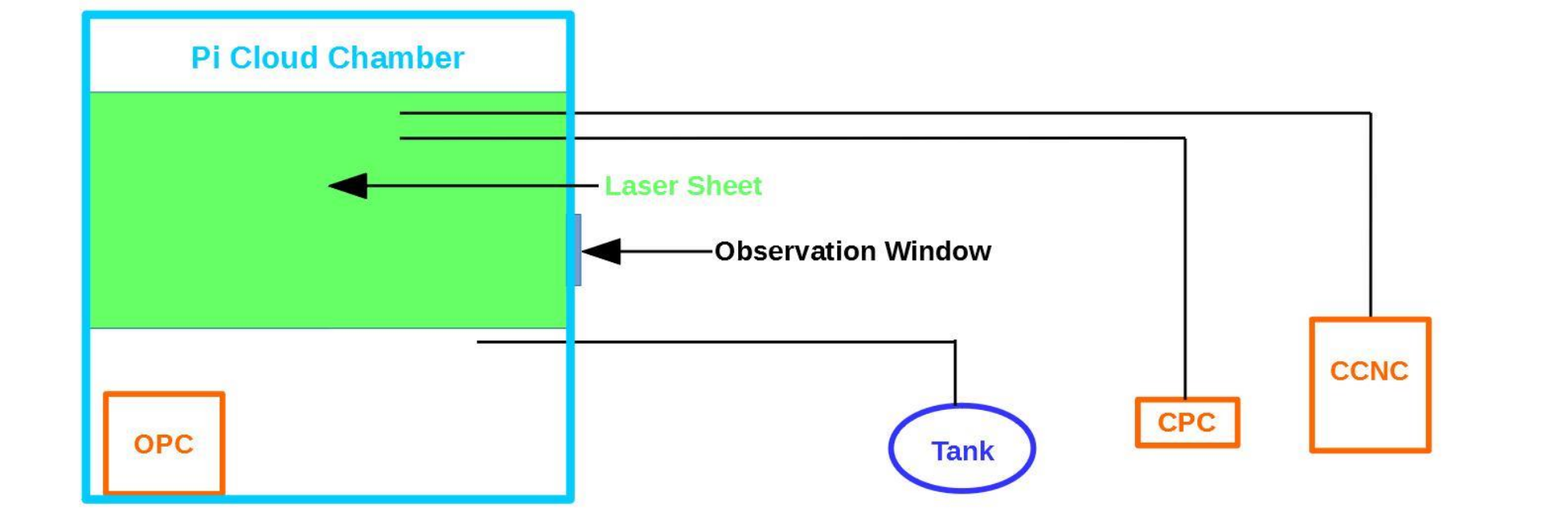
Testing Nucleation Effectiveness and Type of AgI Flares Using the Pi-Cloud Chamber

- Experiments done using the Pi-Cloud Chamber located at Michigan Technological University.
- Capable of generating clouds in two different ways
  - Adiabatic expansion
  - Temperature differencing

(Chang et al. 2016)

- The Tank represents the Particle Injection system
- Three instruments used to measure particle, droplet, and ice concentration in the Pi-Cloud Chamber

1. OPC (Optical Particle Counter)
   - Measures Ice & droplet Concentration
2. CPC (Condensation Particle Counter
3. CCNC (Cloud Condensation Nuclei Counter)
   - Measures Particle Concentration

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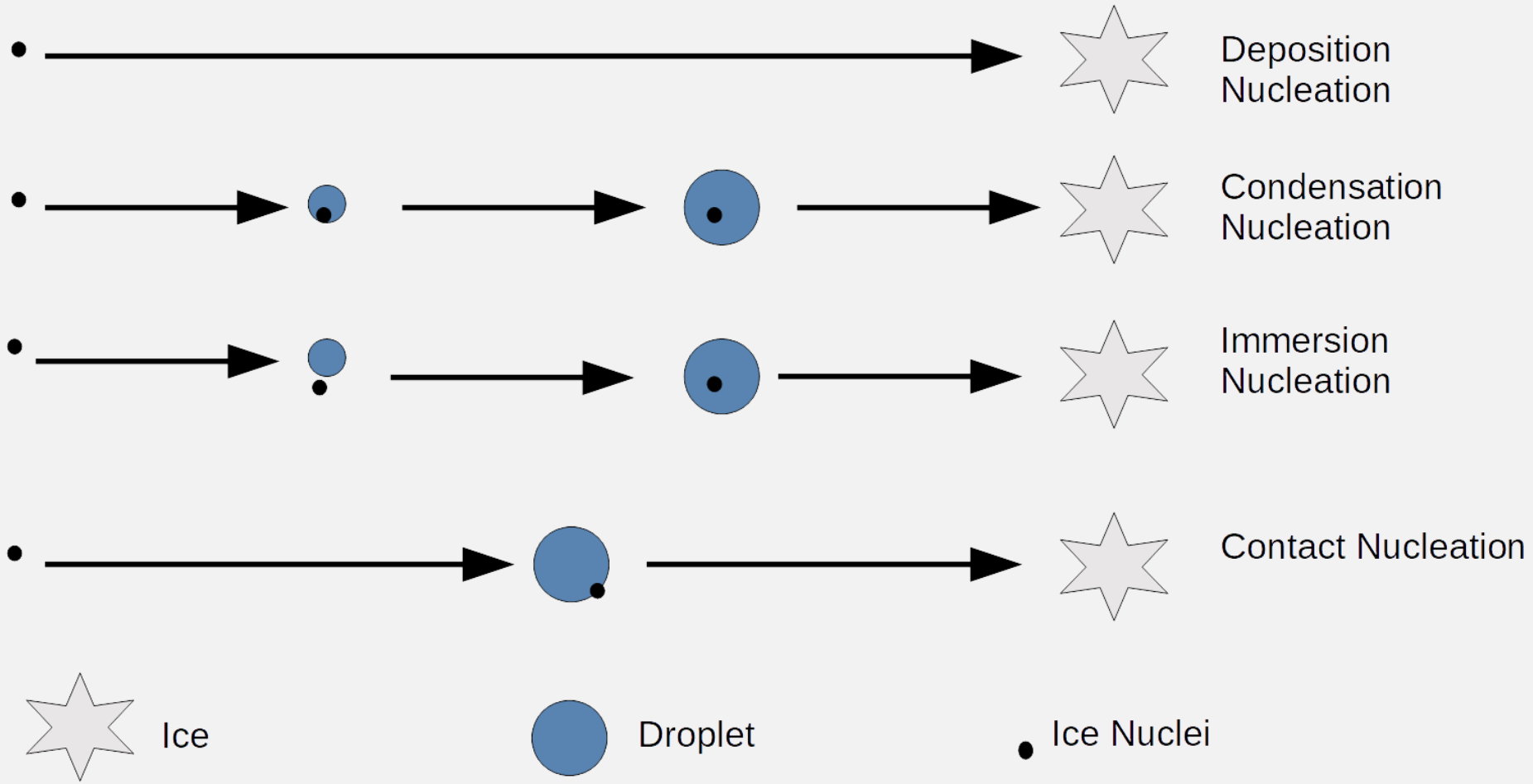
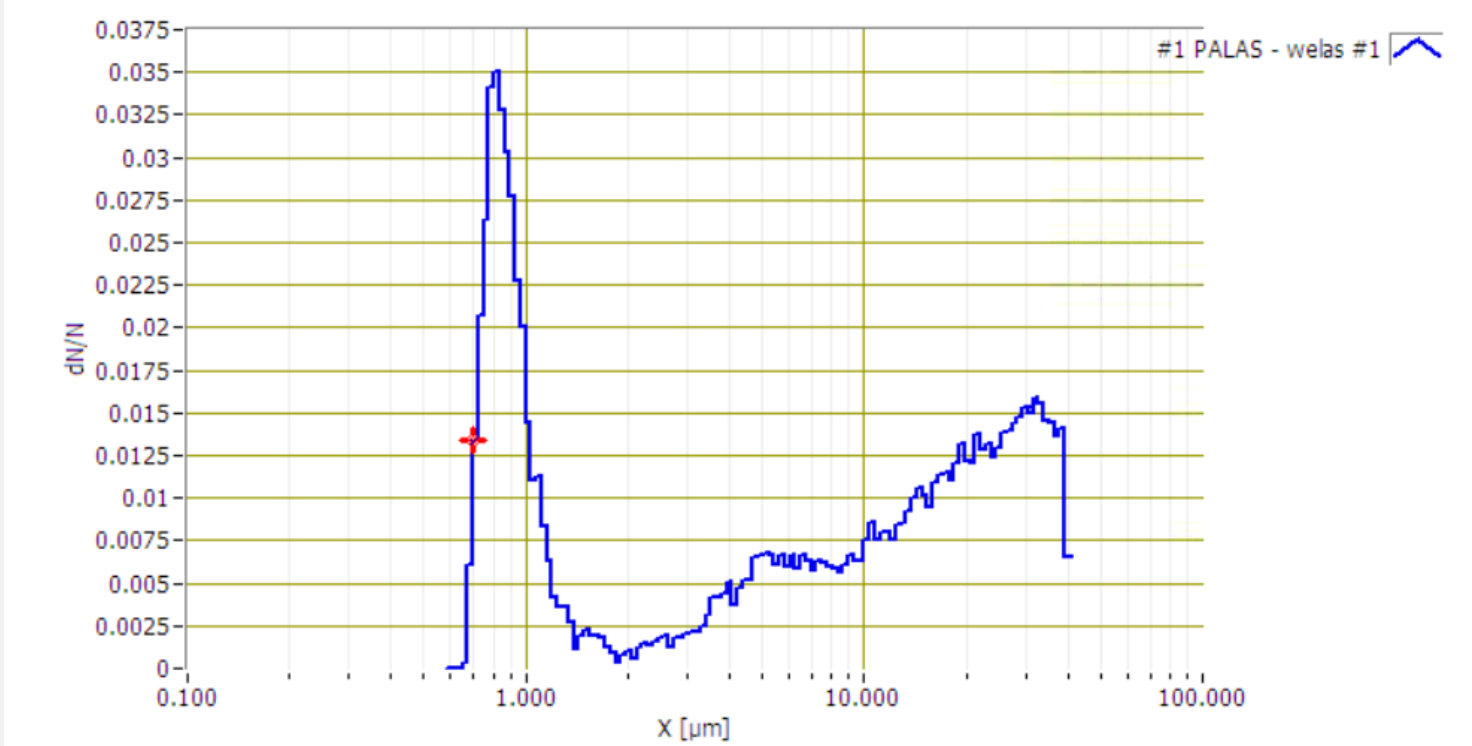
Michigan Tech

Heterogenous Nucleation Methods



Methodology

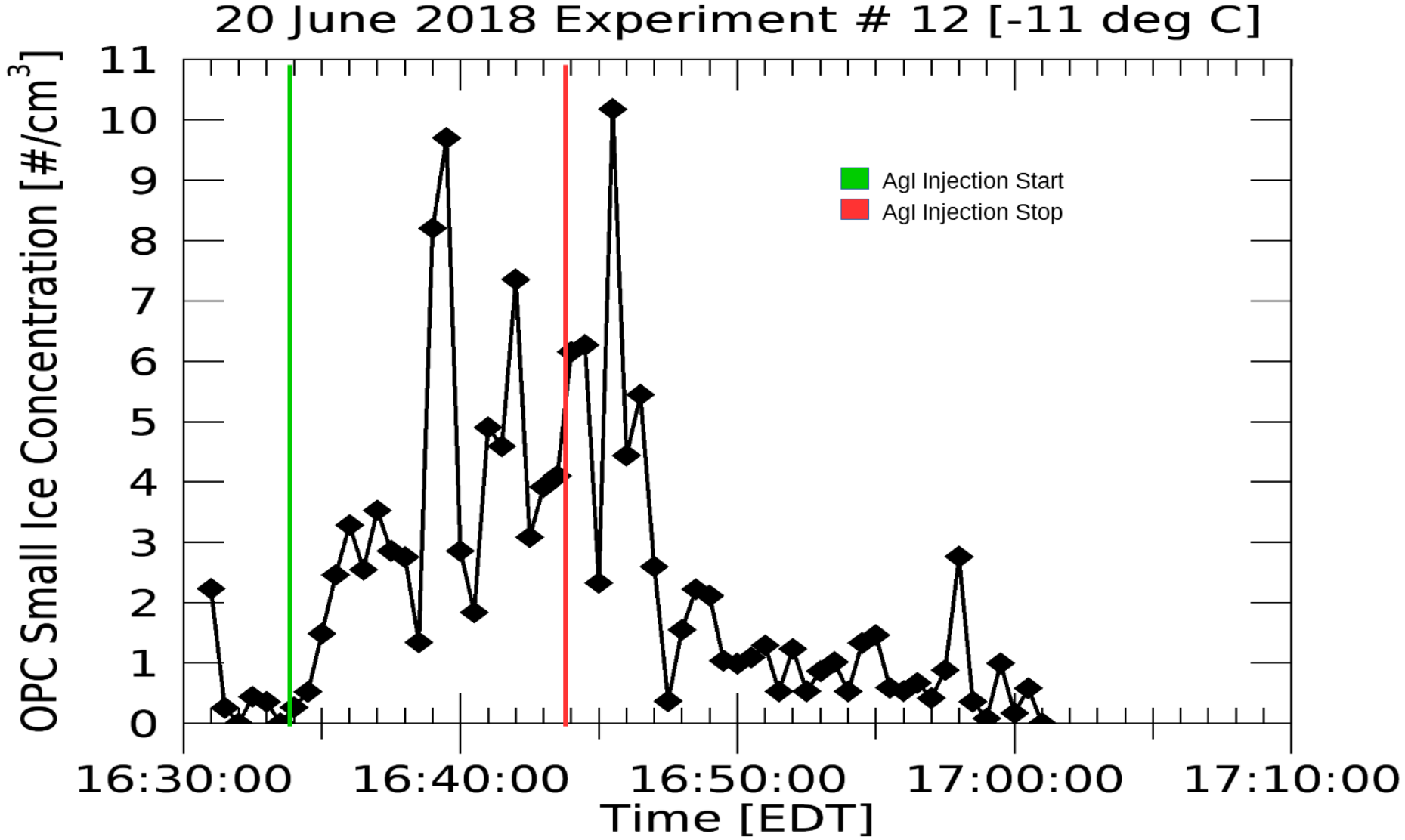


- Burn flares in particle collection system
- Data analysis
  - 10 min AgI injection duration
  - Cloud chamber temperatures of -11˚C & -5.8˚C
  - High initial cloud droplet concentration of 500/cm^3
  - low initial cloud droplet concentration 80/cm^3
- Water drops considered to be between 2 – 10 *µm*
- Ice Crystals considered to be between 20 – 105 *µm*

