Cost-Effective Sensor Networks for Modeled, Highly Accurate Air Quality Monitoring

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NEMC – Minneapolis, MN – August 2023

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Current Air Pollution Trends

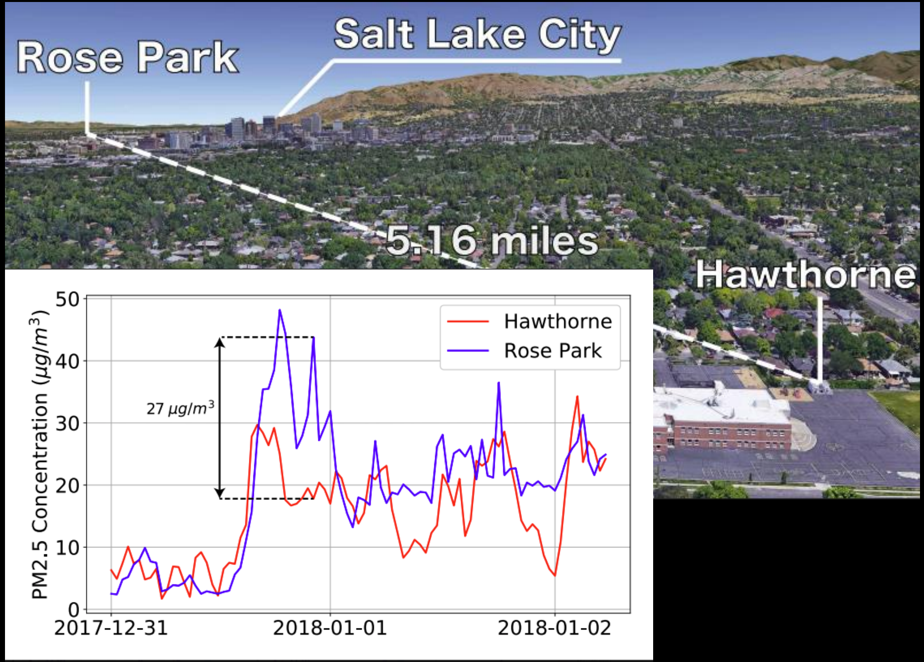
- Over 95% world's population lives in areas that exceed safe air quality standards
- Poor air quality contributes to 6.5 million premature deaths annually

- Salt Lake City, UT – periodically the worst air quality in the United States
- Summertime ozone, winter inversions, frequent wildfires

Shortcomings of Traditional Monitoring Techniques

- FEMs (Federal Equivalent Methods) hosted by state entities
- Ground-truth measurements, but expensive and sparse
- Cannot accurately capture neighborhood-scale pollution microclimates

Fill in the gaps with a cost-effective monitoring network



FEM sites and associated hourly PM2.5 measurements in Salt Lake County, Utah, United States.

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The Rise of Cost-Effective Environmental Air Quality Networks

- Provide extremely high spatial resolution environmental air pollution data
- Reveal neighborhood-scale pollution microclimates
- Foundation for highly accurate machine-learning based statistical modeling
- Couple with highly accurate FEM reference instruments to validate regional pollution measurements

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AQ&U – A Platform For Community-Driven Air Quality Research[1]

- Born out of a 2017 NSF grant to study regional effects of urban environmental air pollution
- Collaborative multidisciplinary effort between citizen scientists and University of Utah researchers
- AQ&U goal and focus:
  1. Design, manufacture, and deploy a network of 150 low-cost air quality monitors throughout Salt Lake County
  2. Collect data from AQ&U Network, EPA, PurpleAir, and other 3rd-party sources
  3. Make filtered, calibrated data available to research groups, lawmakers, and the community

