Low-cost $PM_{2.5}$ measurements in a binational metropolitan area along the U.S.-Mexico border

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Scientific Approach

- The project installed an air monitoring network in the PdN to measure $PM_{2.5}$, at 31 sites in El Paso and Ciudad Juarez (Cd. Juarez).
- The sampling project time was 2 months.
- The 15-month, collaborative effort between the University of Texas at El Paso (UTEP) and Universidad Autonoma de Ciudad Juarez (UACJ).

Research Objectives

Goals:

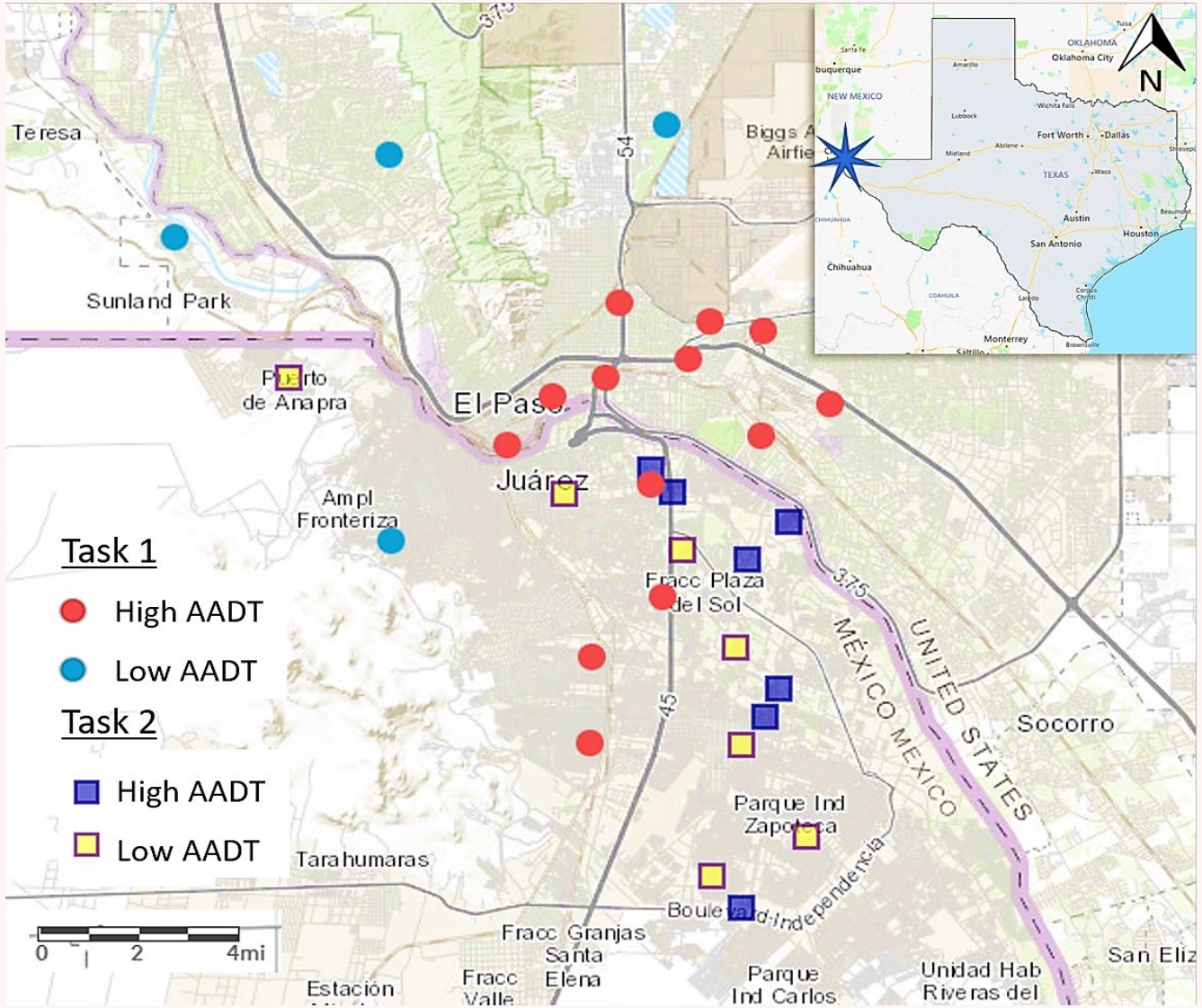
- Improve air quality monitoring in the border region;
- Produce a case study of scientific measurement and analysis of air quality using low-cost air sensors;
- Foster binational technical exchange between government agencies and research institutions in the Paso del Norte (PdN).

