Greater Baltimore Open Air Project

Using citizen science, IoT, & open hardware to measure air quality in Baltimore

Baltimore Open Air Partners

Civic Works

Baltimore Office of Sustainability
People · Planet · Prosperity

GPC
GREATER PASADENA COUNCIL
"Unifying and amplifying the voices of the Pasadena residents for the beautification and revitalization of all of their neighborhoods"

SIERRA CLUB

CLEAN WATER ACTION

CITY OF BALTIMORE

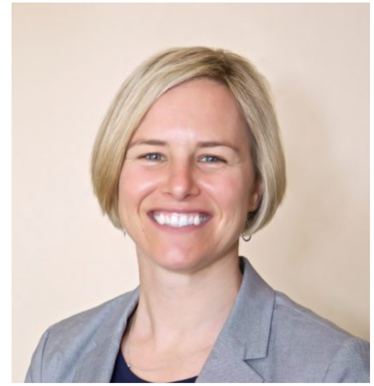
JOHNS HOPKINS UNIVERSITY

BALTIMORE UNDER GROUND SCIENCE SPACE

... and many others

JOHNS HOPKINS
KRIEGER SCHOOL of ARTS & SCIENCES

JOHNS HOPKINS
WHITING SCHOOL of ENGINEERING



Baltimore Office of Sustainability
People · Planet · Prosperity

JOHNS HOPKINS BLOOMBERG
SCHOOL of PUBLIC HEALTH

JOHNS HOPKINS
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JOHNS HOPKINS
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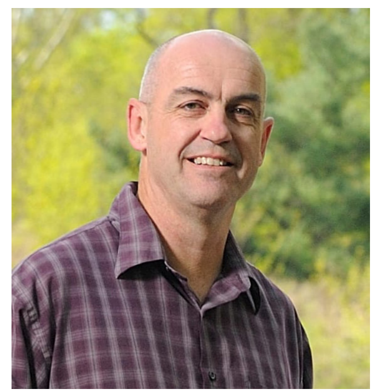
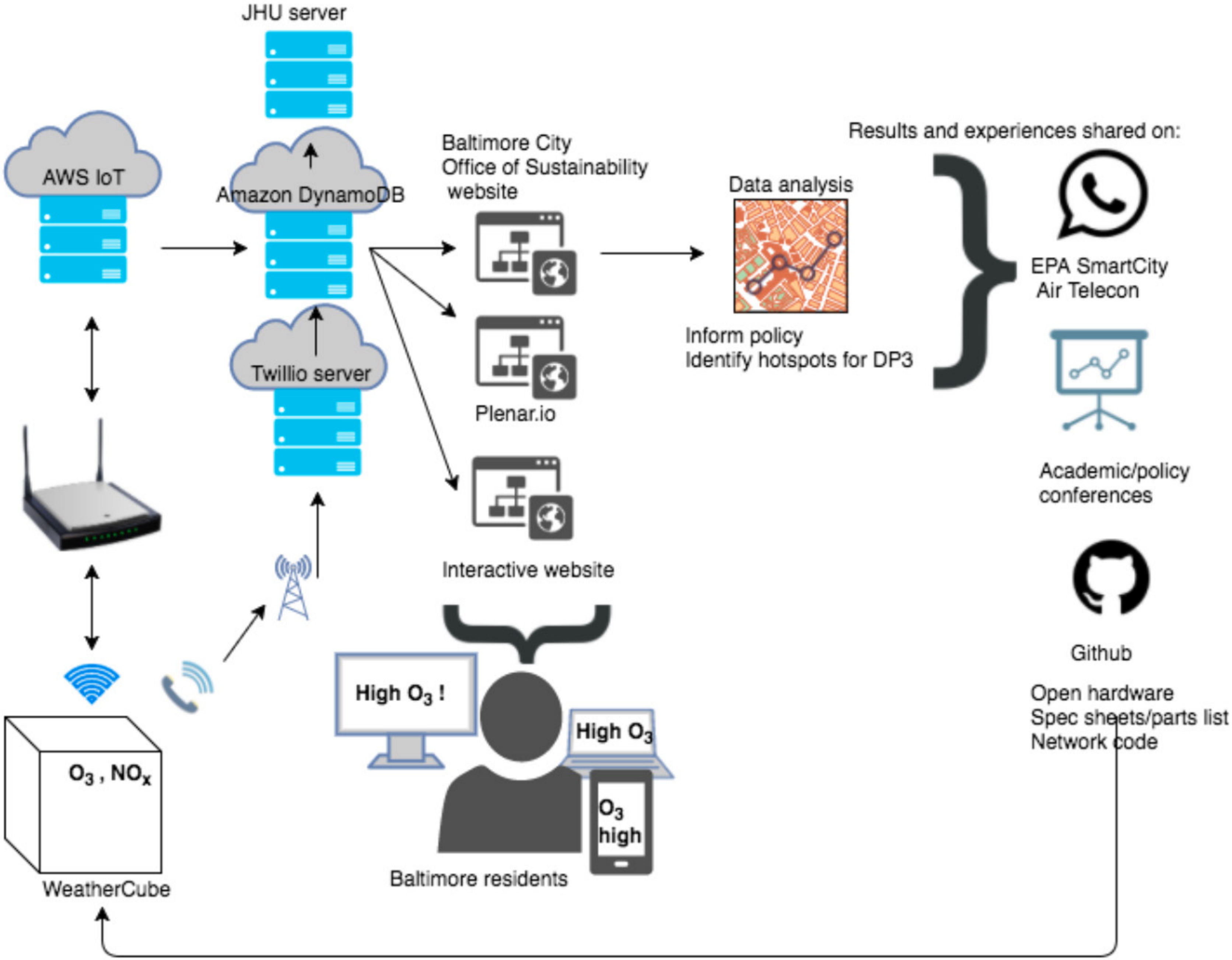


JOHNS HOPKINS
ENVIRONMENT, ENERGY, SUSTAINABILITY & HEALTH INSTITUTE

JOHNS HOPKINS BLOOMBERG
SCHOOL of PUBLIC HEALTH

Specifically, we aim to:
Design and build 300 air quality monitors, working with **citizen scientists** to build and deploy the network, as well as **manage the data & quantify** spatial variability in **air quality**.

OUR AP-
PROACH

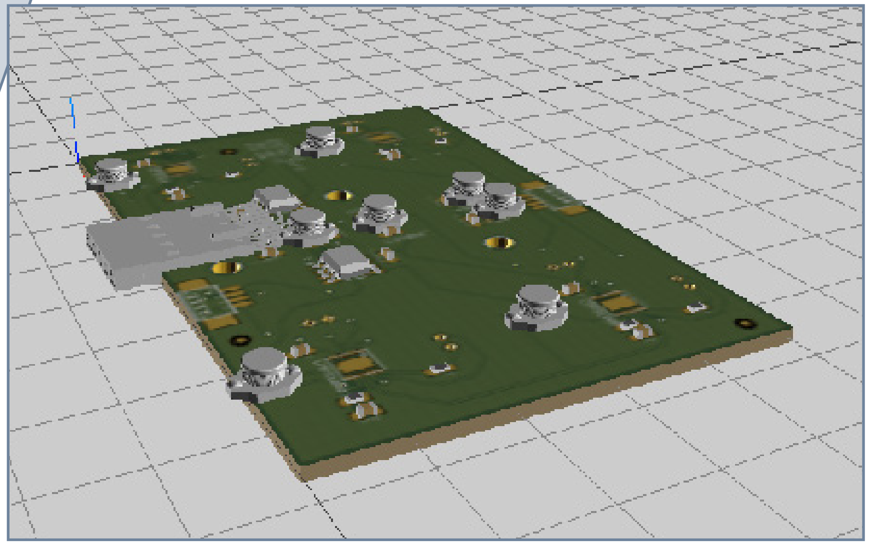


JHU server
AWS IoT
Amazon DynamoDB
Twillio server
Baltimore City
Office of Sustainability
website
Plenar.io
Interactive website
Data analysis
Inform policy
Identify hotspots for DP3
Results and experiences shared on:
EPA SmartCity
Air Telecon
Academic/policy
conferences
Github
Open hardware
Spec sheets/parts list
Network code
High O_3 !
High O_3
O_3
high
Baltimore residents
O_3 , NO_x
WeatherCube

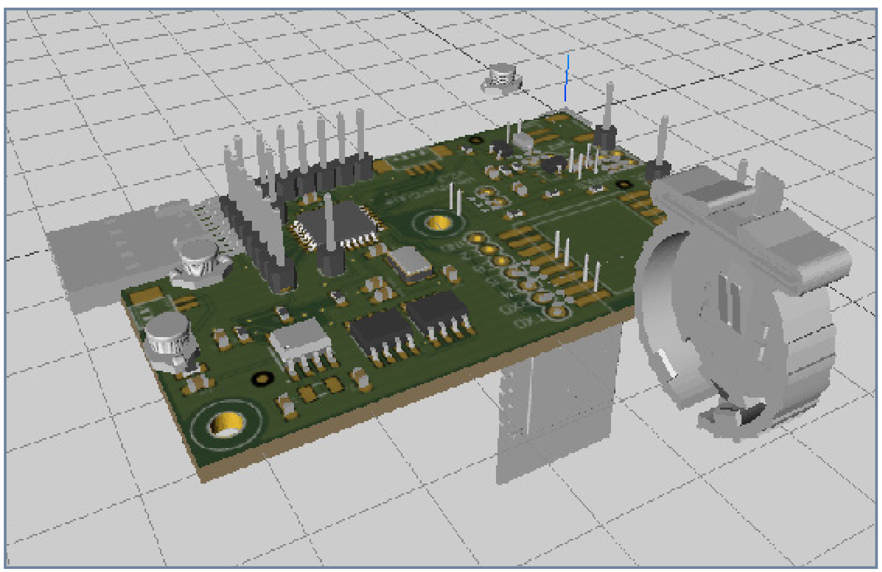
HARD-
WARE

Circuit Design

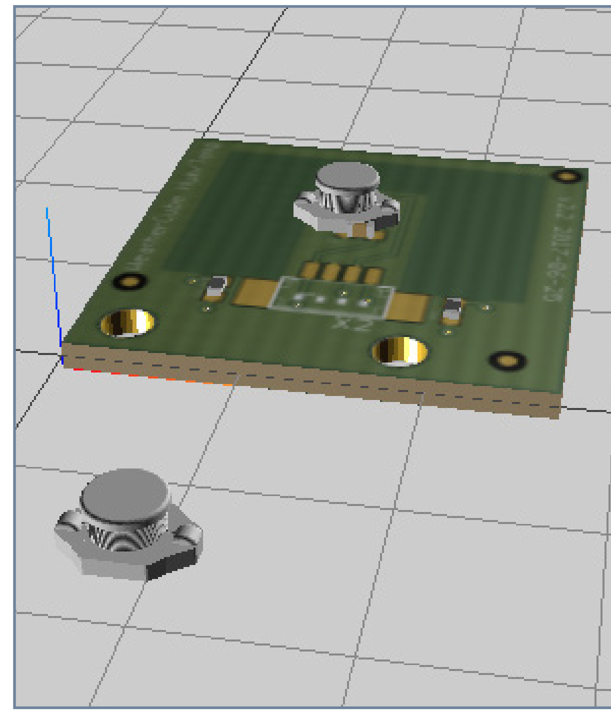
Chris Kelly is a PhD student in the Department of Geography and Environmental Engineering at JHU. His research interests include software and hardware development for water and sanitation monitoring, multi-scale spatial estimates of water and sanitation treatment access, the use of environmental and epidemiological data in infrastructure planning, collaborative GIS, and collaborative infrastructure funding mechanisms.



