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Toward the next generation of air quality monitoring: Particulate Matter

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HIGHLIGHTS

- Summary of particulate matter (PM) air pollution monitors, models, and indicators.
- Data variability makes global comparison of PM concentrations difficult.
- Cheaper, more durable, personal, crowd-sourced PM monitoring technologies needed.
- Improved data sharing, standards, models needed for global indicators.

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ABSTRACT

Fine particulate matter is one of the key global pollutants affecting human health. Satellite and ground-based monitoring technologies as well as chemical transport models have advanced significantly in the past 50 years, enabling improved understanding of the sources of fine particles, their chemical composition, and their effect on human and environmental health. The ability of air pollution to travel across country and geographic boundaries makes particulate matter a global problem. However, the variability in monitoring technologies and programs and poor data availability make global comparison difficult. This paper summarizes fine particle monitoring, models that integrate ground-based and satellite-based data, and communications, then recommends steps for policymakers and scientists to take to expand and improve local and global indicators of particulate matter air pollution. One of the key set of recommendations to improving global indicators is to improve data collection by basing particulate matter monitoring design and stakeholder communications on the individual country, its priorities, and its level of development, while at the same time creating global data standards for inter-country comparisons. When there are good national networks that produce consistent quality data that is shared openly, they serve as the foundation for better global understanding through data analysis, modeling, health impact studies, and communication. Additionally, new technologies and systems should be developed to expand personal air quality monitoring and participation of non-specialists in crowd-sourced data collections. Finally, support to the development and improvement of global multi-pollutant indicators of the health and economic effects of air pollution is essential to addressing improvement of air quality around the world.

1. Background and objective

Over the past century, atmospheric scientists and environmental regulators have focused on particulate matter (PM) as one of the major areas of air pollution study and pollution control. PM includes both primary particles such as soot and dust from combustion sources and agricultural practices, and secondary particles such as sulfate and nitrate that form though chemical reactions in the atmosphere from

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sulfur dioxide, nitrogen oxide, and ammonia emitted from power plants, industries, automobiles, and agriculture. The current regulatory focus is on subsets of fine particulate matter, specifically PM_{10} and $PM_{2.5}$, particles less than 10 microns and 2.5 microns in diameter, respectively. Epidemiologic research on long-term exposure to ambient fine particulate air pollution has documented serious adverse health effects, including increased mortality from chronic cardiovascular and respiratory disease, lung cancer, and adverse reproductive outcomes, with outdoor $PM_{2.5}$ estimates at causing approximately 3.1% of all disability adjusted life years worldwide (e.g., Pope et al., 2009; Lim et al., 2012). Increasingly, researchers are finding that PM chemical composition is a significant variable in its health impacts, but supporting datasets are limited (Lippmann, 2012).

Regulation and control of emissions has been enabled by advancements in PM monitoring and modeling. The ability to separate ambient PM levels into different particle sizes as well as to speciate the chemical components were major developments in monitoring technology that serve as the regulatory foundation today. These data have also been used to support chemical transport models (CTMs) that describe the formation of secondary particles and help estimate and forecast PM concentrations based on known emissions and meteorological conditions. In the past 15 years, remote sensors on satellites have expanded understanding of the spatial distribution and movement of PM, primarily by calculation of aerosol optical depth (AOD), which can serve as a surrogate for tropospheric pollution, as summarized by Hoff and Christopher (2009).

Air pollution information is communicated to the public and decisionmakers through air quality indices. These are typically based on health studies for both long-term (annual) and short-term (daily) exposure, converted from concentration to a simple unitless numerical scale and color-coded for visualization. The public may use these data to modify their behavior to reduce exposure to pollution and the regulatory decisionmakers use them to make changes in regulatory controls. Exceedance of national standards is the most common indicator communicated to policymakers.

While there have been considerable advancements, challenges remain: PM monitoring technologies and models require experienced users, satellite and ground-based data measure related but different phenomena, and data collection and indicators are inconsistent globally and does not represent actual personal exposure. The ability for air pollution to travel across geographic boundaries makes PM a global problem that would benefit from consistent indicators for global intercomparisons. Therefore, the objective of this paper is to review the current status of PM monitoring at a high-level and make recommendations to improve the links between PM monitoring, modeling, and communication in ways that better enables global participation. This paper is one of four review papers and a synthesis paper describing key aspects of air pollution monitoring and proposed research and policy topics to support improved global indicators.

