Gone With the Wind? Impact of Meteorology on Air Pollution in Houston

Manuel Croitoru, Jenny Kwon, Yan Li, Hongyu Mao
STAT 435

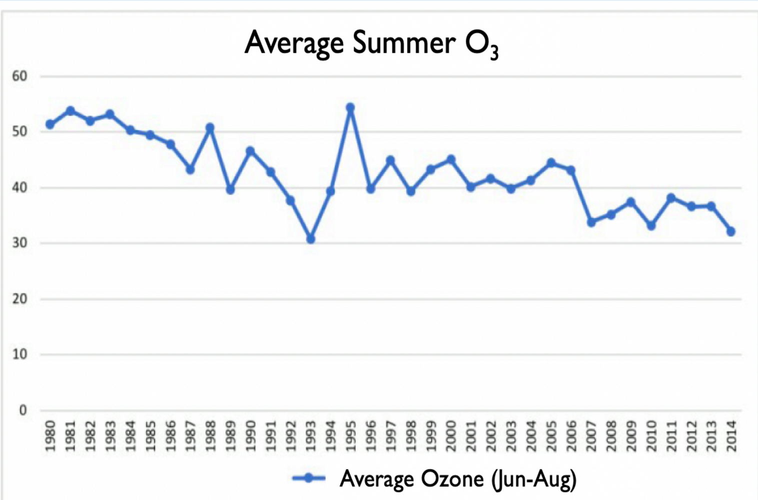
Background & Motivation

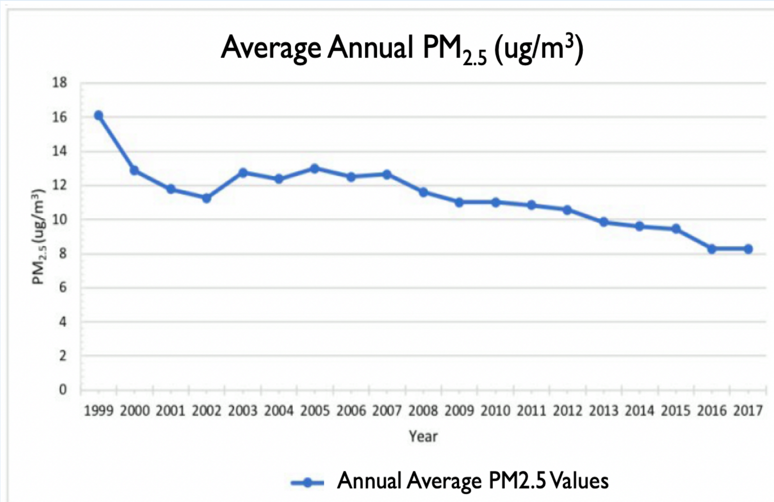
Houston continues to violate federal standards for ground-level ozone despite efforts in reducing emissions. Particulate matter, another major pollutant, does not currently violate federal standards, and thus does not receive as much attention. However, PM is deadlier than ozone, and it may be worthwhile to study this common pollutant.

Our goal is to better understand the spatial and temporal patterns of ozone and PM concentrations in the greater Houston area with its meteorology. We also predict how different weather patterns influence air pollution in the area.

The concentrations of these common pollutants have been falling over the past two decades. In the big picture, this project may help to determine how impactful federal regulations have been to this decrease.

Key Words:
- **Air pollution**: The mixture of harmful gases and particles present in the air
- **Ground-level ozone**: Pollutant created by chemical reactions in the presence of sunlight between oxides of nitrogen (NOx) and volatile organic compounds
- **PM 2.5**: Fine particulate matter less than 2.5 um in aerodynamic diameter, which is detrimental to human health