LMP9100

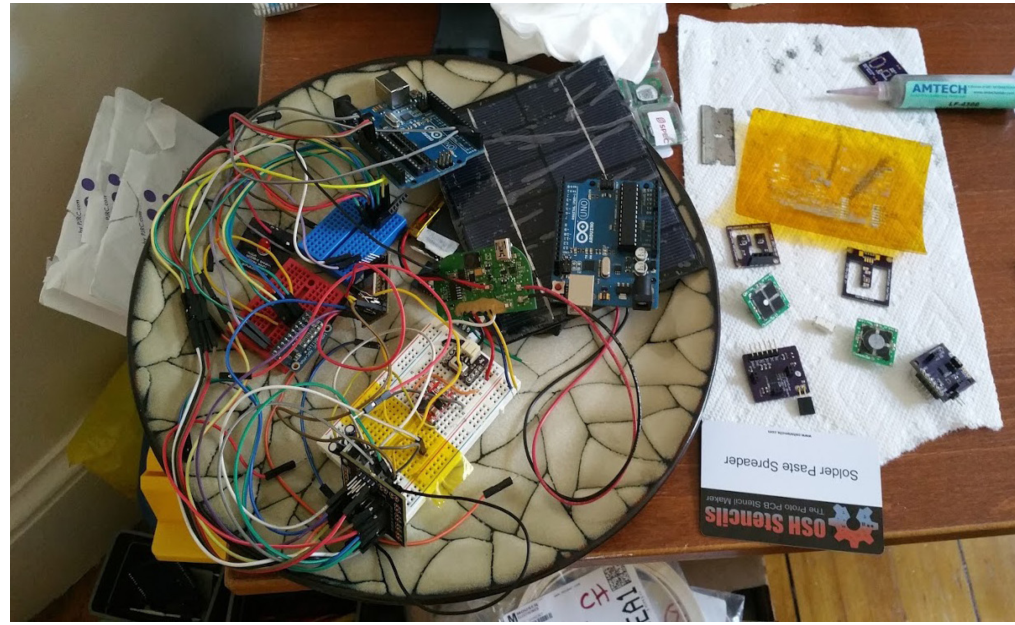


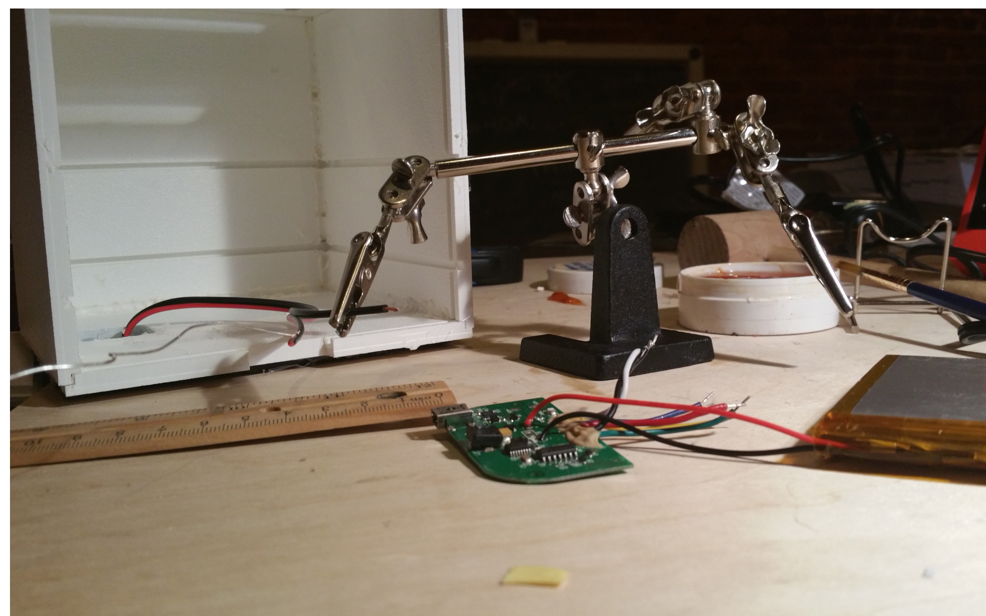
Main Board



Humidity

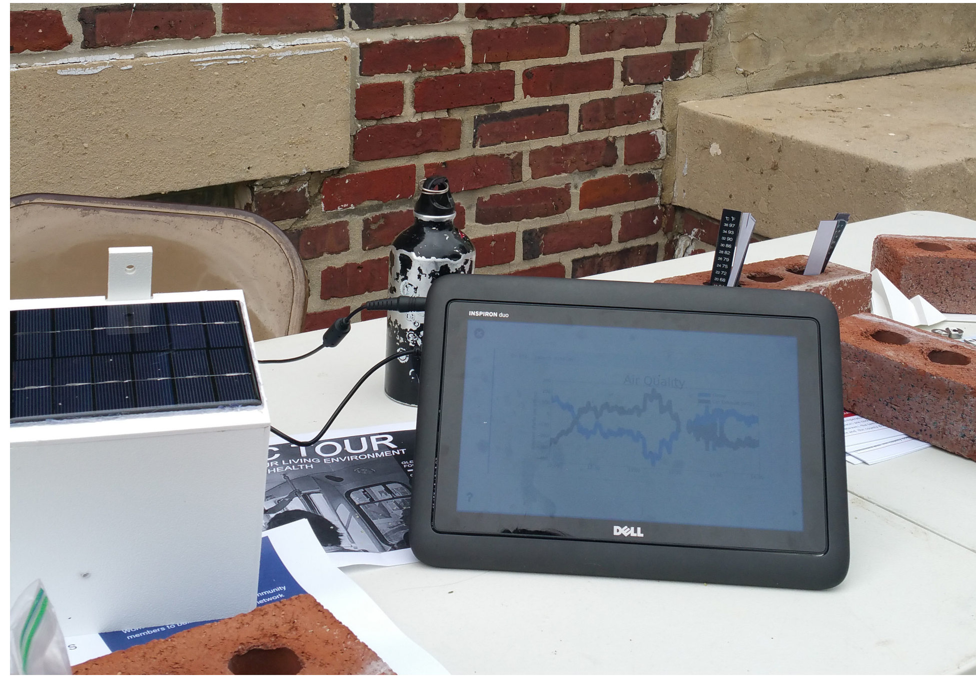

WeatherCube
v1.0
UNREG
24ANPR
5
Invoice No.: 044020213

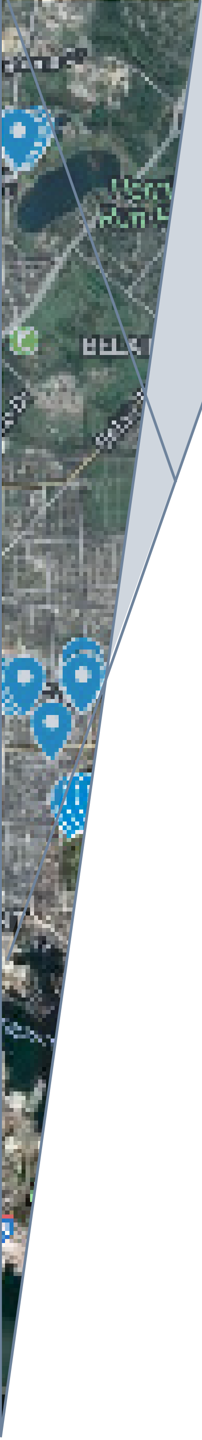

AMTECH
Solder Paste Spreader
OSH Stencils
The Proto PCB Stencil Maker



Case Design

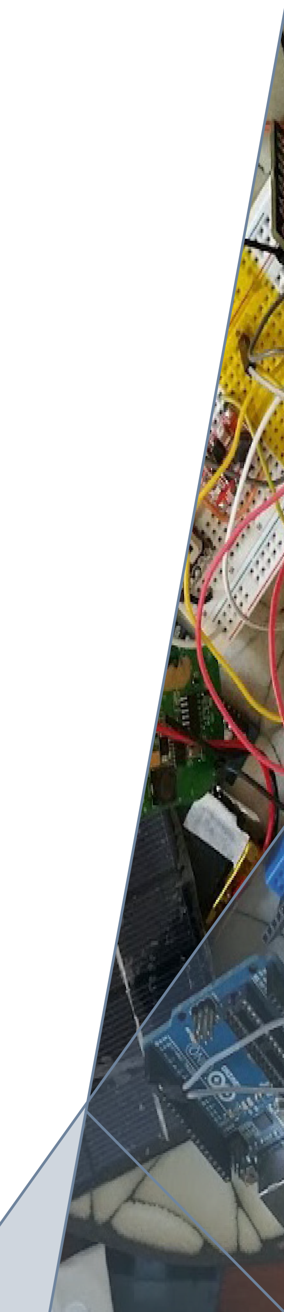
Yan Azdoud is a Postdoctoral fellow in the civil engineering department at Johns Hopkins University. He is interested in computational modeling in solid mechanics and has broader interest in interdisciplinary research.


INSPIRON duo
DELL

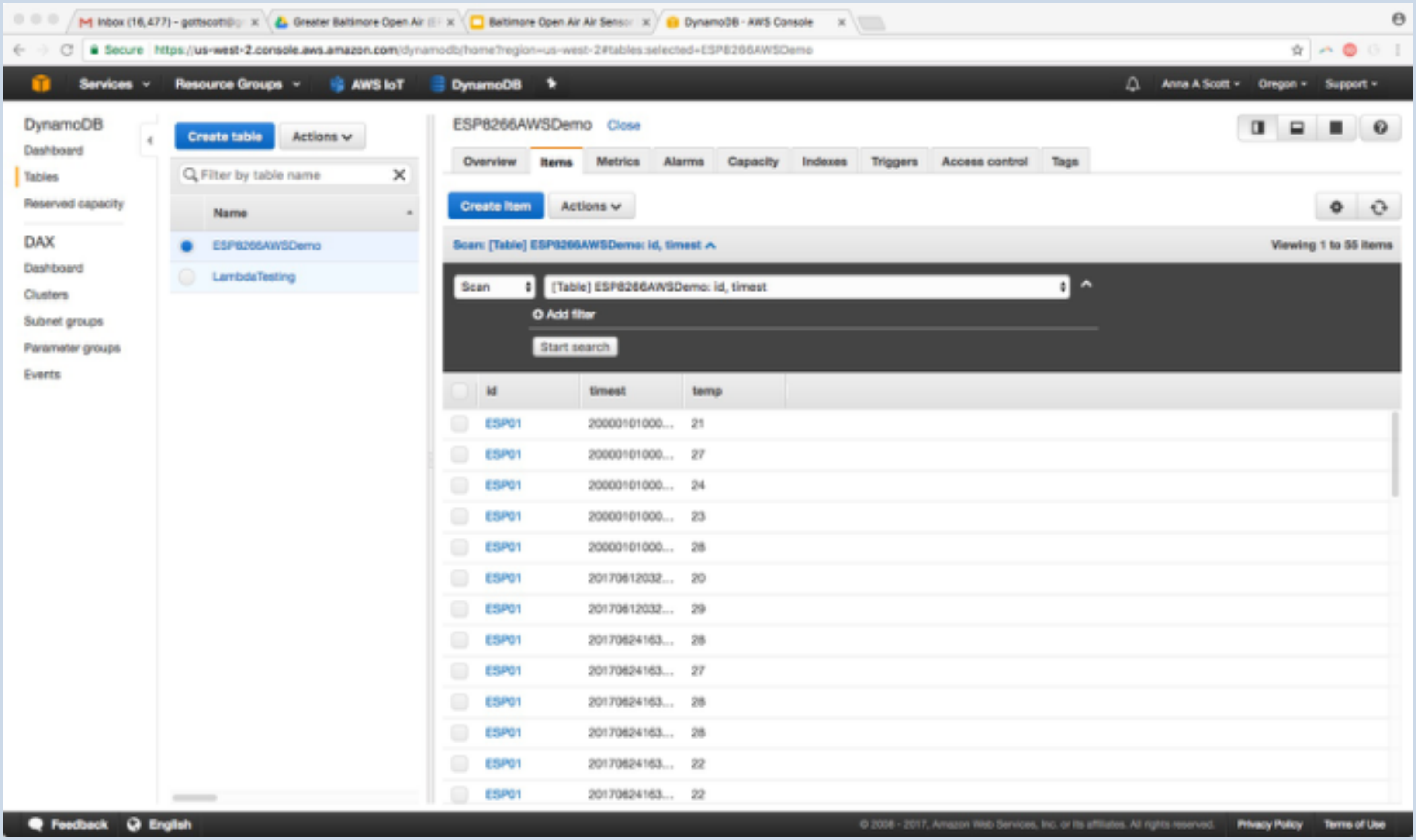


Upcoming hardware improvements

- Cellular modem integrated into circuit board (expected Aug. 2017)
- Wired connectivity (Aug. 2017)
- More compact circuit board (Nov. 2017)



