Simple Interactive Models for Better Air Quality

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Ten Frequently Asked Questions about Particulate Matter

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FAQ'S

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Ten Frequently Asked Questions about Particulate Pollution

Particulate matter (PM), among many pollutants is the most talked about pollutant and probably the main indicator to human health in urban centers. Among the other pollutants, noteworthy ones are the sulfur dioxide, nitrogen oxides, carbon monoxide, hydrocarbons, especially the polycyclic aromatic hydrocarbons, and ozone.

From a regulatory perspective, PM is studied, measured, and monitored the most for multiple reasons. Such as, being the critical pollutant for health concerns (asthma, breathing troubles, eye irritation, etc), being a critical ingredient to a visual form of pollution (smog) leading to visibility issues, and commonly the most visual pollutant out a chimney (often in the form of black soot).

World Health Organization (WHO)[1] estimated that urban air pollution from PM accounts for ~800,000 deaths annually and the burden occurs primarily in developing countries[2].

It is important that we understand more about the pollutant that concerns the most (sources, strengths, and weakness) to formulate rational, effective policies, and make informed investment decisions related to air quality improvements[3].

The focus of this paper is to put forward some basic theory behind this pollutant. Note that the details are provided for individual topics in other working papers.

The **Ten Frequently Asked Questions (FAQs)** discussed in this paper are

1. Primary vs. Secondary?
2. What to monitor?
3. Emissions Inventory?
4. What is Source Apportionment?
5. Is Transport the main culprit?
6. Is PM the most harmful?
7. Dispersion Modeling?
8. Indoor vs. Outdoor?
9. Local vs. Global?
10. Where do we start?

[1] WHO challenges world to improve air quality – www.who.int/mediacentre/news/releases/2006/pr52/en
[2] Comparative Quantification of Health Risks - http://www.who.int/publications/cra/en/
[3] SIM Series 2008-003 "Informed Decision Support for AQM in Developing Cities" @ http://www.urbanemissions.info/simair

1. Primary vs. Secondary?

PM pollution is a mix of primary and secondary sources.

By definition, primary pollution, is a direct emission source and forms a significant portion of the PM pollution, in the form of soot from the coal and diesel burning, also known as black carbon. A good portion of these emissions is also called organic carbon. Besides the carbon, the primary PM emissions also include metals in various forms. For example, the metals in coal, after combustion get vented through a chimney, along with a multitude of other pollutants.

Other primary pollutants include sulfur dioxide, nitrogen oxides, volatile hydrocarbons, methane, carbon monoxide, and carbon dioxide.

The secondary pollution is due to chemical transformation of the primary emissions. In case of PM, the secondary components include sulfates from sulfur dioxide emissions, nitrates from nitrogen oxide emissions, and organic aerosols from hydrocarbon emissions. The path and the quantity of chemical transformationation depend not only on the strength of the pollutant emissions, but also on their mix. In an atmospheric chemical mechanism, the number of interlinkages can run as long as 300 equations (among the known studies).

Most of the secondary pollutants, sulfates, nitrates, and secondary organic aerosols, form part of the fine PM ($PM_{2.5}$).

Other secondary pollutants include ozone.

A primary source, which is not a direct product of combustion activities, but dependent on the combustion activities, is re-suspension of the dust. Along the corridors, depending on the silt loading, the road dust is known problem. This emission, though a primary source, depends on the local conditions –vehicular activity, relative humidity in the air to support the re-suspension and the silt loading on the roads.

In a measured sample of PM, the secondary pollution is known to form a significant portion of the fine PM, which is a vital indicator for health impacts. Hence, any decision to control PM pollution needs to be a multi-pollutant strategy, in order to maximize the cost-effectiveness of the measures.

2. What to Monitor?

PM is generally measured in terms of the mass concentration of particles within certain size classes:

- Total suspended particulates (TSP, with aerodynamic diameter <~30 microns (μm)
- PM_{10} (with an aerodynamic diameter of less than 10 μm, also referred to as **coarse**)
- $PM_{2.5}$ (with an aerodynamic diameter of less than 2.5 μm, also referred to as **fine**)
- Ultrafine PM are those with a diameter of less than 0.1 micron

These size distinctions result because coarse and fine particles come from different sources or formation mechanisms, which lead to variation in composition and properties. The range of sizes also affects the atmospheric lifetime, spatial distribution, indoor-outdoor ratios, temporal variability, and health impacts of particles.

To date, most measurements are conducted for PM_{10} and most of the developing country cities still monitor PM_{10} as an indicator. Slowly, with the growing knowledge on the higher importance of $PM_{2.5}$ and finer fractions on human health, the new regulations are prescribing a focus change and make the $PM_{2.5}$ the new criteria indicator.

What to monitor is a tricky question. Depending on the purpose of the experiment, the monitoring equipment and the monitoring scales change. For example, for a regulatory body, it is important to know the ambient levels of criteria pollutants only, at various designated locations, along with some meteorological parameters. However, for a research body, it is important to measure more than the criteria pollutants, to better understand the chemical mechanisms leading up to the measured ambient levels and also to study the evolution of the pollution.

