

Supplemental Material

Particulate matter concentration and composition in the New York City subway system

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Line #1

Samples for line #1 were collected on 10th December 2021. Among all nine lines, the #1 line has the most polluted stations, where the average on-platform concentration of its 37 stations (30 underground and 7 aboveground stations) was $167 \pm 24 \mu\text{g}/\text{m}^3$. The average concentrations of the platforms of underground (South Ferry to 191 Street station) and aboveground stations (Dyckman Street to 242 Street station) were $194 \pm 27 \mu\text{g}/\text{m}^3$ and $46 \pm 12 \mu\text{g}/\text{m}^3$, respectively (figure S1). With this train, end-to-end travel takes around one hour, where riders are exposed to, on average $99 \pm 7 \mu\text{g}/\text{m}^3$ $\text{PM}_{2.5}$ onboard. The concentration varies quite significantly inside train cars throughout the travel, as well as on the platforms. #1 train's platform of 181st street station in uptown Manhattan was found to be the most polluted station in the NYC subway system, with an average concentration of $600 \pm 84 \mu\text{g}/\text{m}^3$. The next station, 168th street station, was the second most polluted station, with a concentration of $557 \pm 71 \mu\text{g}/\text{m}^3$.

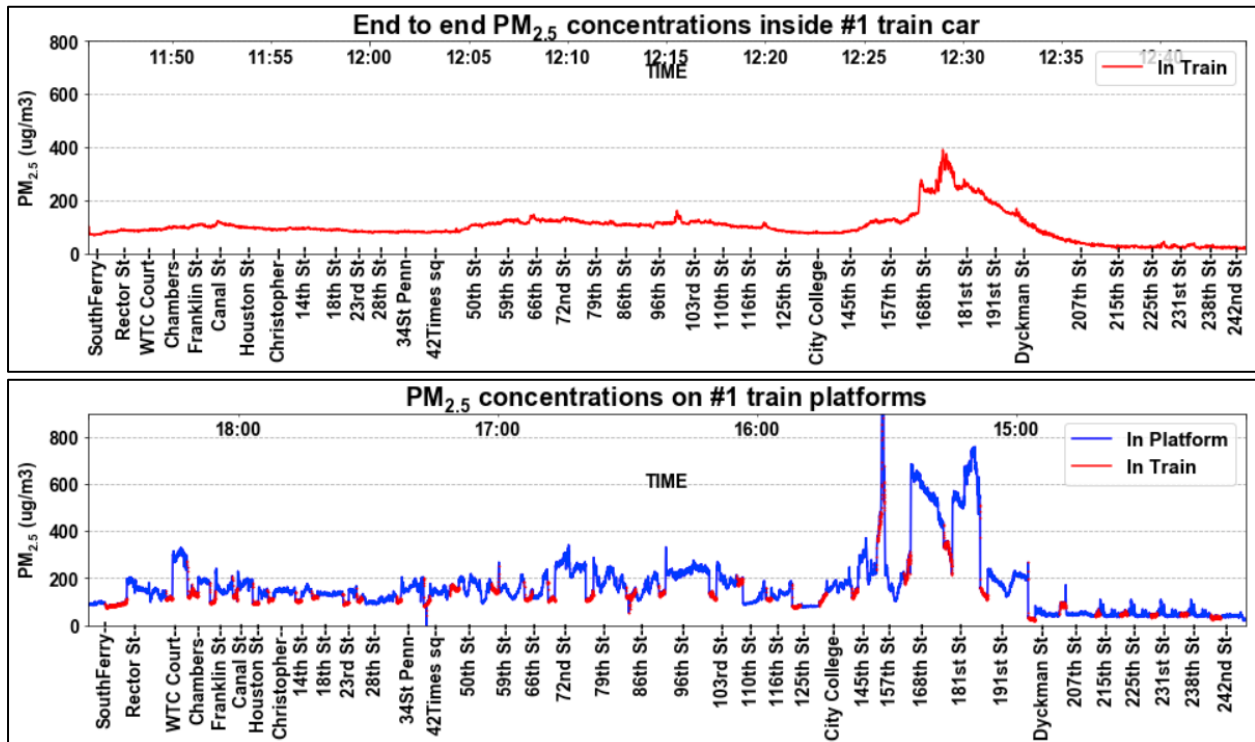


Figure S1: (top) $\text{PM}_{2.5}$ concentration inside train car for the end-to-end trip of a #1 train. Measurements started from South Ferry station at 11:45 AM. (bottom) $\text{PM}_{2.5}$ concentration on the platforms (blue color) of the #1 train. The red color in the plot represents the on-train samples while traveling between stations. Sampling started from 242nd Street station at 2:00 PM.