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AQ&U

PurpleAir

AirU Air Quality Monitor

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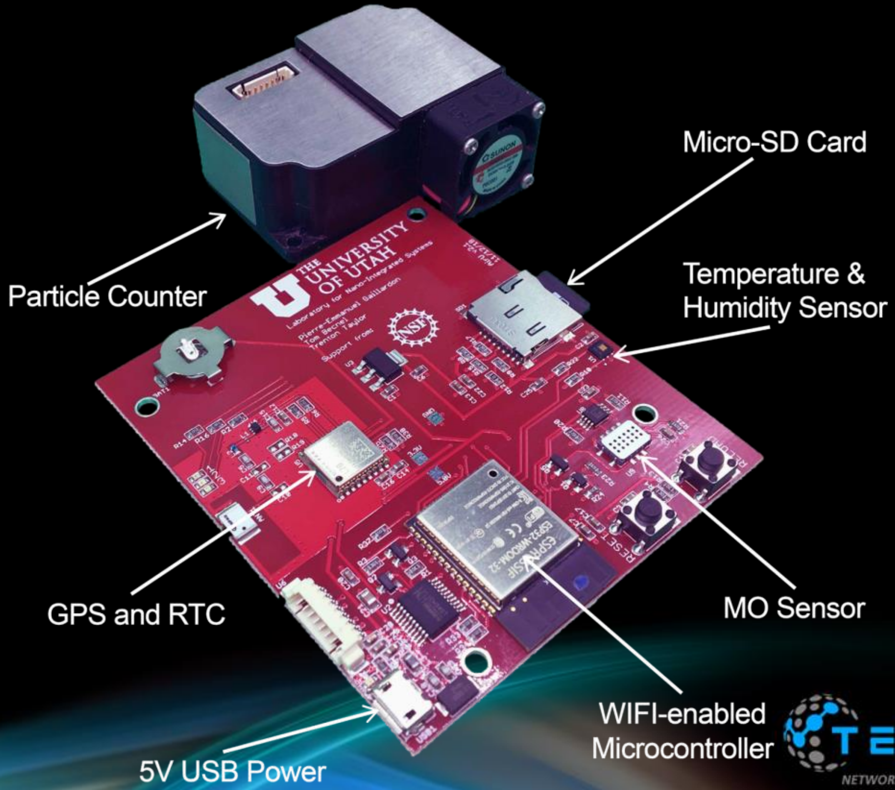
AirU Air Quality Monitor



- Particle counter chosen for robustness and inter-sensor repeatability
- AirU uses WIFI to send data to a secure cloud database
- Backup micro-SD card – upload data from offline periods

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Genesis of AirU Sensors

AirU

- Original NSF grant provided funds for 150 devices
- Strong interest from other municipalities – Created a company to manufacture and sell
- Became TELLUS in 2022
  - Greatly improved AirU quality-of-life
  - Expanded product capabilities: Ozone, NO2, VOCs, Noise Pollution, Solar, Cellular, LoRaWAN on the way!

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Sensor Calibration and Quality Assurance

- Low-cost particle counters have excellent inter-sensor correlation ($R^2 > 0.98$) but moderate cross-sensitivities
- Particle properties and humidity are the dominating parameters
- For example: different correction factors for wildfires, summertime haze, and winter inversions
- Originally produced lab generated device specific correction factors[2]

Plantower PMS3003 particle counter

The correction factors did not accurately reflect the environmental airshed

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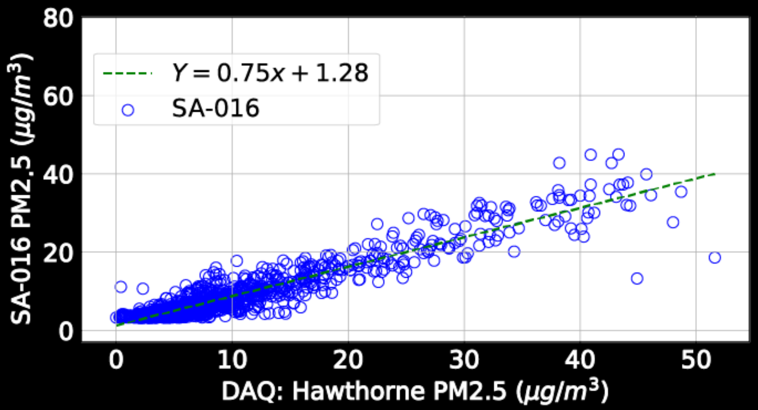
In Situ Calibration



