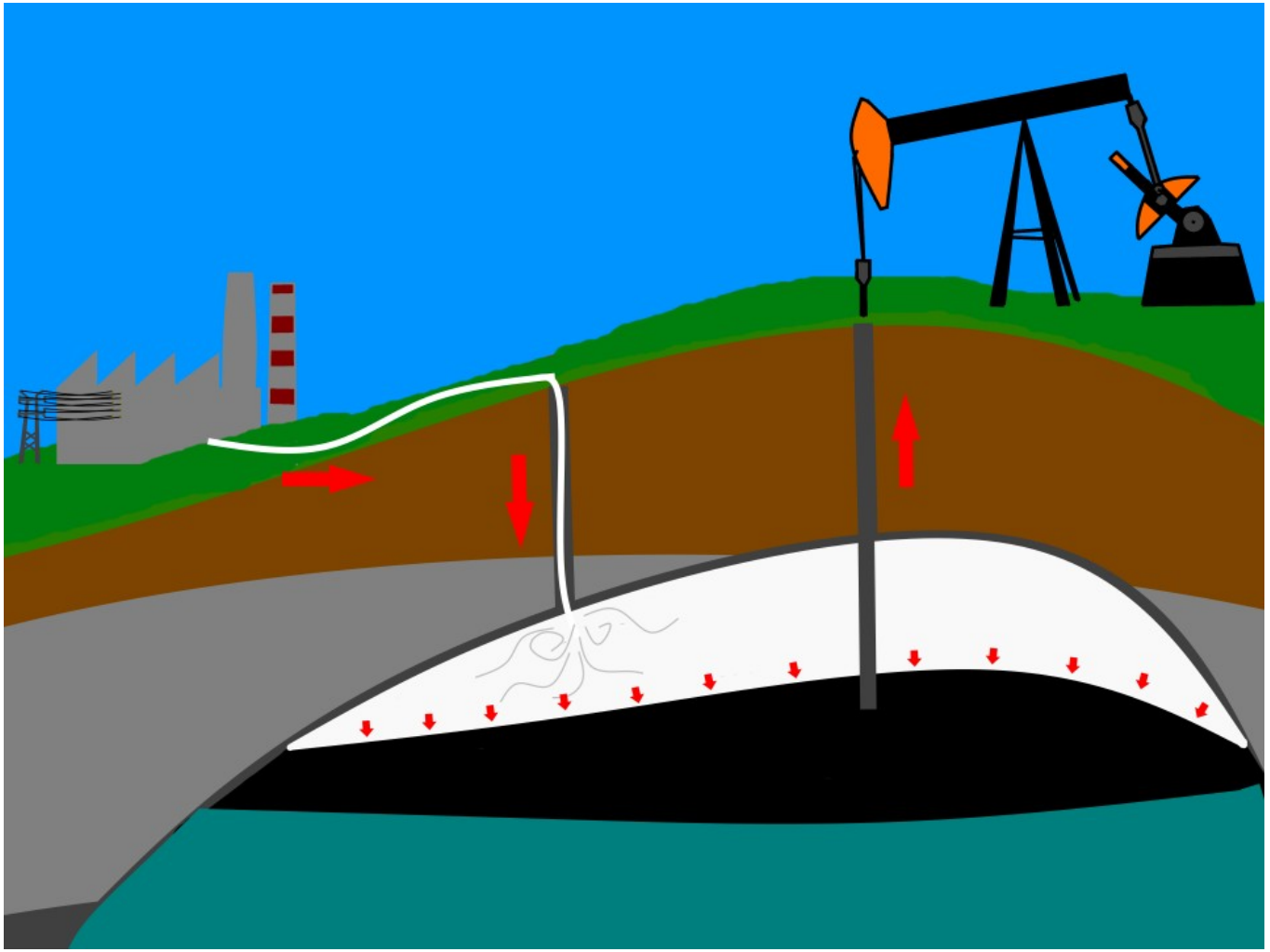
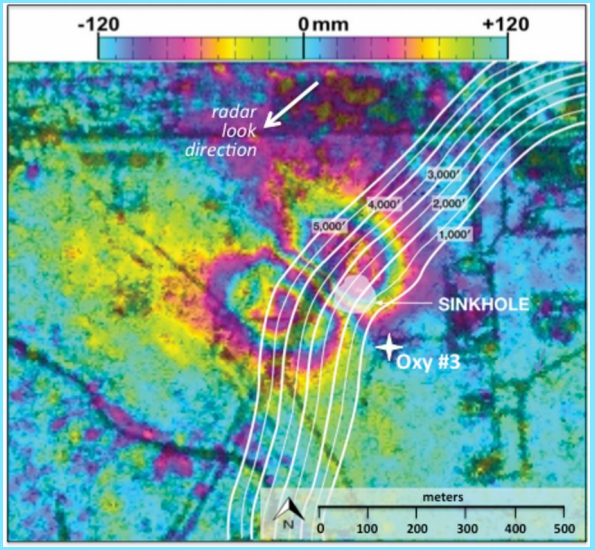
Development and Application of Chemical Sensors for the Detection of Atmospheric Carbon Dioxide and Methane

Wesley T. Honeycutt

Carbon Sequestration



Bayou Corne, LA - 2014



35 Acre Sinkhole

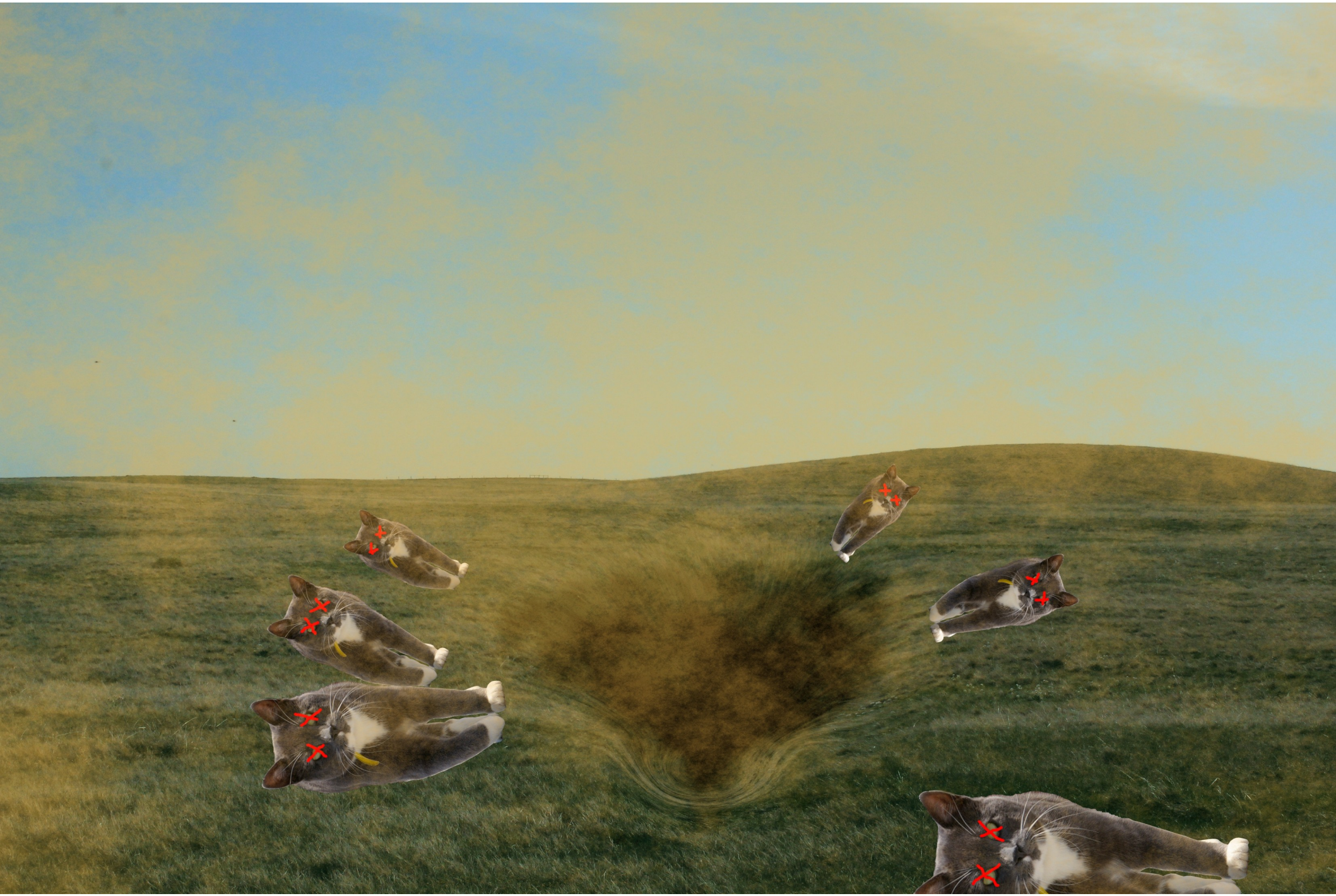
Preventable Disaster

Lake Nyos, Cameroon - 1986

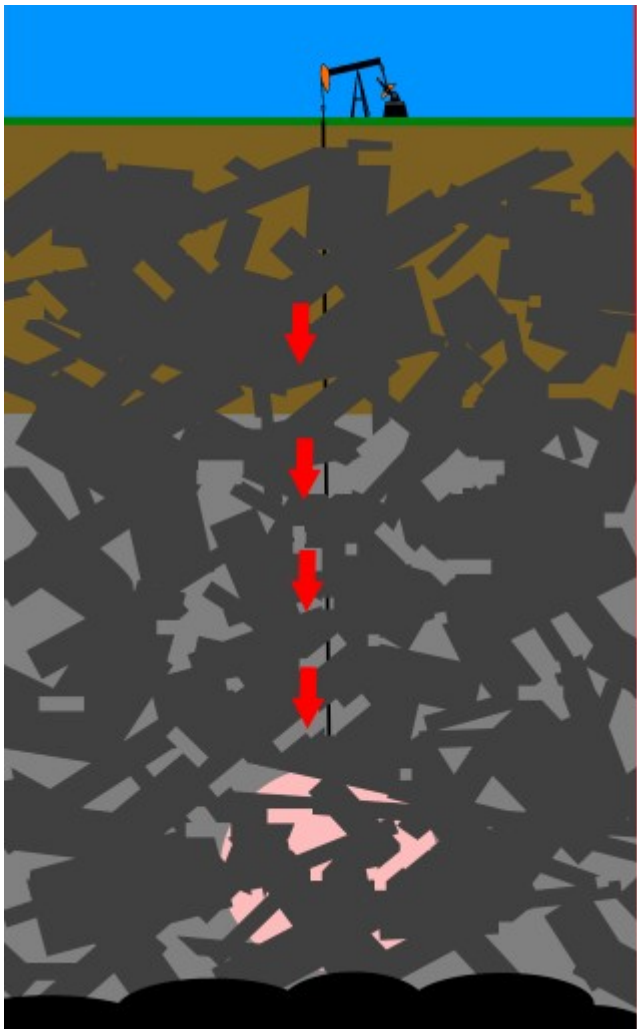
1,700+ Dead in 1km^2

Jones, C. E. & Blom, R. G. Bayou Corne, Louisiana, sinkhole: Precursory deformation measured by radar interferometry. Geology 42, 111–114 (2014).

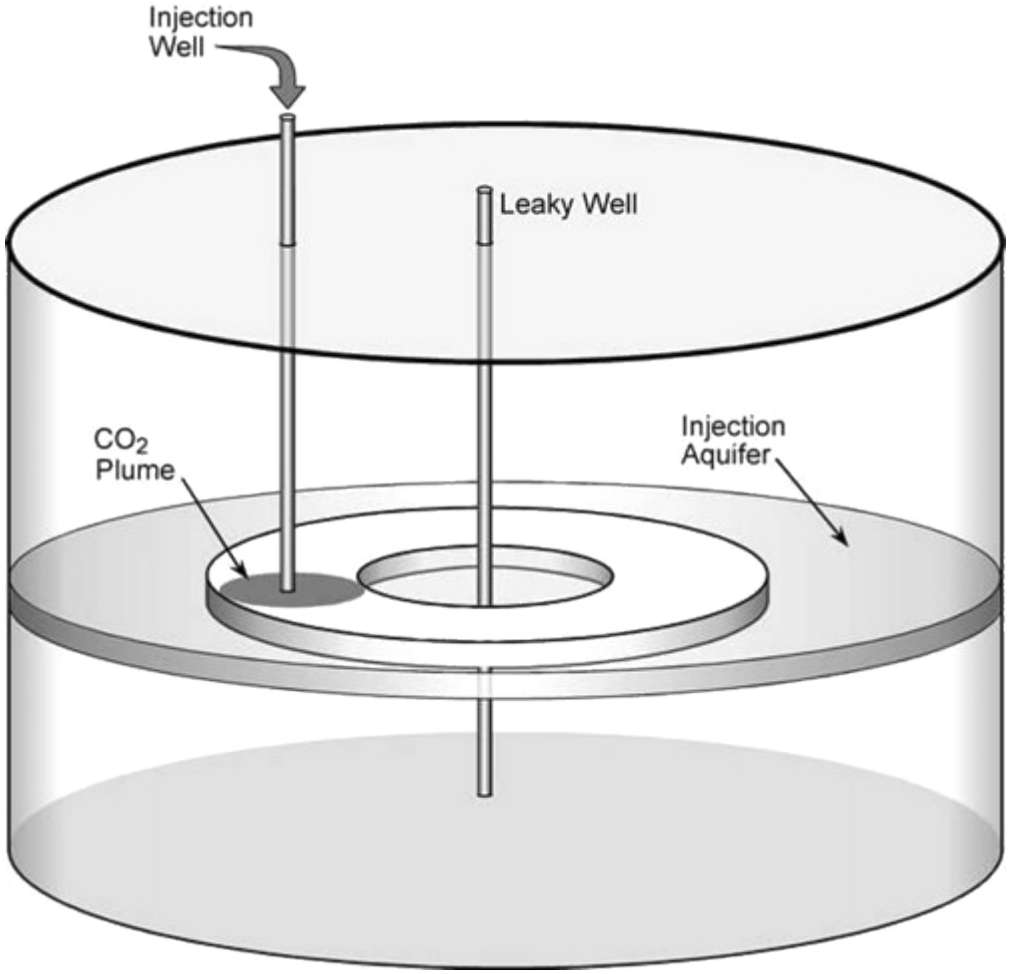
Photo Credit: Peter Turnley, Getty Images, 1986



Microseepage



Well-to-Well Leakage

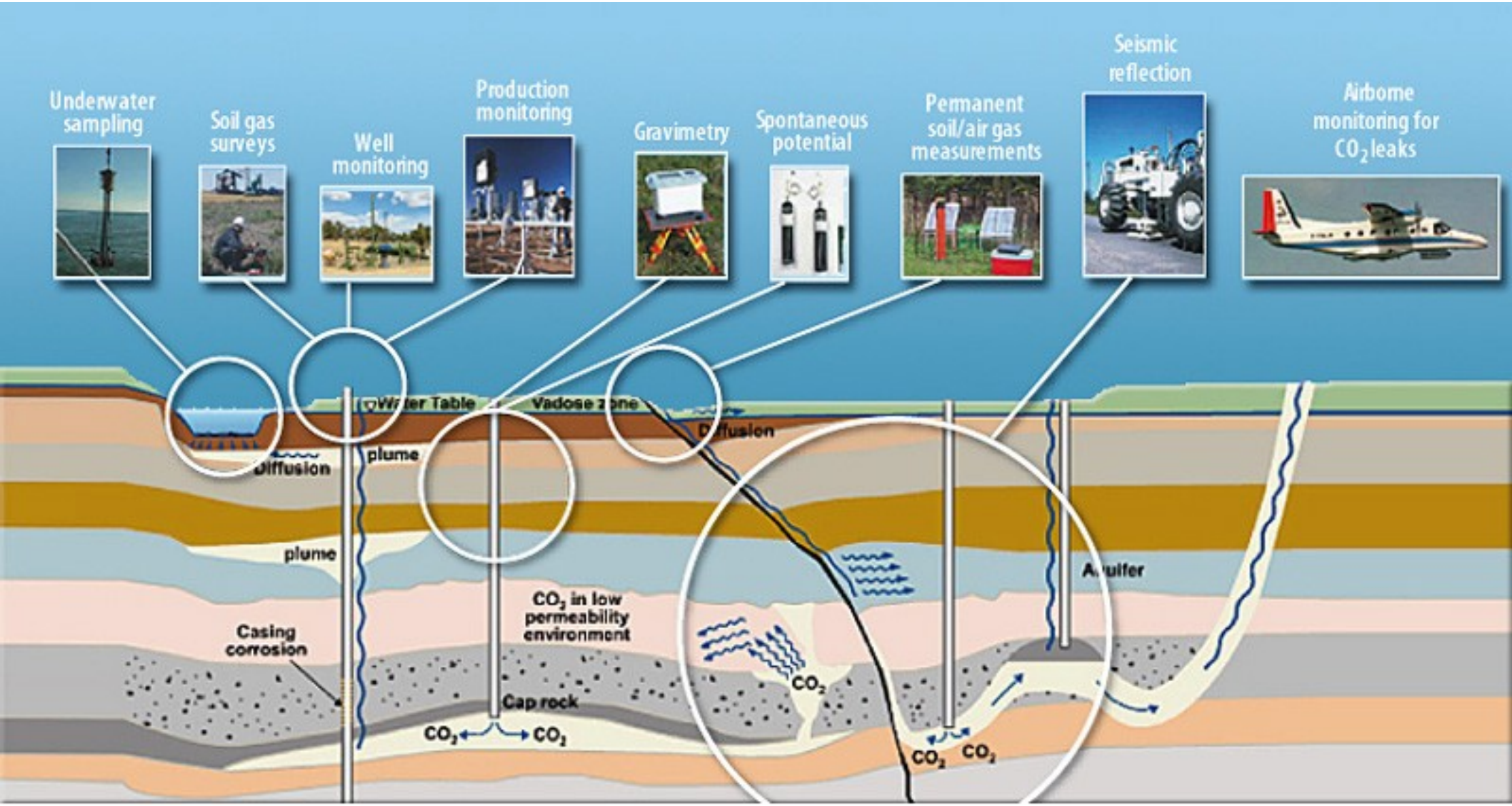


Nordbotten, J. M., Celia, M. A., Bachu, S. & Dahle, H. K. Semianalytical Solution for CO2 Leakage through an Abandoned Well. Environ. Sci. Technol. 39, 602–611 (2005).

Sensing Needs

- Sensitive near global baseline
- Low-Power
- High Sampling Rate
- Remote Monitoring
- Cover a large area
- Bonus Challenge: Do it cheaply

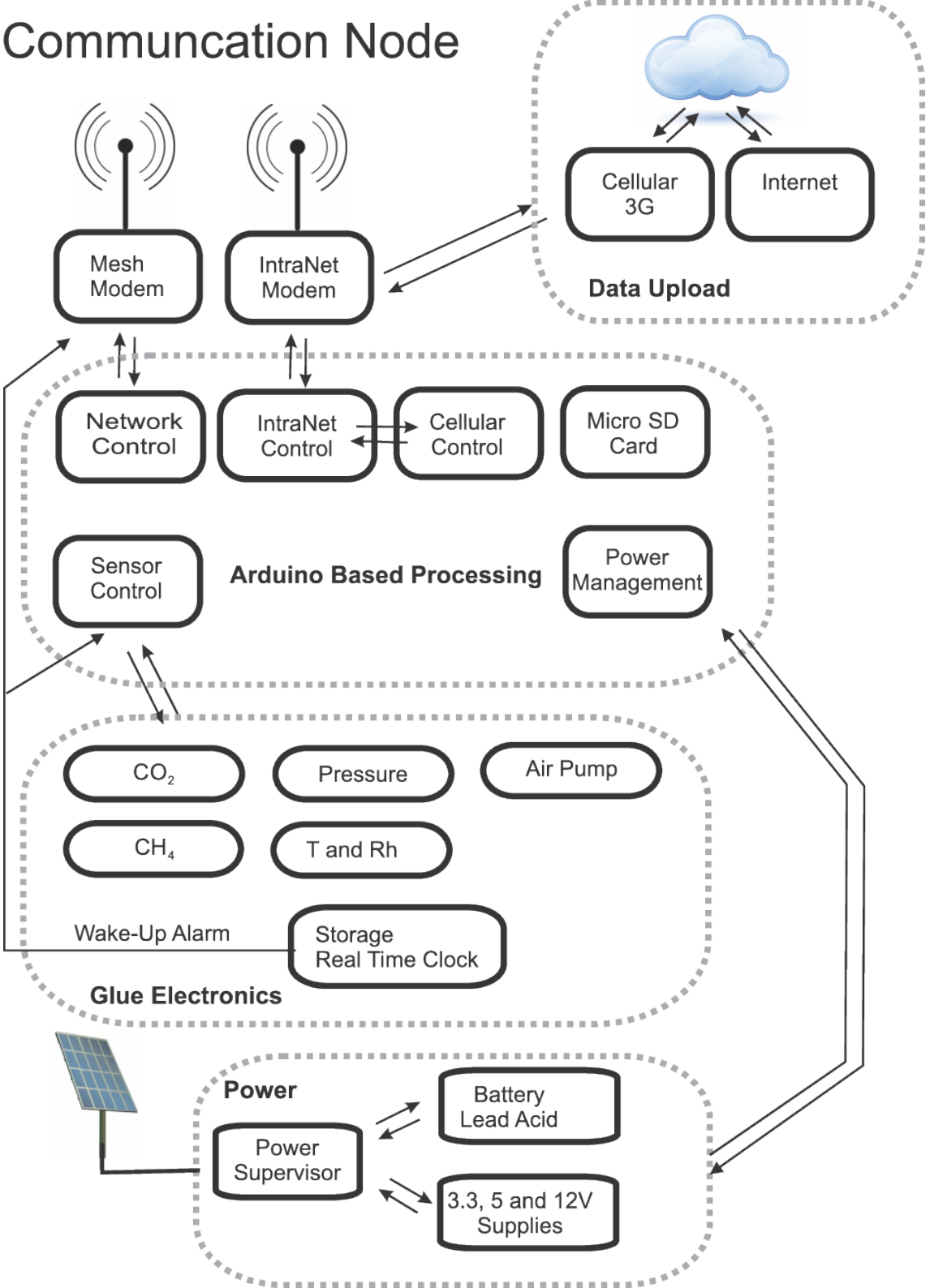
Current Options

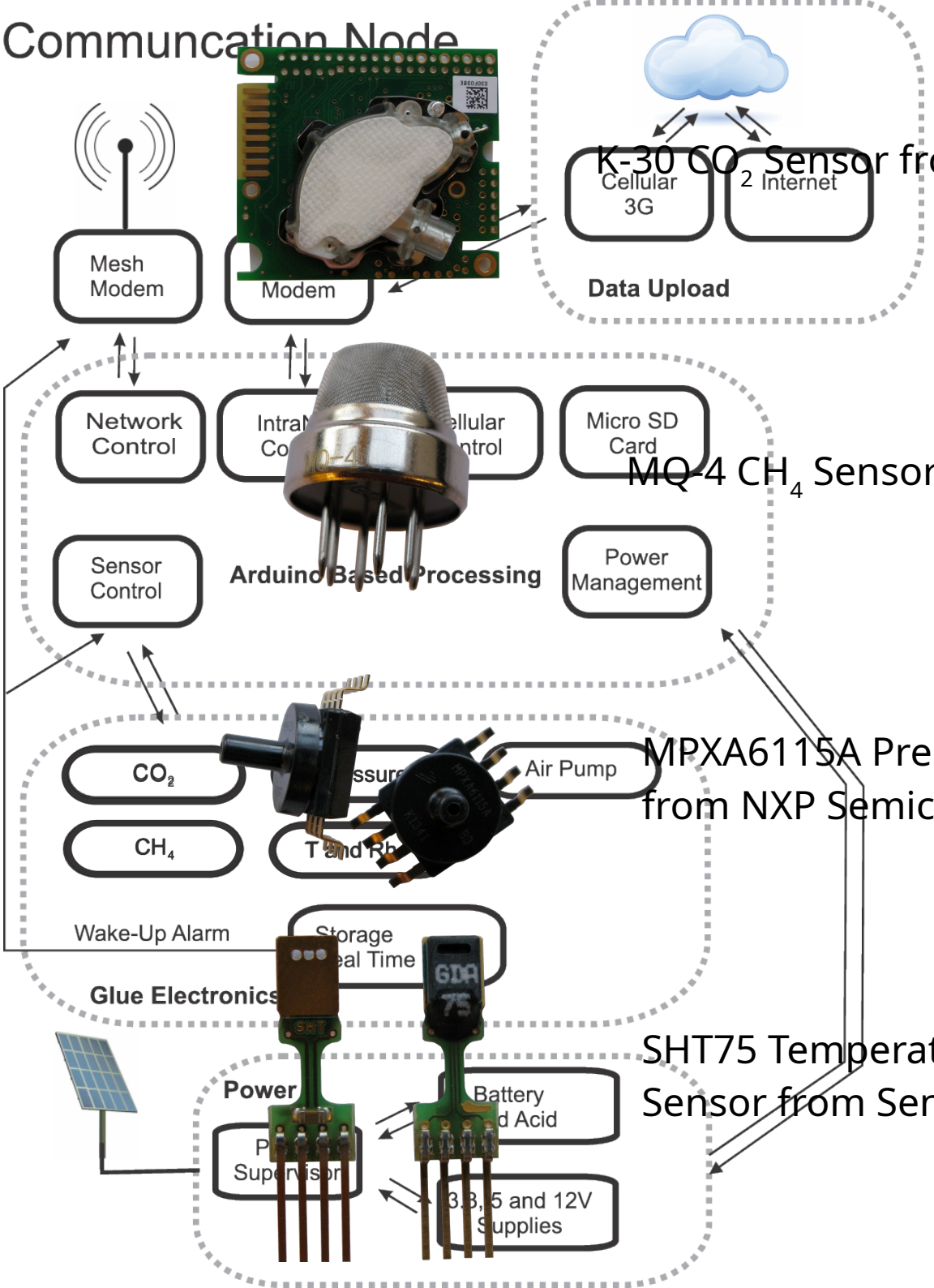


http://www.co2captureproject.org/images/monitoring_diag1.jpg

Importance of the Diel Cycle

- Gas concentrations fluctuate through the day
- Methane is high during the day, carbon dioxide during the night
- Hard to sample
- Common cause of graduate student suffering


Communcation Node
Cellular 3G
Internet
Data Upload
Mesh Modem
IntraNet Modem
Network Control
IntraNet Control
Cellular Control
Micro SD Card
Sensor Control
Arduino Based Processing
Power Management
CO_2
Pressure
Air Pump
CH_4
T and Rh
Wake-Up Alarm
Storage Real Time Clock
Glue Electronics
Power
Battery Lead Acid
Power Supervisor
3.3, 5 and 12V Supplies