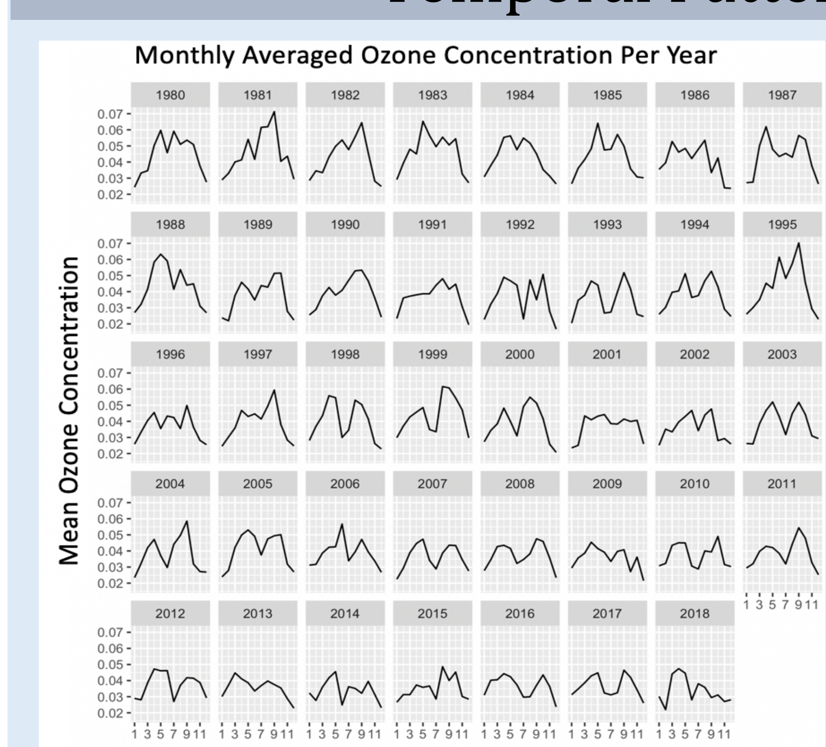




Objective

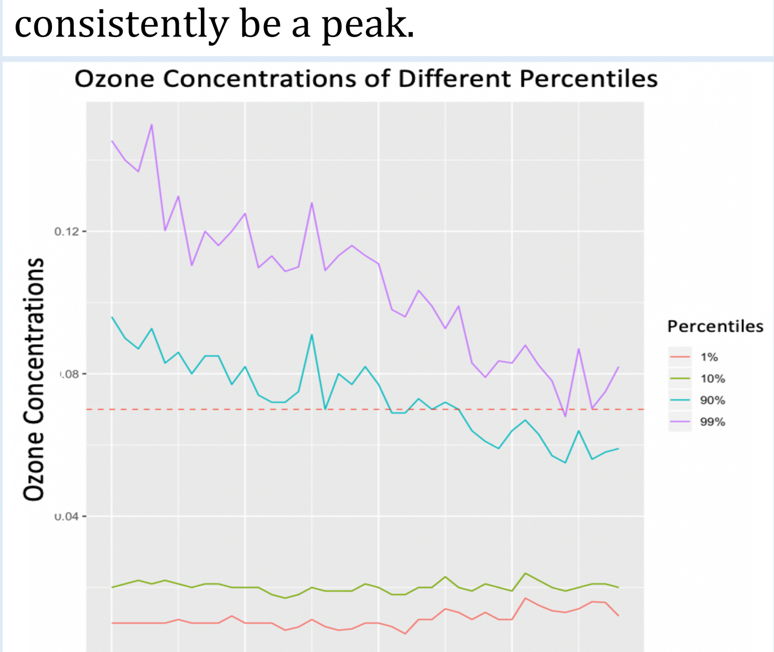
- Identify **spatial and temporal patterns of ground-level ozone and PM concentrations** in the greater Houston area
- Explore methods to **identify large-scale wind flow patterns** and validate their significance. Then, characterize each wind cluster by its meteorological conditions and pollutant concentrations, as well as by their spatial and temporal patterns
- Analyze and **model the possible relations between pollutant concentrations** as well as meteorological conditions