Objectives:

- Provide real-time spatial and temporal concentration patterns of PM to the public.
- Assess air quality and emissions associated with transportation by developing an algorithm to predict air pollution for near-road receptors using land-use regression technique.

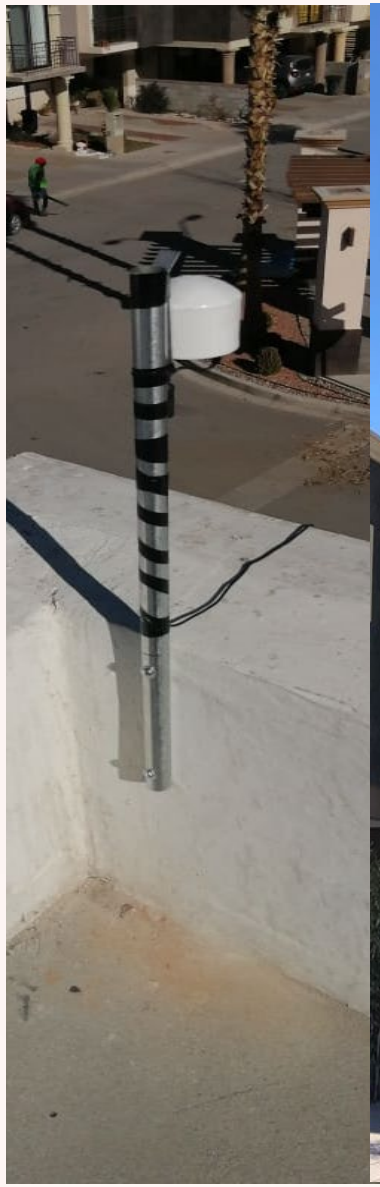
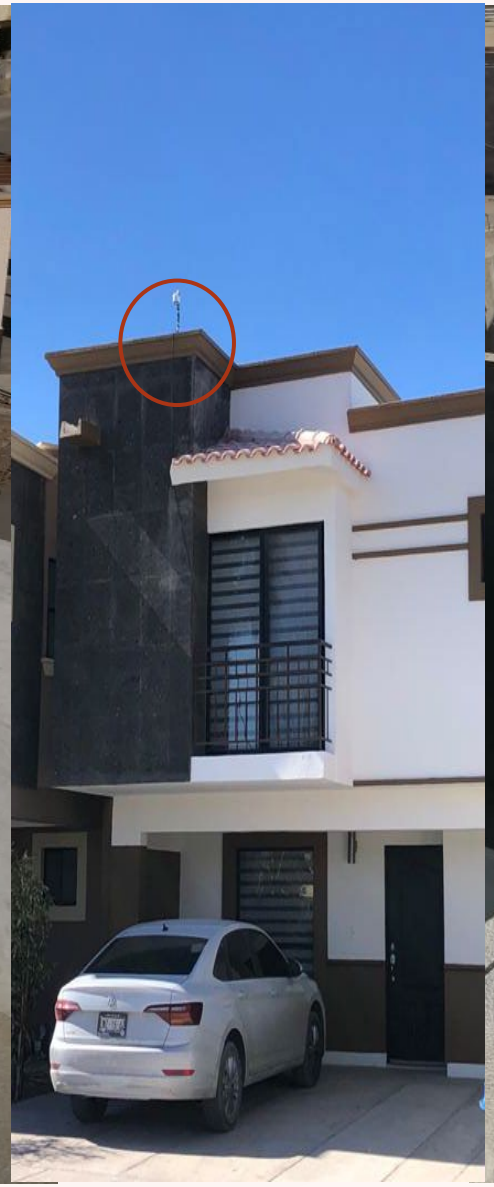
Tasks and Site map

- Task 1
  - Elementary Schools
  - 17 total sites
  - 12 sites in El Paso
  - 5 sites in Cd. Juarez.
- Task 2
  - Industrial Sites
  - 14 total sites
  - 7 in areas of high vehicular flow
  - 7 in areas of low vehicular flow



Map of Purple Air Locations for the PdN including Annual Average Daily Traffic (AADT)

View of Sensor locations


Data correction methodology

- All sensors were compared first co-located with TCEQ's FRM-approved $PM_{2.5}$ monitor.
- 15 day period
- 

