Operational Use of the Air Quality Monitor On ISS and Potential for Air Quality Monitoring Onboard Submarines

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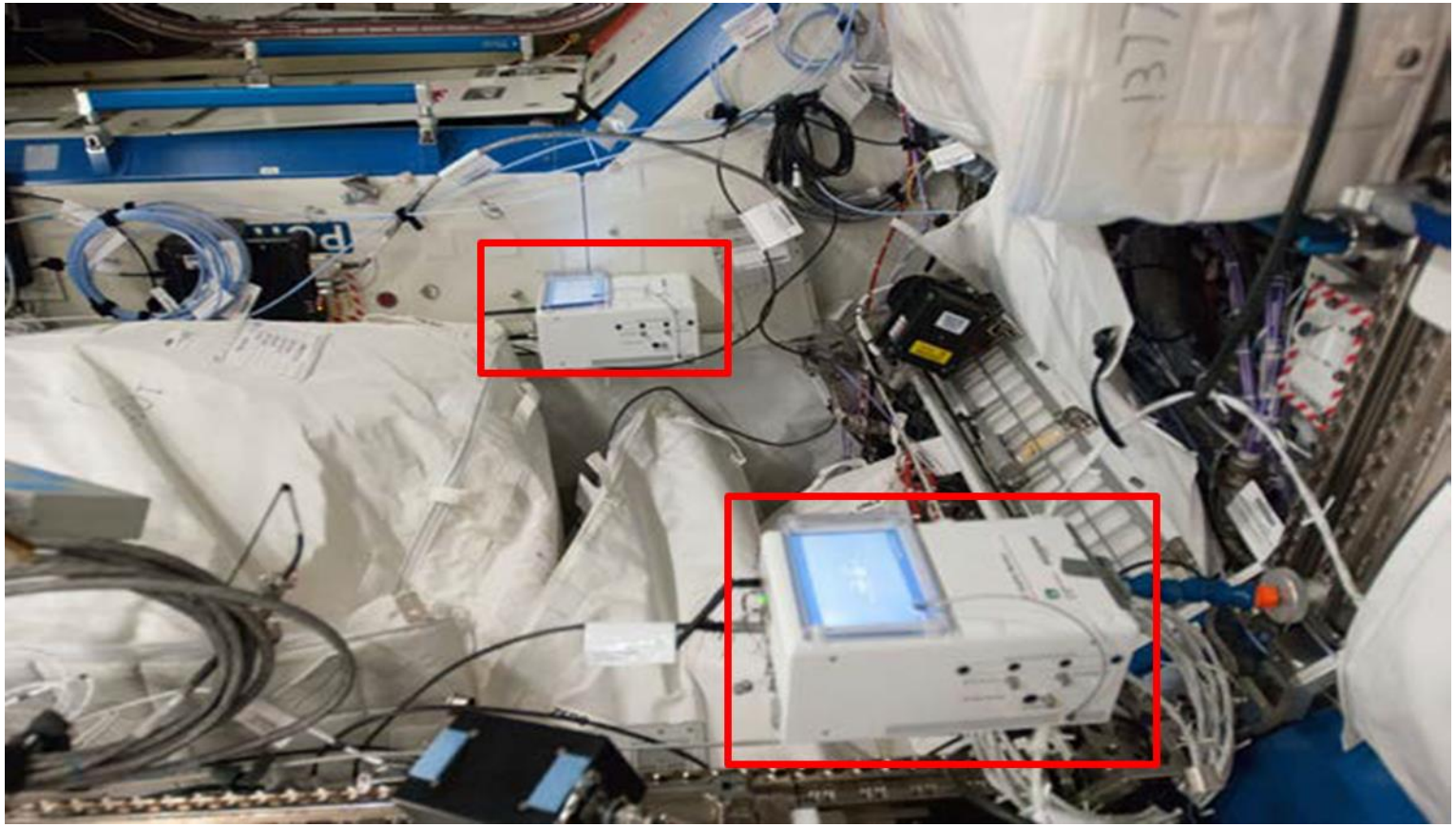
AQM Background

- **Two Air Quality Monitors (AQMs) arrived at ISS in March 2013**
- **Validation was successfully completed January 2014**
  - Last collected validation sample was October 2013

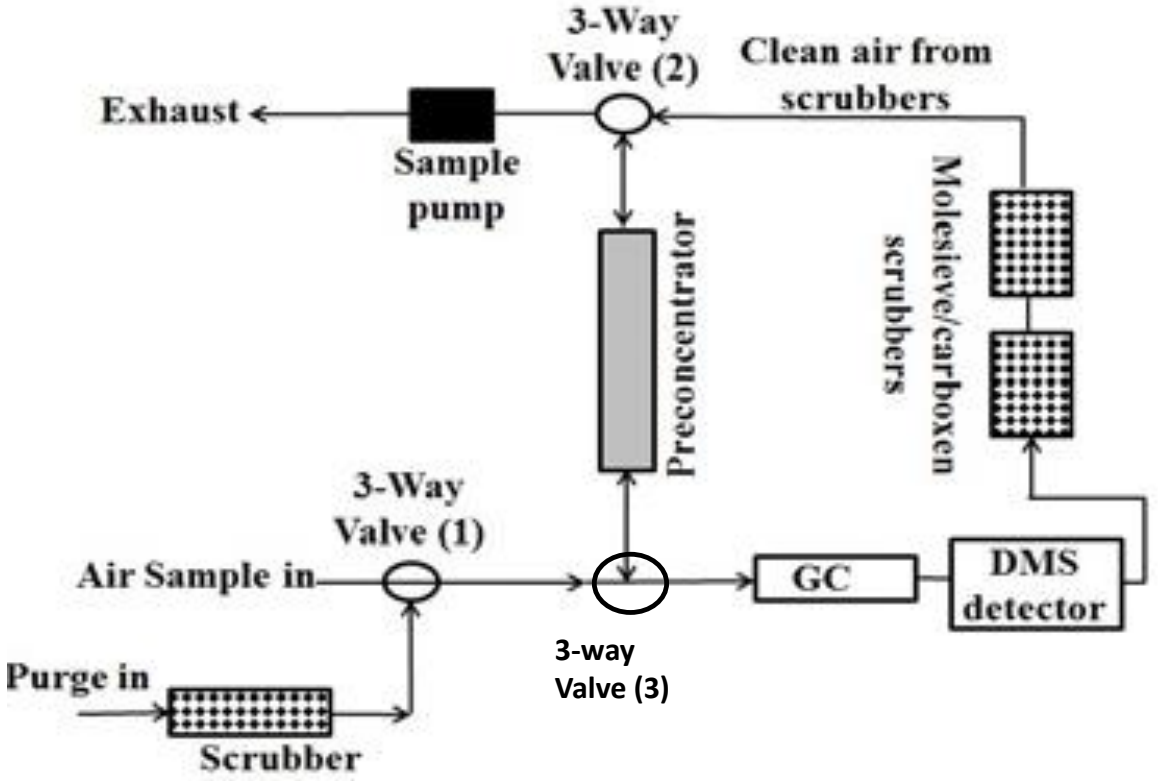


AQM Background

- **The AQM monitors trace concentrations of 23 targeted volatile organic compounds in the ISS atmosphere (Non-target detection capability)**
  - Years of archival data from spacecraft was used to select the target compounds
  - Compounds on the target list had one or more of the following characteristics
    - **Compounds frequently detected in spacecraft atmosphere (ethanol, acetone, xylenes, and 2-butanone)**
    - **Compounds with significant toxicity at low concentrations, even though they are detected infrequently on spacecraft (benzene)**
    - **Compounds that can affect an ECLS system (siloxanes and 2-propanol)**
    - **The target list is fluid, dictated by experience and changes in materials of construction or ECLS systems**
- **Purpose: Assess the air quality on ISS to protect crew health**
  - The data from AQM is used by the NASA toxicologist to assess the air quality aboard ISS. This is particularly important given the reduced archival sampling (GSC) and the long intervals been sampling and analysis on the ground.
  - Provide data for ECLS troubleshooting
  - During and after a contingency: Monitor clean up efforts and/or troubleshooting