Temporal Patterns of Pollutants

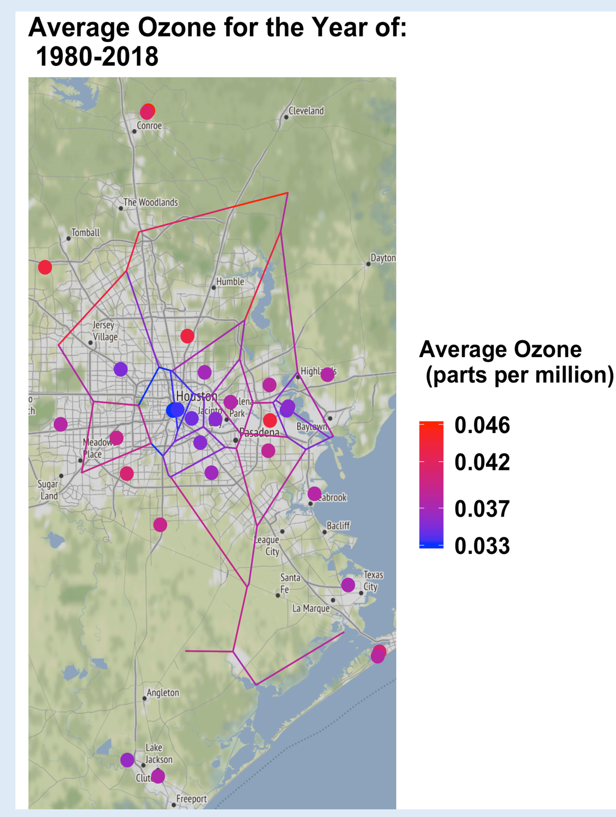


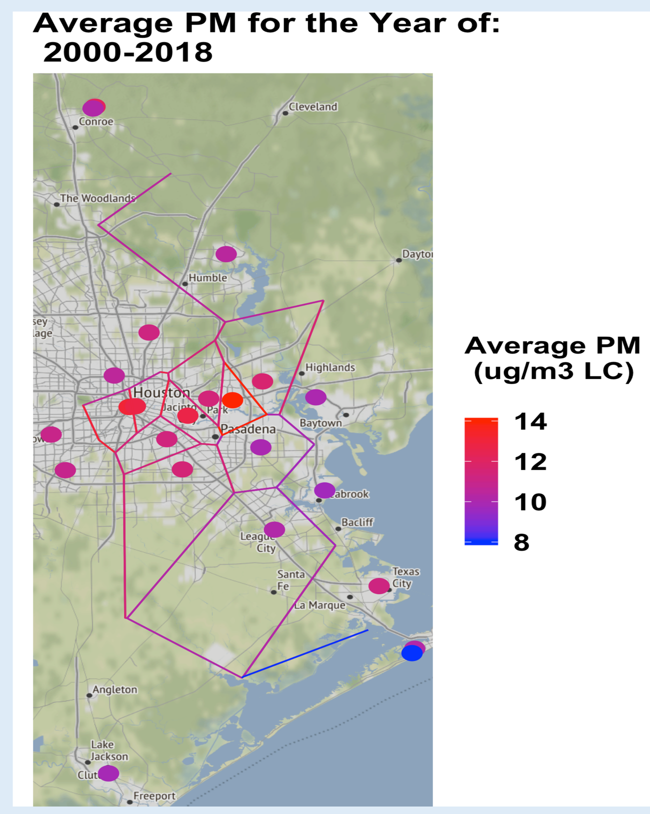
Monthly-averaged ozone concentrations exhibit a consistent **M-shaped pattern**. We conclude that ozone is highly seasonal and April, May, and September tend to display the highest ozone levels. In general, Houston has an "**ozone season**" ranging roughly from **May to September.** On the other hand, **PM 2.5 is not as seasonal** as ozone although July seems to consistently be a peak.

The **99th** and **90th** percentile of the annual average pollutant concentrations have been dropping dramatically. The bottom percentiles, conversely, remain relatively constant. The empirical result is that the **dirtiest days are becoming cleaner whereas the cleanest days are staying clean.**