Methodology

- Nucleation effectiveness determined by a time constant
  - Time constant is the time it takes for a system to react to 63.2% of a change
  - Evaluated from AgI injection start time to first data point above 9/cm^3
- Time constant evaluated for ice concentration by the OPC
- If exponential growth in ice concentration is evident, an exponential growth equation can be applied to the ice concentration growth period

Results: high initial cloud droplet concentration case (500/cm^3)



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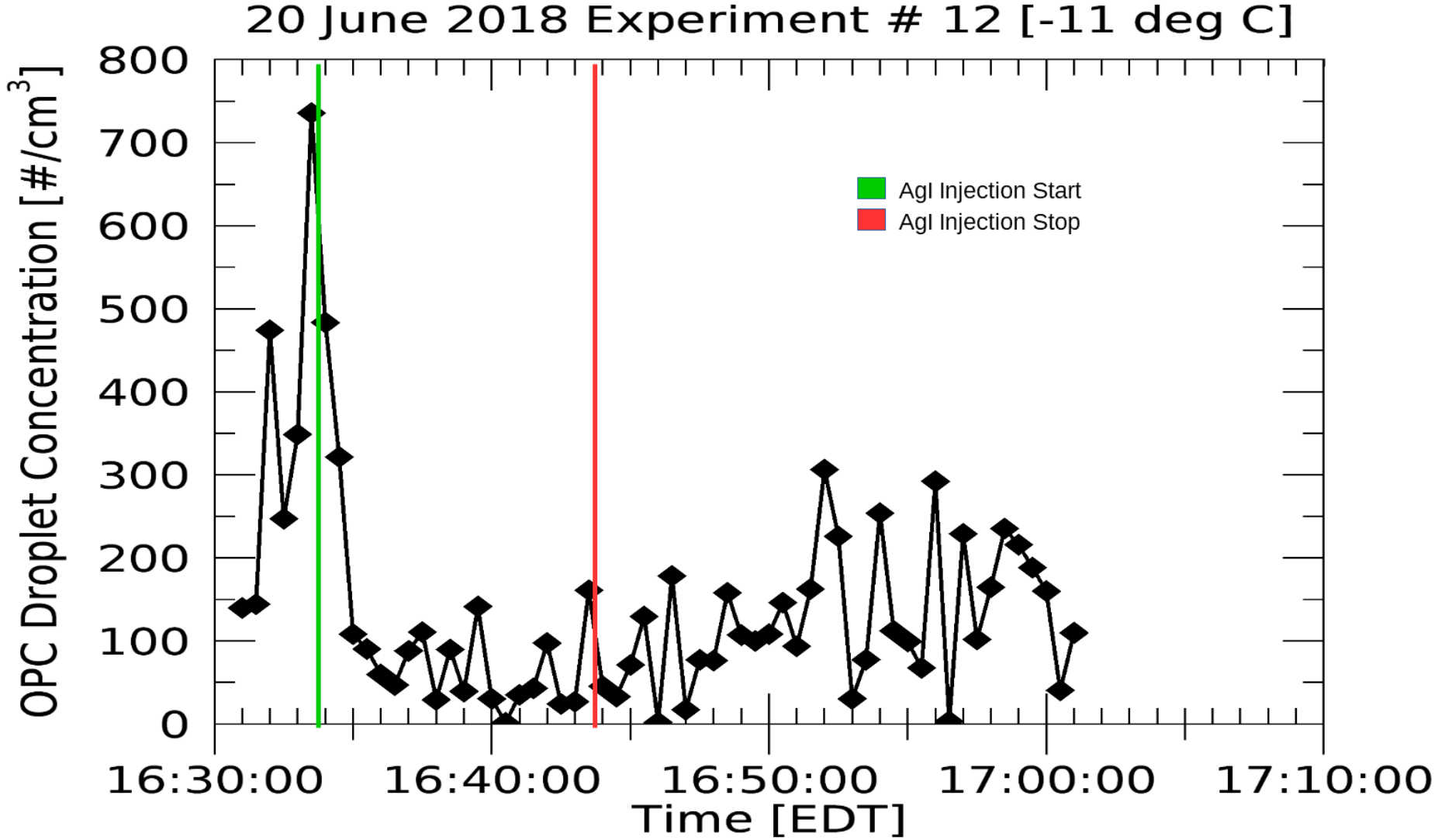
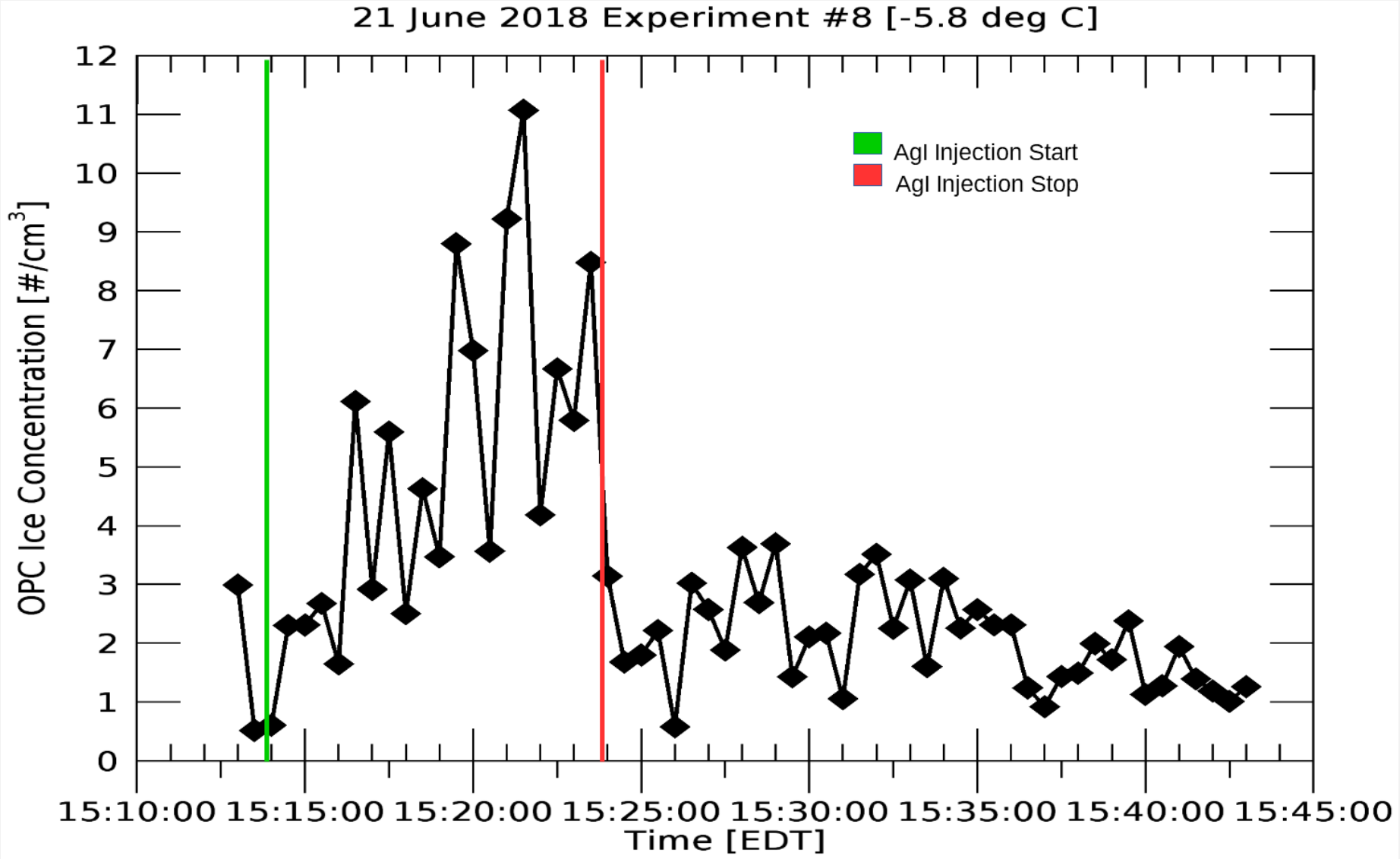
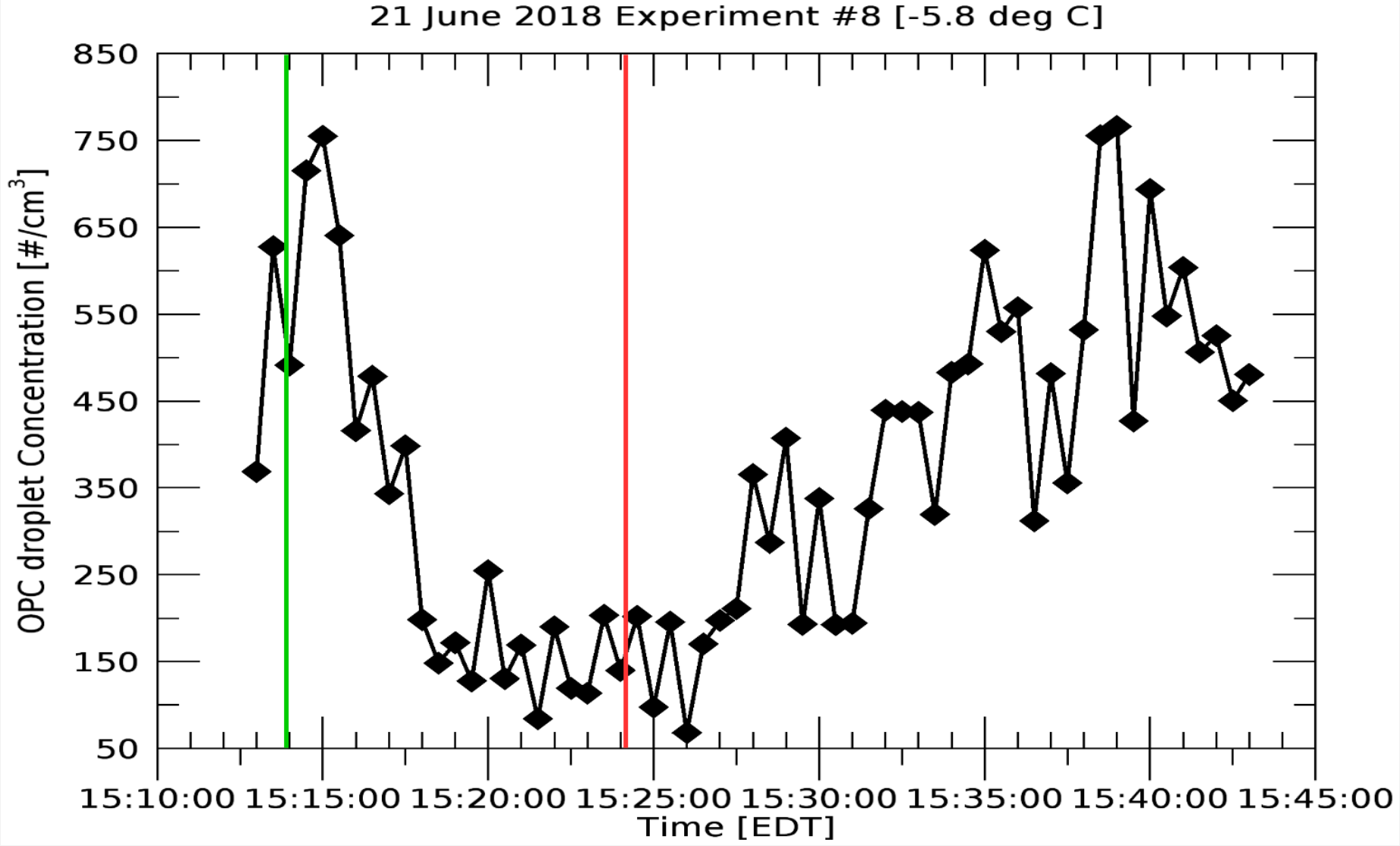


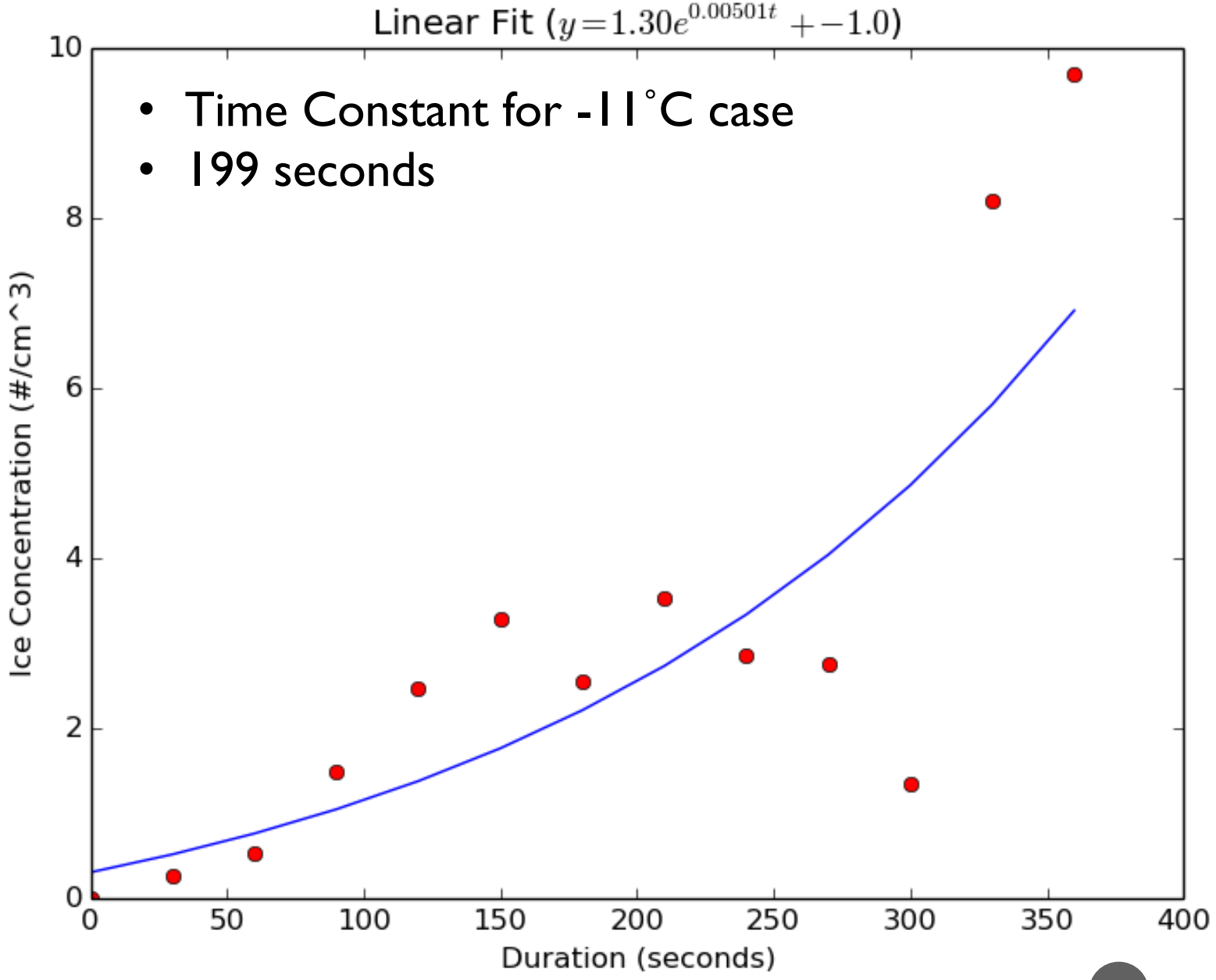
Results: high initial cloud droplet concentration case (500/cm^3)



