A Vision of the Next Generation of Earth Observing System and the Role of Machine Learning

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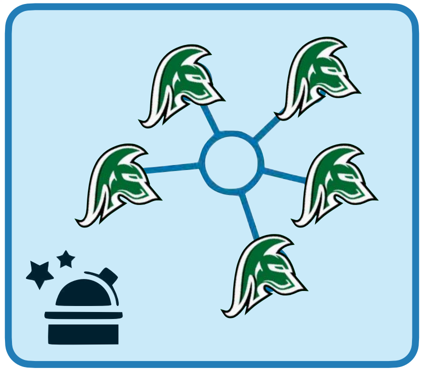
MINTS Multi-Scale Multi-Use Integrated Intelligent Interactive Sensing and Simulation

The Next Generation

MINTS Environmental & Social Observatory for Actionable Insights



Cyber Physical Observatory

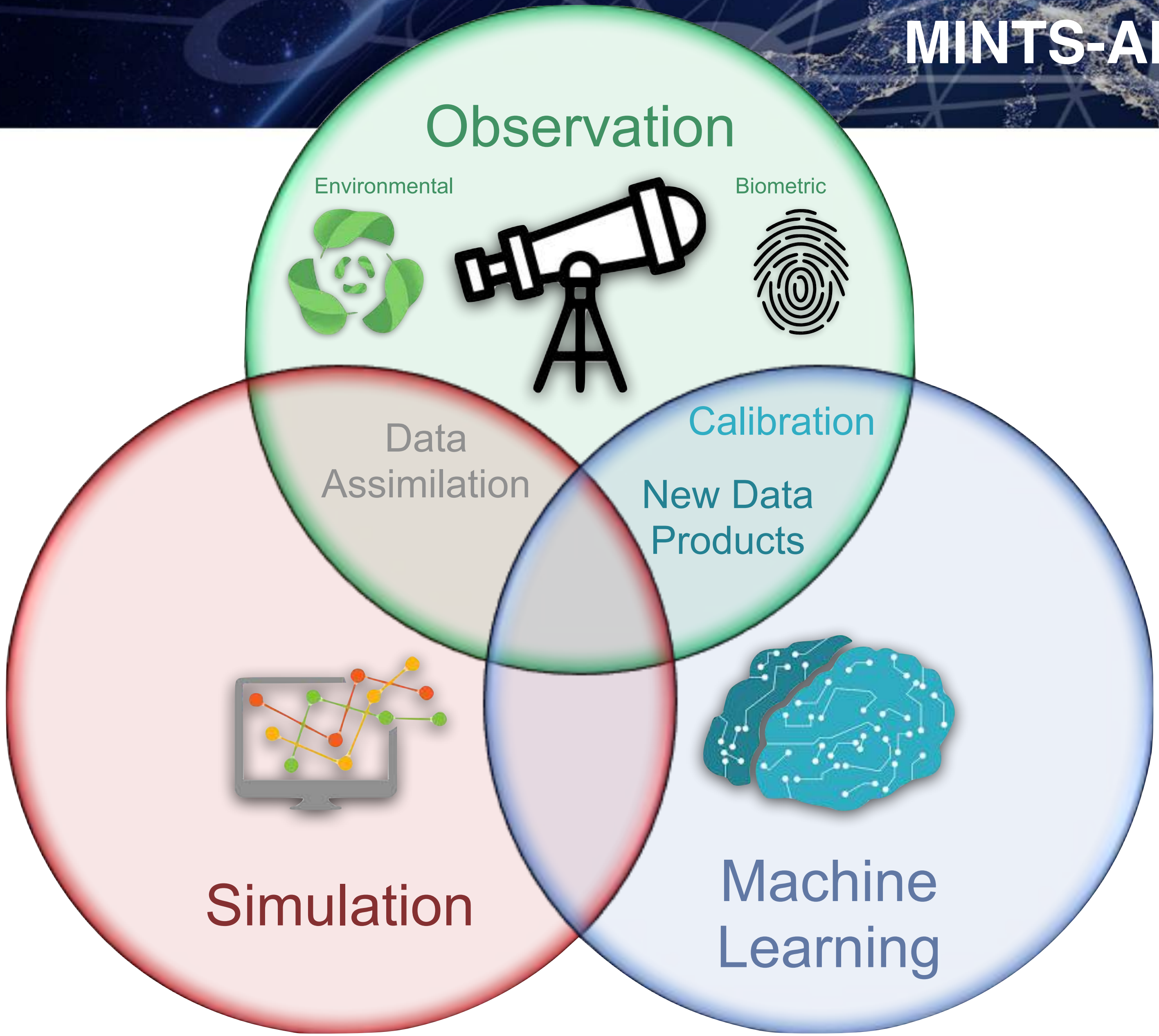
Measure -- Simulate -- Protect & Improve
Intelligent Prediction -- Advanced Detection -- Accelerated Intervention
Towards Decoding Human Chem-Bio Detection

Multi-Use Multi-scale Integrated Interactive Intelligent Sensing and Simulation providing Actionable Insights

Vision Statement

Holistic smart sensing and simulation to provide timely actionable insights and transparent transformative data for data driven decisions.

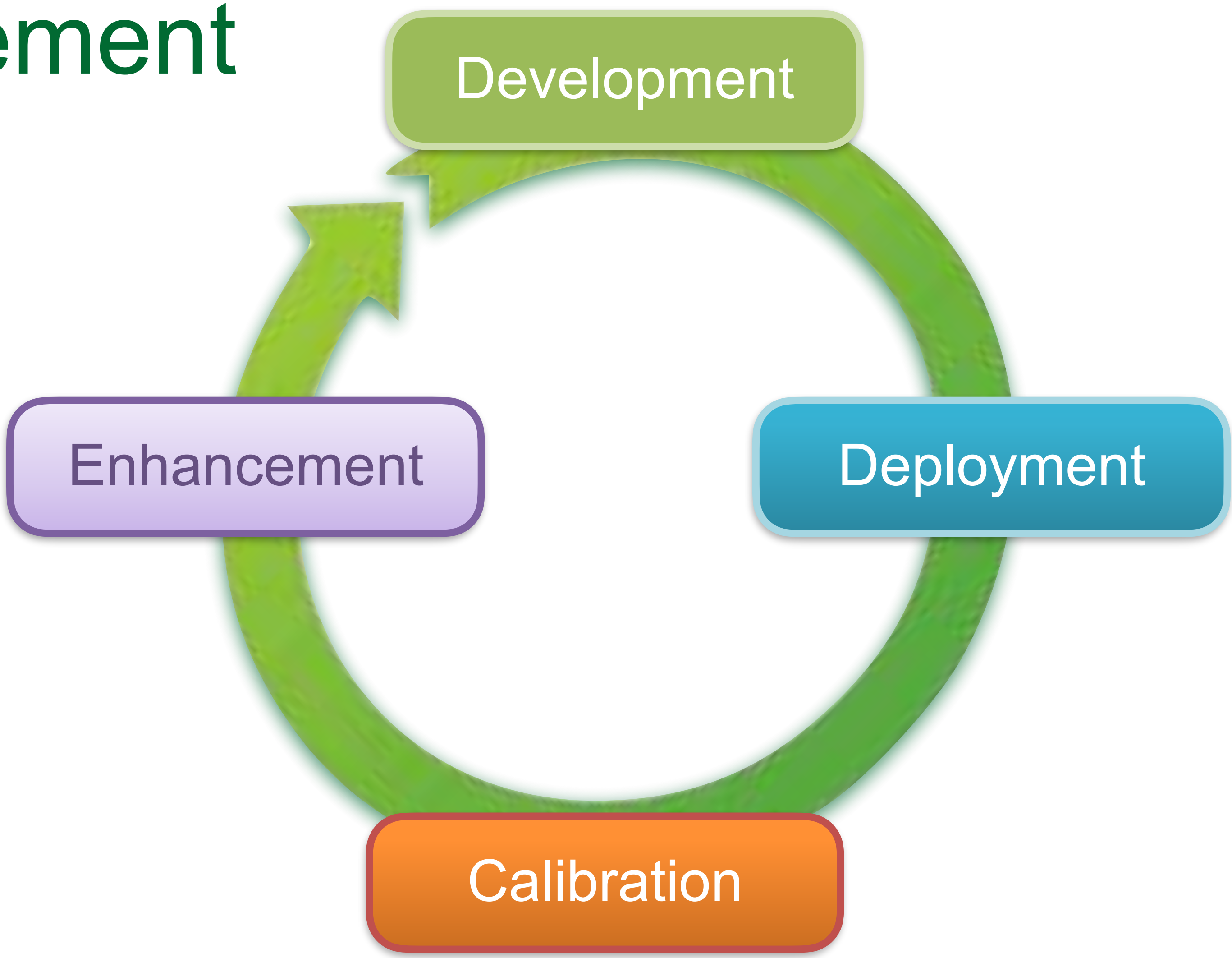
Machine learning combined with holistic sensing as a service is a powerful tool in addressing a wide range of challenging issues.



Uses of machine learning:

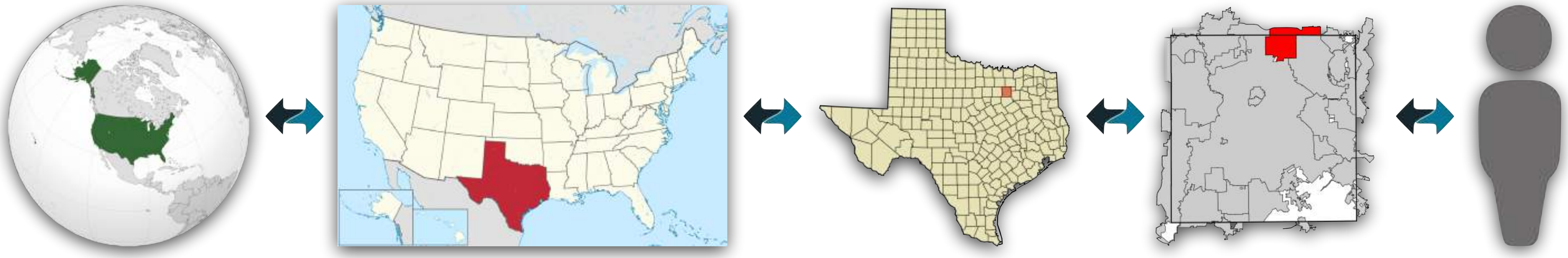
1. Calibration of low-cost sensors
2. Creation of new data products (e.g. remotely sensed products)
3. Super-resolution
   - Spatial
   - Wavelength
4. Physics based machine learning, e.g. for solving ODEs for chemically reactive systems with inference of missing terms

Continuous Enhancement



Multi-Use **M**ulti-scale **Int**egrated **Int**eractive **Int**elligent **S**ensing & **S**imulation