Spatial Patterns of Pollutants

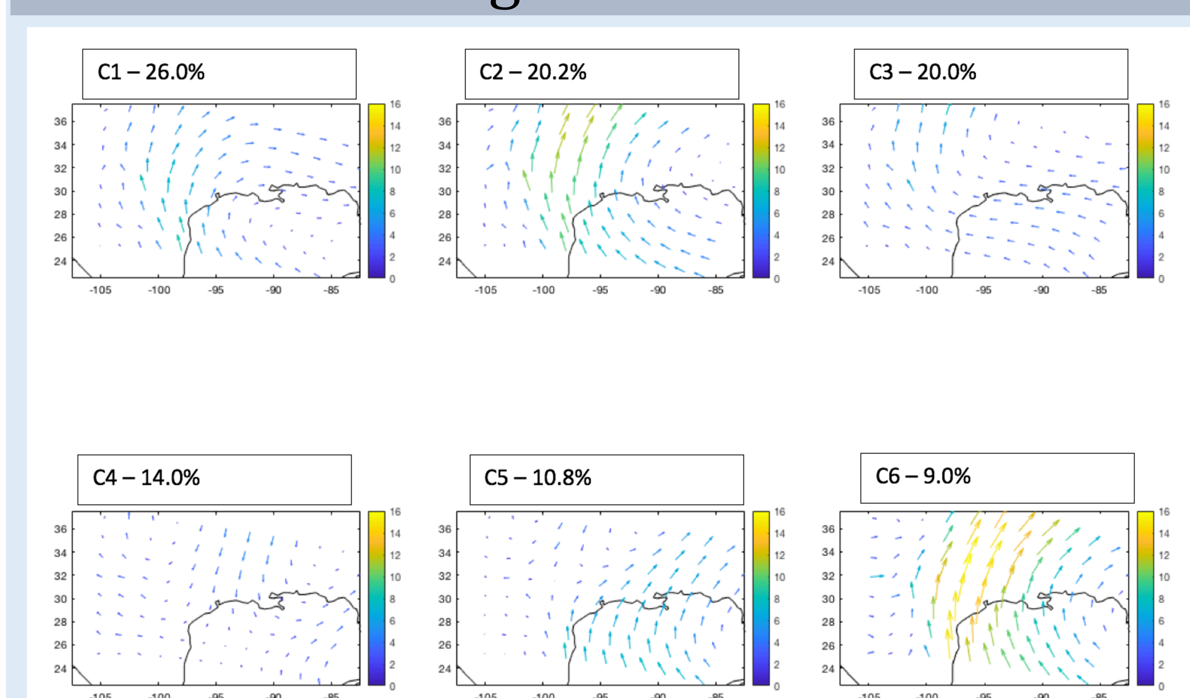




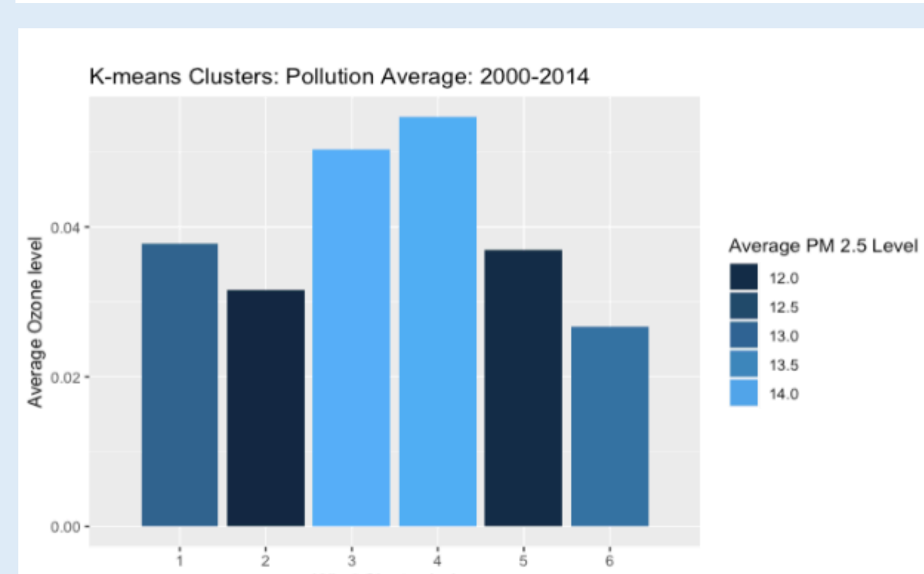
East Houston has higher pollution levels because it is adjacent to the Houston Ship Channel which has high emissions. Pollution is also lower along the coast, which is likely because of the fresh ocean air.

Whereas **PM concentration is greater in urban areas and lower in the suburbs, ozone concentration follows the opposite pattern.** This is because ozone needs time to form and can be **carried by wind**, so it tends to appear downwind. On the other hand, PM is directly emitted into the air and thus tends to register closer to its source.

