The Difference of Point Source Pollution in the Atmosphere from Different Sources

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***Abstract*—In this project, I use different models to analyze the difference in areas of point source pollution. The idea is that different point air pollution affect the problem of pollution in different ways. A flue stack and a car exhaust are a part of the same problem but affect it differently. The differences this project is going to focus on are the basic differences of how they diffuse into the atmosphere and where it is diffusing into the atmosphere.**

To do this, I have mainly focused on the Gaussian Plume Model and the PUFF model. The Gaussian Plume Model is good for getting a statistical evaluation on a maximum and minimum of pollution plume oscillation. This is good for getting a measurement for how pollution can move outwards from the point and what space is it diffusing into as it does so. The PUFF model looks at the advection in the x, y, and z direction of the particle being affected by a force. The PUFF model usually accounts for the wind force of these advection forces. Here I use this idea to look at these wind advection forces on the pollution particles. To do this modeling, I have chosen both Python and R programming languages.

***Index Terms*—Gaussian, PUFF, Advection, Dispersion, Pasquill-Gifford**

I. Background

As I started this research, my intention was to take the most preferred models used by the EPA and use them to compare different pollution sources to each other. However, as I learned more about AEROMOD and CALPUFF (two of the more preferred models), I started to realize there were many theories and calculations that made these models precise which may not be appreciated, or in my case noticed, by an amateur like myself. The takeaway was that I needed to build up to those models. Given the short period I had to do this research and modeling in, I needed to look at the basics of which those two models were based off of. The model in which most pollution models are based on was a model called the Gaussian Plume Model. The other model I focused on was one that took wind data in order to show its affect on particles was the PUFF model. In this section I'll explain a bit about both of these.

A. Gaussian Plume Model

The Gaussian Plume Model is a model that uses Gaussian distributions in a 3D space in order to predict the area of which a plume can diverge to as wind pushes it from the point source. This is a classical method of measuring plume dispersion that most models are either based on or related to in some manner. There are a few variations to this formula based on the theory you choose to use. The one that has the most pertinence here is: $C(x,y,z) = \frac{Q}{2\pi u\sigma_y\sigma_z}\exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right)+\exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right]$. For the most part, I won't really be referring to this formula much because there are tool-kits to handle this calculation. This formula can be visualized in the following diagram to understand what it is measuring:

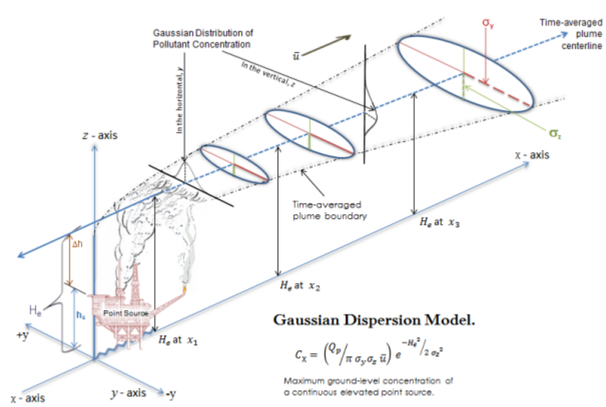

Fig. 1. A Gaussian Plume Model Diagram.

While this is a very complex equation to model, there are some optimizations and simplifications to make the results very attainable and in the end we can parameterize the model to the variables: Source Emission Rate, Source Height, Wind speed, Pasquill-Gifford Value, and Diameter of source. The big secret behind this is in understanding the Pasquill-Gifford scale also known as the Pasquill stability class. This is a method of categorizing the stability of a region of the atmosphere in terms of the horizontal surface wind, the amount of solar radiation, and the fractional cloud cover. A version of this table looks like this:

Table 1. Pasquill stability classification scheme

Wind speed at 10 m ($m\ s^{-1}$)	Insolation			Night	
	Strong	Moderate	Slight	Thinly overcast or $\geqslant 4/8$ low cloud	$\leqslant 3/8$ cloud
< 2	A	A–B	B	—	—
2–3	A–B	B	C	E	F
3–5	B	B–C	C	D	E
5–6	C	C–D	D	D	D
> 6	C	D	D	D	D

Fig. 2. Pasquill Stability Class Diagram.