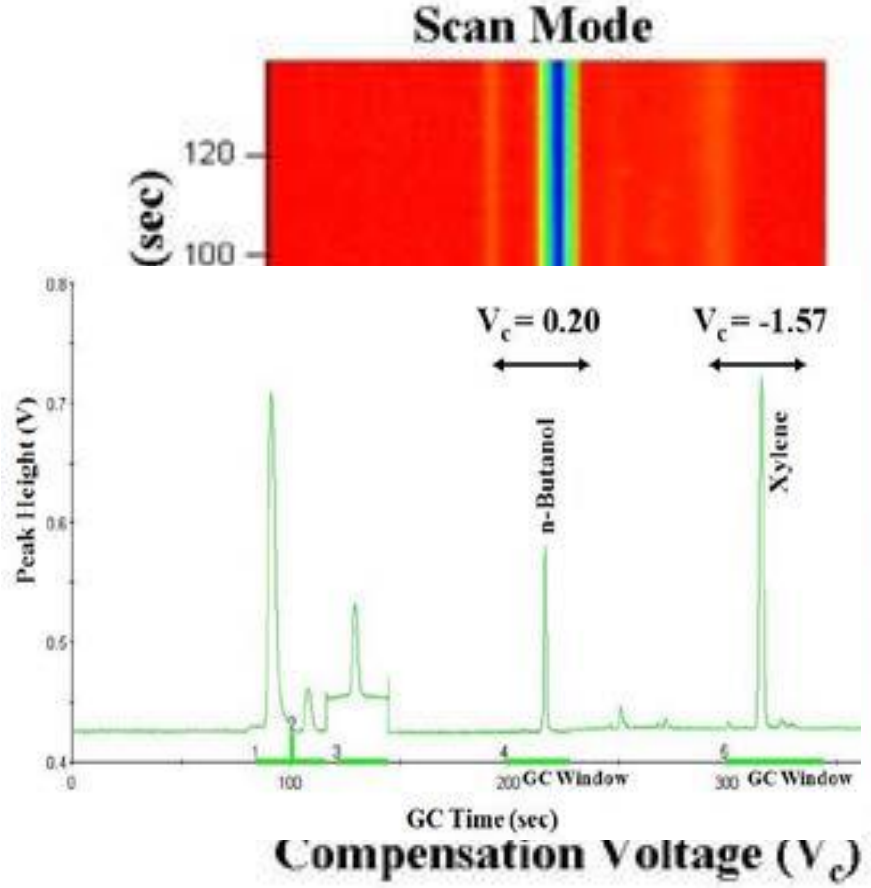
Technical Overview

- The key feature of the AQM is that the GC carrier and detector make-up gases are recirculated air
  - Operation
    - Ambient air samples are acquired as valves align flow through the inlet and the preconcentrator, then air is vented by the sample pump
    - Valve 1 is switched and air is pulled through a scrubber and the preconcentrator to remove trapped water
    - Valve 1, 2, and 3 are switched, the preconcentrator is heated and the VOCs are transferred to the GC column
    - Compounds elute from the column and are ionized by a 63Ni source and the ions are detected in the DMS



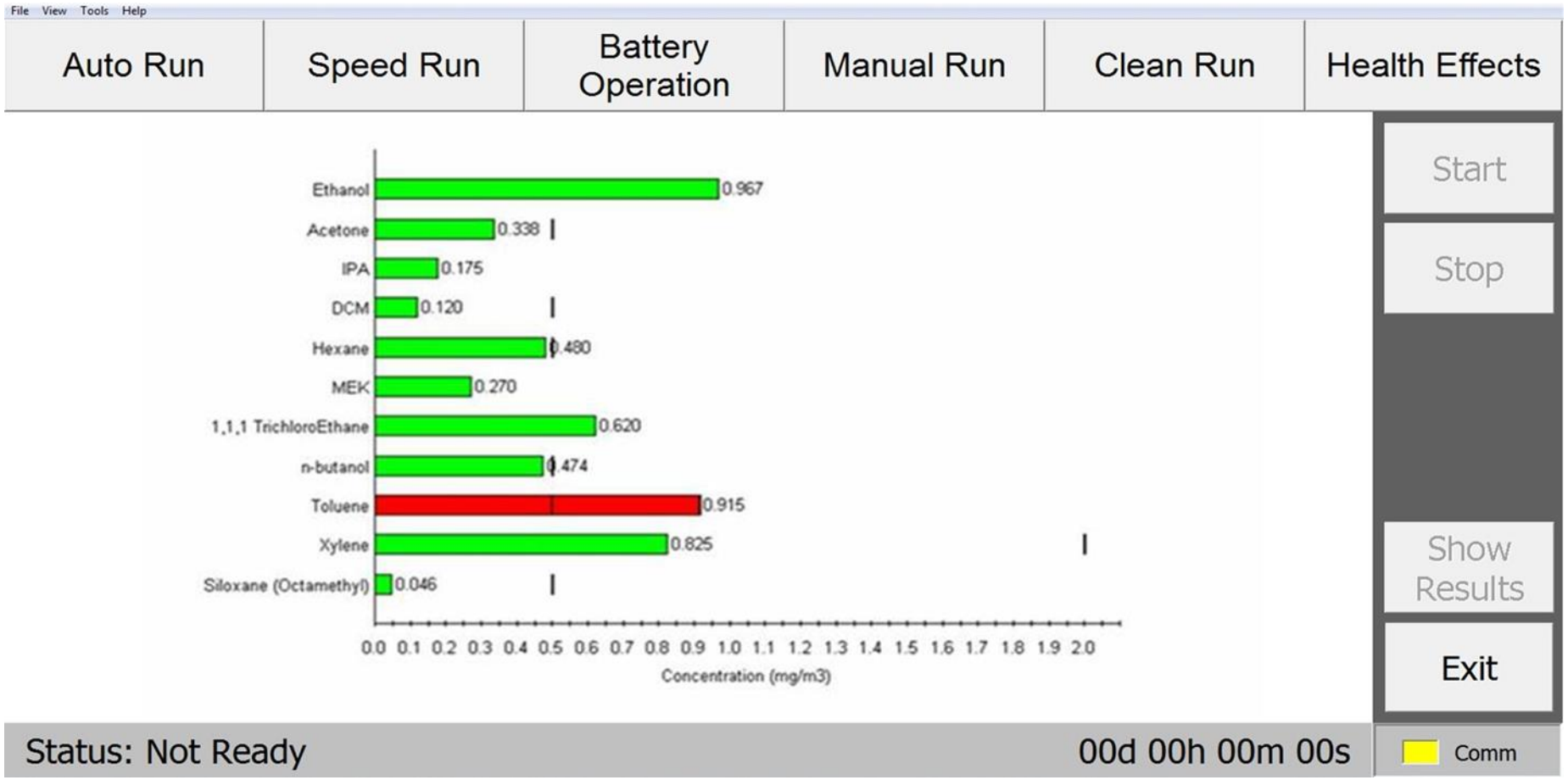
Technical Overview

- Data Format: GC Mode
- Data Format: Scan Mode
  - GC runs provide high sensitivity and characterization:
    - All V_c are scanned to obtain GC RT, RF, polarity, and V_c to set "detection" windows for target VOCs
    - GC RT and Vc are used to identify the VOC target
    - The peak is integrated and concentrations automatically determined by comparing area to a look up table
  - Scan runs also provide a means to detect, identify and trend unknowns
  - Manual quantitative analysis can be performed from scan runs
- Results are displayed on the unit's GUI and stored on the flash drive