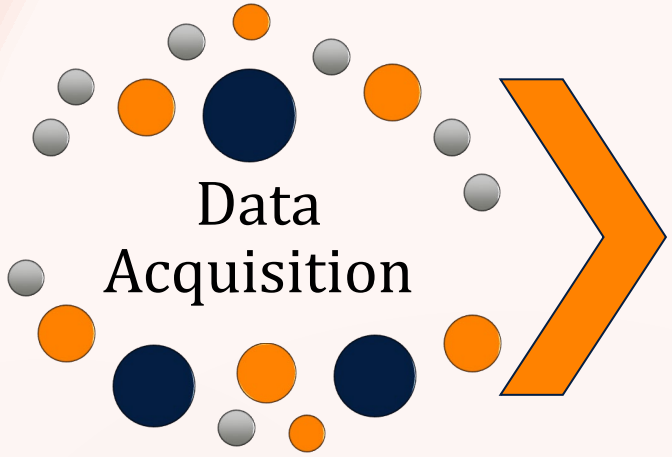
48 sensors immediately adjacent to TCEQ's CAMS 12 site.

Data correction methodology

- Evaluate the correlations between the low-cost sensor and the reference station.
- The data generated by the monitors was calibrated according to the methodology of Munir et. al., (2019).
  - Multiple regression model was developed, including humidity and temperature variables:

$$Ref = \beta_0 + \beta_1(Sensor) + \beta_2(HR) + \beta_3(Temp) + \varepsilon$$

Data processing



Preliminary Data Cleaning

In-depth Cleaning

Hourly Averaged Data Set

- Data is uploaded to "Thingspeak" servers
- Data is downloaded

Data outside of operating range eliminated

- Humidity
- $PM_{2.5}$

Parameter	Operation Range
Effective Range ($PM_{2.5}$ standard)	0 to 500 µg/m^3
Maximum Range ($PM_{2.5}$ standard)	≥1,000 µg/m^3
Temperature Range	-40 °F to 185 °F (-40°C to 85°C)
Humidity	Response time (τ63%): 1 s Accuracy tolerance: ±3% RH Hysteresis: ≤ 2% RH

- Create a $PM_{2.5}$ Hourly Mean between channel A/B
- Length of Data is not <20
- Length of Data is not <75%
- A/B Percent Difference is not >70%
- A/B Hourly Difference is not > 5

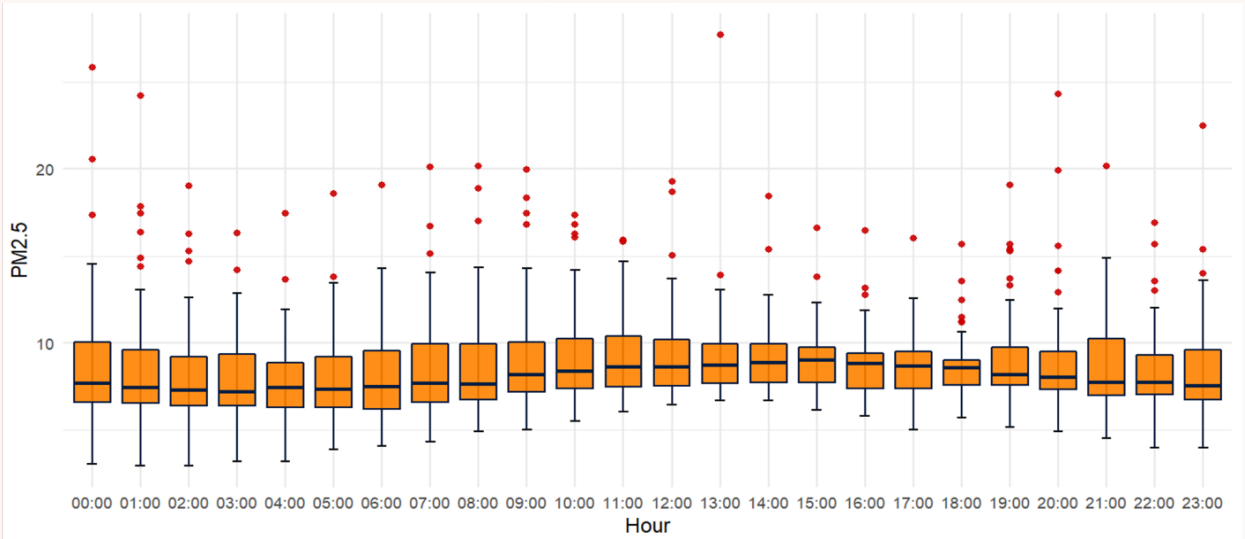
Correlation analysis: Duplicated Sensor Sites

- 12 sites with duplicates, represents ~38% of the monitoring network
- Correlation greater than 0.97
- Equipment works correctly, in relation to other PurpleAir sensors.