<u>Ubiquitous</u> Multi-use



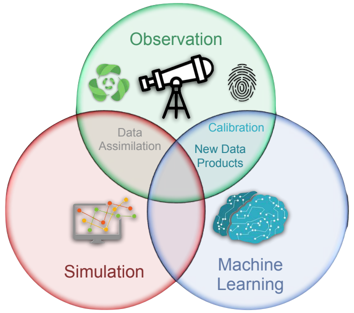
Spatial

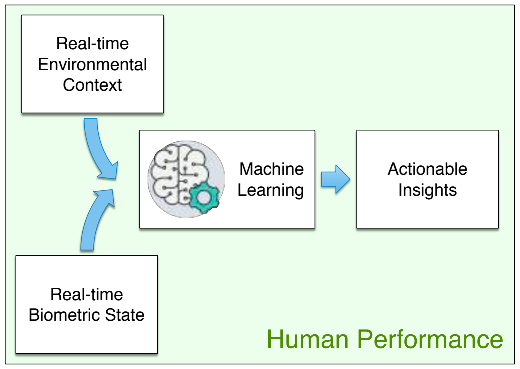
Temporal

Physical Environment **Social Environment**

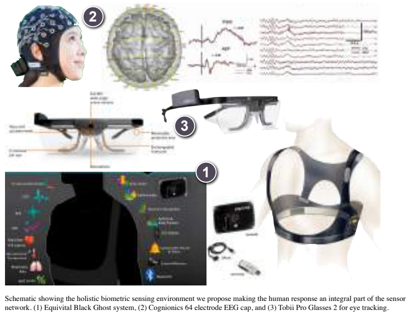
MINTS-AI

MINTS Comprehensive Context Engine





Biometrics Package



Human Sentinels Wearable Sensors

Nine Sentinel Types

Simulation Sentinels

Remote Sensing Sentinels

Aerial Survey Sentinel

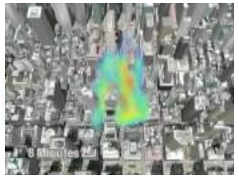
24/7 Streaming Distributed Sentinels

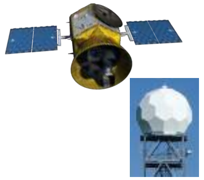
Walking Sentinels

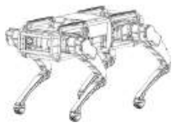
Ground Survey Sentinels

Robotic Boat Sentinel

Underwater Sentinel

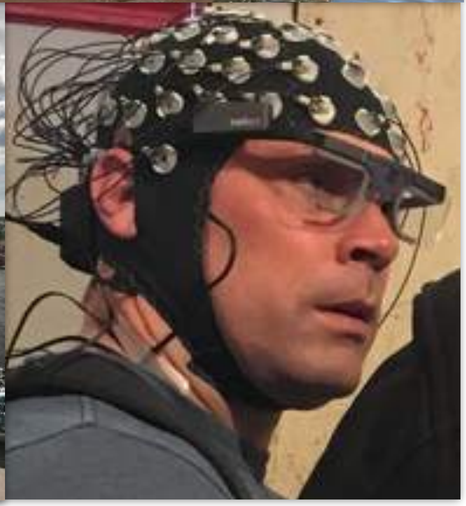






Example Platforms

Platform

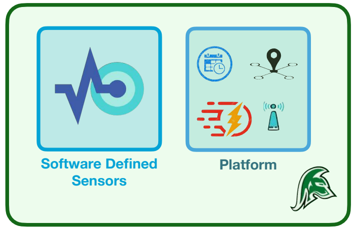


Platform: Provides sensor with power, time and location stamps all observations, provides communication, and where relevant mobility. This may include wearable sensors.

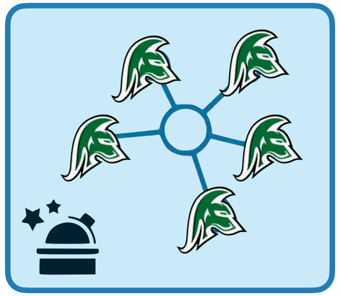
Concept Definitions

Software Defined Sensors

Platform



Sentinel



Cyber Physical Observatory

- **Software Defined Sensor**: Smart sensor package which combines a physical sensing system with software/machine learning providing a variety of calibrated data products which can be updated via an app store.
- **Platform**: Provides sensor with power, time and location stamps all observations, provides communication, and where relevant mobility. This may include wearable sensors.
- **Sentinel**: Software Defined Sensor + Platform
- **Robot Team**: A collection of co-operative autonomous sentinels
- **Cyber Physical Observatory**: A collection of sentinels and/or robot teams providing real time actionable insights.

Fully Autonomous Robotic Team

For Data Product Creation and Automated Cal/Val

Test Site in Nacona, TX

System Capability

- Autonomous Robotic Aerial Vehicle — FreeFly Alta-X (USA)
  - Remote sensing payload
  - In-situ aerosol and gas sensing payload
  - On board machine learning

- Autonomous Robotic Boat — Maritime Robotics Otter (Norway)
  - Remote sensing payload
  - In-situ water sensing payload
  - In-situ aerosol and gas sensing payload
  - In-situ meteorological sensing payload

- Ground remote control stations

Autonomous Aerial Vehicle with Payload

Real-Time Onboard Georectification

Goal

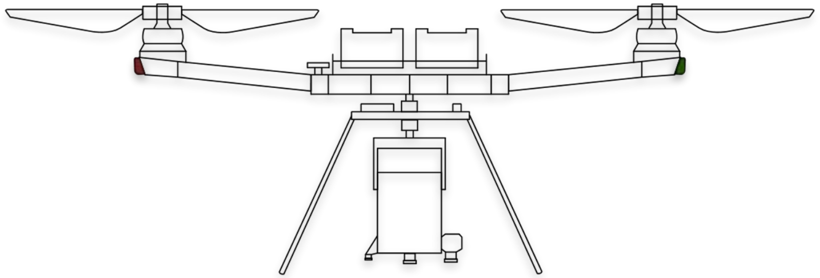
- Generate the precise latitude & longitude for each hyper-spectral image pixel.

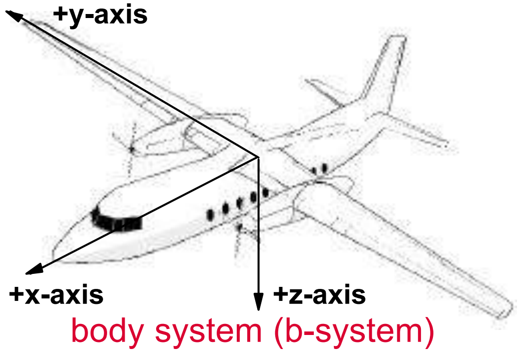
Data Products Generated by the Resonon Pika XC2 Hyper-Spectral Camera

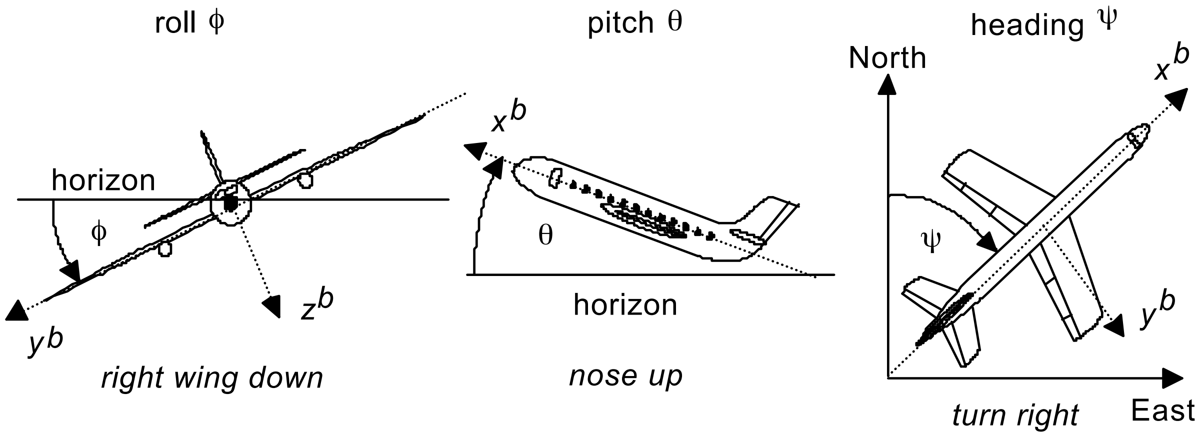
- 1,600x1,000 pixels
- 462 wavelengths from 391–1,011 nm (Visible to VNIR)
- ~ 4 Gb per image
- ENVI binary format
- Latitude, longitude and altitude from the Global Positioning System (GPS)
- Roll, pitch, and yaw from the Inertial measurement unit (IMU)

Assumptions

- The GPS, IMU and hyper-spectral imager are collocated.







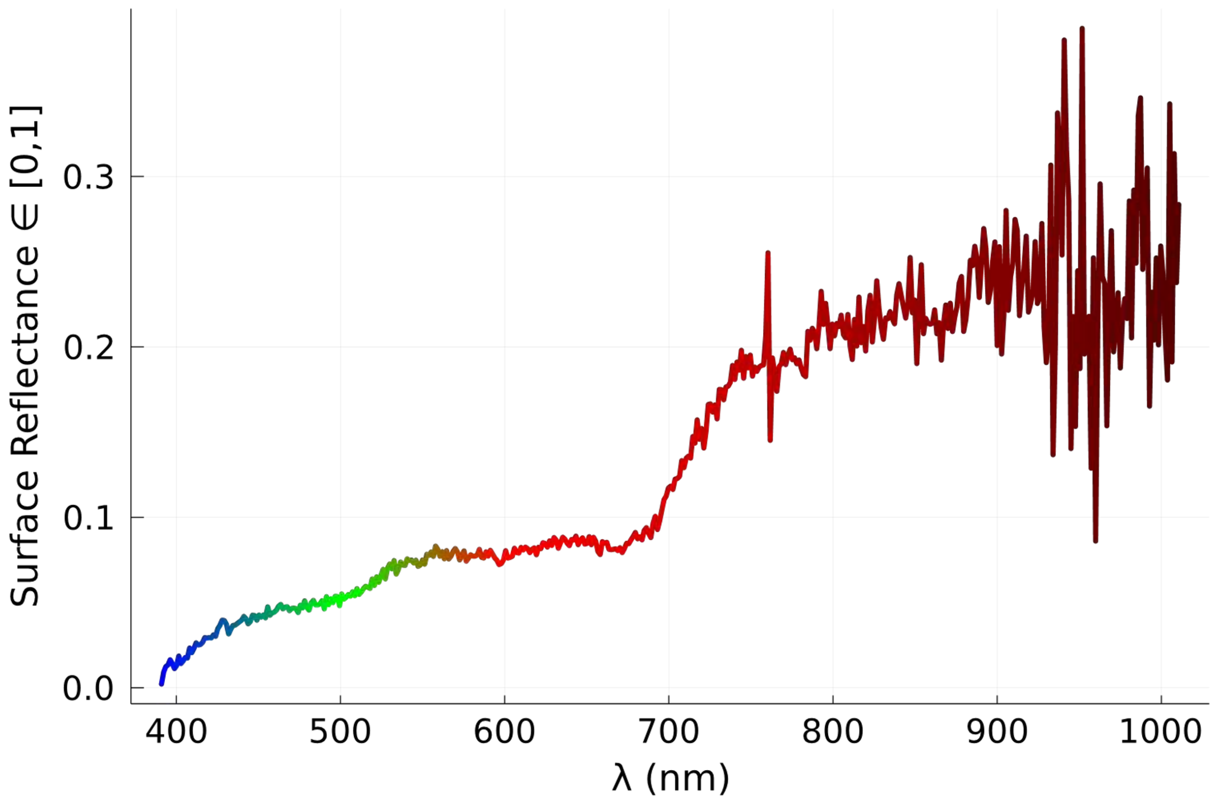
Hyper-spectral Spectrum

Create a HDF5 file containing:

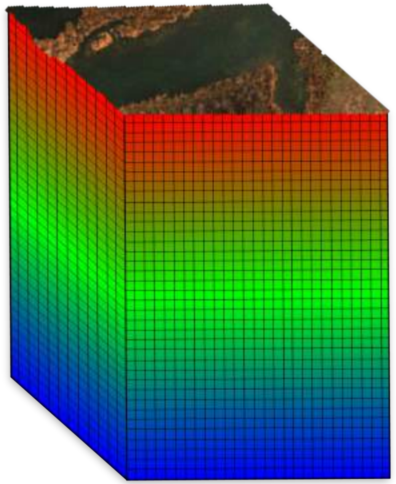
- Datacube
- Wavelengths
- Georectified Coordinates
- Pixel Times
- Pixel Resolutions

The HDF5 files may be compressed for more efficient use of storage.