AQM Features

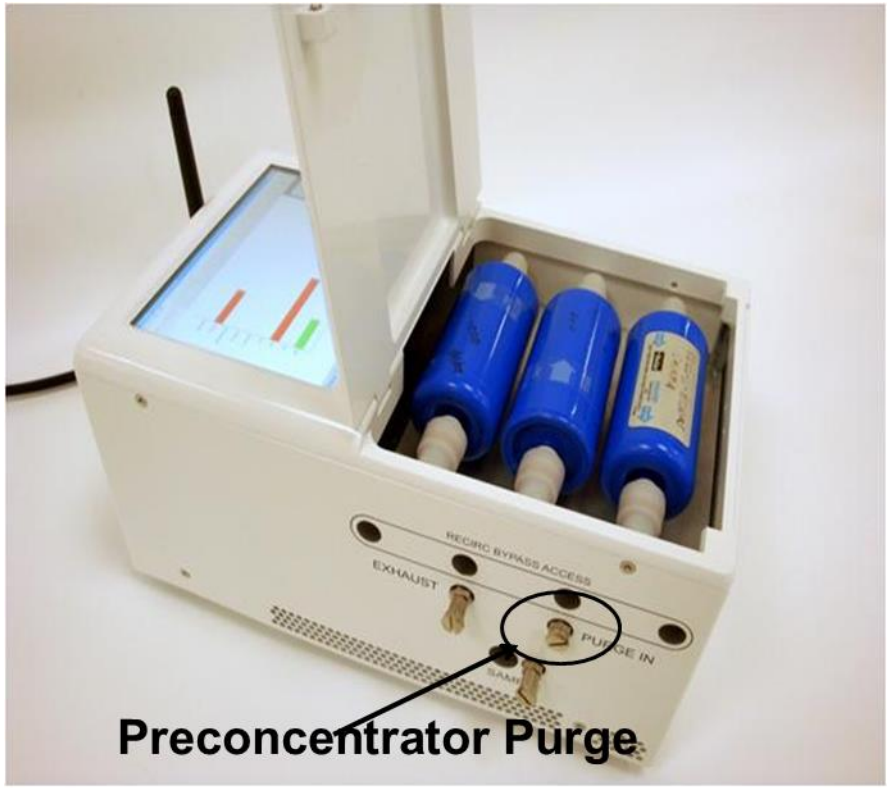
AQM Crew GUI

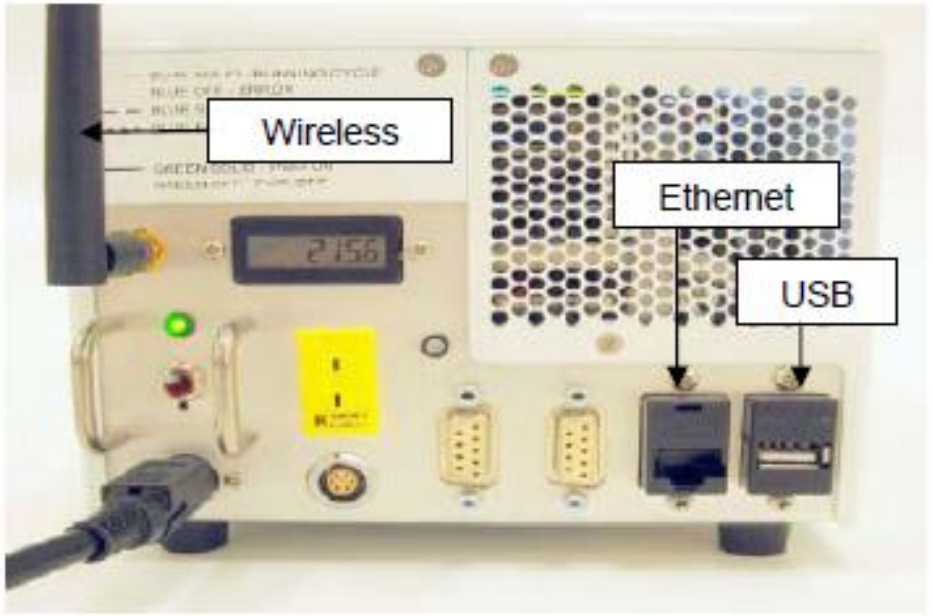


Autonomous operation with scripts planning run frequency and results available to crew or ground

AQM Features

- **Replaceable sieve packs and Wireless Communication**





Wireless Capability + Ethernet and USB ports (Fully auotmated operation through ISS wireless)

Target List (Joint development by ECLS and Toxicology)

GFE TARGET COMPOUNDS

Target Compounds	Unit 2218	Unit 2221	Target Compounds	Unit 2218	Unit 2221
Methanol	X		Trimethylsilanol		X
Acetaldehyde		X	Benzene	X	
Acrolein	X		n-butanol		X
Ethanol		X	Toluene	X	X
Acetone	X		Hexanal	X	
2-Propanol	X		Hexamethylcyclotrisiloxane	X	x
Dichloromethane		X	m/p-Xylene	X	X
Hexane	X		o-Xylene	X	X
Dichloroethane	X		Octamethylcyclotetrasiloxane	X	X
2-Butanone (MEK)		X	Decamethylcyclopentasiloxane	X	X
Ethyl Acetate		X	Ammonia		X

AQMs Maintain Calibration

- 2+ years on orbit
- No real changes in accuracy from first runs

Target Compound	AQM*	GSC*	%Diff	Matches/#GSCs
2_Propanol	0.15	0.28	46	11/12
2-Butanone	Trace	Trace	Match	15/15
Acetaldehyde	0.28	0.26	-8	12/15
Acetone	0.23	0.37	38	11/12
Acrolein	ND	ND	Match	12/12
Benzene	ND	ND	Match	12/12
Decamethylcyclopentasiloxane	2.88	0.58	-397	0/15
Dichloroethane	ND	Trace-0.02	Match	12/12
Dichloromethane	ND	Trace	ND-Trace	15/15
Ethanol	5.9	8.5	31	14/15

Target Compound	AQM*	GSC*	%Diff	Matches/#GSCs
Ethyl Acetate	0.05	0.03	Match	14/15
Hexamethylcyclotrisiloxane	2.0	2.3	12	13/15
Hexanal	ND	ND	Match	12/12
Hexane	ND	ND	Match	12/12
Methanol	0.38	0.37	-3	12/12
mp- Xylene	ND	ND-0.01	Match	15/15
n_Butanol	0.12	0.06	-111	2/15
Octamethylcyclotetrasiloxane	Trace	0.08	Match	15/15
o-Xylene	Trace	TRACE-0.02	Match	14/15
TMS	0.32	0.12	-167	0/15
Toluene	ND	ND	Match	15/15

***Compounds: Unit 2218: Dec 2014; Unit 2221: Feb 2015**

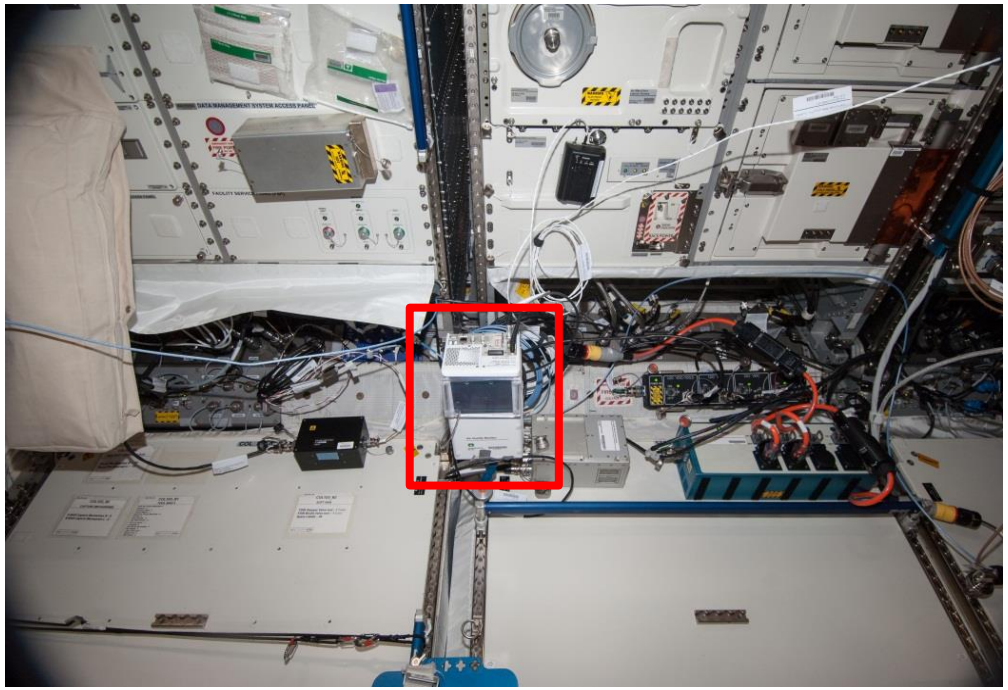
ND<Minimum Detection Limit (MDL)
Trace: >MDL, but <Minimum Quantitation Limit (MQL)

Match: Conc <0.1mg/m3; ±0.05
Match: Conc <0.5mg/m3; ±50%
Match: Conc >0.5mg/m3; ±40%