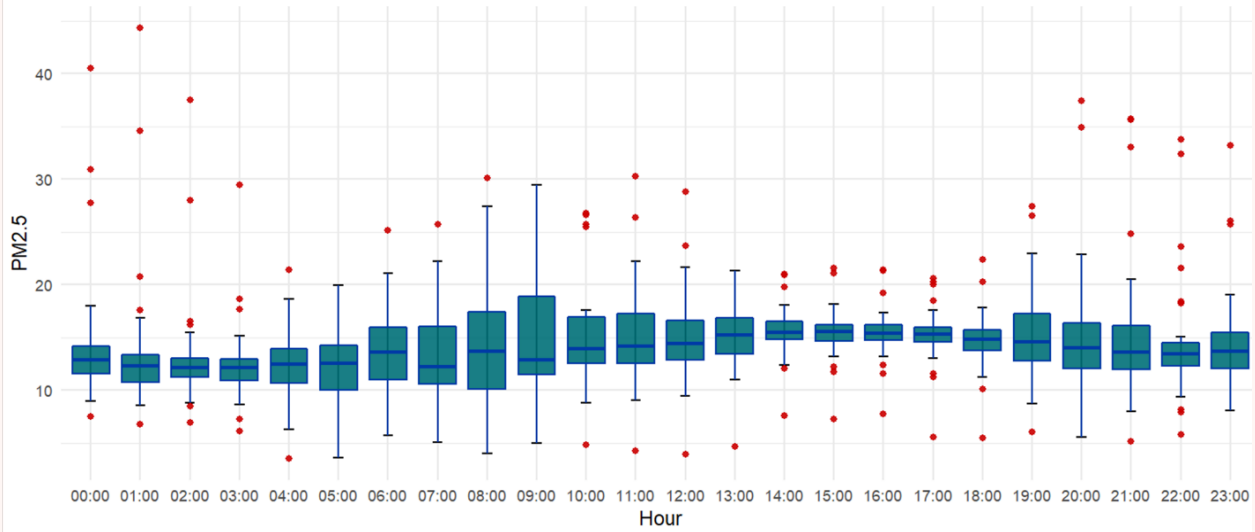
ID	Name on PurpleAir	AADT	Type of Site	R^2
C2	Zavala 2	High	Elementary School	**0.99**
C23	Zavala			
C4	Aoy 2	High	Elementary School	**0.96**
C10	Aoy			
C22	Park 2	Low	Elementary School	**0.98**
C11	Park			
C5	UTEP 3	High	Calibration Site	**0.98**
C7	UTEP 1			
C6	UTEP 2		Calibration Site	**1.00**
C7	UTEP 1			
C6	UTEP 2		Calibration Site	**0.94**
C5	UTEP 3			
C26	UACJ-PAC22	High	Industrial Sector	**0.99**
C27	UACJ-PAC21			
C28	UACJ-PAC20	High	Industrial Sector	**0.97**
C29	UACJ-PAC19			
C30	UACJ-PAC23	High	Industrial Sector	**0.98**
C31	UACJ-PAC24			
C35	UACJ-PAC26	High	Industrial Sector	**0.99**
C34	UACJ-PAC25			
C44	UACJ-PAC09	Low	Industrial Sector	**0.98**
C45	UACJ-PAC10			
C42	UACJ-PAC02	Low	Industrial Sector	**0.98**
C43	UACJ-PAC03			
C32	UACJ-PAC17	Low	Industrial Sector	**0.99**
C33	UACJ-PAC18			
C38	UACJ-PAC05	Low	Industrial Sector	**0.97**
C39	UACJ-PAC06			

Results: Daily $PM_{2.5}$ Variation

- Hourly $PM_{2.5}$ data during study period summarized to show the diurnal variation at sensor locations in the PdN.
- Most sensors showed $PM_{2.5}$ concentration peaks in afternoons or early evenings before 8:00 p.m.
- Low $PM_{2.5}$ were observed during the nights before the vehicle flow started to increase (6:00 h).