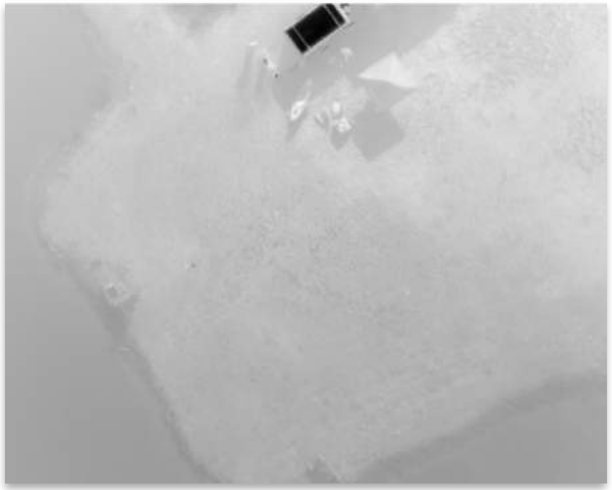
An example spectrum for a single pixel



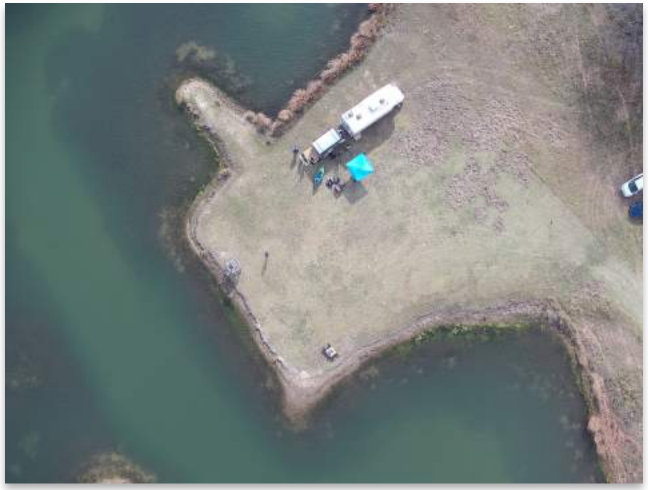
Full UAV Remote Sensing Data Stack



Hyperspectral
Datacube

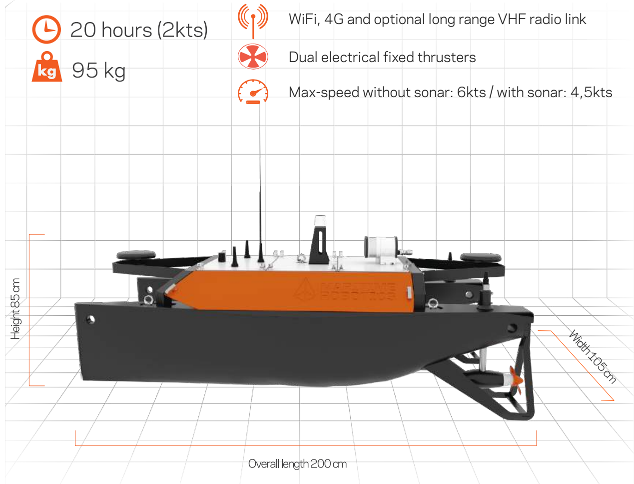


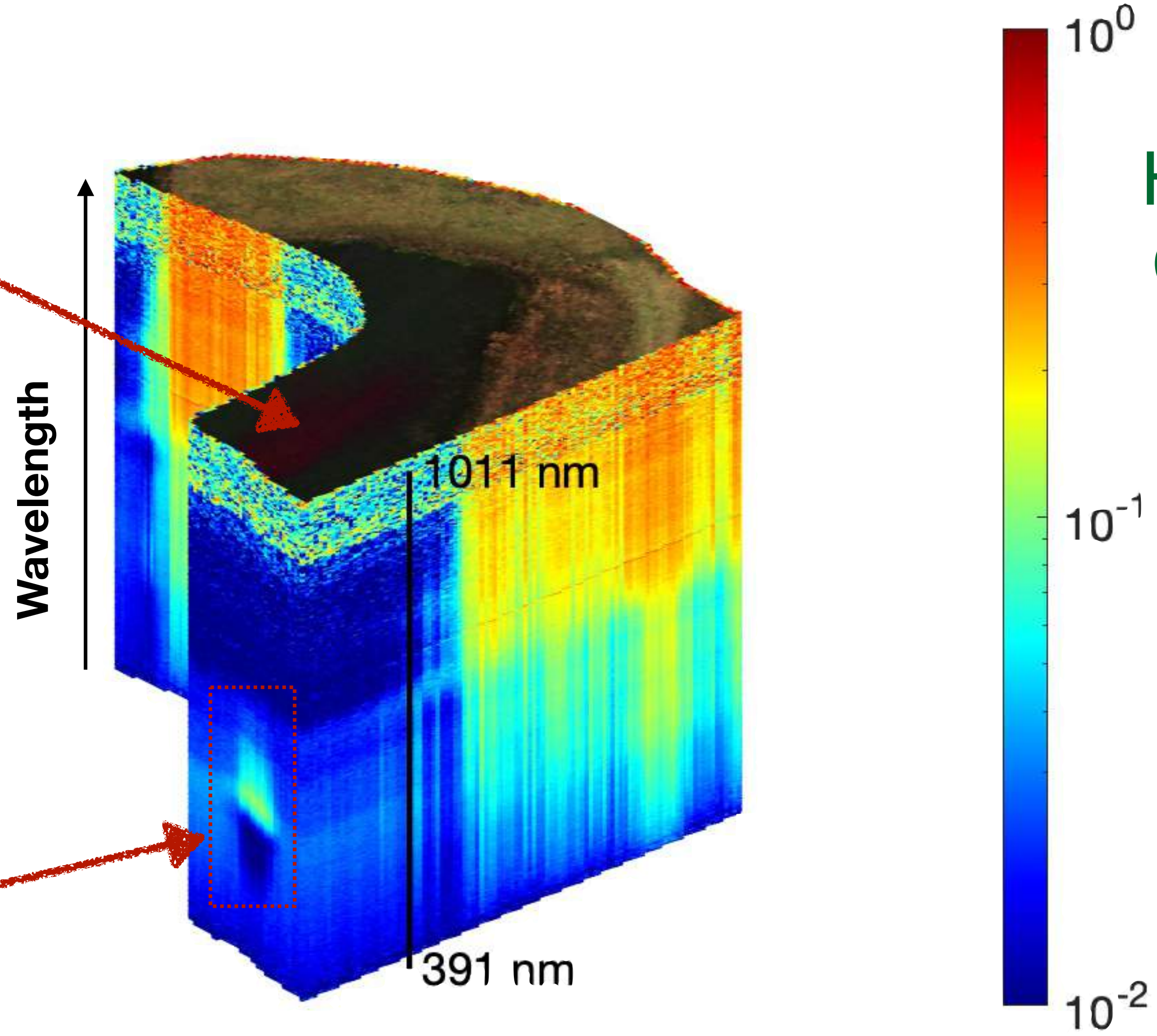
Thermal (Infrared)
Image



High Resolution
Visible Image

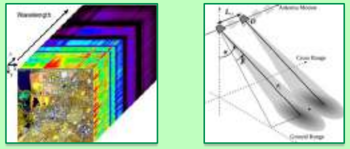
Autonomous Boat: Maritime Robotics Otter





Hyper-Spectral Data Cubes are Acquired

Simulant Spectral Signature

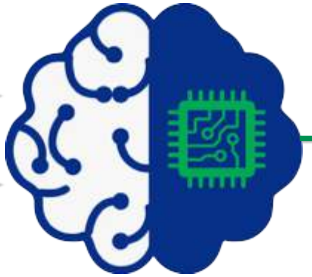


Remotely Sensed Hyperspectral and Synthetic Aperture RADAR Imagery

Rapid Large Area Capability

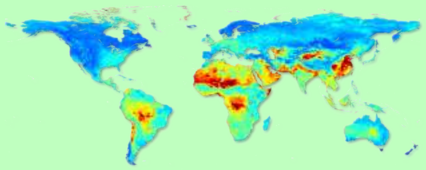
In-situ accurate sensing using mass spectrometers, fluorometers, radiation sensors, etc.