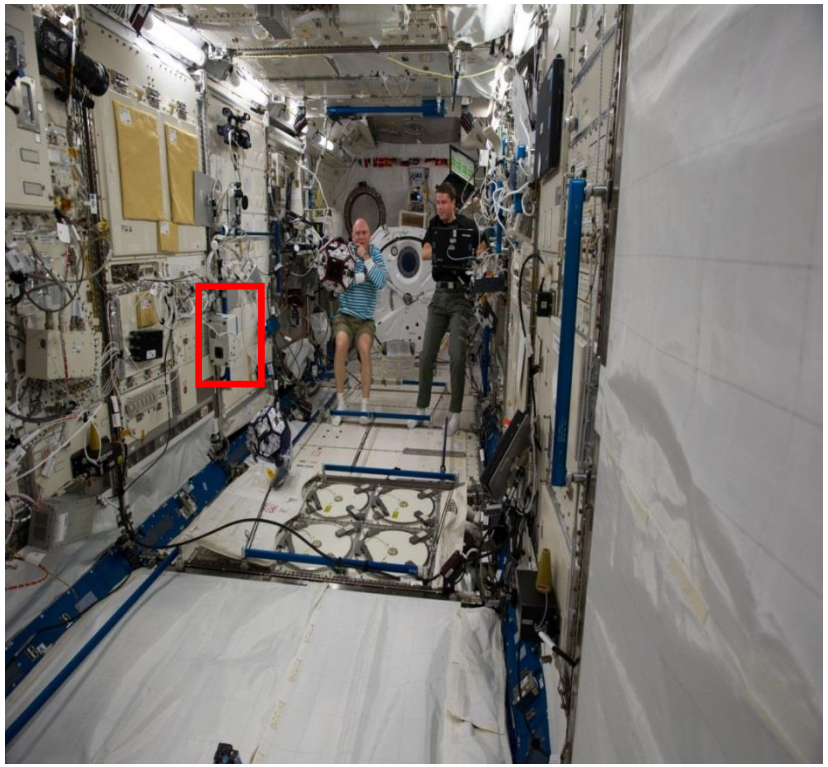
AQM Used for Investigation and Troubleshooting on ISS

Portability: Movement Between Modules

- An AQM module survey was begun after validation to assess the differences in contaminants for LAB, Columbus, and JEM
- Surveys for both units were completed in January 2015.



Columbus

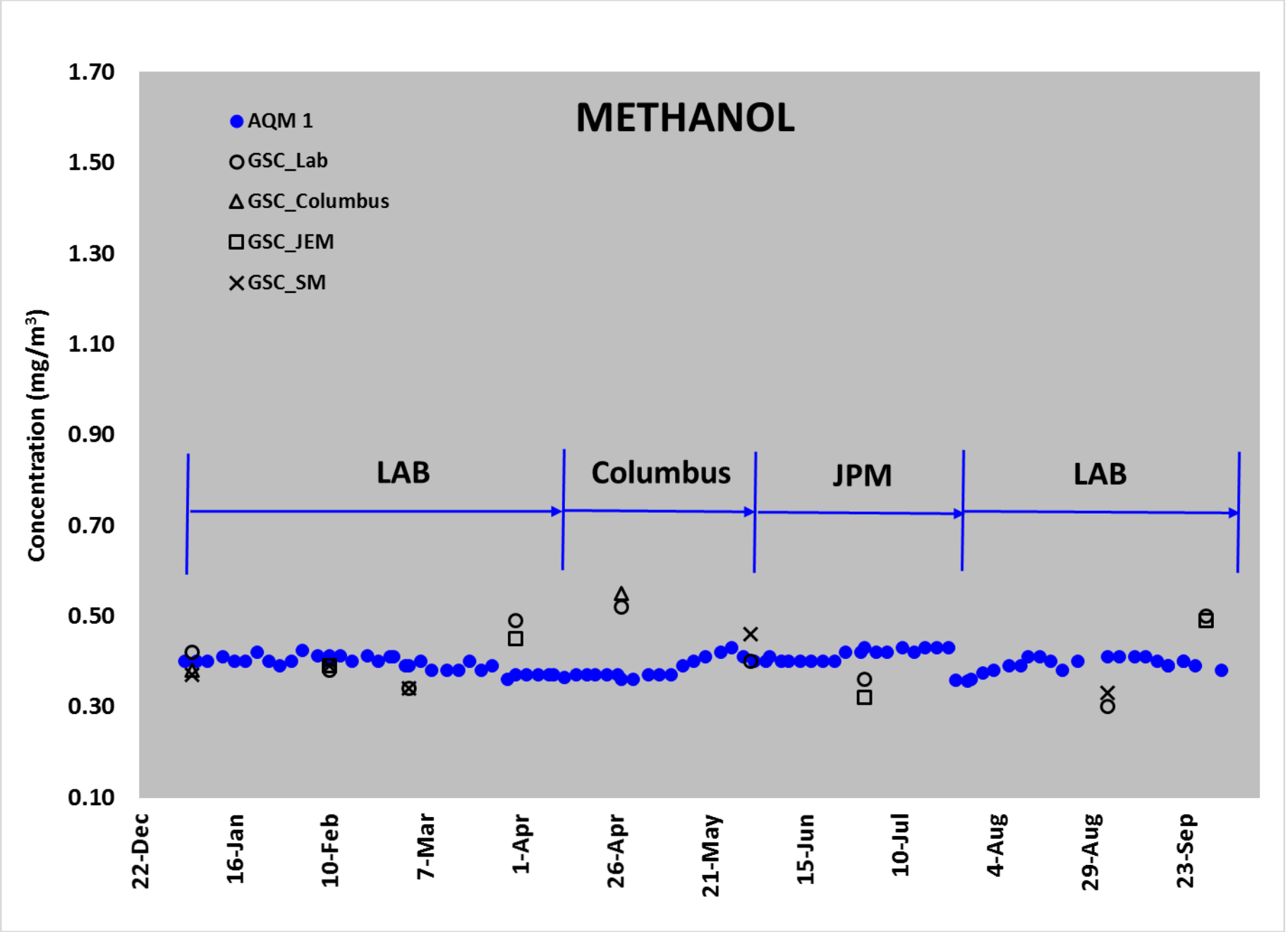


JPM

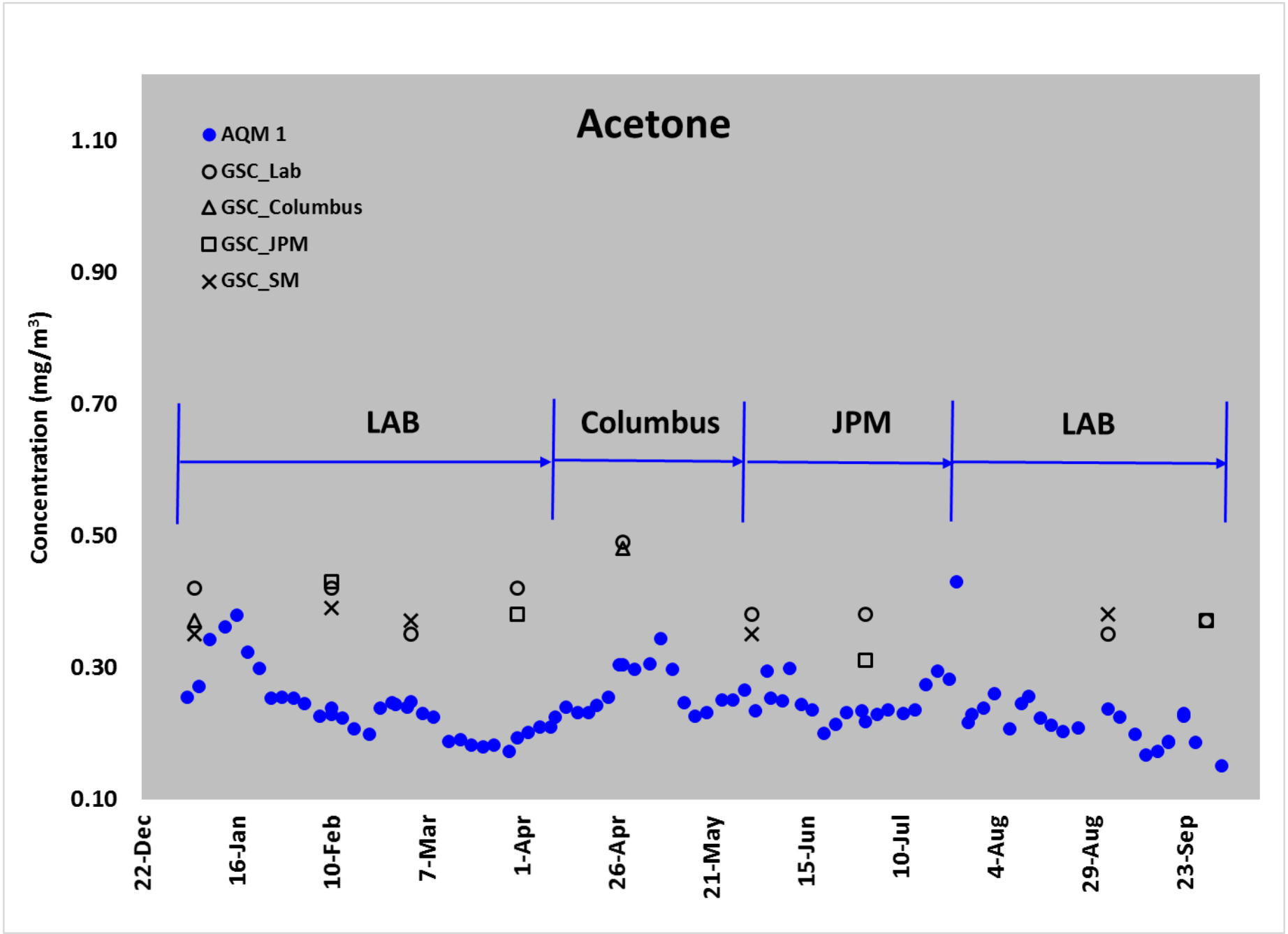
AQM 1 Survey

- Survey began on April 10, 2014 in Columbus
- Moved from Columbus to JPM on June 6, 2014
- Survey completed on July 23, 2014
- GSC results are shown as an independent means to affirm survey results
- A few examples