SOFT-
WARE



Inbox (16,477)
Greater Baltimore Open Air
Baltimore Open Air Air Sensor
DynamoDB - AWS Console
Secure https://us-west-2.console.aws.amazon.com/dynamodb/home?region=us-west-2#tables:selected=ESP8266AWSDemo
Services
Resource Groups
AWS IoT
DynamoDB
Anna A Scott
Oregon
Support
DynamoDB
Dashboard
Tables
Reserved capacity
DAX
Dashboard
Clusters
Subnet groups
Parameter groups
Events
Create table
Actions
Filter by table name
Name
ESP8266AWSDemo
LambdaTesting
ESP8266AWSDemo
Close
Overview
Items
Metrics
Alarms
Capacity
Indexes
Triggers
Access control
Tags
Create item
Actions
Scan: [Table] ESP8266AWSDemo: id, timest
Viewing 1 to 55 items
Scan
[Table] ESP8266AWSDemo: id, timest
Add filter
Start search
id
timest
temp
ESP01
20000101000...
21
ESP01
20000101000...
27
ESP01
20000101000...
24
ESP01
20000101000...
23
ESP01
20000101000...
28
ESP01
20170612032...
20
ESP01
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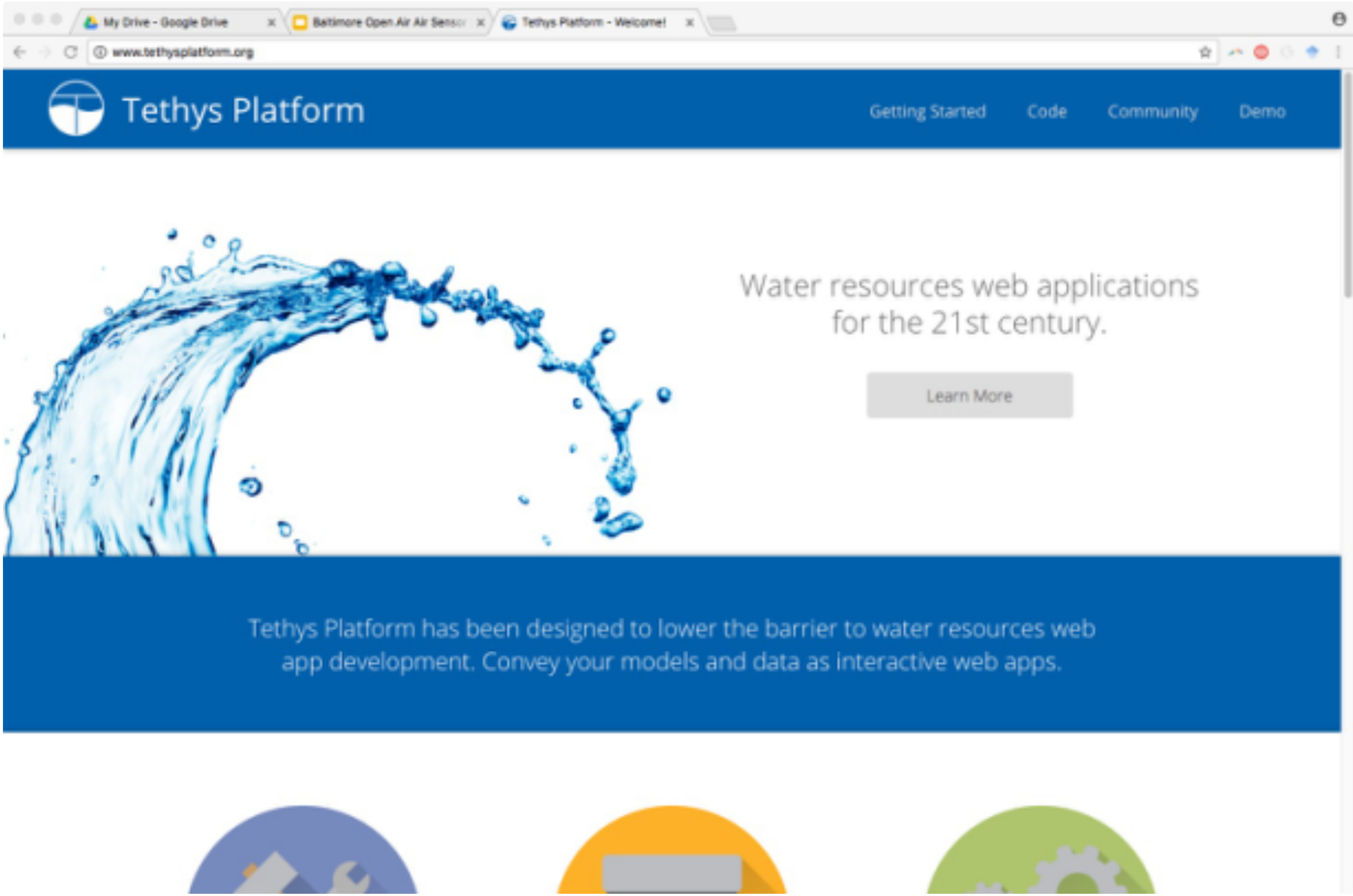
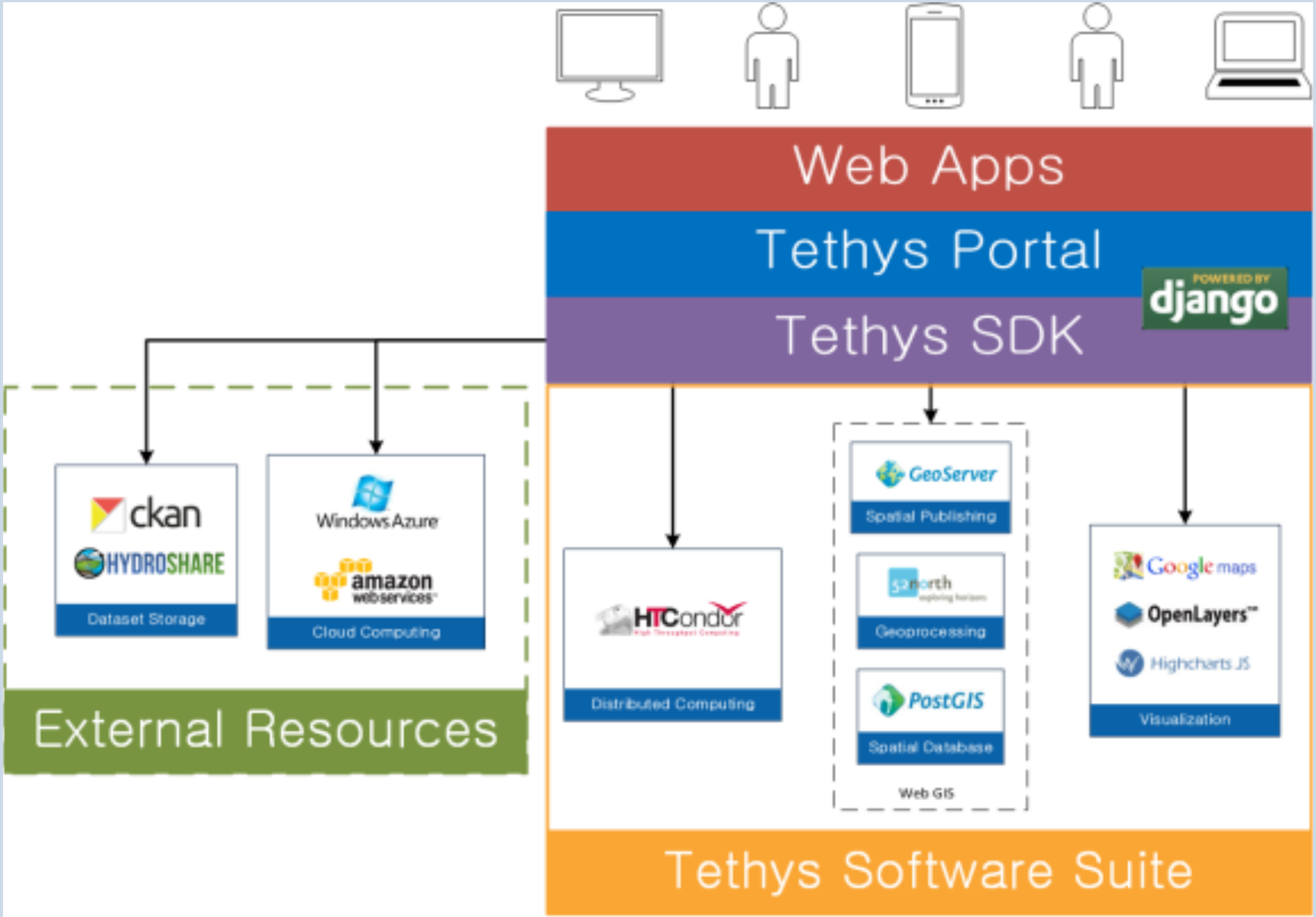
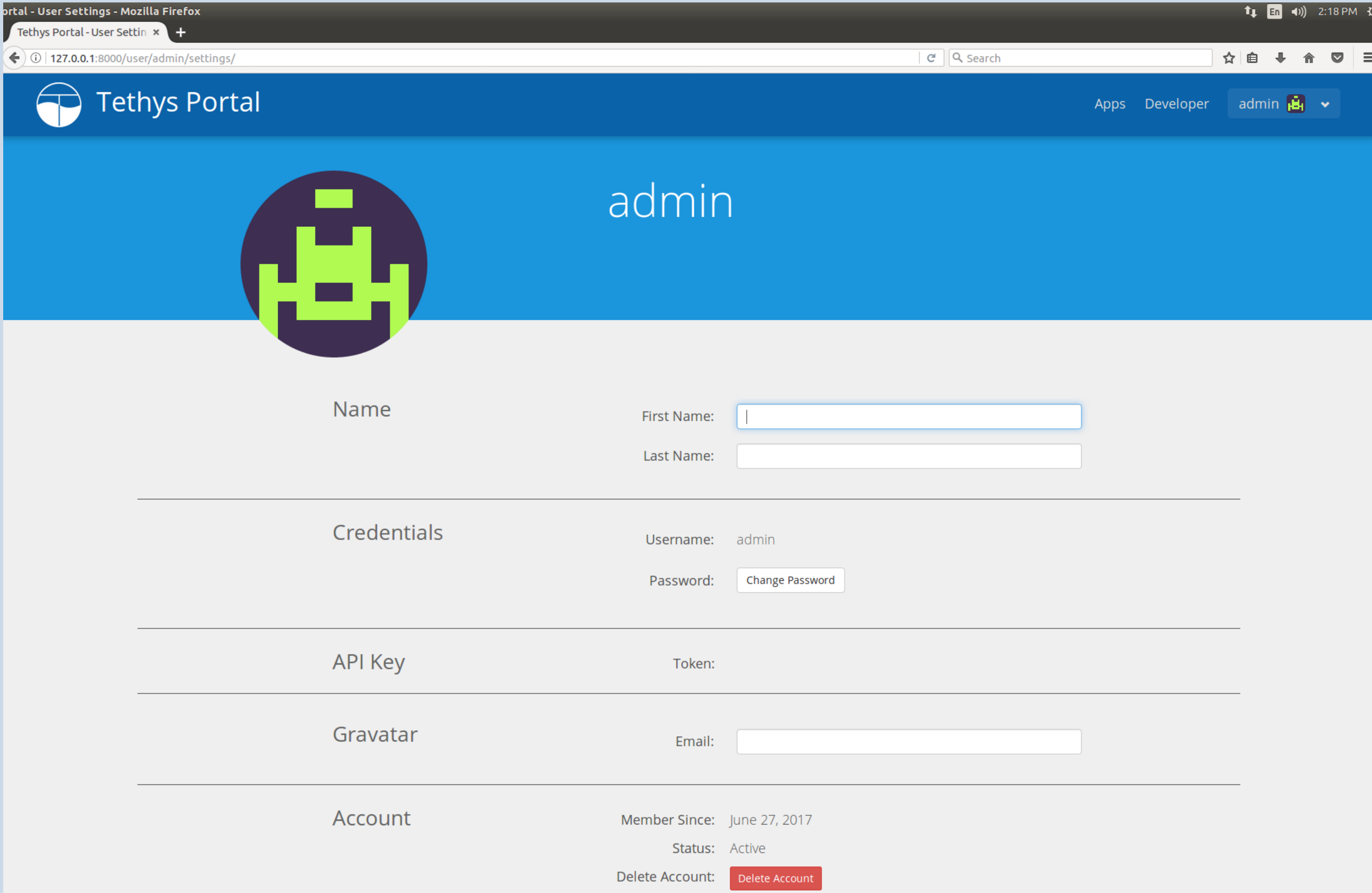
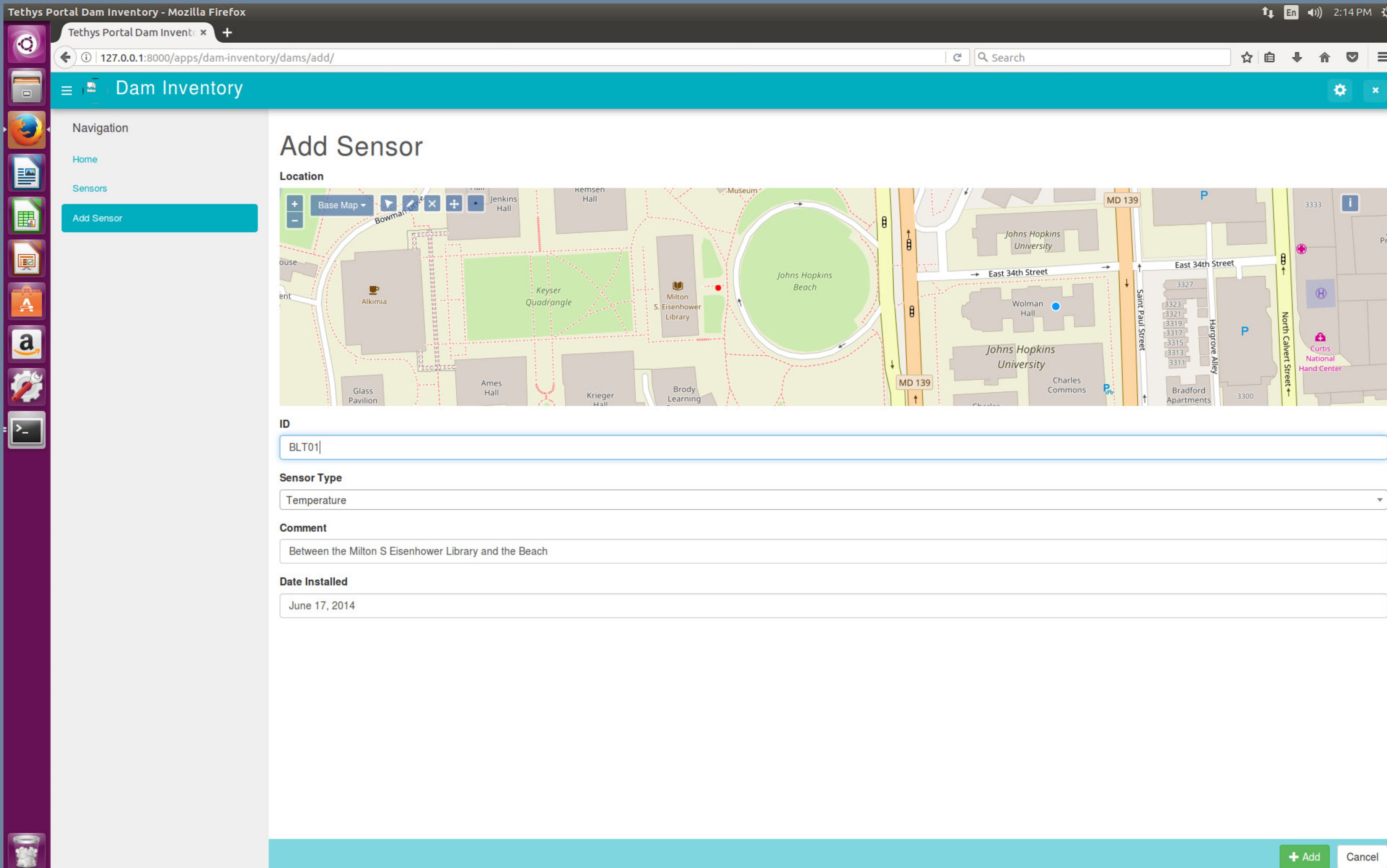
29
ESP01
20170624163...
28
ESP01
20170624163...
27
ESP01
20170624163...
28
ESP01
20170624163...
28
ESP01
20170624163...
22
ESP01
20170624163...
22
Feedback
English
© 2008 - 2017, Amazon Web Services, Inc. or its affiliates. All rights reserved.
Privacy Policy
Terms of Use