Local Accurate Capability



Supervised Machine Learning

Learn specific signatures



Large Area Data Products Provided by Machine Learning

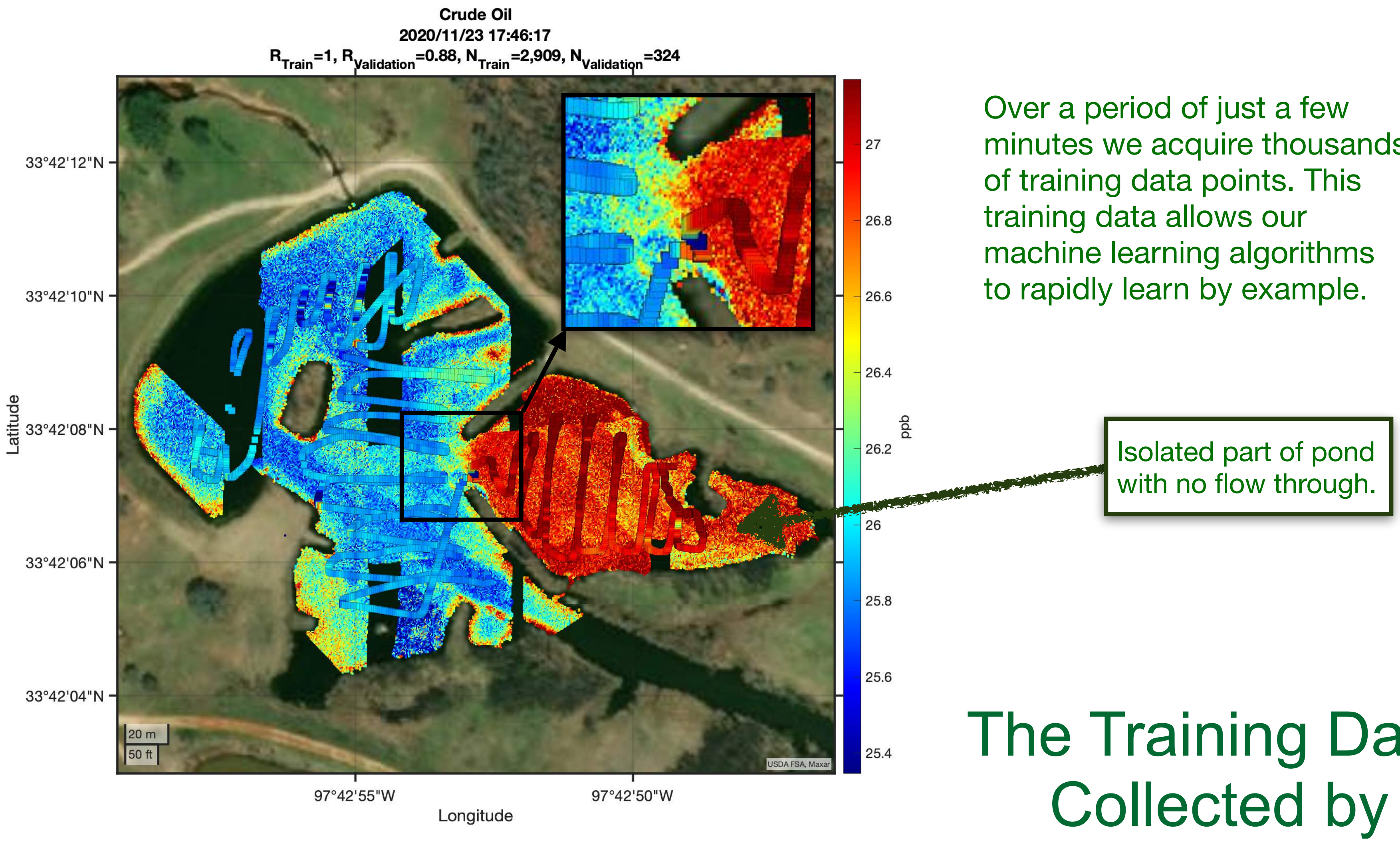
Multi-Variate Regression

$$y = f(x_1, x_2, x_3, x_4, x_5, \ldots x_n)$$

x_1	x_2	x_3	x_4	x_5	...	x_n	y
Training Data							
Inputs	Inputs	Inputs	Inputs	Inputs	Inputs	Inputs	Output(s)

Mode 1: Coordinated robots using onboard Machine Learning for specific data products

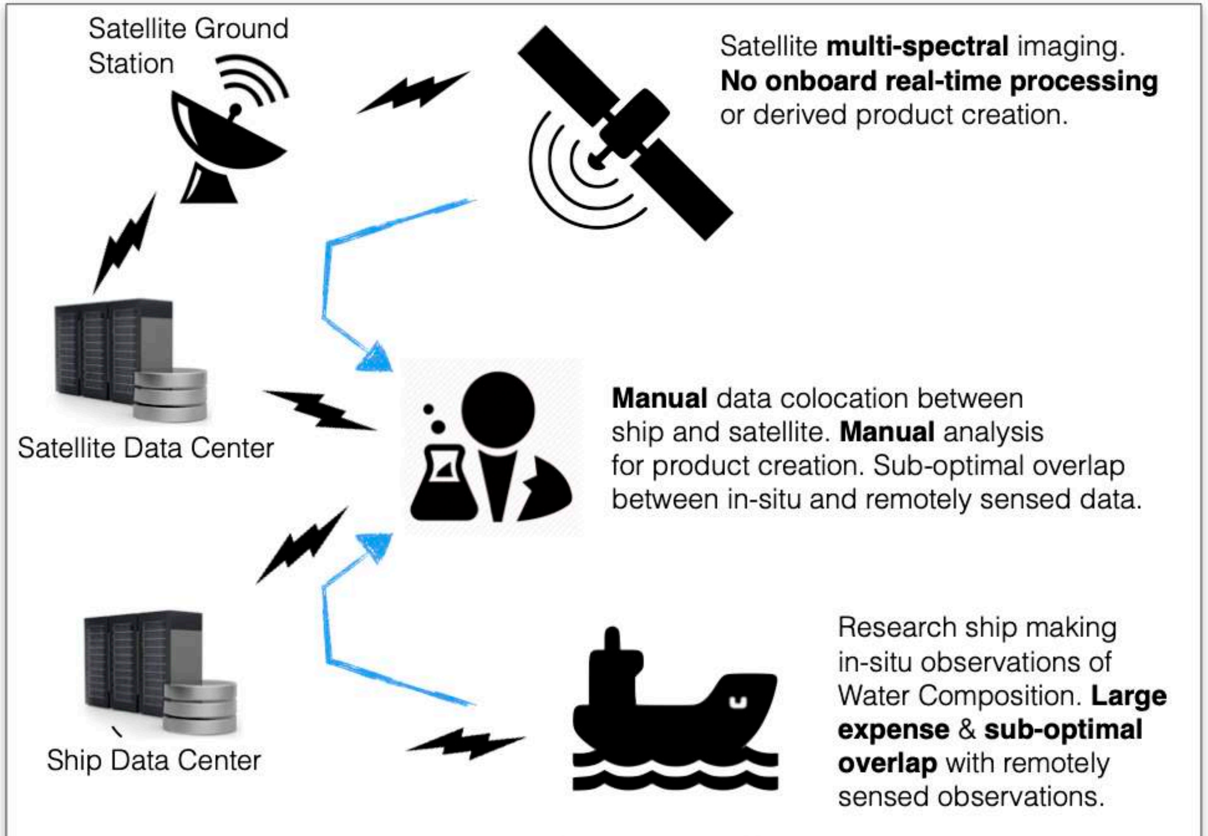
MINTS-AI



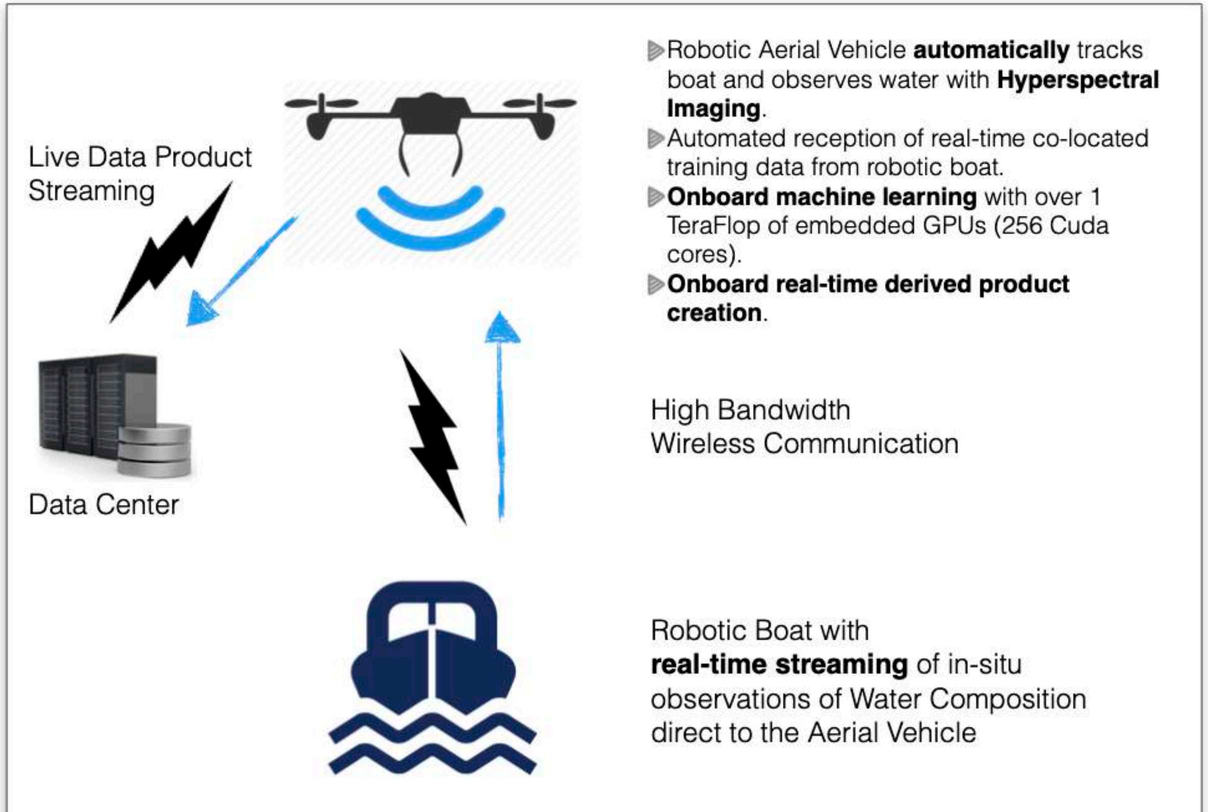
Over a period of just a few minutes we acquire thousands of training data points. This training data allows our machine learning algorithms to rapidly learn by example.

The Training Data is Autonomously Collected by the Robot Team

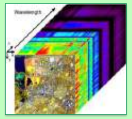
Automating Remote Sensing Data Product Creation

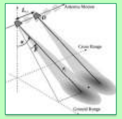


Data Product Development Timescale of many months to years



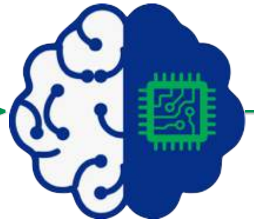
Near Real Time Data Product Development Timescale with
Automated Quality Control & Validation





Remotely Sensed Hyperspectral and Synthetic Aperture RADAR Imagery

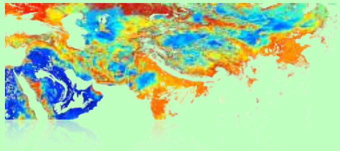
Rapid Large Area Capability



Learn Signatures

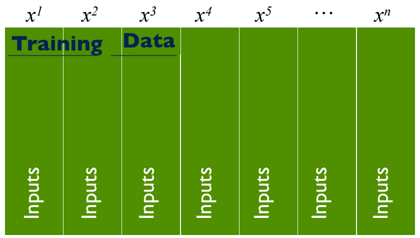
Mode 2: Use remote sensing signatures to suggest optimum sampling patterns

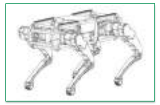
Unsupervised Machine Learning



Classification Provided by Machine Learning

Clustering (Unsupervised Classification)



