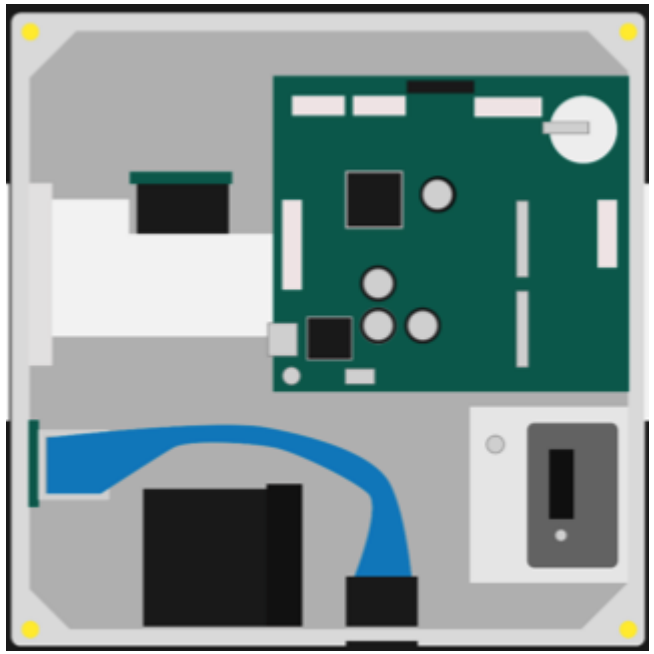
ARISense – Enabling Air Pollution Measurements with Low(er)-cost AQ Sensor Technologies

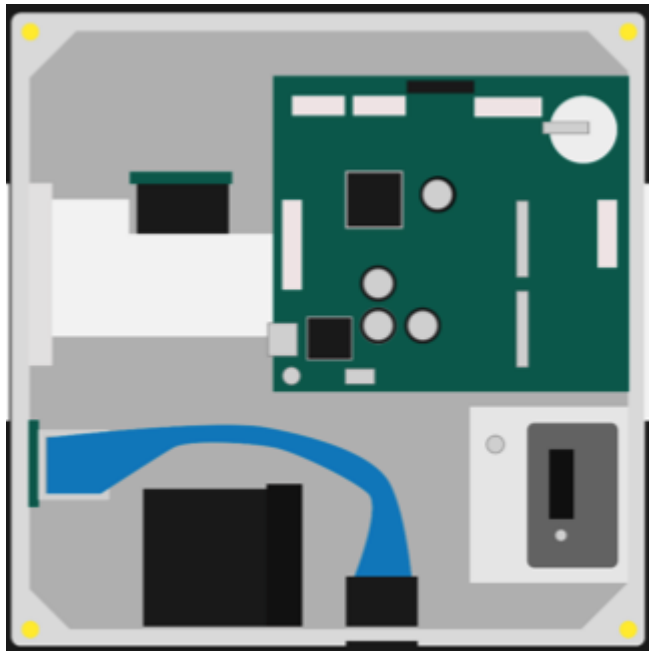


Eben Cross + John Jayne
Michael Kaminsky, Stephen Prescott, Xavier Cabral, Conor Mackinson, Bill Brooks

Oct. 21, 2016
AMS Users conference, Portland, OR

ARISense – ~~Enabling Air Pollution Measurements with Low(er) cost AQ Sensor Technologies~~

focused on ~~facts~~ ‘feelings’



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Take home points

- To adequately capture and characterize one's air quality, measurements must be **fast**, **scalable**, and **reliable.**
- The route from raw sensor output to concentration is non-trivial.
- The interference surface (which responds to Temp, Pressure, Humidity, abs. H_2O, non-analyte species, sensor age, and operational hysteresis) must be determined for each sensor type (and perhaps each individual sensor system).

COMMENT

PUBLISHING Lessons from 30 years of trying to improve peer review p.31

LANDSCAPE From 'Capability' Brown to the US National Park Service p.34

POLICY Fetal-tissue research is key to infant health, say subpoenaed researchers p.37

SOCIAL SCIENCE Physicists, biologists and chemists, why so snooty? p.37

The greater availability of data on air quality has gripped the public, especially in heavily polluted cities such as Beijing.

Validate personal air-pollution sensors

Alastair Lewis and **Peter Edwards** call on researchers to test the accuracy of low-cost monitoring devices before regulators are flooded with questionable air-quality data.

The public is increasingly aware of the health and economic costs of air pollution. Poor air quality is linked to over three million deaths each year, and 96% of people in large cities are exposed to pollutant levels that are above recommended limits[1]. The costs of urban air pollution amount to 2% of gross domestic product in developed countries and 5% in developing countries (see go.nature.com/28qv0ka).

Media attention and the increasing availability of data are reinvigorating efforts in many countries to tackle air pollution, driven as much by local and national politics as by science.

In response, start-up companies are rushing to produce cheap air-monitoring sensors, costing hundreds rather than tens of thousands of pounds. Such devices bridge gaps between sparse government measurements and individuals' wishes to track their personal exposures[2]. In a wealthy city, a single official monitoring station might represent 100,000 people; in emerging economies, one instrument covers millions of citizens.

Although personal sensors have not yet achieved their market potential, applications are promising. Portable sensors are becoming a mainstay of health research by showing people's exposure to environmental factors ranging from noise to particulate matter[3,4]. Live pollution data can be integrated into traffic-management systems to track the impacts of policies such as low-emissions zones. Affordable air-quality devices are being produced for developing countries. For example, the ▶

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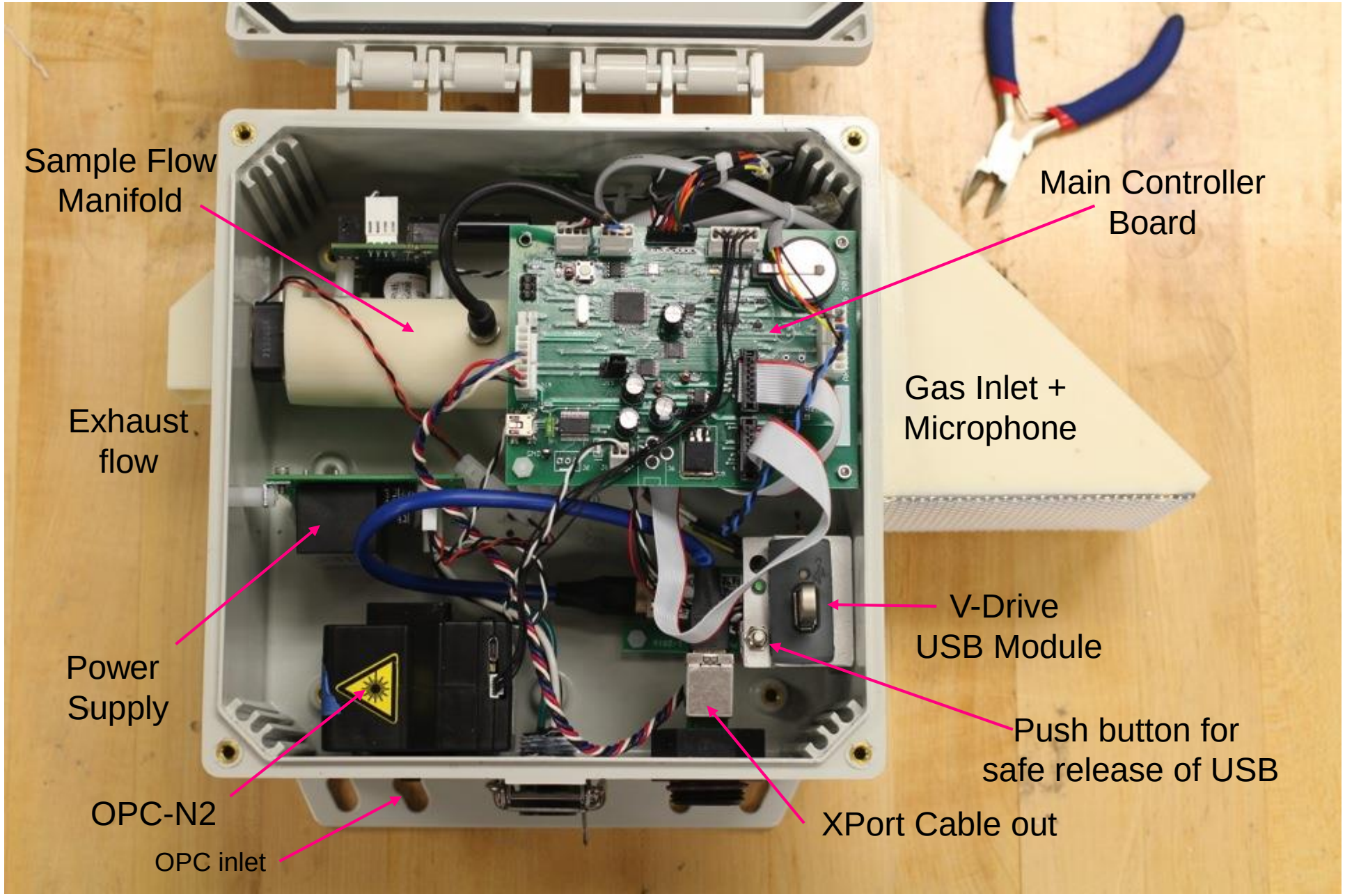
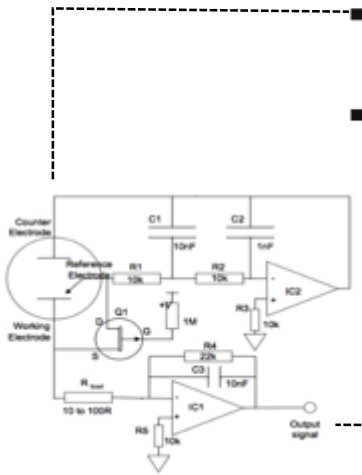
Impetus

"Most researchers view the [low-cost AQ sensor] buzz as being beyond the serious business of academia."


Sample Flow Manifold
Main Controller Board
Exhaust flow
Gas Inlet + Microphone
V-Drive USB Module
Power Supply
Push button for safe release of USB
OPC-N2
XPort Cable out
OPC inlet

Electrochemical sensor guts



Analyte gas molecules ENTER HERE

Working Electrode

{ oxidize or reduce the target analyte species }

Auxillary Electrode

{ track environmental interference (RH, T, P) }

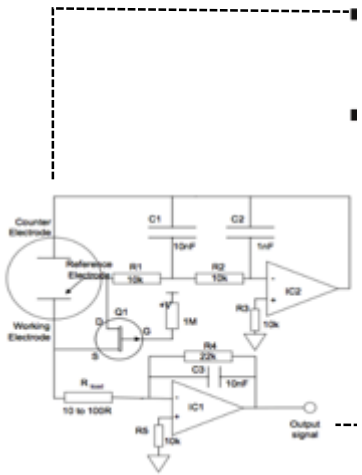
Reference Electrode

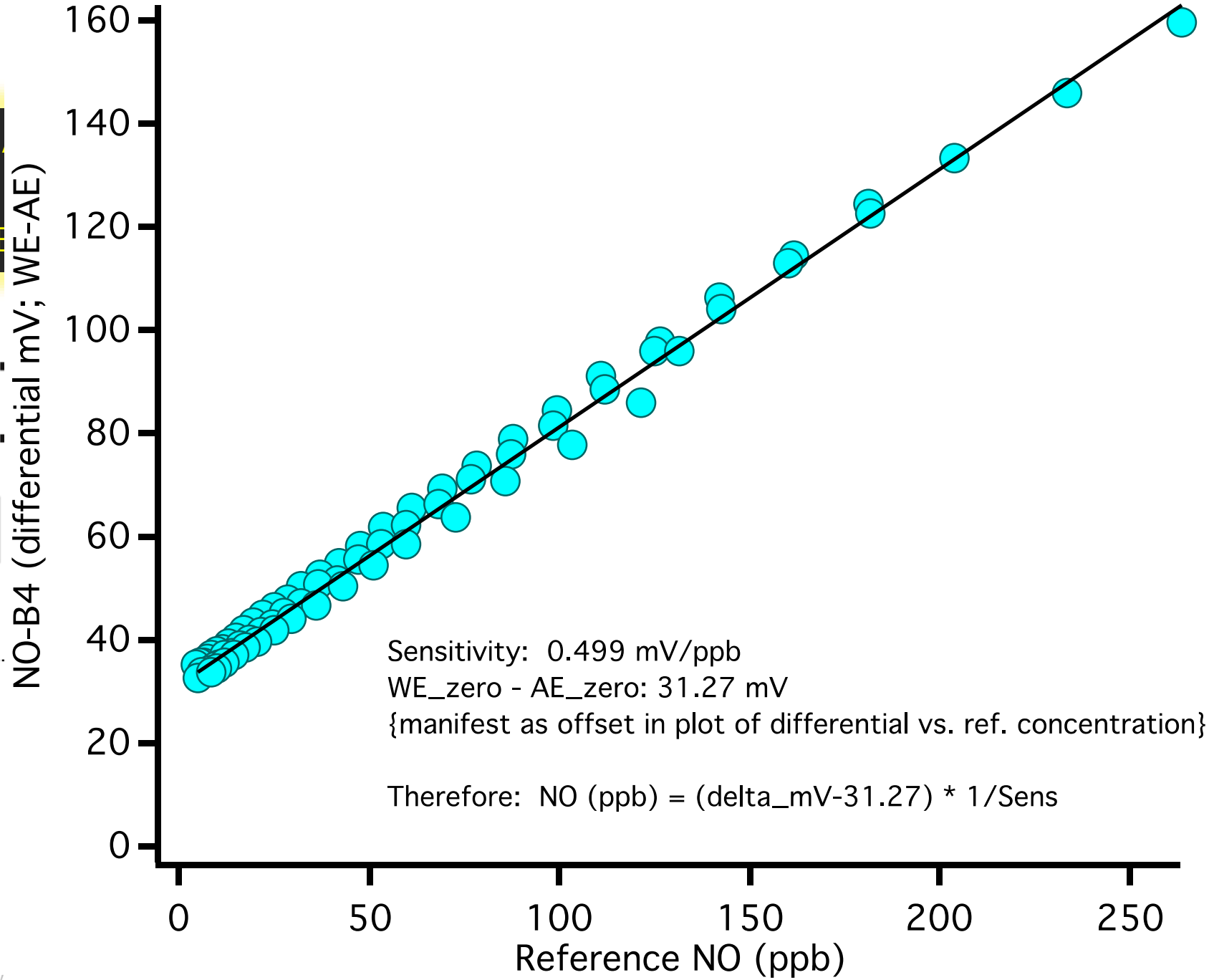
{ Maintain stable potential difference b/t working electrode and electrolyte}

Counter Electrode

{ "Counter" the reaction of the working electrode w/ complimentary reduction or oxidation rxn}

Electrolyte (H_2SO_4)

