Air Quality in Harrisburg

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***Abstract*—The city of Harrisburg, PA has seen remarkable progress in air quality in the last two decades, welcome progress as research shows increasingly strong correlation between pollution and health. Fine particulate matter, or PM_{10}, is one of the pollutants monitored in the Clean Air Act and is one of the most detrimental pollutants to long term health. An analysis of EPA data and meteorological data indicates that the two largest sources of PM_{10} near the citys air quality monitoring site are the Susquehanna Resource Management Complex and the Brunner Island power plant. Gaussian dispersion modelling indicates that these sources likely each contribute a majority of the measured pollutants for specific meteorological conditions, indicating that they are likely responsible for at least part of the historical increase in air quality, and may present compelling targets for further emissions reductions.**

I. Introduction

Air quality has become more of a prevalent concern, especially in the United States, as research shows increasingly strong correlation between pollution and health. The Environmental Protection Agency has been observing the constant stream of studies to adjust the national air quality standards through the Clean Air Act, focusing primarily on the six common pollutants: ground level ozone, particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, and lead. The most recent policy update was in 2015.

Fine particulate matter, PM_{10}, is one the biggest perpetrator of long-term disease and illness, seeing as it is small enough to cross into the bloodstream and through the blood-brain barrier. Various long term studies show that PM exposure increases the likelihood of developing cardiovascular mortality, cardiovascular risk, chronic inflammatory lung injury, and atherosclerosis., Short term exposure also results in increased cardiovascular mortality and hospital admissions, stroke mortality and hospital admissions, myocardial infarction, pulmonary inflammation, altered cardiac autonomic function, and many other illnesses [1], [2]. All of these effects from ultrafine particles combined result in about 500,000 deaths per year [2]. PM_{10} is currently regulated at $12.0\frac{\mu g}{m^3}$ per year of primary emissions, $15.0\frac{\mu g}{m^3}$ per year of secondary emissions and $35\frac{\mu g}{m^3}$ per day of primary and secondary emissions.

Ozone is another air pollutant that has major health risks. This pollutant decreases respiratory functions and increases the likelihood of both cardiovascular and respiratory deaths, especially in the hotter months when there is greater concentration in the air [3]. Ozone is currently regulated at $0.070ppm$ per 8 hours of primary and secondary emissions.

As both the capital of Pennsylvania and a historically industrial city, Harrisburg offers the perfect opportunity to improve the health outcomes of Pennsylvania citizens and set an example for the rest of the state through targeted and intelligent policies to decrease harmful air pollution.

The geographical location of Harrisburg on the Susquehanna river has also contributed to the industrial activity that historically characterized the city from the middle of the 19th century through the middle of the 20th century [4]. This industrialization consisted initially of (primarily) iron and steel production, which produces large quantities of atmospheric pollutants CO, NO2, and SO2 [5].

Our primary concern for the air over Harrisburg, PA is the production of particulate matter. This class of pollutant applies to microscopic clumps of solid and liquid chemicals which we further classify by size into $PM_{2.5}$ and PM_{10}. PM_{10} includes inhalable particulate under 10 micrometers in diameter while $PM_{2.5}$ includes finer particulate under 2.5 micrometers which can be detected only with the use of an electron microscope. Both classes are known to be detrimental to human health as our physiology has no mechanism for removing the pollutants once they have entered the lungs, exacerbating symptoms in asthmatic patients [6]. Especially dangerous are microparticulates, the most fine of particles in the $PM_{2.5}$ range, which infiltrate the bloodstream and have been found to interfere with gene expression [7]. These fine particulates are generated in a variety of places including construction sites, smokestacks, car engines, and especially the diesel engines in commercial vehicles. Fine PM can also form in the atmosphere from reactant chemicals like sulfur dioxide and nitrogen oxides which are also emitted from vehicles and industrial and power plants. $PM_{2.5}$ often becomes visible to the naked eye in moderate concentrations as one of the predominant

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contributors to the ”haze” over any large city, and has been estimated by the World Health Organization to have caused 3 million deaths globally in the year 2012 [8]. While Harrisburg and Dauphin county are currently in attainment with the Environmental Protection Agency's guidelines around particulate matter, they have a history of over-production and we anticipate more stringent EPA regulations in the near future as national regulation catch up with WHO guidelines, which are currently 28% and 66% more strict than those of the EPA for $PM_{2.5}$ and PM_{10} respectively [9].