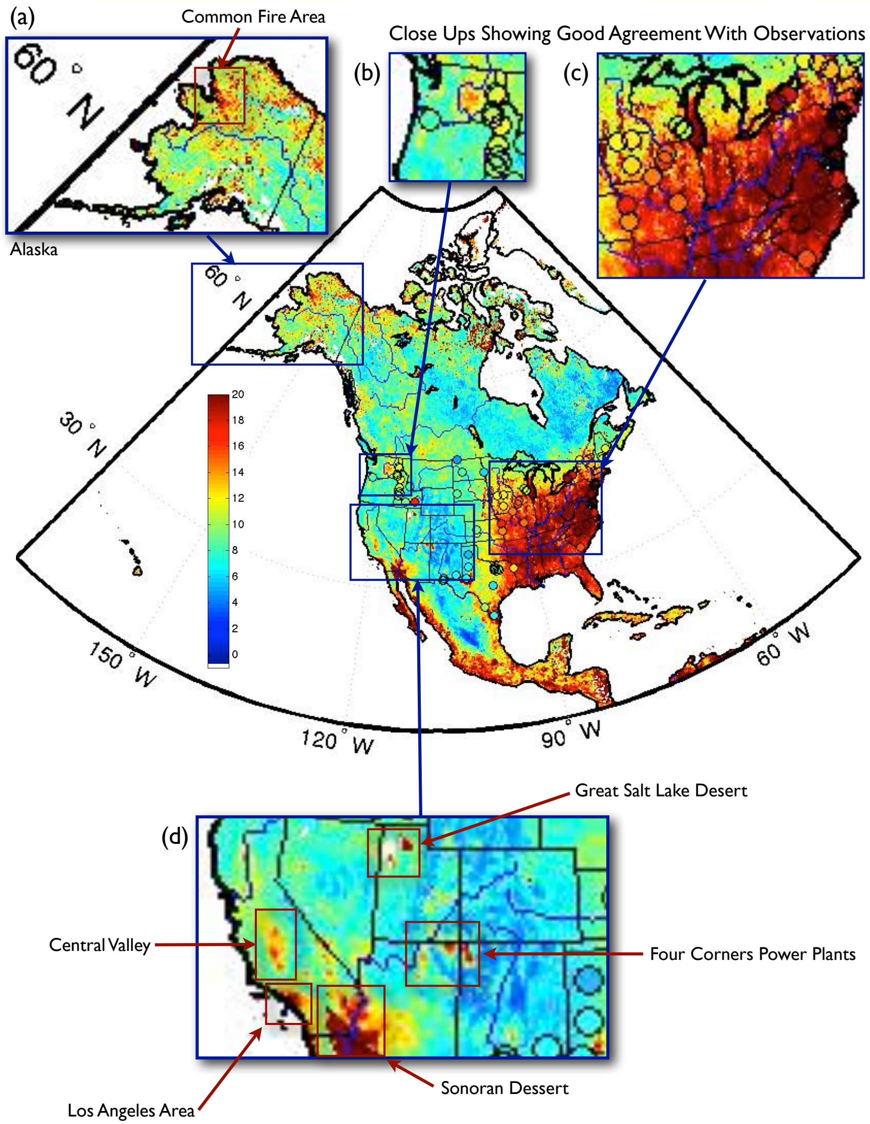


In-situ accurate sensing using mass spectrometers, fluorometers, radiation sensors, etc.

Local Accurate Capability

Tell Surface Robots Where to Take Samples

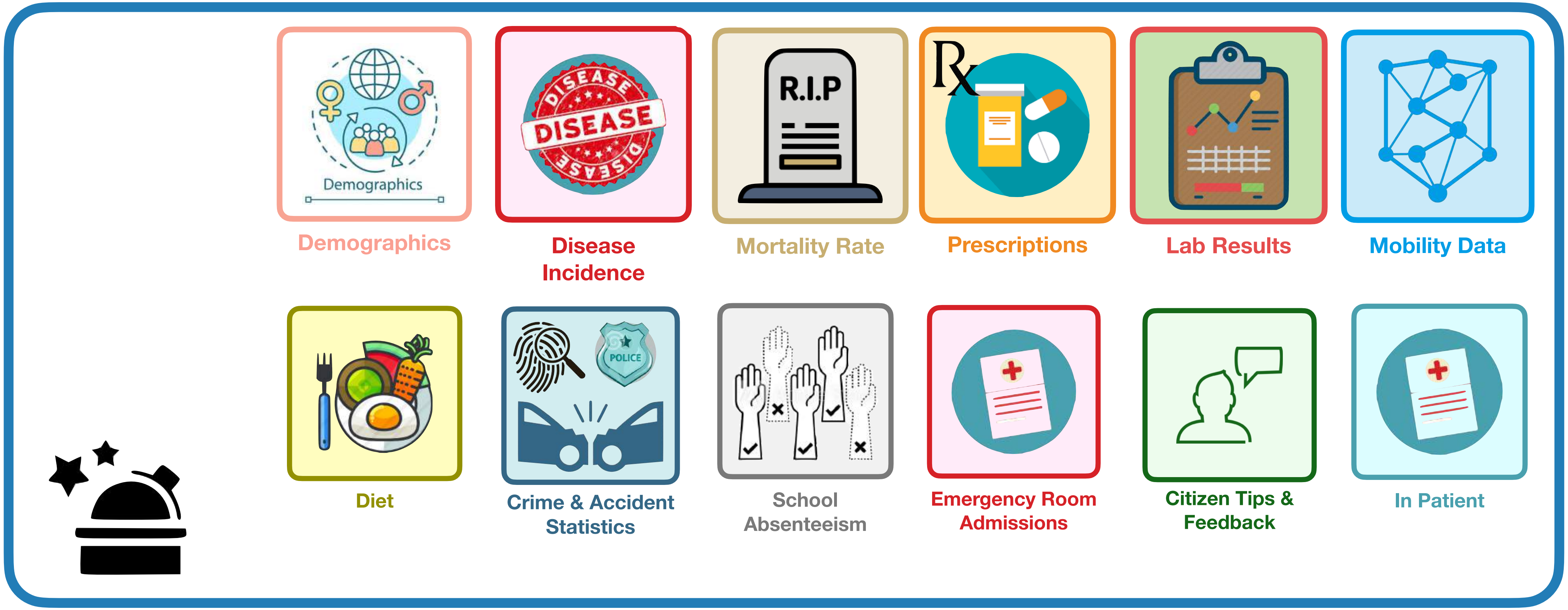
MINTS-AI



Software Defined Sensors

What Resolution Do We Need?