Large-Scale Wind Flow Patterns



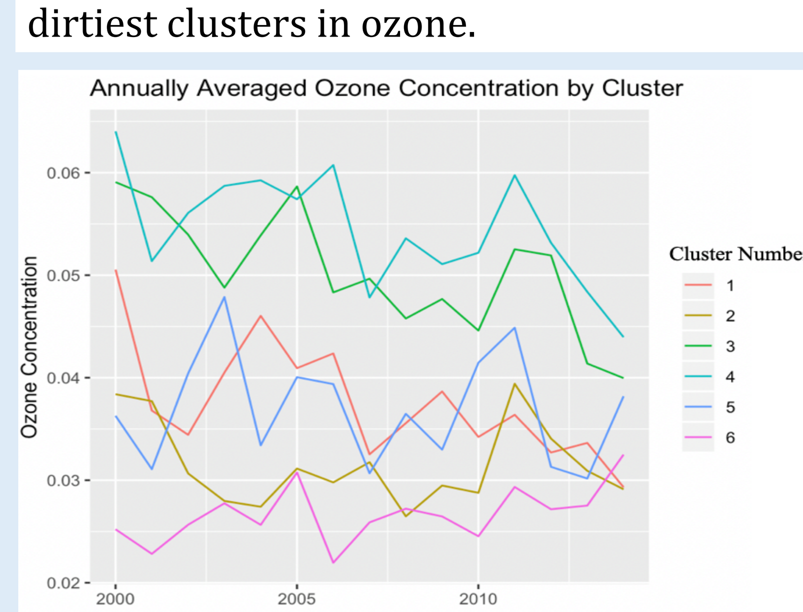
The plots shown are (left) the six main wind flow patterns with their respective frequency in the time frame and (below) the average pollutant concentrations by wind pattern. We employ **consensus clustering** to ensure the validity of these clusters.

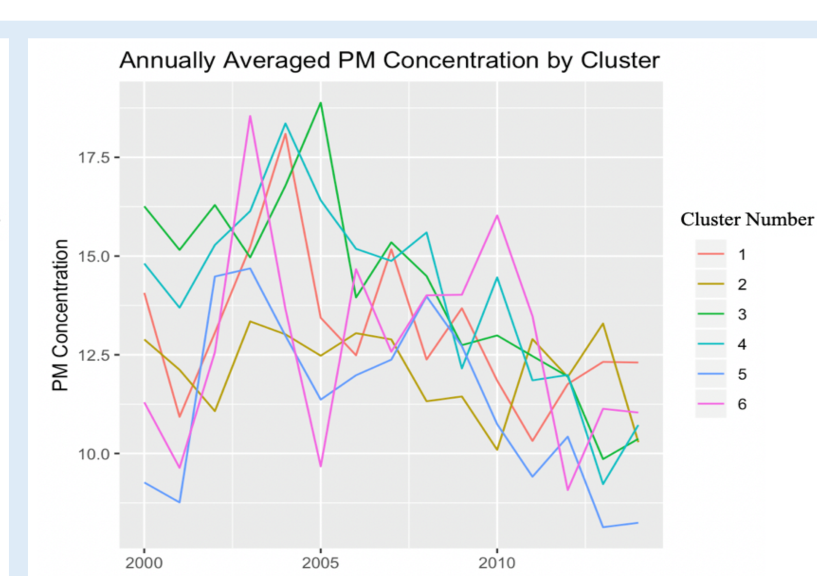


We conclude that the **k-means algorithm with k = 6 yields the most robust clusters.**