What to monitor also depends on the financial status of the city or concerned institution. It is important that as many monitoring stations are established as possible, to better map the city or the area of interest, for each of the pollutant in concern, and this is highly dependent on the local institutional capacity, not only from procuring it, but also to operate and maintain the same.

Since the PM pollution is of the concern for most of the growing cities, effort should be made to monitor the same. With the growing advances in technology, there is a wide array of monitors, in size, precision, and cost, available to the users, and an informed decision will help make the most of what is available.

3. Emissions Inventory?

This is one of the most important and difficult tasks, although the equation that derives the emissions inventory is quite straight forward; Emissions = Activity * Emission Factors; for the direct emissions.

The activity is in terms of the fuel consumed by various types and the emission factor is defined as the amount of pollutant released upon fuel combustion, which depends on the fuel quality, combustion technology, and pollution control efficiency. The level of uncertainty in the definition and the data available on these emission factors is high, but not an impossible task to better understand the same.

Ideally, any institution concerned about the PM pollution, is expected to have an emissions inventory, but due to inherent challenges in collecting the necessary data, disclosure issues with the industries or handling agencies, or lack of institutional and technical capability to handle the knowledge base, leads to an incomplete or inconsistent emissions inventory.

While a detailed emissions inventory covering all possible sources is desired, it is important that an effort is put in place to start the process of establishing the same, even if it means starting with averages, gross consumption levels, and borrowed factors.

Most often, the non-existence of an emissions inventory is primarily due to the lack of this first step and waiting to develop 100 percent capacity, before a preliminary estimate is made, delays the institutional capacity building aspect.

As much as it is important to establish a baseline, it is also important to acknowledge the uncertainty of the factors in use. If average numbers from similar experiments in a different city or nation are being used, that should be noted and when the local capacity is developed to study more, the factors should be corrected for the local numbers. This is a “learning while building” exercise and only by establishing a baseline with what is available that what is lacking and how to improve is better understood.

4. What is Source Apportionment?

By definition, this is the process of estimating the contribution of various sources to the pollution. It is important to keep in mind two concepts.

One method is via an emissions inventory. Once an emissions inventory is established, through a series of surveys, data collection, and multiplication of emission factors, for each of the sectors involved and for the indirect sources such as fugitive emissions, one could arrive at the proportions of contribution of each of the sectors to each of the pollutants.

Second method is via the ambient concentrations. Let's assume the PM measured at various hot spots in the city, the samples are then analyzed for the chemical composition, which are then regressed through the profiles for various sources, to arrive at a series of numbers estimating the possible contribution of the known sources.

It is very IMPORTANT to understand that the two methods are different and the numbers they indicate are different, although they are talking about the same PM pollution.

1. The emissions are not same as ambient concentrations.
2. The contributions estimated from emissions need not be the same as the contributions estimated via the ambient measurements.
3. The emissions inventory is usually for the whole of the city or the area of interest, while the later method represents more of the measurement area features.

The emissions undergo advection and chemical transformation, before they appear as a sample measured for the ambient concentrations.

The long range transport plays a key role in the advection scheme, as the tall sources (industries) tend to disperse farther than the roadside emissions and hence the difference in their signatures in the contribution calculations.

When discussing the emissions inventory, each of the pollutants is discussed separately (such as PM, SO_2, NO_x, CO, etc.) and it is important that the pollutants are NOT added to average the contribution – each of them have a role to play. Whereas, the contribution estimates from PM ambient sampling, is a combination of all the pollutants and sources – primary and secondary.

None the less, both the top-down (ambient) and bottom-up (emissions) methods are very important (and essential) to understand the strength of the sources and their potential to control.

If health impacts are the deciding factors, then the ambient contributions (from the second method discussed above or following the dispersion modeling of emissions) are the most important.

5. Is Transport the Main Culprit?

A common question with a difficult answer of "it depends". Yes, the transport is growing rapidly in most of the developing country cities and the quotient its contribution to local and global air pollution problems is also increasing significantly. Yet, the answer lies in the mathematics of the points raised in the earlier questions.

On one side, the visibility of the growing sector creates an atmospheric cloud that multiples its contribution. Since the people are spending more time on the roads, because of traveling or due to sitting in a congestion zone, tend to experience the most and in such situations, the contribution of transport seem like the main culprit.

Yes, along the main corridors of the major cities, the contribution of the transport sector is the main culprit. However, city as a whole, it is important that a holistic picture and understanding of the sources (including the domestic and industrial) is established before a decision is made on the contribution (source apportionment).

For example, during the Olympics, the city of Beijing, did not achieve the reductions in the air pollution levels by cutting the vehicular fleet by half for the games period. They were able to achieve this reduction in conjunction with closing down a number of small and large industrial sites in the city.

Now, the long range transport plays a critical role. The transport emissions are ground based and tend to increase the local concentrations significantly. However, the industrial sector contributes farther distances. And for pollutants like sulfur dioxide, the transport quotient is even higher and this was also evident in Beijing during the games. A series of measures, based on the modeling studies, resulted in closing down of industries in the neighboring cities, to achieve the necessary air pollution reductions during the Olympic Games.