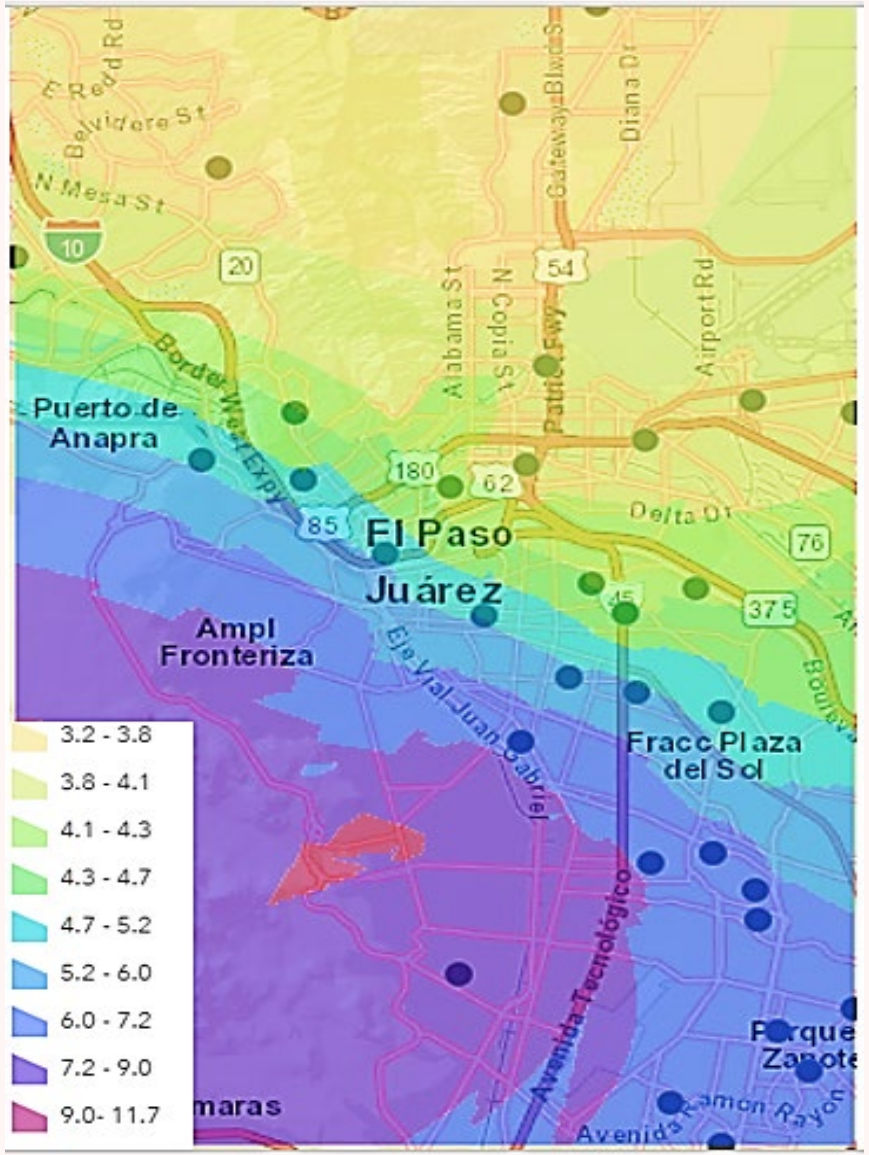
a) Hourly Boxplot for $PM_{2.5}$ during the study period: UTEP 1