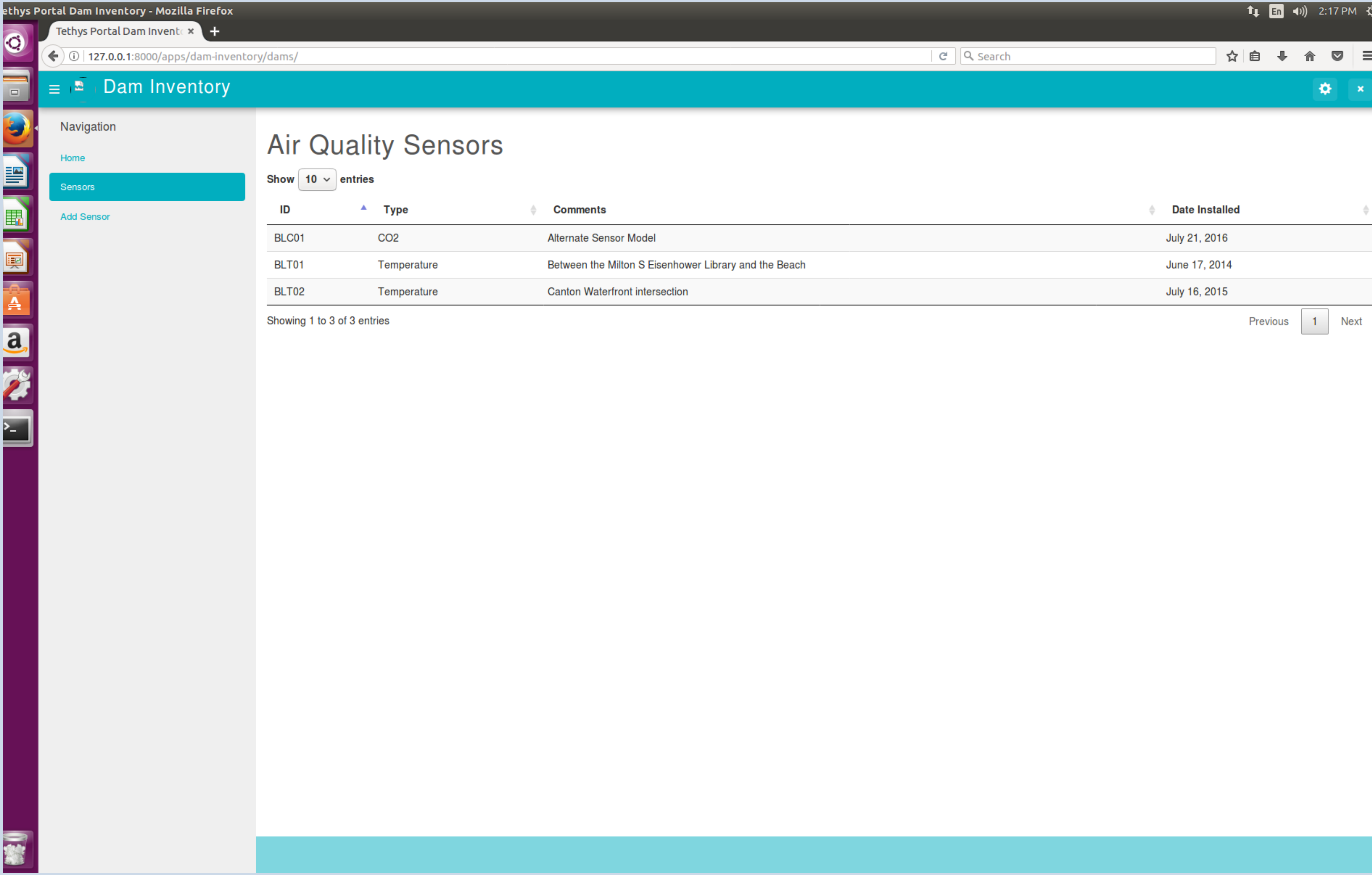

My Drive - Google Drive
Tethys Platform - Welcome!
www.tethysplatform.org
Tethys Platform
Getting Started
Code
Community
Demo
Water resources web applications
for the 21st century.
Learn More
Tethys Platform has been designed to lower the barrier to water resources web
app development. Convey your models and data as interactive web apps.


Web Apps
Tethys Portal
POWERED BY
django
Tethys SDK
ckan
HYDROSHARE
Dataset Storage
Windows Azure
amazon
webservices
Cloud Computing
External Resources
HTCondor
Distributed Computing
GeoServer
Spatial Publishing
Geoprocessing
PostGIS
Spatial Database
Web GIS
Google maps
OpenLayers
Highcharts JS
Visualization
Tethys Software Suite

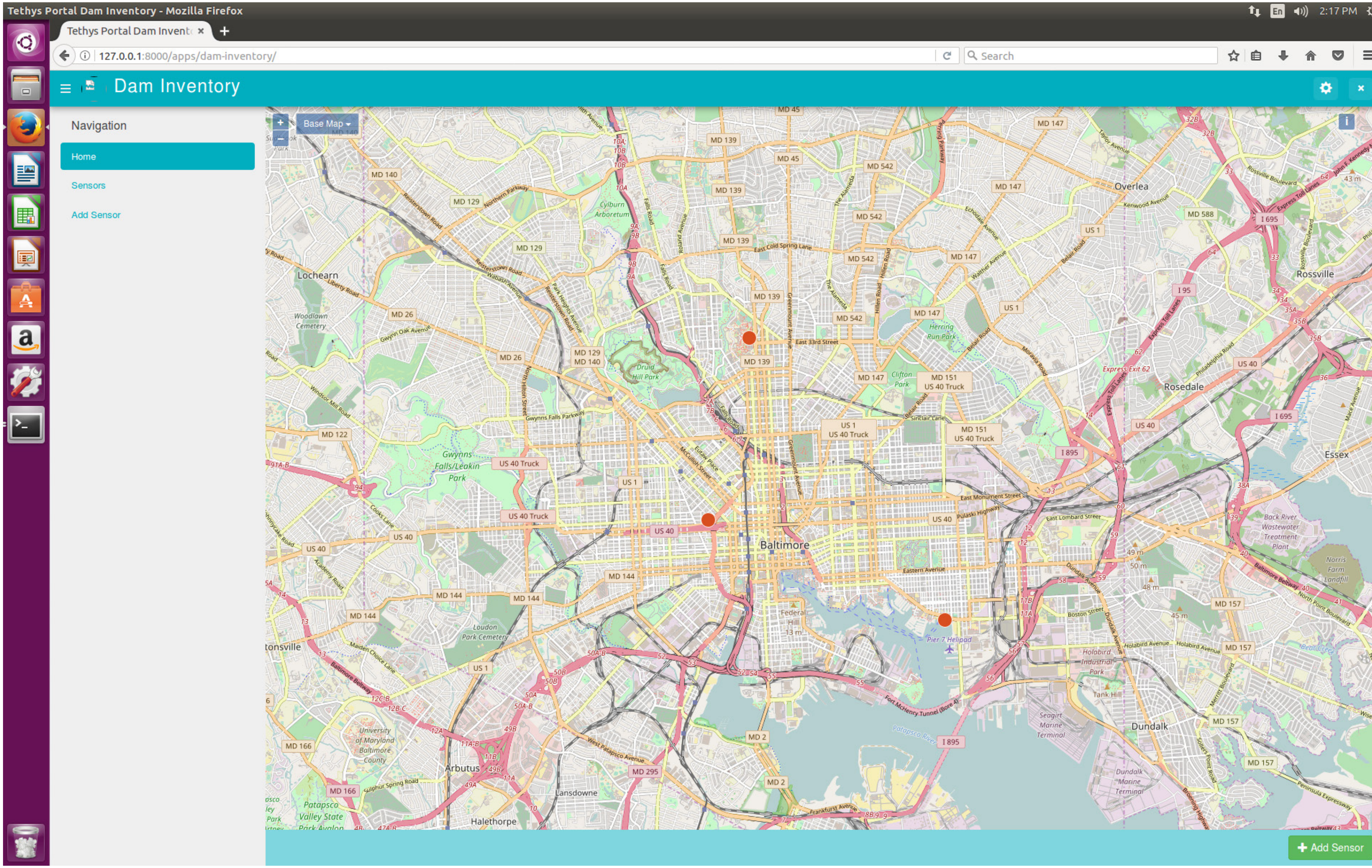

ortal - User Settings - Mozilla Firefox
Tethys Portal - User Settin
2:18 PM
127.0.0.1:8000/user/admin/settings/
Search
Tethys Portal
Apps
Developer
admin
admin
Name
First Name:
Last Name:
Credentials
Username:
admin
Password:
Change Password
API Key
Token:
Gravatar
Email:
Account
Member Since:
June 27, 2017
Status:
Active
Delete Account:
Delete Account



Tethys Portal Dam Inventory - Mozilla Firefox
2:14 PM
Tethys Portal Dam Invent
127.0.0.1:8000/apps/dam-inventory/dams/add/
Search
Dam Inventory
Navigation
Home
Sensors
Add Sensor
Add Sensor
Location
Base Map
Jenkins Hall
Remsen Hall
Museum
Alkimia
Keyser Quadrangle
Milton S. Eisenhower Library
Johns Hopkins Beach
Johns Hopkins University
East 34th Street
Wolman Hall
Charles Commons
Bradford Apartments
Saint Paul Street
Hargrove Alley
North Calvert Street
Curtis National Hand Center
MD 139
Ames Hall
Glass Pavilion
Krieger Hall
Brody Learning
ID
BLT01
Sensor Type
Temperature
Comment
Between the Milton S Eisenhower Library and the Beach
Date Installed
June 17, 2014
Add
Cancel



ethys Portal Dam Inventory - Mozilla Firefox
2:17 PM
Tethys Portal Dam Invent
127.0.0.1:8000/apps/dam-inventory/dams/
Search
Dam Inventory
Navigation
Home
Sensors
Add Sensor
Air Quality Sensors
Show 10 entries
ID
Type
Comments
Date Installed
BLC01
CO2
Alternate Sensor Model
July 21, 2016
BLT01
Temperature
Between the Milton S Eisenhower Library and the Beach
June 17, 2014
BLT02
Temperature
Canton Waterfront intersection
July 16, 2015
Showing 1 to 3 of 3 entries
Previous
1
Next