So, transport is an important culprit, but not necessarily the main culprit at all times.

Another example is Delhi. In 2001-02, while the bus fleet was being converted from diesel to CNG, a major intervention in the industrial sector was to relocate a significant number of smelters out of the city limits, which resulted in significant reductions. However, all the reduction are wiped out due to large increase in the car population; different story !!

6. Is PM the most Harmful?

Similar to the previous question, there is no direct answer for this question.

The new research on the fine PM, ultrafine PM, and nano PM suggest that the impact of the PM particulates on human health is underestimated. The complexity in pointing out a single source or a single pollutant is primarily due to the inter-independencies and the chemical mechanisms involved in the formation of the PM, which combines the properties of most of the criteria pollutants.

While the dose response functions give an indication of the possible impacts of PM pollution, there is more, in terms of smog (visibility impacts), linkages to ozone pollution and agricultural yield, and impact of aerosols on climate change (and inherent impacts of local and global environment).

7. Dispersion Modeling?

The importance of the dispersion modeling, the effect of the long range transport of various pollutants along with their possible chemical transformation was briefly discussed earlier. Similar to the emissions inventory development, the dispersion modeling is also an intense exercise, which requires both computational power (nowadays, which is not a problem) and the data assimilation.

The modeling systems are plenty, with varying capacity and complexity. However, selection of the modeling system should be based on the objective of the program and institutional strength to absorb the analytical challenges.

The table below provides a general understanding of the types of the models available and the level of possible complexity with the handling of physical and chemical mechanisms.

	Box	Plume	Eulerian
Complexity	*	**	****
Data requirement	*	**	****
Pollutant chemistry	*	**	****
Advection of pollutants		**	****
Ease of operations	****	**	*
Computational requirements	*	**	****
Results – level of detail	*	**	****

8. Indoor vs. Outdoor?

Worldwide, in the rural areas, the indoor air pollution is a predominant problem, especially with the women and children, who tend to spend more time in the homes.

While the discussion here is around the outdoor PM air pollution, one cannot ignore the contribution of the domestic sector and the amount (and kind) of fuel combusted in this sector for cooking and heating.

The importance of the indoor air pollution, where the concentrations measured a order higher than the outdoor air pollution, lies with the health as a primary indicator, more so than the outdoor air pollution.

The contribution of indoor activities can be significant, but depends on the geography. For example, in the countries like Mongolia or northern China, due to their inherent climatic conditions, the stoves form a major part of the fuel combustion cycle and contribute significantly to the outdoor air pollution.

In the urban centers, the small scale restaurants can be considered as a source.

9. Local vs. Global?

While health effects drive most of the PM pollution concern, PM also affects regional and global atmospheric chemistry and the radiation balance[4]. Aerosol particles scatter and absorb solar radiation, and also alter the formation of cloud droplets. These physical interactions change the earth's radiation balance, affecting local and global temperatures and possibly precipitation.

The Aerosols (PM) and ozone that are usually considered only in the air quality domain, also affect climate change. The understanding of the impact of aerosols on the climate system and how to evaluate this impact for policy relevant issues is very low. Research continues to assess the effects of many different types of aerosols on climate under different conditions[5].

PM pollution can also impact visibility in urban centers. Mountains or buildings once in plain sight can suddenly be blocked from view. Air pollution that reduces visibility is often called haze or smog[6] [7].

The term smog originally meant a mixture of smoke and fog in the air, but today it refers to any visible mixture of air pollution. The incidents of haze and smog in cities are increasing, which typically starts in cities and travels with the wind to appear in the more remote areas.

One consequence of smog over any given area is that it can change the area's climate. Certain dark particles, such as carbon, absorb solar radiation and scatter sunlight, helping produce the characteristic haze that is filling the skies over the world's megacities and reducing visibility.

[4] Role Of Aerosols In Climate Change Examined @ http://www.sciencedaily.com/releases/2008/09/080905153801.htm

[5] Menon, S.; Hansen, J.E.; Nazarenko, L.; and Luo, Y. (2002). "Climate effects of black carbon aerosols in China and India." Science, 297(5590):2250-2252;
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[6] Chemists Find New Important Contributor To Urban Smog @ http://www.sciencedaily.com/releases/2008/03/080320150032.htm

[7] Watson, J.G. (2002) "Visibility: Science and regulation." J. Air Waste Manage. Assoc. 52(6):628-713.

10. Where do we start?

The first step in PM pollution modeling is to collate the existing knowledge base.

This includes information about stakeholders, especially ones that could provide rich sources of information such as environmental agencies, NGOs, universities, research institutes, traffic-related departments, and important point source emitters.

The knowledge base would primarily focus on:

- Pollutants of interest
- Primary emission sources
- Emission characteristics
- Air quality (historical and current monitoring data)
- Health impacts (e.g. any local epidemiological study results)
- Characteristics of technical and policy options/scenarios to be considered.