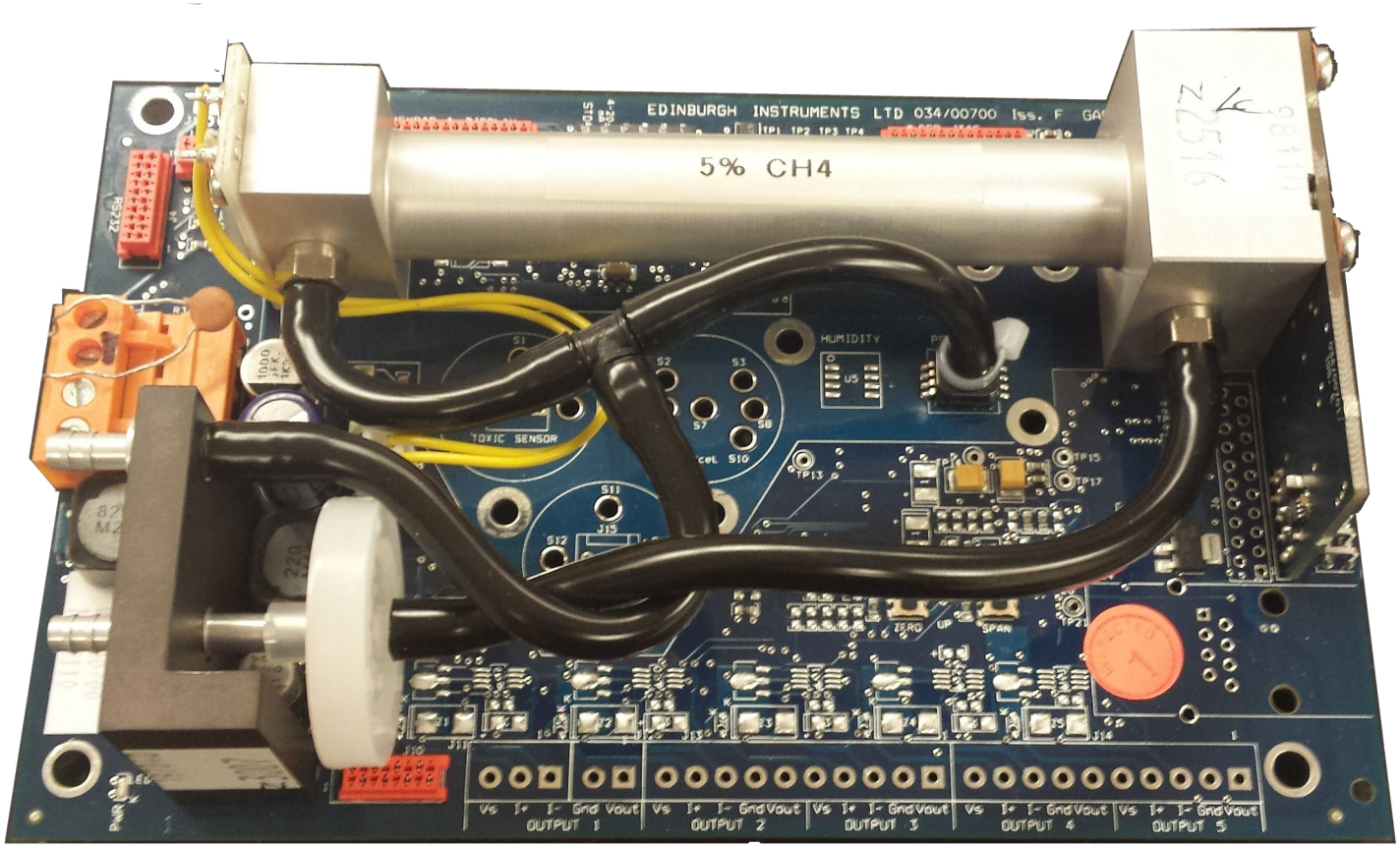


K-30 CO_2 Sensor from CO2Meter

MQ-4 CH_4 Sensor

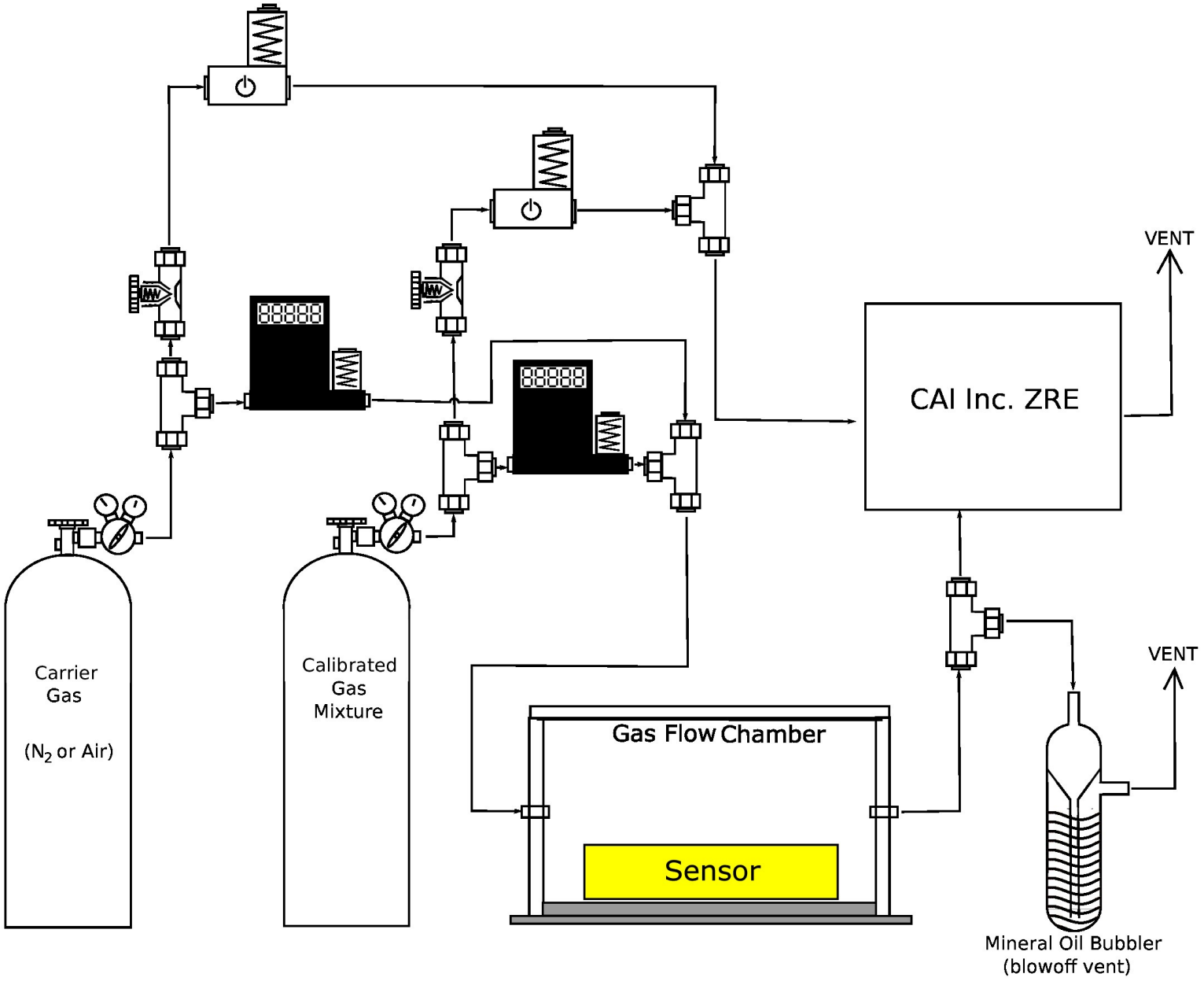
MPXA6115A Pressure sensor from NXP Semiconductors

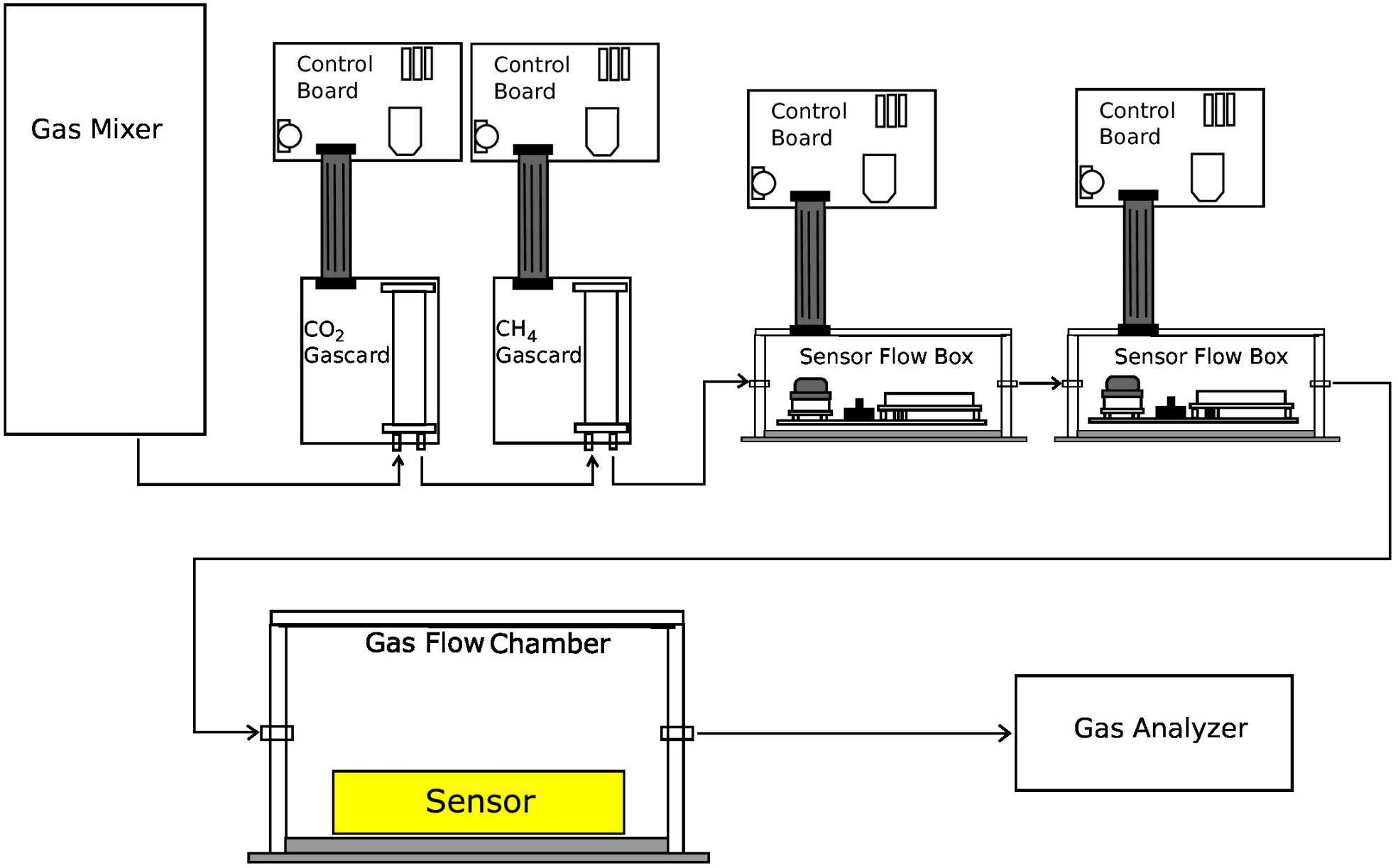
SHT75 Temperature/Humidity Sensor from Sensirion



Edinburgh Gascard CH_4 – From Edinburgh Sensors

- Accurate and Precise Methane Detection
- Temperature and Pressure Correction
- Higher Power Consumption
- Requires Flow Regime
- Costs ~1000x as much as the MQ-4

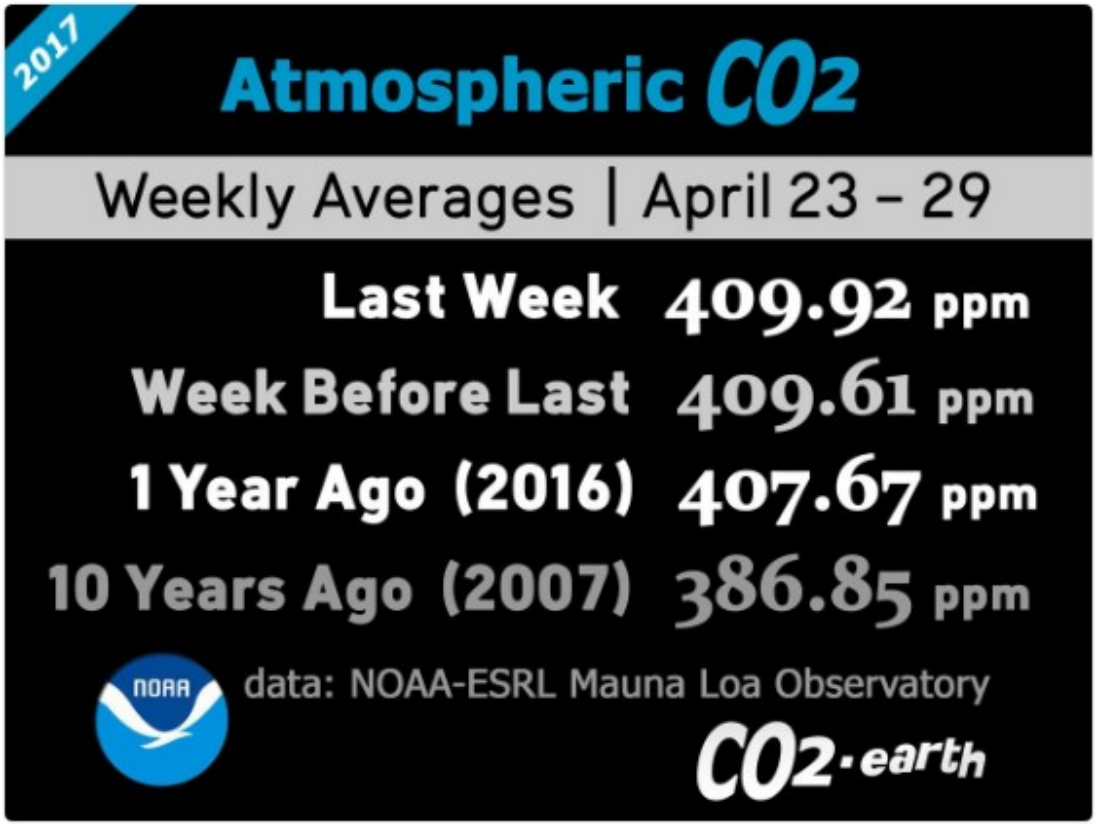

VENT
CAI Inc. ZRE
Carrier
Gas
(N_2 or Air)
Calibrated
Gas
Mixture
Gas Flow Chamber
Sensor
VENT
Mineral Oil Bubbler
(blowoff vent)
Needle Valve
T - Connector
Solenoid Valve
Flow Controller


Gas Mixer
Control Board
Control Board
Control Board
Control Board
CO_2 Gascard
CH_4 Gascard
Sensor Flow Box
Sensor Flow Box
Gas Flow Chamber
Sensor
Gas Analyzer

CO2 earth
@CO2_earth

Follow

📈 409.92 parts per million #CO2 in the 17th week of 2017 🌏 Up from 407.67 in 2016 🌏 #NOAA weekly data via co2.earth/weekly-co2