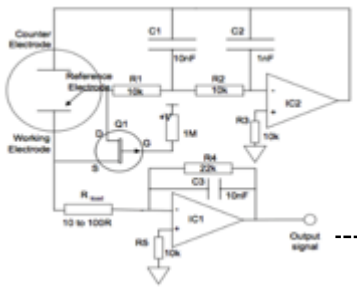


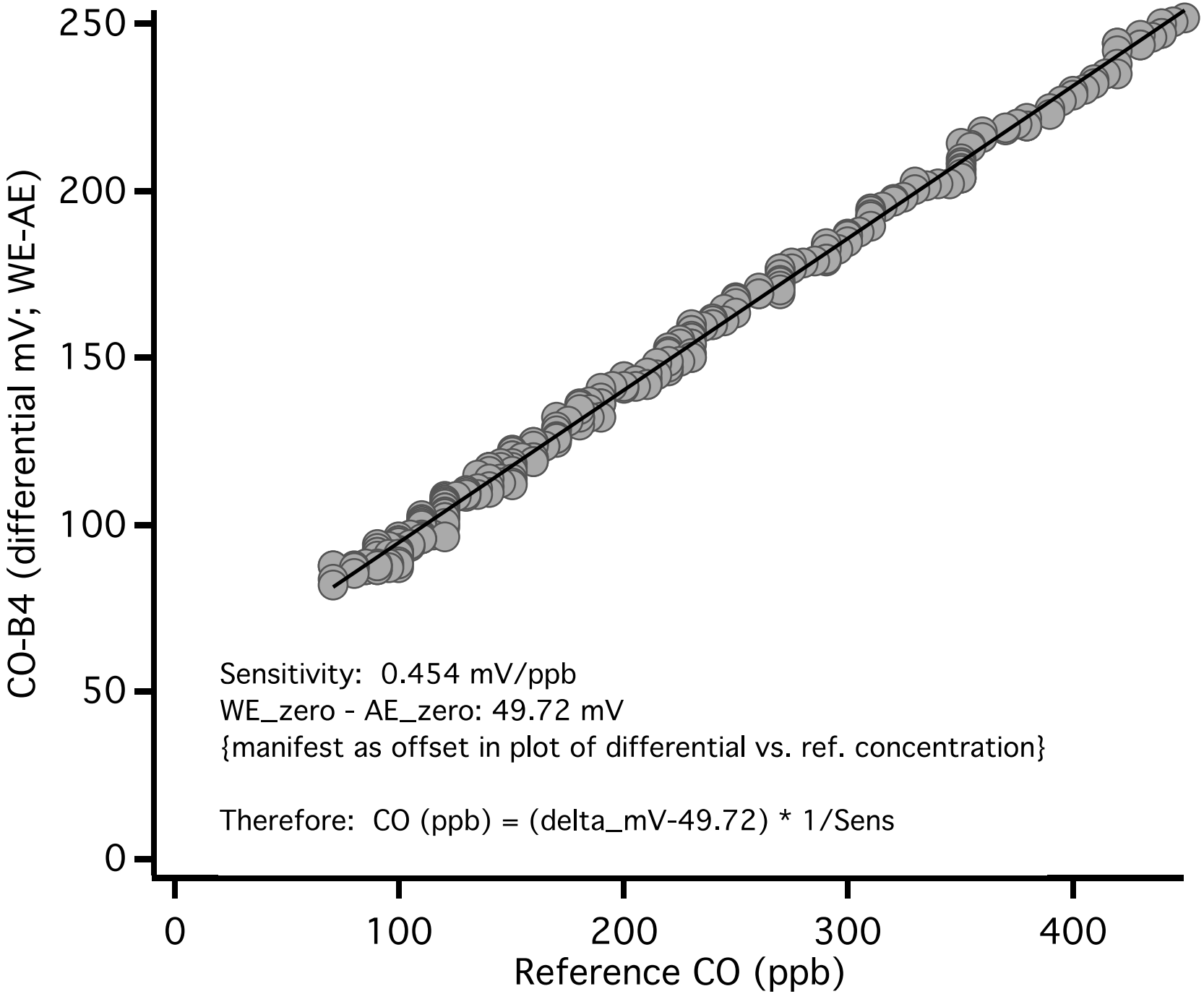


ental
, T, P) }

difference b/t
trolyte}

the working
y reduction





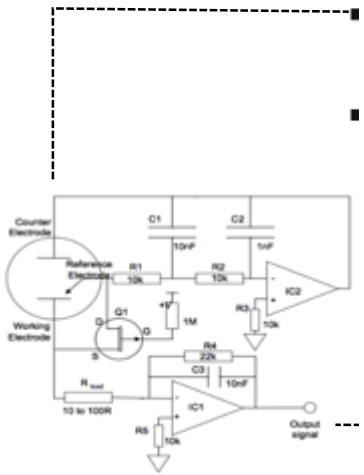
Sensitivity: 0.454 mV/ppb
WE_zero - AE_zero: 49.72 mV
{manifest as offset in plot of differential vs. ref. concentration}

Therefore: CO (ppb) = (delta_mV-49.72) * 1/Sens

ental
, T, P) }

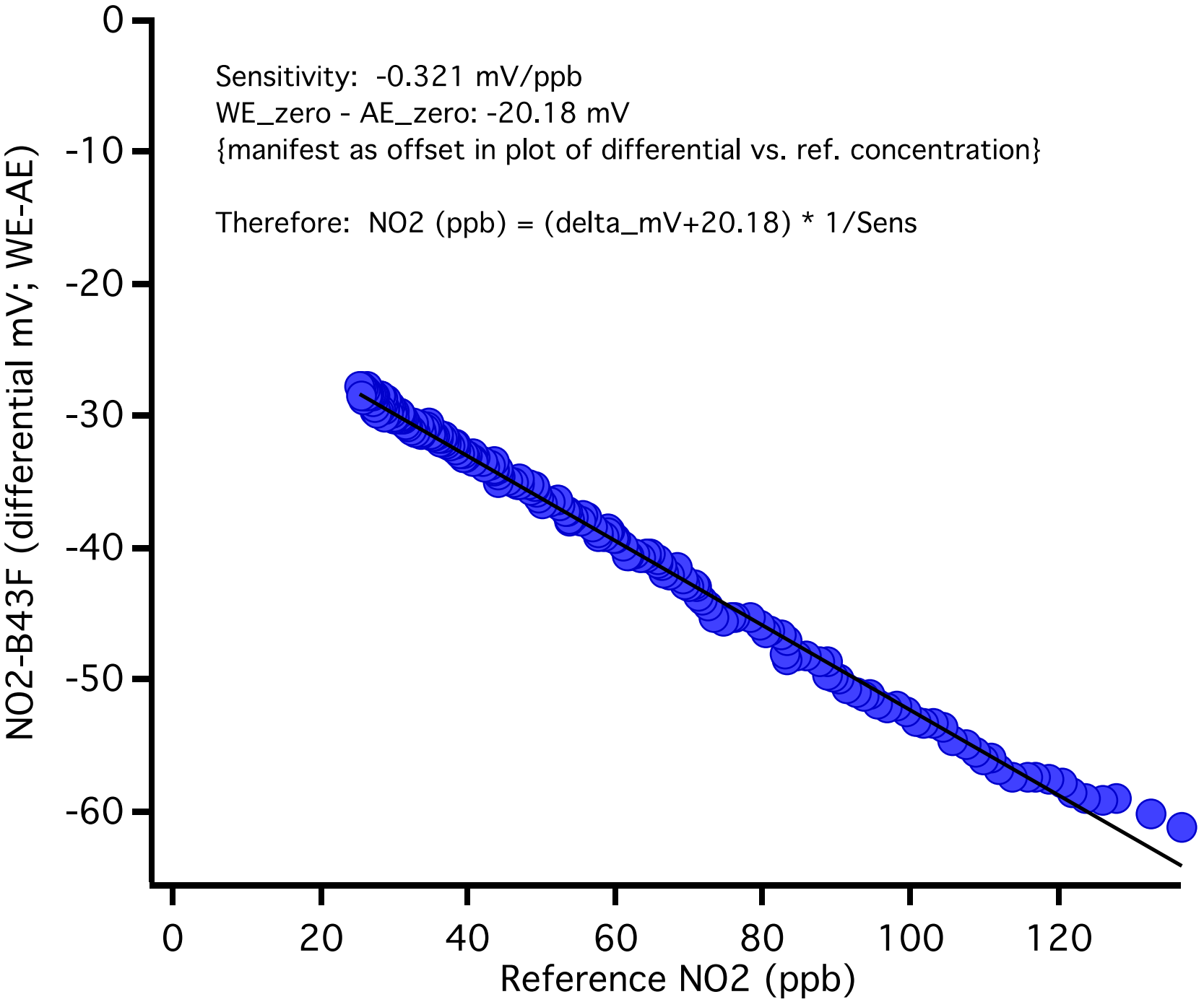
difference b/t
trolyte}

the working
y reduction



Sensitivity: -0.321 mV/ppb
WE_zero - AE_zero: -20.18 mV
{manifest as offset in plot of differential vs. ref. concentration}

Therefore: NO2 (ppb) = (delta_mV+20.18) * 1/Sens



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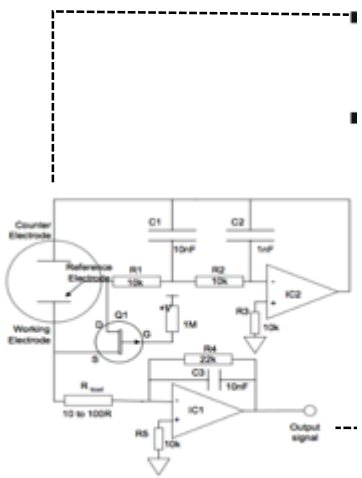
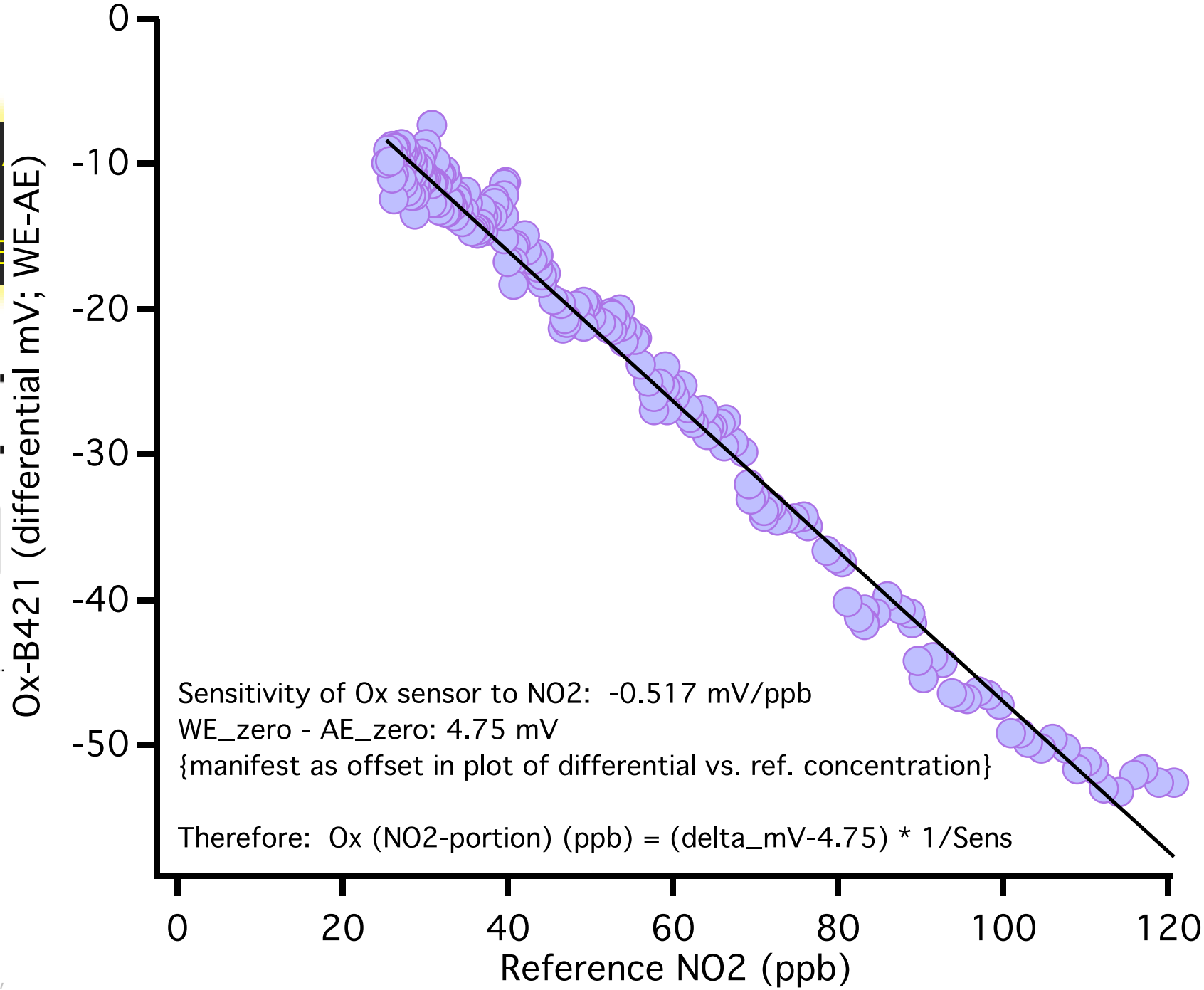
, T, P) }

difference b/t
trolyte}

the working
y reduction

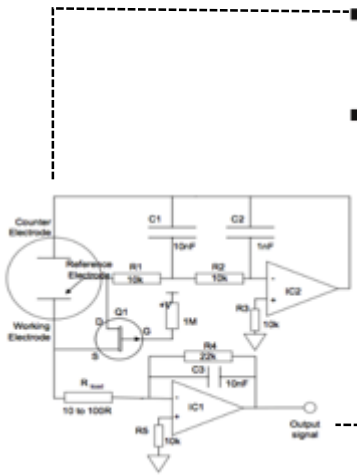




ental
, T, P) }

difference b/t
trolyte}

the working
y reduction



Sensitivity of Ox sensor to O3: -0.232 mV/ppb
WE_zero - AE_zero: -12.11 mV
{manifest as offset in plot of differential vs. ref. concentration}

Therefore: Ox (O3 portion) (ppb) = (delta_mV+12.11) * 1/Sens

NO2-B43F data pnts show lack of
cross-sensitivity of NO2-B43F sensor to O3

Ox-B421 (differential mV; WE-AE)

NO2-B43F response to O3

0
-10
-20
-30
-40

0 20 40 60 80 100 120 140 160

Reference O3 (ppb)

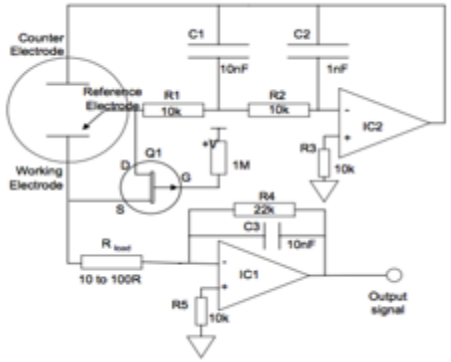
ental
, T, P) }

difference b/t
trolyte}

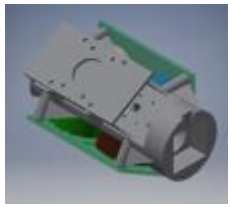
the working
y reduction

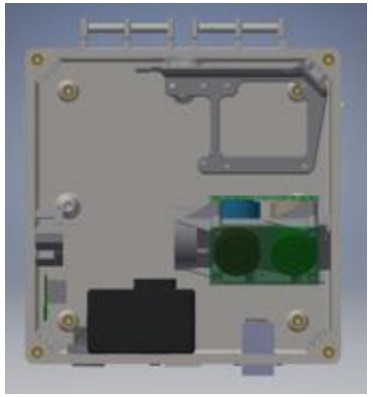
Logic path to 'data'

OEM hardware modifications



mechanical design





raw data

↓ current: I_{sense} ~ [g_1]