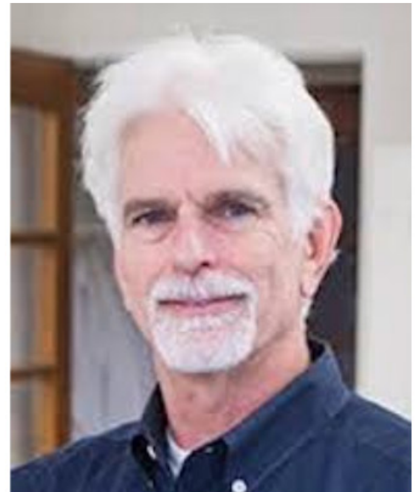
Tethys Portal Dam Inventory - Mozilla Firefox
2:17 PM
Tethys Portal Dam Invent
127.0.0.1:8000/apps/dam-inventory/
Search
Dam Inventory
Navigation
Home
Sensors
Add Sensor
Base Map
Baltimore
Overlea
Rossville
Rosedale
Essex
Dundalk
Lochearn
Arbutus
Lansdowne
Halethorpe
Add Sensor

This spring, we have:

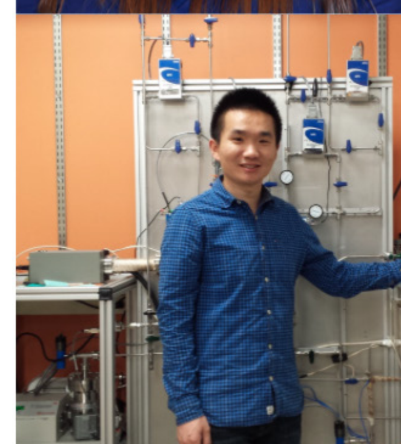
» Designed a wireless, solar powered air quality monitoring platform
» Began laboratory calibrations of air quality sensors
» Created computer code to upload data to Amazon Web Services (AWS) database DynamoDB
» Began writing code to utilize AWS IoT lambda rule engine
» Hosted community workshops
» Began coordinating with site hosts for monitor installation
» Continued outreach online: website, twitter

CALIBRA-
TION

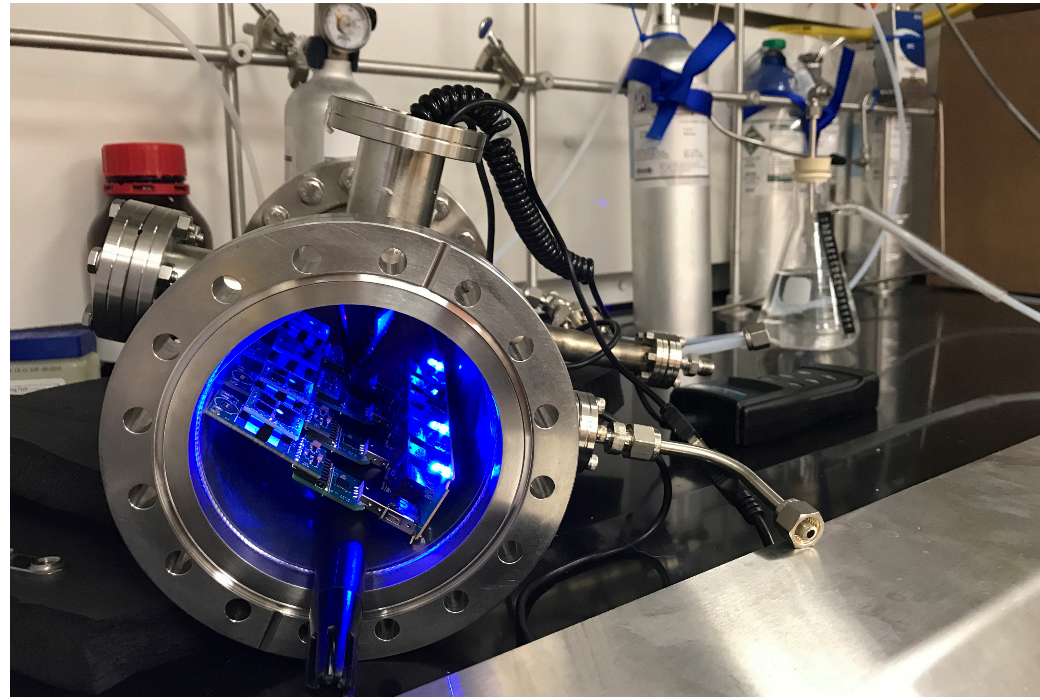
Calibrations took place at University of Maryland and in Professor Sarah Horst's lab at Johns Hopkins Univeristy.



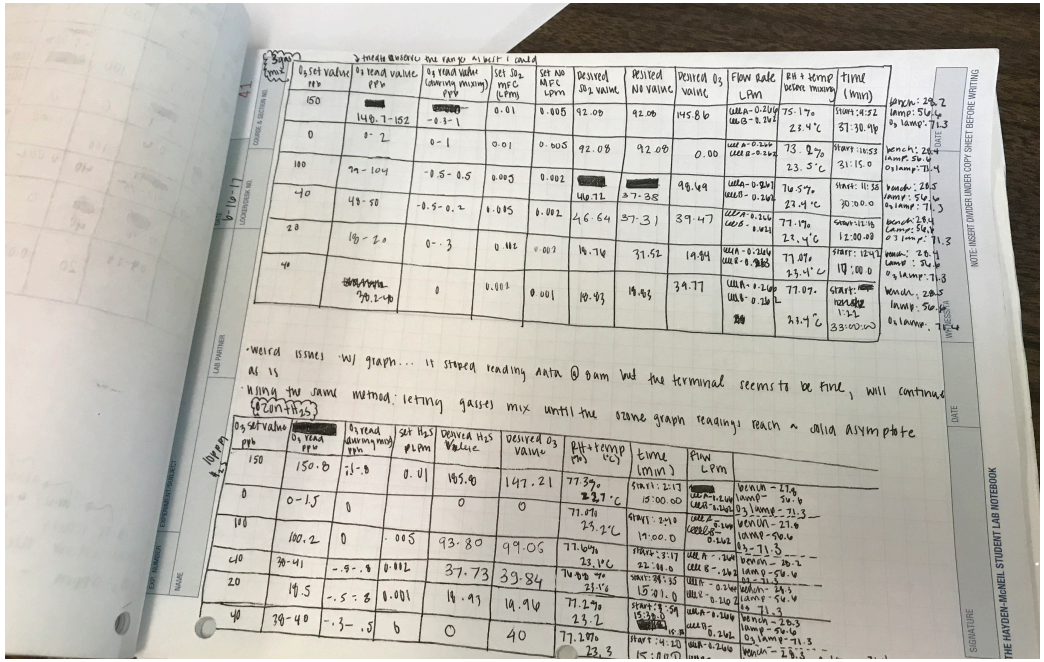
JOHNS HOPKINS
UNIVERSITY



UNIVERSITY OF
MARYLAND



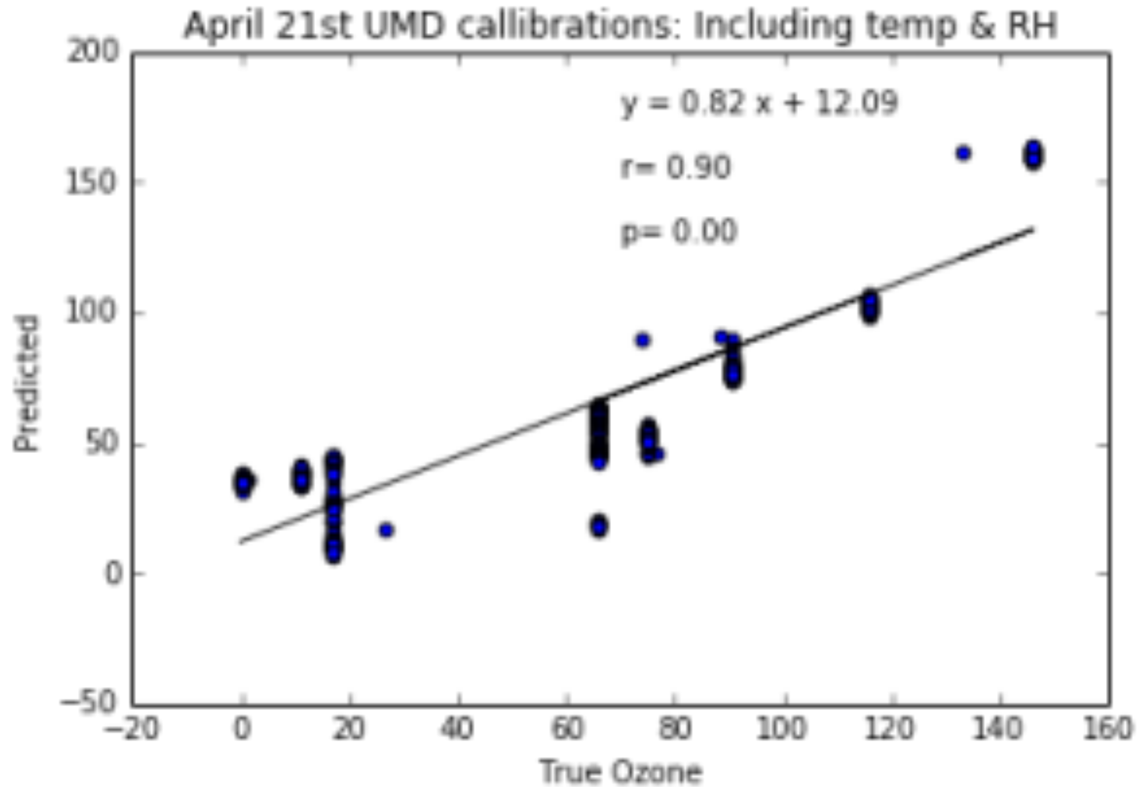

NITROGEN
XL-65



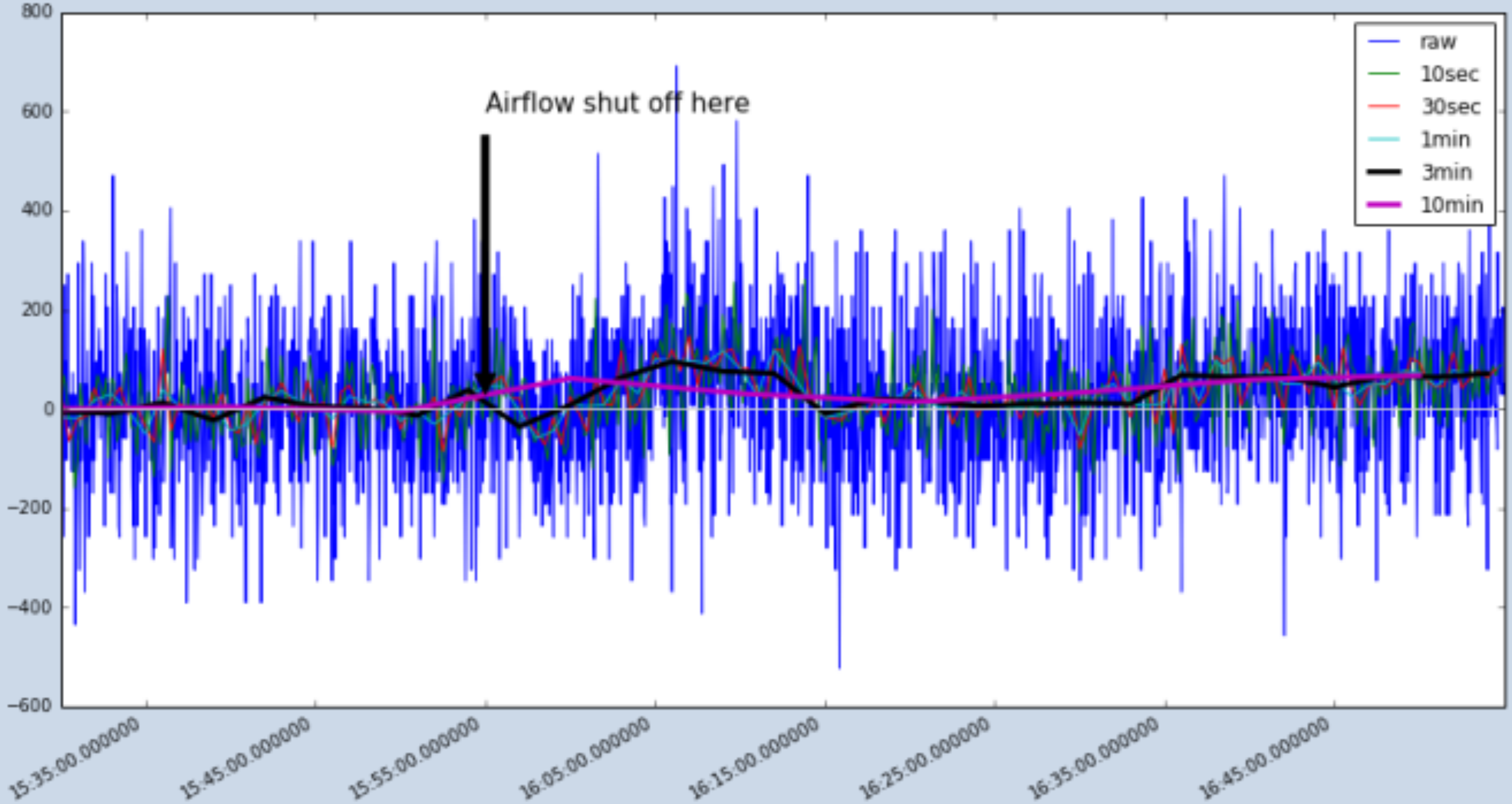
12-Jun					
O3 Set Value (	duration (min)	O3 Read Value	total flow rate	RH (%)	Start time
150	30	150.7	1.924	81.2	Didn't record
0	15	21	1.953	80.1	14:20
100	15	99.6	1.933	79.9	14:43
25	15	24.2	1.953	79.3	15:20
10	15	10	1.933	78.6	15:43
0	15	2	1.936	77	16:03

```
lab_df['o3'].loc['2017-06-12 14:20:01':'2017-06-12 14:43:00'] = 21
lab_df['o3'].loc['2017-06-12 14:43:01':'2017-04-21 15:20:00'] = 100
lab_df['o3'].loc['2017-06-12 15:20:00':'2017-04-21 15:43:00'] = 24
lab_df['o3'].loc['2017-06-12 15:43:00':'2017-06-12 16:03:00'] = 10
lab_df['o3'].loc['2017-06-12 16:03:00':'2017-06-12 16:18:00] = 2
```