2. Overview of existing monitoring and indicators

The existing infrastructure and processes for monitoring, modeling, and communicating information about particulate matter is well documented. Therefore, this section highlights only key information related to each area.

2.1. Ground-based measurements

Ground-based PM monitoring is commonly performed using either filter-based manual sampling or semi-continuous measurement using a wide range of PM monitors. Filter-based sampling is normally performed over a sampling period (usually 24 h), followed by gravimetric mass determination, to provide the mass concentration measurements for different particle size ranges such as total suspended particles (TSP), PM_{10} and $PM_{2.5}$. The mass is reported for "dry" PM, commonly at relative humidity of 35–50%. In many developing countries TSP mass is still regulated and monitored (Maggiora and López-Silva, 2006; Kim Oanh et al., 2012); while in most of developed countries TSP is collected for lead content analysis only. Monitoring for PM_{10} requires less human and laboratory resources and skills than for $PM_{2.5}$, which, combined with the lack of $PM_{2.5}$ standards in many countries, make $PM_{2.5}$ data relatively scarce outside of the U.S. and Europe. PM chemical speciation monitoring requires significant laboratory resources, thus is available in only limited networks or in short timeframe campaigns.

Real-time PM measurements provide a better insight into the temporal variations of contributing sources and secondary particle formation. Automated monitoring techniques are available to measure online mass/mass equivalent, e.g., beta attenuation monitors (BAM or β-gauge), tapered element oscillating microbalance (TEOM), among others (Chow et al., 2008). Several particle properties, i.e., light scattering and light absorption, can also be monitored online and used as the PM mass surrogate. Accordingly, simpler PM monitors such as a nephelometer can be used to estimate PM mass while an Aethalometer can be used to measure or report light absorption on a filter tape reported as black carbon mass.

National monitoring networks vary in their emphasis on TSP, PM_{10}, and $PM_{2.5}$. Where a standard permanent automatic monitoring network is available, PM_{10} (and $PM_{2.5}$ in some cases) data are generated routinely. Such networks commonly use automated PM monitoring techniques to produce online hourly PM data in many cases with co-located manual PM samplers (U.S. EPA, 2012; ECWG, 2002). In addition to urban data, monitoring at remote sites is particularly important in assessment of regional and long-range transport. However, remote sites and countries with inadequate infrastructure have significant problems related to the accessibility to the sites, to electricity and water, and to technical capacity, which results in a scarcity of data.

All ground-based measures only represent a single location, which, combined with a few other monitors in a city or region, are assumed to represent a typical exposure to pollutants. However, exposure is highly personalized, dependent on how and where an individual travels, works, cooks, and lives (O'Neill et al., 2003). Personal monitors have been used in only very small studies, with an emphasis on indoor air quality (e.g., Williams et al., 2000). Additionally, no significant effort has been made to improve spatial resolution by expanding monitoring locations by orders of magnitude to hundreds or thousands of monitors.

2.2. Satellite measurements

To provide a better overview of air pollution over large geographical areas, satellite observations can provide valuable information relevant to ground-level $PM_{2.5}$ concentrations (Martin, 2008; Hoff and Christopher, 2009). The most commonly used instruments for estimating global ground-level $PM_{2.5}$ concentrations are the Moderate Resolution Imaging Spectroradiometer (MODIS) and Multi-angle Imaging Spectroradiometer (MISR). Both instruments are onboard the Terra satellite in a sun-synchronous orbit with a 10:30 am equator crossing time. A second MODIS instrument is onboard Aqua satellite with a 1:30 pm equator crossing time. Both instruments offer retrievals of aerosol optical depth (AOD; a measure of extinction of radiation by aerosols in the entire atmospheric column) for cloud-free and snow-free conditions (Levy et al., 2013). The spatial resolution of operational AOD retrievals is typically about 10 km × 10 km for MODIS and 18 km × 18 km for MISR. A 3 km MODIS AOD product recently