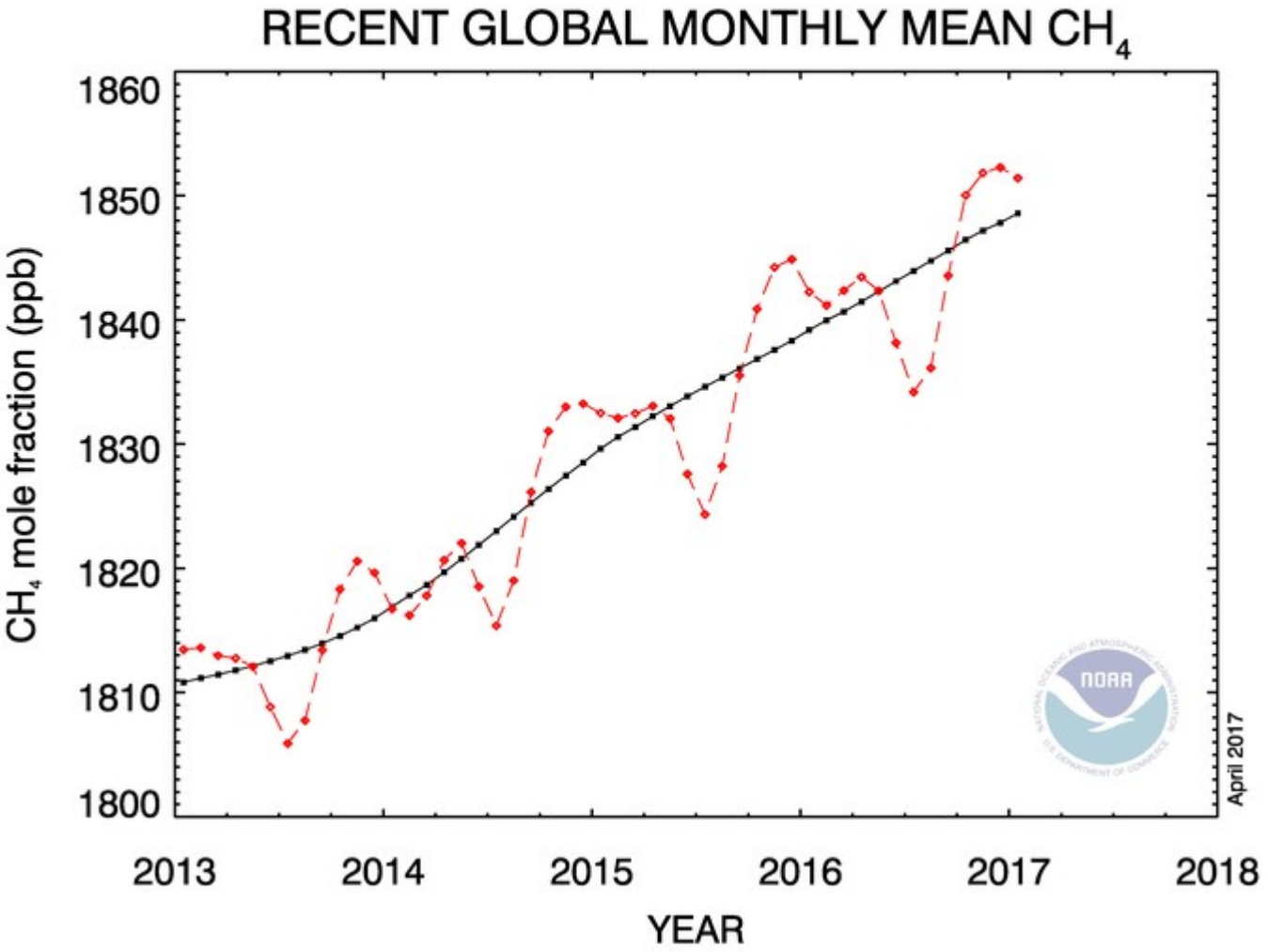
RETWEETS 37 LIKES 28

9:01 AM - 30 Apr 2017

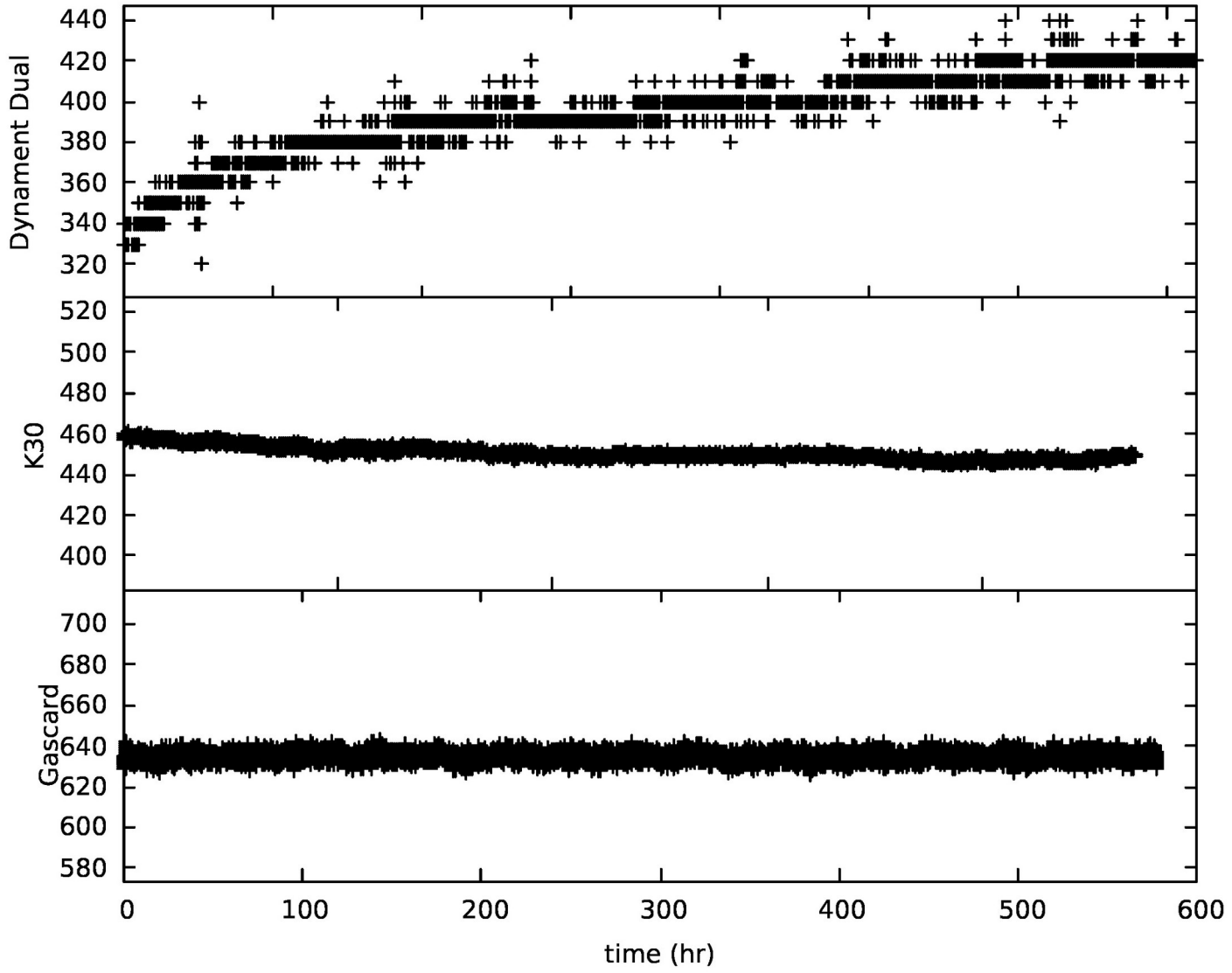
37 28

January 2017:	1851.4 ppb
January 2016:	1842.3 ppb

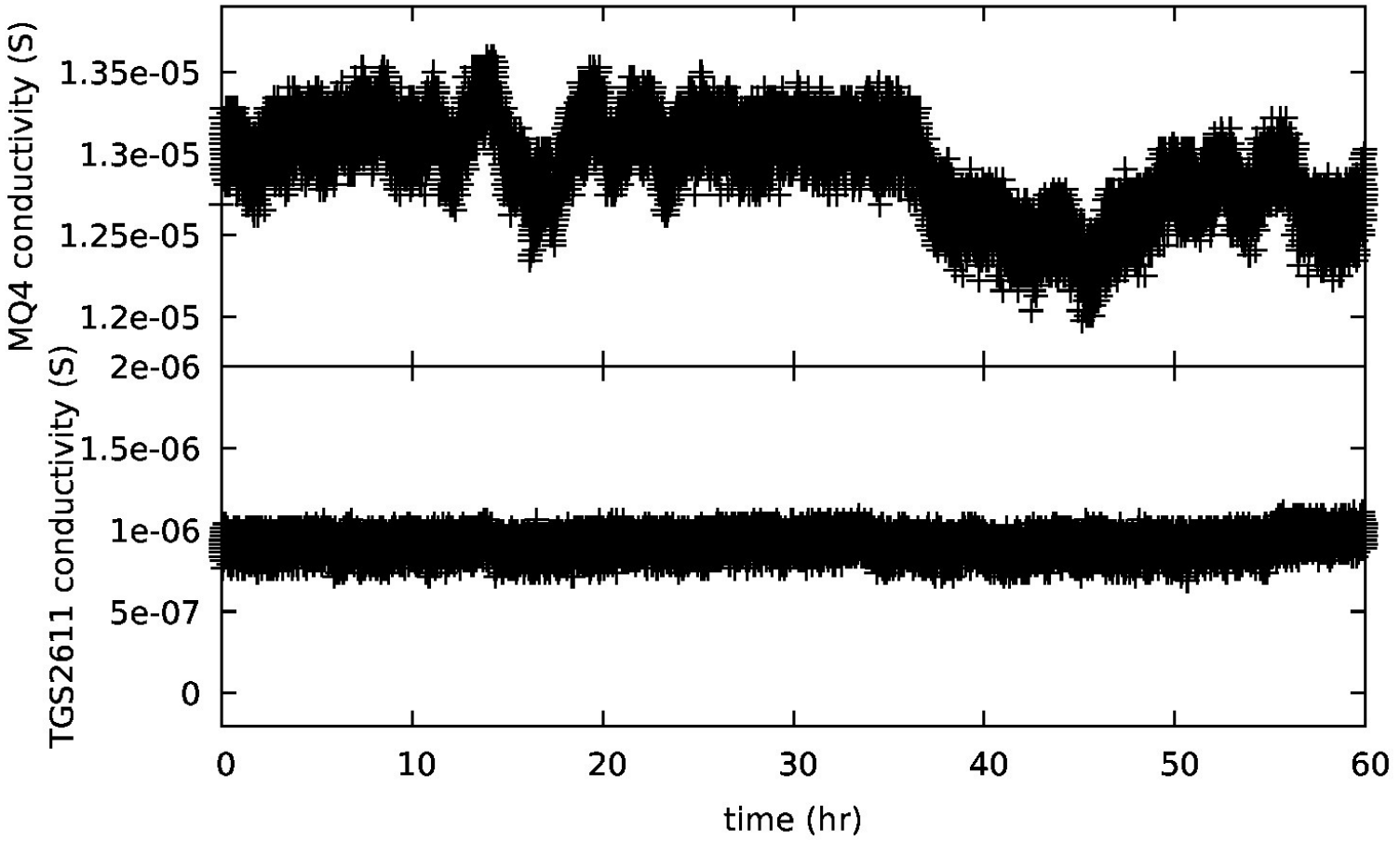
Last updated: April 5, 2017



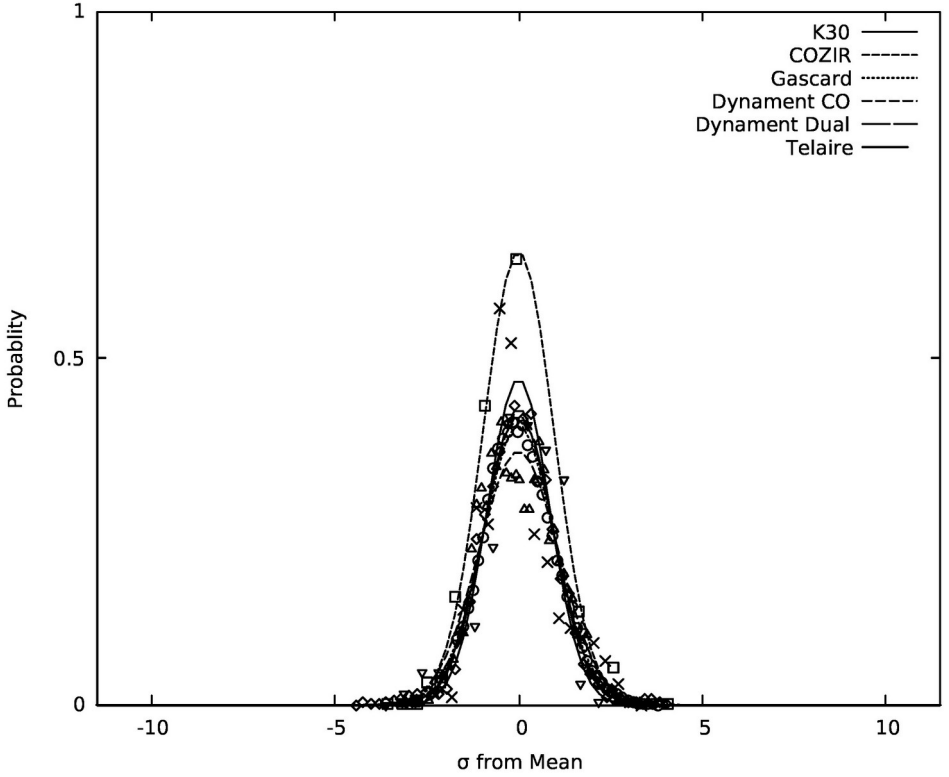
CO_2 Sensor Baseline



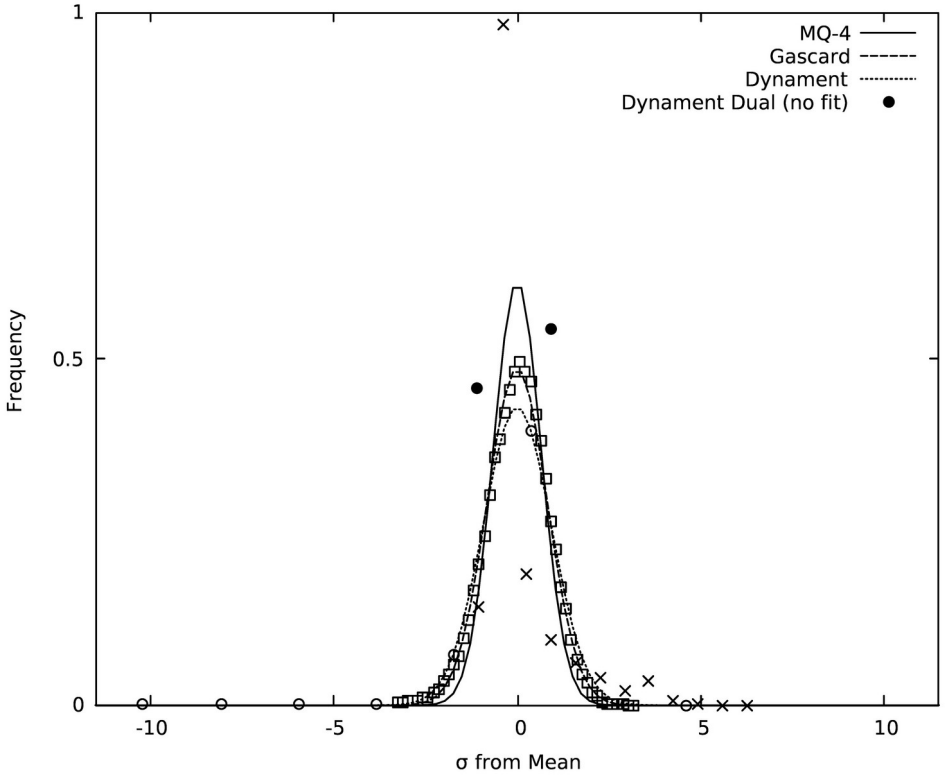
CH_4 Sensor Baseline



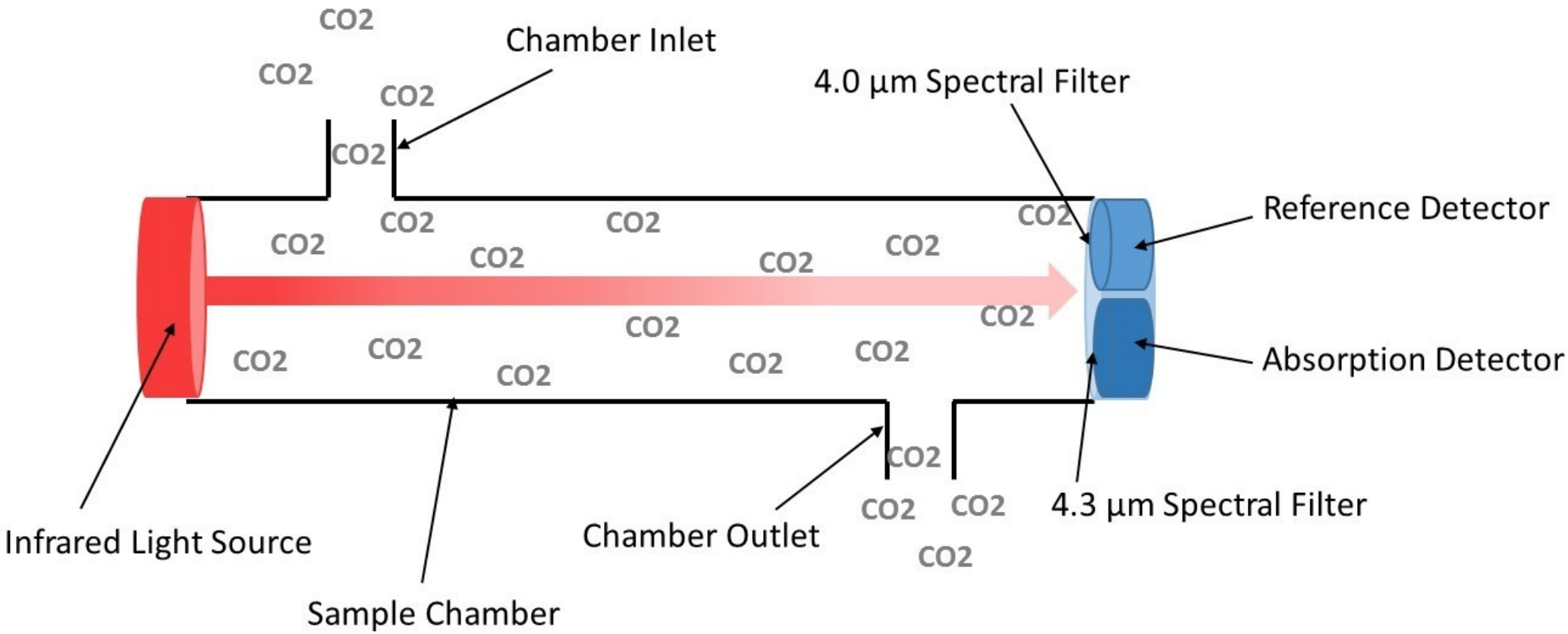
CO_2


K30
COZIR
Gascard
Dynament CO
Dynament Dual
Telaire
Probablity
σ from Mean
1
0.5
0
-10
-5
0
5
10

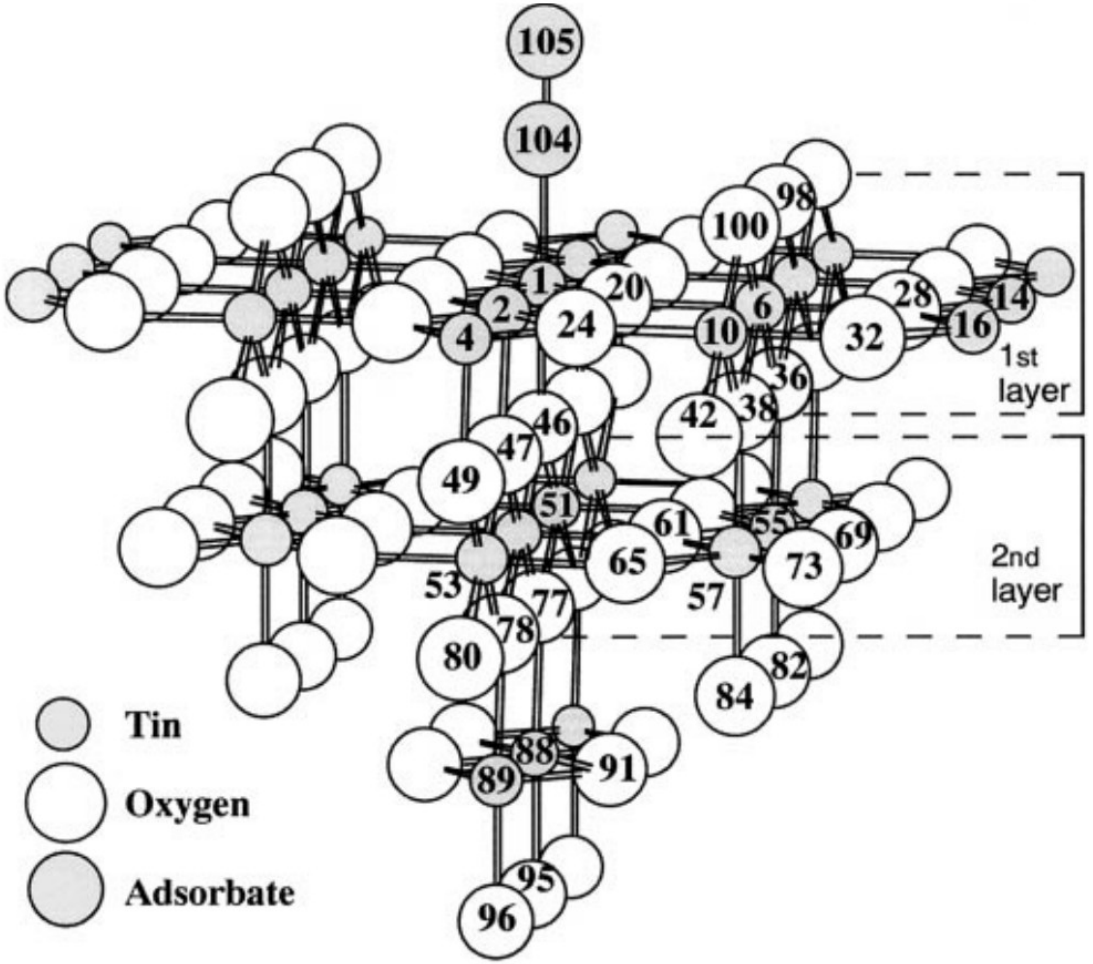
CH_4

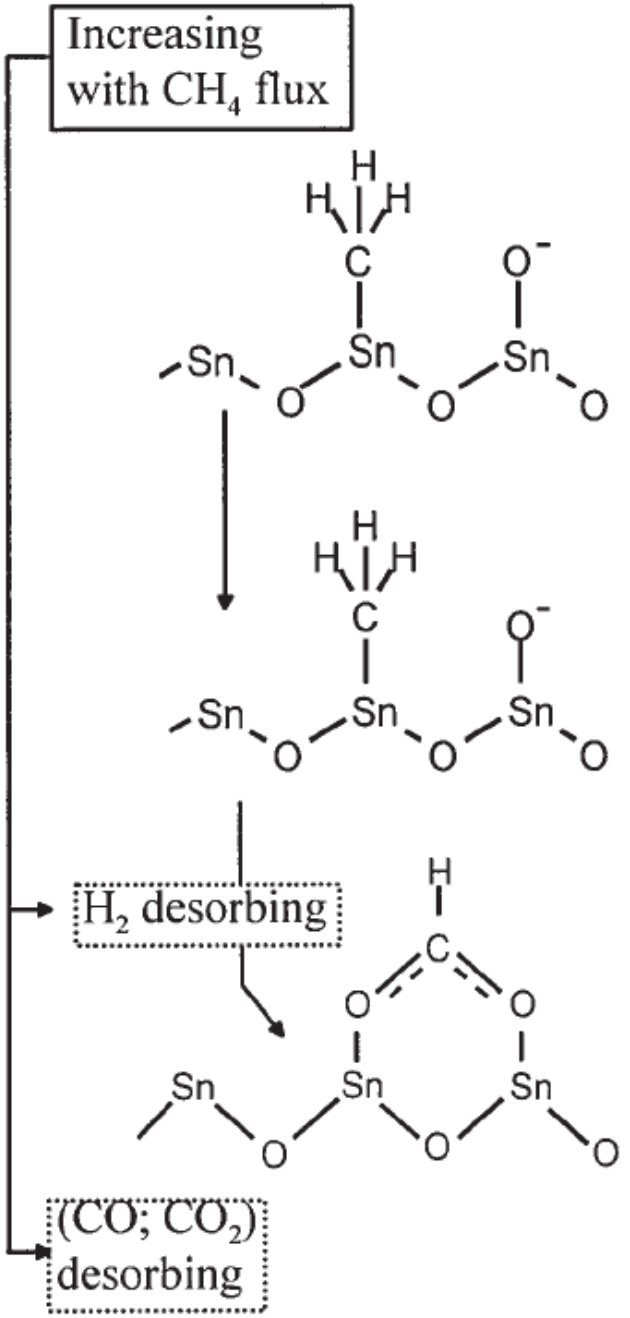

MQ-4
Gascard
Dynament
Dynament Dual (no fit)
Frequency
σ from Mean
1
0.5
0
-10
-5
0
5
10

Optical vs. Chemiresitive



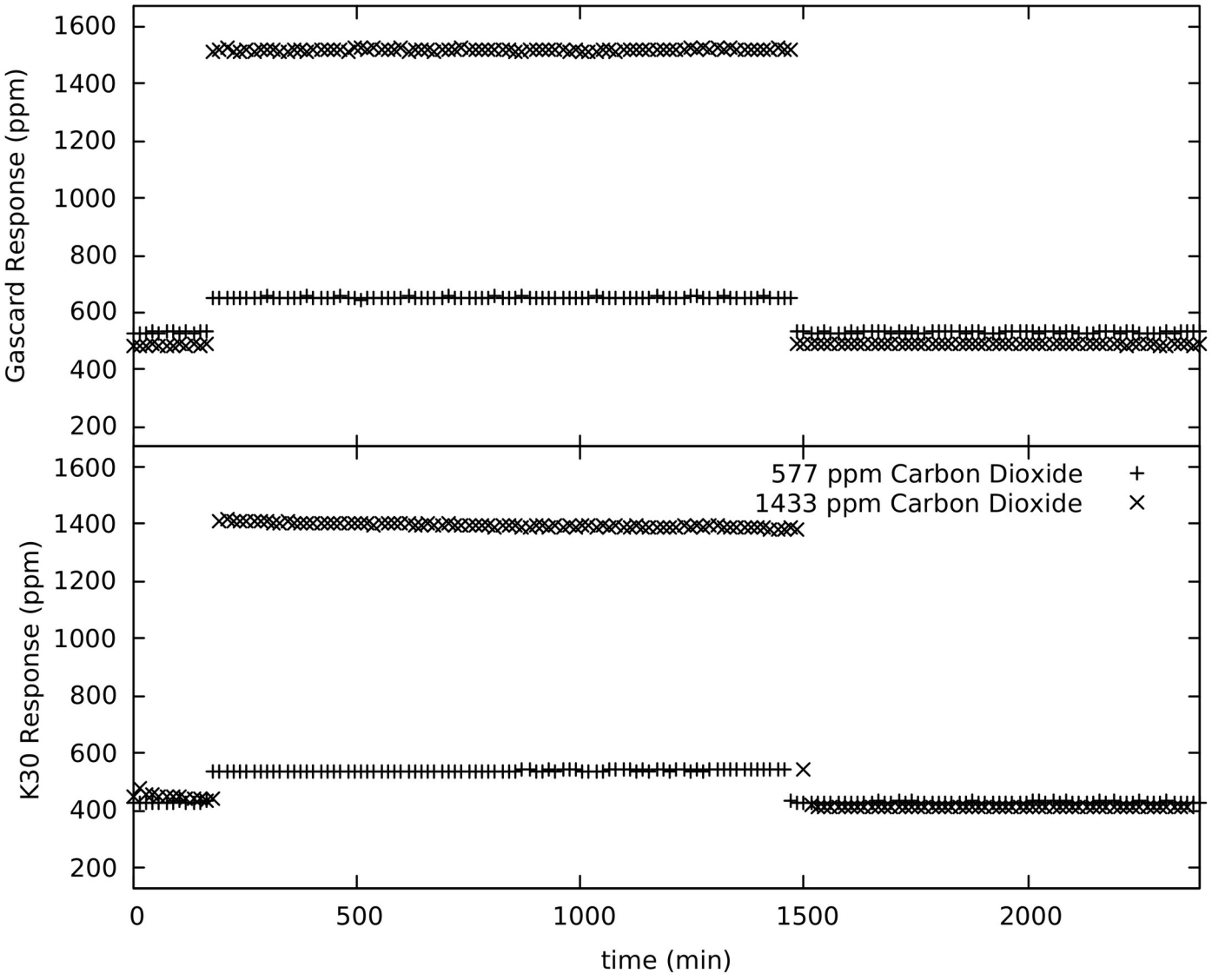
http://www.edaphic.com.au/knowledge-base/articles/gas-articles/ndir-explained/



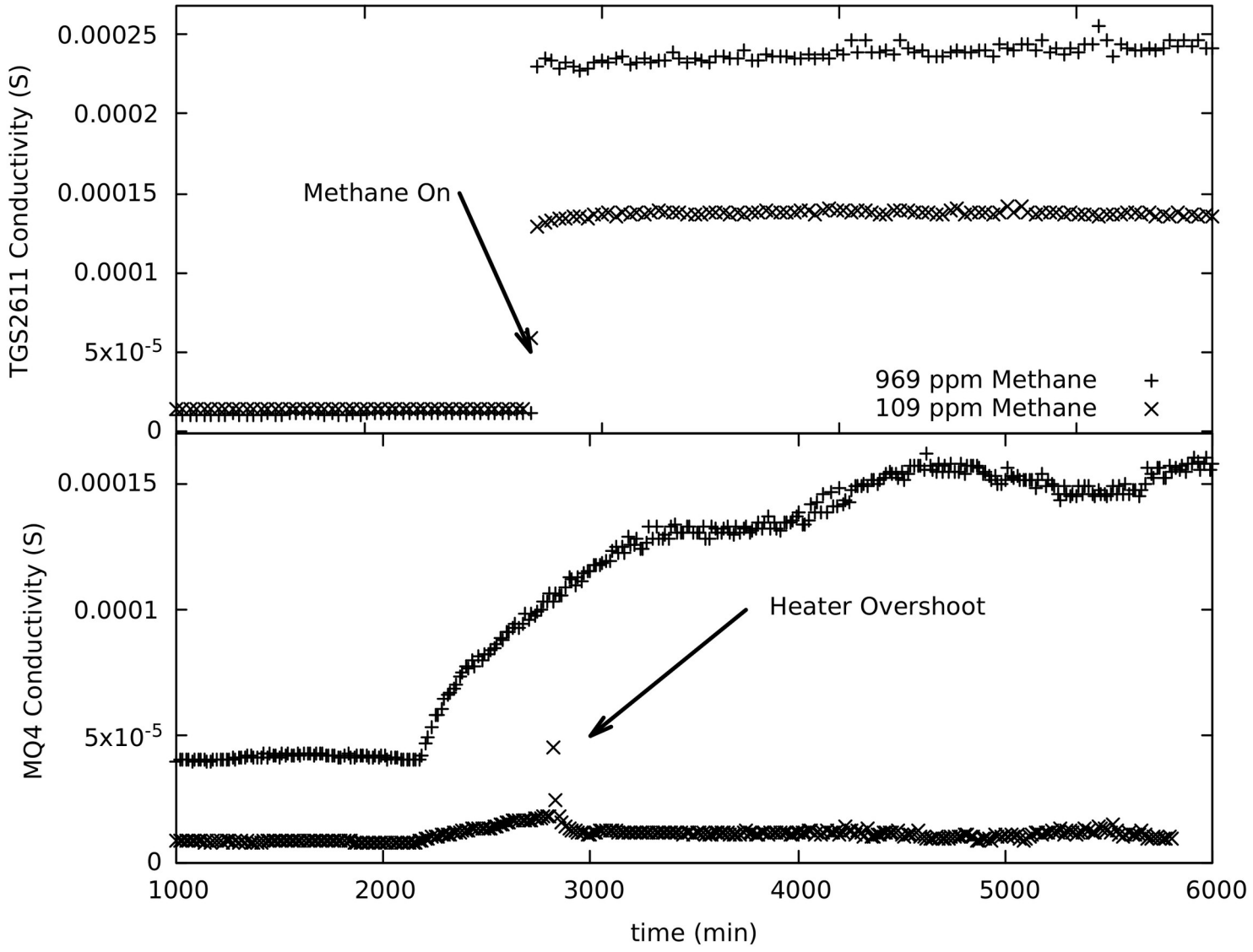


Barsan, N., Schweizer-Berberich, M. & Göpel†, W. Fundamental and practical aspects in the design of nanoscaled SnO2 gas sensors: a status report. Fresenius' Journal of Analytical Chemistry 365, 287–304 (1999).

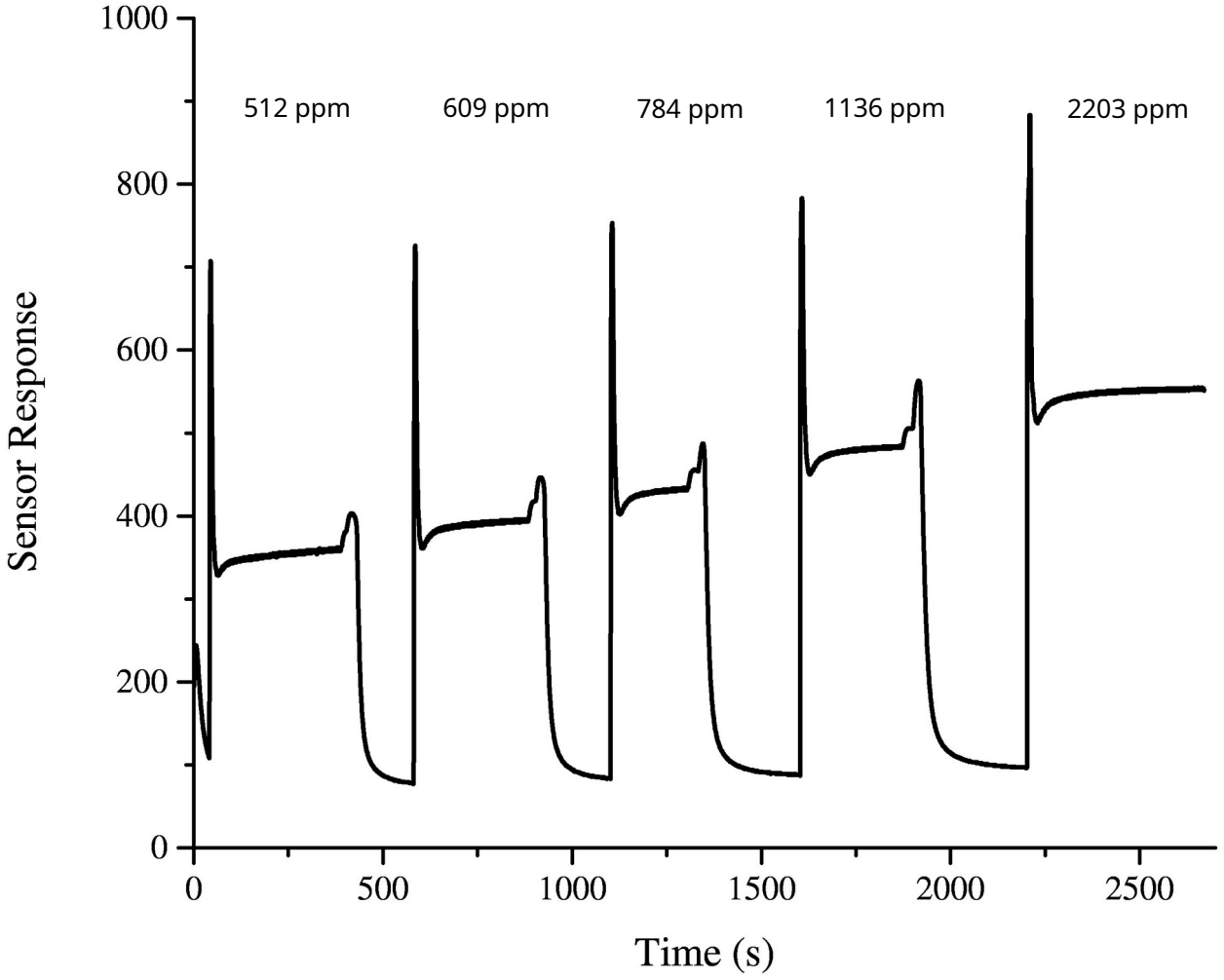
Optical Sensor Response

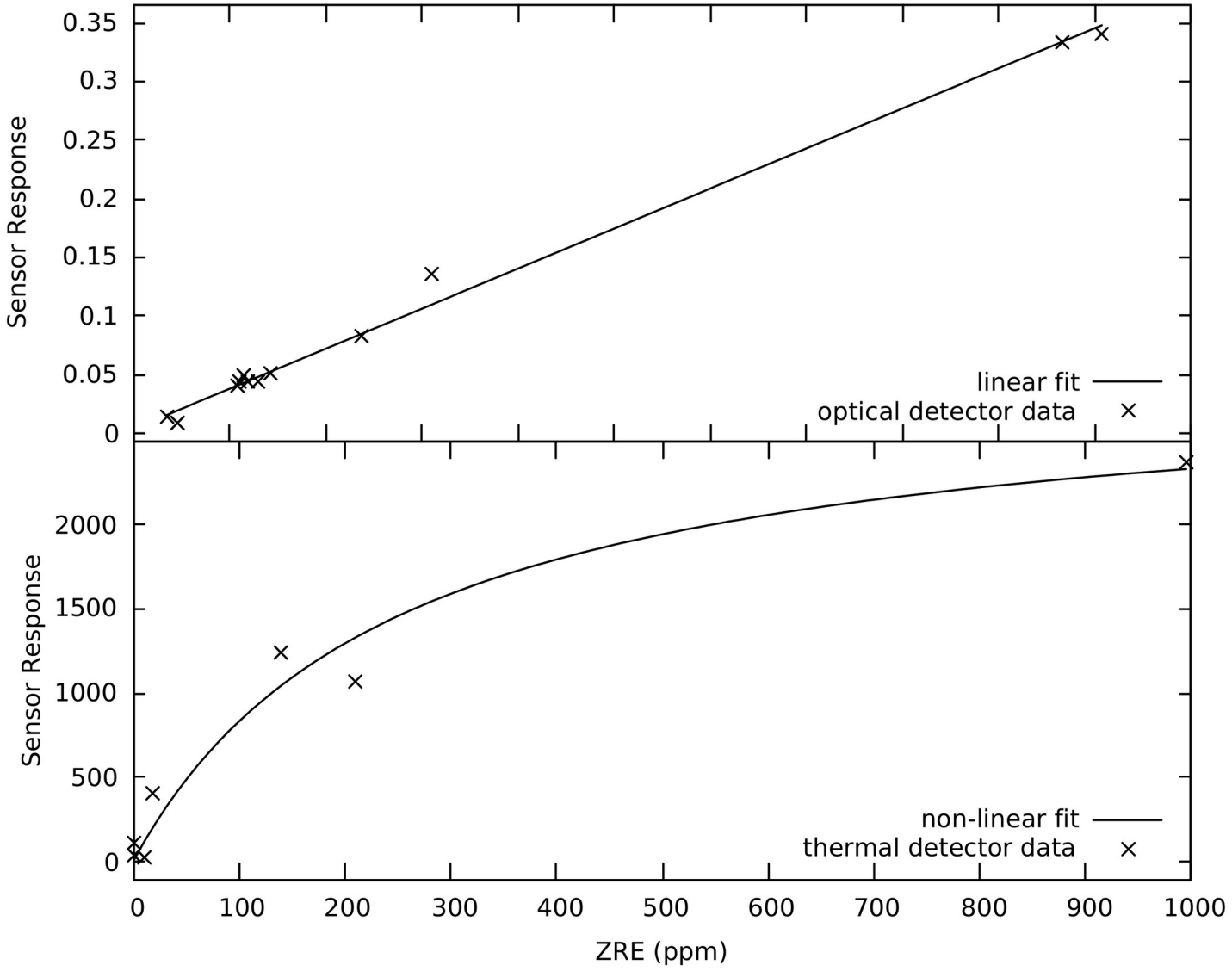


Chemiresistive Sensor Response



Overshoot Spikes





$$x = \mu_{ZRE,peak} - \mu_{ZRE,baseline}$$

$$y = \mu_{sensor,peak} - \mu_{sensor,baseline}$$

Optical
Linear Response

$$y = m \cdot x + b$$

Chemiresistive
Nonlinear Response

$$f(x) = \frac{a \cdot b \cdot x}{1 + b \cdot x}$$

$$L_D = 3 \cdot \sigma$$

$$L_{D(cor)} = m \cdot L_D + b$$

$$L_{D(cor)} = \frac{a \cdot b \cdot x}{1 + b \cdot L_D}$$

CO_2

	$L_{D(corr)}$
K-30 SE-0018	31.1
COZIR AMB GC-020	65.7
Gascard CO_2	0.00862
MSH-P/HC/CO2/	57.6
MSH-DP/CO2/	6.60
Telaire T6615	22.9