$Sens_{g1}$ = x nA/ppm

potentiostat circuitry

↓ Analog output voltage

adc

↓ Digital output: bits → mV

* Note: raw data is your friend

mirco-controller

↓ Signal processing, smoothing, filtering

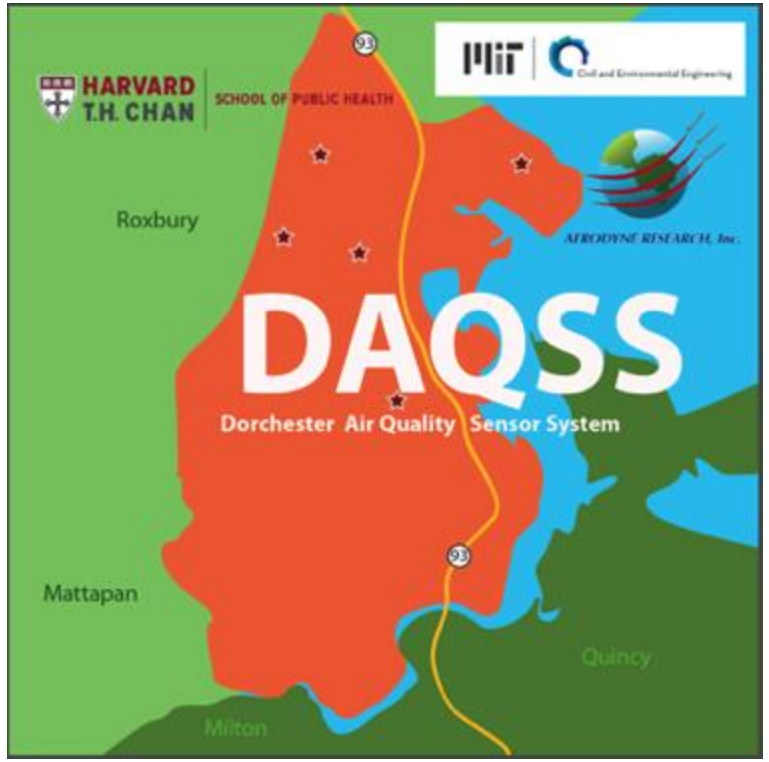
'data'

firmware

calibration

- spec sheet
- lab cal
- field cal
- higher-order node intelligence

Dorchester Air Quality Sesnsor System (DAQSS) Project



- 5 AQ sensor nodes (4 in field, 1 in lab)
- DEP co-location (x2 sites)
- Real-world community-embedded
- Deployed Jan. 2016

- Gary Adamkiewicz and Ann Backus (HSPH)
- Thomas McGrath, Leslie Collyer, John Lane, Emmy Andersen, Kevin Gauvreau {Ma State DEP}; George Allen {NESCAUM}
- Megara Flanigan, Ricky Guerra {Dorchester Bay Economic Development Corporation}
- James Regis, Tawanna Moals, Jose Figueroa {Maloney Properties, Inc.}
- Timothy Dransfield, Jay Messana, Jamie Soule, Chris Sweeney {UMass Boston}
- DAQSS Network was initially funded through NIEHS grant # P30 ES 000002

NIH National Institute of Environmental Health Sciences
Your Environment. Your Health.

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Powerful ideas for a healthier world

MIT Civil and Environmental Engineering

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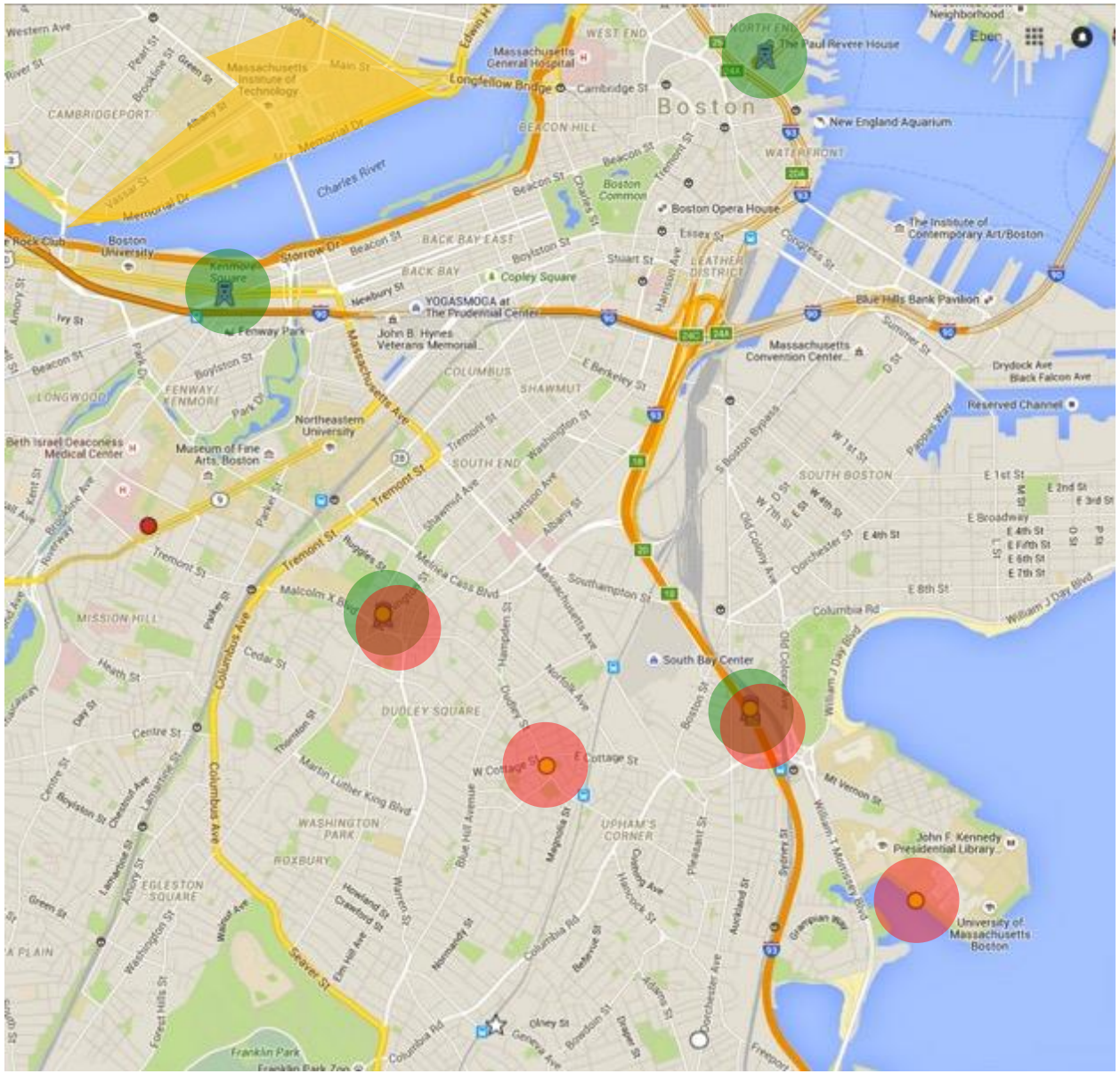

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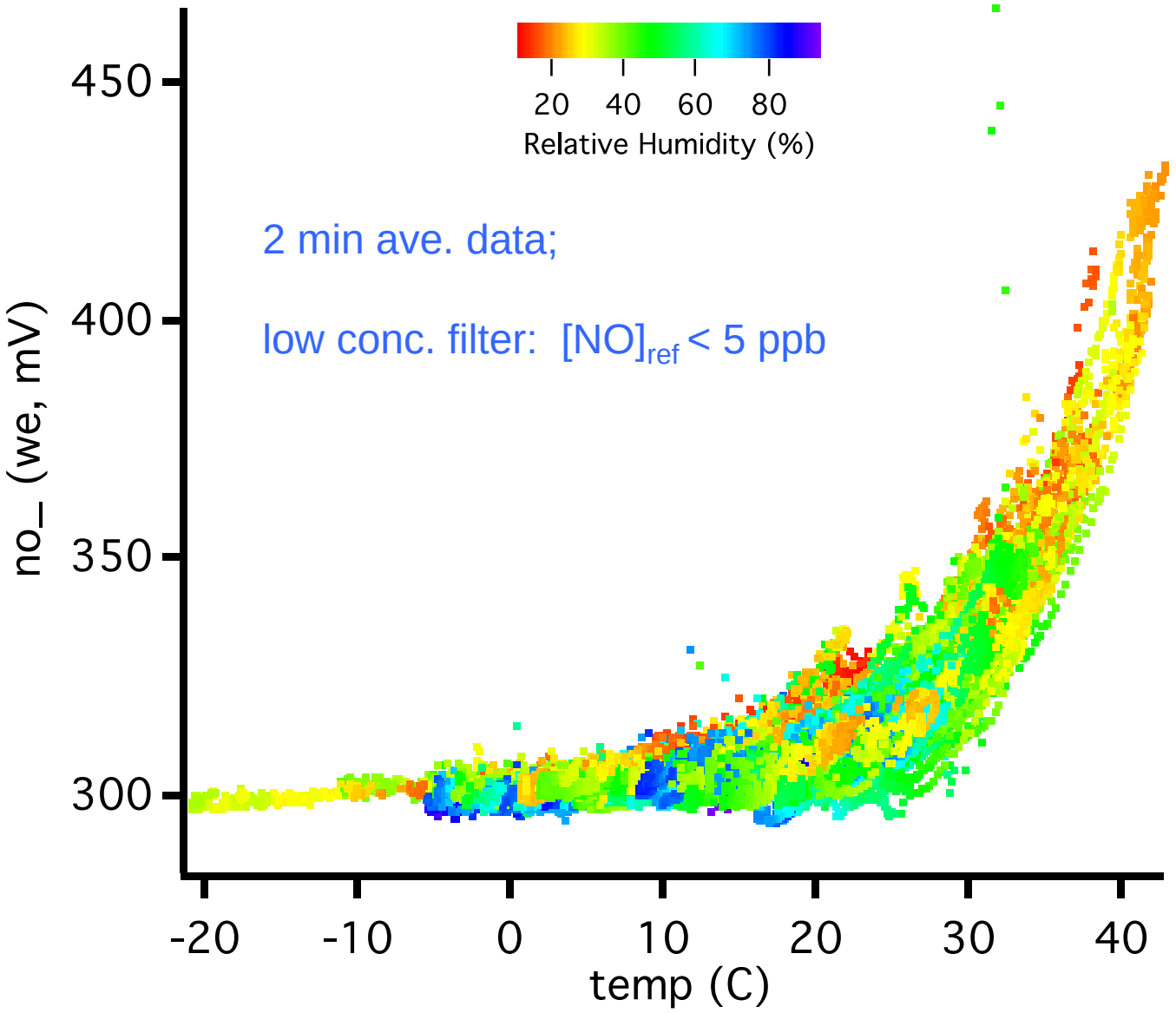
Tracking electrode response to temp, humidity; NO-B4 Sensor



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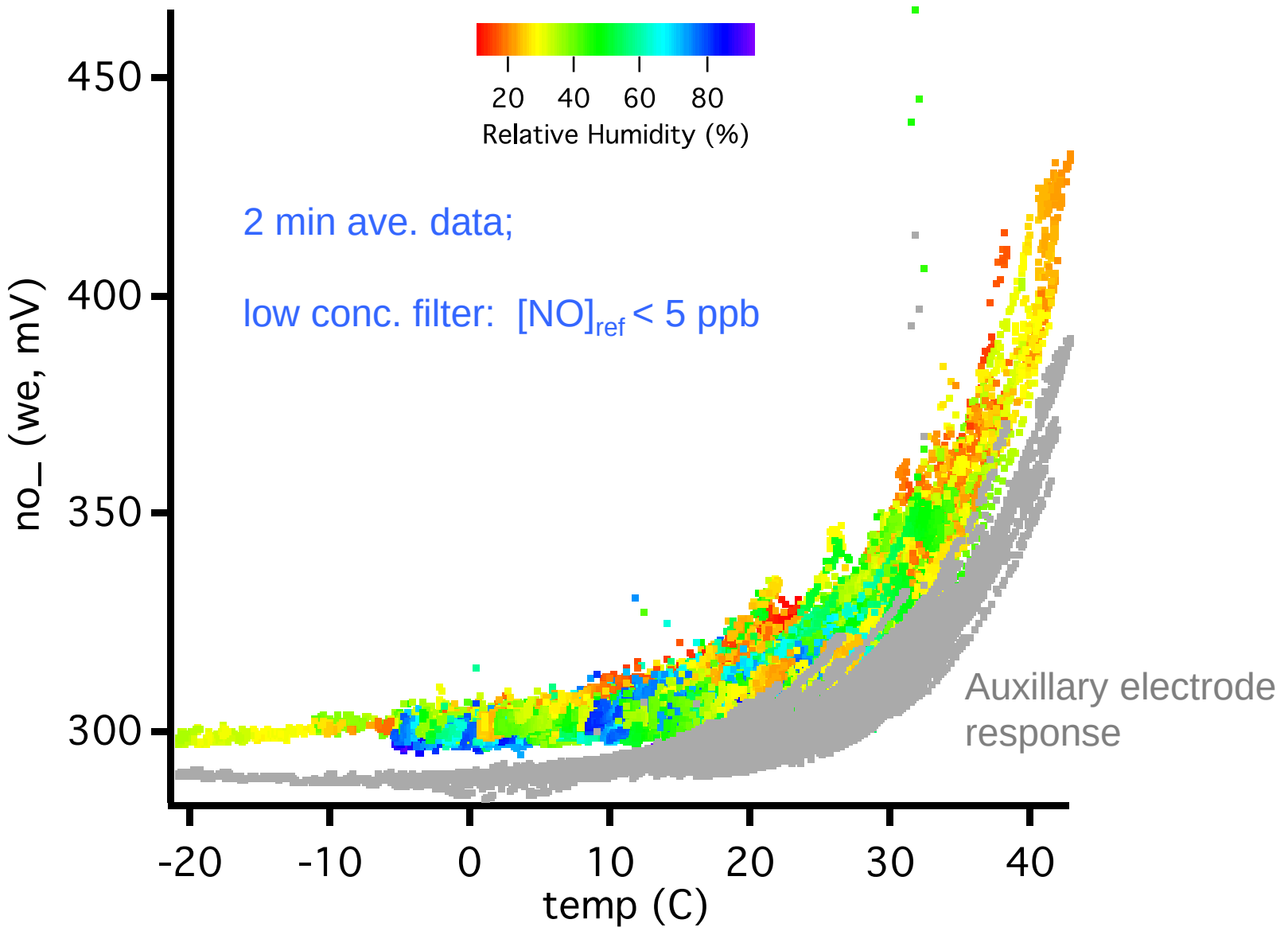