- Post deployment calibration (still vet sensors in lab and ensure good correlation)
- Leverage existing FEM infrastructure as ground-truth
- Demonstrate good correlations with co-located and nearby low-cost sensors and develop a seasonal, *regional* calibration factor
- Exploit low inter-sensor variability and apply *regional* calibration to all devices in the regional network
- $R^2 > 0.9$ and RMSE < 6 on average for FEM co-located AirUs – typical for seasonal calibration periods

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Modeling & Visualization

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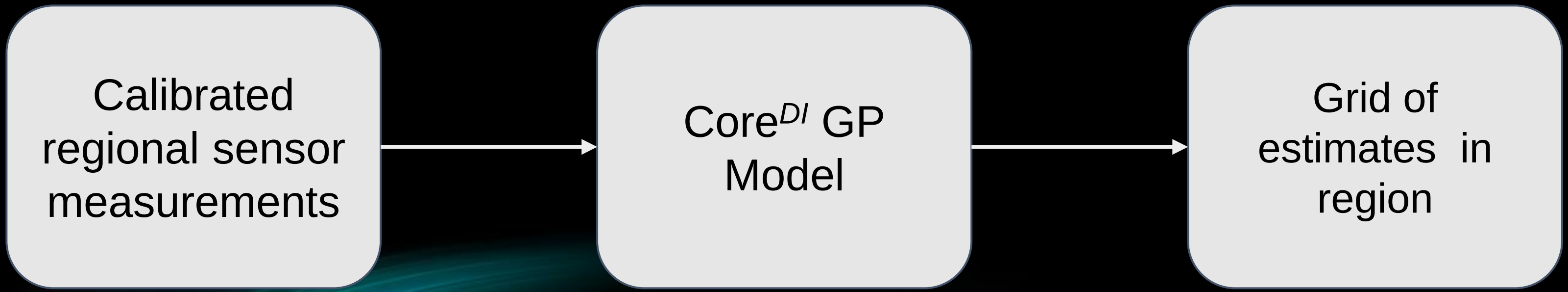
TELLUS Core^{DI} – *A Machine Learning - based Spatial Modeling Tool*

- Gaussian Process (GP) based model developed at the University of Utah[3]
- Train model on regional time-series data to produce estimate (and estimate confidence) anywhere in region



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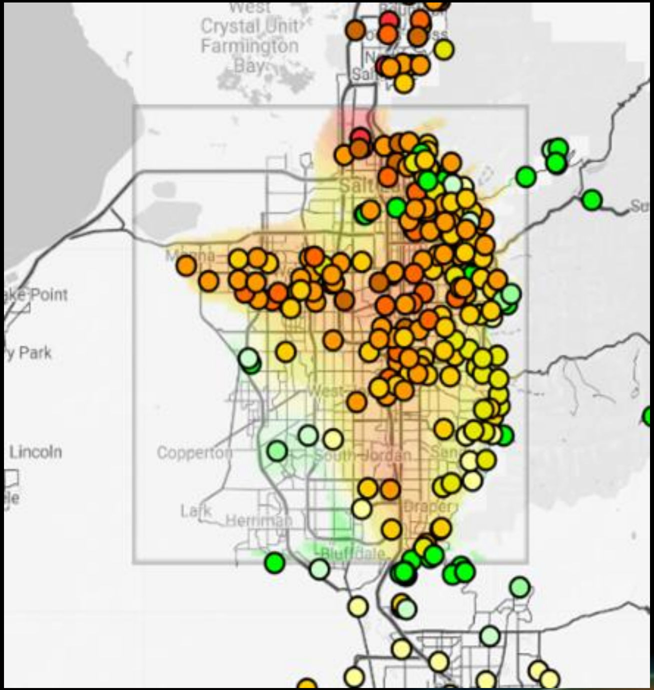
Core^{DI} High-Level Algorithm