CH_4

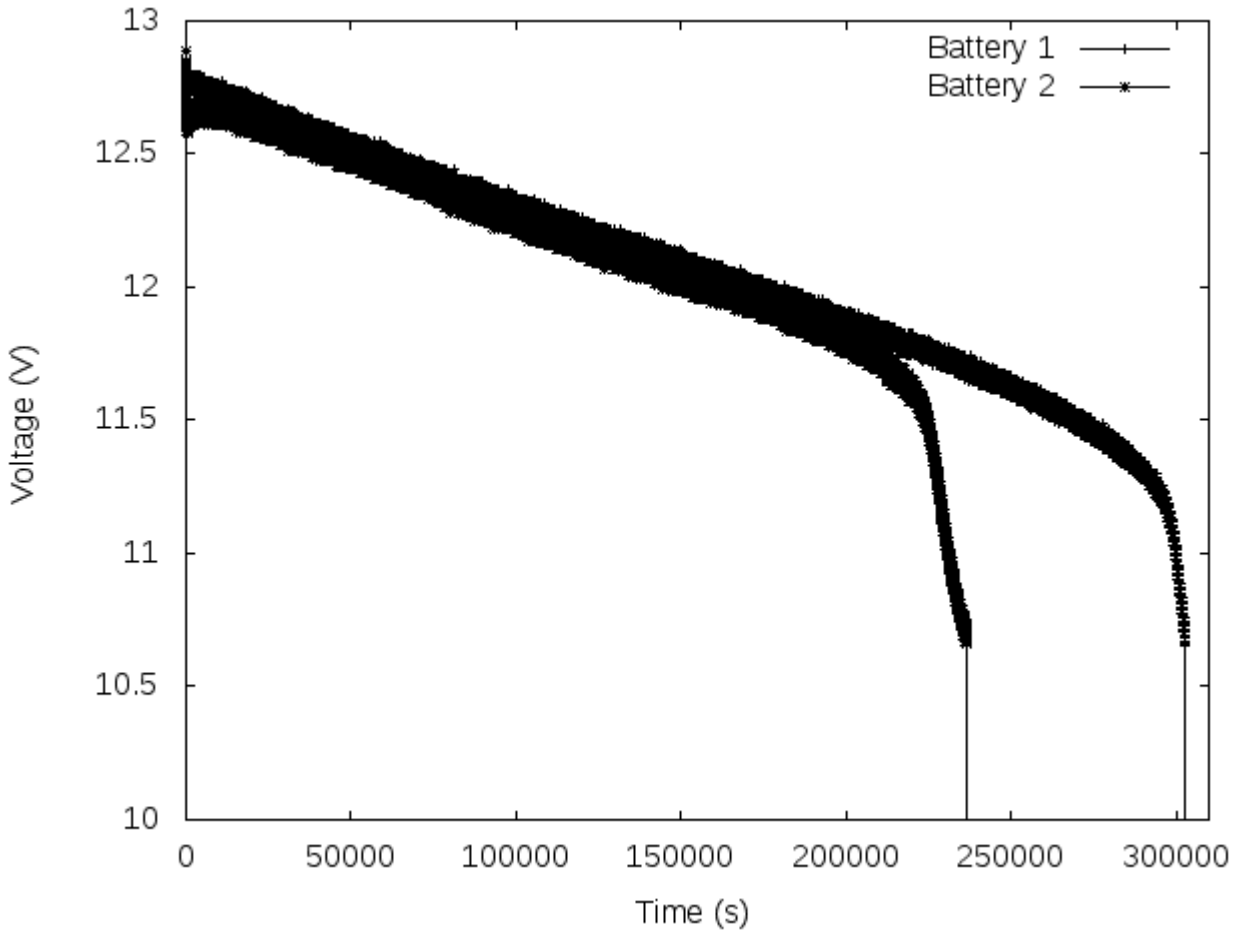
	$L_{D(corr)}$
MQ-4	1.24†
Gascard CH_4	0.569
MSH-P/HC/CO2/	7.44‡
MSH-DP/HC/	2.42‡
TGS-2600	33.3†
TGS-2610	29.0†
TGS-2611	3.95†

† Calculated from Langmuirian fitting.

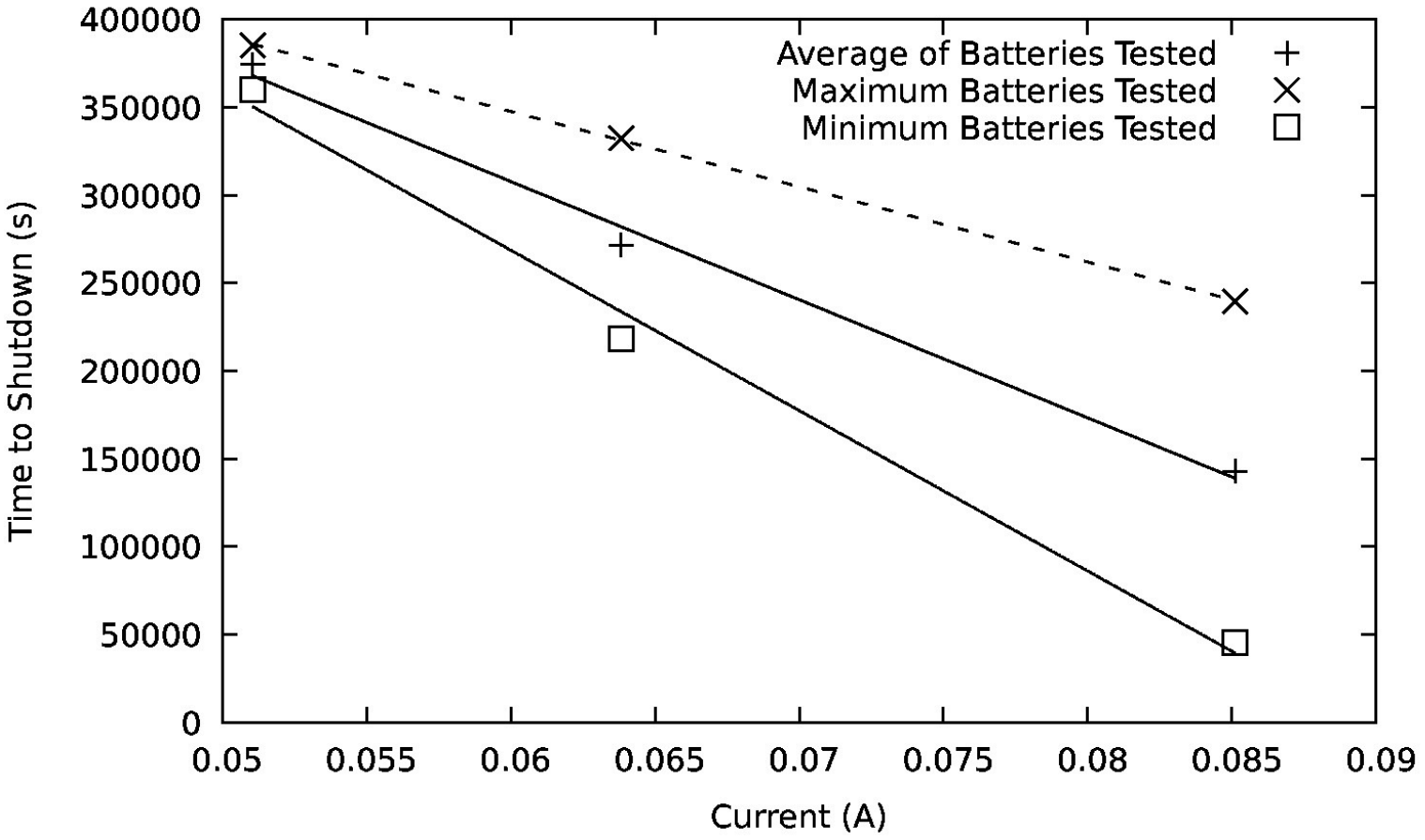
‡ Failed to produce consistent response within tested range.

Tycon Power Systems. RemotePro Data Sheet. (2014).

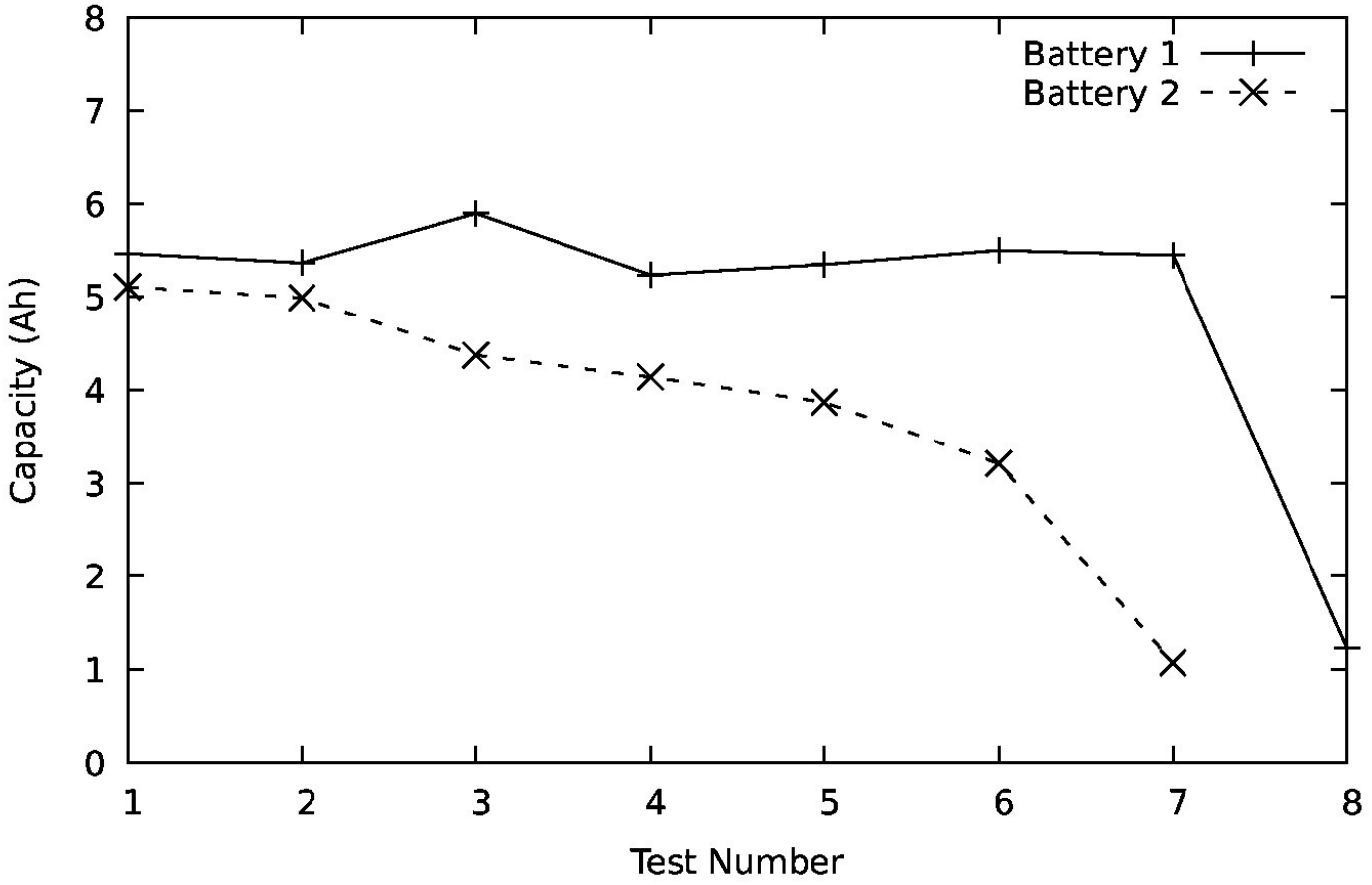
Discharge at 144Ω



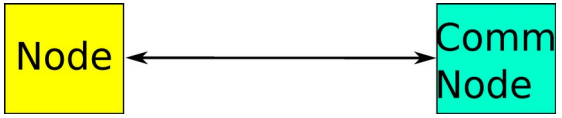
Time to Shutoff with Current



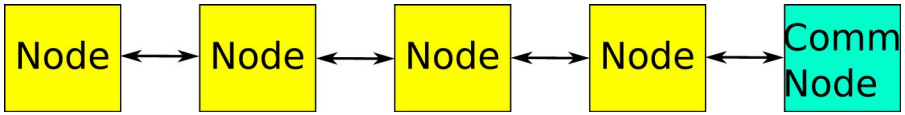
Capacity Loss of Batteries



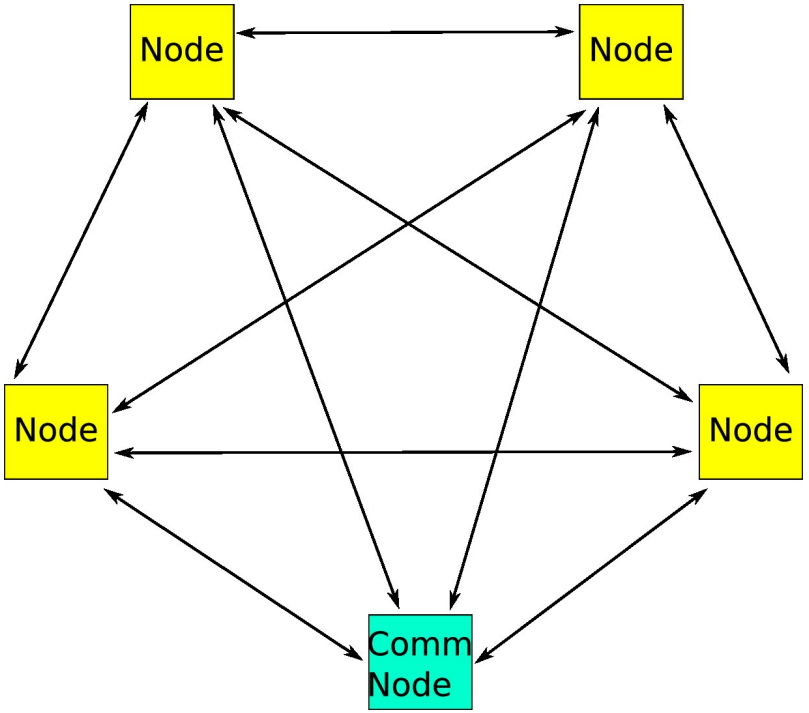
PTP Network



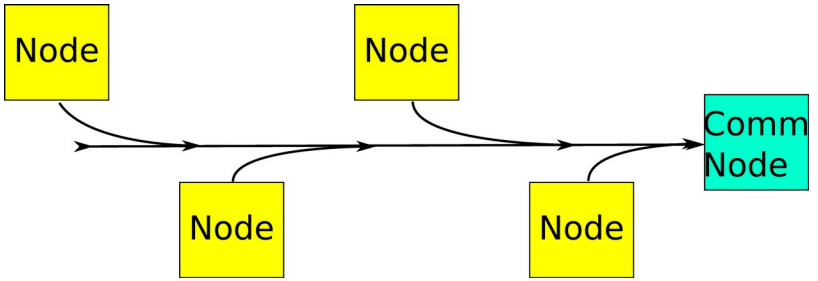
Linear Network

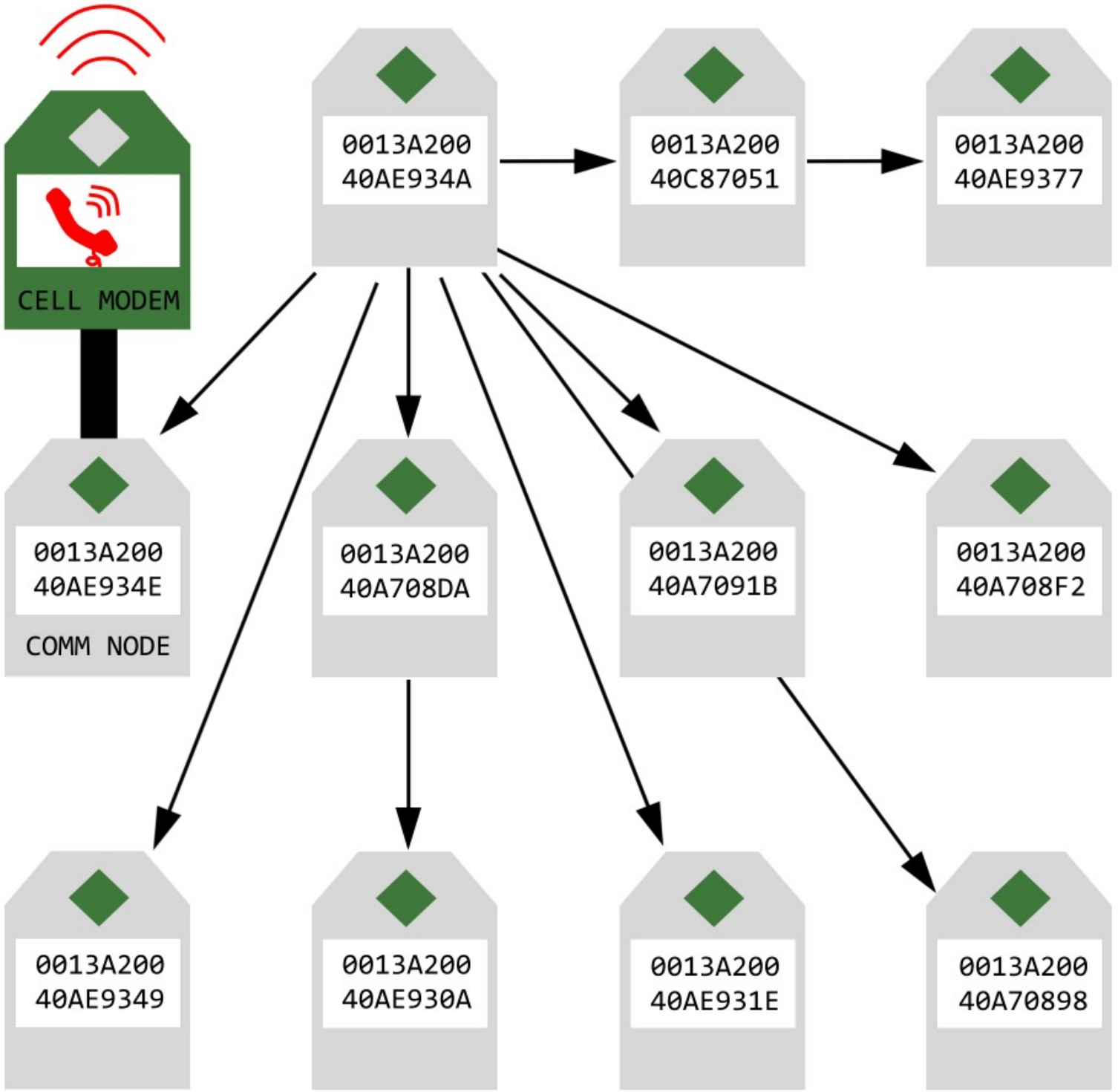


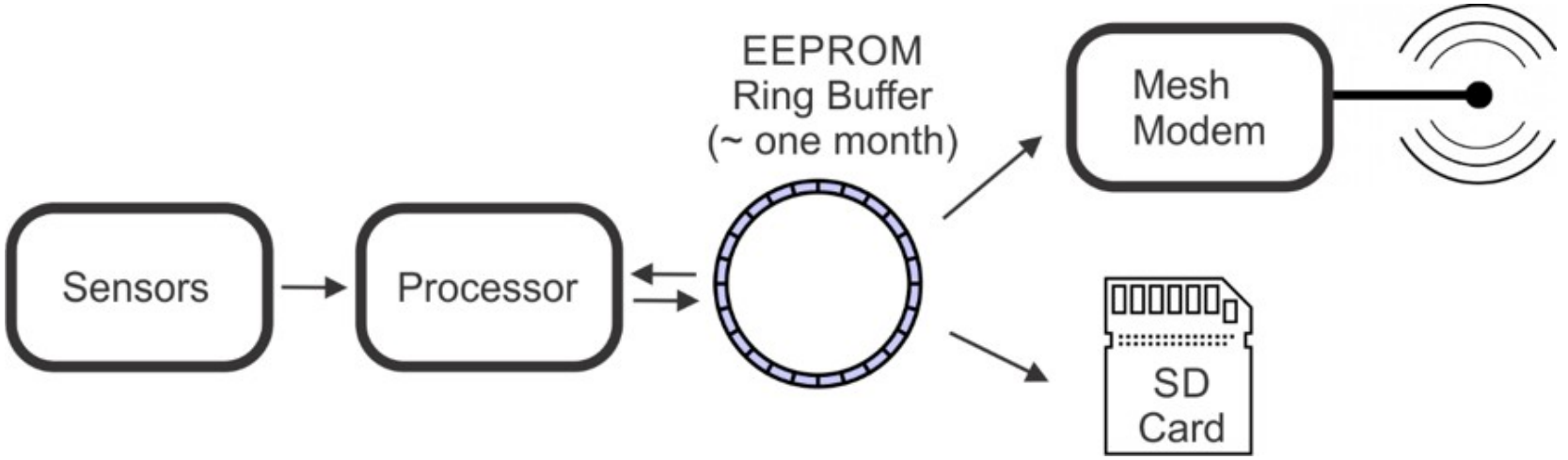
Mesh Network

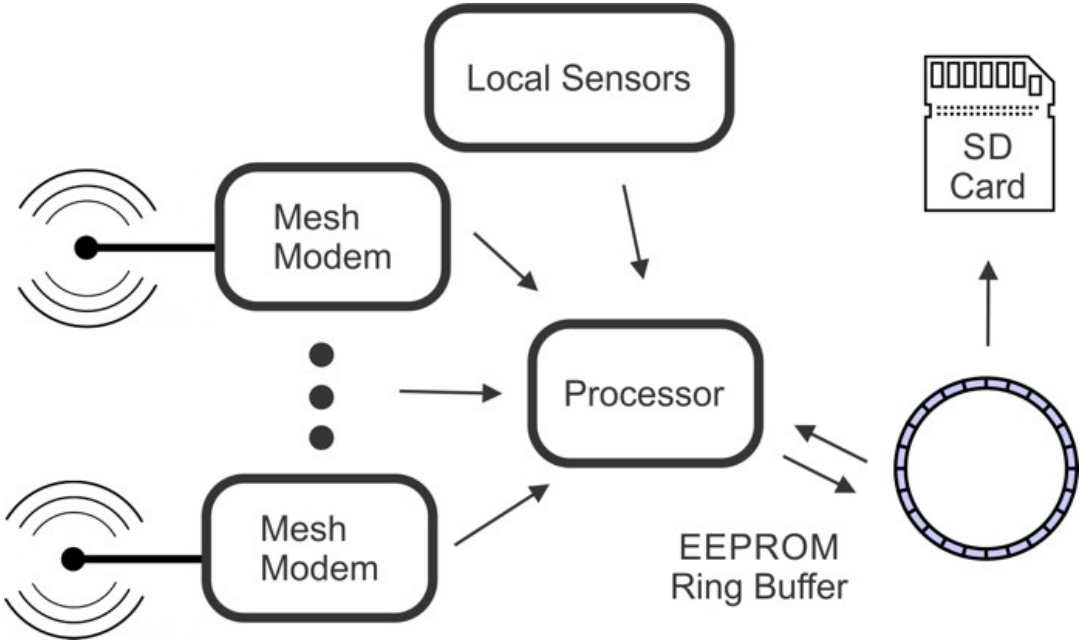


Bus Network



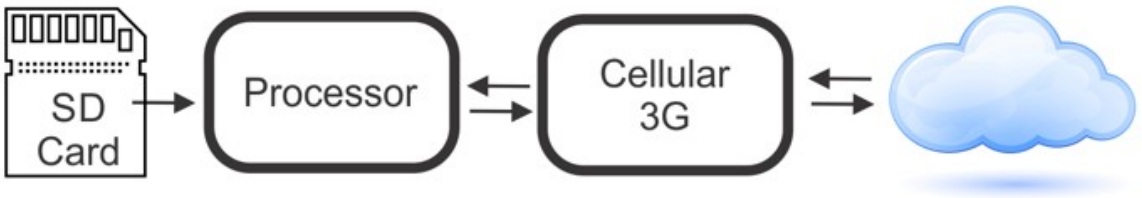

CELL MODEM
0013A200
40AE934A
0013A200
40C87051
0013A200
40AE9377
0013A200
40AE934E
COMM NODE
0013A200
40A708DA
0013A200
40A7091B
0013A200
40A708F2
0013A200
40AE9349
0013A200
40AE930A
0013A200
40AE931E
0013A200
40A70898