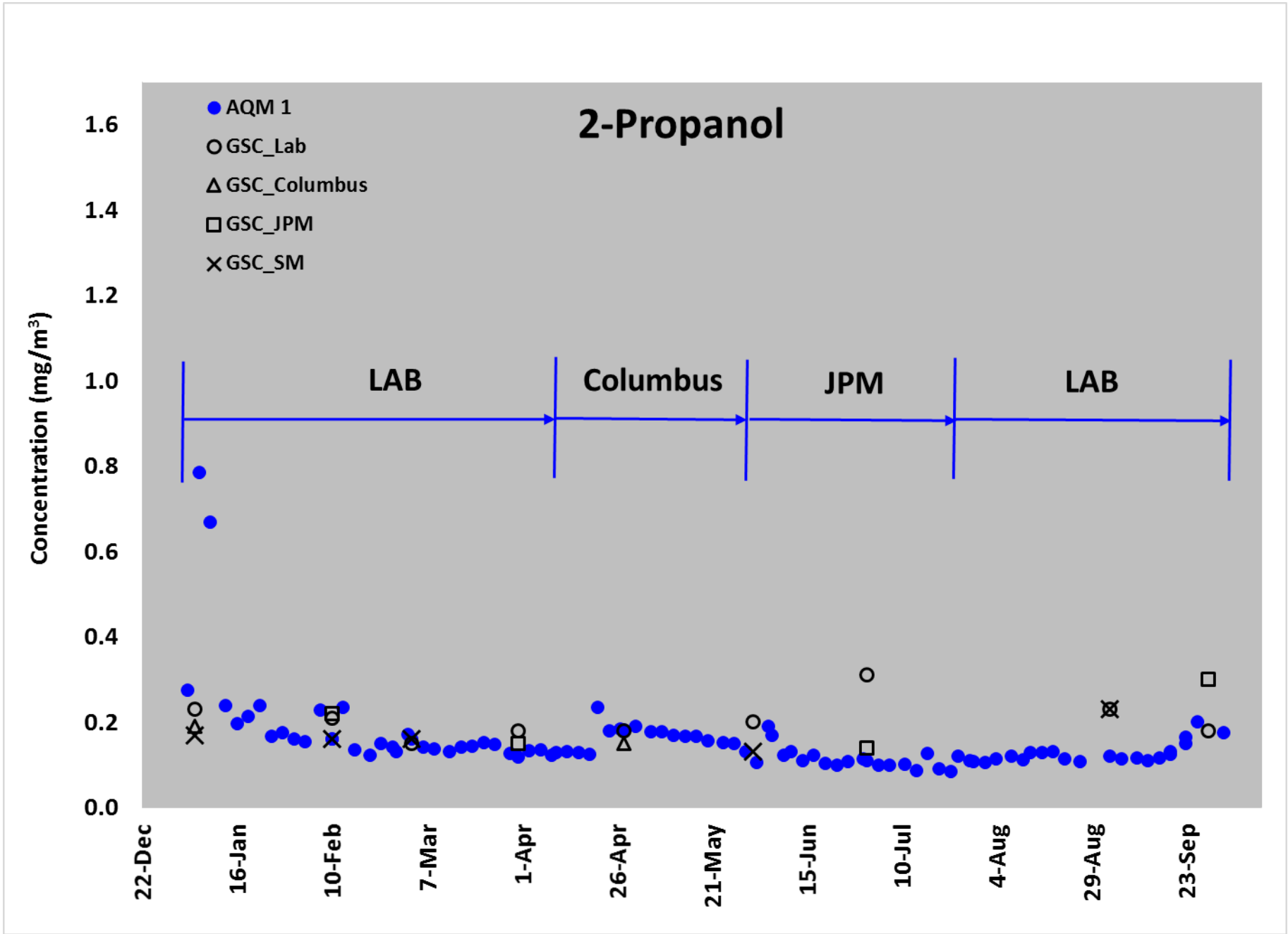
AQM 1


METHANOL
AQM 1
GSC_Lab
GSC_Columbus
GSC_JEM
GSC_SM
LAB
Columbus
JPM
LAB
Concentration (mg/m3)
1.70
1.50
1.30
1.10
0.90
0.70
0.50
0.30
0.10
22-Dec
16-Jan
10-Feb
7-Mar
1-Apr
26-Apr
21-May
15-Jun
10-Jul
4-Aug
29-Aug
23-Sep

AQM 1


Acetone
AQM 1
GSC_Lab
GSC_Columbus
GSC_JPM
GSC_SM
LAB
Columbus
JPM
LAB
Concentration (mg/m3)
1.10
0.90
0.70
0.50
0.30
0.10
22-Dec
16-Jan
10-Feb
7-Mar
1-Apr
26-Apr
21-May
15-Jun
10-Jul
4-Aug
29-Aug
23-Sep

