inputs to the Global Platform (proposal of the small group plus discussion)</td>
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<tr>
<td>9:45</td>
<td>Plans on the development of methods for air quality assessment based on atmospheric transport models and their inputs to the Global Platform (proposal of the small group + discussion)</td>
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</tbody>
</table>
10:30  *Coffee break*

11:00  Plans on the development of methods for air quality assessment based on remote sensing and their inputs to the global platform (proposal of the small group plus discussion)

11:45  Methods of data integration and estimation of population exposure for the Global Platform (*M. Brauer, Y. Liu* plus discussion)

13:00  *Lunch break*

14:00  Resources and organizational framework of the Global Platform (*C. Dora* plus discussion)

15:30  *Coffee break*

16:00  Follow up actions
   - Tasks of Global Platform partners
   - Timetable

17:00  Closure of the Consultation