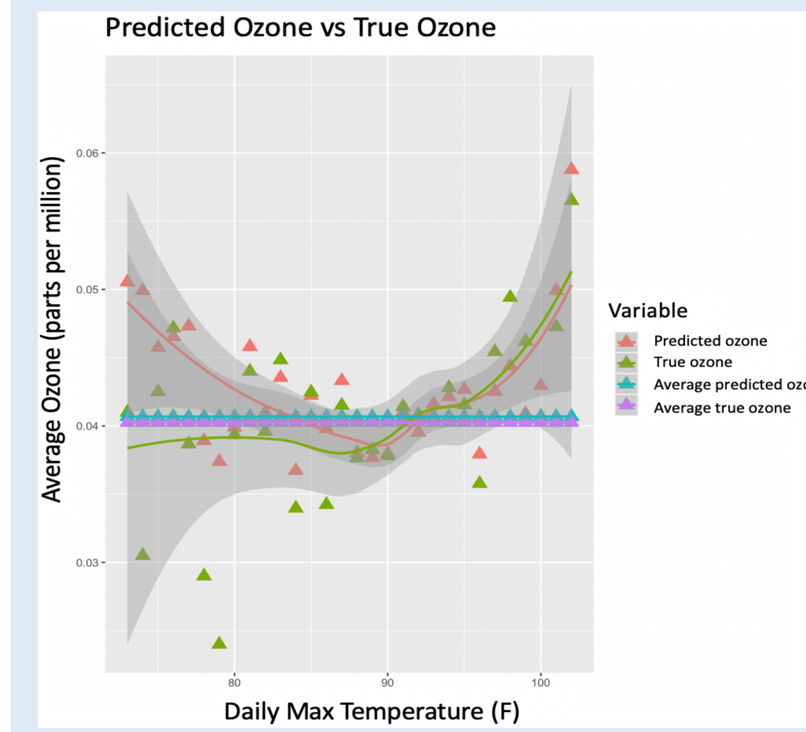
The two plots below are the temporal patterns of the wind clusters for each pollutant. There are more defined "clean" and "dirty" patterns for ozone than for PM, which resonates with the fact that **ozone is more willingly affected by meteorology than is PM**

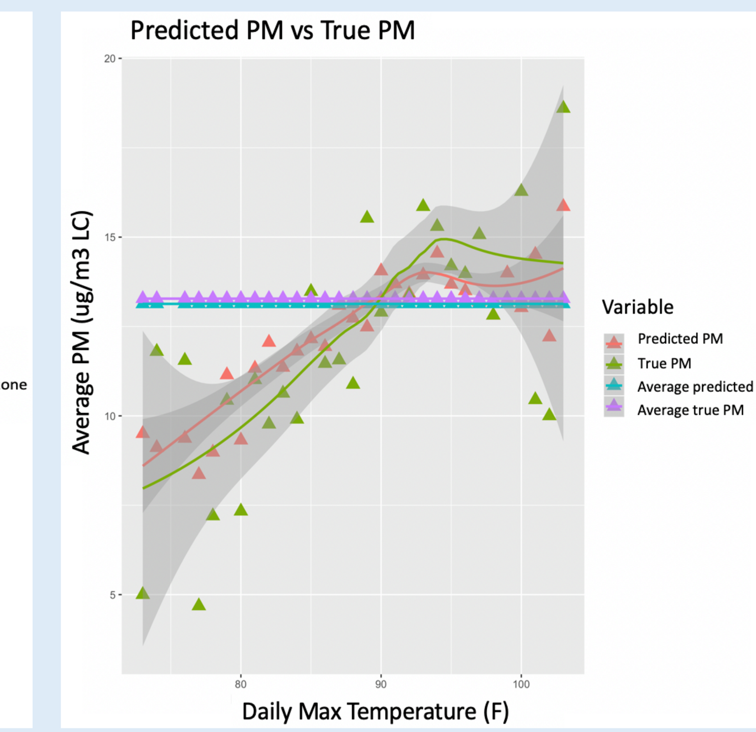
There also seems to be a **general downward trend** for all the clusters in PM and for the dirtiest clusters in ozone.