Social Observatory

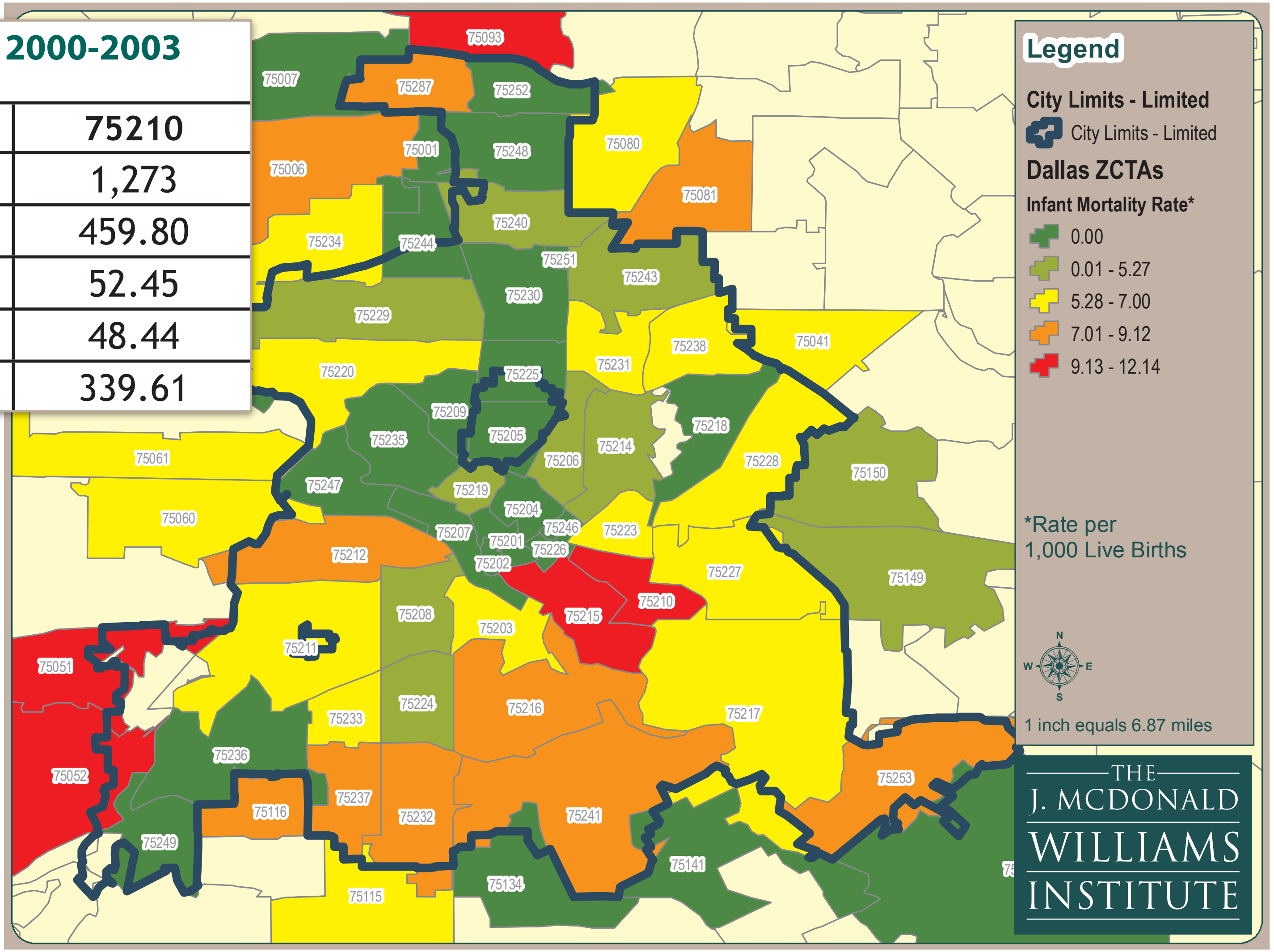


Social Observatory

The social observatory provides real time social context

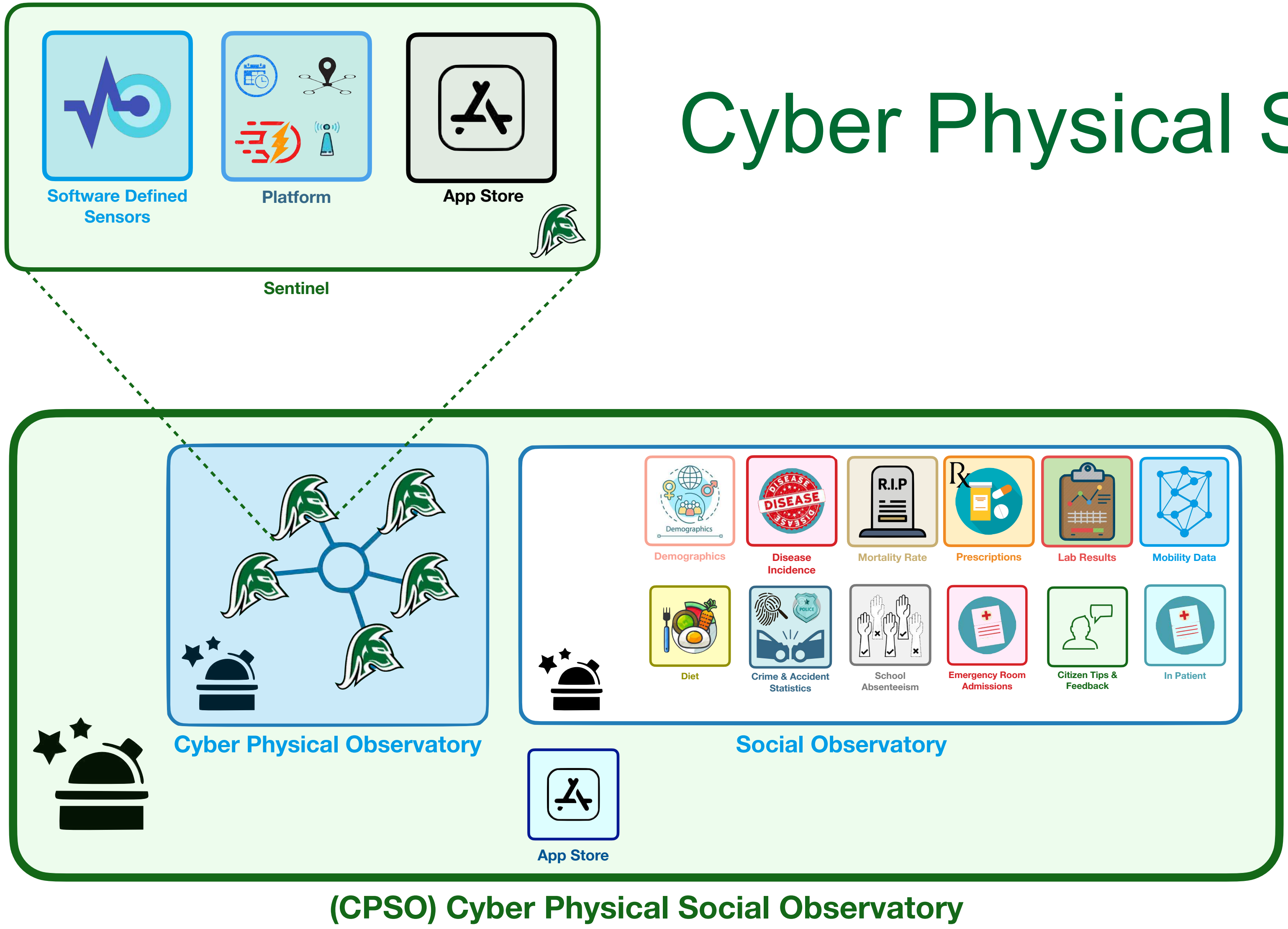
Table 2. Age-Adjusted Death Rates Per 100,000, Years 2000-2003

	Texas	Dallas County	City of Dallas	75210
All causes	876.98	883.88	907.00	1,273
CVD	252.65	260.83	263.53	459.80
Diabetes	31.80	19.38	26.82	52.45
Stroke	63.38	63.35	64.20	48.44
Cancer	191.28	198.18	202.86	339.61

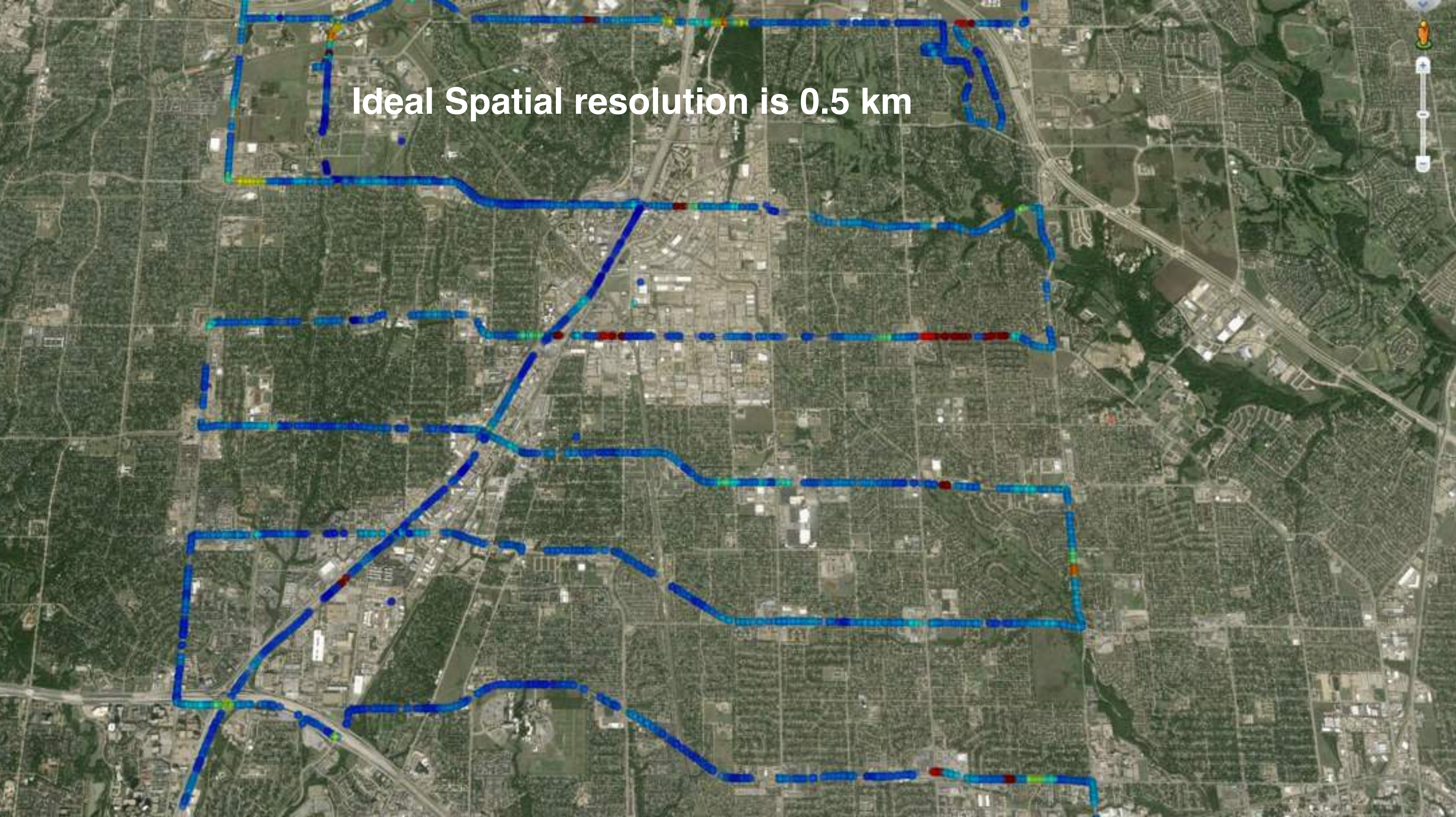


Infant Mortality per 1,000 Live Births by Zip Code,

Cyber Physical Social Observatory

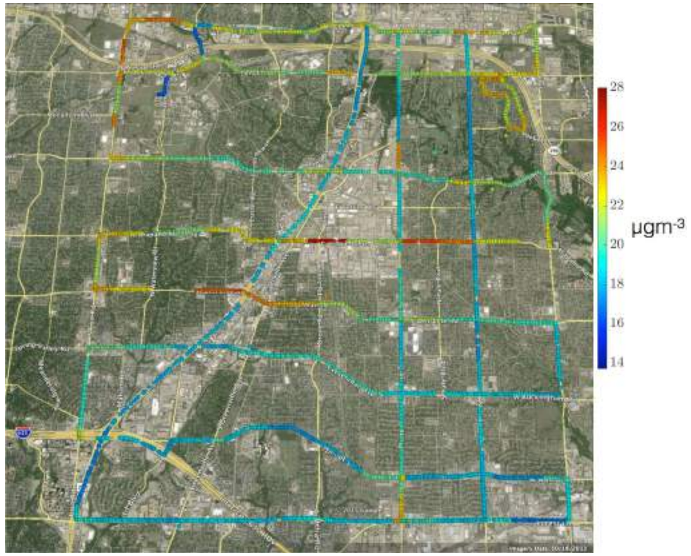


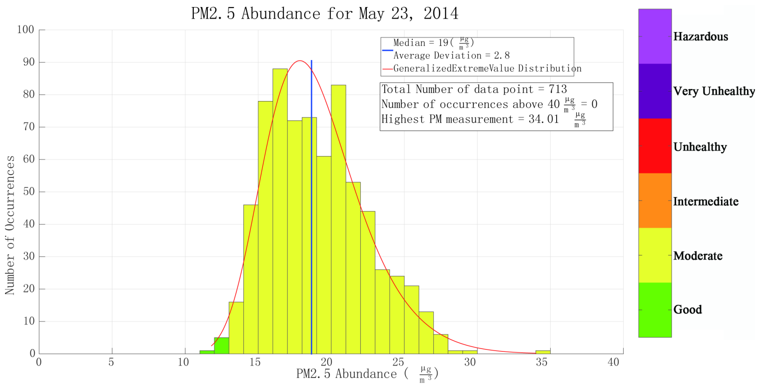
Real time holistic environmental and social data for actionable insights. With App stores for on the fly generation of new data products.