EEPROM
Ring Buffer
(~ one month)
Mesh
Modem
Sensors
Processor
SD
Card

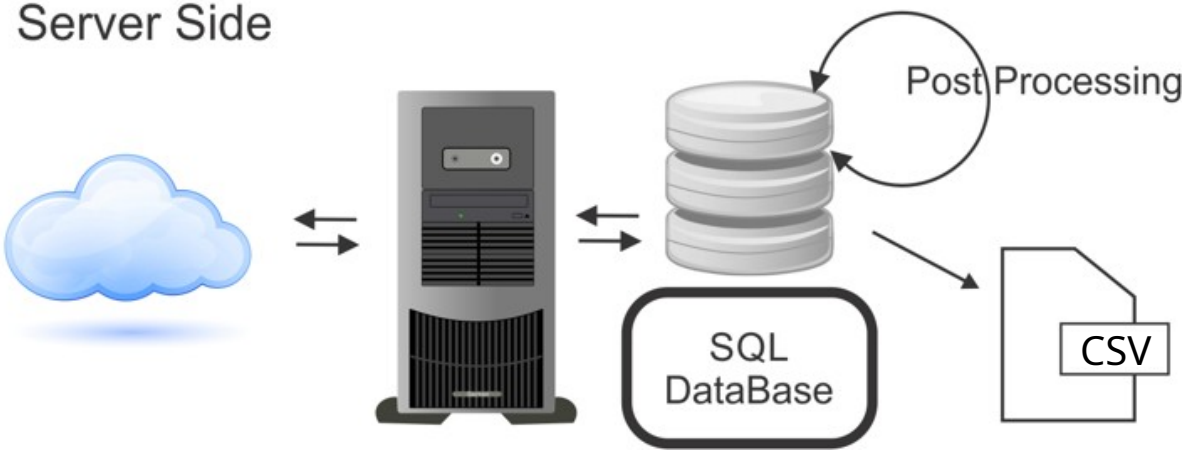

Local Sensors
SD
Card
Mesh
Modem
Processor
Mesh
Modem
EEPROM
Ring Buffer

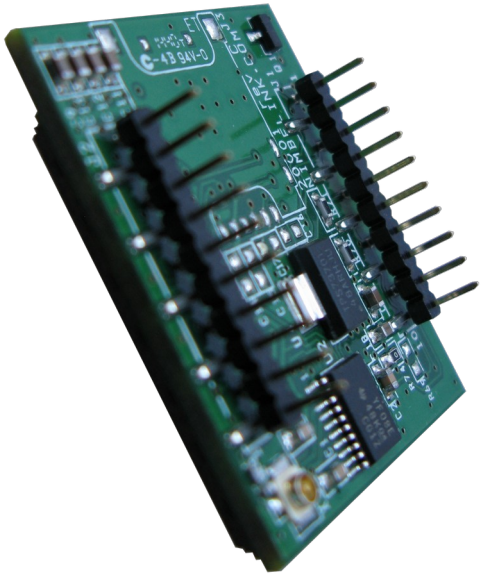

Digi
XBee
PRO S3B

Communication Node



Server Side





Sensor Node Boards

Programming Serial Interfaces

EEPROM and SD Storage

Switch Circuits

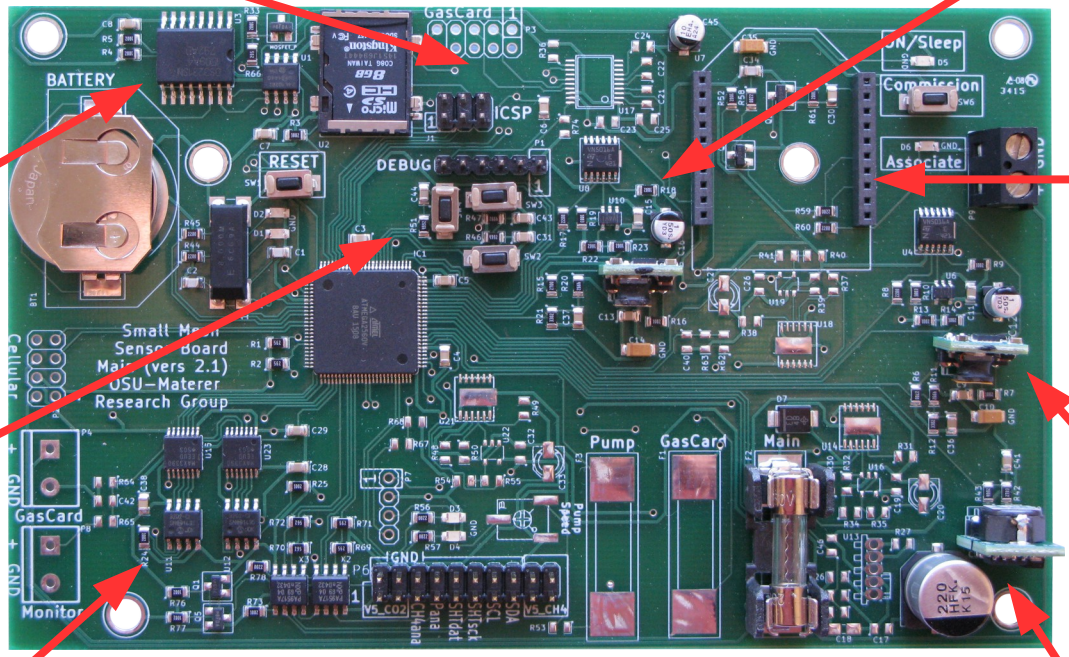
Level shifters and converters

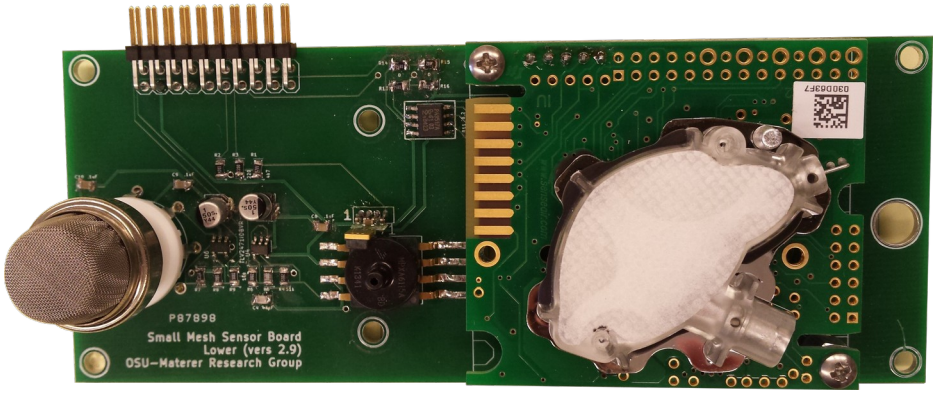
12V to 5V Supply

Xbee Communication

12V to 5V Supply

12V to 3.3V Supply

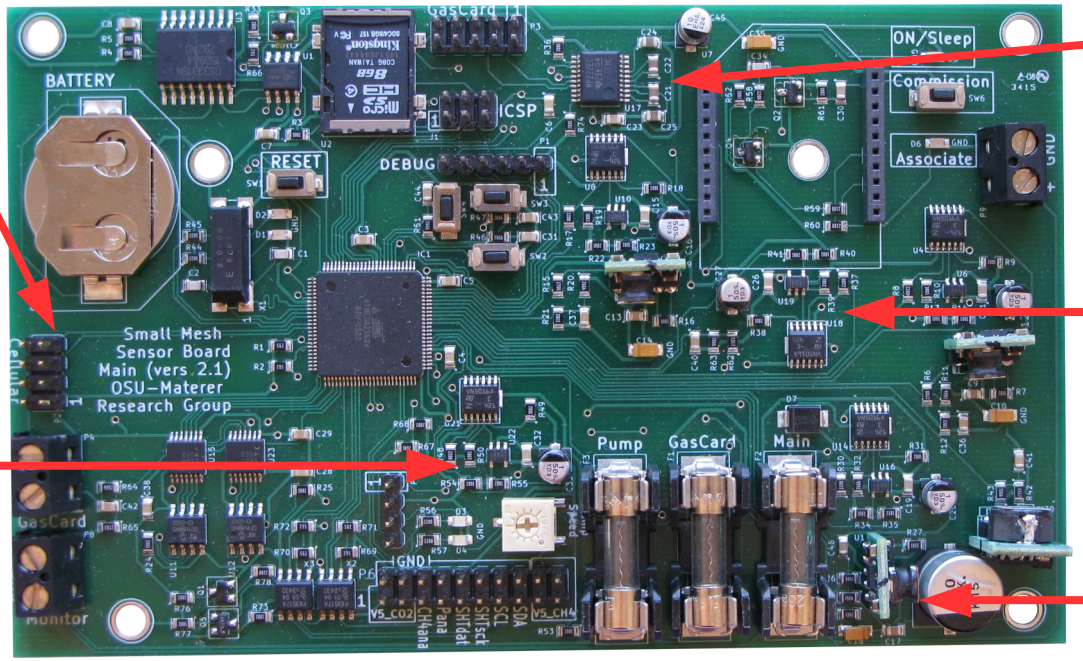




Communication Node Boards

Cellular Modem Breakout Header

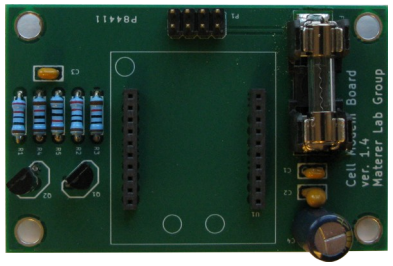
Pump Controller, Power Supply

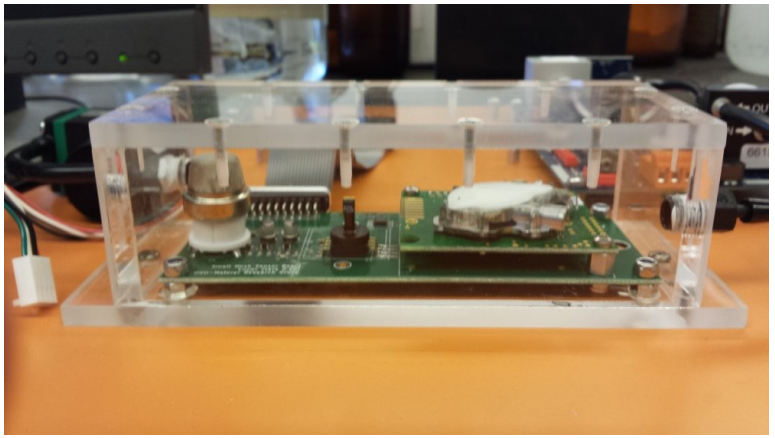


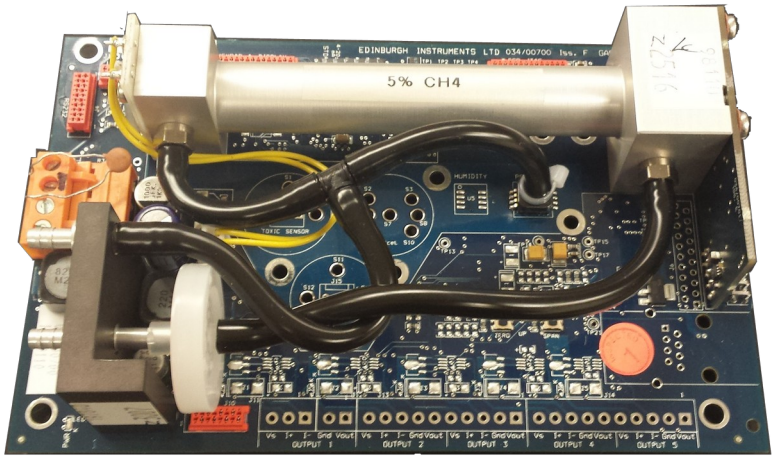
Gascard header, Level converter

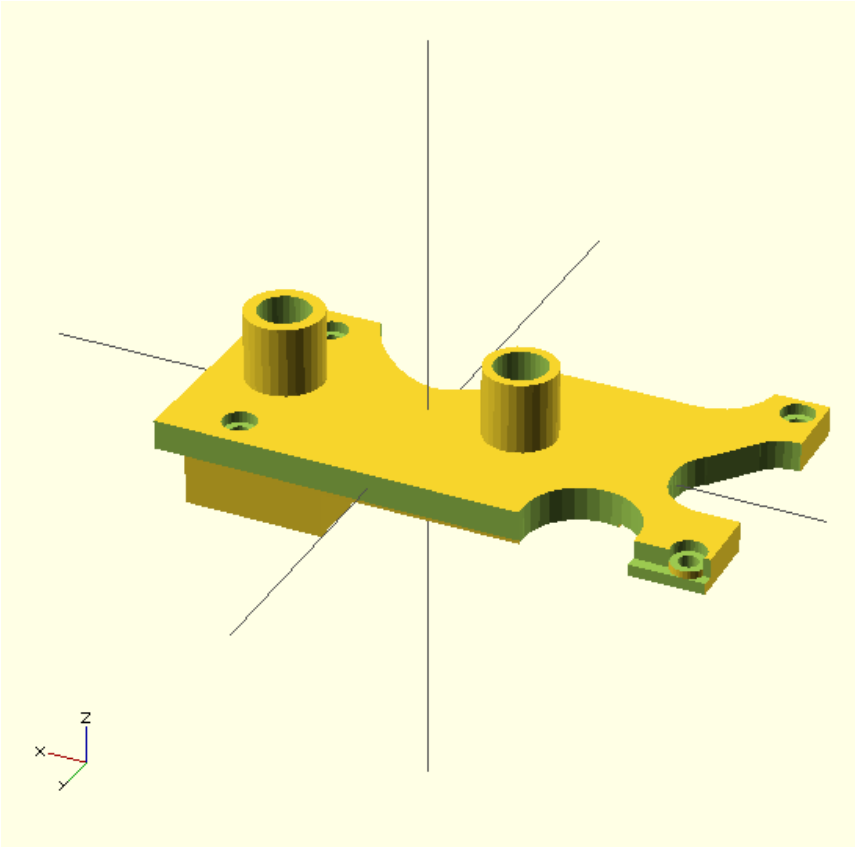
Cellular Modem Power Supply

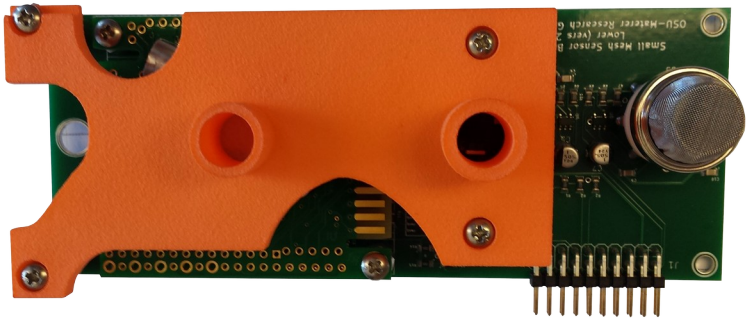
12V to 5V Supply

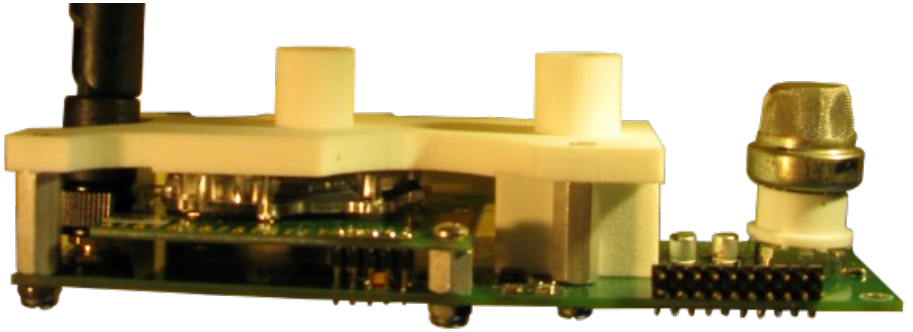






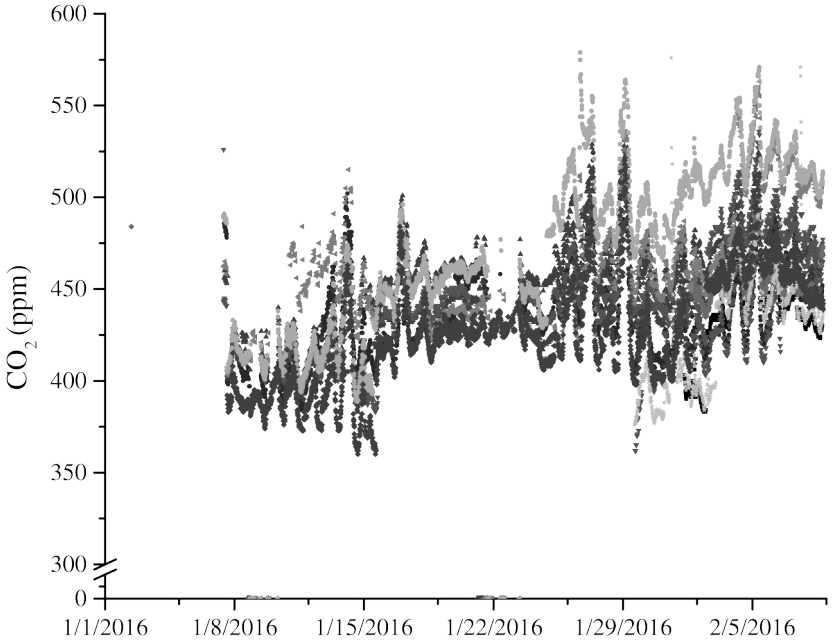


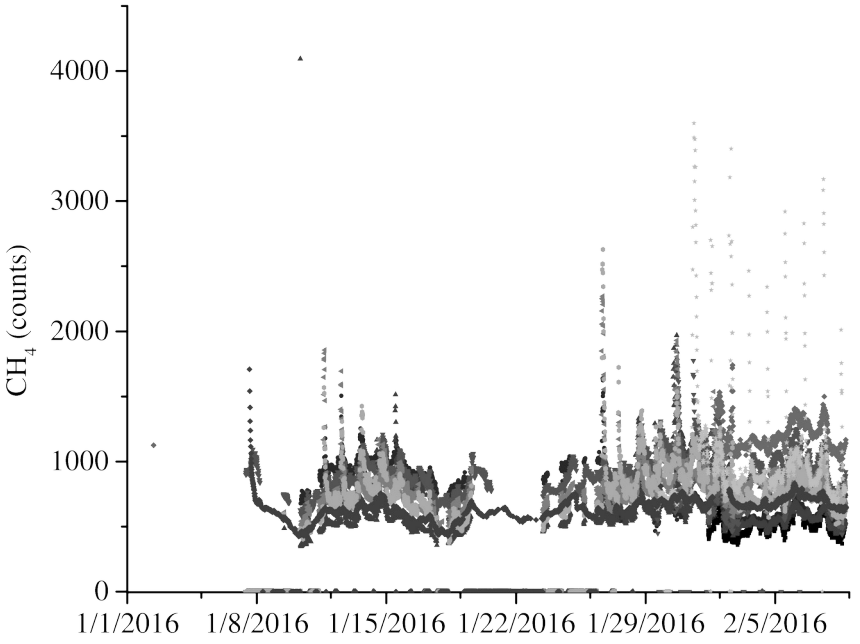


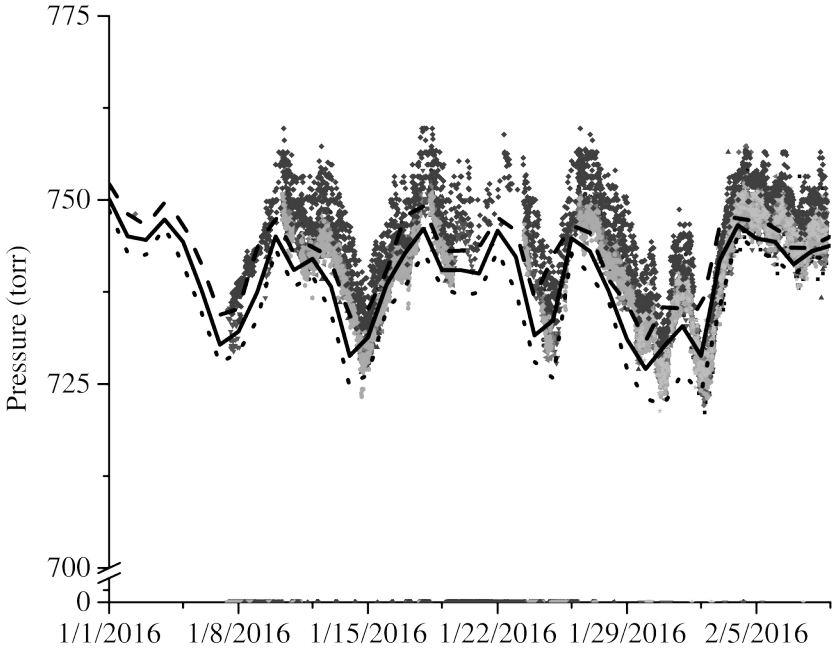


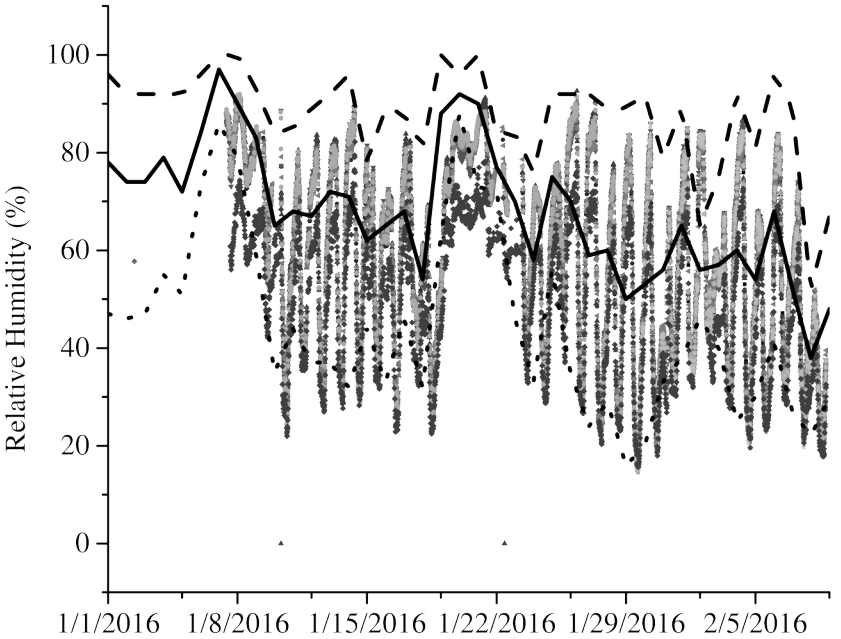
Kintel, M. & Clifford Wolf, C. OpenSCAD, The Programmers Solid 3D CAD Modeller. (2011).