Results: high initial cloud droplet concentration case (500/cm^3)

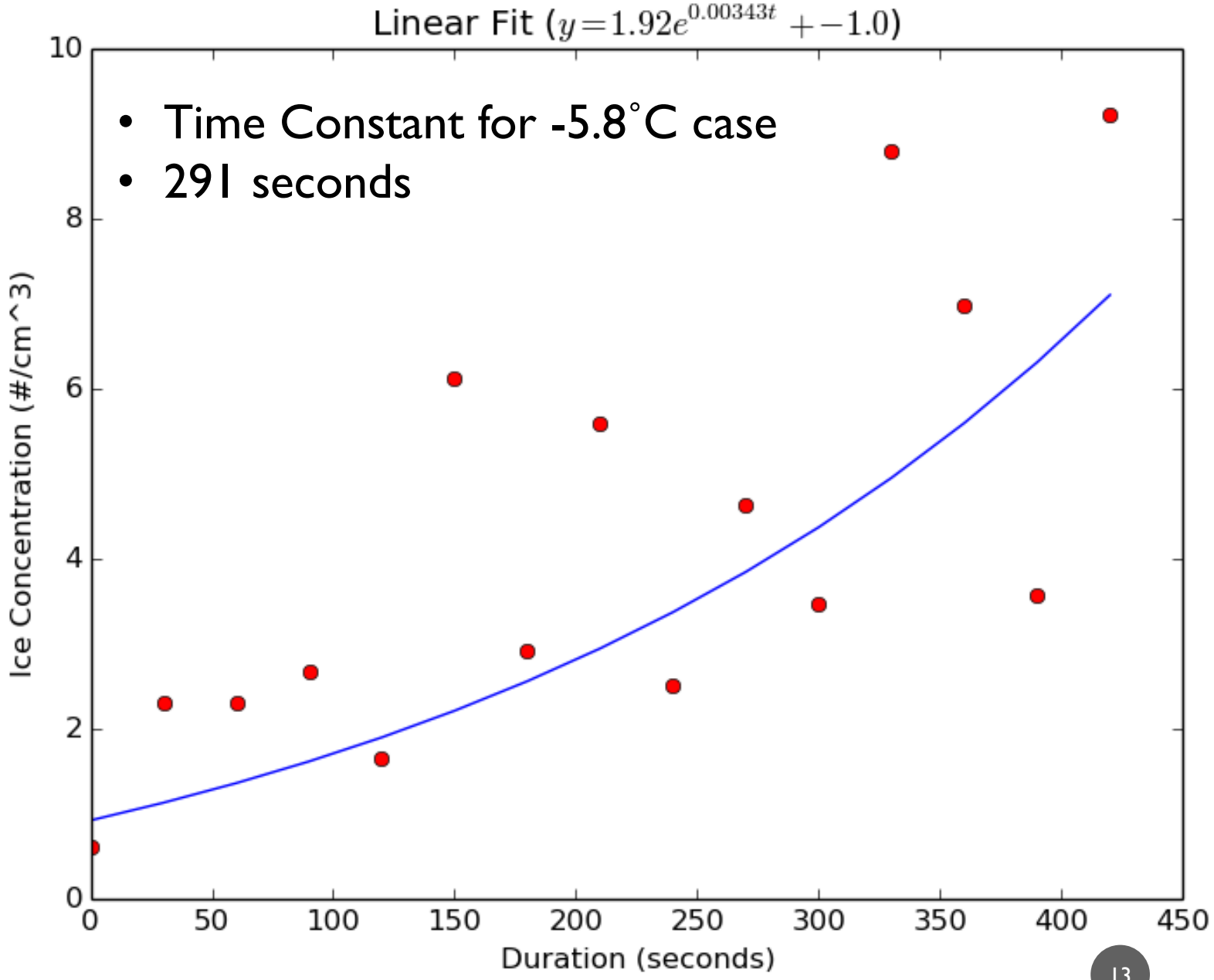


Results: curve fitting of ice concentration growth period



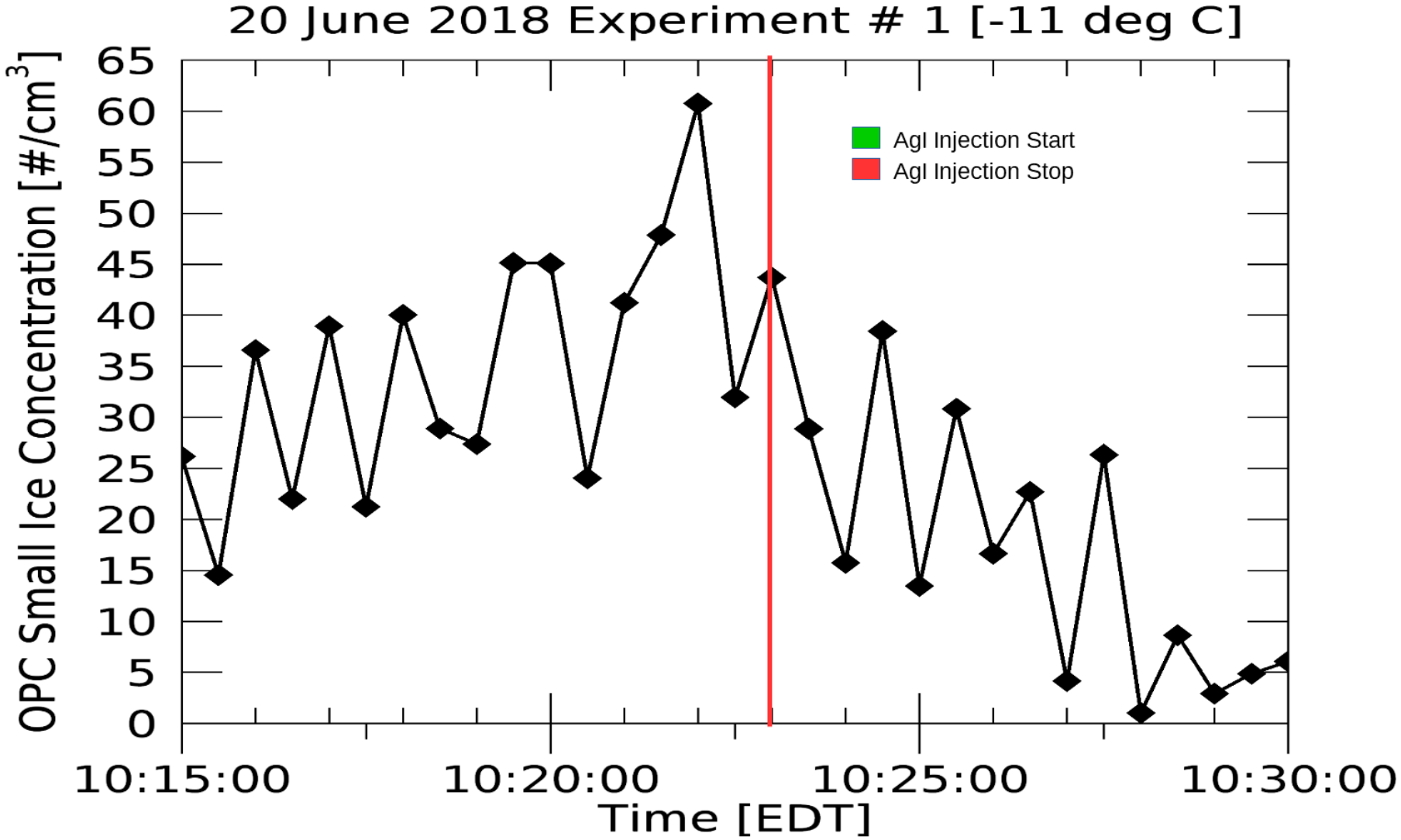
- Time Constant for -11°C case
- 199 seconds

Results: curve fitting of ice concentration growth period

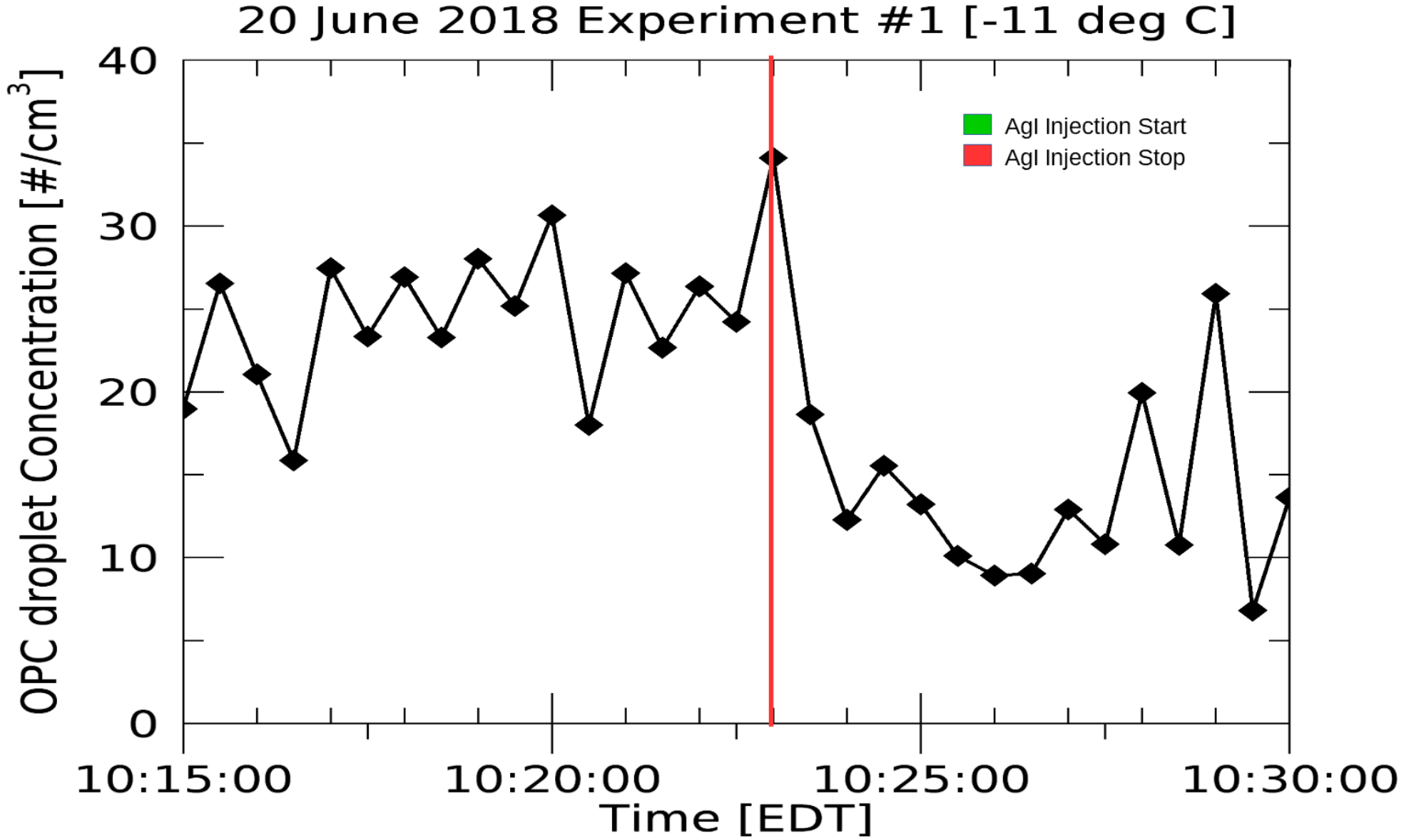


- Time Constant for -5.8˚C case
- 291 seconds

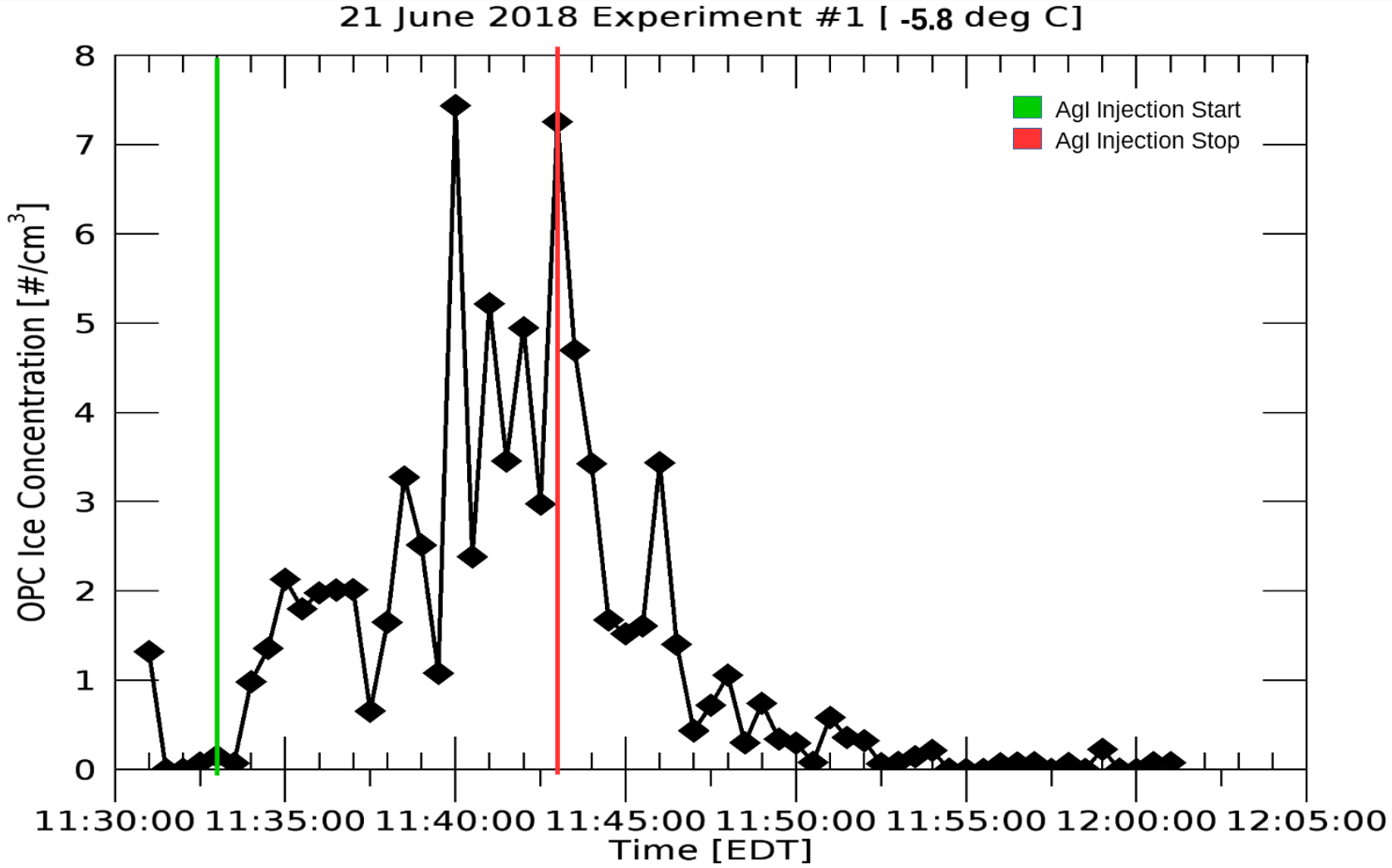
Results: low initial cloud droplet concentration case (80/cm^3)