Ideal Spatial resolution is 0.5 km

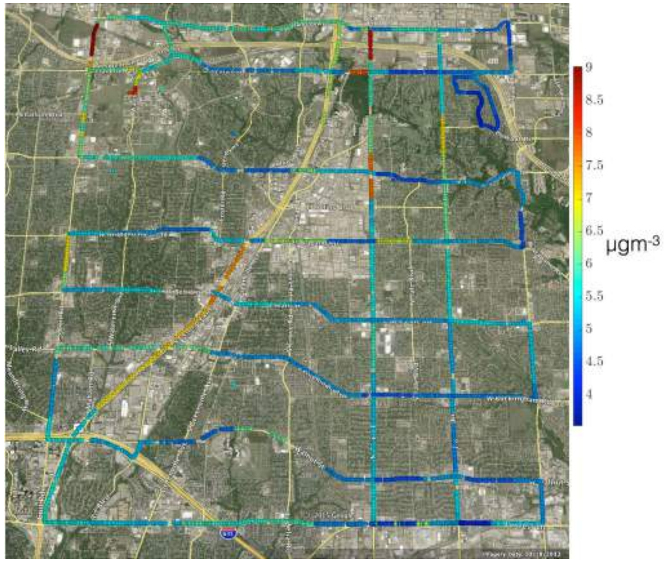
MINTS-AI

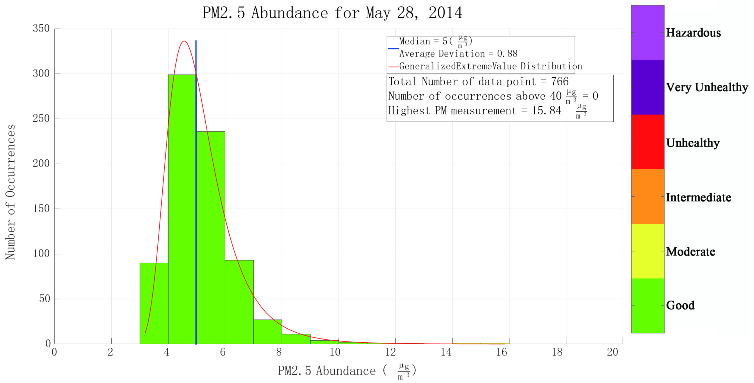
May 23, 2014



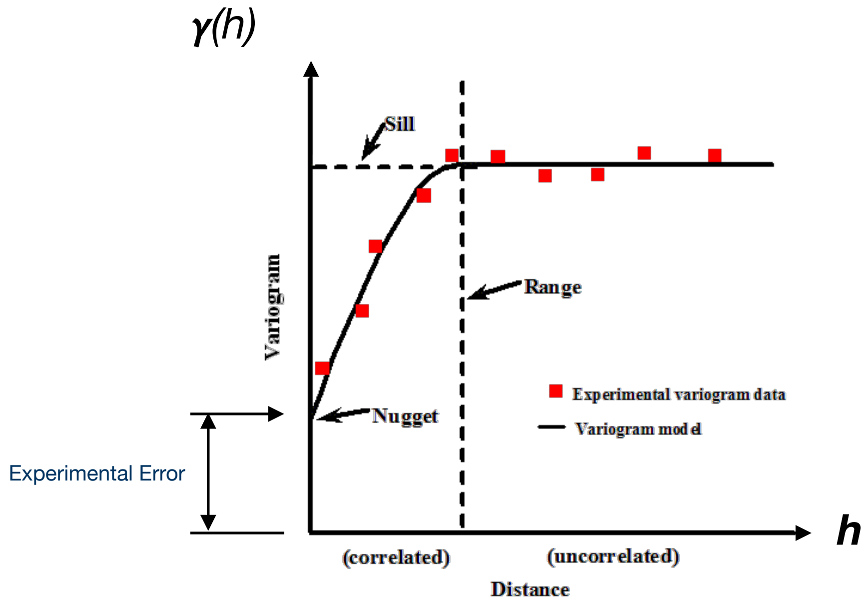


May 28, 2014



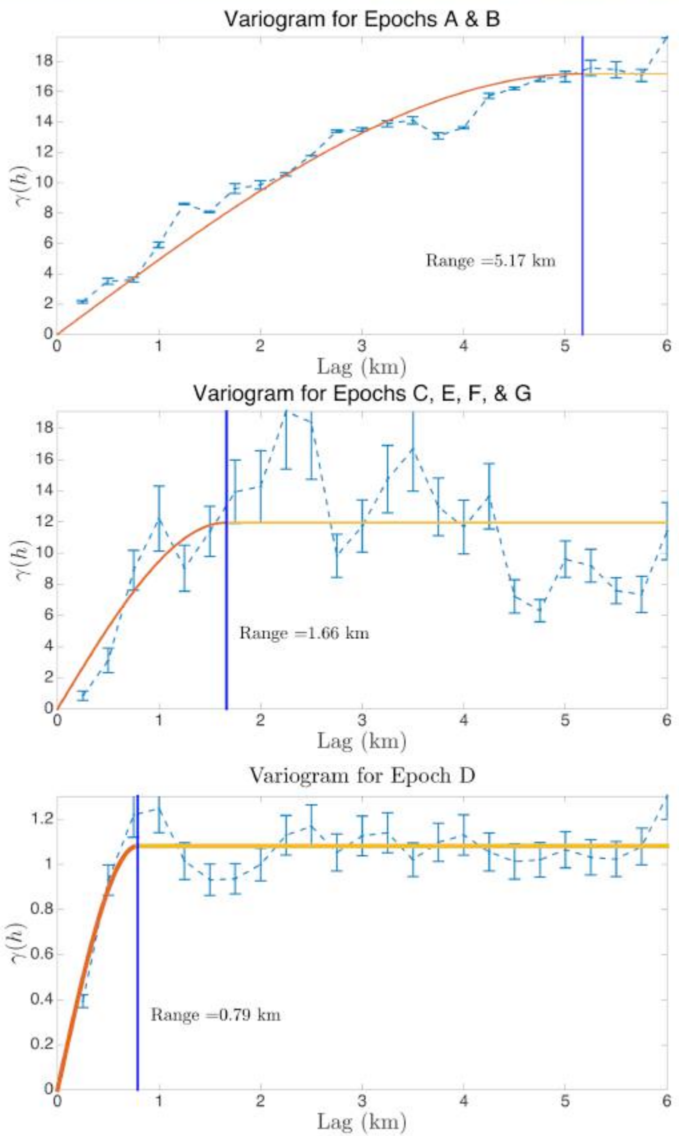


What Resolution Do We Need?



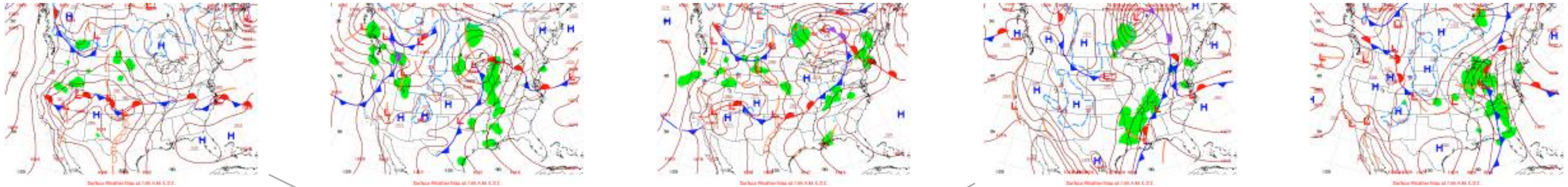
$$\gamma(h) = \frac{\sum\left(y\left(x_i + h\right) - y\left(x_i\right)\right)^2}{2N}$$

Half of the variance

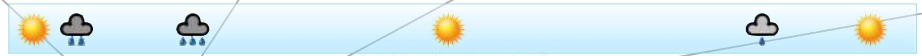


MINTS-AI

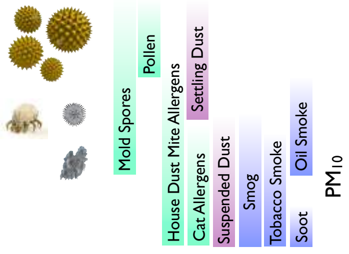
Low pressure front moving in		Low pressure front moving out	High pressure front moving in	Stationary high pressure front