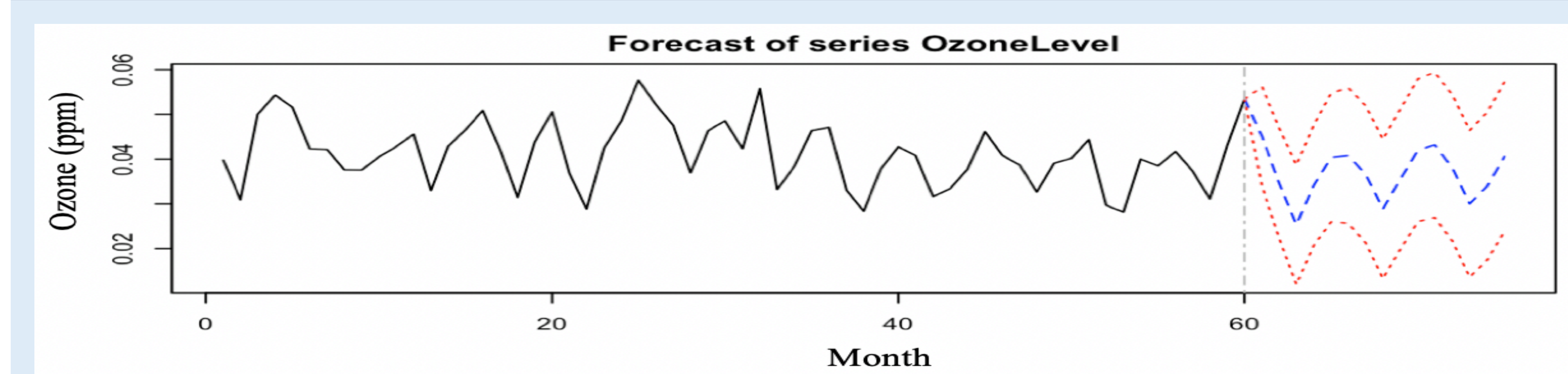
Random Forest Model

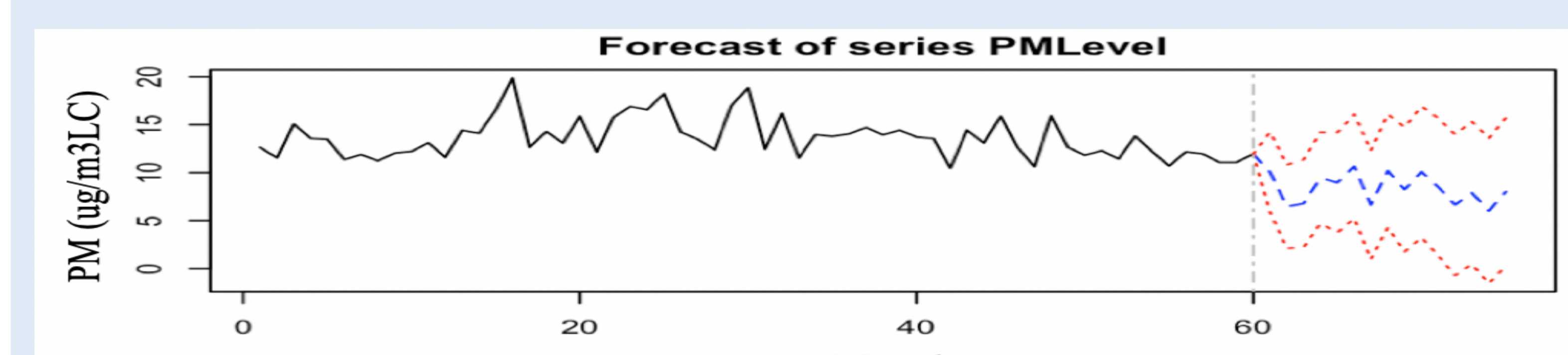




For both ozone and PM, there is decent predictability for days with medium temperatures. At the ends, i.e. when the days display more extreme temperatures, predictability is lower. For ozone, the **percentage error of the random forest model is lower that of the naïve model** (26% vs 37%). However, for PM, random forest's error is **almost the same** as naïve model's error (33% vs 34%). Thus, **ozone seems to be easier to predict** with our current meteorological variables. This makes sense because ozone takes time to form, and is thus more easily affected by meteorology.

Vector Autoregressive Model





Above we display our graphs for modeling each pollutant's concentration using its relationship with **both optimally lagged values of daily temperature and itself.** The black line represents the observed pollutant concentration and the blue line depicts the prediction of ozone and PM for 15 months ahead. The red lines represent the 95% confidence interval for prediction. **Ozone seems to be easier to predict** using temperature than is PM, which makes sense because of its formation with sunlight. This echoes our result from random forest. Also, compared to the benchmark model, VAR decreases the percentage error from 37% to 26% for ozone and from 34% to 33% for PM.

Conclusion

Ozone and PM in the Houston area have decreased over the past two decades. Dirtier days seem to be getting cleaner and the cleanest days are staying clean. The pollutants display seasonal and spatial patterns consonant with their chemical properties. Large-scale wind flow patterns also seem to affect pollutant concentrations. The relatively lower error rates achieved through our predictive modeling indicate that the variables that we are studying meaningfully affect the pollutant concentrations. Throughout these analyses, we find that **pollutant concentrations have been decreasing overall across seasonal, spatial, and meteorological factors**. This may be evidence that federal emission reduction policies have played a role in the decrease. We hope that our findings shed some light to understand how much federal policies have benefitted air quality in Houston.