In the models I use today, we assume a certain amount of wind near an average of 3-5 mph and moderate conditions, which we define at the value of "C". This is correlated into the σ values in the equation. This is extremely useful for making this model accessible. The rest of the values in the equation can be interpreted from the parameterized values using sigma values based off these stability grades.

B. PUFF Model

The PUFF model is another popular weather and pollution model to measure how particles are traced in the atmosphere using 4-Dimensional Wind data. These 4 dimensions are Time, Altitude, Longitude, and Latitude for the x-value, y-value, and z-value of the entire wind vector. These are usually attained from .NC values that the National Oceanic and Atmospheric Administration (NOAA.gov) has available to download. This data is measured on a Gaussian grid of the Earth with 10m in between each wind vector. This data has been collected since 1977 and is still being collected to this day. It is a very expansive data set for many purposes, however there are a few problems I will cover in the discussion portion.

This Model is a Lagrangian modeling type for the simulation of atmospheric pollution dispersion. This type of model is what the preferred model CALPUFF is based on, which is a preferred model for assessing long range transport of pollutants and their impacts on Federal Class I areas and on a case-by-case basis for certain near-field applications involving complex meteorological conditions (Stated by Exponent Engineering and Scientific Consultancy). However, CALPUFF uses the full data set for a large scale watch on landmasses and air masses crossing those landmasses. In this case, the PUFF model is being used to simulate very small scale areas.

In it's original form; the factors taken into consideration are dispersion, settling, and advection terms. The process is that the particles will first disperse, then settle due to gravity and particle weight in the atmosphere, and then wind advection will move the particles. In the advection step, interpolation is used to calculate how the particles move in between the 10m spaced Gaussian wind values. In large scale pollution or meteorological models, this works perfectly fine. In my small scale models, this introduces a certain amount of unchangeable error.

II. METHOD

Initially, my plan was to use Python to do all the coding in order to have one document with all coding on it. However, I found that there were certain methods better suited for Python and others better suited for R. with that in mind, in this section I'll explain my reasoning for the methods I chose.

A. Python Modeling

When I narrowed down my goals to PUFF and Gaussian Plume Modeling, I was really excited in making a PUFF model. I could only find one example of this done in a language I knew which made it very difficult. I found one blog like website made by a student at the University of Illinois back in 2015 in which they made a PUFF model for a volcano. The student, who is now a graduate, is named Jeffrey Kwong. I contacted him and asked him about some of his model, and he responded linking me with some of the work he did on it. After studying his model and understanding how the variables and calculations worked with each other; I updated the functions to newer Python syntax, developed a few definitions I needed to place the point sources where I needed them, and adapted the calculations to my smaller scale model.

B. R Modeling

While I was researching different Plume modeling methods, I came across a few methods that didn't have the accessibility I was looking for. I finally came across an R package named "Plume" made by David Holstius from University of California, Berkeley. While I initially wanted to use all python code for this project, the suite of tools in this package was exactly what I needed to easily set up my variables. It also introduced me to how wind speed and the Pasquill-Gifford scale (also known as the Pasquill scale) worked with each other. While using other coding options might have let me edit the underlying code a bit more, I did not necessarily need to do that with this package so it was my optimal choice. The only down side was that 3D modeling of the plume was not going to be possible and only a Birdseye view of the process was attainable. However with the PUFF model handling the 3D aspect, I felt that the upper hand of having optimal calculations and access to altering parameters was key to getting a rounded model perspective in this project.