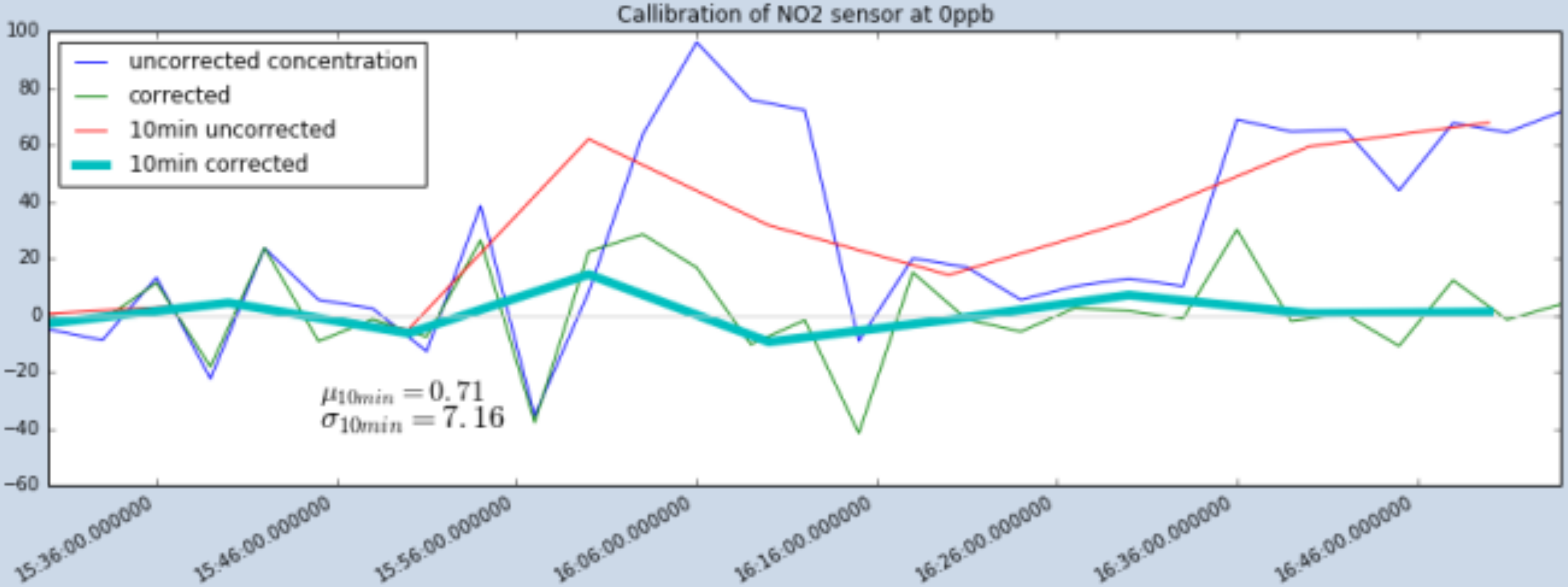
Sensor Calibrations



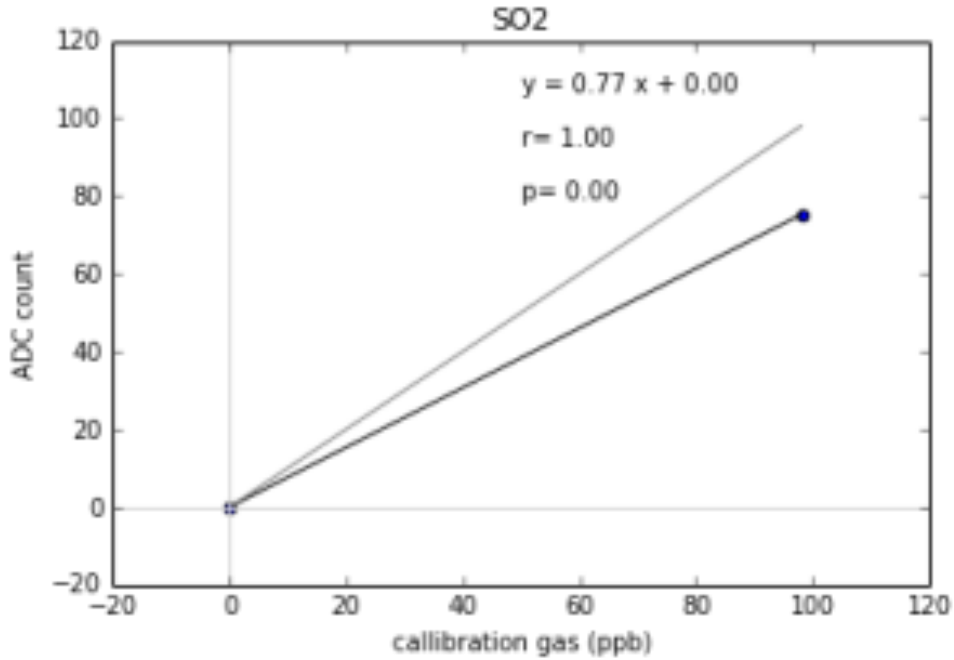
Protocol following: McElroy, F. F. "Transfer standards for calibration of air monitoring analyzers for ozone." EPA Technical Assistance Document (1979).

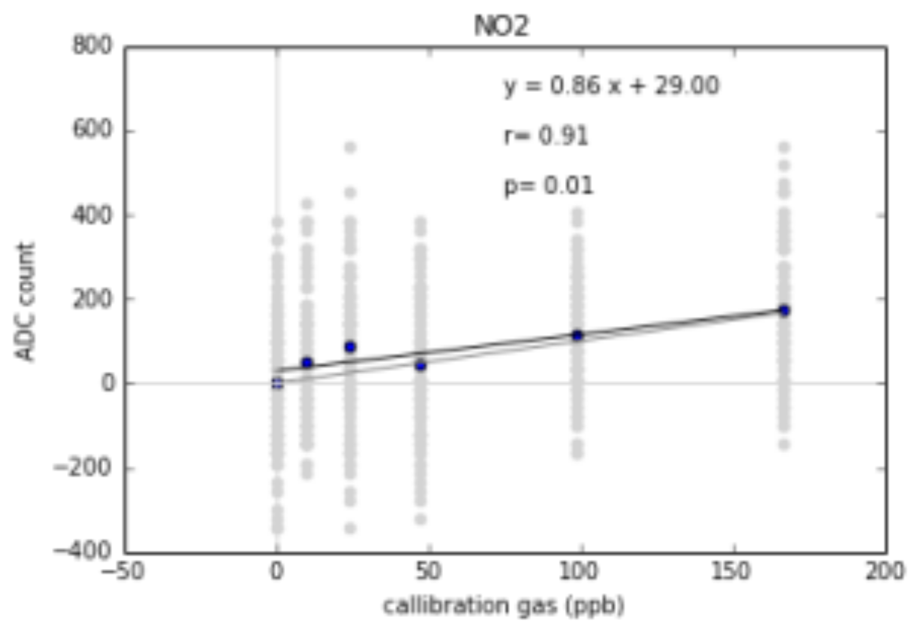


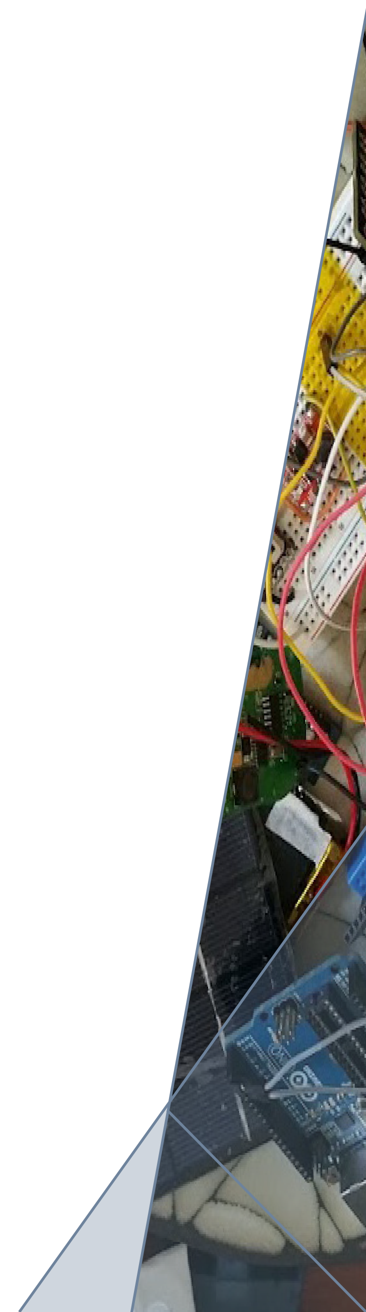
Airflow shut off here
raw
10sec
30sec
1min
3min
10min
800
600
400
200
0
−200
−400
−600
15:35:00.000000
15:45:00.000000
15:55:00.000000
16:05:00.000000
16:15:00.000000
16:25:00.000000
16:35:00.000000
16:45:00.000000



Callibration of NO2 sensor at 0ppb
uncorrected concentration
corrected
10min uncorrected
10min corrected
$\mu_{10min} = 0.71$
$\sigma_{10min} = 7.16$
100
80
60
40
20
0
−20
−40
−60
15:36:00.000000
15:46:00.000000
15:56:00.000000
16:06:00.000000
16:16:00.000000
16:26:00.000000
16:36:00.000000
16:46:00.000000

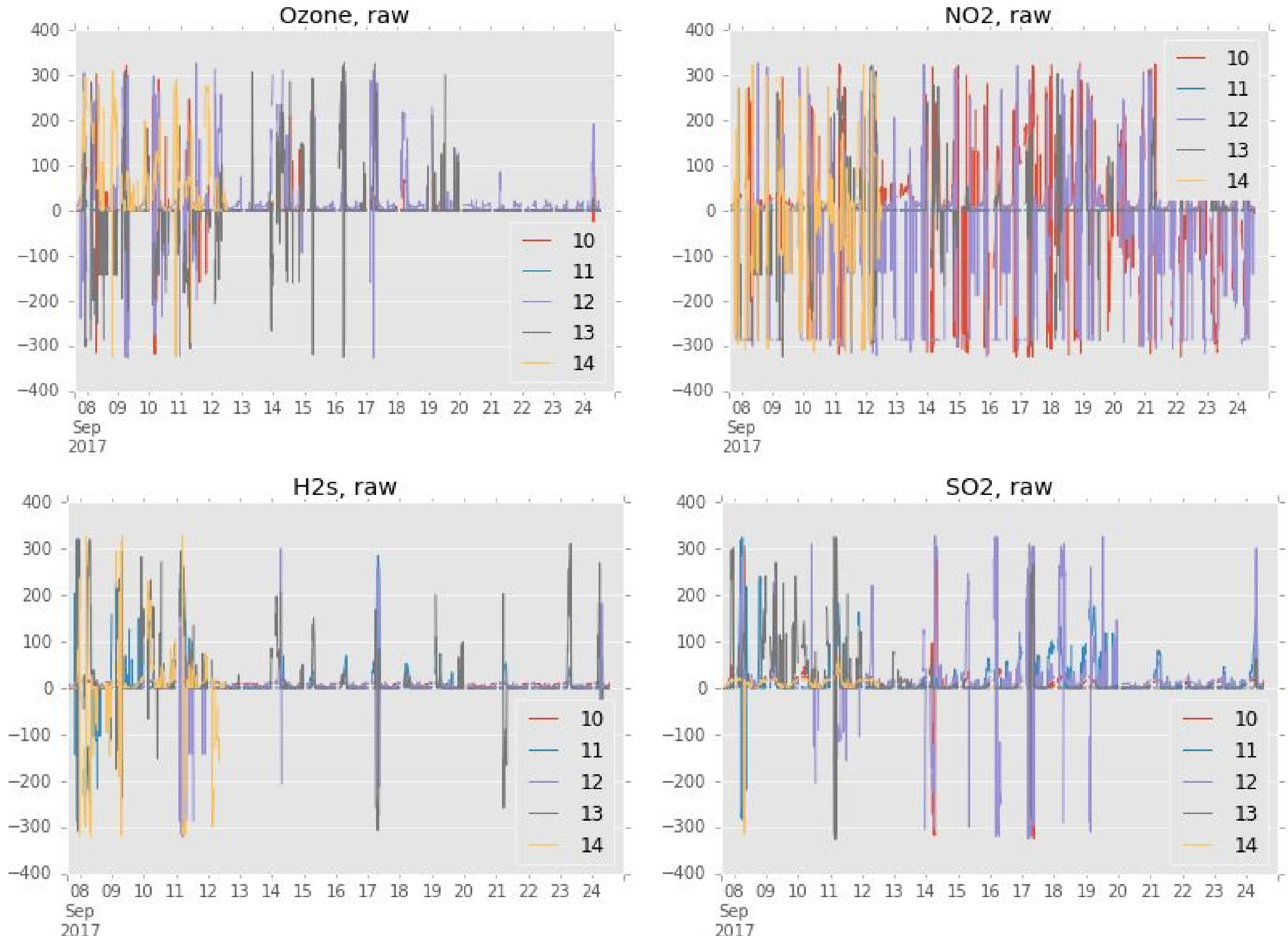

SO2
y = 0.77 x + 0.00
r= 1.00
p= 0.00
ADC count
callibration gas (ppb)


NO2
y = 0.86 x + 29.00
r= 0.91
p= 0.01
ADC count
callibration gas (ppb)



Raw data

Raw ADC counts are very noisy.