II. Methods

We performed an analysis of pollutant concentration data collected by the Pennsylvania Department of Environmental Protection and reported to the Environmental Protection Agency at an Air Quality Monitoring site in the southern section of Harrisburg, along Bobali Dr. The site is located 0.76 miles Northeast of the Susquehanna river, which flows through Harrisburg and the mountains to the North (Figure 1).

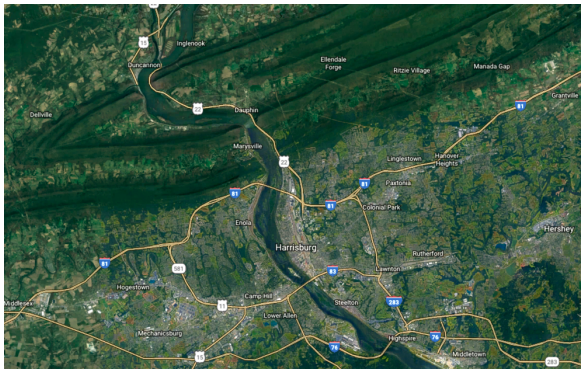

Fig. 1. Geographical map of Harrisburg showing the Susquehanna River running through the city and Appalachian Mountains to the north

Based on the heavily industrialized history of Harrisburg and historical attainment information from the EPA, we selected PM_{10} as the primary pollutant to focus our analysis on, with some analysis steps also using $PM_{2.5}$ data. Current major industrial sources of PM_{10} and $PM_{2.5}$ that surround the monitoring site can be found in Table I.

The data received by the air quality monitoring site was used to examine PM_{10} levels from 2001 through 2011, the longest stretch of contiguous years with complete data. Having done so, we inspected the annual mean PM_{10} levels for each year, as shown in Figure 2. In order to gain more visibility into specific sources of the particulate matter, we also analyzed diurnal concentration cycles, as computed by clustering measured data by hour of the day, then averaging through a specific year (Figure 4).

In order to further investigate specific sources of the measured pollutants, we augmented the data set with meteorological data from the nearby Capital City Airport, which is located a short distance southwest of our measurement site. In cases where wind data was unavailable for the exact time at which pollutant concentration data was taken, we linearly interpolated the nearest available wind vector measurements.

To inspect specific sources, we used Gaussian Dispersion Modelling to predict the concentration of pollutant we expect downwind from each site, based on prevailing winds and atmospheric stability (Figures 5 and 6). We compare those predicted concentrations to observed concentrations, allowing us to analyze which specific pollutant sources likely contributed directly to the long-term trends seen earlier in the analysis.

III. Results and Analysis

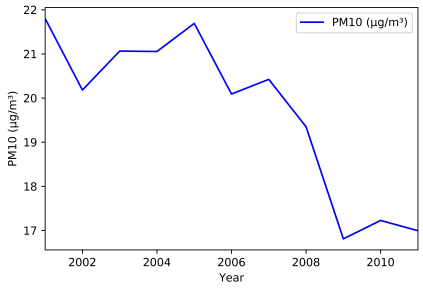

Fig. 2. Average annual concentration of PM_{10}, measured from 2001-2011

Using the largest continuous block of years of available PM_{10} data (Jan 1 2001 - December 31 2011), Figure 2 plots the mean annual PM_{10} concentrations. It shows that PM_{10} concentration in Harrisburg decreased during the duration of the study from $22\frac{\mu g}{m^3}$ in 2001 to $17\frac{\mu g}{m^3}$ in 2011, with the biggest decrease between 2008 and 2009. An explanation behind this drastic change in emissions could be the change in politicians. Mayor Stephen Reed had been the mayor for 30 years, 1981 to mid-2009, and was arrested on corruption charges for not properly allocating or managing resources, misplacing audits, and conducting convoluted transactions, including swap agreements. This raises the question of whether or not pollution emissions from generators and factories in Harrisburg were adhering to regulations that correlate to the concentrations displayed in the graph, as will be discussed later in the analysis.