1. Collect several hours of data for the given region
2. Filter the raw data outliers
3. Apply seasonal calibration
4. Train Gaussian Process Model
5. Query model at grid points to construct image



Core^{DI} regional snapshot in Salt Lake City, Utah

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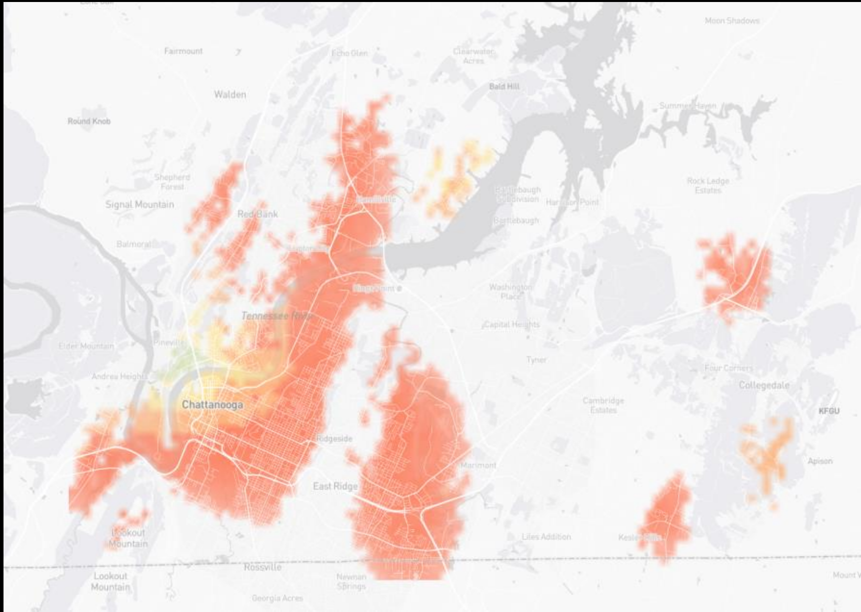
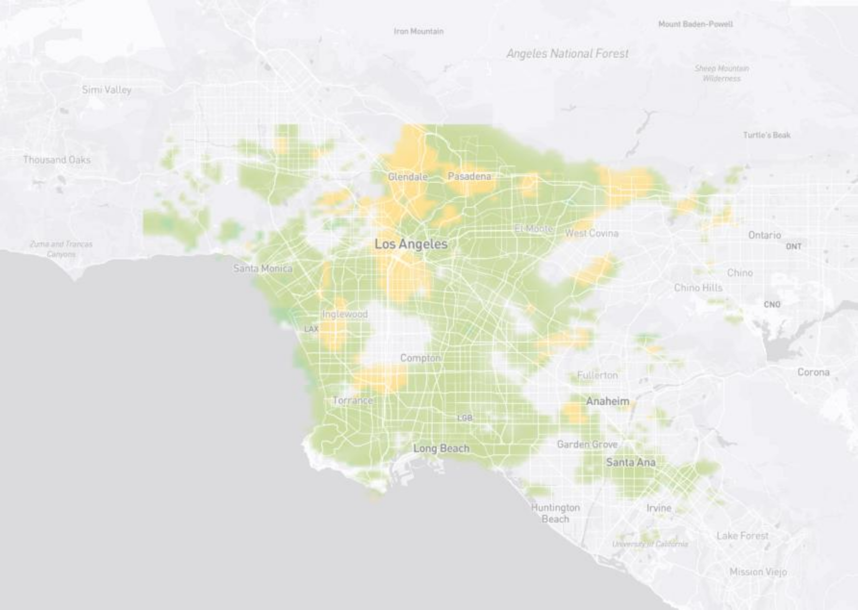
Core^{DI} Regional $PM_{2.5}$ Snapshots