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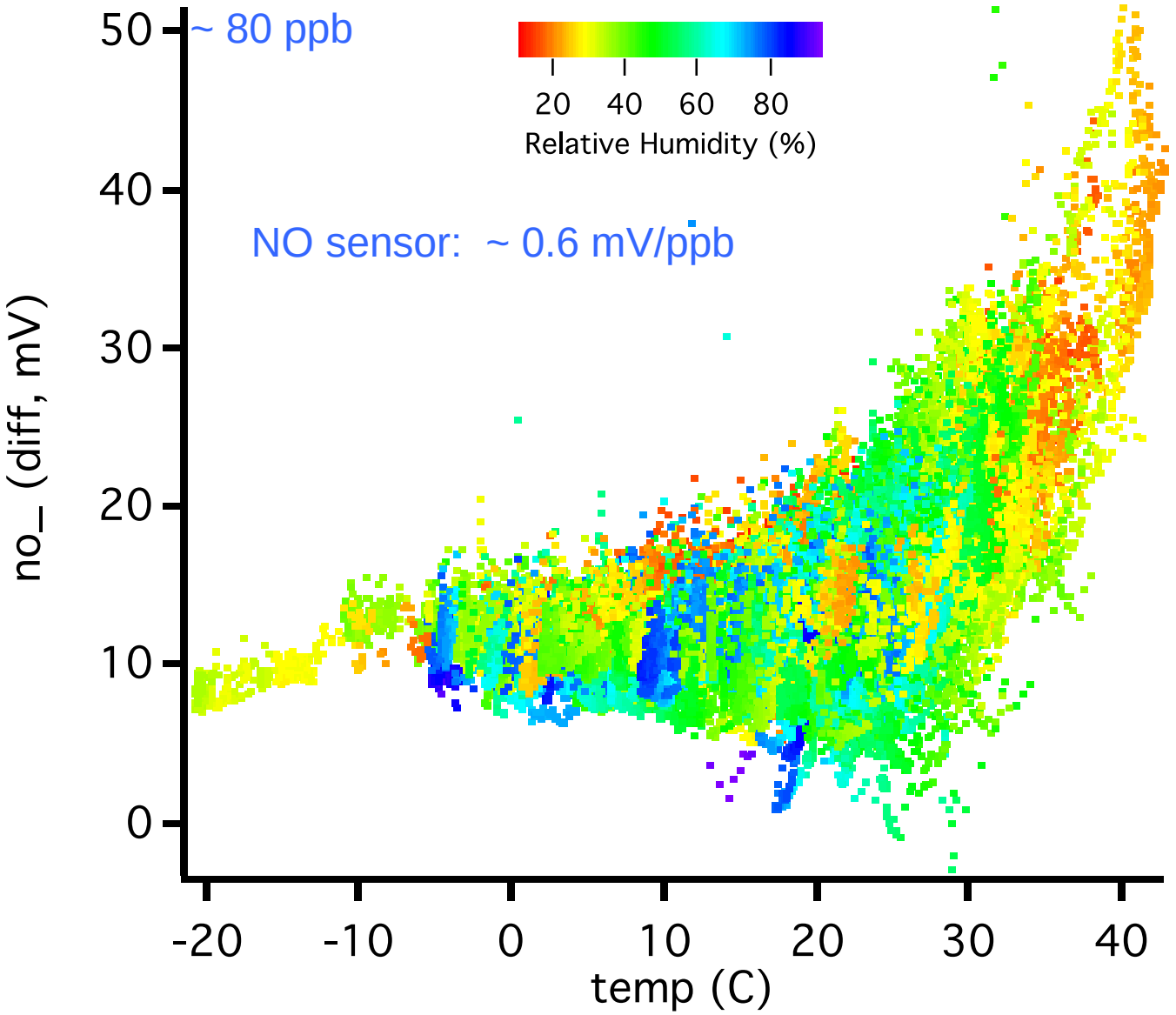

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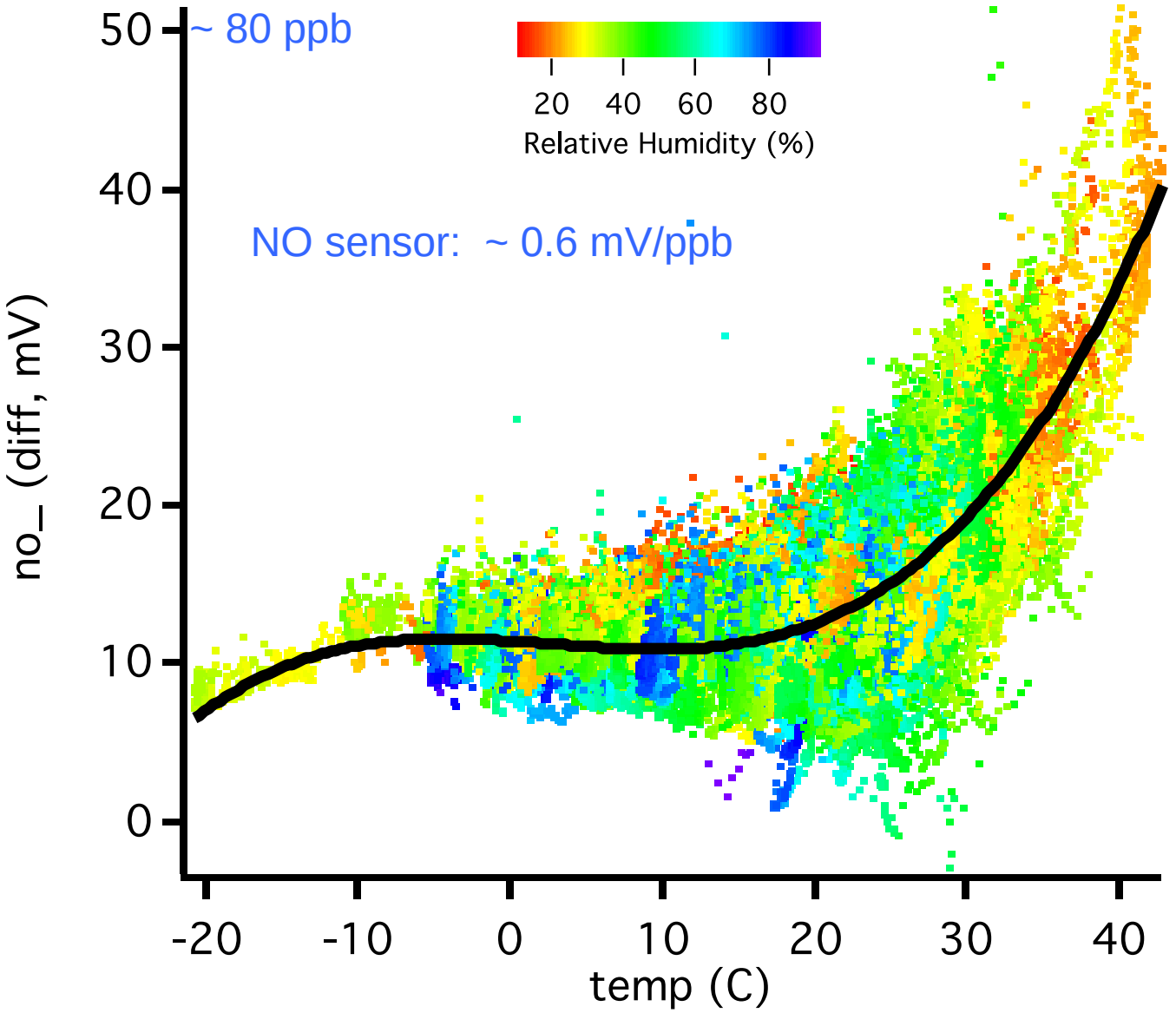
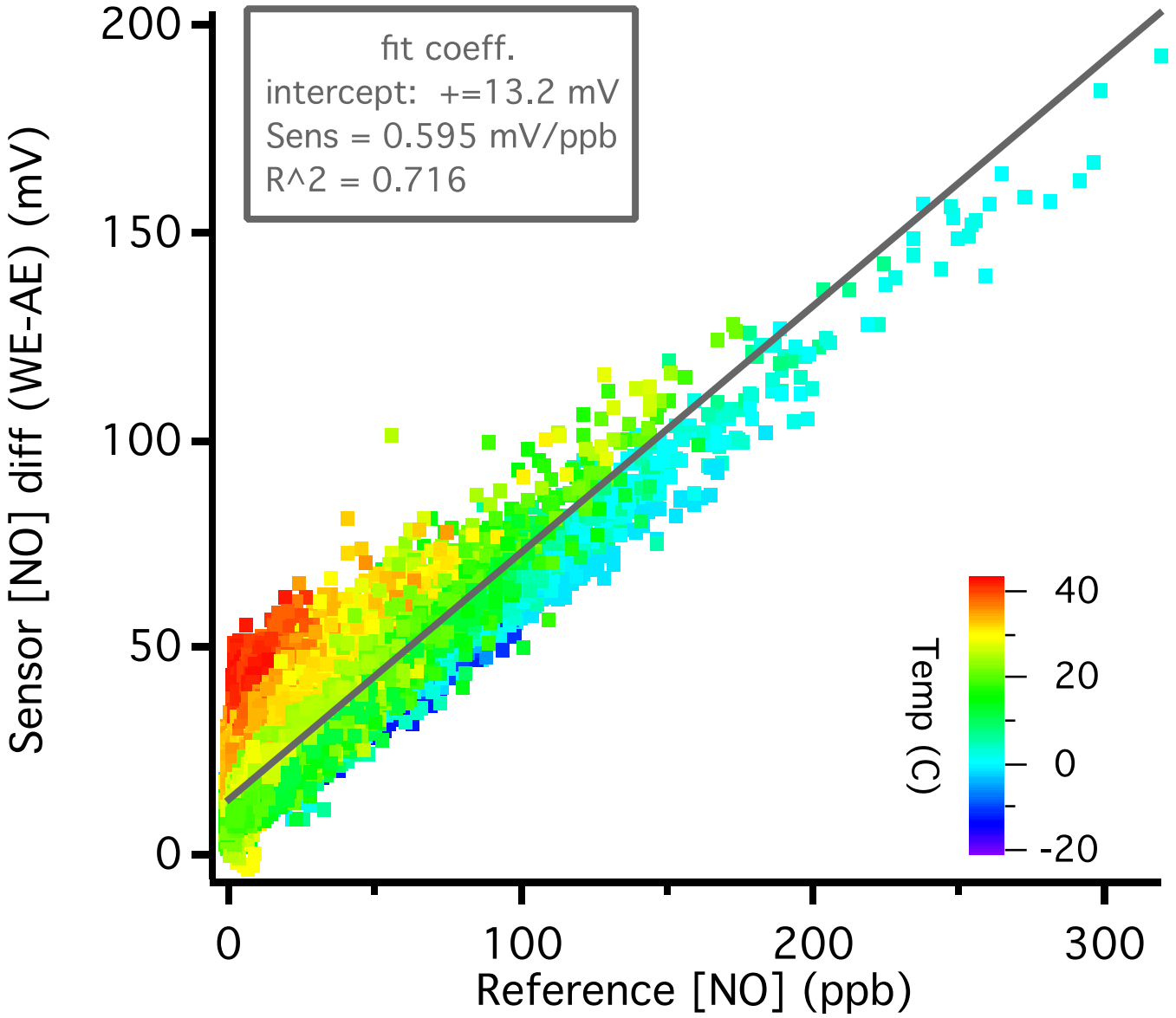


Raw sensor output vs. reference [NO]



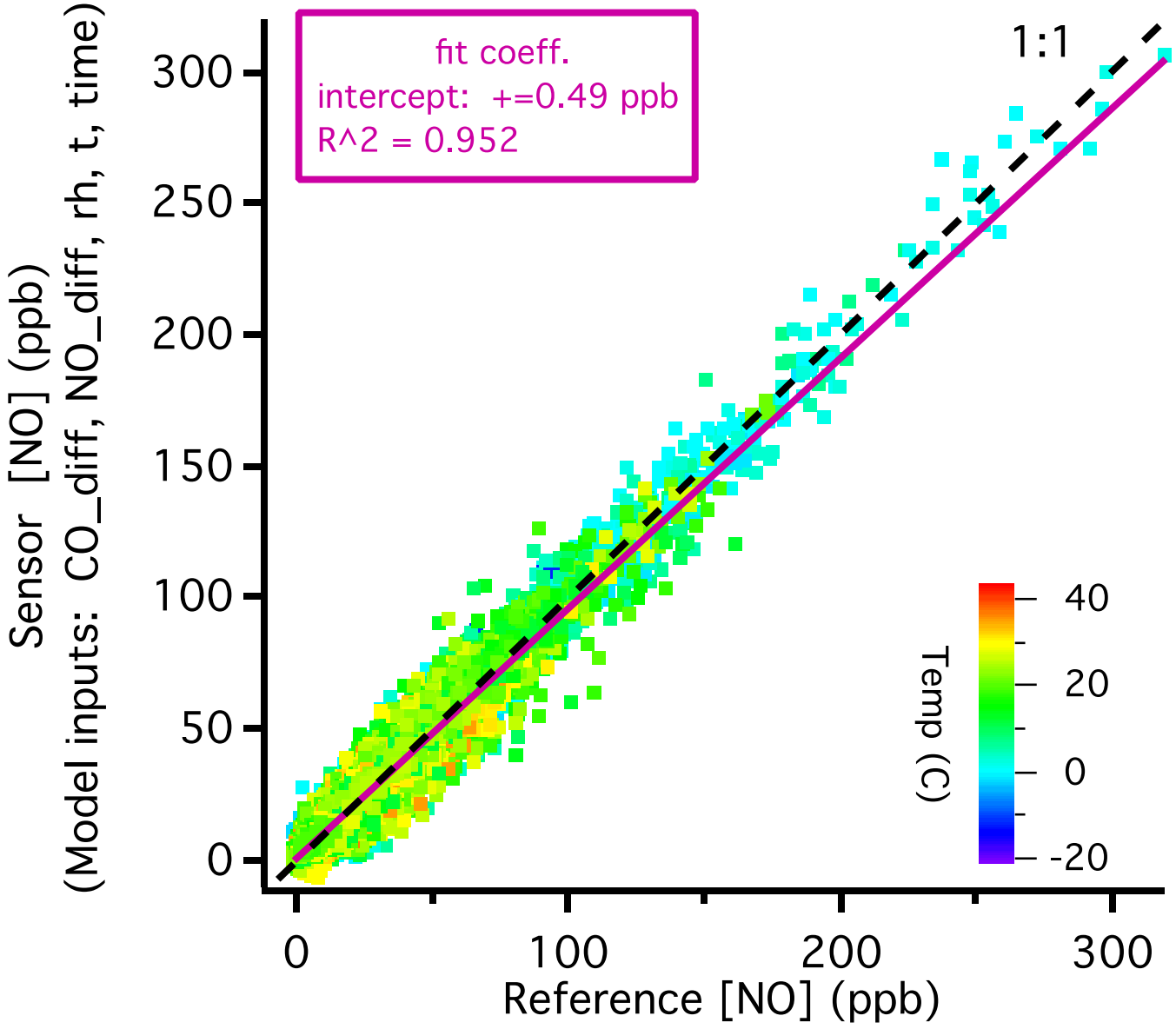
HDMR { High-Dimensional Model Representation }
a.k.a. 'magic'

- PURPOSE: Analyze and reduce the dimensionality of complex IO systems
- INPUT: Raw sensor data, meterological parameters, and co-located reference data
- OUTPUT: Finite hierarchical correlated function expansion (2nd or 3rd order) written in terms of our raw sensor inputs (NO_we (x_1), NO_ae (x_2), CO_we(x_3),... Temp(x_n))