III. RESULTS

In this section I'll go over the resulting models that I have made in both Python and R. These are output .PNG's of the models I made. Note: The PUFF model was originally a moving .GIF file but there were problems trying to paste one onto a document PDF.

A. Gaussian Plume Model

The following parameters were used to make the Gaussian Plume Model for the point source of a car:

Source emission rate - 24.6861 g/s

Source height – 5 m (Based on length of car exhaust pipe)

Wind speed – 4.23 (m/s)

Pasquill Value – ‘C’

Diameter - 0.0762 m (tail pipe diameter)

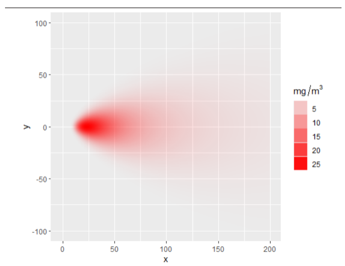

Fig. 3. The Gaussian Plume Model of a Car’s Exhaust.

The following parameters were used to make the Gaussian Plume Model for the point source of a Fluestack/Chimney:

Source emission rate – 297.51 g/s

Source height – 420 m (Based on Example)

Wind speed – 4.23 (m/s)

Pasquill Value – ‘C’

Diameter - 30 m (Chimney Diameter)

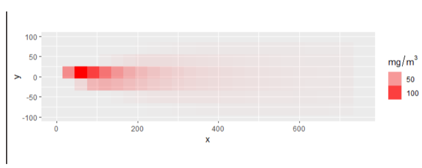

Fig. 4. The Gaussian Plume Model of a Chimney’s Plume.

The results obtained in these two models match expected values. We expect the car’s output to be between $18\frac{mg}{m^3}$ to $40\frac{mg}{m^3}$. Seeing the simulated value come out to $25\frac{mg}{m^3}$ and only spread at most to 200 meters falls within reasonable results. While the deep red makes the results look very thick, it is fairly accurate to the density it would be numerically. For the Chimney mode, the results are in a believable range. My only concern is not having more on the scale to interpret the lighter color density. However, with the output provided, the results look viable and accurate. The higher dispersion on the x axis than the y axis shows that it is a pretty stable output compared to the car.

B. PUFF Model

1) Point Pollutant: Car: In this figure, we have a car that is about .2 meters off of the ground. The point source is oriented in a horizontal fashion. The wind data described earlier is applied here.

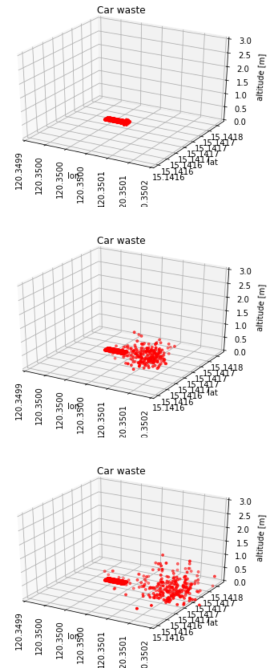

Fig. 5. The PUFF Model of a Car’s Exhaust.

2) Point Pollutant: Chimney/fluestack: In this figure, the we have a power plant chimney (which is called a flue stack) placed about 420 meters high. The point source is vertical fashion. Again, the same wind data is used.

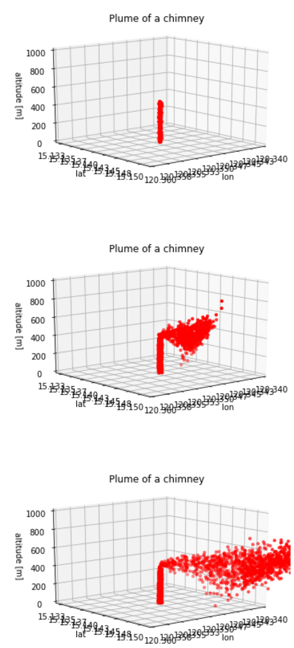

Fig. 6. The PUFF Model of a Chimney’s Plume.