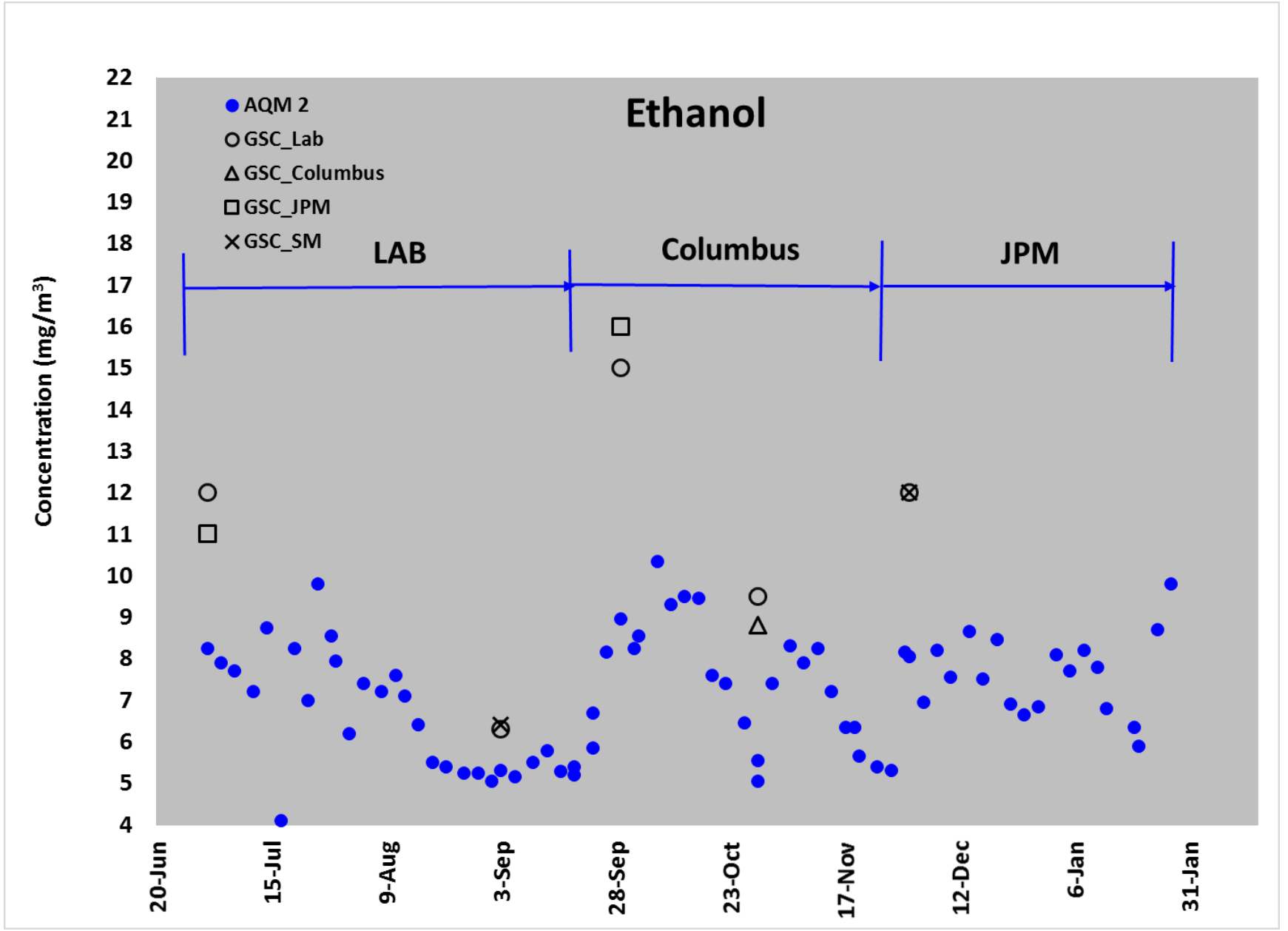
AQM 1


2-Propanol
AQM 1
GSC_Lab
GSC_Columbus
GSC_JPM
GSC_SM
LAB
Columbus
JPM
LAB
Concentration (mg/m³)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
22-Dec
16-Jan
10-Feb
7-Mar
1-Apr
26-Apr
21-May
15-Jun
10-Jul
4-Aug
29-Aug
23-Sep

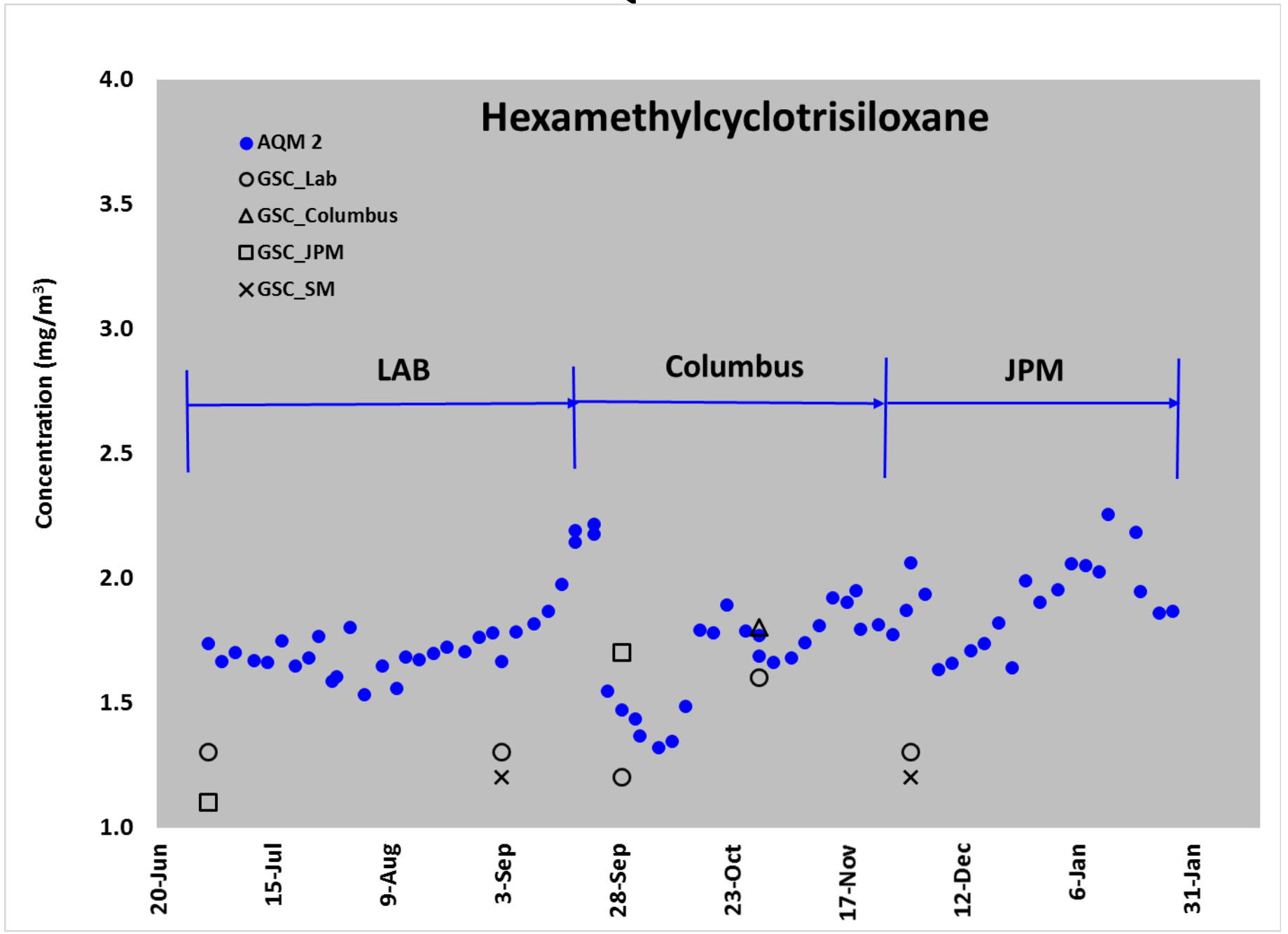
AQM 2 Survey

- Survey began on September 19, 2014 in Columbus
- Moved from Columbus to JPM on November 20, 2014
- Survey completed on January 19, 2015
- GSC results are shown as a means to affirm survey results
  - Due to scheduling issues, GSCs were not collected when AQM 2 was in the JPM
- A few examples

AQM 2


Ethanol
AQM 2
GSC_Lab
GSC_Columbus
GSC_JPM
GSC_SM
LAB
Columbus
JPM
Concentration (mg/m³)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
20-Jun
15-Jul
9-Aug
3-Sep
28-Sep
23-Oct
17-Nov
12-Dec
6-Jan
31-Jan