b) Hourly Boxplot for $PM_{2.5}$ during the study period: UACJ01

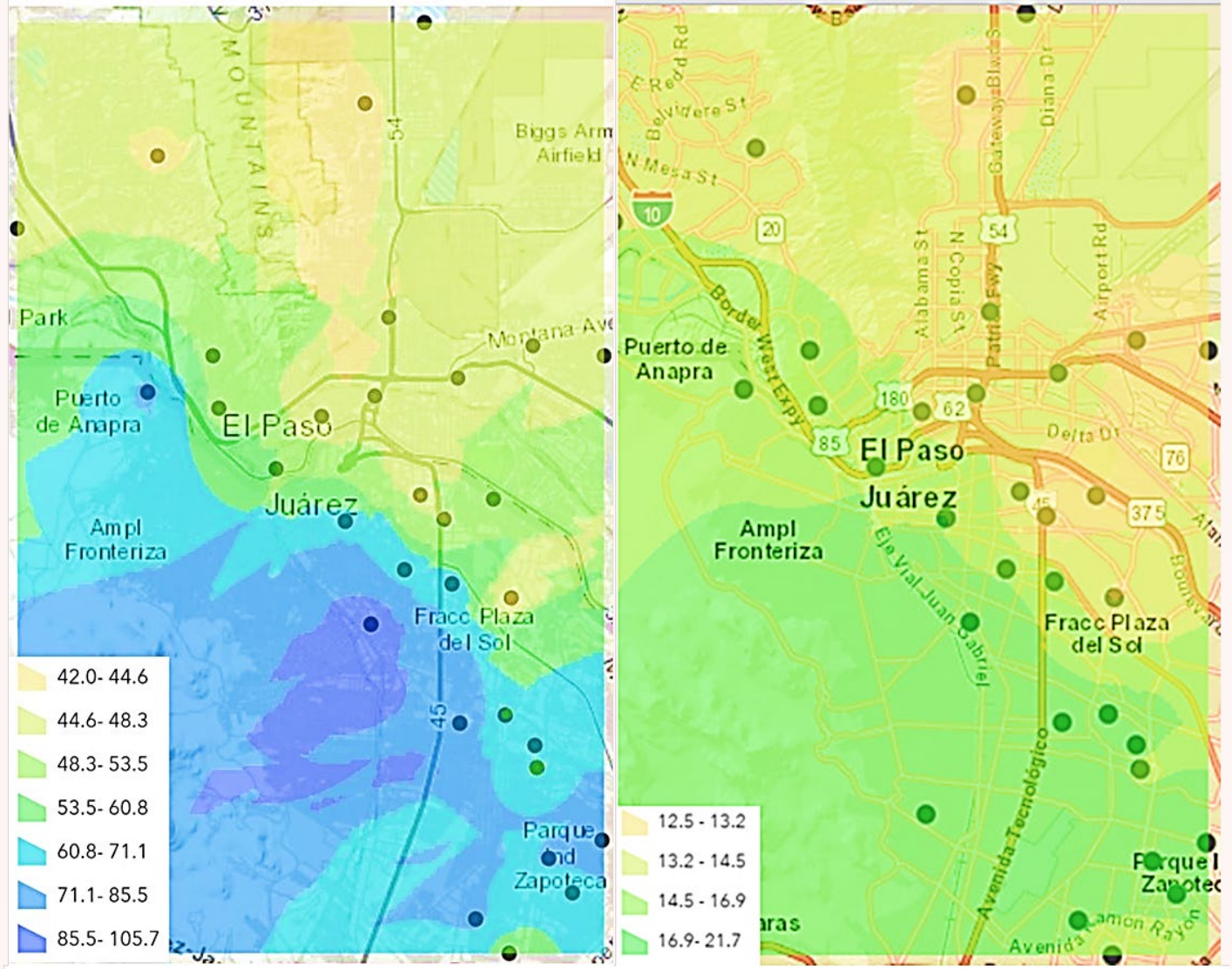
Heat Map of $PM_{2.5}$ Period Average

- Averages for all sensors are plotted from March – April
- Period Average suggests that the concentration of Cd. Juarez is higher than the concentration of El Paso