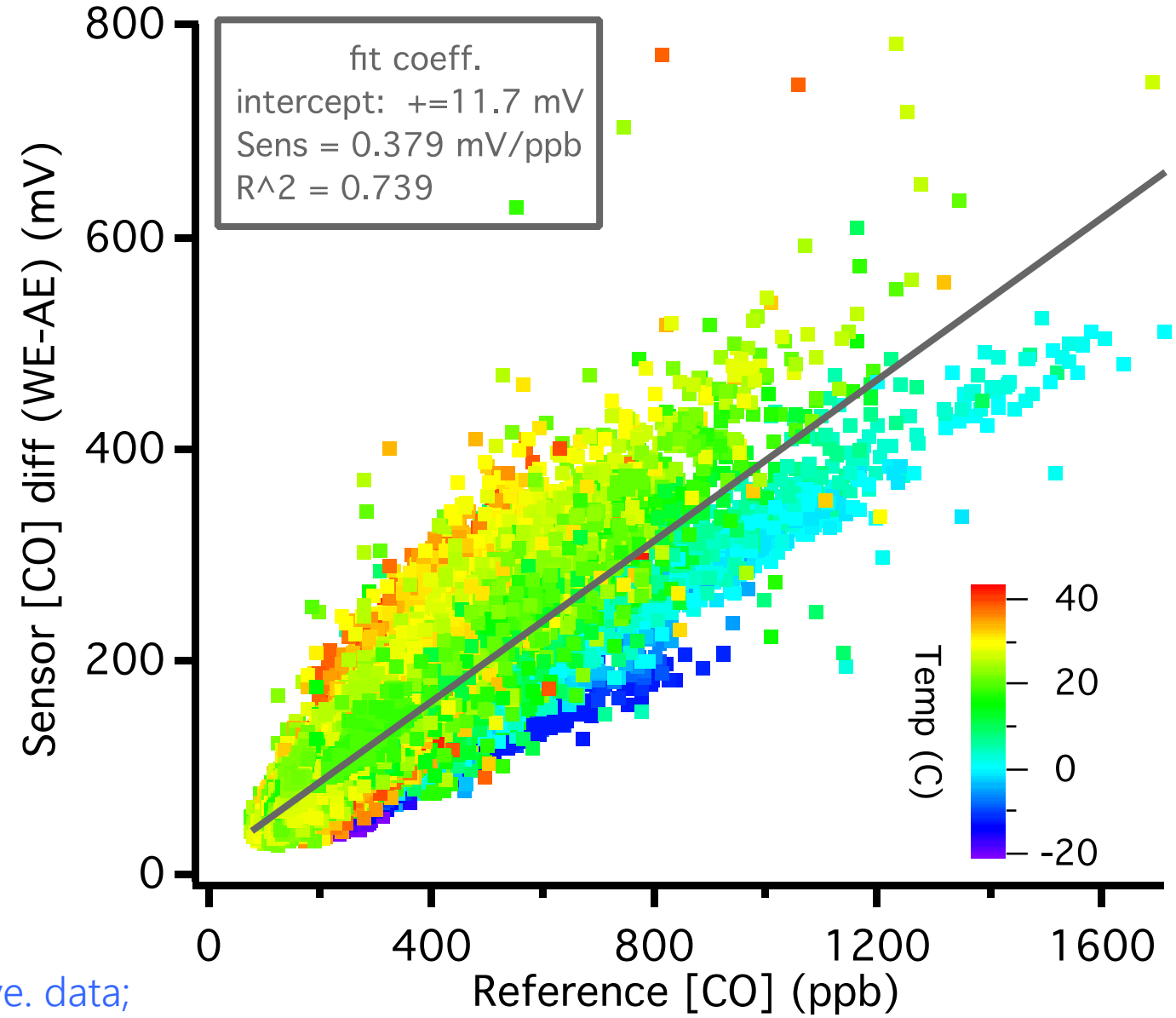
$$f(x) \approx f_0 + \sum_{i=1}^{n} f_i(x_i) + \sum_{1 \le i < j \le n} f_{ij}(x_i, x_j) + \ldots$$

- CLUES: Quantify/rank order the most influential input parameters pairs (in the case of 2nd order run)
- END GAME: 'Map' raw sensor data (with limited physical meaning) onto an output surface defined in concentration units (useful!)

HDMR model output vs. reference [NO]

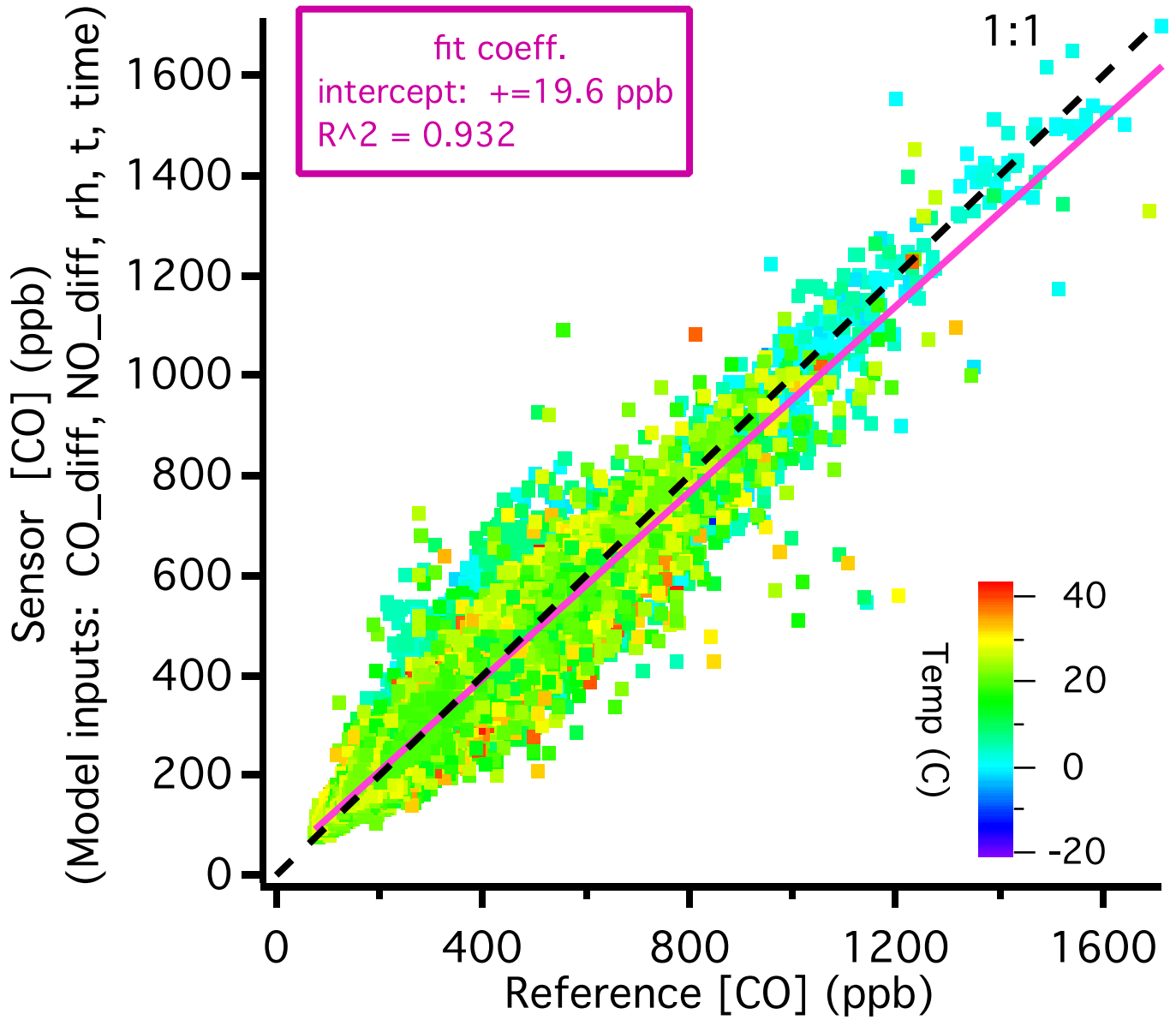


Raw sensor output { CO-B4 } vs. reference [CO]



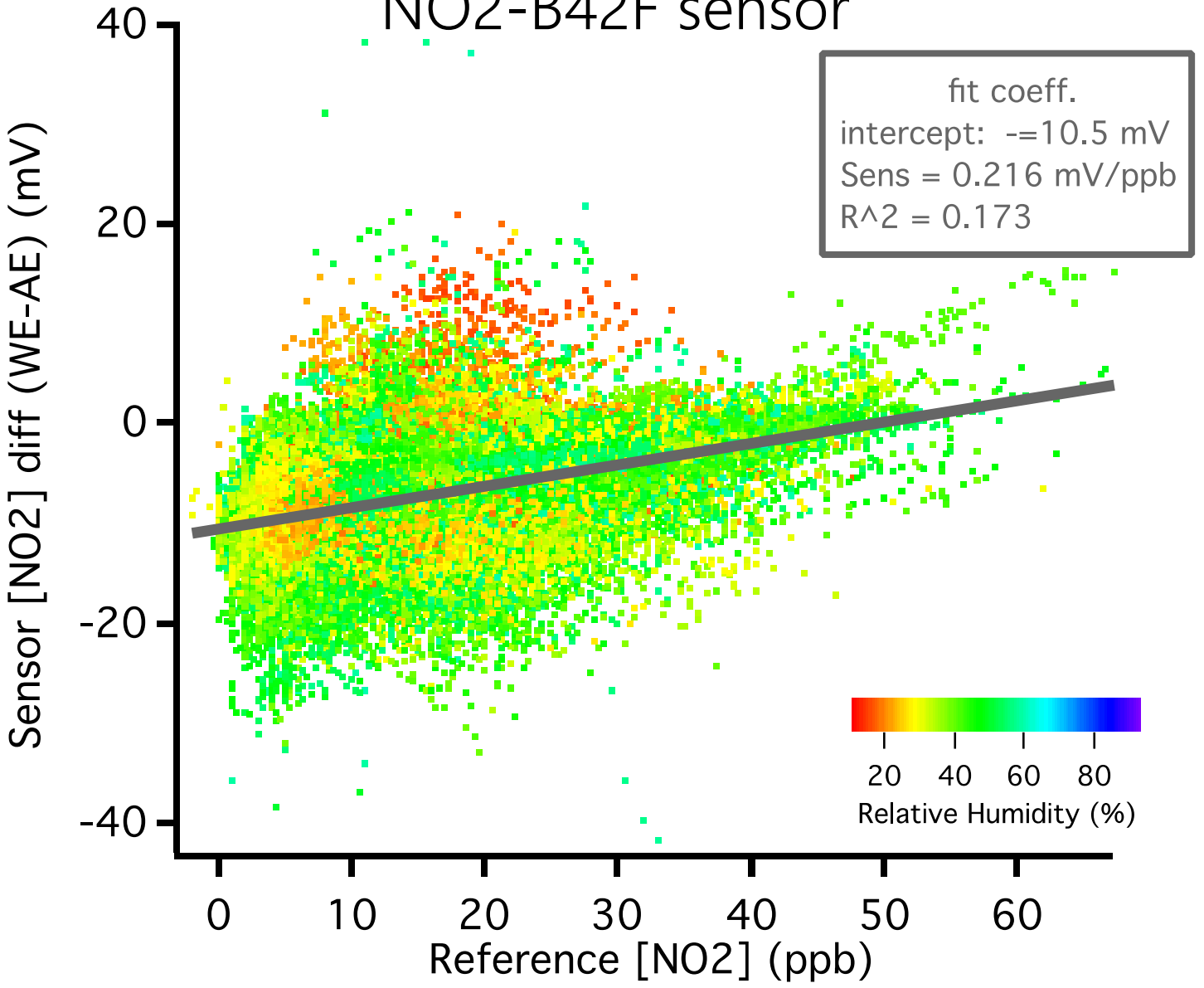
2 min ave. data;
all data

HDMR model output vs. reference [CO]



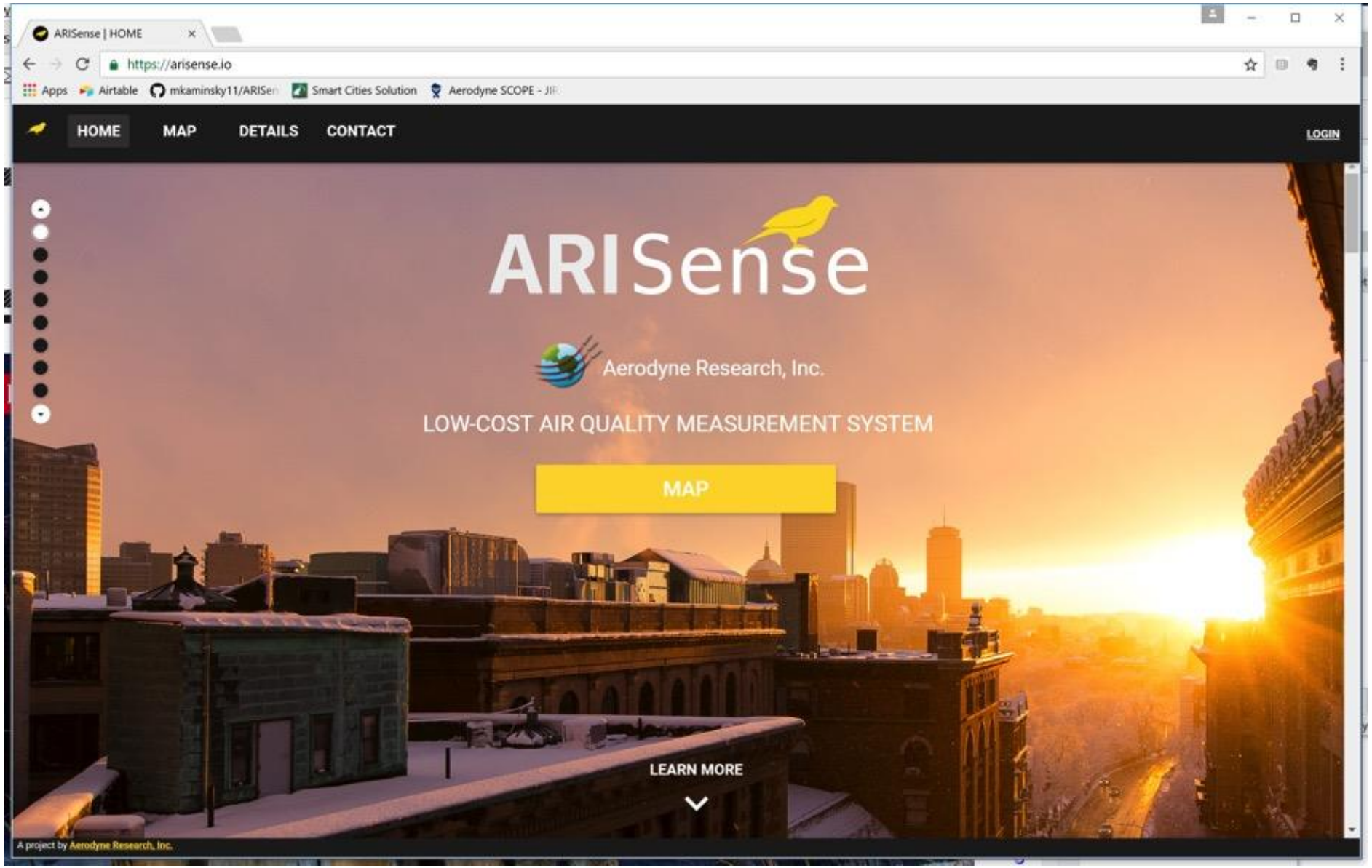
Tracking electrode response to temp, humidity

