Characterizing the Temporal Variation of Airborne Particulate Matter using Variograms

Gokul Balagopal, Dr.David Lary, Dr.Lakitha Wijeratne, Prabuddha Madusanka, Mazhar Iqbal, John Waczak, Adam Aker
University of Texas at Dallas

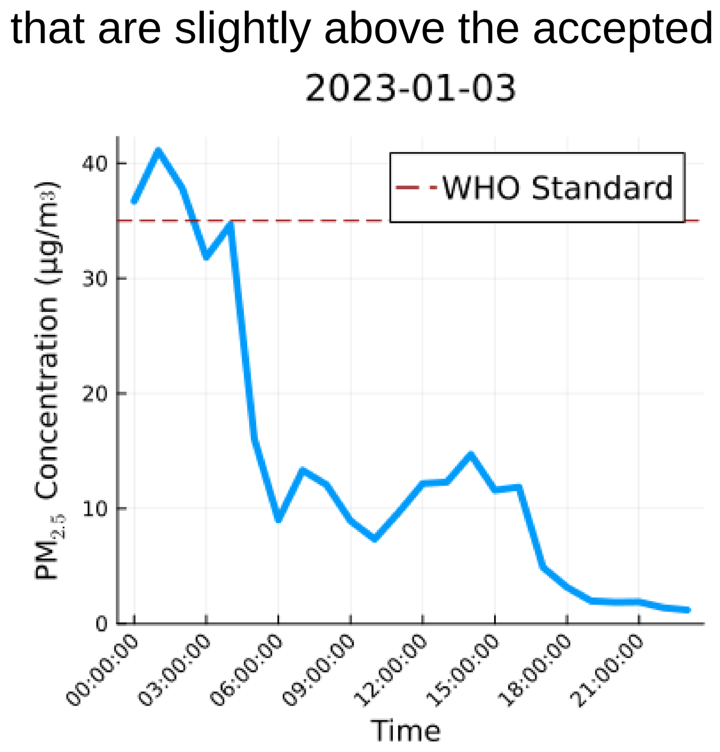
ABSTRACT

Airborne particulates (aerosols) are criterion pollutants that have a wide range of negative impacts on human health. They can permeate deep into our bodies and can be the cause of respiratory diseases, cardiovascular diseases, and even cancer. Apart from this they also play an important role in atmospheric radiative transfer and atmospheric chemistry, which in turn affects the climate and weather. Climate change and human health protection are the key challenges to maintaining a sustainable environment.

This study is based on the temporal variation of these airborne particulate concentrations in a neighborhood. As Environmental Agencies only report airborne particulate concentration once every hour, the sudden fluctuations in PM concentrations won't be noticed. So, we use the Central Node which is a powered stationary sensor system comprising an array of sensors developed in our lab. Every second, this system measures the various PM (Particulate Matter) levels. The data for this study comes from the Central Node located in Joppa, a neighborhood in Dallas where the PM levels are mostly above the WHO standards. The temporal variations are calculated for a day, a week, a month, and even up to a year. For an initial study, we are considering the fluctuation of PM concentration and count throughout the day.