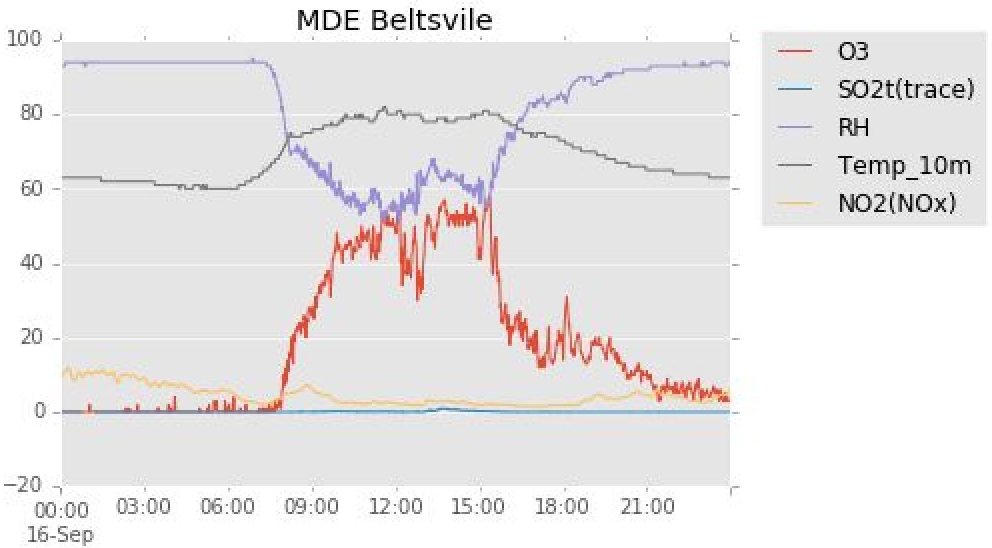
Sensor calibrations

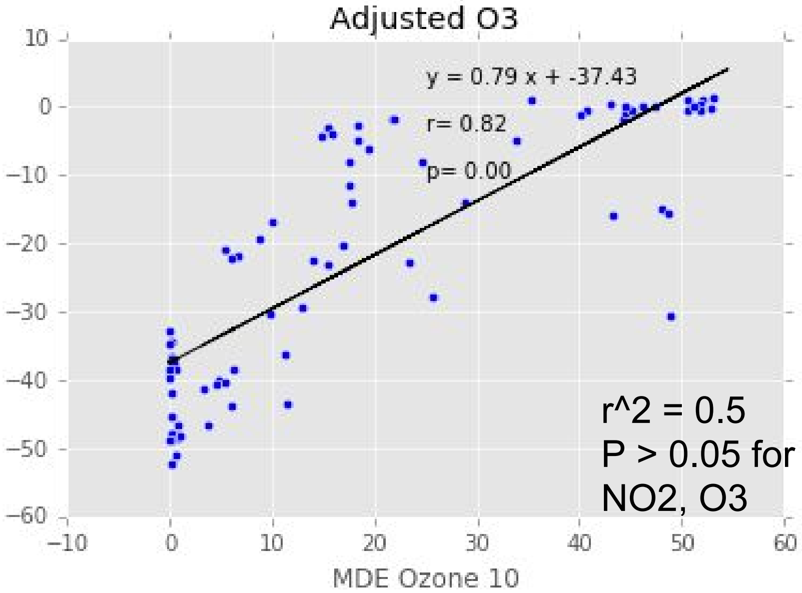
$$[NO_2]_{sensor} = x_1[NO_2]_{true} + x_2[O_3] + x_3[H_2S] + x_4[SO_2] + ...$$

Sensor values are a function of the target gas, but also other gasses. We want to solve for:

$$[NO_2]_{true} = 1/x_1 \cdot (-[NO_2]_{sensor} + x_2[O_3] + x_3[H_2S] + x_4[SO_2] + ...)$$

Ozone sensor calibration





$r^2 = 0.5$
$P > 0.05$ for NO2, O3

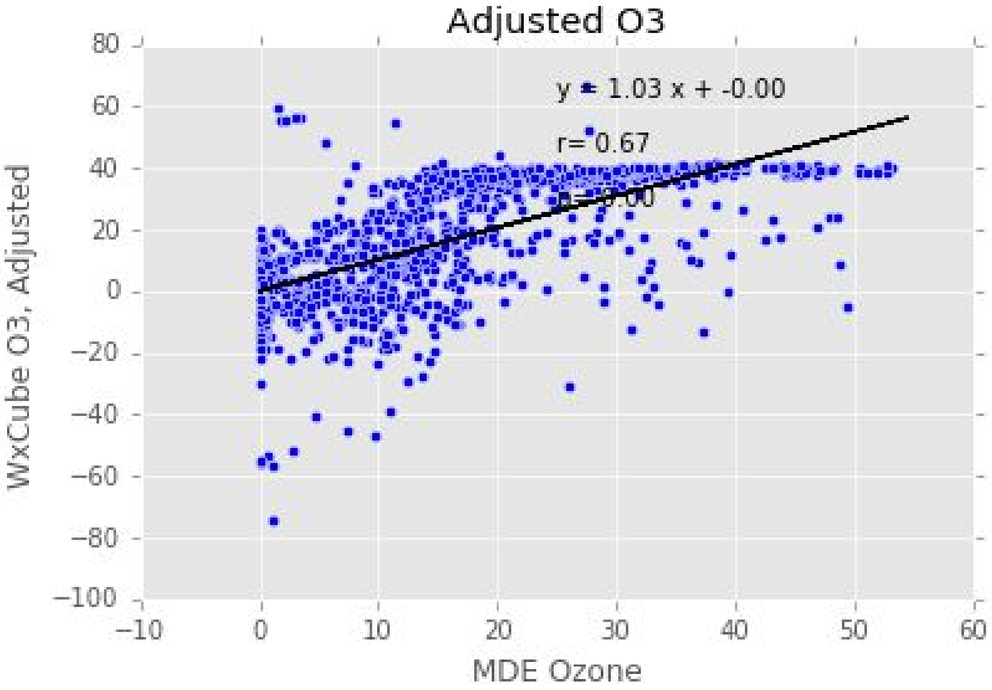
$$O_3 = -0.55 + -0.07 \cdot [O_3]_{true} + 0.036 \cdot [NO2] + 0.187 \cdot [SO_2] + 3.62 \cdot [H_2S]$$

Ozone sensor calibration

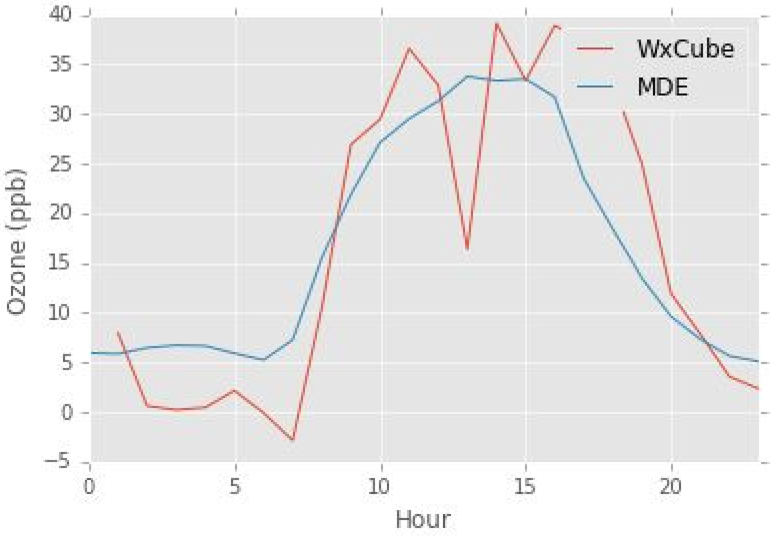
The previous result assumes that the true ozone is known. Here, we remove known ozone and apply the regression coefficients:

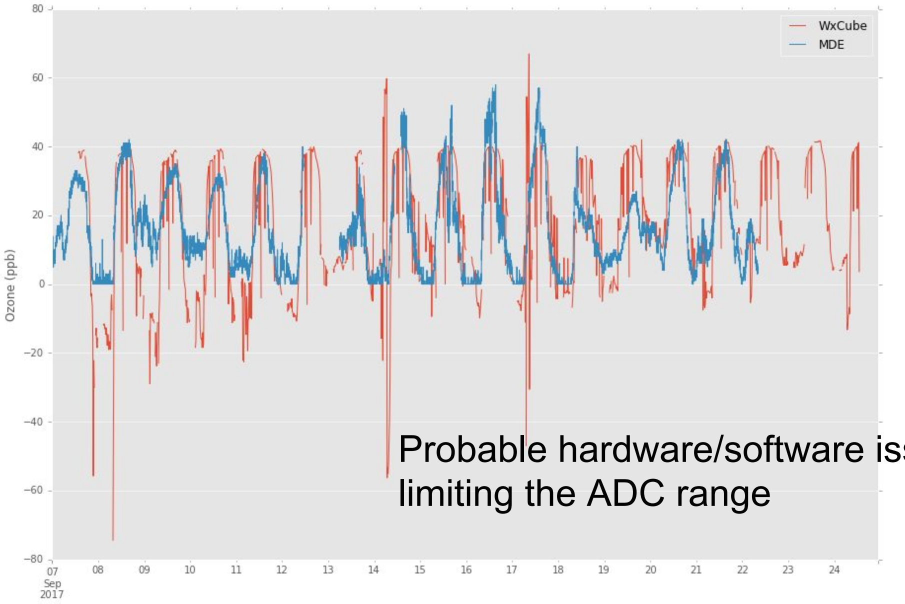
$$O_3 = -0.55 + 0.036 \cdot [NO2]$$
$$+0.187 \cdot [SO_2] + 3.62 \cdot [H_2S]$$

Mean error = 1.05 ppb.