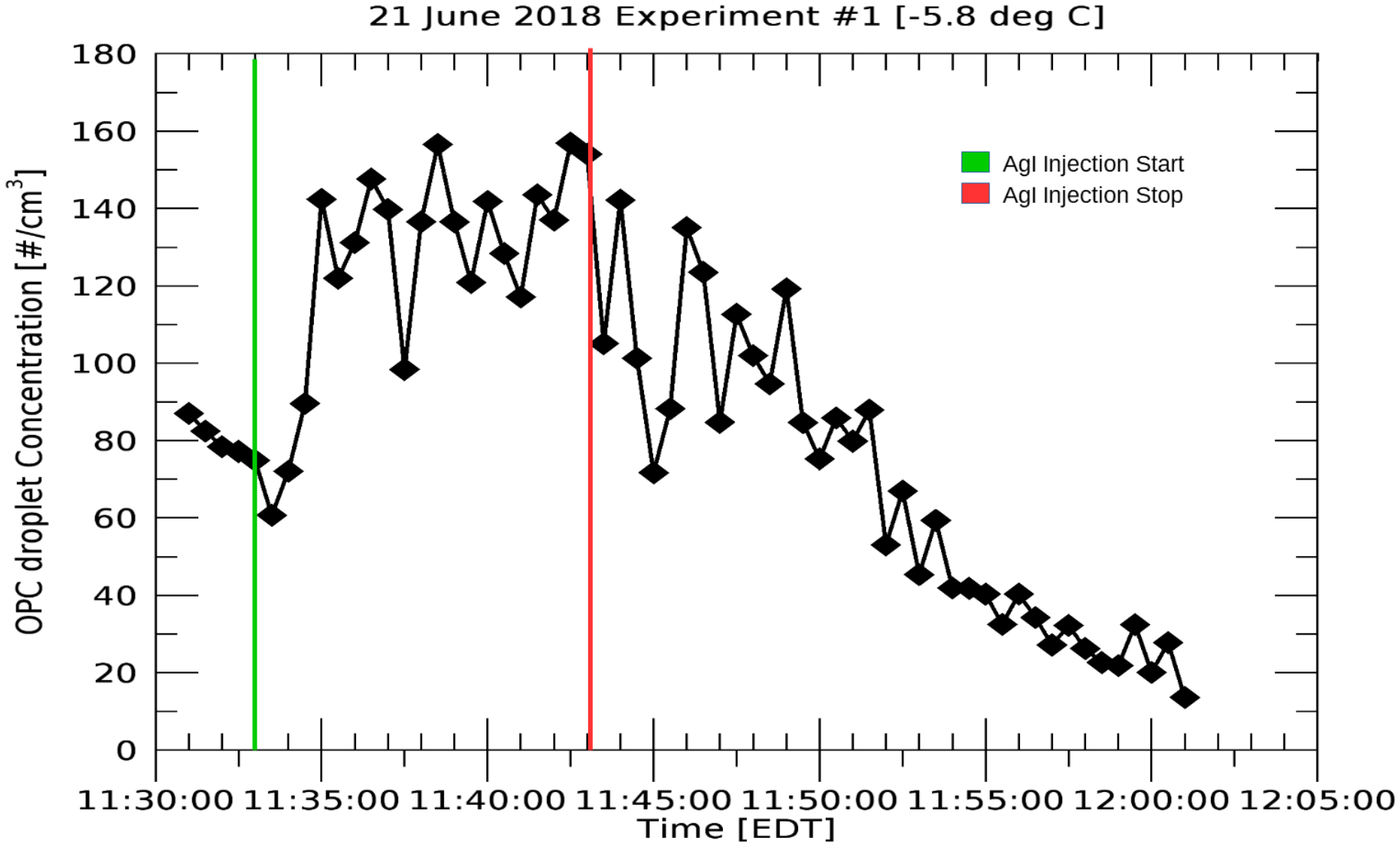
Results: low initial cloud droplet concentration case (80/cm^3)



Results: low initial cloud droplet concentration case (80/cm^3)



Results: low initial cloud droplet concentration case (80/cm^3)



CONCLUSIONS

- Contact nucleation appears to be the main nucleation mechanism occurring
- High initial cloud droplet concentration cases
  - Quick rise in ice concentration
  - Fast drop in droplet concentration
- Low initial cloud droplet concentration cases
  - Slower, and almost linear Ice growth
  - No drop in droplet concentration
- Demot 1983 used Colorado States Expansion type cloud Chamber
  - Found that contact nucleation is the dominate mode for AgI nuclei at temperature warmer than -16˚C

CONCLUSIONS

- AgI ice nucleation is more effective at -11˚C than at -5.8˚C
  - -11˚C time constant = 199 seconds
  - -5.8˚C time constant = 291 seconds
- Turbulent mixing may be causing variability in the data

Future Work & Recommendations for next project

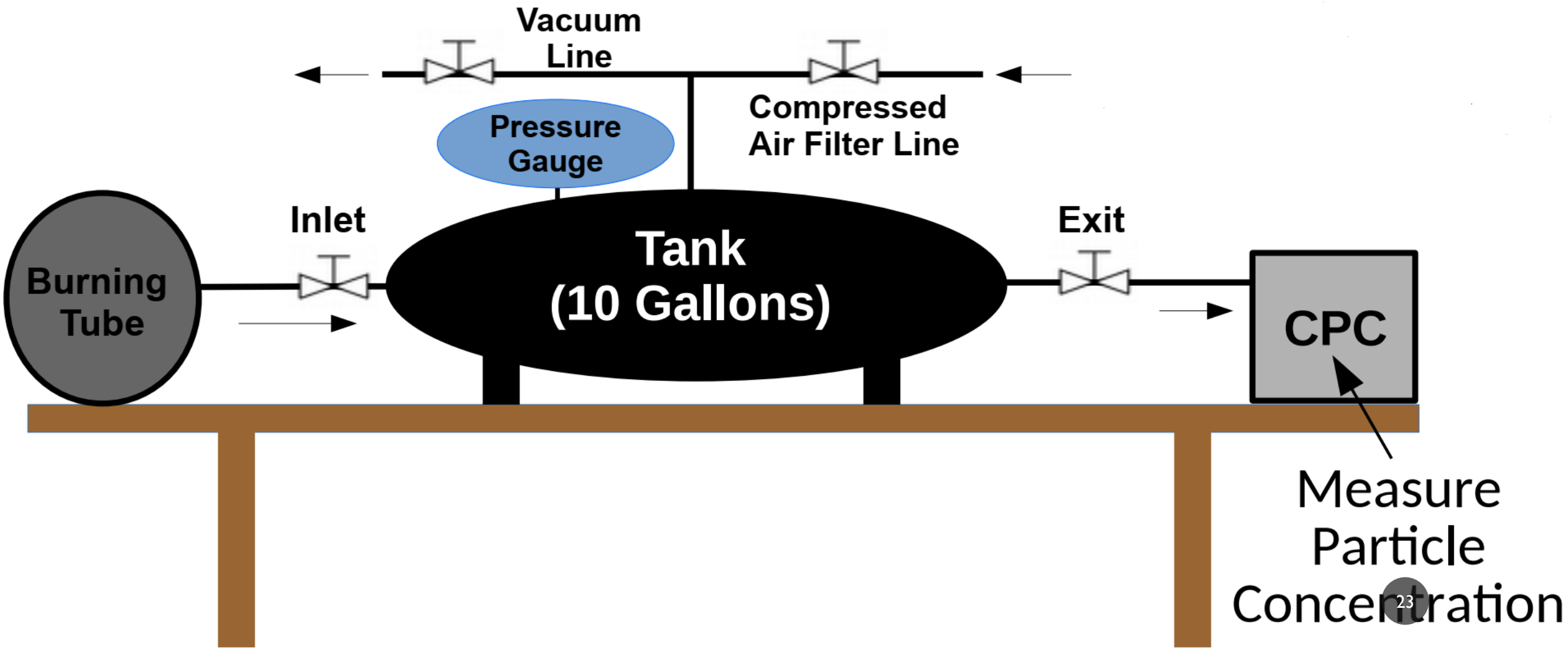
- Analyze Experiments done with a cloud chamber temperatures of -3.2˚C
  - What would be AgI nucleation effectiveness?
  - Is contact nucleation still evident?
- Use a better instrument to measure ice concentration
  - WEALS Optical Particle Counter is better for measuring water concentration
  - Difficulties affording better instruments

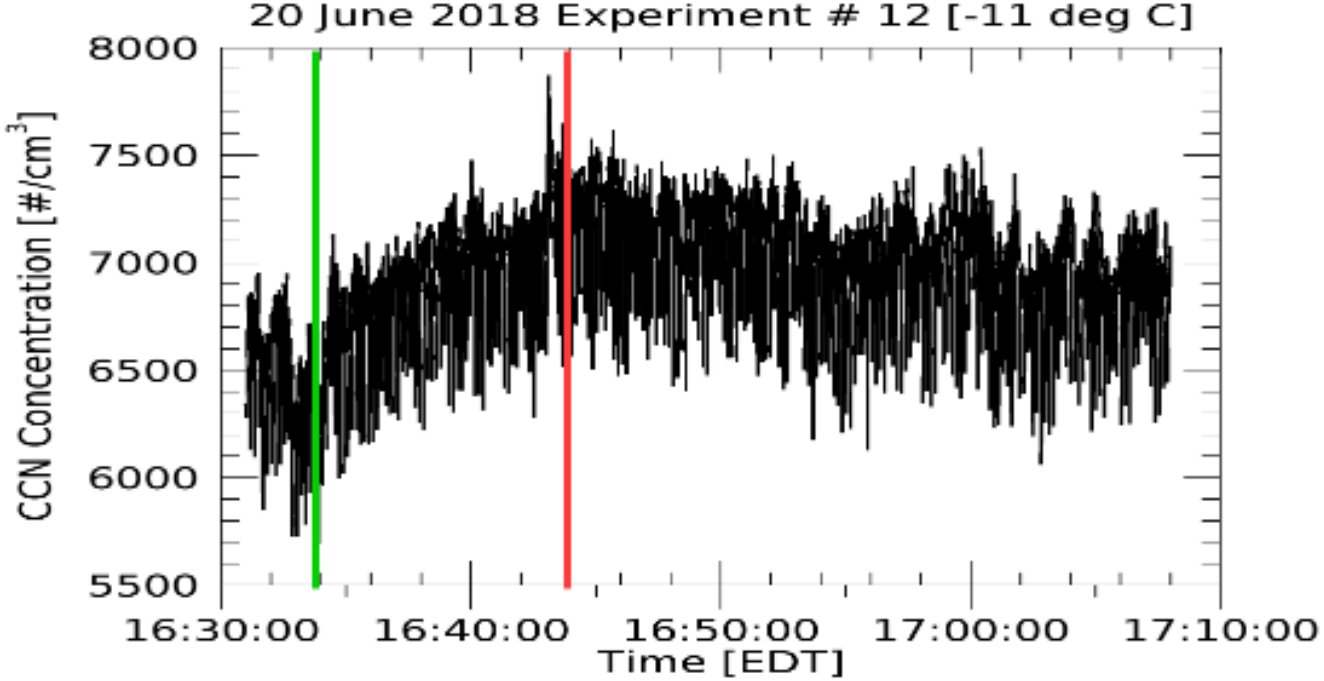
REFERENCES

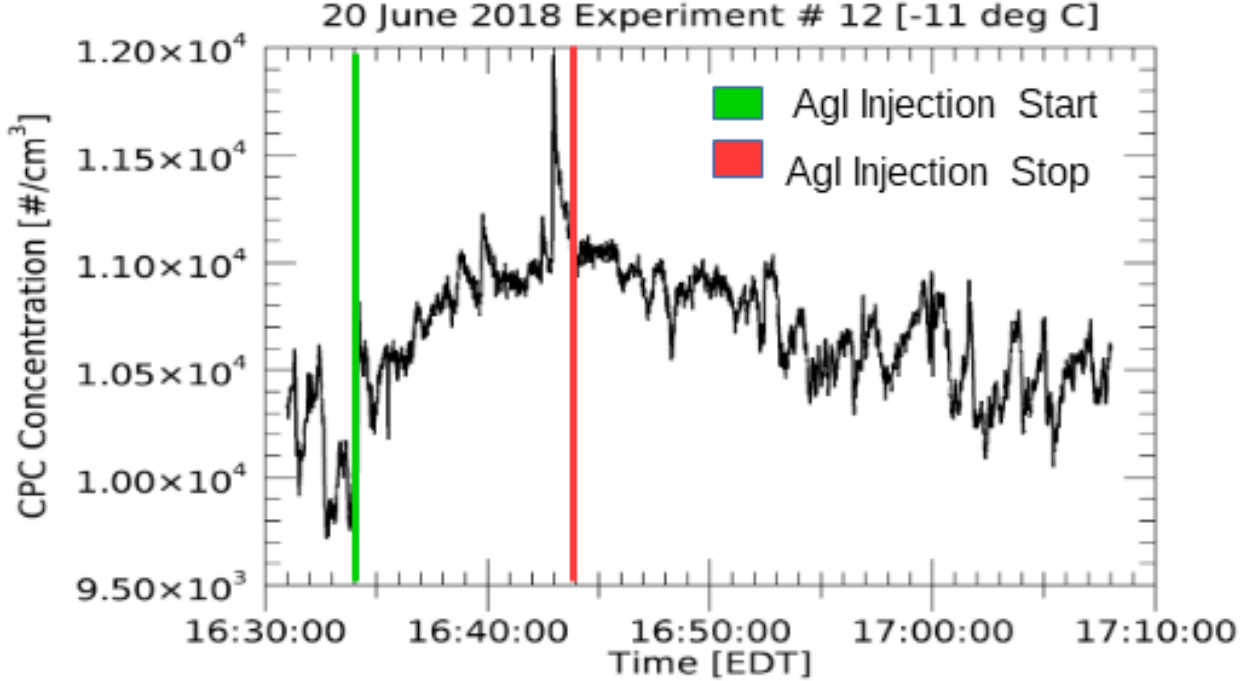
- Blair, D. N., B. L. Davis, and A. S. Dennis, 1973: Cloud Chamber Tests of Generators Using Acetone Solutions of AgI-NaI, AgI-KI and AgI-NH4I. J. Appl. Meteorol., 12, 1012–1017, doi:10.1175/1520-0450(1973)012<1012:CCTOGU>2.0.CO;2.
- Chang, K., and Coauthors, 2016: A laboratory facility to study gas-aerosol-cloud interactions in a turbulent environment: The Π Chamber. Bull. Am. Meteorol. Soc., doi:10.1175/BAMS-D-15-00203.1. http://journals.ametsoc.org/doi/10.1175/BAMS-D-15-00203.1 (Accessed May 2, 2016).
- DeMott, P. J., W. G. Finnegan, and L. O. Grant, 1983: An Application of Chemical Kinetic Theory and Methodology to Characterize the Ice Nucleating Properties of Aerosols Used for Weather Modification. J. Clim. Appl. Meteorol., 22, 1190–1203, doi:10.1175/1520-0450(1983)022<1190:AAOCKT>2.0.CO;2.
- ——, and Coauthors, 2011: Resurgence in Ice Nuclei Measurement Research. Bull. Am. Meteorol. Soc., 92, 1623–1635, doi:10.1175/2011BAMS3119.1.
- Young, K. C., 1974: The Role of Contact Nucleation in Ice Phase Initiation in Clouds. J. Atmospheric Sci., 31, 768–776, doi:10.1175/1520-0469(1974)031<0768:TROCNI>2.0.CO;2.