Table S1: Sampling time and PM_{2.5} concentration of each station of line #1

Station name	Location	PM _{2.5} Concentration (µg/m ³)		sample start (hh:mm:ss)	sample end (hh:mm:ss)
		Mean	SD		
242nd St	Aboveground	37.1	6.0	14:07:04	14:12:52
238th St	Aboveground	48.0	13.4	14:15:13	14:20:34
231st St	Aboveground	48.0	13.4	14:22:11	14:27:32
225th St	Aboveground	48.0	13.4	14:29:04	14:34:25
215th St	Aboveground	47.9	14.2	14:36:12	14:40:49
207th St	Aboveground	48.1	13.3	14:41:51	14:48:42
Dyckman St	Aboveground	48.8	11.9	14:50:07	14:55:46
191st St	Underground	190.6	32.0	14:57:26	15:06:45
181st St	Underground	599.3	83.9	15:08:31	15:14:53
168th St	Underground	557.2	70.7	15:16:58	15:24:30
157th St	Underground	173.1	52.8	15:26:06	15:30:29
145th St	Underground	251.8	46.2	15:32:24	15:36:47
City College	Underground	168.1	16.2	15:38:10	15:44:04
125th St	Underground	80.3	5.8	15:45:43	15:50:04
116th St	Underground	135.5	18.4	15:51:58	15:56:48
110th St	Underground	111.5	26.8	15:57:55	16:03:24
103rd St	Underground	193.4	28.6	16:04:44	16:09:28
96th St	Underground	227.3	22.9	16:11:05	16:21:28
86th St	Underground	160.0	34.6	16:22:47	16:28:14
79th St	Underground	193.4	31.3	16:30:20	16:37:53
72nd St	Underground	252.2	24.7	16:39:41	16:46:45
66th St	Underground	152.8	40.7	16:48:30	16:52:10
59th St	Underground	151.2	27.9	16:53:56	16:59:46
50th St	Underground	161.8	33.5	17:01:33	17:09:02
42Times sq	Underground	139.6	12.4	17:11:04	17:15:42
34St Penn	Underground	163.4	18.4	17:17:15	17:22:22
28th St	Underground	107.3	12.6	17:23:30	17:31:26
23rd St	Underground	142.3	13.4	17:32:40	17:34:29
18th St	Underground	132.3	4.8	17:35:53	17:41:45
14th St	Underground	147.6	13.9	17:43:04	17:45:27
Christopher	Underground	144.4	9.3	17:46:54	17:51:58
Houston St	Underground	137.7	14.4	17:53:16	17:55:21
Canal St	Underground	177.9	15.9	17:56:45	18:00:09
Franklin St	Underground	157.6	24.1	18:01:22	18:05:18
Chambers	Underground	186.4	11.7	18:06:36	18:09:20
WTC Court	Underground	289.8	33.4	18:11:52	18:15:16
Rector St	Underground	151.1	23.2	18:16:48	18:25:50

Line #3

Samples for line #3 were collected on 10th December 2021. We started on-train measurements during the morning rush from New Lots Avenue, and from noon we started on-platform measurements from 148th Station (figure S2). The onboard concentration of the express subway line #3 is quite high, with an average of $101 \pm 20 \mu\text{g}/\text{m}^3$. The onboard concentration inside the train peaks when it approaches stations such as Borough Hall ($132 \pm 6 \mu\text{g}/\text{m}^3$), Wall Street ($143 \pm 18 \mu\text{g}/\text{m}^3$), 96th street ($131 \pm 18 \mu\text{g}/\text{m}^3$), Hoyt Street ($126 \pm 6 \mu\text{g}/\text{m}^3$). Looking at the on-platform concentrations, Borough Hall was found to be the most polluted station of this line, where the average concentration was $311 \pm 41 \mu\text{g}/\text{m}^3$, followed by 72nd street ($232 \pm 24 \mu\text{g}/\text{m}^3$), Hoyt Street ($219 \pm 12 \mu\text{g}/\text{m}^3$), 96th Street ($212 \pm 16 \mu\text{g}/\text{m}^3$), and Wall Street ($199 \pm 43 \mu\text{g}/\text{m}^3$). The average concentration on the platforms of underground stations of line #3 was $145 \pm 21 \mu\text{g}/\text{m}^3$. Surprisingly, both the on-board and on-platform concentrations were high for aboveground stations between New Lots Avenue and Sutter Ave-Rutland Road. This may cause by the heavy on-road construction works below the stations that took place during the time of sampling.