NO2-B42F sensor



2 min ave. data;
Filter for RH: plotted data is < 60% RH

https://arisense.io



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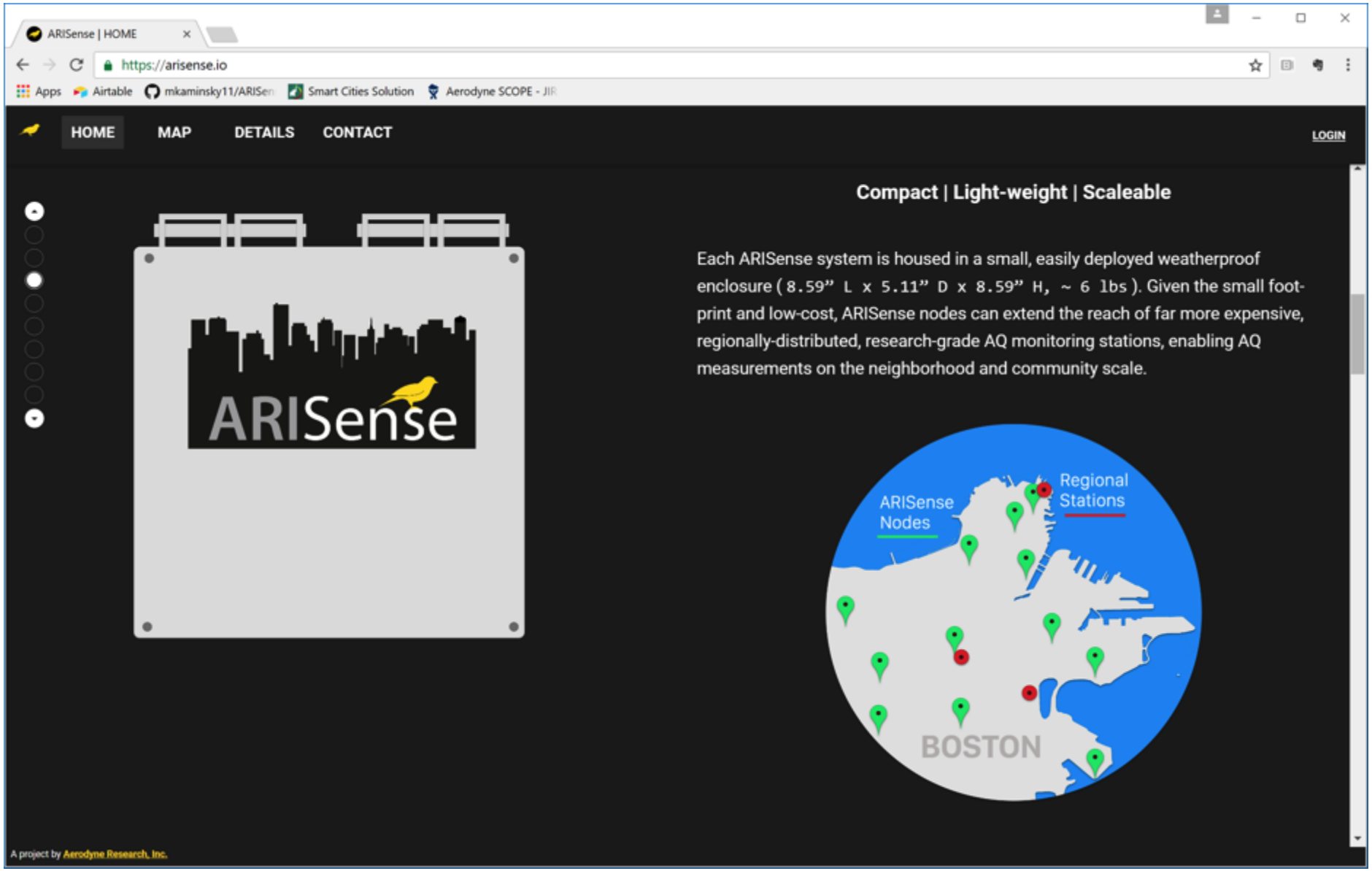

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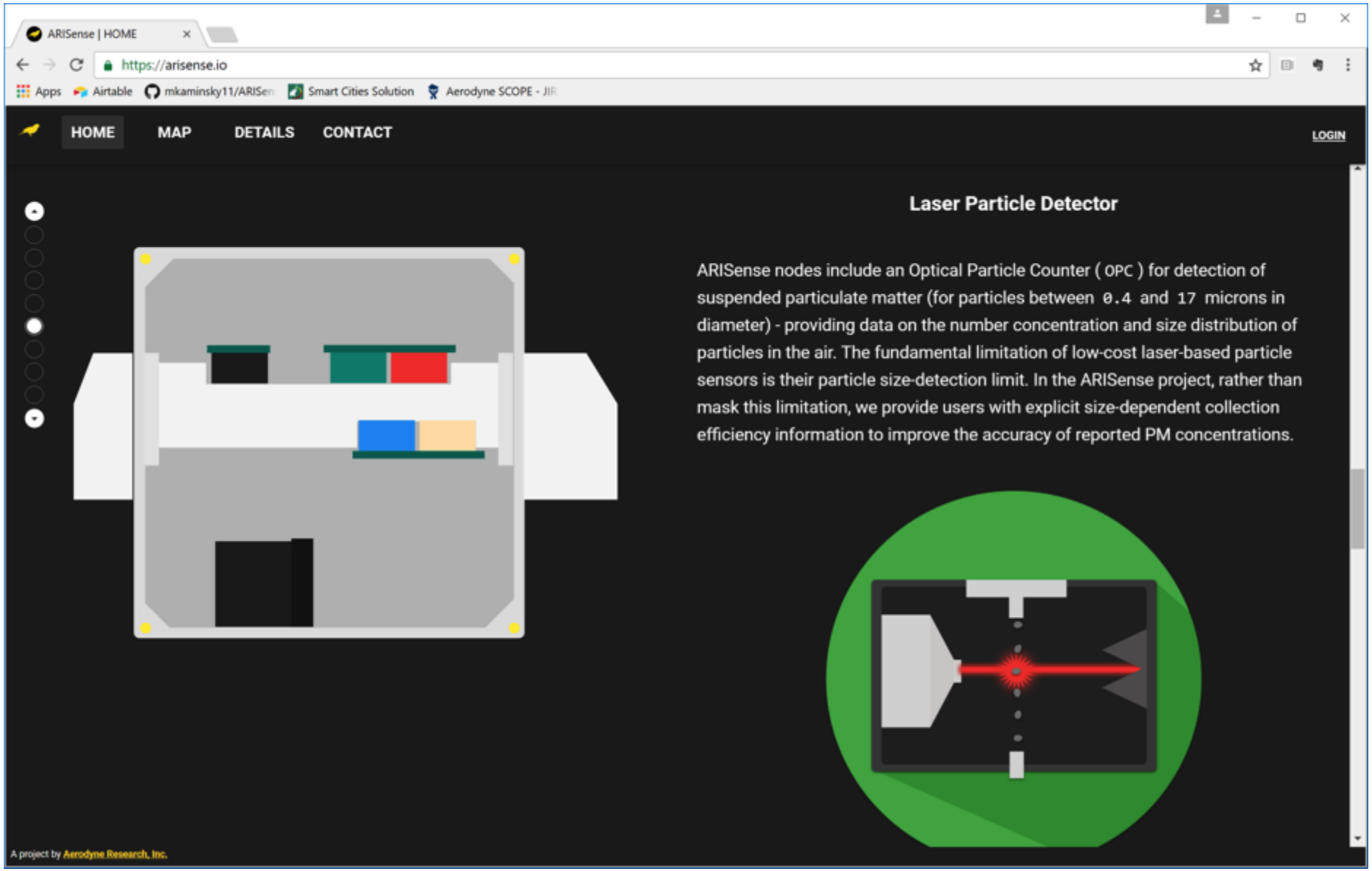

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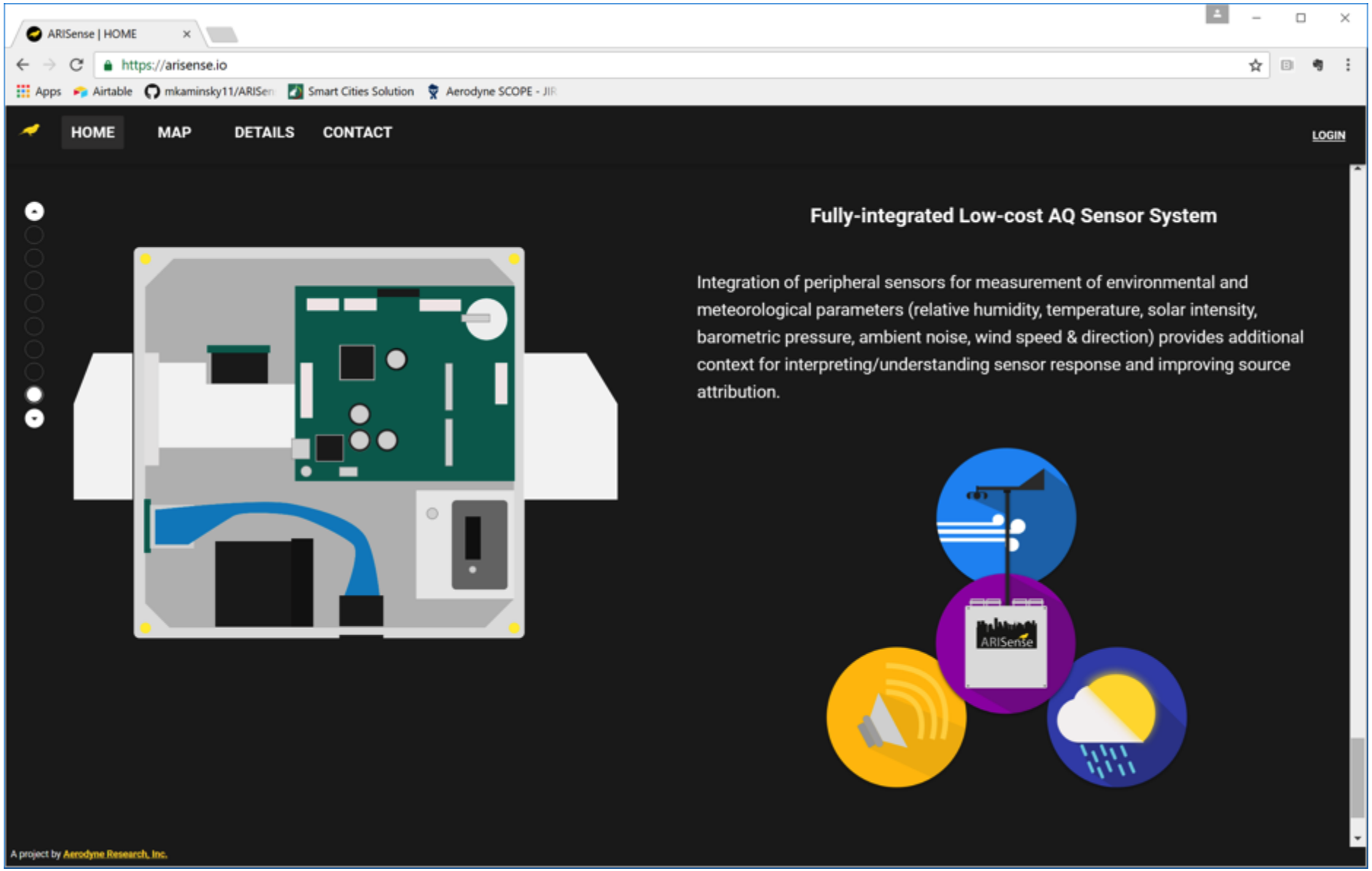

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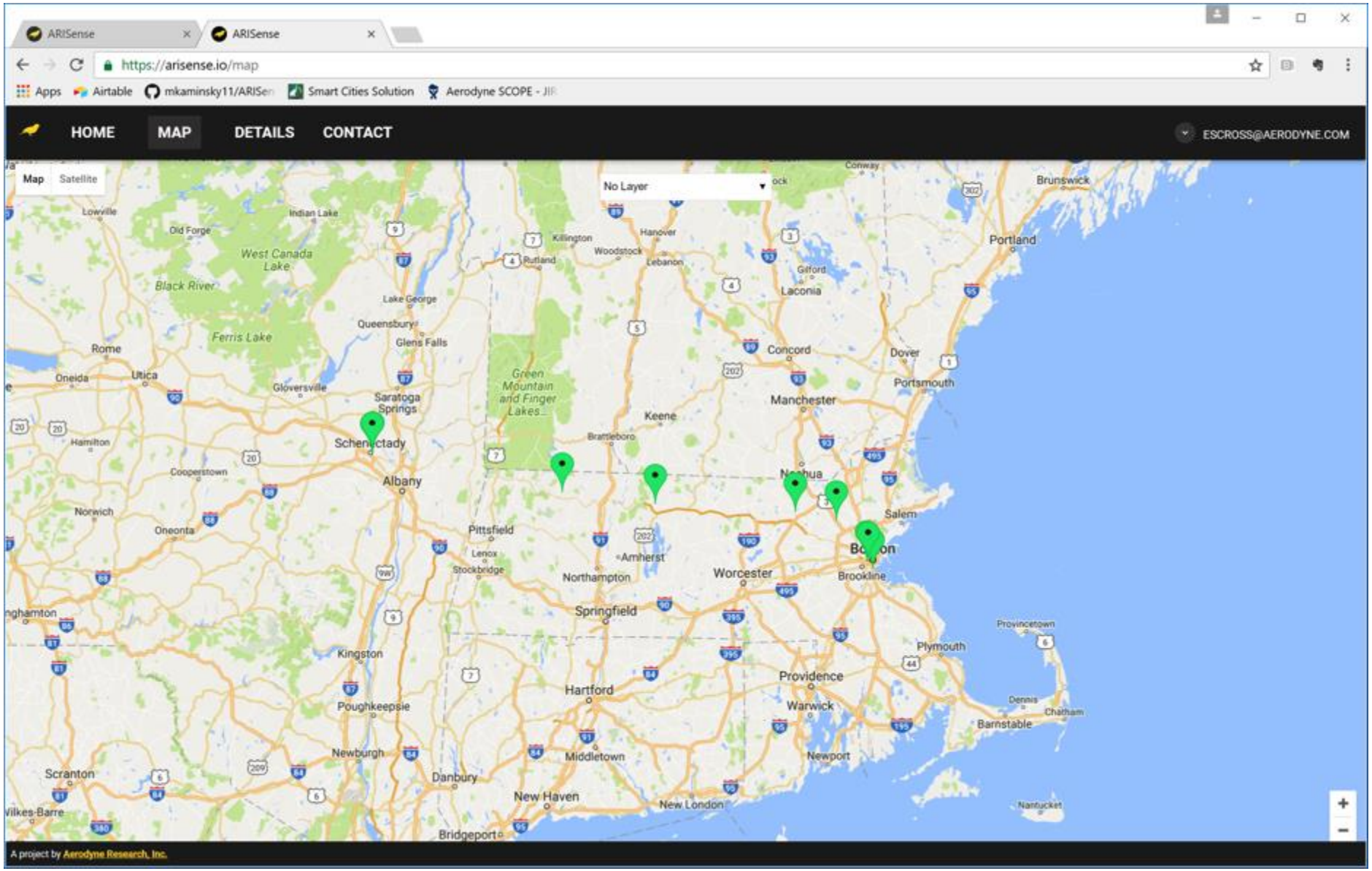