Core^{DI} regional snapshot: Chattanooga, TN



Core^{DI} regional snapshot: Los Angeles, CA

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Core^{DI} Regional $PM_{2.5}$ Animations

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Case Study - AQ&U Network Reveals Unseen Differences in Air Quality[4]

- AQ&U network reveals $PM_{2.5}$ heterogeneity across Salt Lake County during July 4th fireworks
- Traditional EPA AirNow model cannot account for neighborhood-scale discrepancies

$PM_{2.5}$ estimate maps generated by GP model (left) and EPA AirNow (right) for firework event on July 4, 2018

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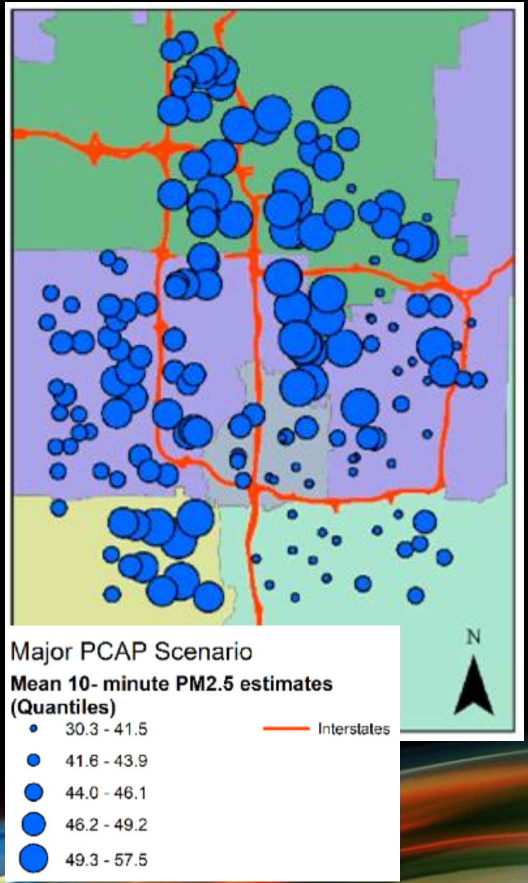
Case Study - Environmental Inequality in Salt Lake Public Schools[3]

- Research shows large variance in $PM_{2.5}$ concentrations across schools during winter inversion
- Schools serving economically deprived students experienced disproportionate exposure
- Exposes need for policy to protect school-aged children from environmental harm



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Aims For Expanding Core^{DI}

- Improve RMSE and automate regional calibrations
  - Implement *scaled-window* rolling calibrations to better capture spontaneous events
  - Predictive calibration using data fusion model in underrepresented regions

- Expand models from $PM_{2.5}$ predictions to include NO_2, ozone, PM_{10}, and many others!

- Expand model geographically to more regions

Conclusion

- We have designed, manufactured, and deployed a large-scale, cost-effective air quality monitoring network, which has been active in multiple cities throughout the United States since 2017
- We perform seasonal, regional network calibrations using ground-truth sources to improve the accuracy of the network
- We developed a software-based spatial modeling tool – Core^{DI} – to further improve the spatial resolution of air quality data and provide insightful air quality visualizations

TELLUS stands ready to respond to this growing interest by expanding cost-effective air quality sensor networks to serve more communities, providing valuable information and insights on local air quality.

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Thank You

Questions?

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[4] K. E. Kelly, W. Xing, T. Sayahi, L. Mitchell, T. Becnel, P.-E. Gaillardon, M. Meyer, and R. T. Whitaker. Community-based measurements reveal unseen differences during air pollution episodes. Environmental science & technology 55, no. 1 (2020): 120-128.

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