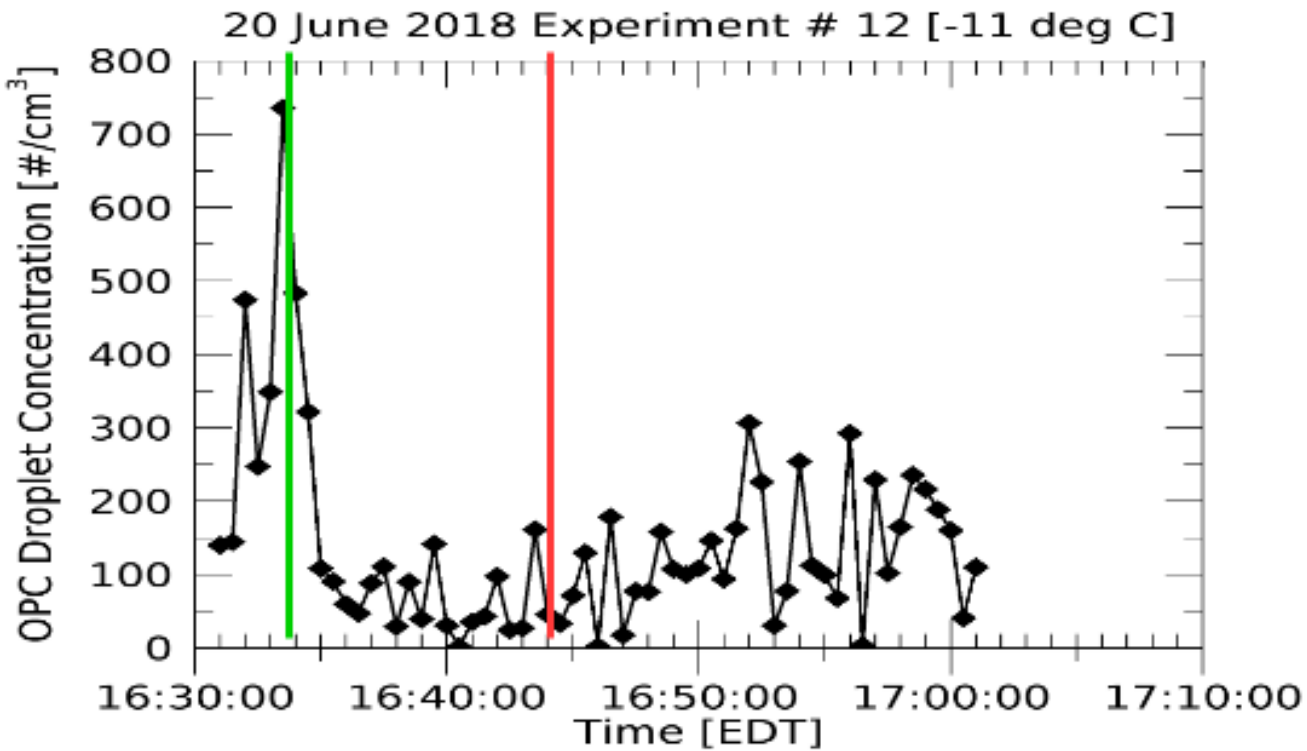
ADDITIONAL SLIDES

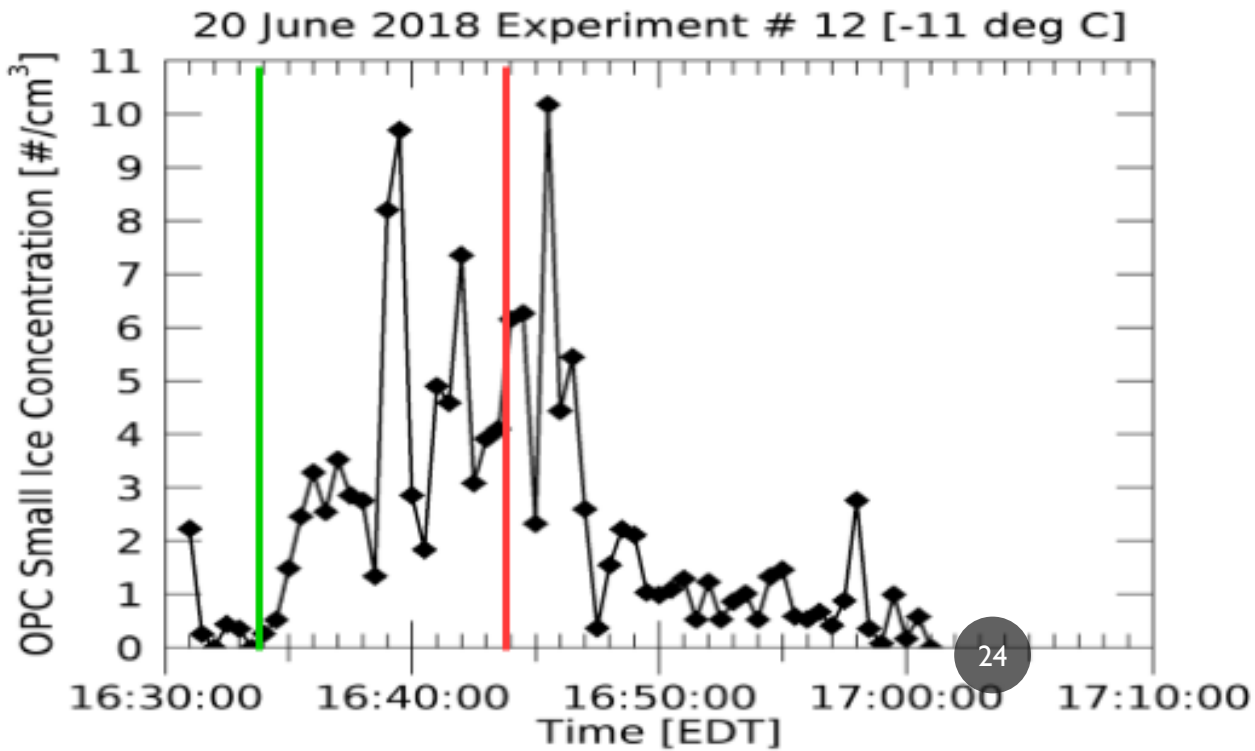
AgI flare collection tank system

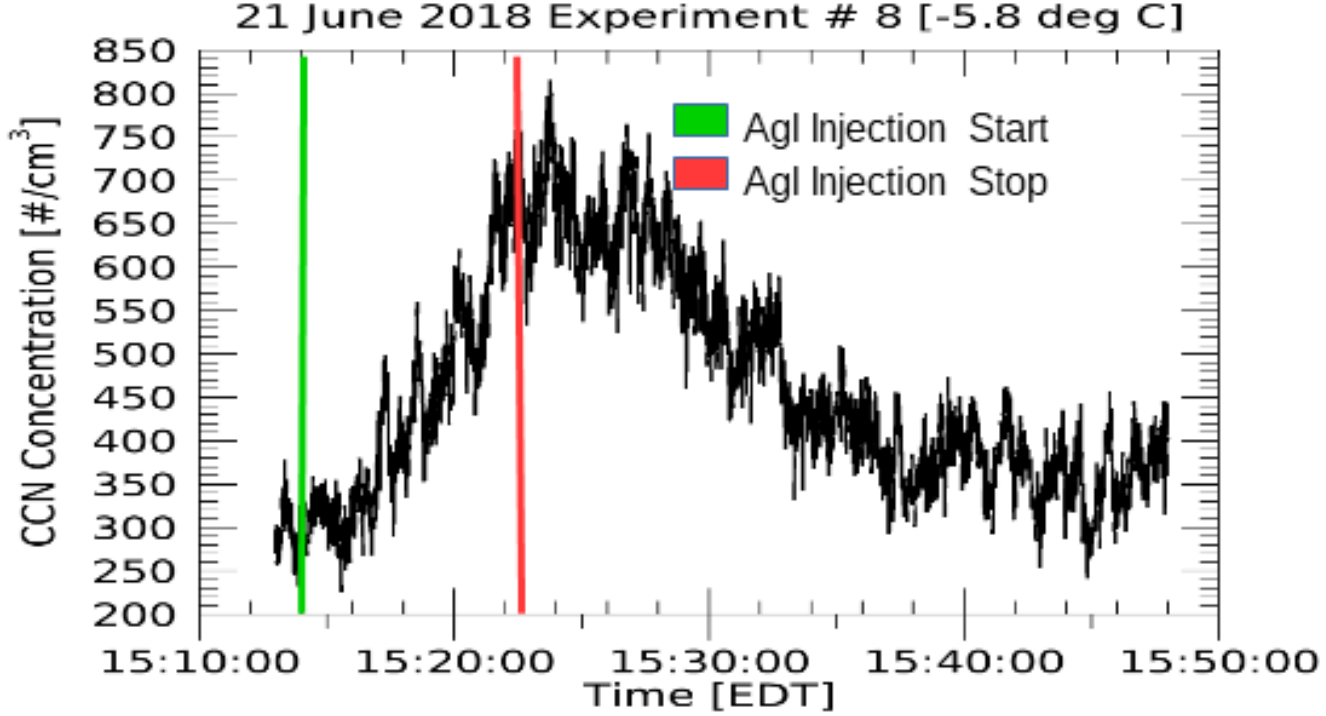


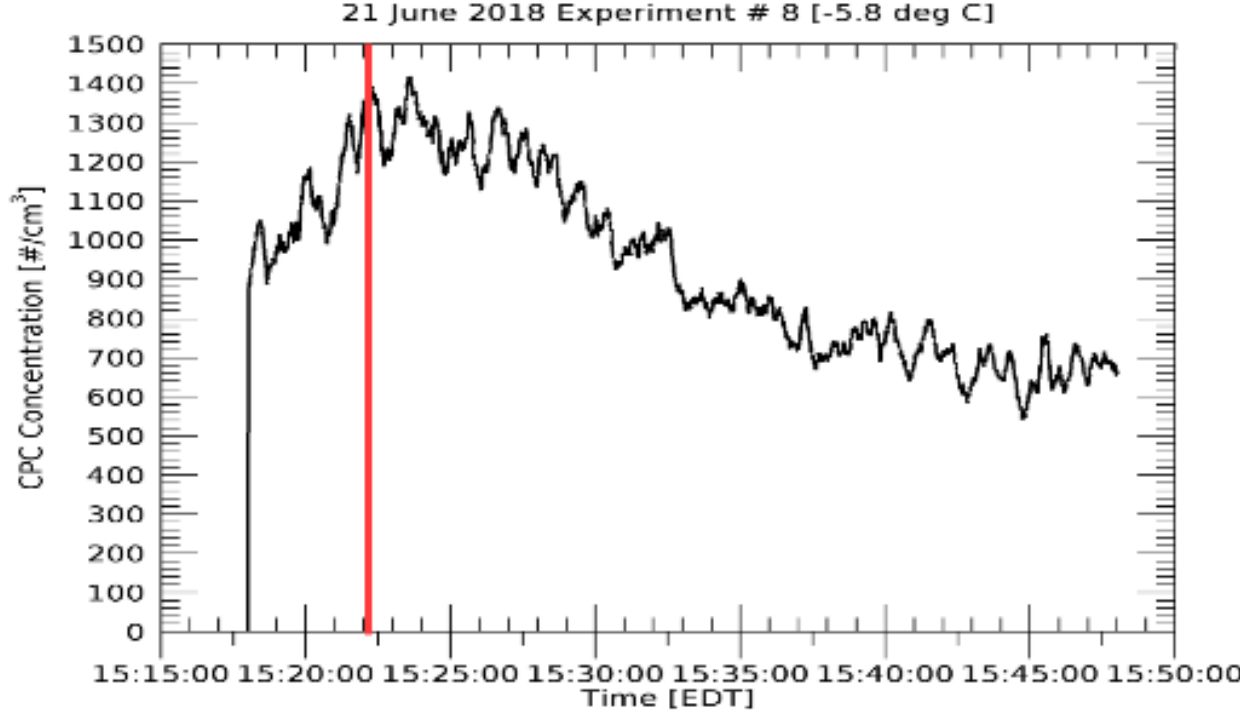

20 June 2018 Experiment # 12 [-11 deg C]
CCN Concentration [#/cm^3]
8000
7500
7000
6500
6000
5500
16:30:00
16:40:00
16:50:00
17:00:00
17:10:00
Time [EDT]