Heat Map of $PM_{2.5}$ Max 1-hr & Max 24–hr

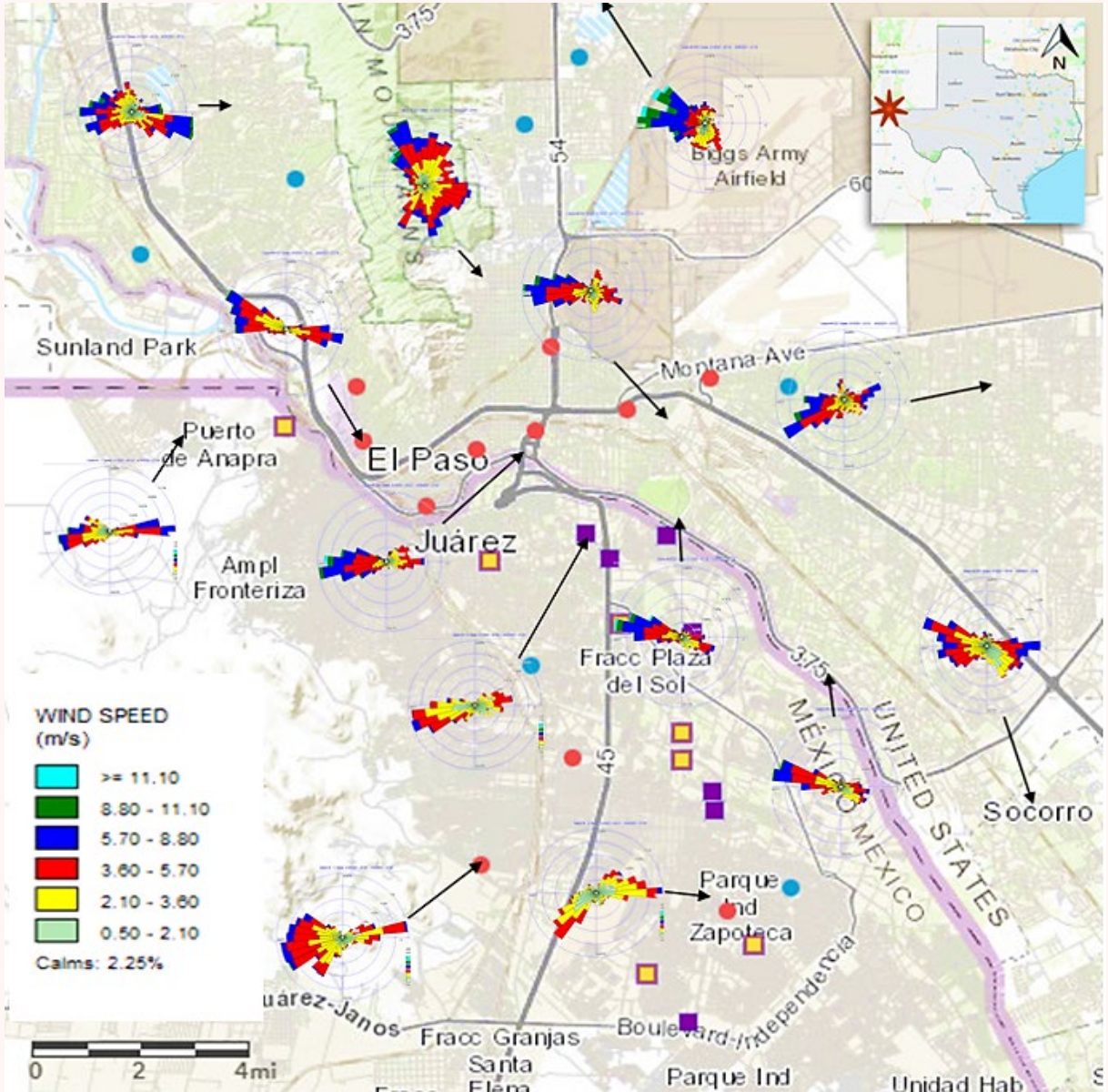
- Heat map shows 1-hr average PM concentration variation throughout the basin.
- The max 24-hour average showed the pollutant varied slightly, higher concentrations in the southern regions of Ciudad Juarez.