Proving Grounds – North of OSU


600
550
500
450
400
350
300
0
CO_2 (ppm)
1/1/2016
1/8/2016
1/15/2016
1/22/2016
1/29/2016
2/5/2016

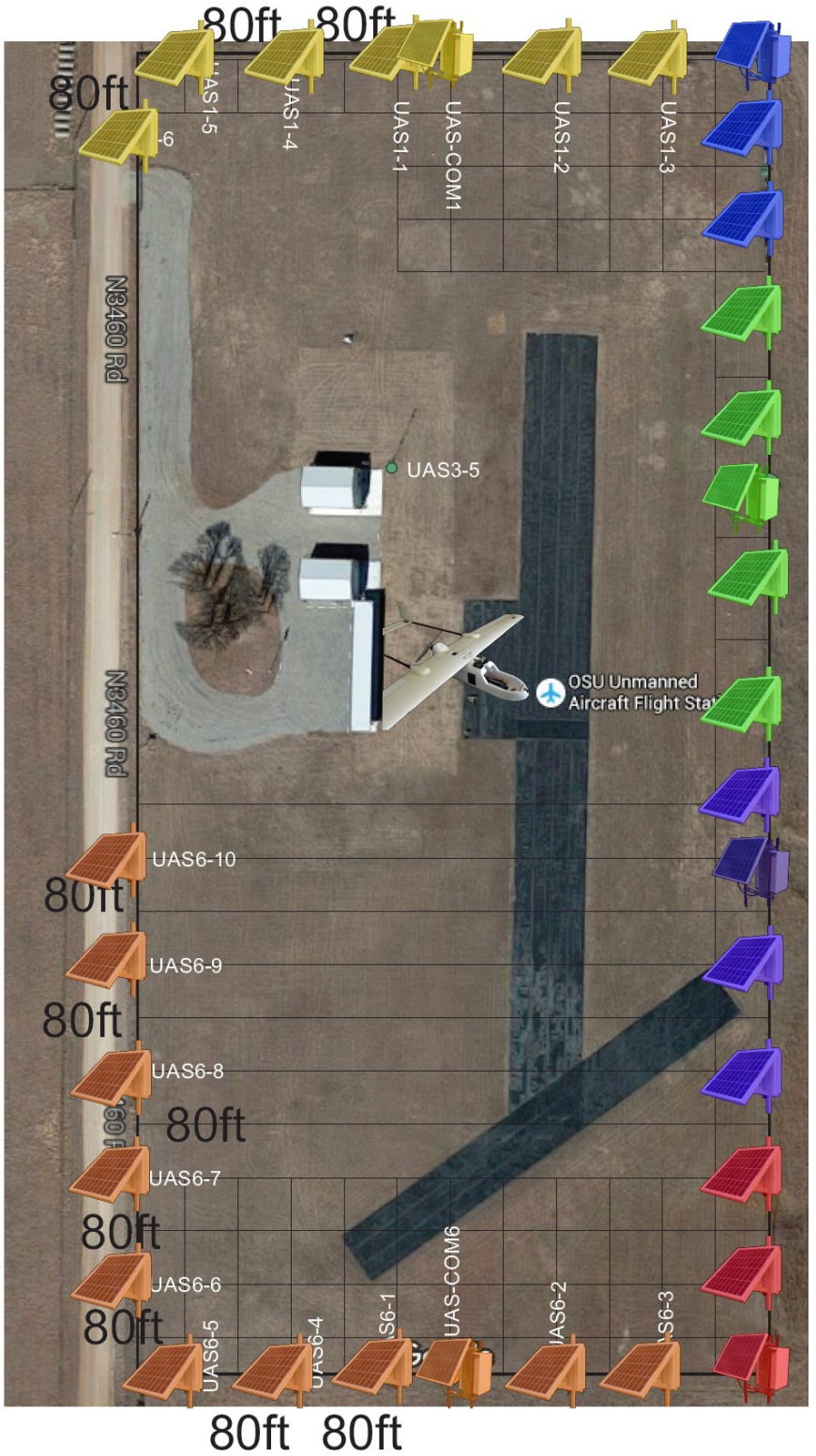

4000
3000
2000
1000
0
CH_4 (counts)
1/1/2016
1/8/2016
1/15/2016
1/22/2016
1/29/2016
2/5/2016



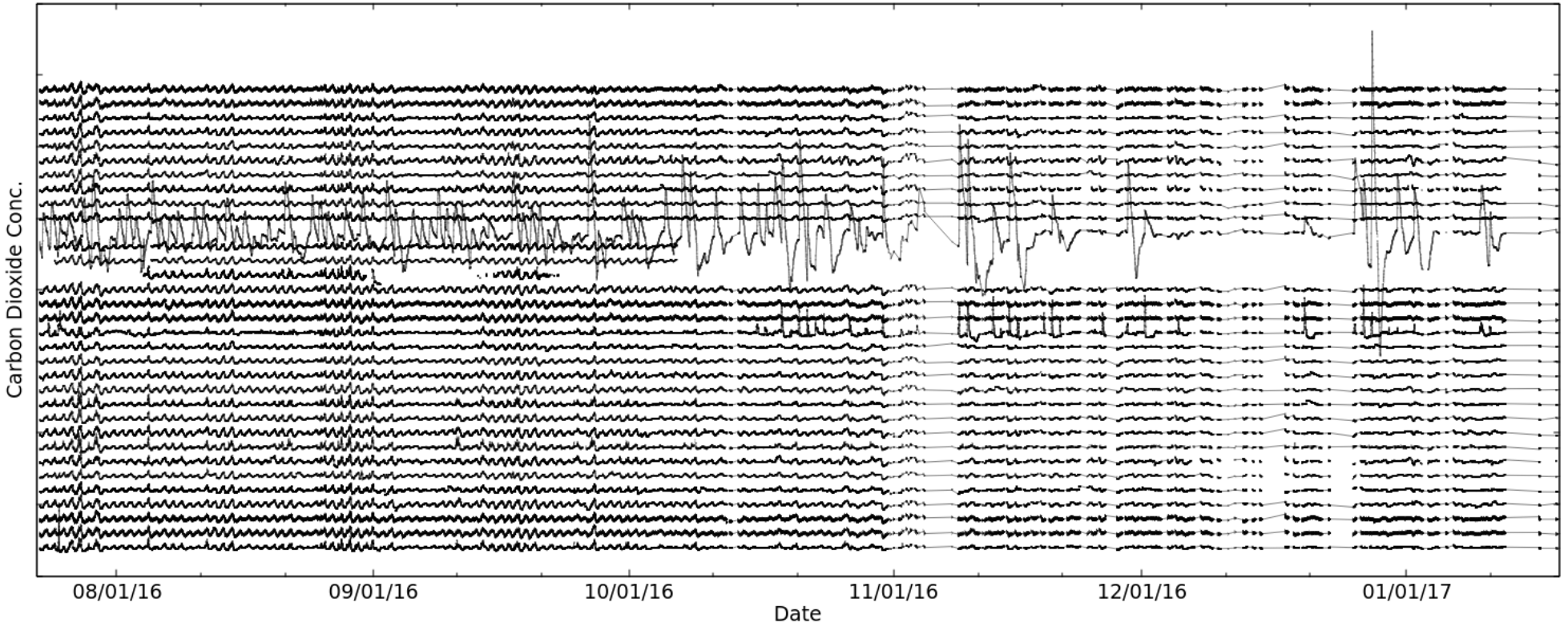


KSWO. Weather History for KSWO from July 1, 2014 to July 31, 2015 [Dataset]. (Weather Underground, 2015).