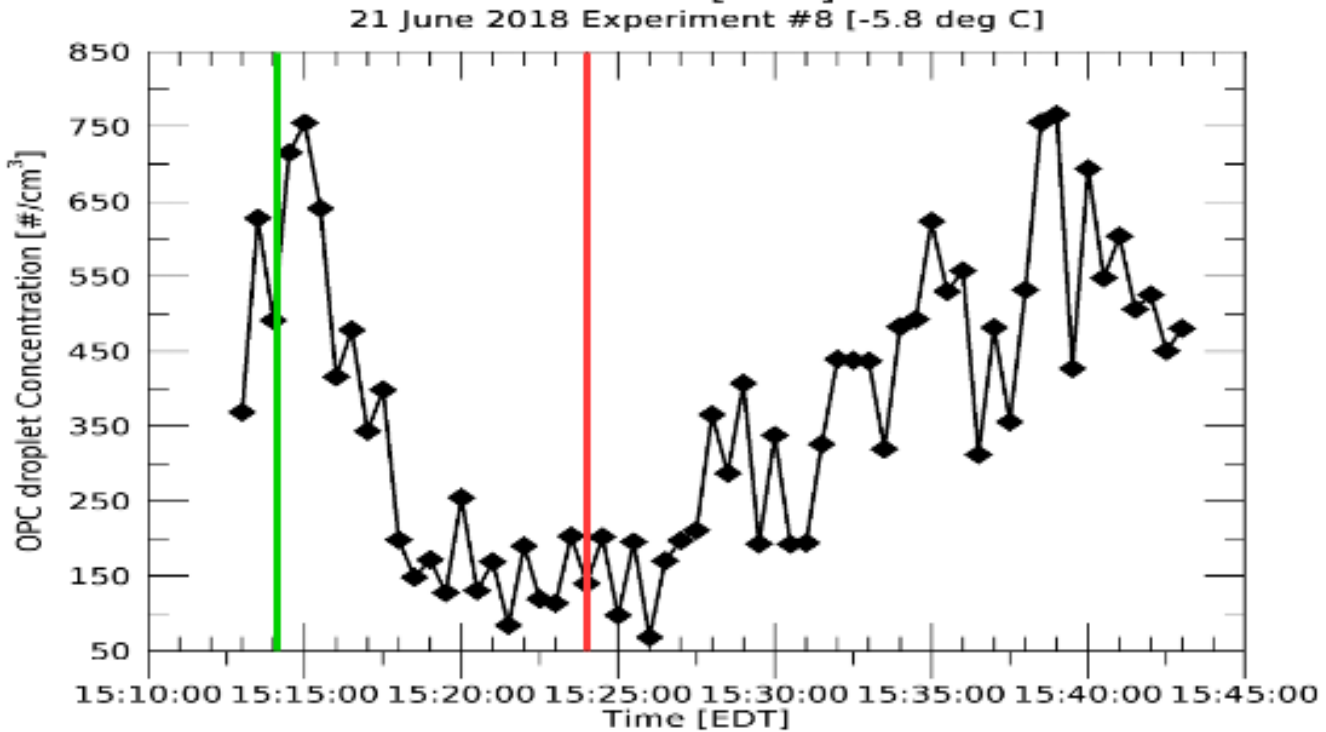

20 June 2018 Experiment # 12 [-11 deg C]
CPC Concentration [#/cm^3]
1.20×10^4
1.15×10^4
1.10×10^4
1.05×10^4
1.00×10^4
9.50×10^3
AgI Injection Start
AgI Injection Stop
16:30:00
16:40:00
16:50:00
17:00:00
17:10:00
Time [EDT]

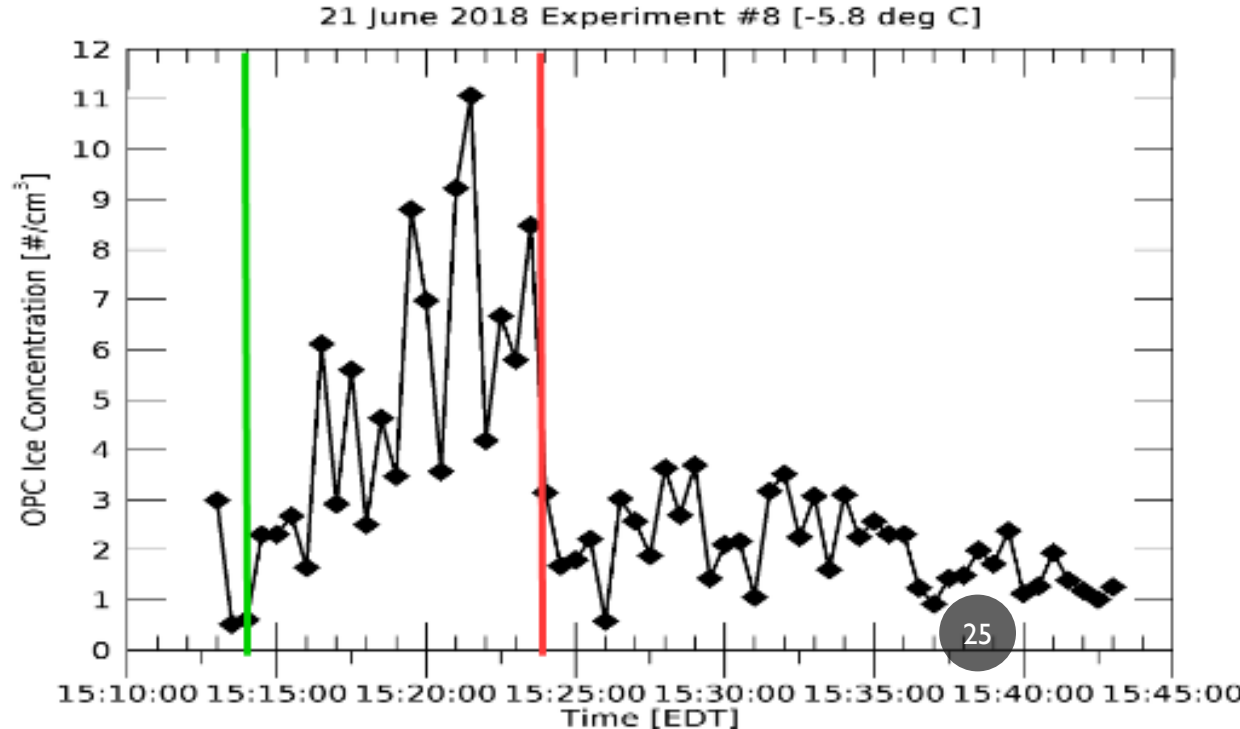

20 June 2018 Experiment # 12 [-11 deg C]
OPC Droplet Concentration [#/cm^3]
800
700
600
500
400
300
200
100
0
16:30:00
16:40:00
16:50:00
17:00:00
17:10:00
Time [EDT]

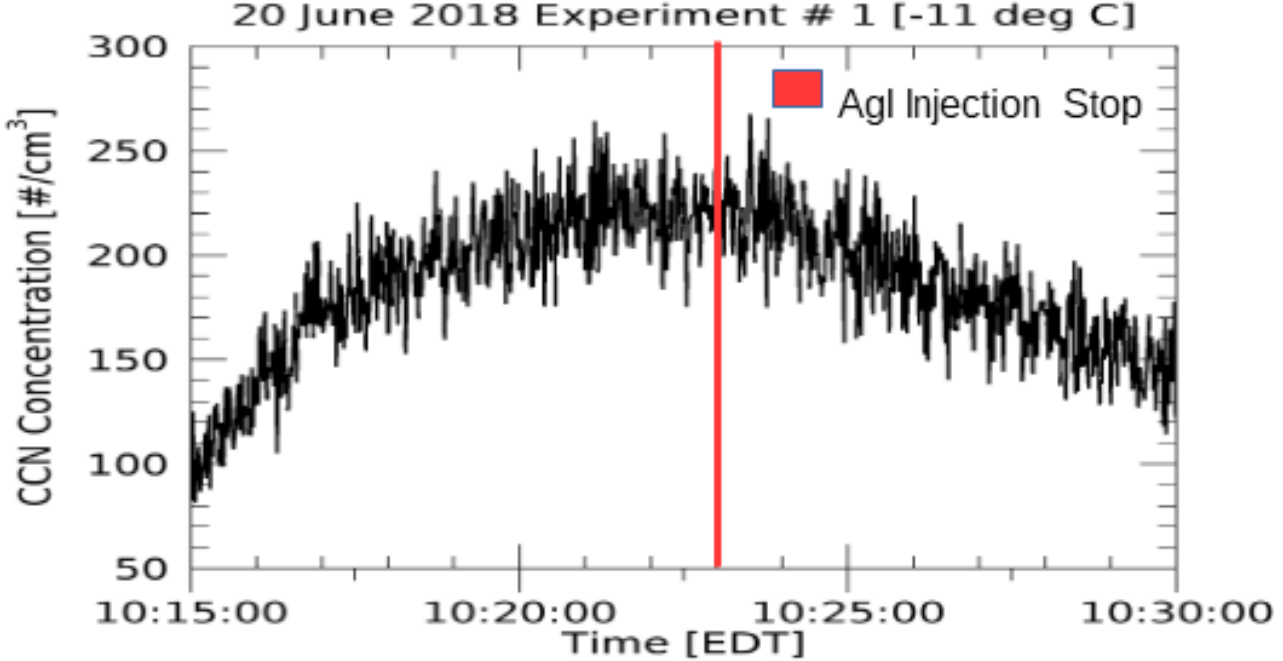

20 June 2018 Experiment # 12 [-11 deg C]
OPC Small Ice Concentration [#/cm^3]
11
10
9
8
7
6
5
4
3
2
1
0
16:30:00
16:40:00
16:50:00
17:00:00
17:10:00
Time [EDT]