Ozone sensor calibration

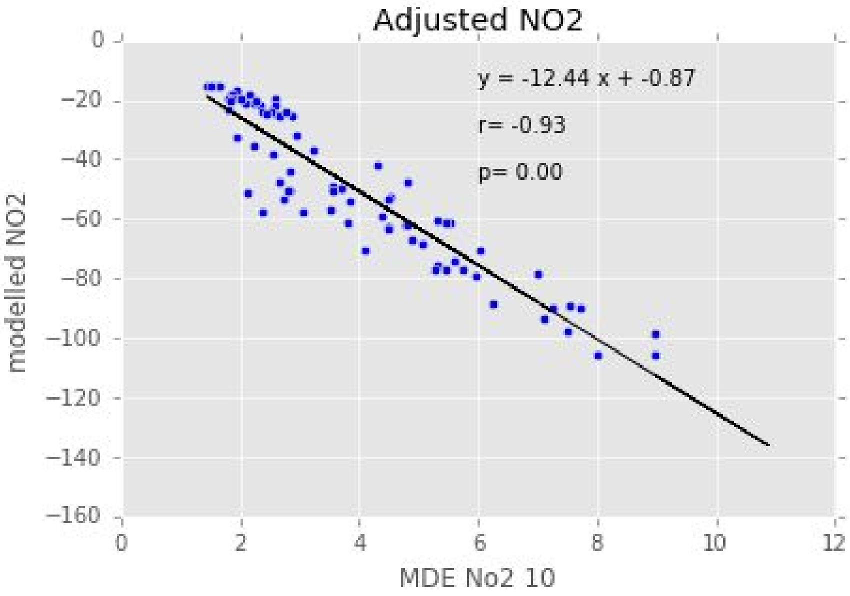


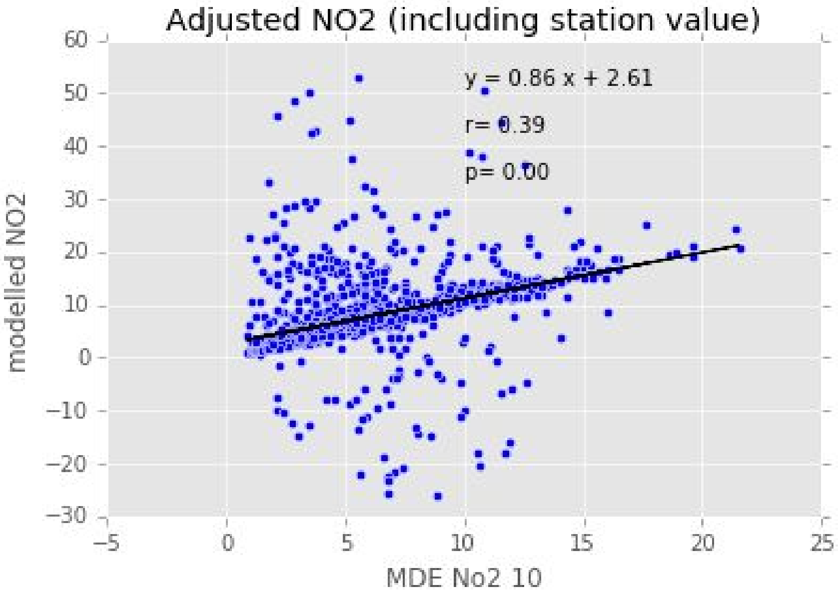


Probable hardware/software issue limiting the ADC range

Final regression captures the diurnal cycle of ozone well, but not the range

NO2 sensor calibration

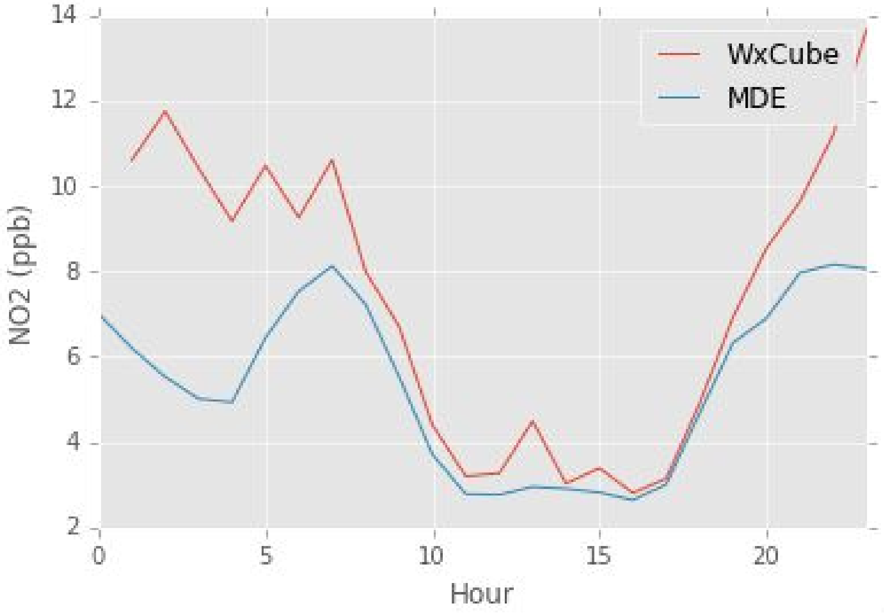


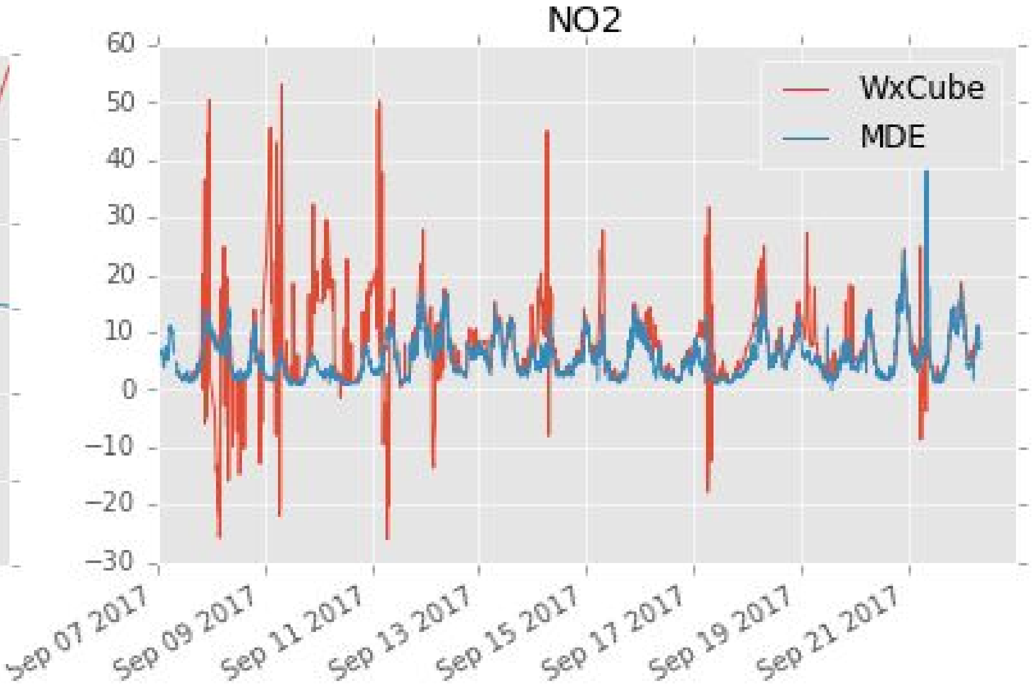


$$NO_2 = 20.8 - 8.13 \cdot [NO2]_{true}$$
$$-0.29 \cdot [SO_2] - 2.58 \cdot [H_2S] + 0.1 \cdot [O_3]$$

r^2 = 0.385
p> 0.05 for O3

NO2 sensor calibration





Mean difference = -1.91 ppb

Sensor calibrations

We used a day of data for one sensor and compared it to Maryland Department of the Environment (MDE) data.

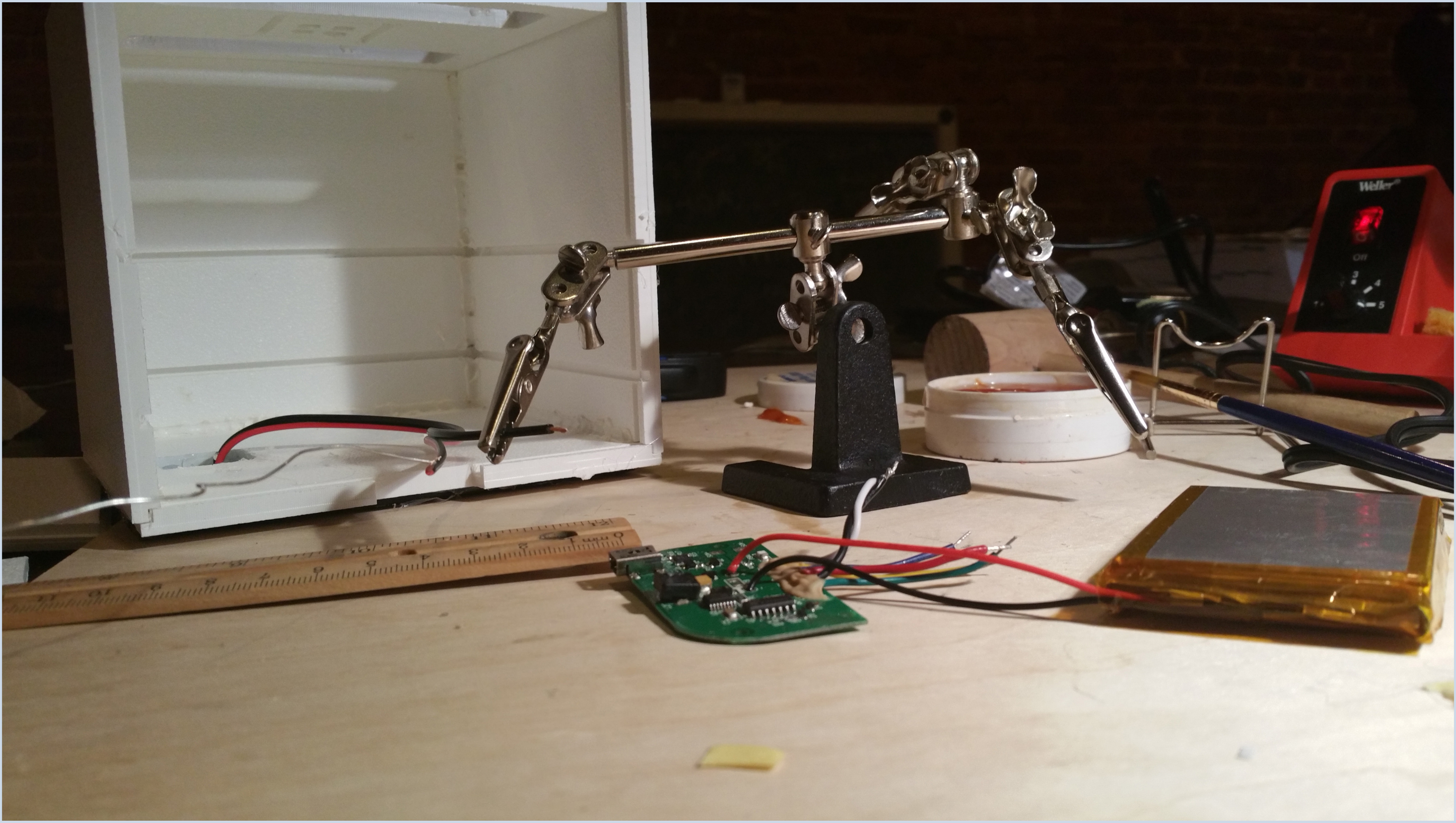
Sensors were co-located.

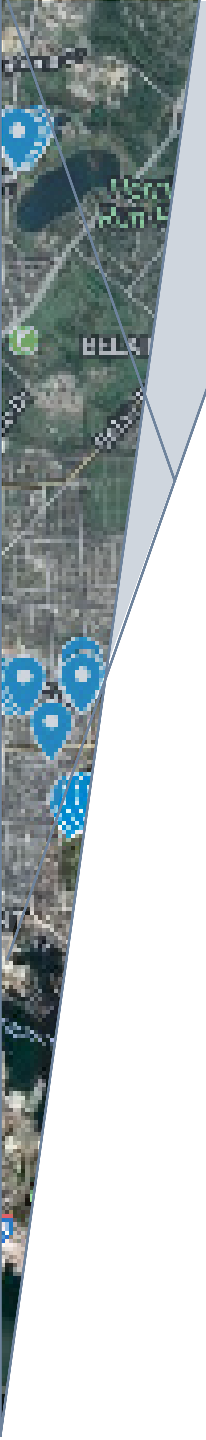
Our sensors report 3 minute averages every 12 minutes.

MDE samples at 1 minute frequency (data has not undergone QA procedures).

A linear regression was computed in Python (statsmodels ols function).

ASSEM-
BLY


Weller



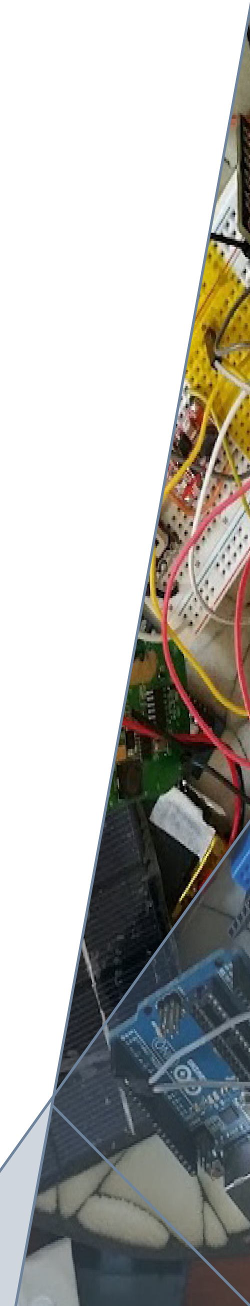
Upcoming challenges:

Manufacturing July 19-

Field calibration August X-

Deployment with community centers in August

Visualization website in late July



bmoreopenair@gmail.com
ascott47@jhu.edu
@bmoreopenair