In order to further understand the character of PM_{10} concentrations, we analyzed the diurnal cycle of PM_{10}

TABLE I. MAJOR PM_{10} AND $PM_{2.5}$ SOURCES NEAR SITE

Source name	Source Type	PM_{10} (tons/yr)	$PM_{2.5}$ (tons/yr)	Distance from Site
STEELTON LLC	Steel Plant	29	27	1.4 miles SSW
SUSQ RESOURCE MGMT COMPLEX	Municipal Waste Combustor	30	28	0.4 miles West
BRUNNER ISLAND	Electricity Generation	1548	753	13 miles SW
NRG ENERGY CTR PAXTON	Steam regional heating plant	6.43	6.41	2 miles NW

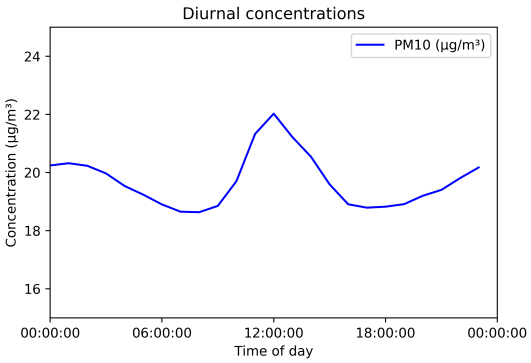

Fig. 3. Diurnal cycle of PM_{10} concentration, averaged over 2001-2011

averaged over the entire data set. Figure 3 shows that PM_{10} concentrations remain nearly steady at $19\frac{\mu g}{m^3}$ for most of the day, with the notable exception of a sharp spike in concentrations beginning at 10:00am, peaking near $23\frac{\mu g}{m^3}$ at noon.

Because this peak is so well-defined and consistent, we believe that it reflects a specific industrial source in conjunction with meteorological effects. As such, the most likely explanation for this peak is a single large particulate matter plume that is pushed towards the air monitoring site when the wind pattern shifts throughout the day.

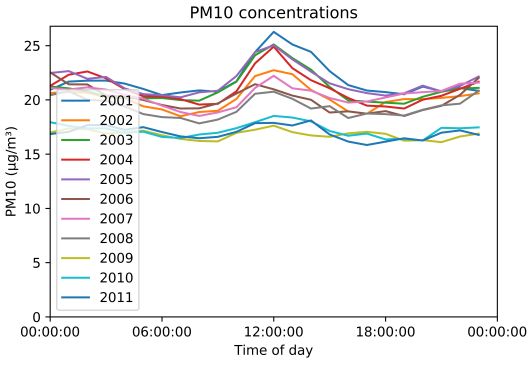

Fig. 4. Diurnal cycle of PM_{10} concentration for each year between 2001 and 2011.

Figure 4 displays the PM_{10} measurements taken throughout a whole year averaged into a diurnal cycle. Each year is represented with its own curve spanning from 2001 to 2011. As expected from Figure 2, overall concentrations decrease during the duration of the study. Additionally, PM_{10} concentrations peak at noon, in every year studied. However, in the earliest years of the study, the magnitude of that peak is more dramatic than that seen in Figure 3, increasing by approximately $6\ \frac{\mu g}{m^3}$ between 9:00am and noon in 2001. In the later years of the study, the peak nearly disappears, representing an enhancement over the baseline of only $2\ \frac{\mu g}{m^3}$ during 2011.

We hypothesize that this decrease in intensity of the midday peak, particularly in the period of 2006-2009, indicates the substantial decrease or effective emission regulations of a single large emissions point source, likely industrial in nature. Because prevailing wind direction changes during the course of the day for natural reasons, decreased emissions a large source near the measurement site could account for both the decrease in intensity of the peak, as well as some of the decrease in overall average levels.

In order to further investigate this source, we infused wind data from the Capital City Airport to understand the directions from which wind was blowing during times with high concentrations of PM_{10}. As seen in Figures 5 and 6, the pollution concentrations are substantially higher when the wind is blowing straight from the west, averaging approximately $15\frac{\mu g}{m^3}$.

The concentrations from the West are substantially higher in the early years of the data (Figure 5), and decrease disproportionately by the later years of the data (Figure 6). This leads us to believe that a significant proportion of the observed pollution levels decrease is due to reduction in PM_{10} emitted straight to the west of the site. As indicated in Table I, the SRMC incinerator complex is a likely source of these pollutants, as we will investigate further below.

Additionally, Figures 5 and 6 indicate that winds from the south, although rare, also bring high PM_{10} levels to the monitoring site, averaging approximately $22\frac{\mu g}{m^3}$. The most likely source of these pollutant concentrations is the Brunner Island coal power plant.