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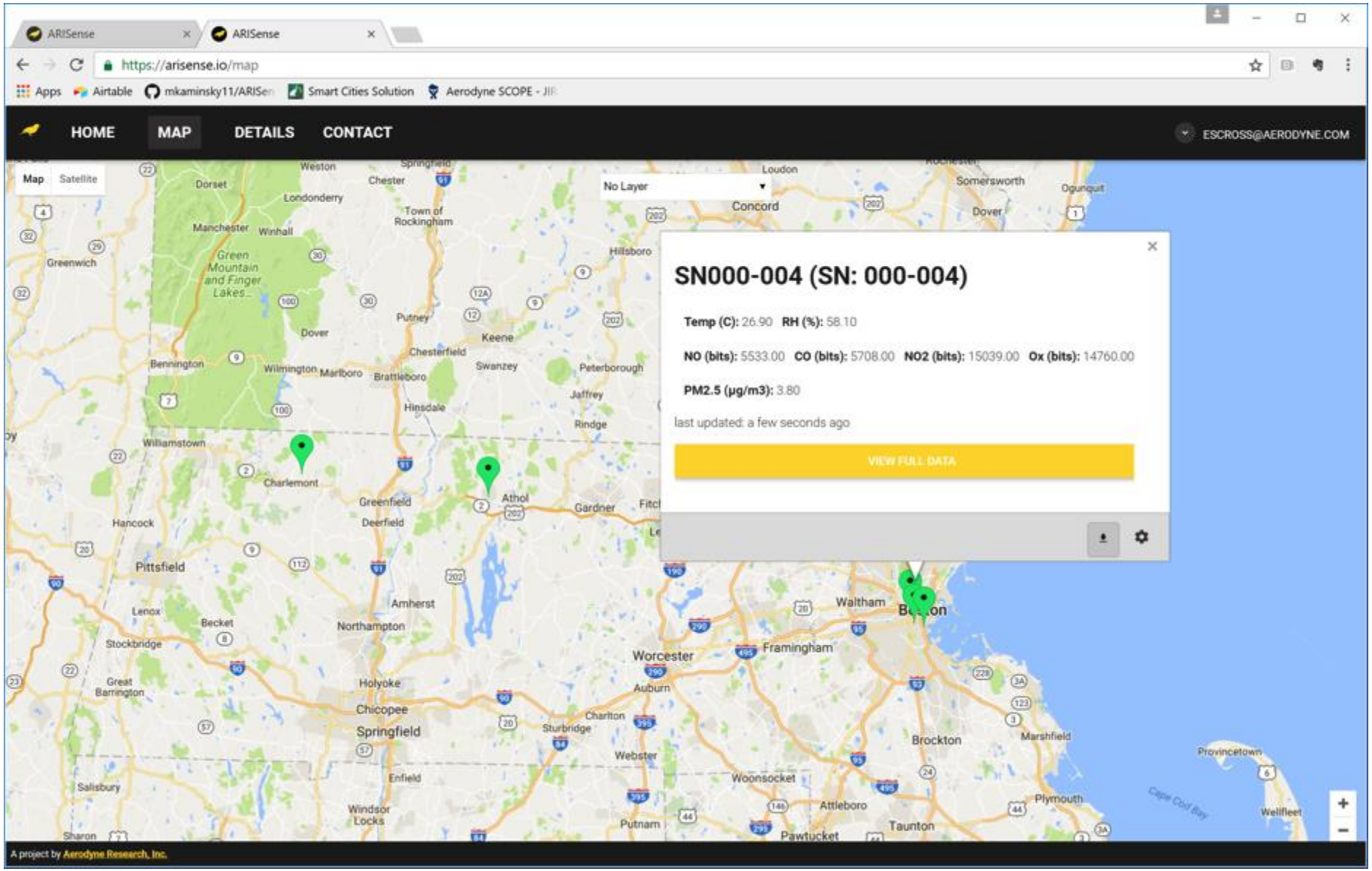

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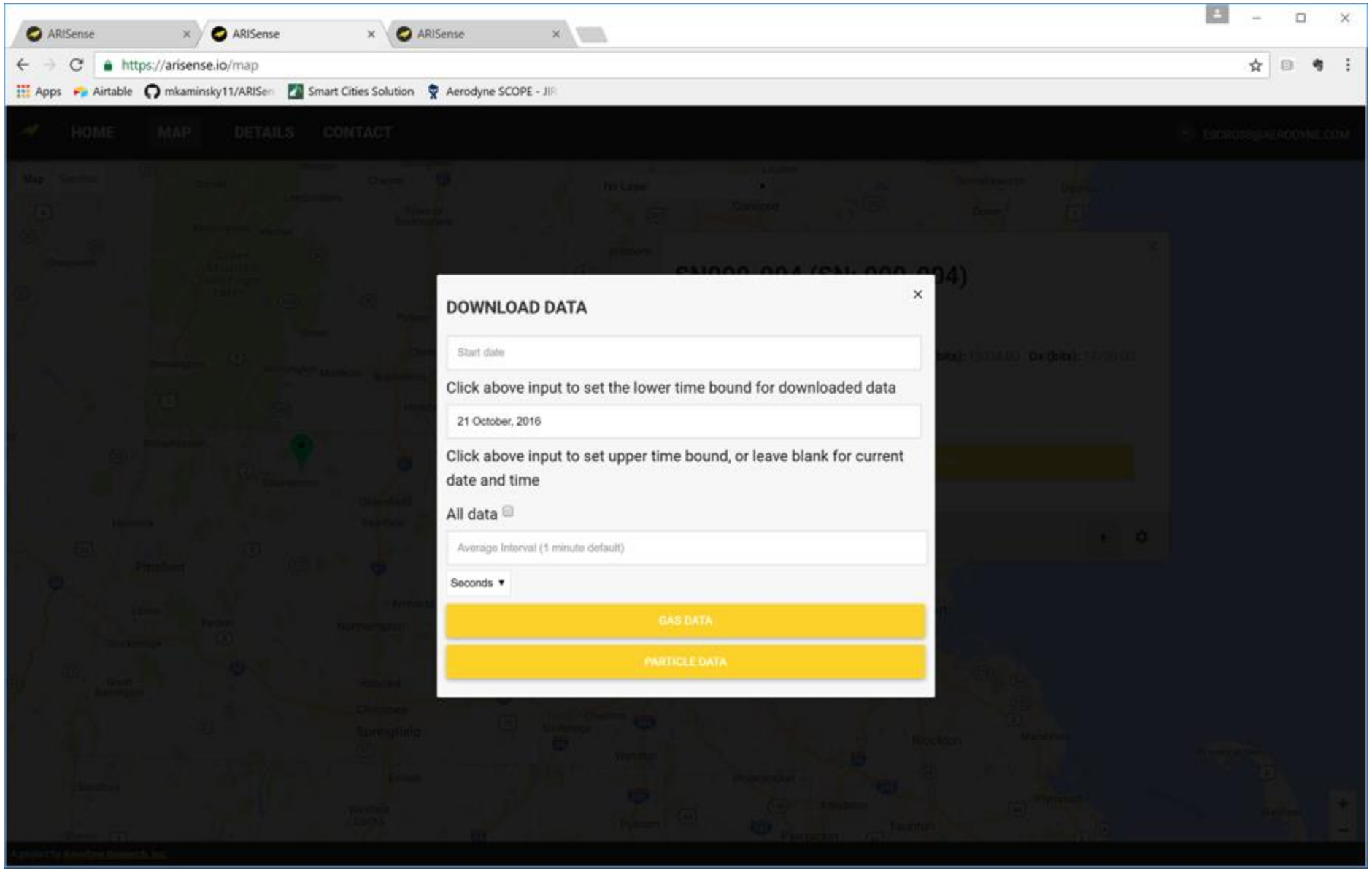

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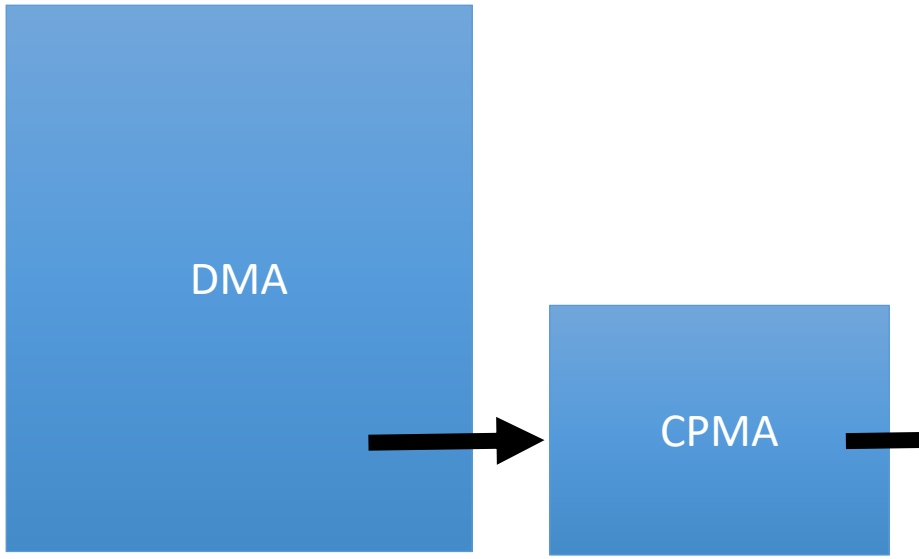
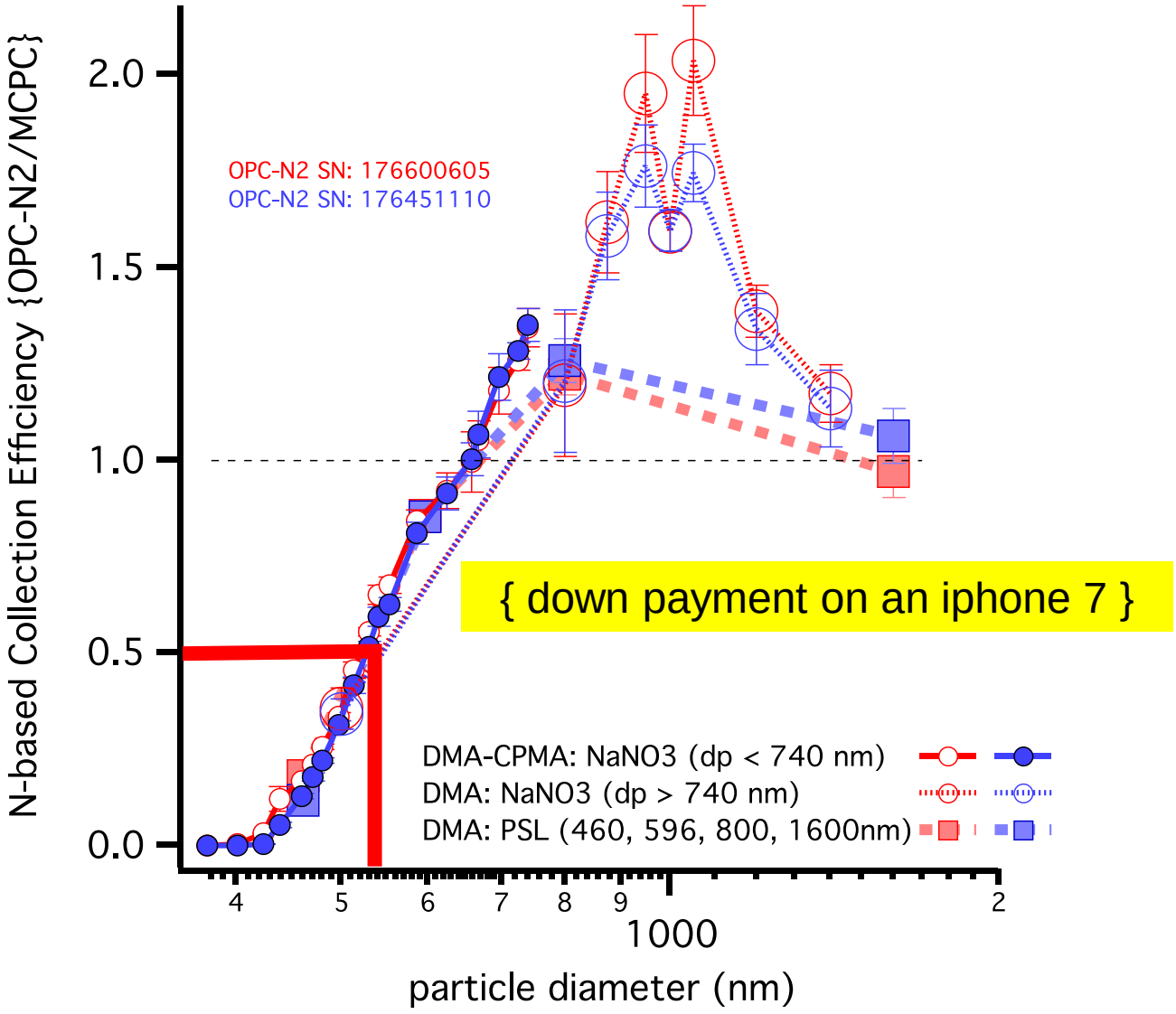
Explicit size-dependent collection efficiency of Alphasense OPC-N2