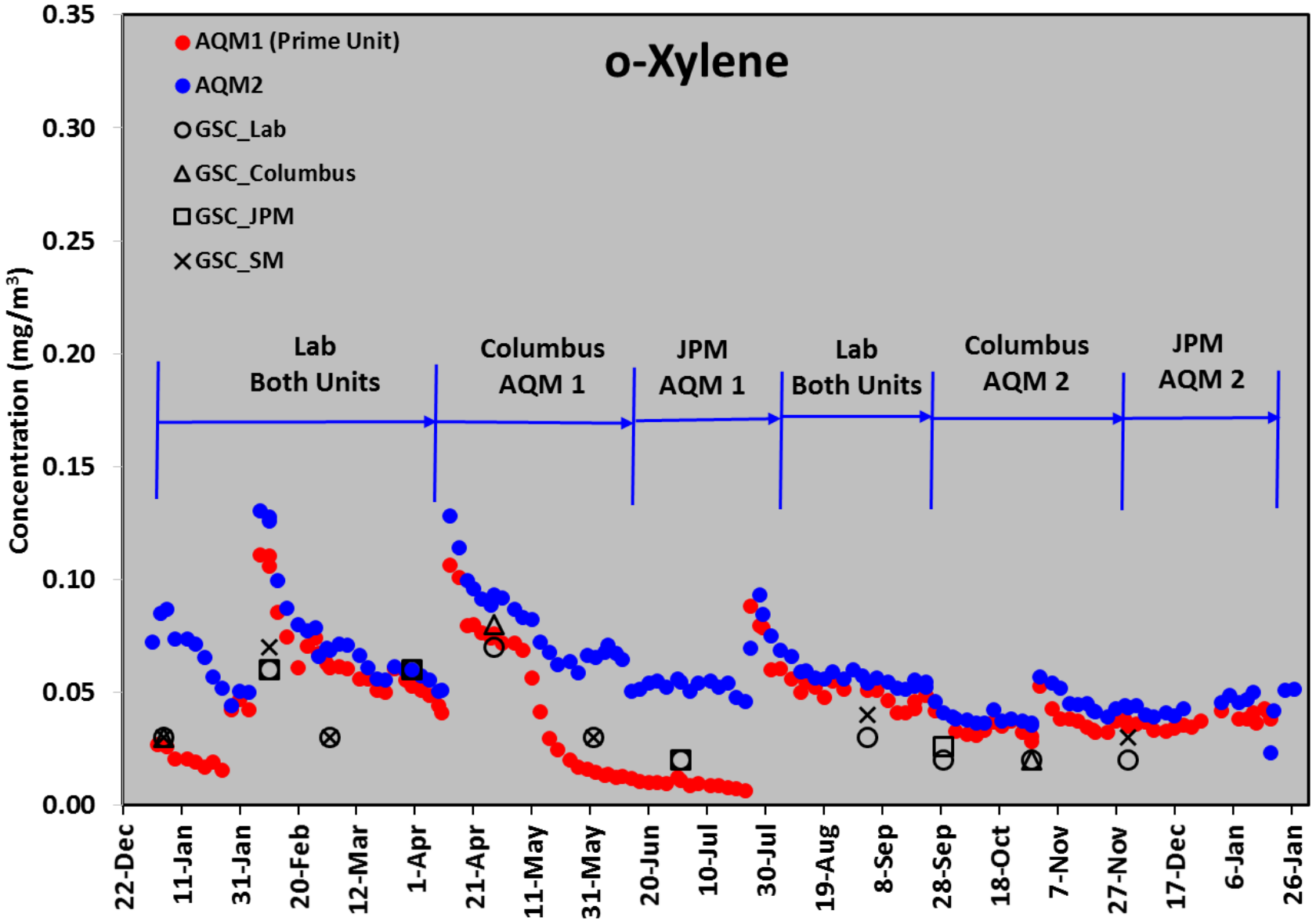
AQM 2


Hexamethylcyclotrisiloxane
AQM 2
GSC_Lab
GSC_Columbus
GSC_JPM
GSC_SM
LAB
Columbus
JPM
Concentration (mg/m³)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
20-Jun
15-Jul
9-Aug
3-Sep
28-Sep
23-Oct
17-Nov
12-Dec
6-Jan
31-Jan

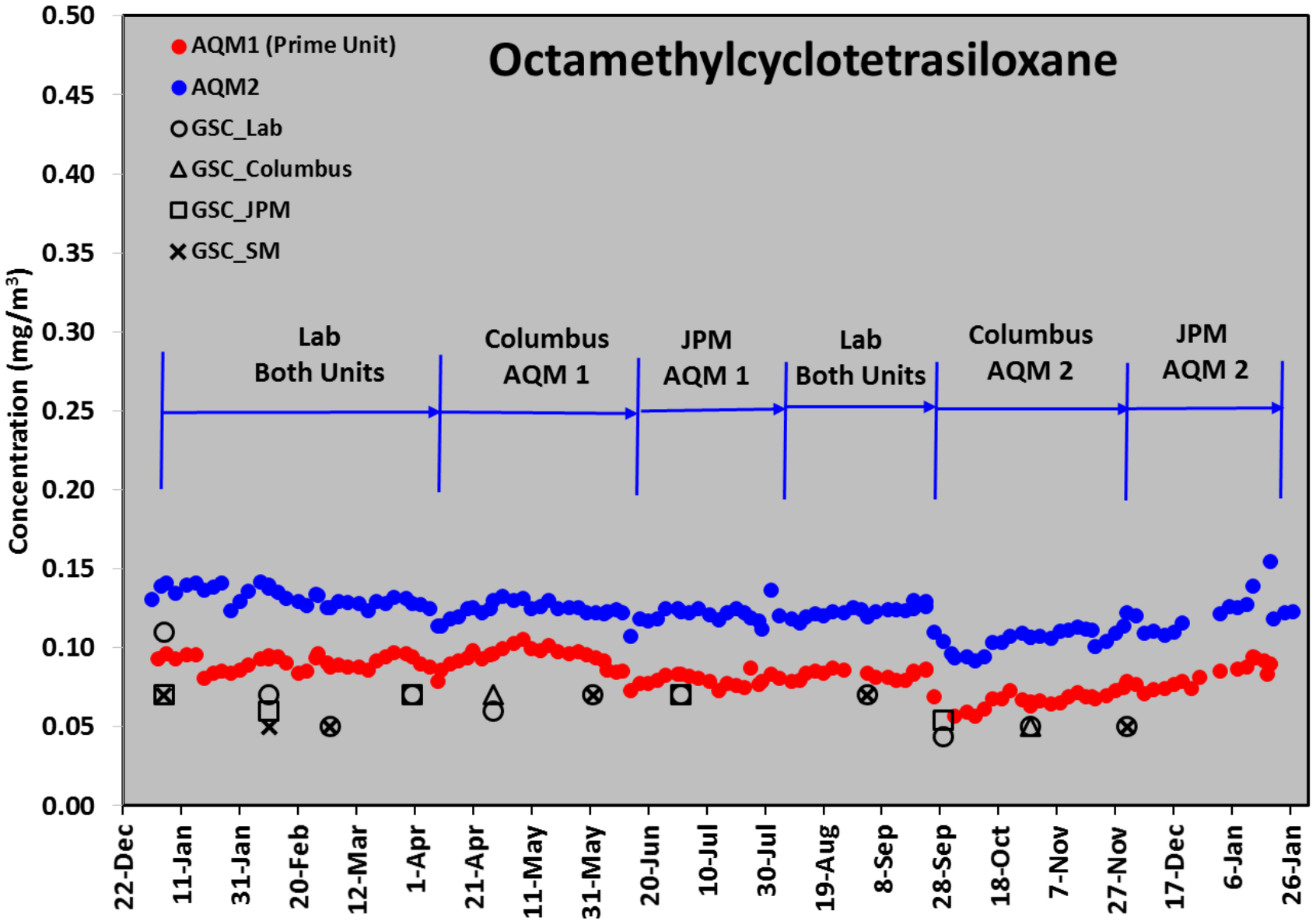
AQM 1 and 2
December 2013-January 2015

- One unit is always in the lab module, while the other is surveying the IP modules
- The o-xylene graph shows that the concentrations measured by both units are very close for the survey even when the units were in different modules
- Although there is a slight offset (probably due to calibration) in Octamethylcyclotetrasiloxane concentrations between the two units, they are still close and have the same concentration profile whether in the same or different modules