To understand the contribution of these sources to the measured pollution concentrations at the site, we conducted a Gaussian dispersion analysis using point

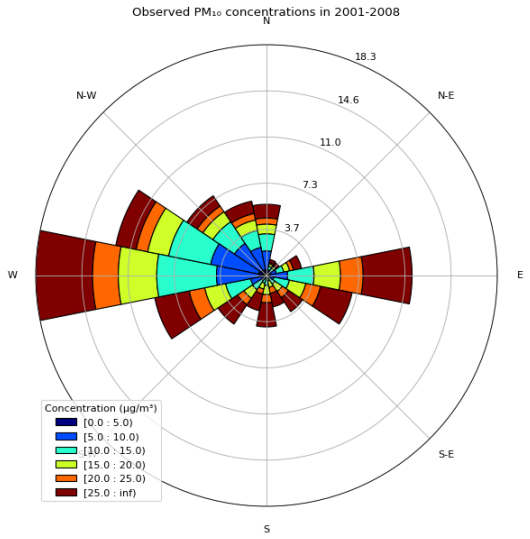

Fig. 5. Pollution levels as a function of prevailing wind speeds, between 2001 and 2008. Notice the substantially higher pollution concentrations when the wind is coming from the West, Southwest, and South, compared to the Northwest and North.

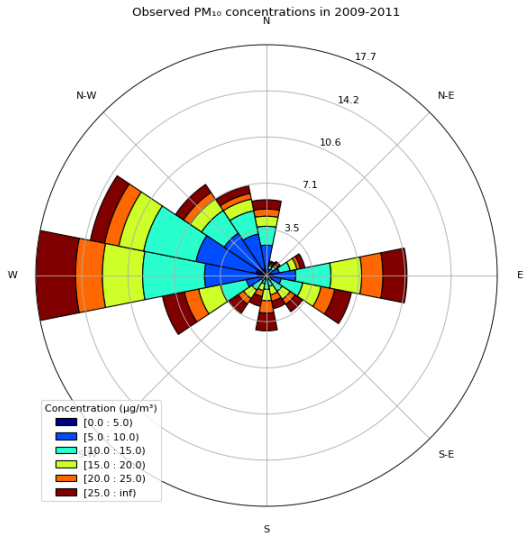

Fig. 6. Pollution levels as a function of prevailing wind speeds, between 2009 and 2011. Notice the overall decrease in concentrations, as well as the significant drop in high-concentrations from the west.

source emission data from Table I and wind speed data averaged over all measurements with the given source direction. Figure 7 shows the resulting plume shape from the incinerator on a day with stability class C, typical of a summer day in the Harrisburg area. Maximum concentrations at the site reach $12\frac{\mu g}{m^3}$, very close to the $15\frac{\mu g}{m^3}$ measured in air from the west. This indicates that PM_{10} emissions from the incinerator site likely comprise a significant fraction of the ground-level pollutant concentration observed when wind is coming from the west.

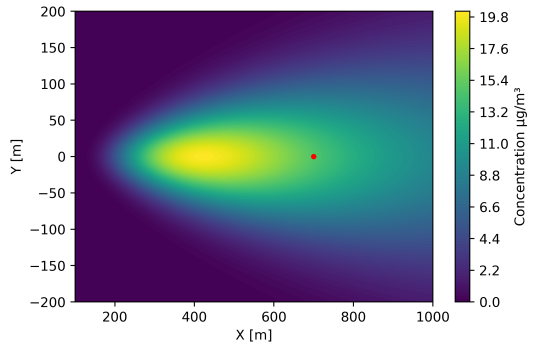

Fig. 7. Gaussian dispersion model of particulate distribution from SRMC incinerator. The red dot indicates the distance of the measurement site.

Similarly, Figure 8 shows the dispersion plume from the Brunner Island coal power plant with a typical wind blowing north and class C stability. This model indicates that peak concentrations at the measurement site should be $18\frac{\mu g}{m^3}$, which represents a substantial fraction of the $22\frac{\mu g}{m^3}$ observed in available data. This indicates that the Brunner Island power plant, even though it is located several miles outside of Harrisburg, can still account for a significant fraction of the pollution in the city on days with particularly unlucky meteorological conditions.

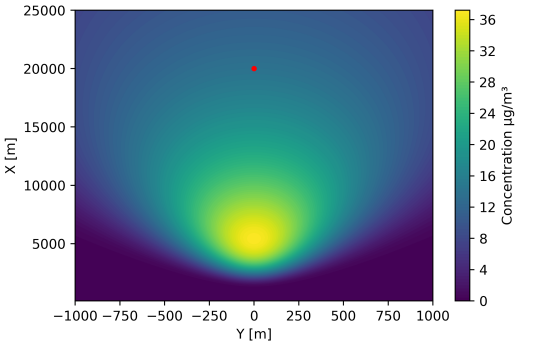

Fig. 8. Gaussian dispersion model of particulate distribution from the Brunner Island coal power plant. The red dot indicates the distance of the measurement site.

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