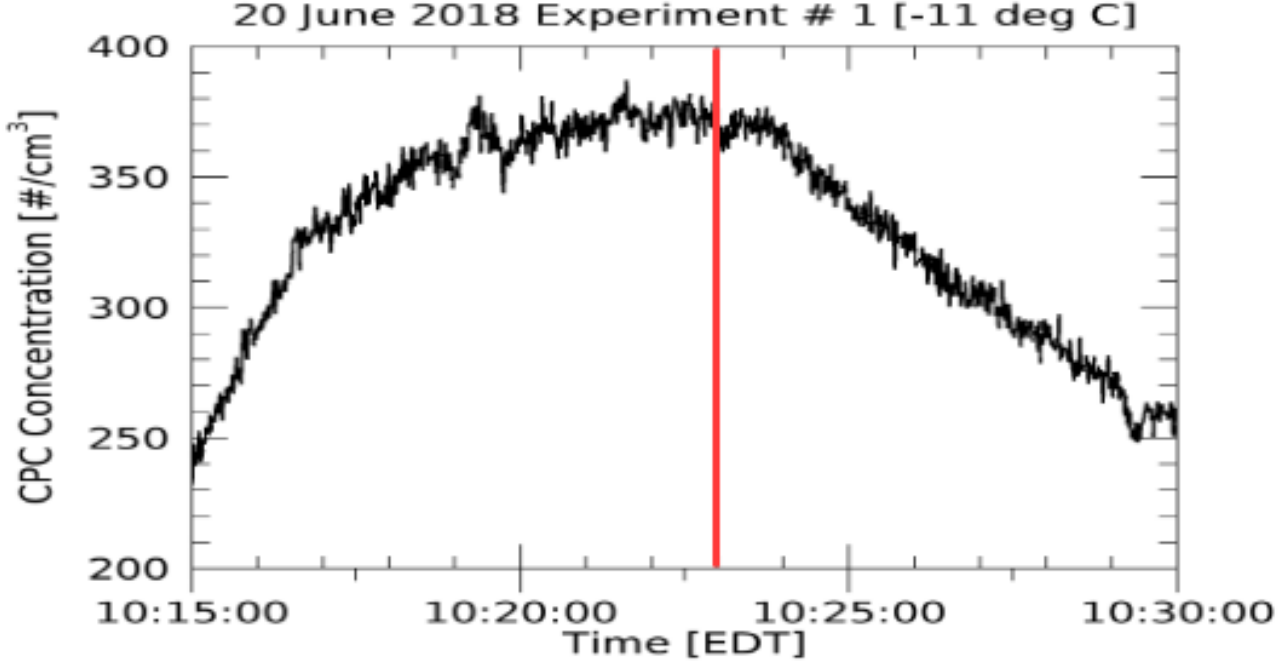

21 June 2018 Experiment # 8 [-5.8 deg C]
AgI Injection Start
AgI Injection Stop
CCN Concentration [#/cm3]
Time [EDT]

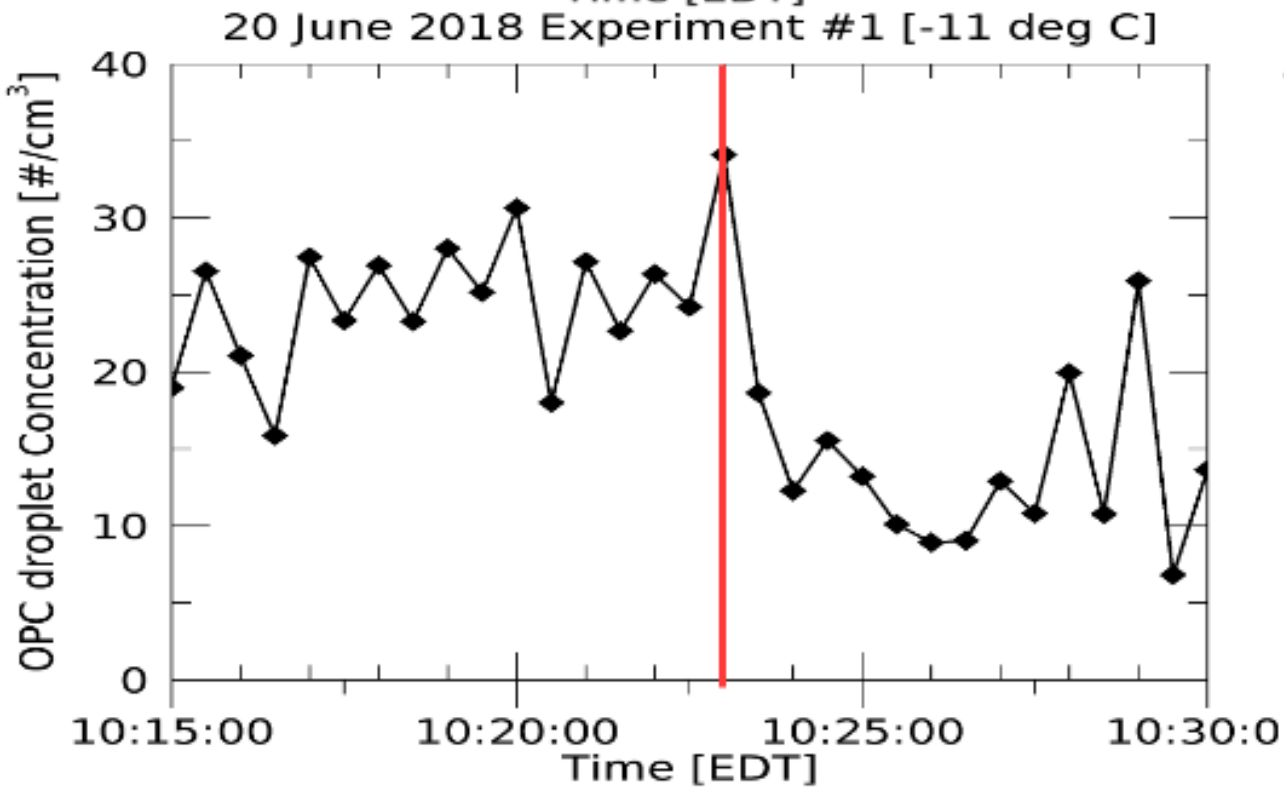

21 June 2018 Experiment # 8 [-5.8 deg C]
CPC Concentration [#/cm3]
Time [EDT]

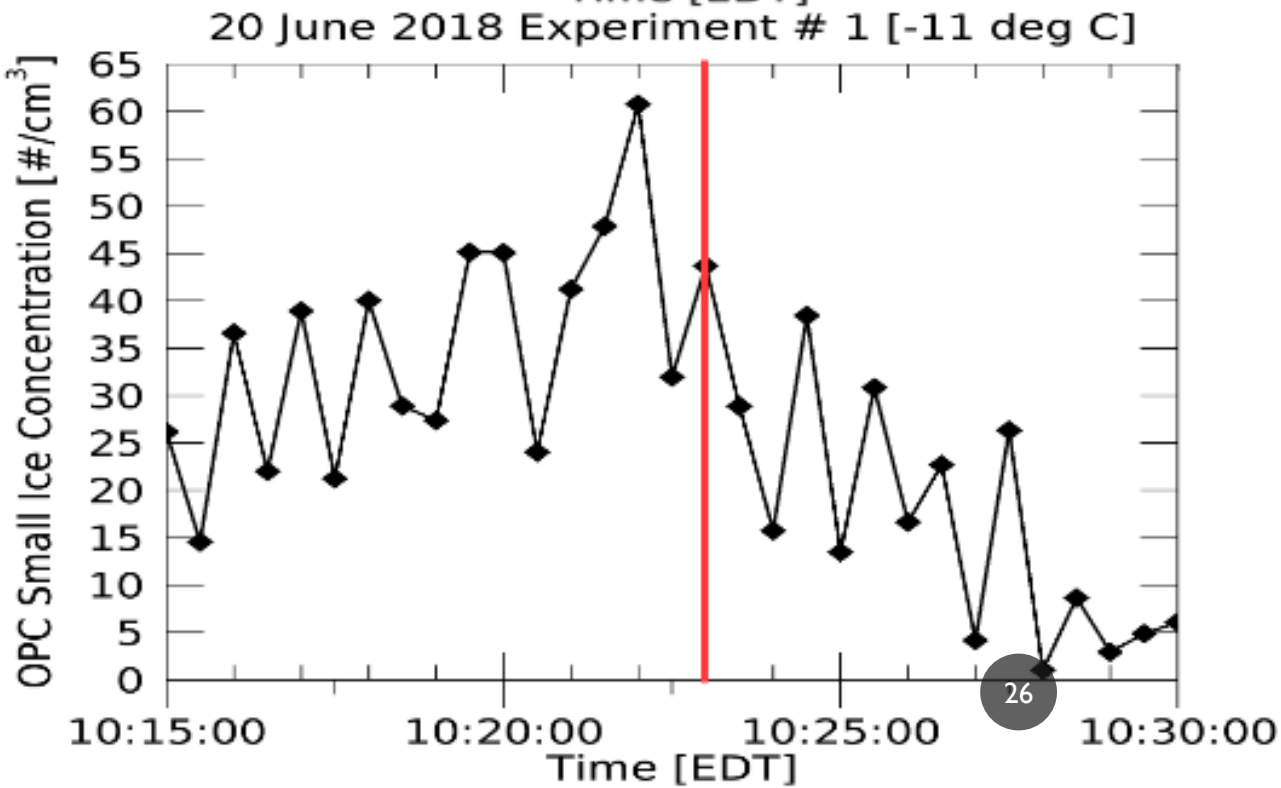

21 June 2018 Experiment #8 [-5.8 deg C]
OPC droplet Concentration [#/cm3]
Time [EDT]

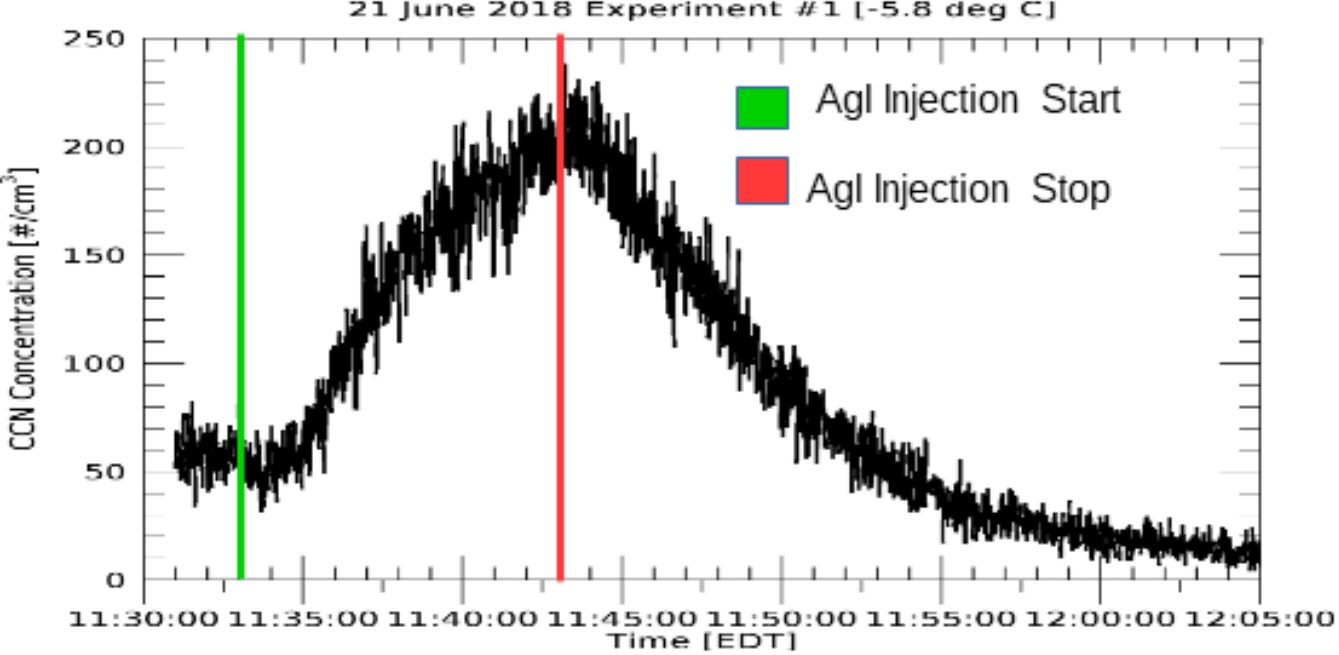

21 June 2018 Experiment #8 [-5.8 deg C]
OPC Ice Concentration [#/cm3]
Time [EDT]

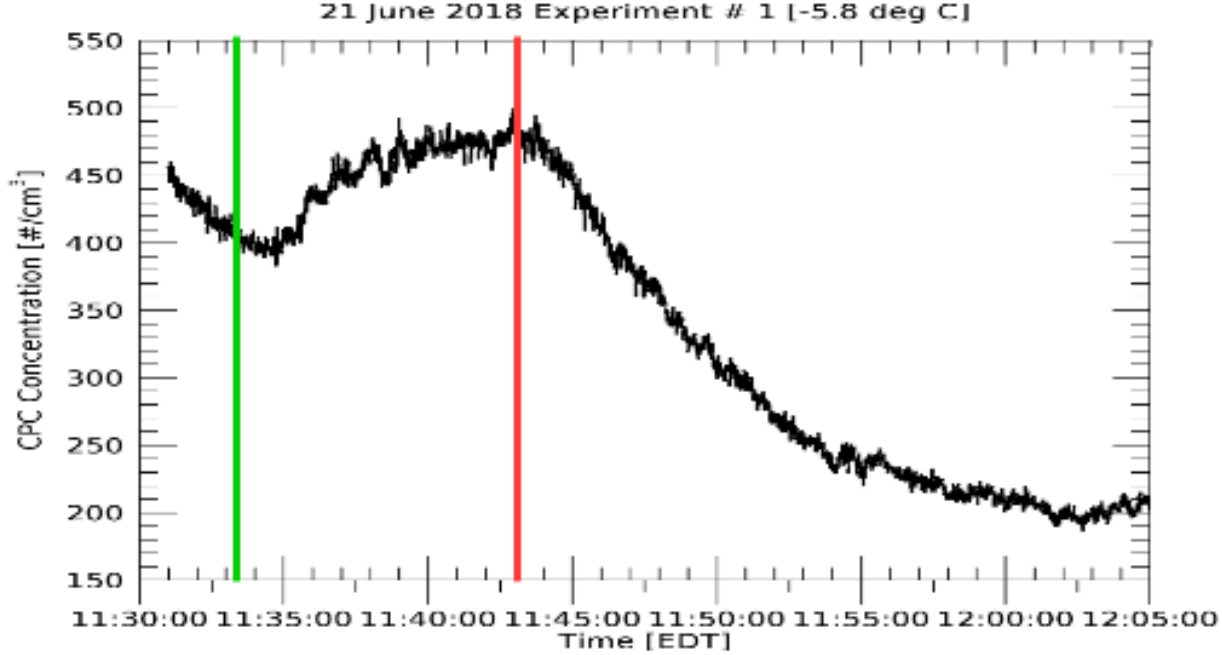

20 June 2018 Experiment # 1 [-11 deg C]
AgI Injection Stop
CCN Concentration [#/cm3]
300
250
200
150
100
50
10:15:00
10:20:00
10:25:00
10:30:00
Time [EDT]

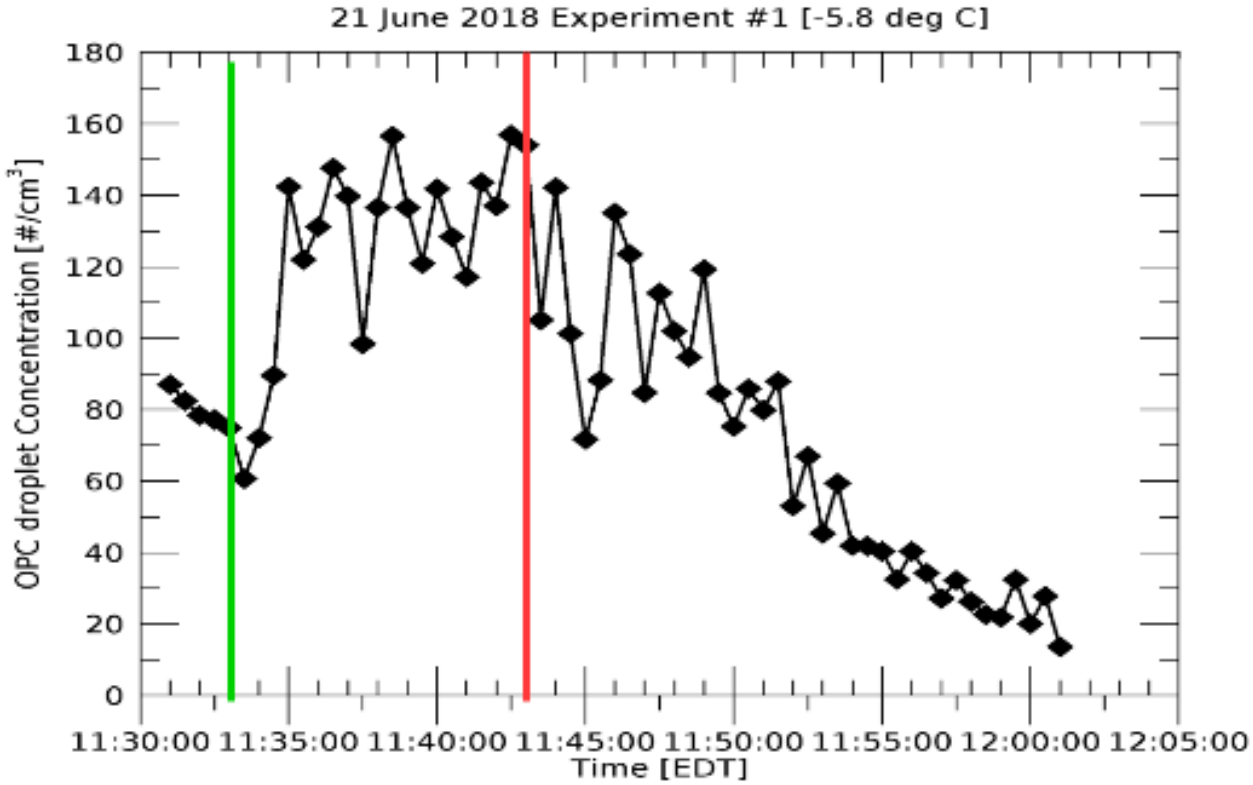

20 June 2018 Experiment # 1 [-11 deg C]
CPC Concentration [#/cm3]
400
350
300
250
200
10:15:00
10:20:00
10:25:00
10:30:00
Time [EDT]