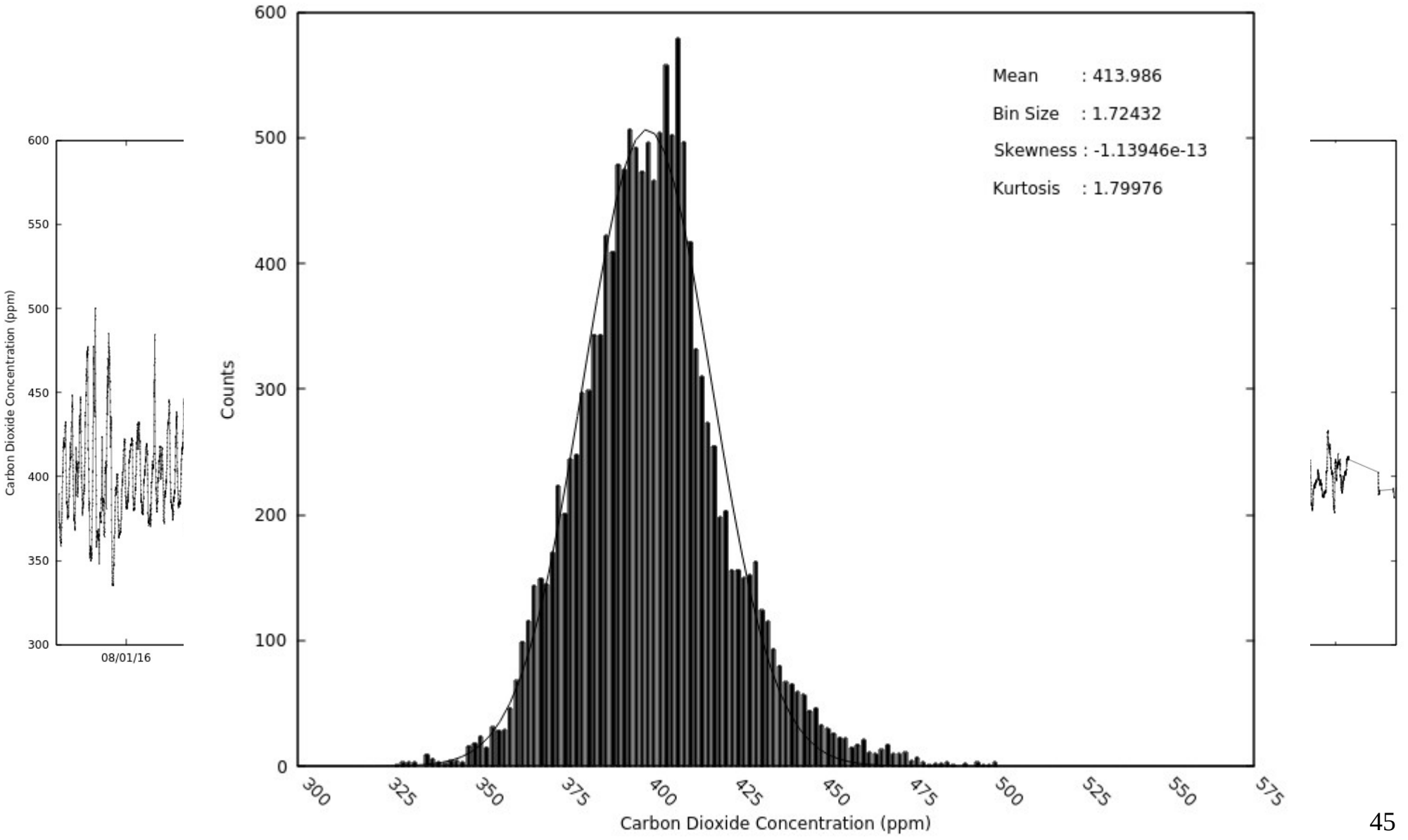
Unmanned Aircraft Flight Station



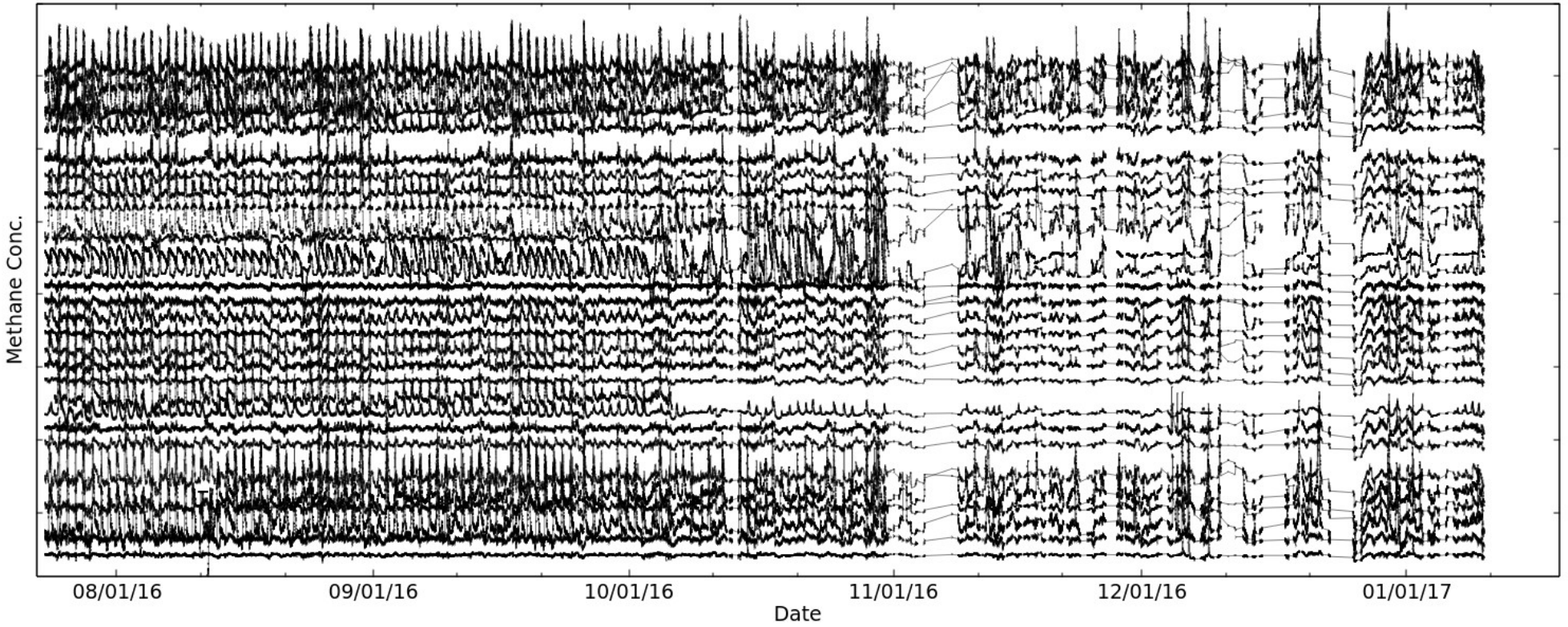
CO_2 Sensor Response



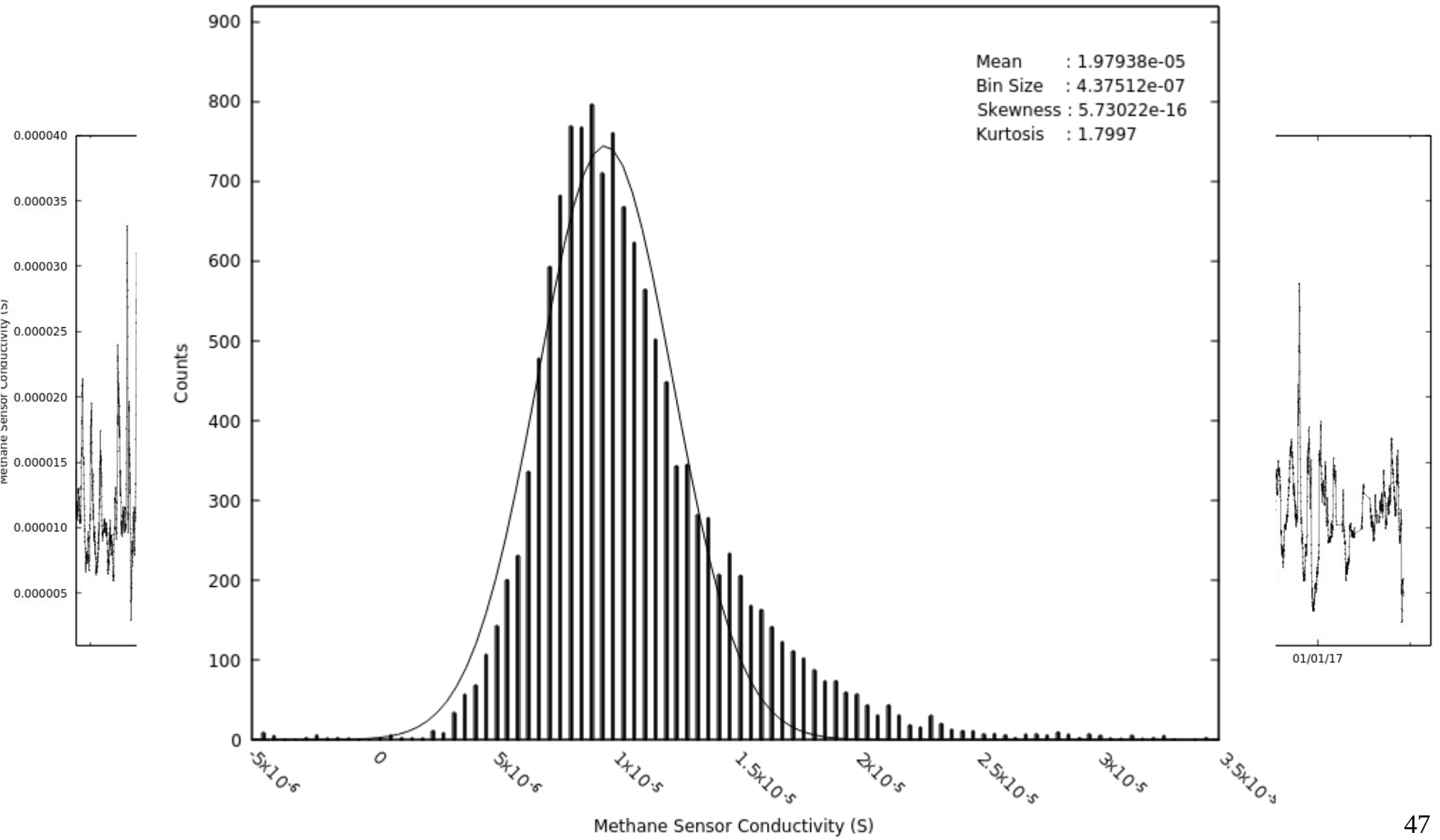
CO_2 Average at UAS



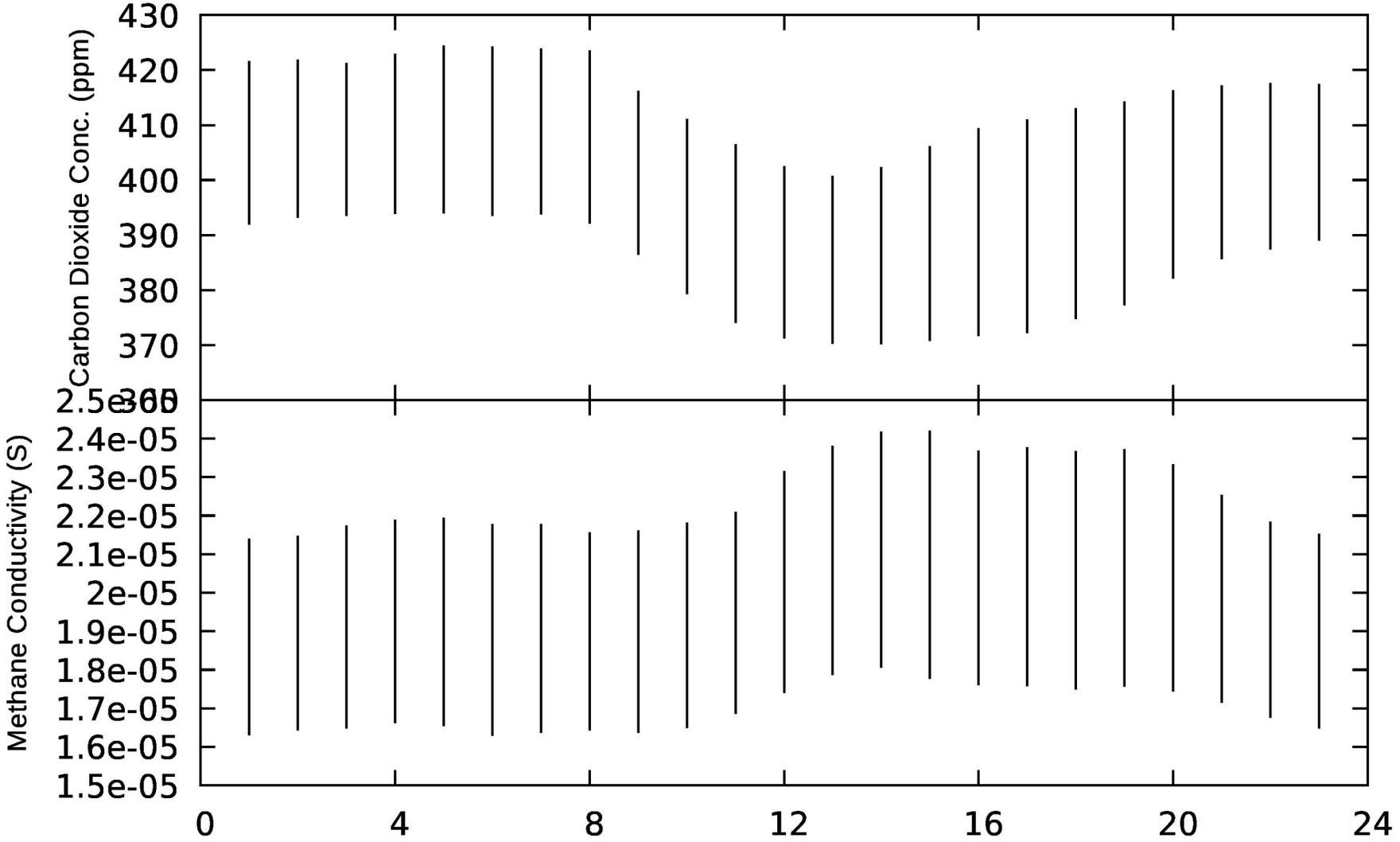
CH_4 Sensor Response



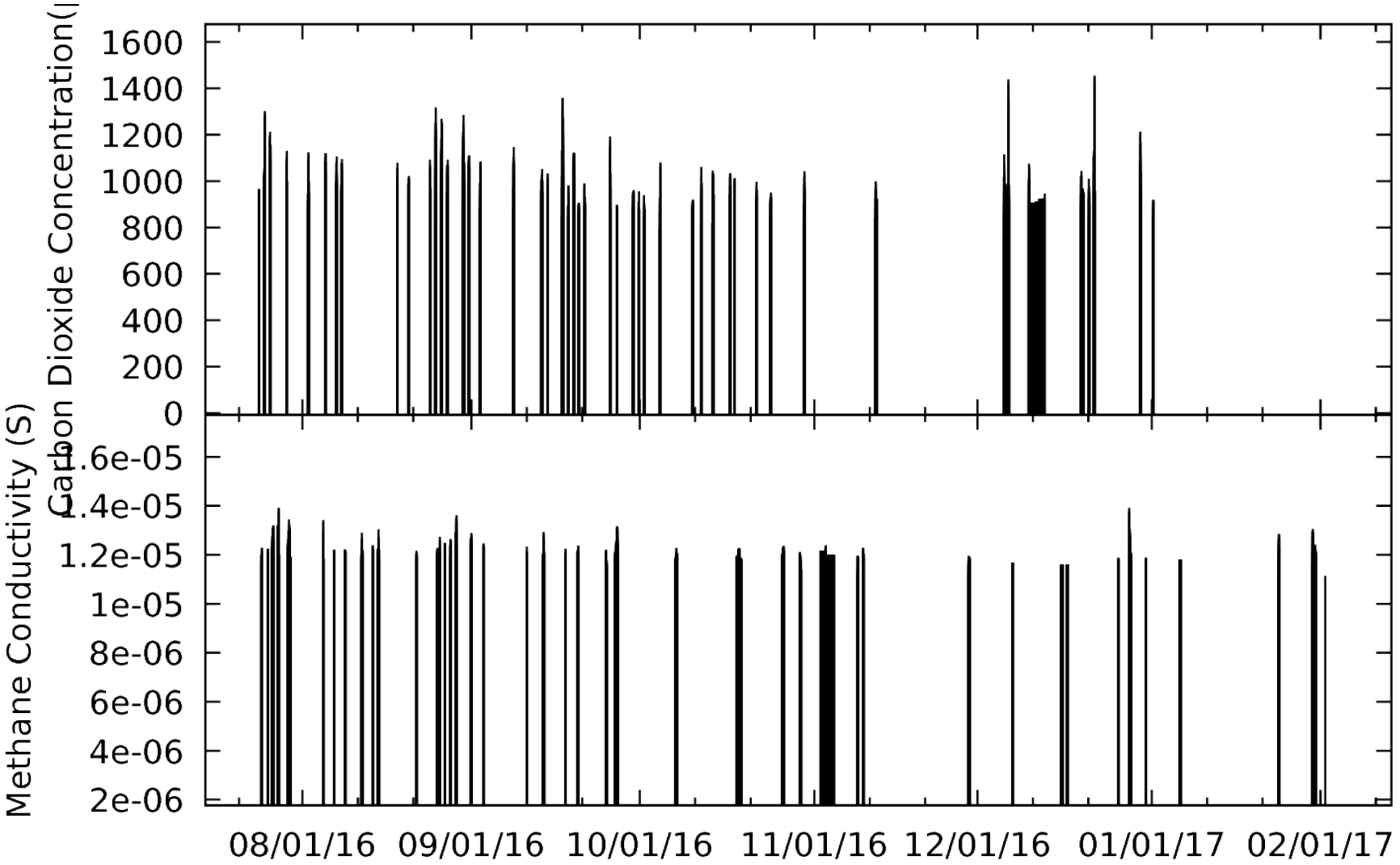
CH_4 Average at UAS



Daily Gas Concentration Cycle



Events: Greater than 2σ



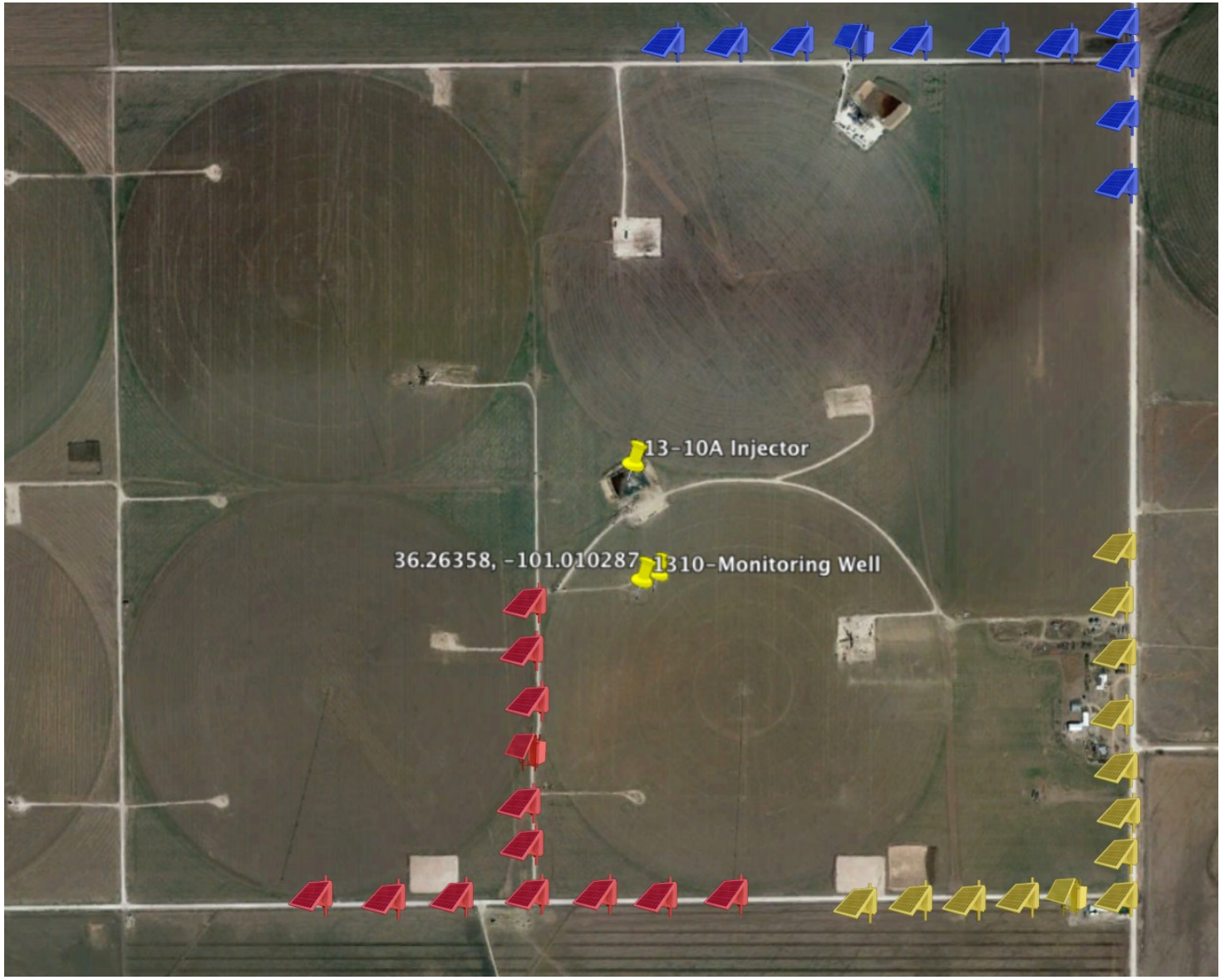
CO_2

CH_4

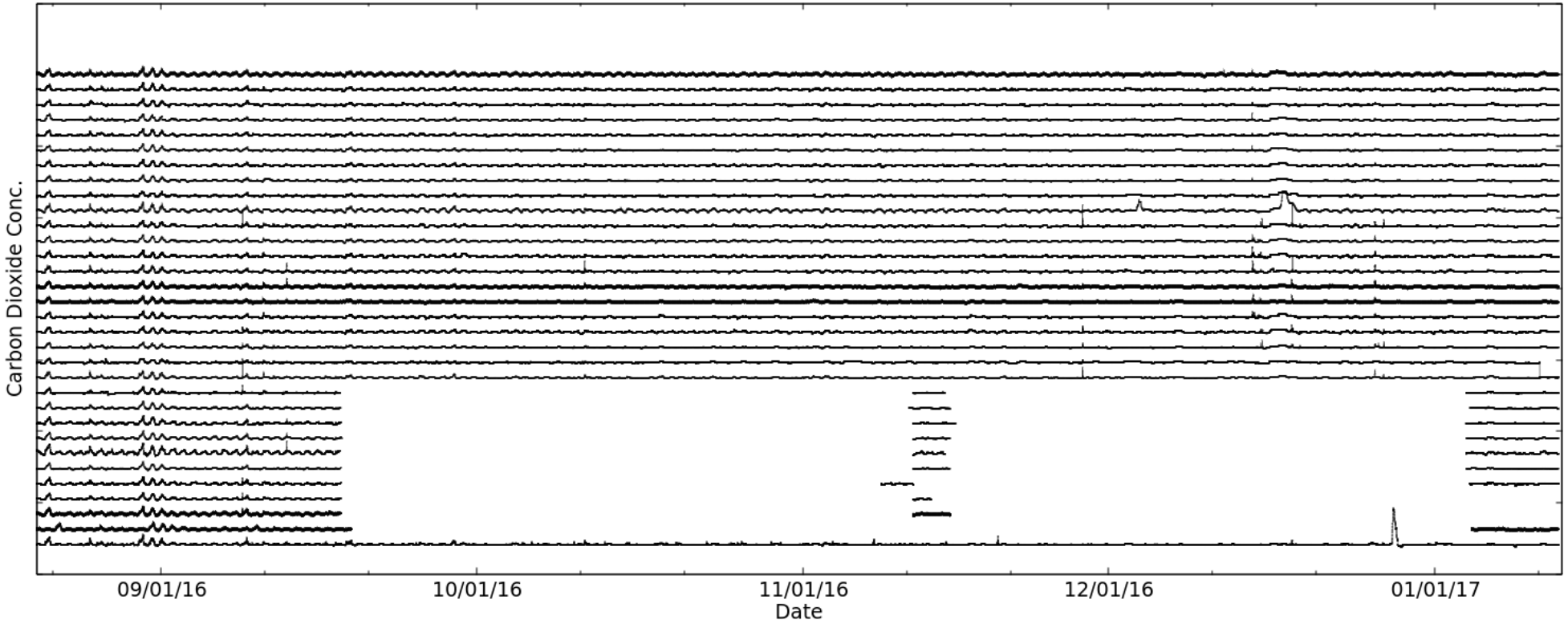
1s in video = 8.33hr data

@ 100 fps

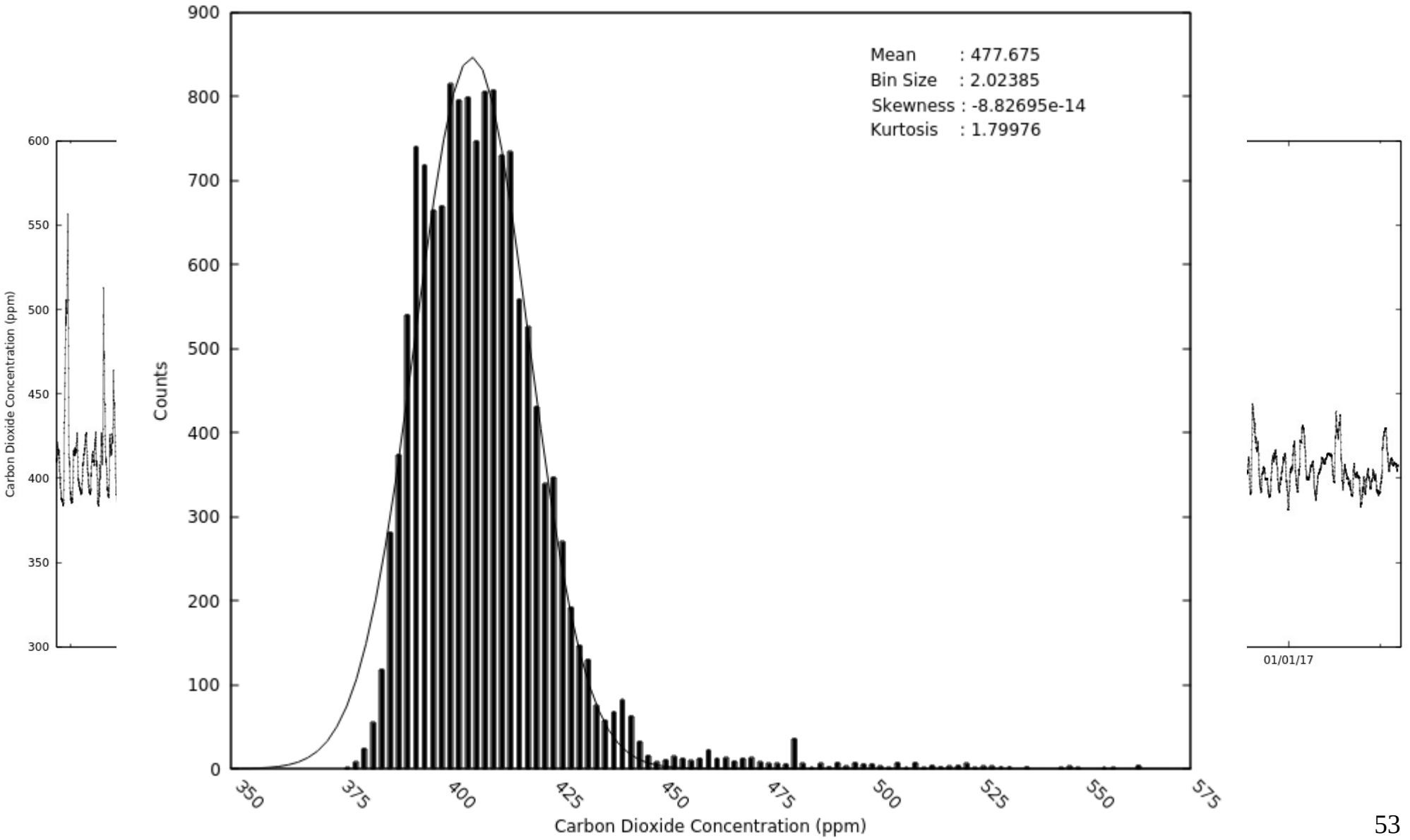
CO_2 Enhanced Oil Recovery Pilot Well in the Anadarko Basin near Farnsworth, TX



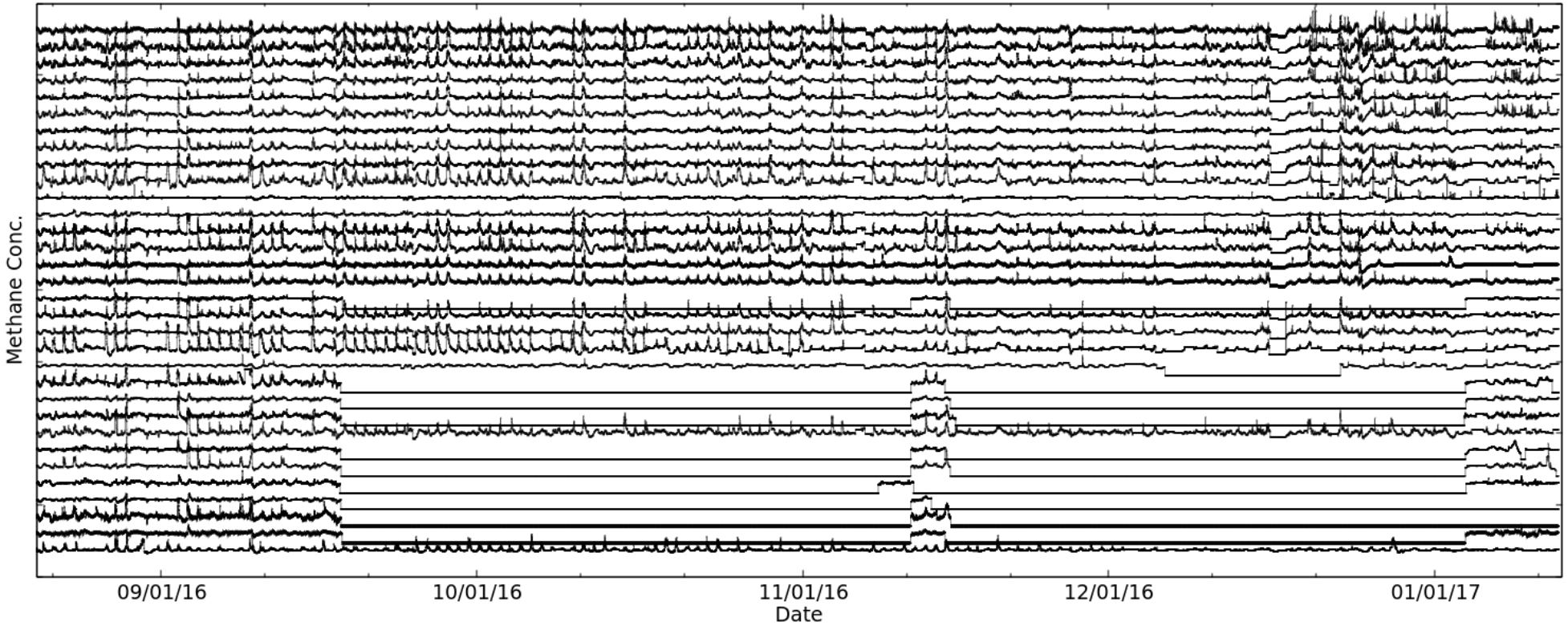
CO_2 Sensor Response



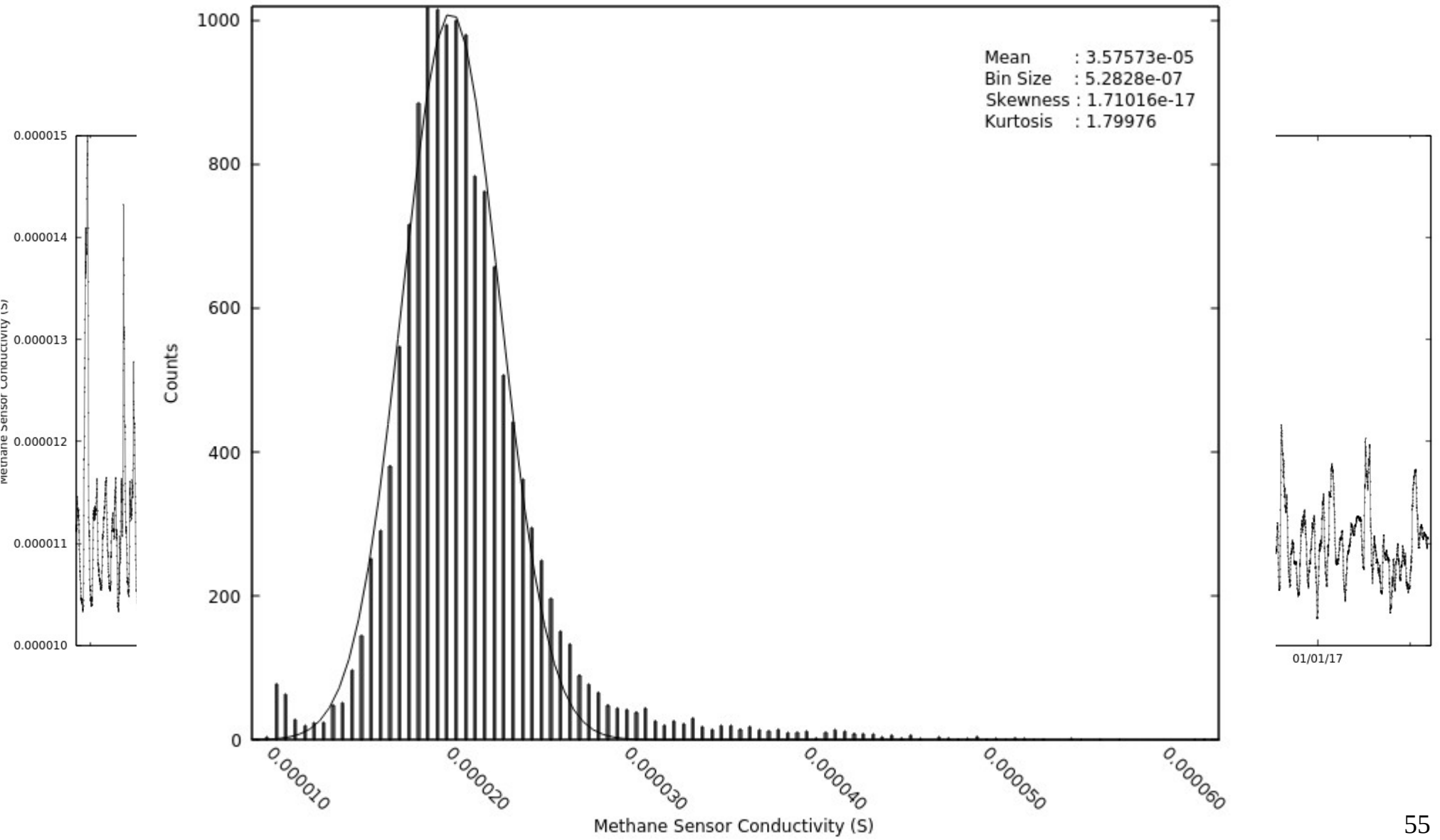
CO_2 Average at Farnsworth, TX



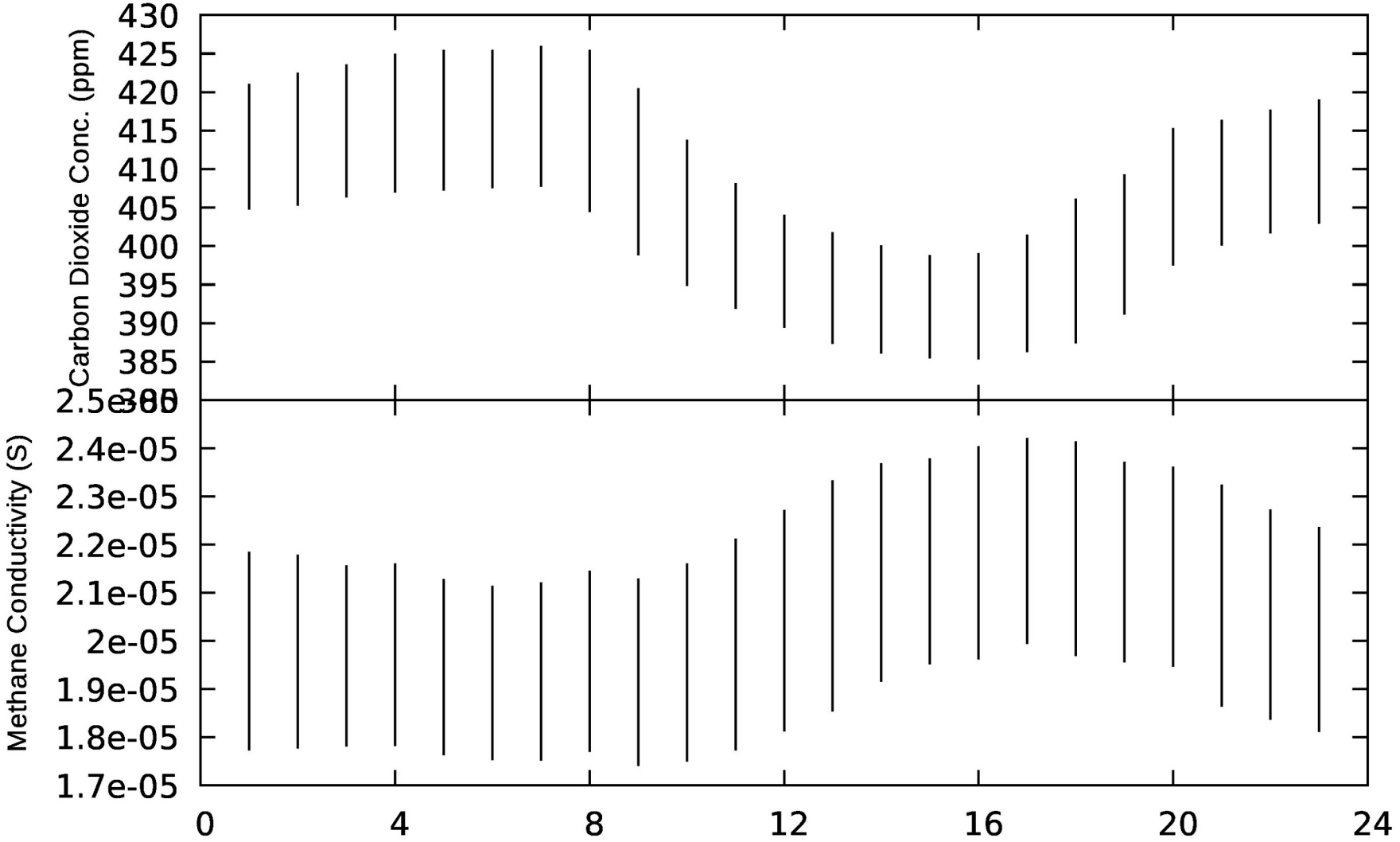
CH_4 Sensor Response



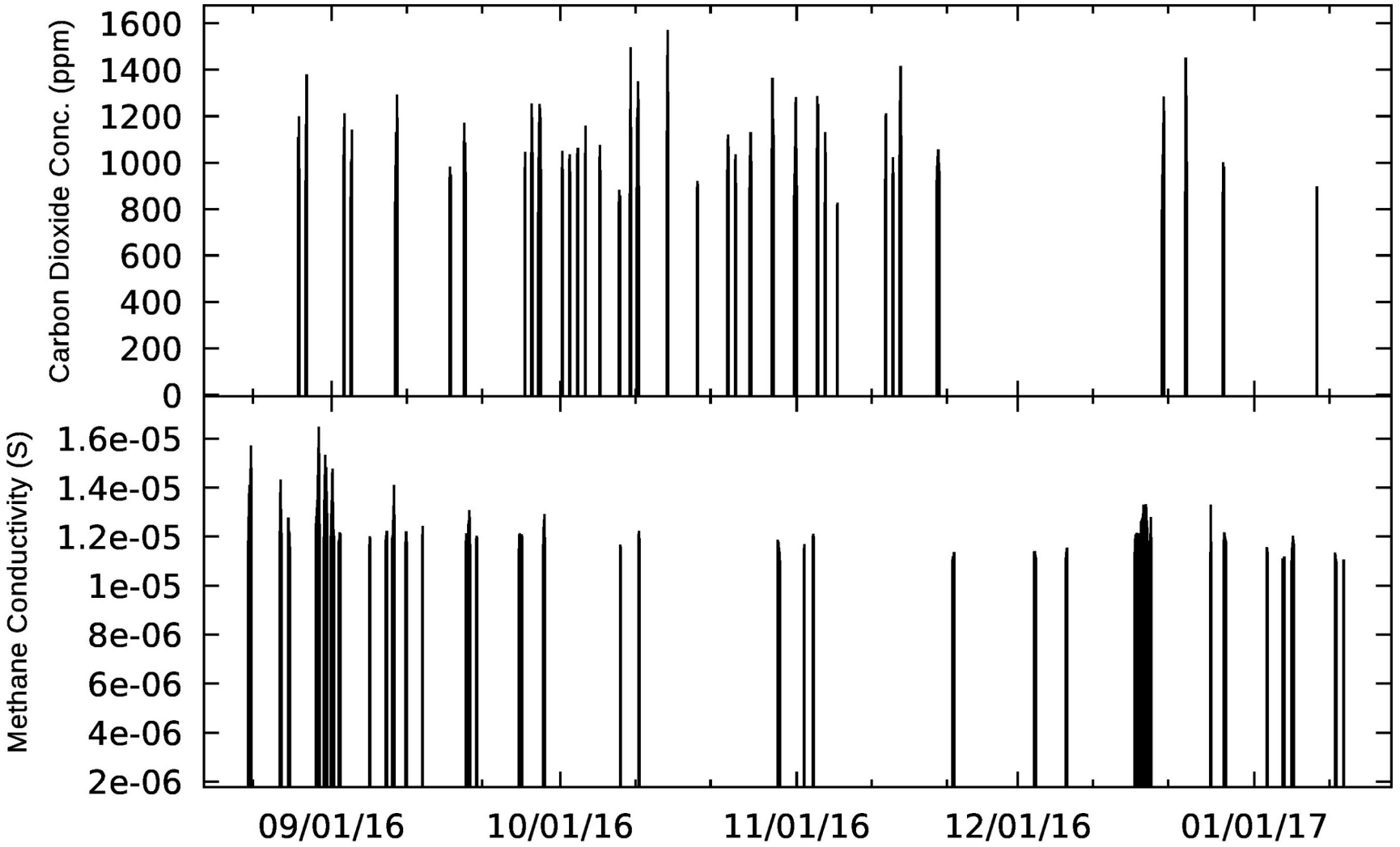
CH_4 Average at Farnsworth, TX



Daily Gas Concentration Cycle



Events: Greater than 2σ



Conclusions

- Networked sensor arrays can monitor large areas of land effectively for changes in gas concentration.
- Microseepage events can be detected by the sensor array, and these are currently being compared against known releases.
- Controlled release tests of gas in the UAS airfield are planned to observe how the network behaves during a significant release.
- Devices are being applied to other applications for remote monitoring…

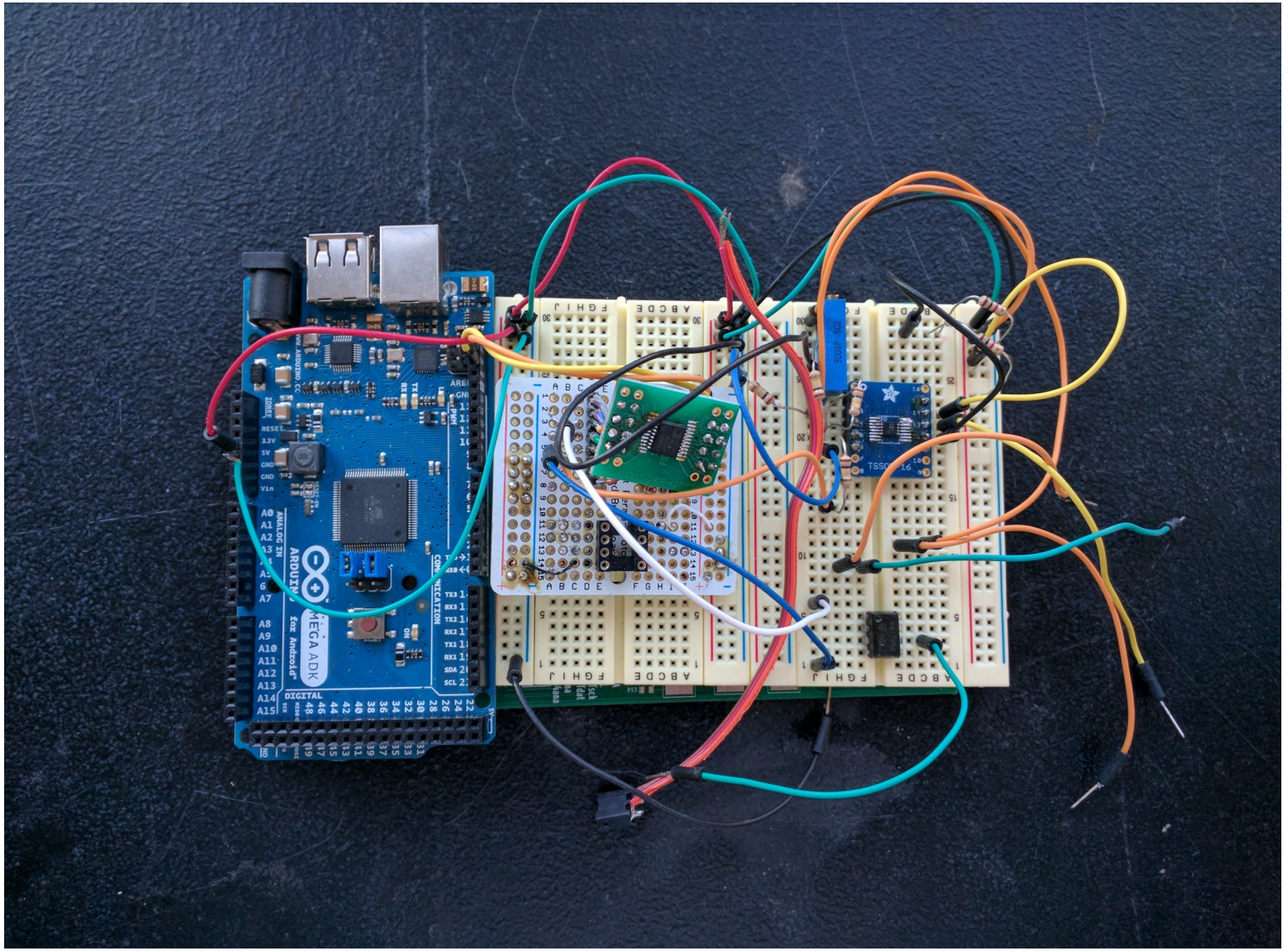
If the platform is the big development...