We can see here another good representation of the differences between the two point-sources. We see how the car exhaust particles do move away and spread however in certain areas the particles will remain in a gas mass for a bit which is how pollution tends to act as it first is exhausted, but overall the dispersion is exemplatory of the physical motion we expect. We also see how this type of pollution does not tend to rise immediately given the parameters used here, meaning this pollution is more likely to affect the altitude where we breathing. In the Chimney example we can see that the particles are more likely to diffuse outwards at its higher altitude, however these particles do settle into lower parts of the atmosphere as well. This type of pollution being so high up tends to affect greenhouse gas problems more than human health problems, but it still can affect human health as well in long term climate change.

IV. Discussion

There are some sources of error to address in this project. The first is the interpolation calculation problem within the PUFF model. This is mostly a problem with the data available itself. That is because the data is measured every 10 meters from the last point. This is not an issue if you are looking at a volcano erupting or the plume of a huge explosion because you are attaining measurements over many kilometers. In our car point pollution example, we are measuring about 200 meters at a maximum. For the chimney simulation, it's only about 600 meters as well. The particles during the wind advection terms are being interpolated multiple times by the same wind vector in the same direction where in reality these vectors would most likely differ in some regard. The only fix for this is a finer (less coarse) data set. The NOAA does not have a smaller data set to my knowledge. This would require a set of sensors on a smaller scale which would be a costly endeavor.

Another issue with the PUFF model happens to be values which were originally empirically gained. The model I based my model off used empirically gained data for the dispersion terms for particles coming from the volcano. Data like this can vary from source to source given velocities of the pollution dispersing from it's point source. There are other factors to consider as well in this regard but the takeaway is that for this model to be more realistic, dispersion constants would have to be measured using sensors in real life to measure these constants for these systems. For this model, I used the given dispersion constants in the vertical and horizontal directions and downsized them to fit their respective point sources. While this produced a mostly accurate model, a more valid model would have experimentally gained values for these dispersion terms.

Lastly, further research needs to be incorporated in to decide whether pollution at the 600 meter level or the ground level is worse in the immediate problems we have. While both need to be solved, it is only an assumption that pollution at the breathing level is worse in the long run. Also, a list of technologies to help address the different point sources for pollution and how to help them should be compiled in order to best analyze which solutions may be easier to accomplish. For example, carbon capture is a popular technology that can capture carbon based pollution from fluestacks. If we started using more electric cars and parameterized the pollution to power plant fluestacks instead of many different engines, we could use carbon capture to best capture this pollution and reduce pollution over all. However, would this technology address raised amount noxides reaching the upper levels of the atmosphere? What solutions are there for non carbon based pollution that can be worked into this study? While I've looked into a few (not stated in this paper), this research could be enhanced greatly with more tools in the tool box to make suggestions for fixes to the point sources of the pollution.

V. Conclusion

Point source pollution near the layer of the atmosphere we live our daily lives in is comparably worse than that of point pollution in higher layers. However, the atmosphere is an open system and pollution in the higher layers can settle into the lower ones over time. With the larger distance that chimney pollution reaches, this upper hand is not very great.

A takeaway from this is how to diffuse and settle the argument about if electric cars are worse than regular cars. I can safely say the answer is no. While averagely a good fuel emission car in the US would have about 250 g/mi for its CO2 rating while a regular Tesla Model 3 would have about 100 g/mi of CO2 based off its energy consumption (in Northern Virginia, can vary from area to area given energy practices). Even if it is sourcing all it's energy from plants that pollute through chimneys into the atmosphere, it is still arguably better than having 10-100 cars polluting at even higher rates than the ones I modeled polluting into the lower atmosphere. Furthermore, if carbon capture technology gets better, it is key to parameterize it around these tall chimneys instead of a bunch of moving engines. There are plenty of other health risks these results can speak to, but this is just one of the conclusions I have decided to show.

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