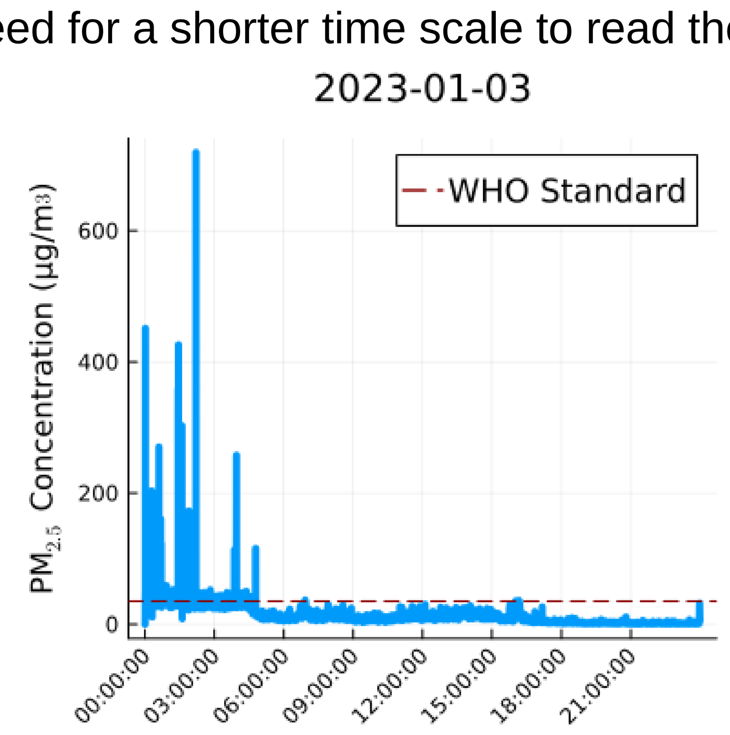
INSPIRATION & OBJECTIVES

- The hourly variation in $PM_{2.5}$ concentration shows values that are slightly above the accepted level.



Time Series plot of $PM_{2.5}$ Concentration averaged over every hour

- But the following time series plot for every second shows extreme values of $PM_{2.5}$ that are 10 to 20 times greater than the accepted level. Hence, proving the need for a shorter time scale to read the PM data.



Time Series plot of $PM_{2.5}$ Concentration for every second

- The frequency of temporal variation needs to be determined depending on how long particulate matter has been concentrated in one place.
- The variation can be attributed to a variety of factors, including changes in Temperature, Pressure, Humidity, Windspeed ,and Direction, as well as the intensity of particulate matter sources, such as changes in traffic, and emissions from nearby factories.
- Based on the variogram analysis, we can characterize the frequency at which airborne particulate observations should be made to adequately resolve the time series.

METHODOLOGY

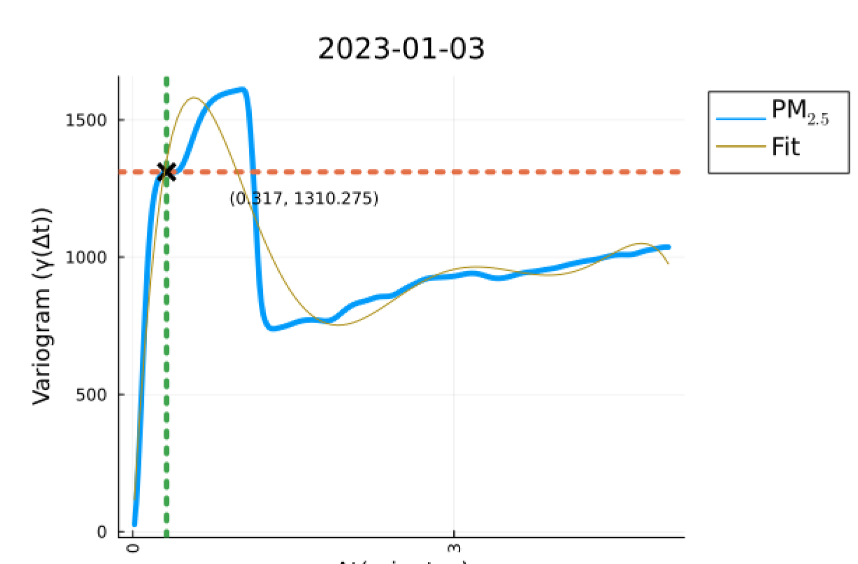
- The variogram also known as semi-variogram is the average squared difference between the points separated by a distance.
- Equation for a Variogram:

$$\gamma(\Delta t)=\frac{1}{2N}\sum_{i=1}^{N}[PM(t_i+\Delta t)-PM(t_i)]^2$$

- The main characteristics of a variogram are the *Range, Sill ,and Nugget*.
- The important feature that we are focusing on is the *Range*. It characterizes the temporal scale beyond which the separation of the data is no longer significantly correlated.
- It's obtained by finding the x coordinate corresponding to the first maxima of the variogram curve.
- Sliding windows are used to find the range concerning each time step.
- Equation for a Rolling Variogram:

$$\gamma(\Delta t)=\frac{1}{2N}\sum_{j=1,i=j}^{M,N+j}[PM(t_i+\Delta t)-PM(t_i)]^2$$