Detected on AQM 1 and AQM 2



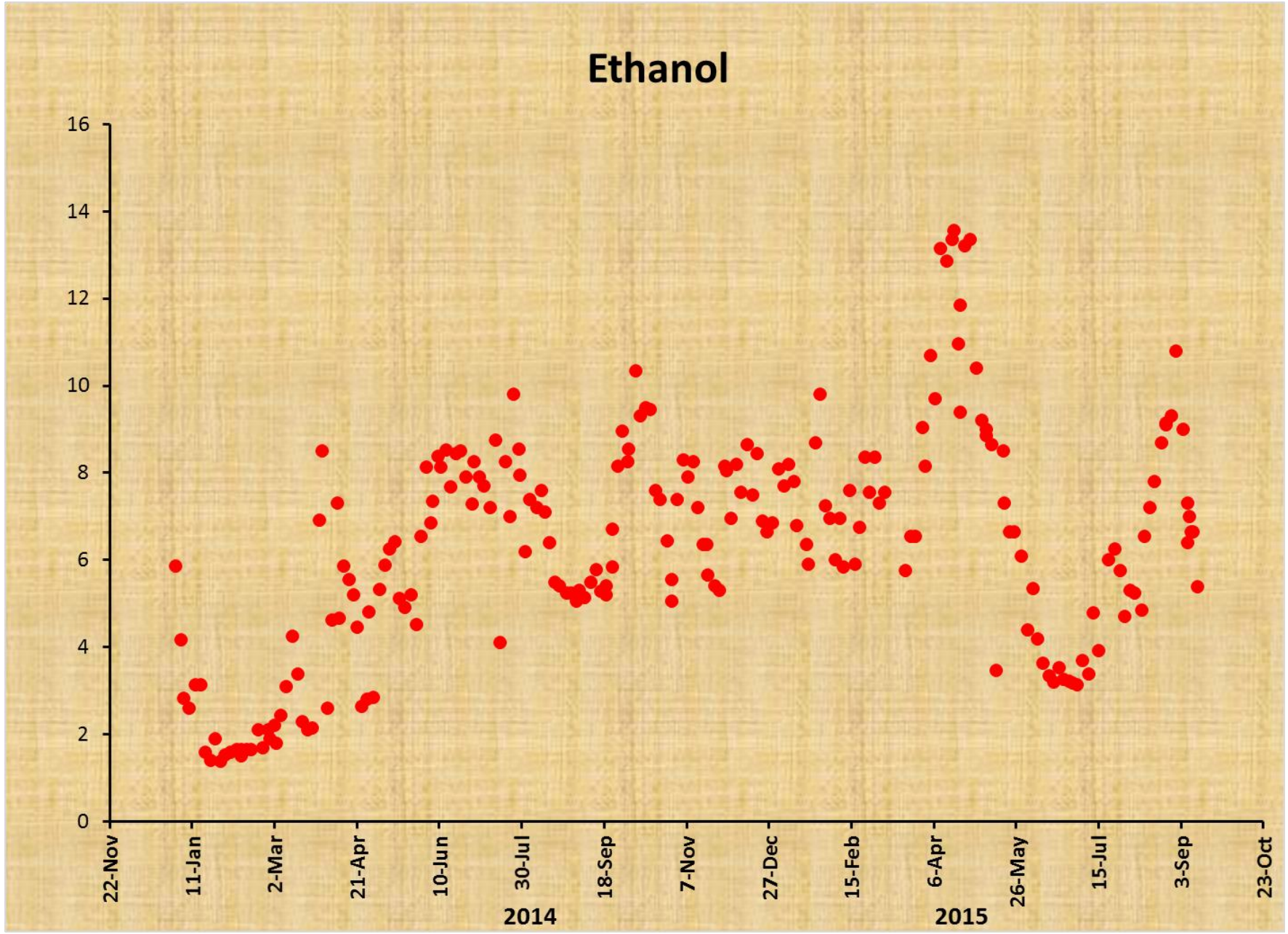
Detected on AQM 1 and AQM 2



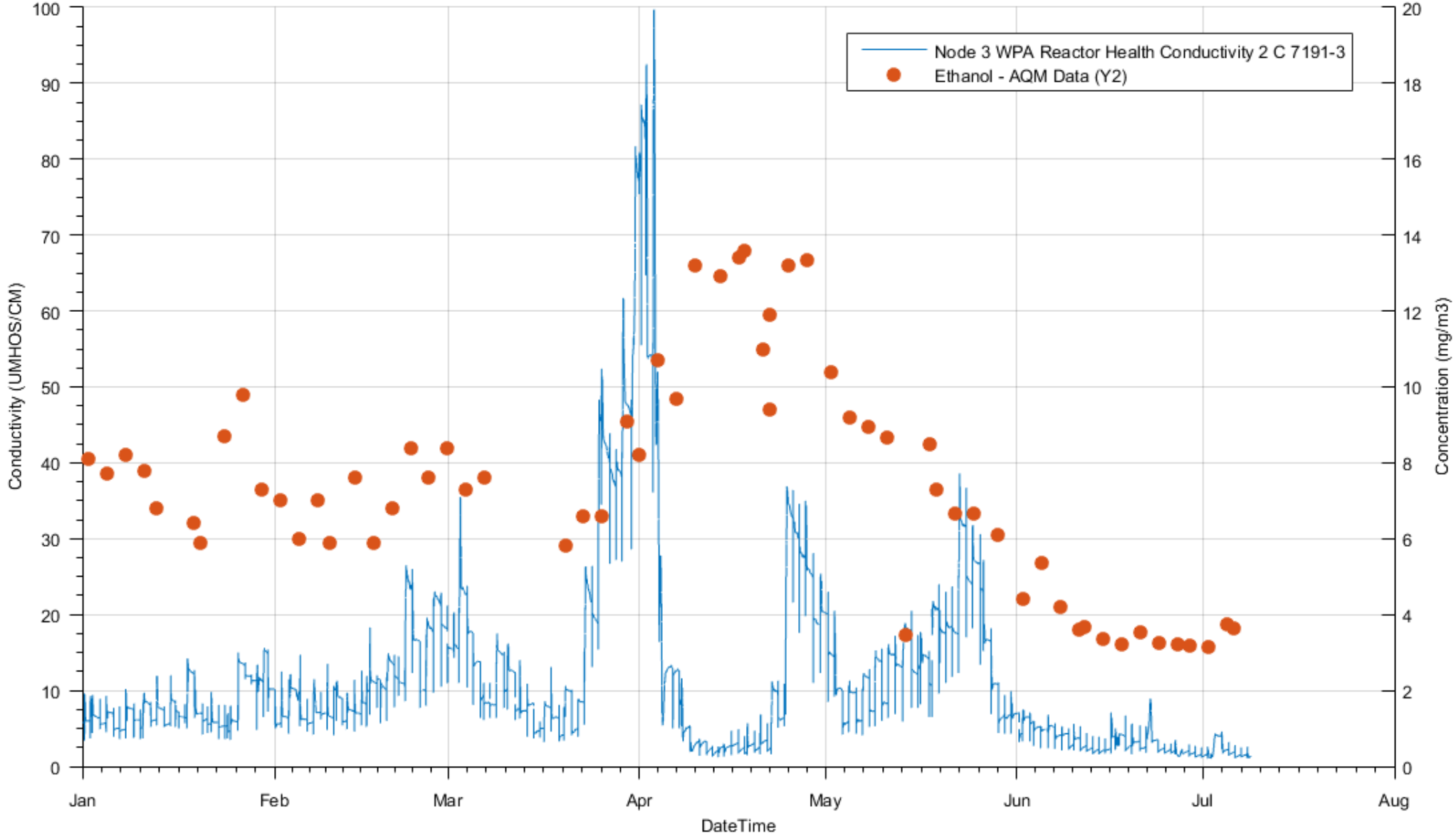
Conclusion of AQM Module Survey

- Survey results from both units (AQM1 and AQM2) confirm previous results from archival sampling that the atmosphere is well mixed and there is little deviation in contaminant concentrations between modules (JEM, LAB, and Columbus) during nominal operations
- These results show that further surveys are unnecessary

Ethanol Increases



Correlation of Water Processor Conductivity and Ethanol Air Concentration



Potential Ammonia Leak

- **On January 14, an alarm indicated an ammonia leak near Node 2**
  - Crew evacuated to the SM safe haven
  - There were pressure fluctuations in the LAB indicative of an ammonia leak
  - Crew did not smell ammonia or experience symptoms
- **ECLS engineers reviewed downlinked data and were leaning toward this being a false alarm. There were only two options to verify**
  - Send the crew, with PPE into the unknown LAB atmosphere to take Draeger tube measurements
  - Control the AQM from the ground to analyze the atmosphere and downlink the data
    - **AQM can provide a qualitative (zero, low, high concentrations) measure of ammonia**
- **AQM was activated and at 6:30 am data was received that show no ammonia in the atmosphere.**
  - Given the seriousness of the situation, a subsequent analysis was performed and verified that no ammonia was present.

Air Quality Monitor (AQM) Role in Resolution of Potential Ammonia Leak

- **AQM data confirmed the ECLSS engineer's conclusion and the crew was sent back to the LAB (with PPE) with high confidence that they were not entering a harmful environment**
- **The AQM permitted confirmation of the LAB atmosphere situation without putting the crew or their safe haven at risk.**

Potential for Air Quality Monitor (AQM) Monitoring of VOCs on Submarines

- **Monitor an array of VOCs at trace concentrations (low ppb to low ppm)**
- **Calibration stability: Years between calibration**
- **Reliability: Continuous operation for 2+ years on ISS**
- **Unattended operation: Scripts permit the AQM to follow a sequence of runs, display results (if needed) or wirelessly move results to a computer or server. The GUI provides multiple scripts for various scenarios**
- **Maintenance: Replace 3 sieve packs every 6 months. Requires a few minutes for replacement of all 3.**

Potential for Air Quality Monitor (AQM) Monitoring of VOCs on Submarines

- **AQM can provide necessary data to confirm the air quality is meeting standards in a closed environment**
- **Uses of AQM on ISS point to valuable uses of the device**
  - **Confirm sensor readings**
  - **Contribute to troubleshooting of ECLS problems and crew health issues**

Update

- **Two new AQMs are due to arrive to ISS in December 2015**
- **Upcoming sea trial of AQM and MGM (later presentation) on a U.S. submarine**
- **New business approach by Draper Labs, includes building AQMs as orders are received**

International Conference on Environmental Systems (ICES)
Vienna, Austria 2016

- **Sessions**
  - **Environmental Control and Life Support**
  - **Managing Air Quality in Closed Environments**

Air Quality Monitor (AQM)