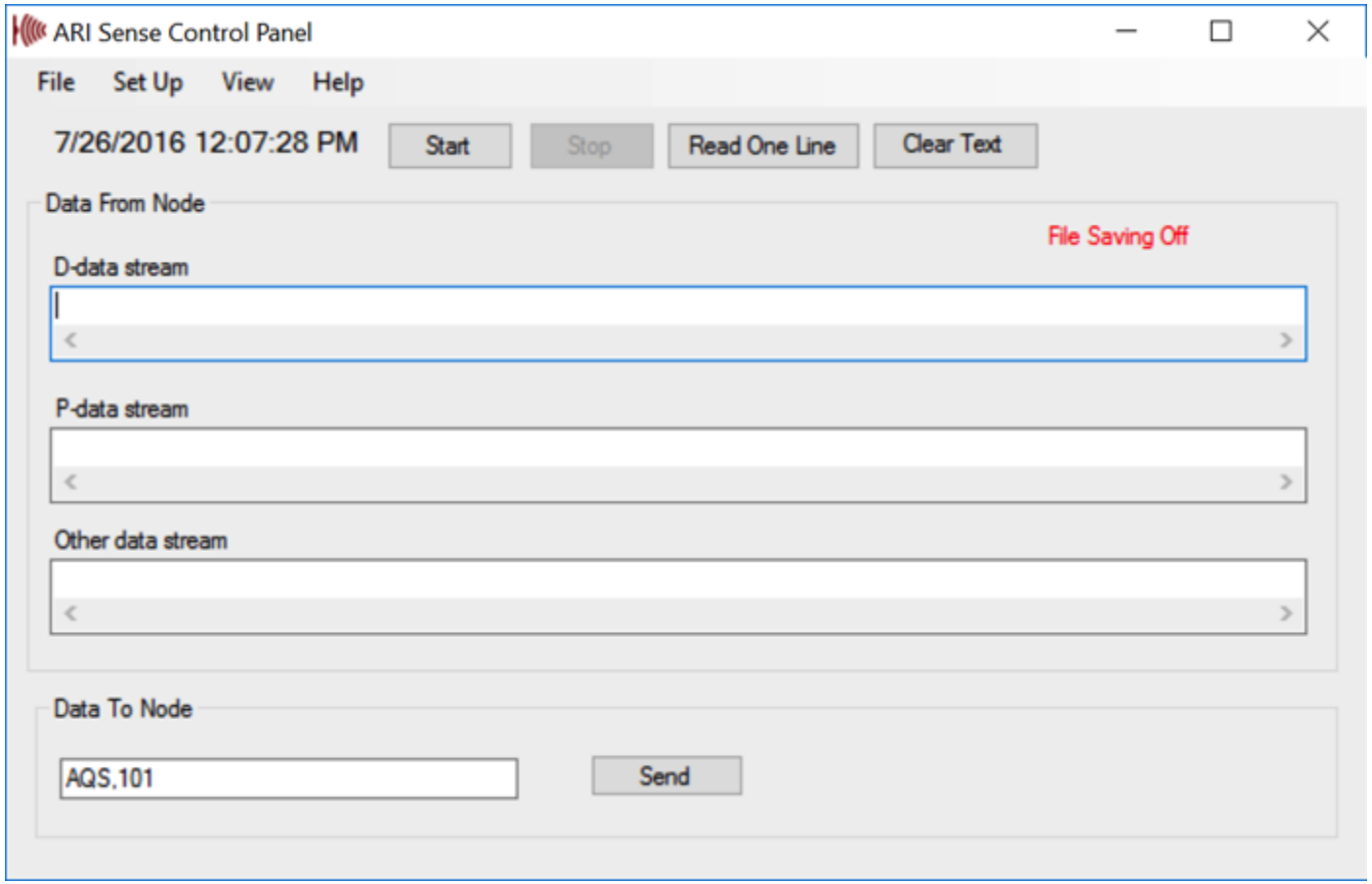


{ down payment on 1500 sq ft condominum 15 miles outside of Boston }



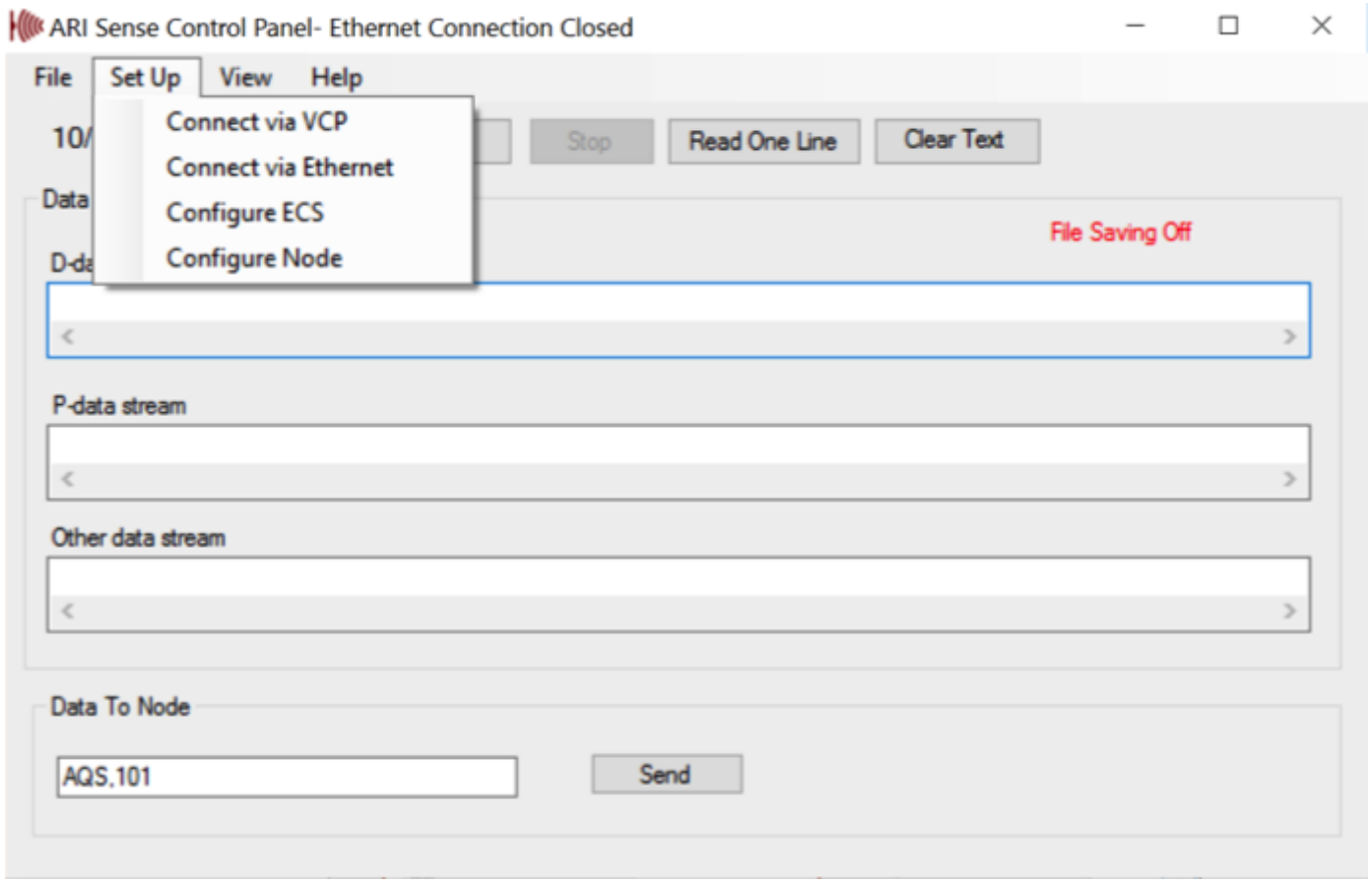
{ down payment on an iphone 7 }

DAQ control software



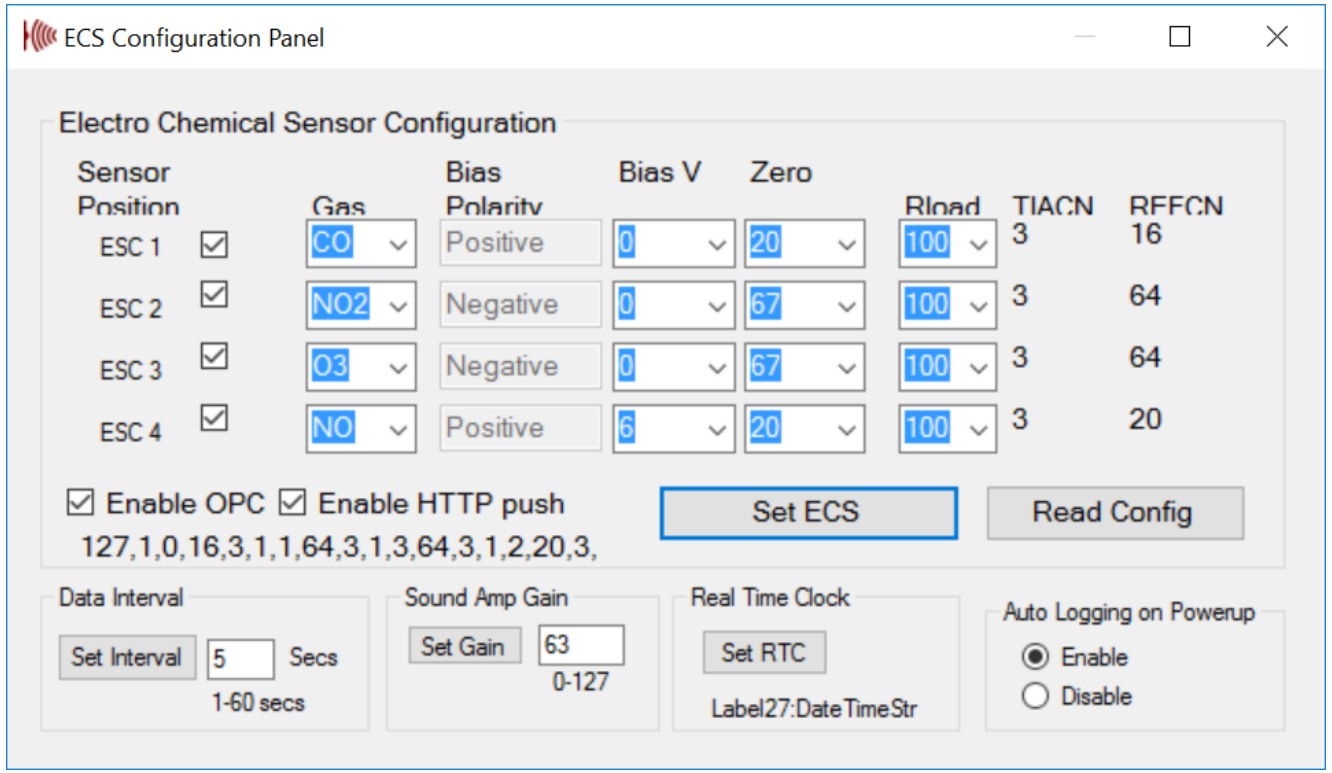
- Main DAQ screen

DAQ control software



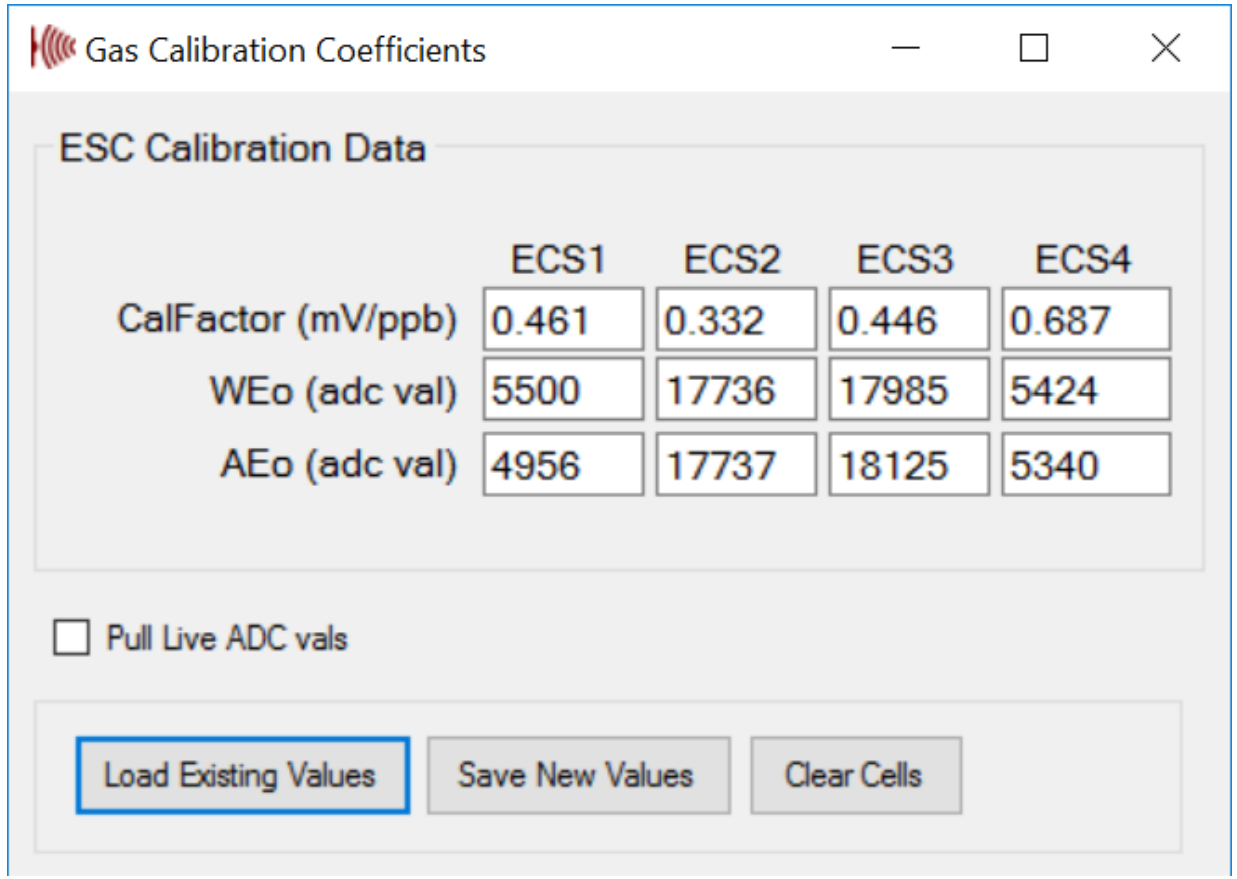
- Direct or remote connectivity options

DAQ control software



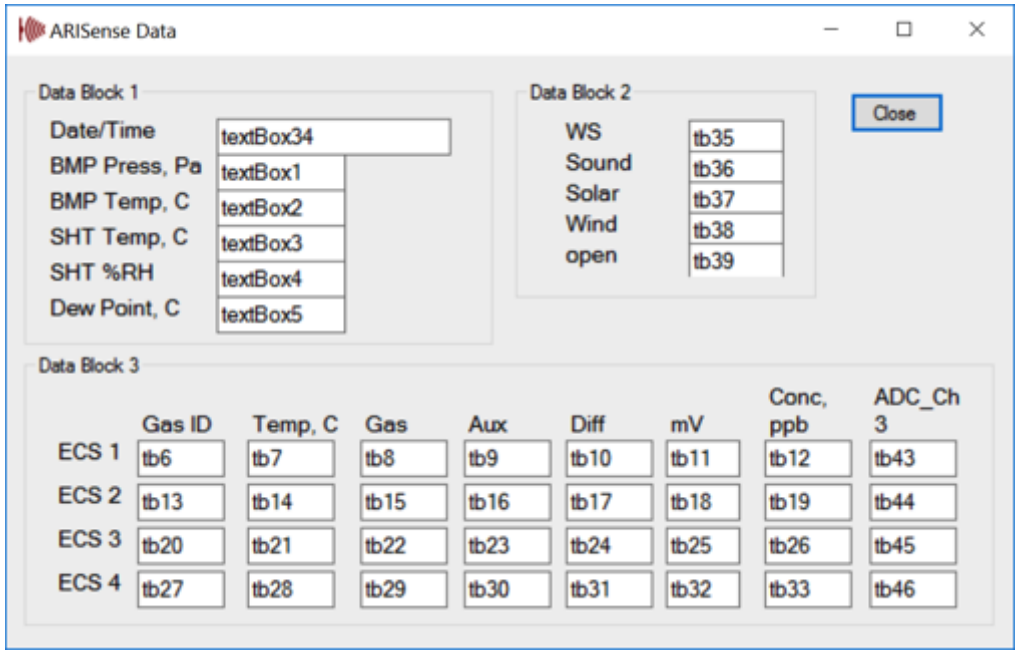
- Enable/disable various node components
- User-defined data acquisition rates
- Auto-logging on power up

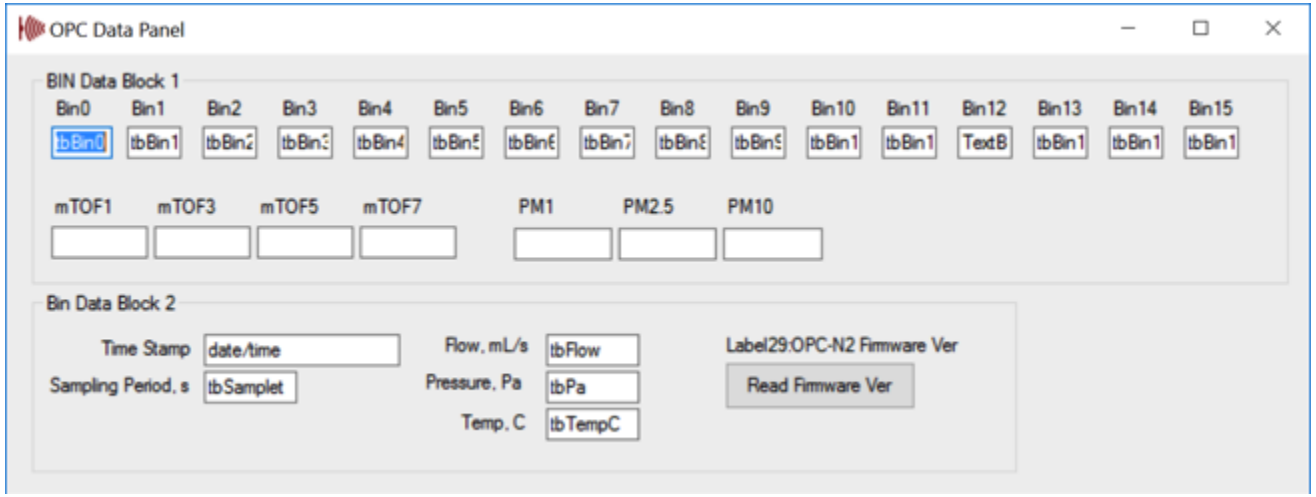
DAQ control software



- Define sensitivity and zero parameters for each sensor
- 1st order calibration (mV → ppb)

DAQ control software





- View data within panel
- Quick diagnostic of node's health state