a) Max 1-hr b) Max 24-hr

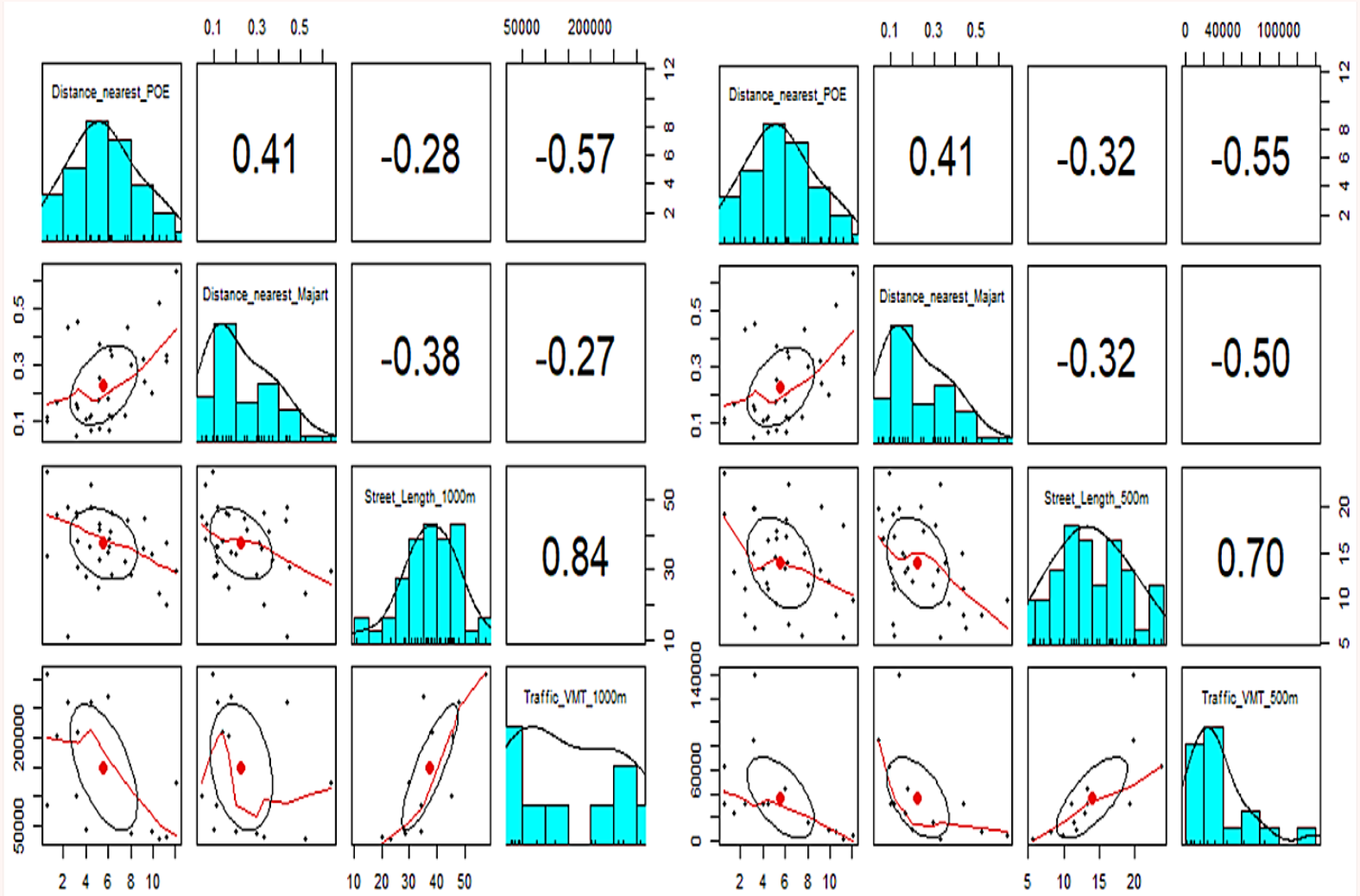
Surface Meteorological Conditions

- Wind predominantly coming from west and southwest directions



Land Use Linear Regression

- Algorithm developed to analyze pollution in relation to predictor variables associated with land use of an area.
- Variables:
  - Distance to the nearest major arterial road
  - Street length within 500m impact zone
  - Street length within 1000m impact zone
  - Distance to the nearest port of entry (POE)
  - Traffic vehicle miles traveled within 500m zone
  - Traffic vehicle miles traveled within 1000m zone.



a) Scatterplot Matrix of Pairs of Four Traffic Variables: 500 m radius

b) Scatterplot Matrix of Pairs of Four Traffic Variables: 1000 m radius

Univariate Linear Regression

- Distance to nearest POE was found to be the only significant traffic variable in modeling of $PM_{2.5}$ for the period average ($\beta 1 = -0.190$, p-value=0.024).
- High $PM_{2.5}$ value is related to the shorter distance to the POE.
- **$PM_{2.5}$** value increases by 0.190 µg/m3 per one-unit decrease of **Distance nearest Major POE (in km)**

Yvar		Traffic Variables	Estimate	Std. Error	t value	Pr(>|t|)
$PM_{2.5}$ Period Average	500m Traffic Variables	(Intercept)	4.222	0.180	23.411	0.000
		Distance nearest Major Arterial	-1.091	1.589	-0.687	0.504
		Street Length 1000m	-0.049	0.037	-1.336	0.204
		Distance nearest Major POE	**-0.190**	**0.075**	**-2.545**	**0.024**
		VMT 1000m	-0.001	0.003	-0.281	0.783
$PM_{2.5}$ Period Average	1000m Traffic variables	(Intercept)	4.205	0.200	20.975	0.000
		Distance nearest Major Arterial	-1.807	1.750	-1.032	0.321
		Street Length 500m	-0.037	0.072	-0.508	0.620
		Distance nearest Major POE	-0.140	0.085	-1.640	0.125
		VMT 500m	-0.008	0.008	-0.984	0.343

Discussions and Conclusions

Correlations:

- Consistency between Channel A and Channel B values in each individual sensors,
  - Generally, R^2 of 0.8
- Consistency between duplicate sensors at deployed sites
  - Vary in correlation but generally good R^2
- Correlation between collocated sensors at Federal Reference Method (FRM) or Federal Equivalent Method (FEM) stations
  - Varied over time, decreased from December to April months.

Low-Cost Sensors Performance

- Sensors collocated in school zones in El Paso:
  - High AADT sites measured a slightly higher average (9.26±0.59) µg/m3 than that presented in low AADT sites (8.63±0.54) µg/m3.
- Ciudad Juarez two site categories: 1) school zones, and 2) industrial zones.
  - In school zones, high AADT sites registered values of (11.66±0.87) µg/m3
  - In the industrial zones, high AADT sites measured (9.48±0.61) µg/m^3 which was lower than measured at low AADT sites (10.06±1.07) µg/m^3.
    - due to construction in low AADT sites during study period

Limitations and Future Studies

- Considering the number of identifiable traffic and geographic variables, the application of the LUR model in this study requires further investigation
  - Traffic variables based on long-term measurements
  - Traffic-related variables currently not available in Ciudad Juarez and other data.
- The monitoring campaign extended for a 12-month period in the PdN.
- Collocated monitoring at two reference stations will be continued for quality control and performance evaluation of the low-cost sensors.

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