let’s see what else we can do with it

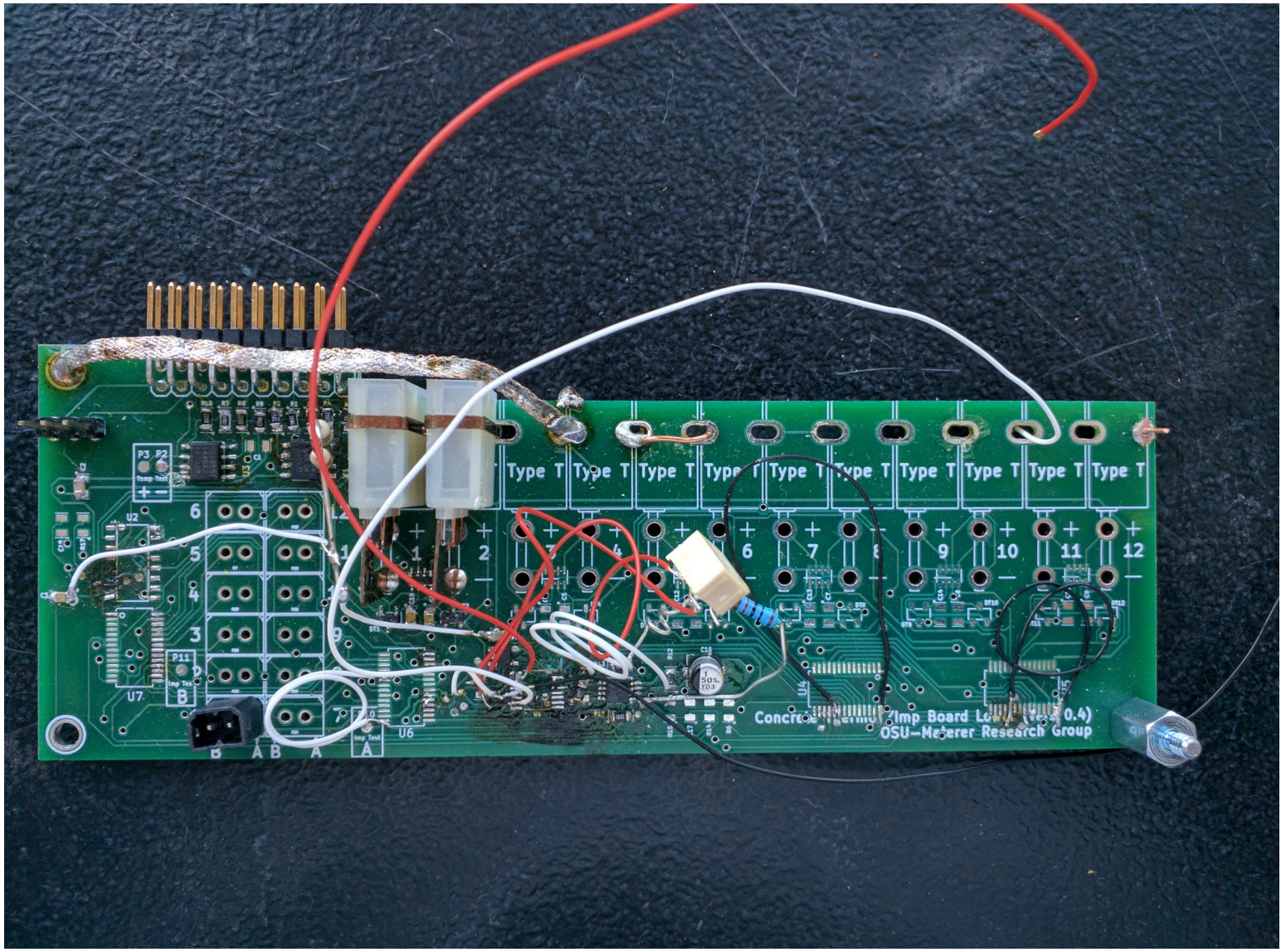
Corrosion of Concrete

- Concrete undergoes redox chemistry during corrosion. It is important to quantify this to predict potential failures.
- Impedance measurements
- Temperature dependent

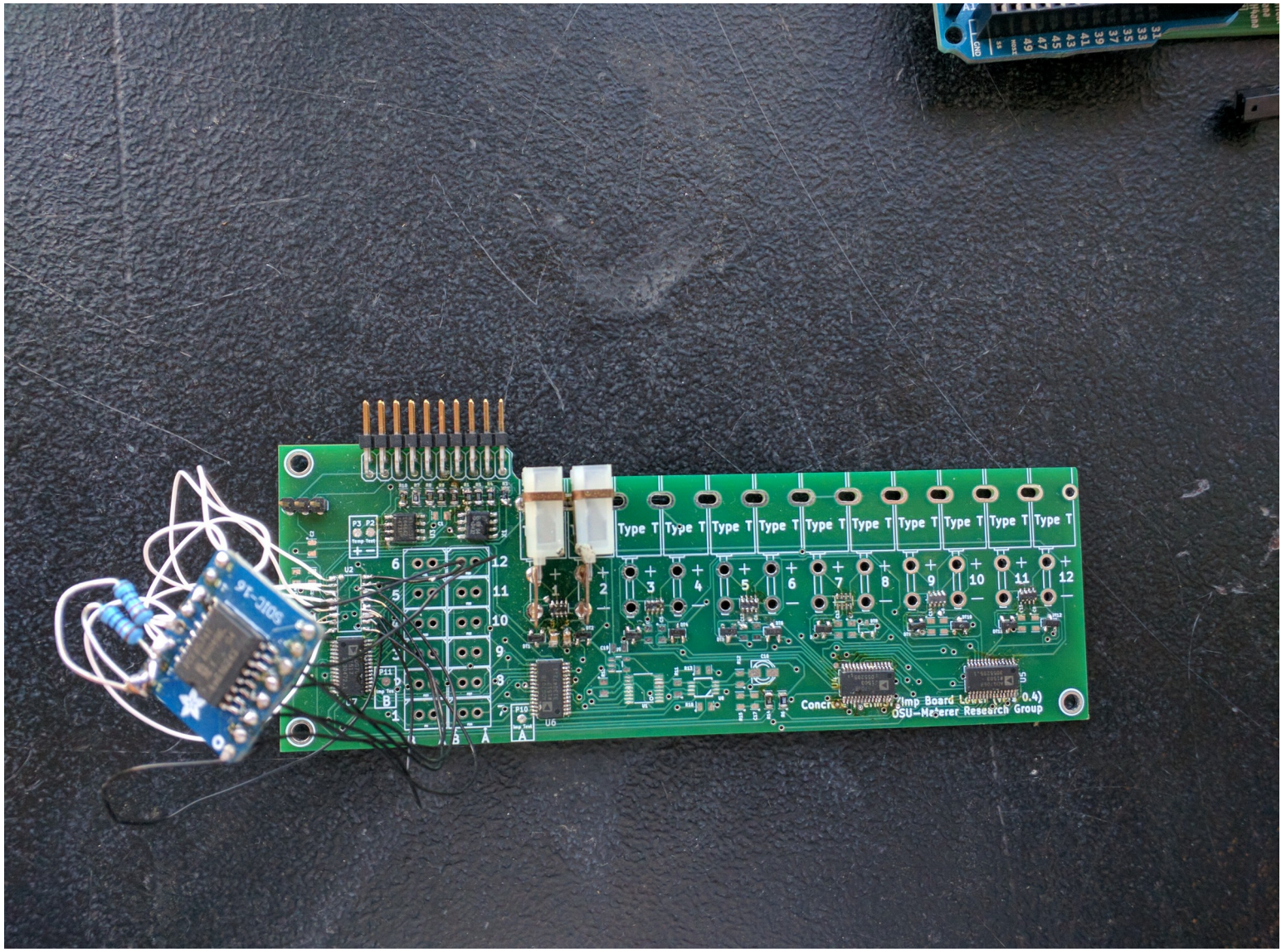
Concrete Testing - Circuit



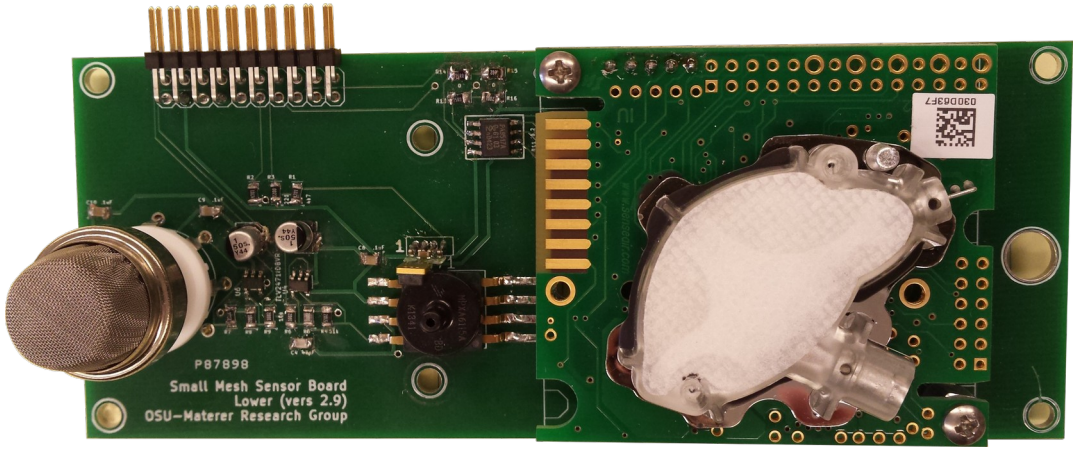
Concrete Testing – Board V1

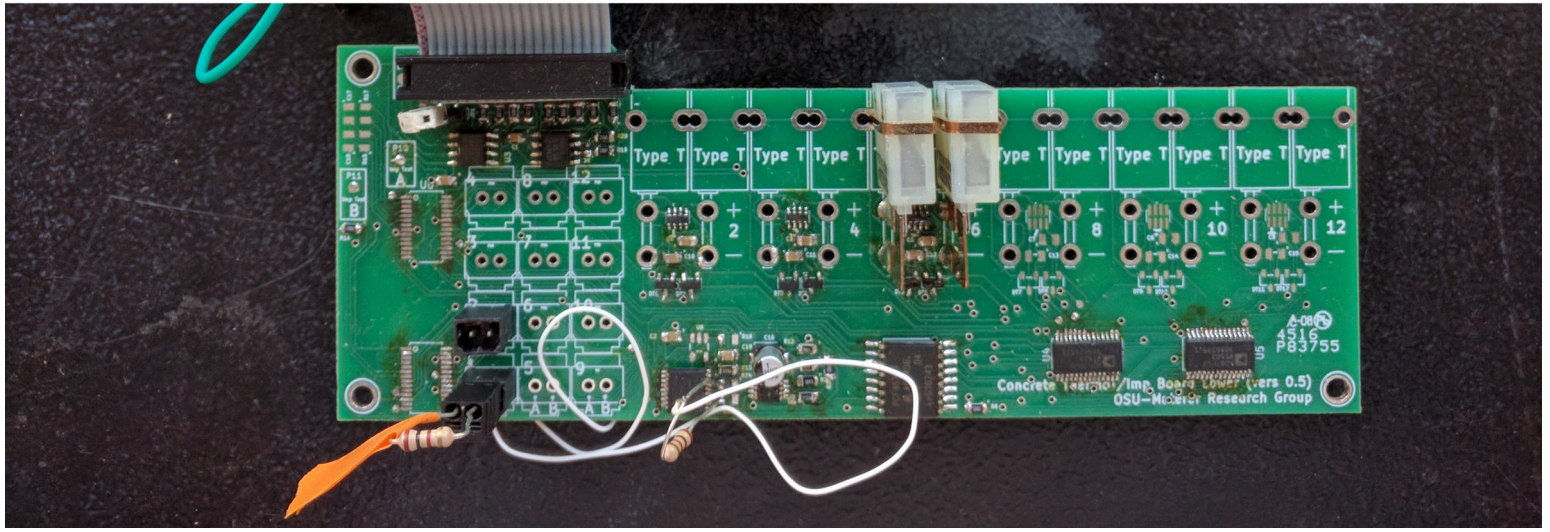


Concrete Testing – Board V2



Concrete Testing – Latest Board





Conclusions

- Multiple impedance measurements can be performed by a single unit.
- Allows for remote monitoring of concrete structures
- Keeps all of the benefits of the gas detector network of sensors.

Acknowledgements

--Committee--
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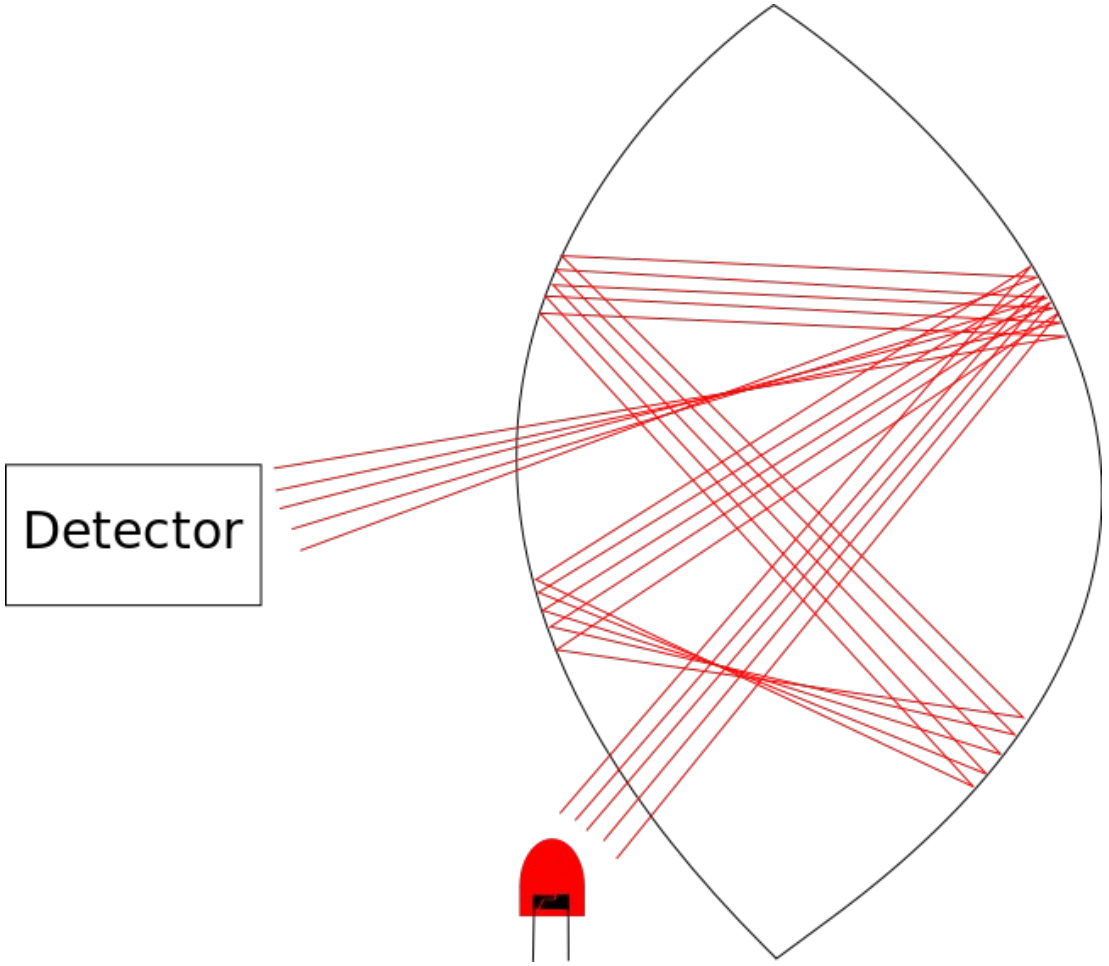
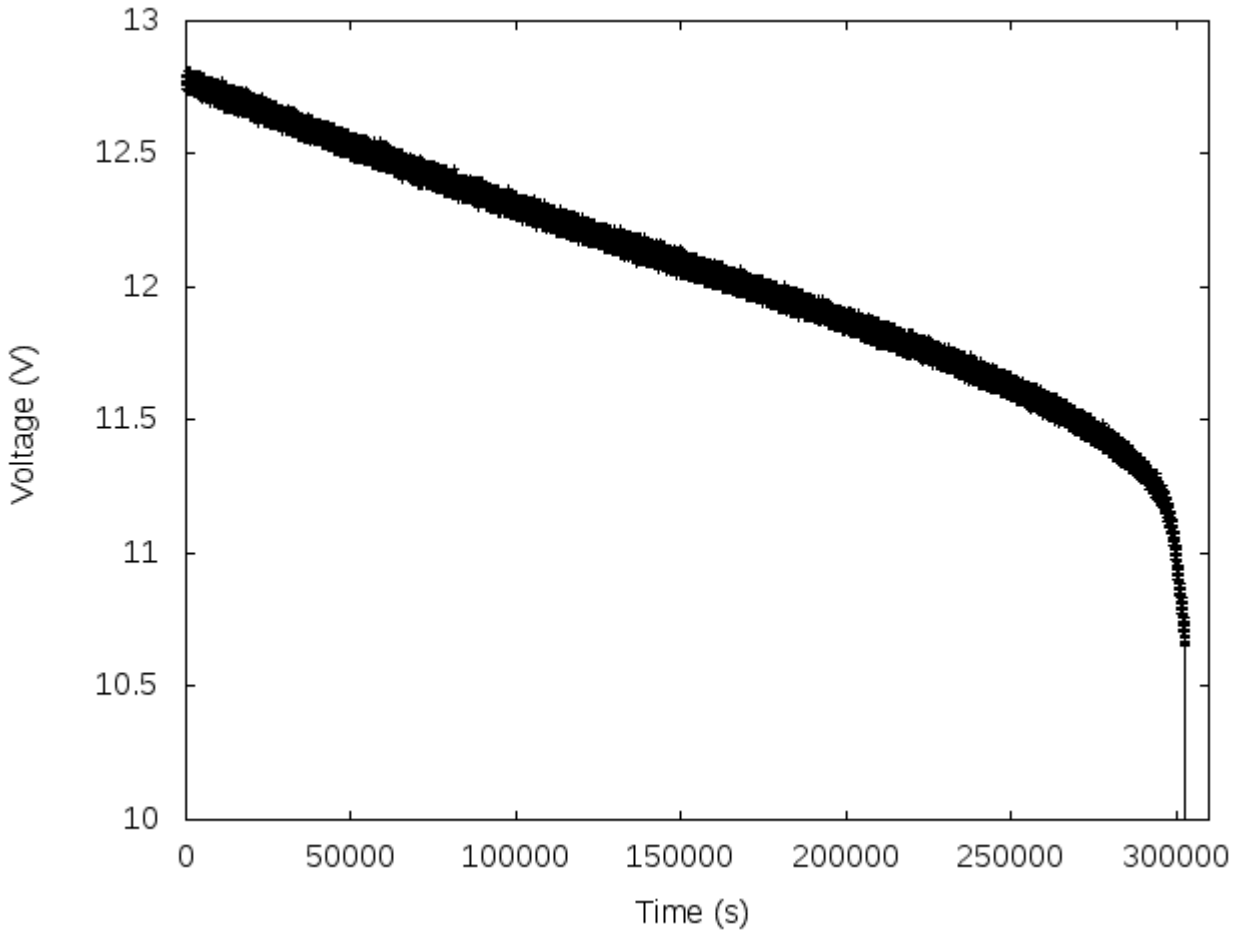
Questions?

K-30 FTIR Optical Sensor

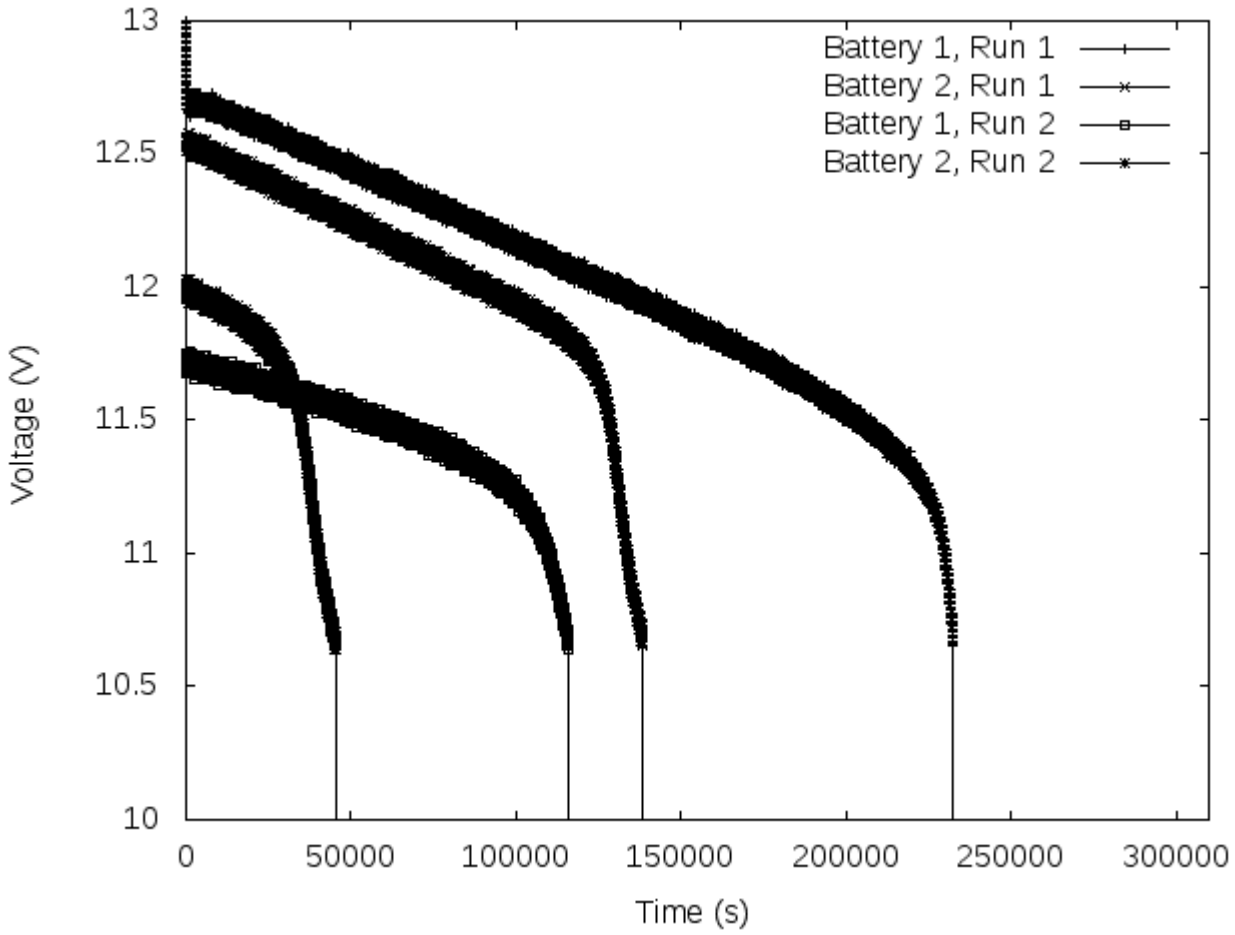


$A=\varepsilon bc$

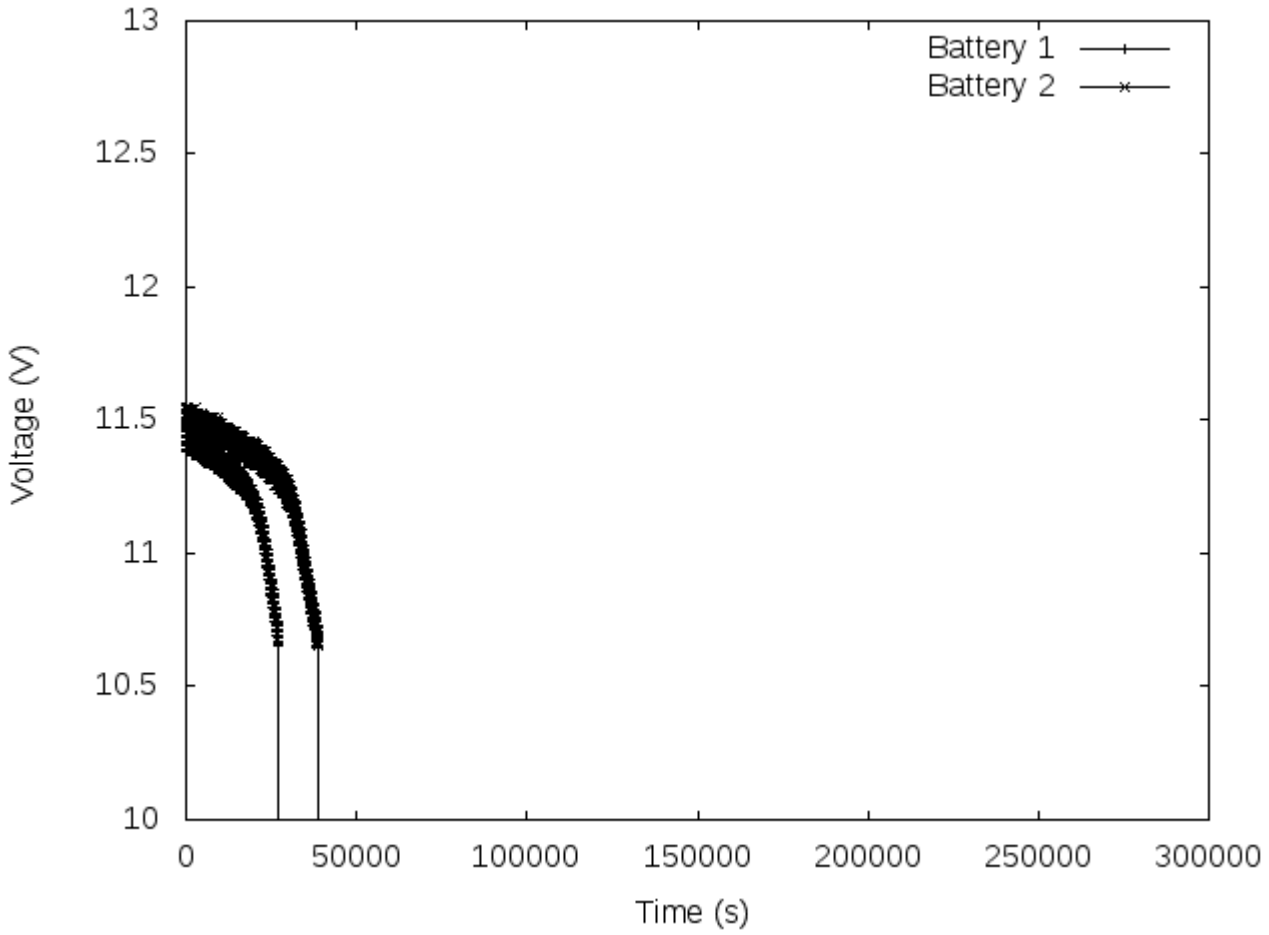
General Battery Discharge



Discharge at 181Ω



Discharge at 235Ω



Weather Damage