RESULTS

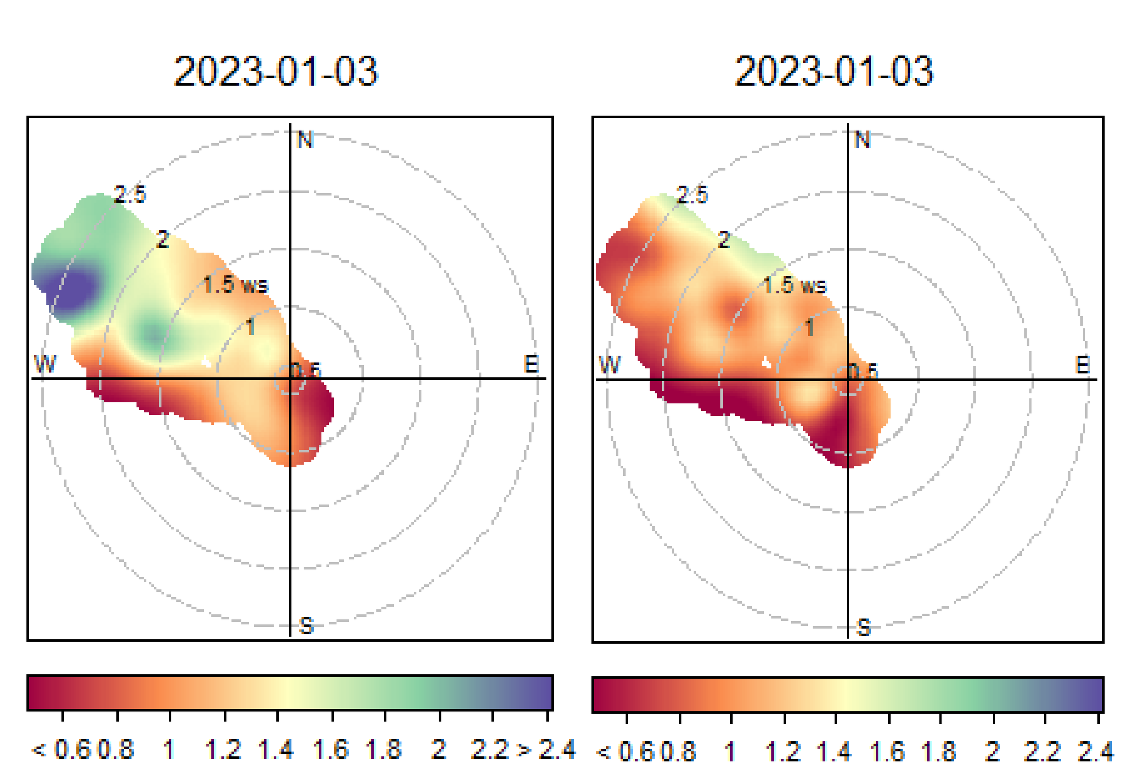


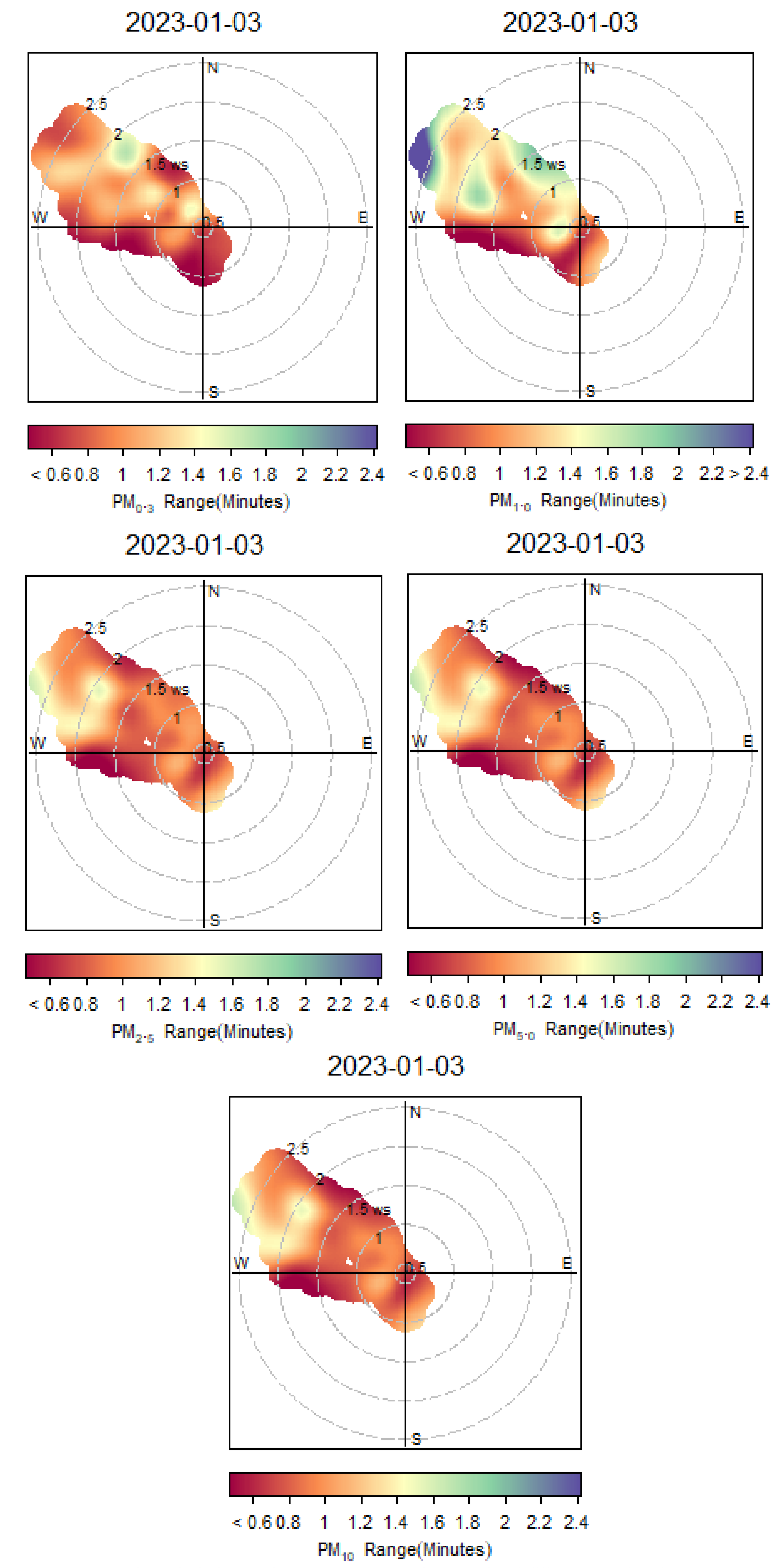
$PM_{2.5}$ Variogram Curve for the first window of 3rd January 2023

- The above plot shows the first-time window of the rolling variogram for $PM_{2.5}$. The window length N = 15 minutes and the maximum time lag, Δt = 5 minutes.
- The coordinates of the first maxima are marked with a cross.
- From the above plot we can see that the x coordinate, 0.32 minutes is the time scale at which the $PM_{2.5}$ must be measured for the first window.
- The Measurement Time Scale/Range values for the first window of different PM levels are given below:

PM levels	Time Scale (minutes)
$PM_{0.1}$	1.03
$PM_{0.3}$	0.33
$PM_{0.5}$	0.30
$PM_{1.0}$	0.32
$PM_{2.5}$	0.32
$PM_{5.0}$	0.32
$PM_{10.0}$	0.32

- The Polar plot shows variation of Wind Speed vs Wind Direction across the Measured Time Scales. These time scales are obtained from the Rolling Variogram, for 3rd January 2023.





Polar Wind plot for the Measurement Time Scale of different PM levels

CONCLUSION

- The warmer areas of the Polar Wind Plot show that in those regions, the PM levels must be measured at a faster rate.
- It can also be noted that across the different PM levels, the time scale is shorter near the sensor indicating a high PM concentration near the sensor.
- But across the various PM size fractions the time scale varies mostly for lower PM size fractions like $PM_{0.1}$ and $PM_{1.0}$ indicating the dominance of larger PM size fractions. It may be attributed to variations in temperature, pressure, and humidity, as well as the presence of a nearby source and transportation.
- Since, PM is generated from unsustainable practices, like burning fossil fuels, transportation, and factory emissions, it is necessary to control the PM levels to maintain a cleaner and healthier environment for the future generation. This can be achieved by monitoring the PM levels at a faster rate.

REFERENCES

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  William A. Harrison, David Lary, Brian Nathan, Alec G. Moore
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  D. J. Lary, D. W. Waugh, A. R. Douglass, R. S. Stolarski, P. A. Newman, and H. Mussa

CONTACT

If you have any further questions regarding the research project, please contact us at:

Gokul Balagopal: gokul.balagopal@utdallas.edu

Dr.David Lary: david.lary@utdallas.edu