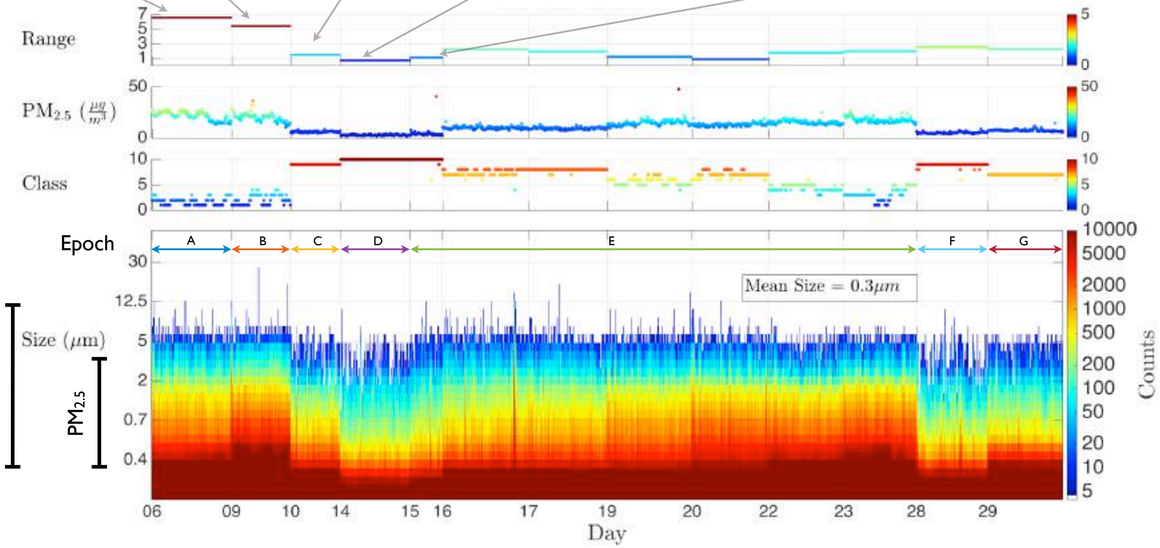


May 6 May 9 May 10 May14 May 15



May 2014





No significant rain in 16 days

0.56" of rain on May 8

0.91" of rain for May 12, 13, and early morning on May 14 combined

0.27" of rain for May 25, 26, and 27 combined

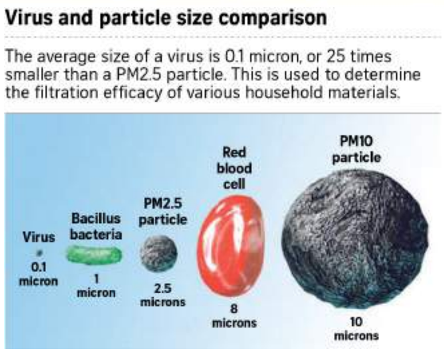
Cheaper Commercial Sensors

Standardized Commercial Sensors

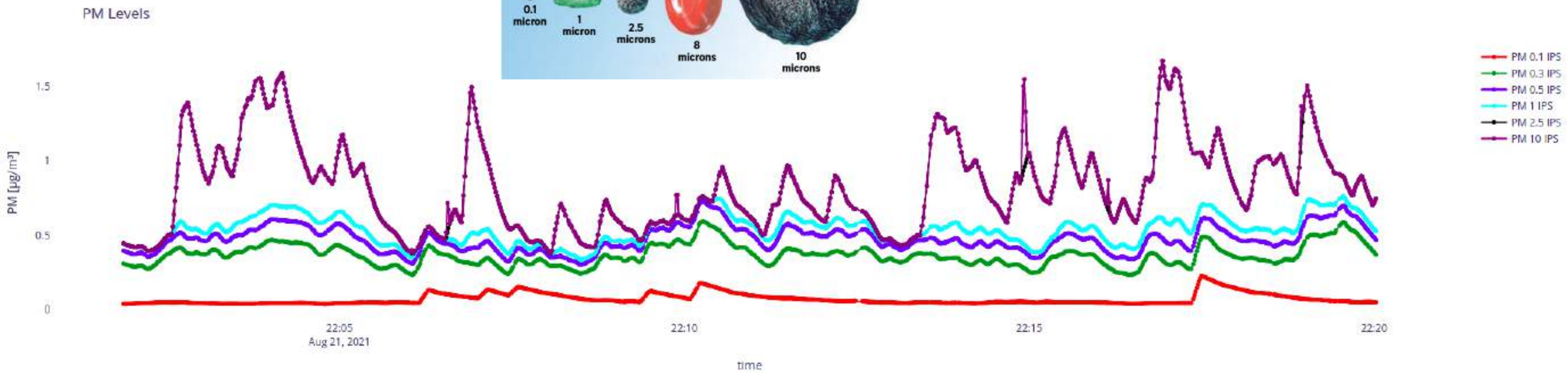
Research Grade Sensors

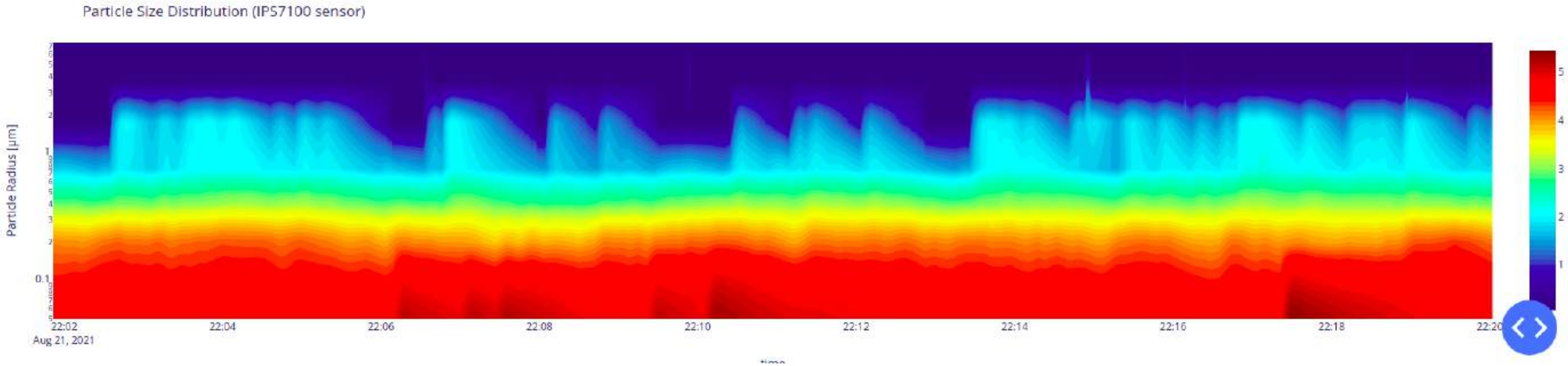
FRM / FEM Sensors

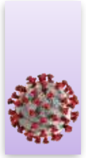
Sensing Hierarchy

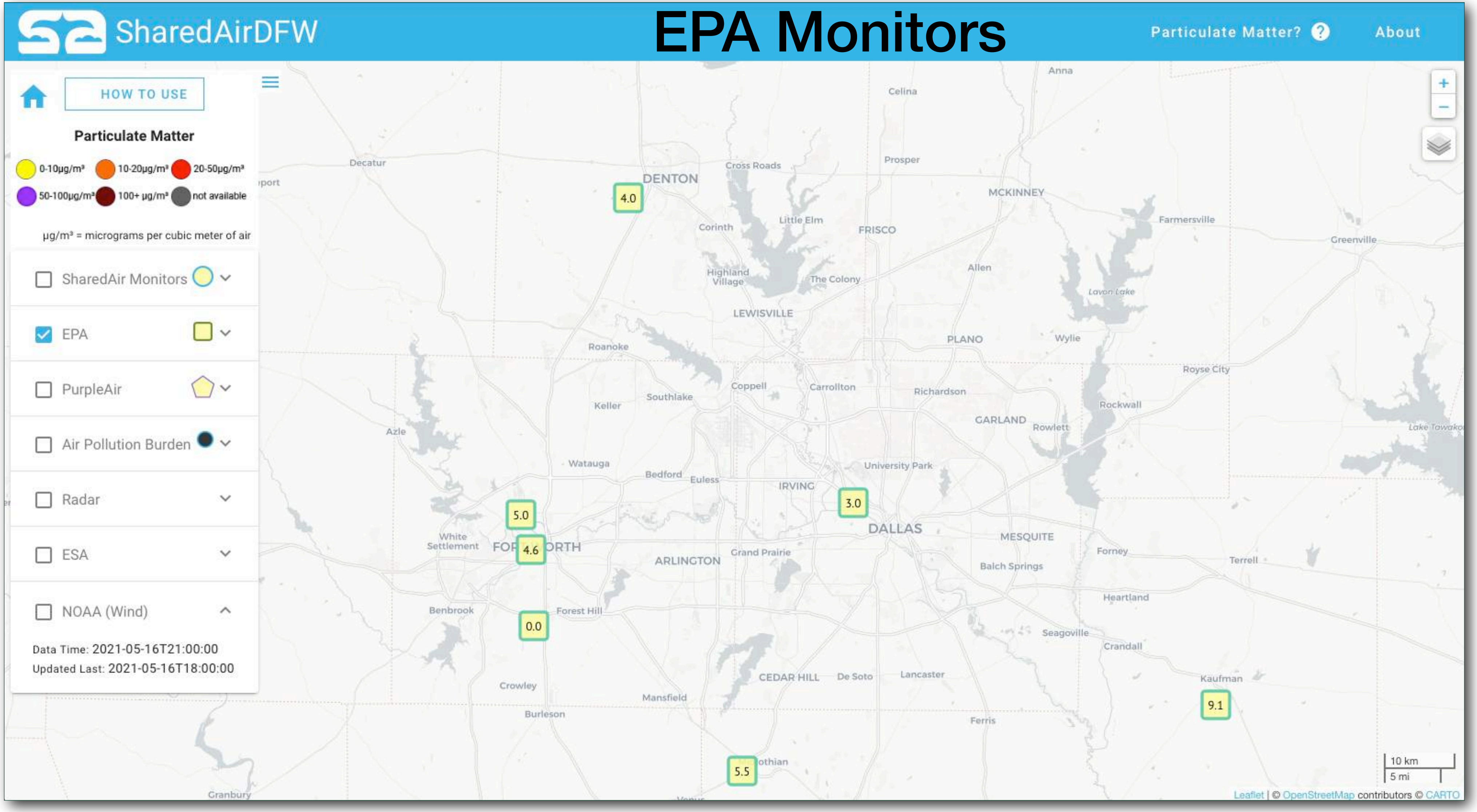


Break-through Family of Sensors







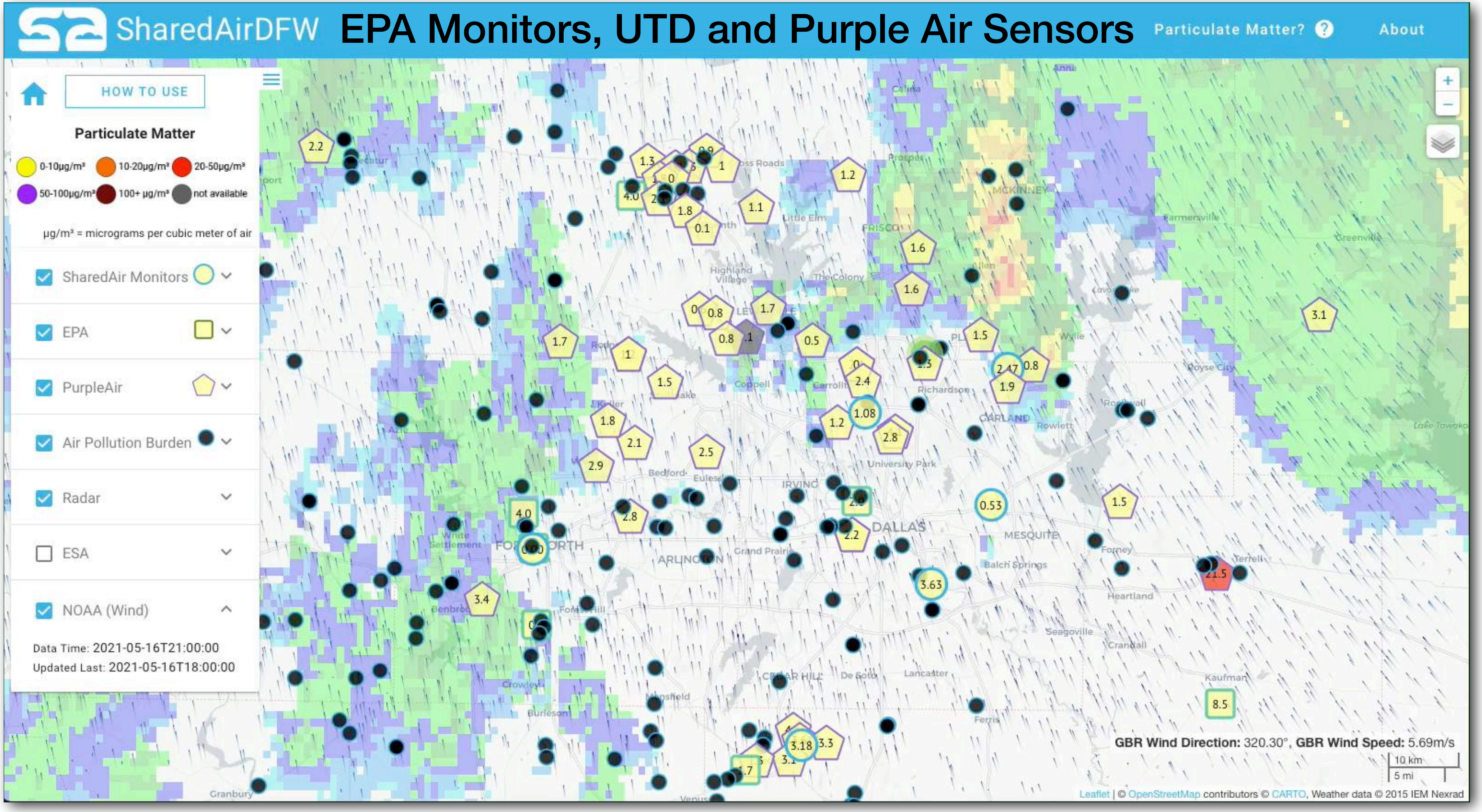

SharedAirDFW
EPA Monitors
Particulate Matter?
About
HOW TO USE
Particulate Matter
0-10µg/m³
10-20µg/m³
20-50µg/m³
50-100µg/m³
100+ µg/m³
not available
µg/m³ = micrograms per cubic meter of air
SharedAir Monitors
EPA
PurpleAir
Air Pollution Burden
Radar
ESA
NOAA (Wind)
Data Time: 2021-05-16T21:00:00
Updated Last: 2021-05-16T18:00:00
4.0
5.0
4.6
0.0
3.0
5.5
9.1
DENTON
DALLAS
ARLINGTON
IRVING
PLANO
MCKINNEY
FRISCO
GARLAND
MESQUITE
LEWISVILLE
10 km
5 mi
Leaflet | © OpenStreetMap contributors © CARTO

https://www.sharedairdfw.com

MINTS-AI

esa

EPA Monitors, UTD and Purple Air Sensors



Three-dimensional rendering of a FAST3D-CT simulation showing geometric complexity of the urban geometry database and the good vertical mixing caused by the building vortex and recirculation patterns in midtown Manhattan.

Real-Time Complex Terrain Simulation & Sensing for Dense Urban Environments