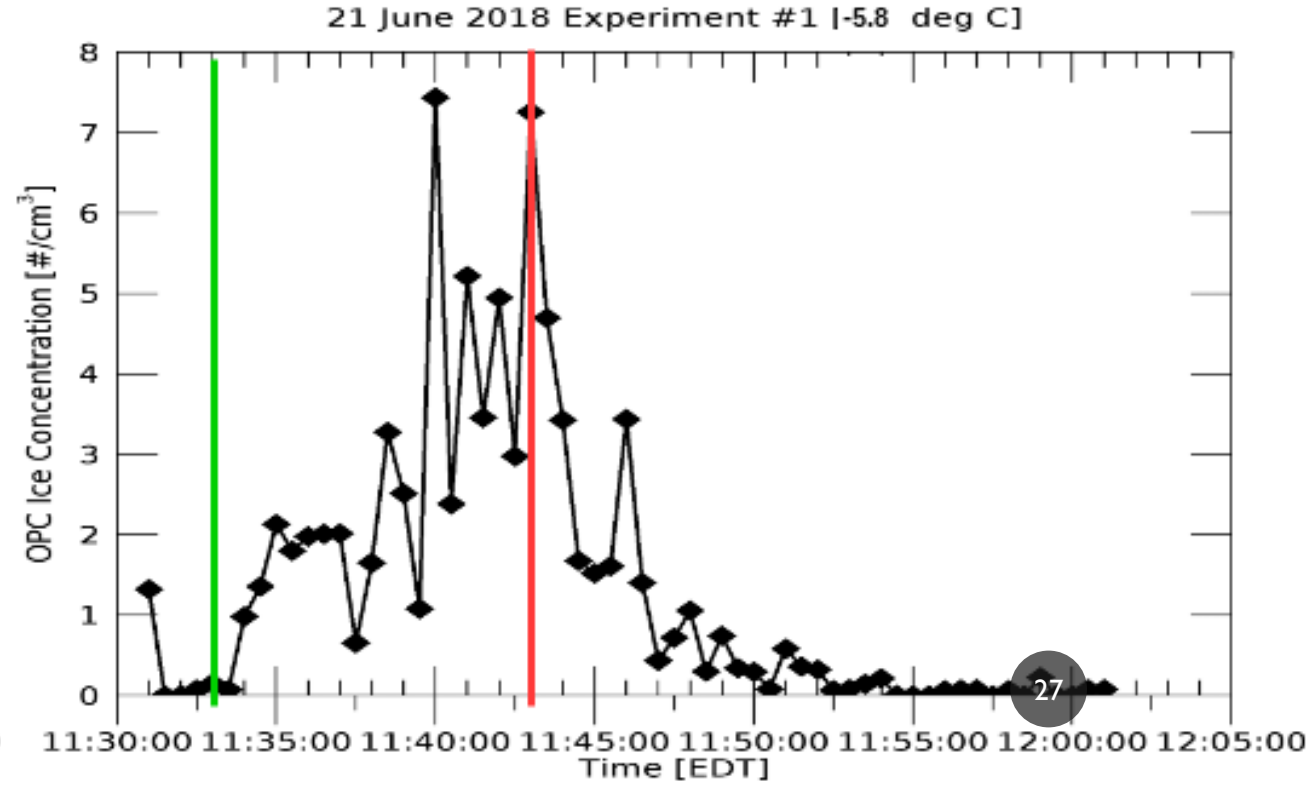

20 June 2018 Experiment #1 [-11 deg C]
OPC droplet Concentration [#/cm3]
40
30
20
10
0
10:15:00
10:20:00
10:25:00
10:30:0
Time [EDT]


20 June 2018 Experiment # 1 [-11 deg C]
OPC Small Ice Concentration [#/cm3]
65
60
55
50
45
40
35
30
25
20
15
10
5
0
10:15:00
10:20:00
10:25:00
10:30:00
Time [EDT]


21 June 2018 Experiment #1 [-5.8 deg C]
AgI Injection Start
AgI Injection Stop
CCN Concentration [#/cm3]
Time [EDT]


21 June 2018 Experiment # 1 [-5.8 deg C]
CPC Concentration [#/cm3]
Time [EDT]

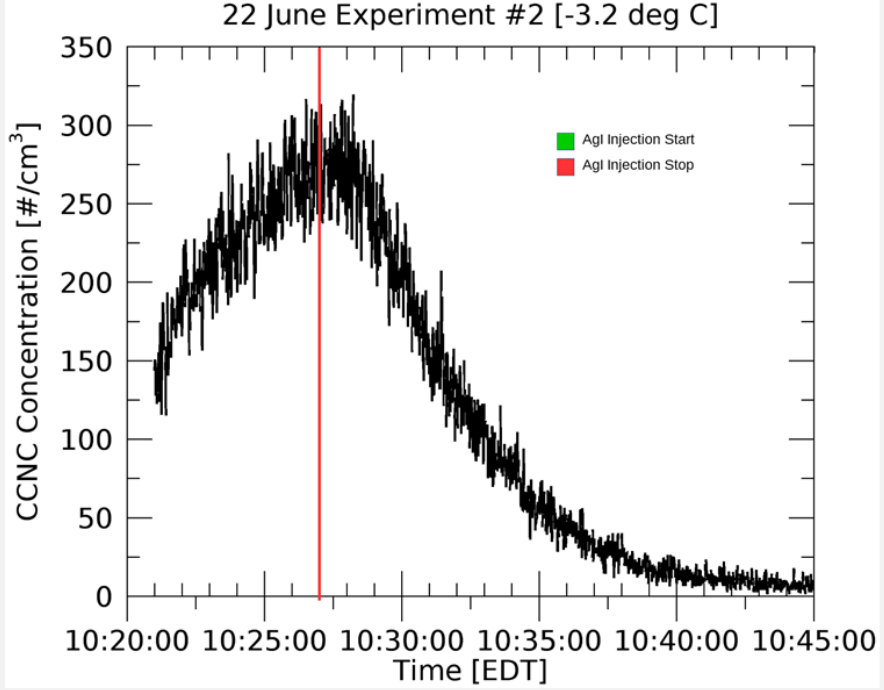

21 June 2018 Experiment #1 [-5.8 deg C]
OPC droplet Concentration [#/cm3]
Time [EDT]

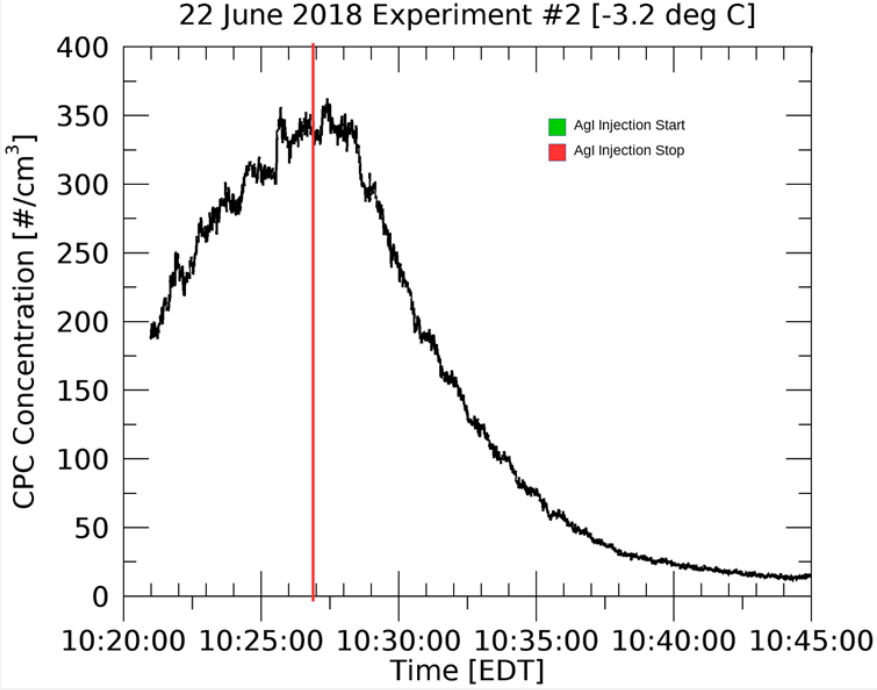

21 June 2018 Experiment #1 [-5.8 deg C]
OPC Ice Concentration [#/cm3]
Time [EDT]

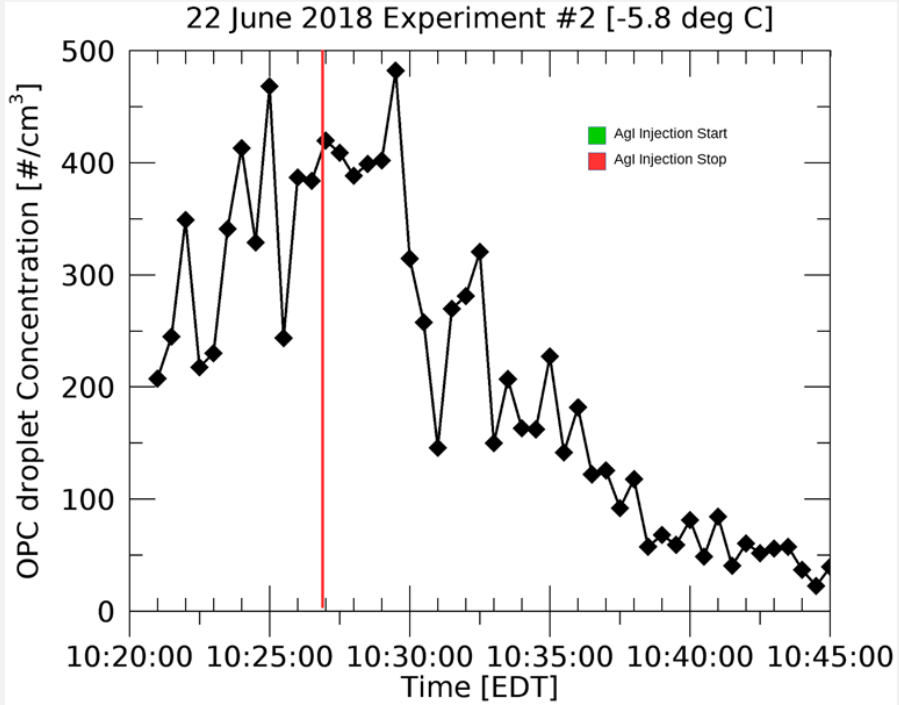
Chamber Liquid Water Content

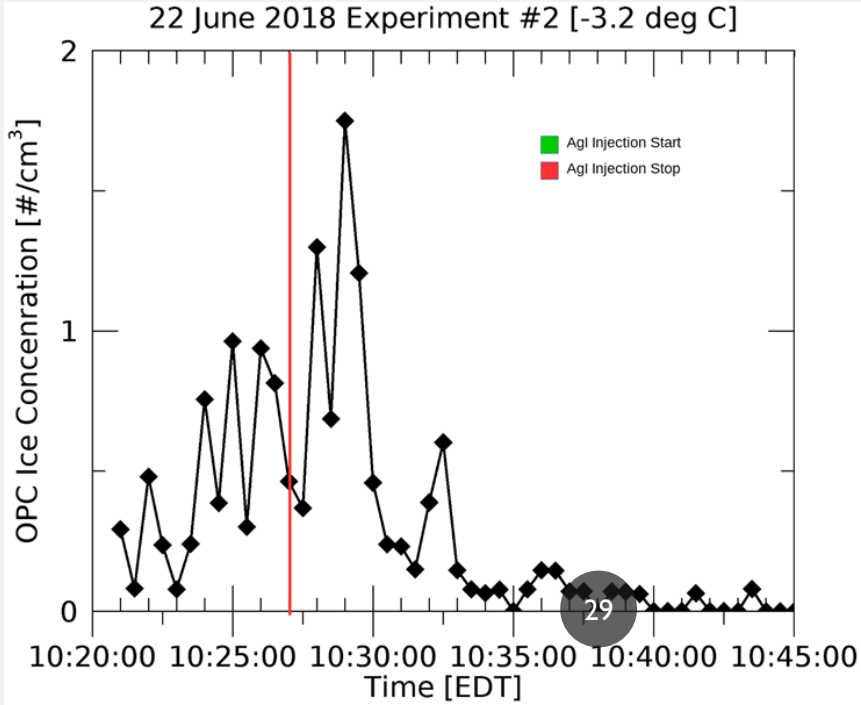
- LWC for High initial cloud droplet concentration cases\
  - .016755 g/m^3
- LWC for Low initial cloud droplet concentration cases
  - .0026808g/m^3

Initial results to -3.2˚C Case









Experimental table

Date Temp	Number [#]	Temperatue [°C]	Start Time [EDT]	End Time [EDT]	Duration [Sec]	Injection Start [EDT]	Injection Duration [Min]	Injection Rate [lpm]
6/20/2018	1	-11.0	10:15:00 AM	10:30:00 AM	900	10:13:00 AM	10	1
-11˚C	2	-11.0	10:35:00 AM	10:46:00 AM	629			
	3	-11.0	10:47:00 AM	11:10:00 AM	1330	10:48:00 AM	5	1
	4	-11.0	11:11:00 AM	11:44:00 AM	1800	11:13:00 AM	2	1
	5	-11.0	11:57:00 AM	12:13:00 PM	720			
	6	-11.0	12:13:00 PM	12:44:00 PM	1800	12:14:00 PM	10	1
	7	-11.0	12:47:00 PM	01:18:00 PM	1800	12:48:00 PM	6	1
	8	-11.0	01:19:00 PM	02:43:00 PM	1800	01:20:00 PM	2.5	1
	9	-11.0	03:20:00 PM	03:46:00 PM	1547	03:25:00 PM	2.5	1
	10	-11.0	03:47:00 PM	04:06:00 PM	1119	03:48:00 PM	0.5	n/a
	11	-11.0	04:08:00 PM	04:29:00 PM	1011	04:09:00 PM	5	1
	12	-11.0	04:31:00 PM	05:08:00 PM	1800	04:34:00 PM	10	1
6/21/2018	1	-5.8	11:31:00 AM	12:05:00 PM	1799	11:33:00 AM	10	1
-5.8˚C	2	-5.8	12:06:00 PM	12:29:00 PM	1390	12:07:00 PM	5	1
	3	-5.8	12:30:00 PM	12:47:00 PM	994	12:32:00 PM	2.5	1
	4	-5.8	12:48:00 PM	01:09:00 PM	1254	12:49:00 PM	5	2
	5	-5.8	01:18:00 PM	01:31:00 PM	766	01:19:00 PM	10	2
	5D	-5.8	01:32:00 PM	01:52:00 PM	1186			
	6	-5.8	02:17:00 PM	02:45:00 PM	1657	02:18:00 PM	2.5	1
	7	-5.8	02:47:00 PM	03:13:00 PM	1501	02:48:30 PM	5	1
	8	-5.8	03:13:00 PM	03:48:00 PM	1800	03:14:00 PM	10	1
	9	-5.8	03:49:00 PM	04:22:00 PM	1800	03:50:00 PM	10	2
	10	-5.8	04:23:00 PM	04:47:00 PM	1454	04:24:00 PM	5	1
	11	-5.8	04:48:00 PM	05:10:00 PM	2331	04:49:00 PM	n/a	2
6/22/2018	1	-3.2	09:27:00 AM	09:57:00 AM	1800	09:30 & 9:43 AM	2.5 & 10	1
-3.2˚C	2	-3.2	10:21:00 AM	10:45:00 AM	1471	10:17:00 AM	10	2
	3	-3.2	10:46:00 AM	11:12:00 AM	1548	10:47:00 AM	6	2
	4	-3.2	11:13:00 AM	11:33:00 AM	1206	11:14:00 AM	5	1
	5	-3.2	11:34:00 AM	11:54:00 AM	1193	11:35:00 AM	2.5	2
	6	-3.2	01:12:00 PM	01:38:00 PM	1566	01:14 & 01:21 PM	3.5 & 10	1 & 2
	7	-3.2	01:54:00 PM	02:03:00 PM	556	01:55:00 PM	5.5	2
	8	-3.2	02:16:00 PM	02:35:00 PM	1171	02:18:00 PM	6	n/a
	9	-3.2	02:41:00 PM	03:09:00 PM	1685	02:44:00 PM	13	2
	10	-3.2	03:14:00 PM	03:37:00 PM	1364	03:16:00 PM	3	1
	11	-3.2	03:38:00 PM	03:53:00 PM	930	03:39:00 PM	2.5	2
	12	-3.2	03:54:00 PM	04:22:00 PM	1683	03:56:00 PM	5	3