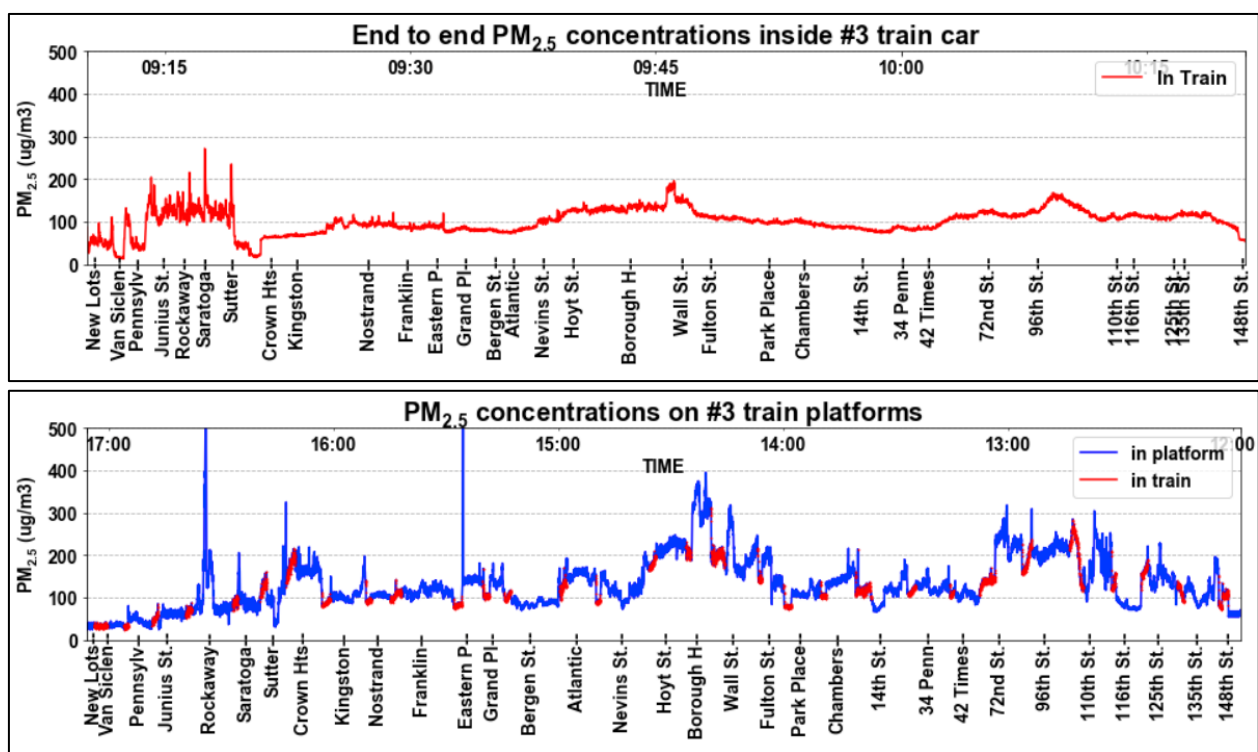


Figure S2: (top) PM_{2.5} concentration inside train car for the end-to-end trip of a #3 train. Measurements started from New Lots Avenue station at 9:10 AM. (bottom) PM_{2.5} concentration on the platforms (blue color) of the #3 train. The red color in the plot represents the on-train samples while traveling between stations. Sampling started from 148th Street station at 12:00 PM.

Table S2: Sampling time and PM_{2.5} concentration of each station of line #3

Station name	Location	PM _{2.5} Concentration (µg/m ³)		sample start (hh:mm:ss)	sample end (hh:mm:ss)
		Mean	SD		
148th St.	Underground	58.5	7.1	11:57:57	12:01:08
135th St.	Underground	114.5	27.8	12:03:49	12:13:02
125th St.	Underground	146.1	23.9	12:14:52	12:22:44
116th St.	Underground	81.5	12.1	12:24:29	12:31:11
110th St.	Underground	181.4	47.2	12:32:27	12:39:55
96th St.	Underground	212.0	15.7	12:43:36	12:53:39
72nd St.	Underground	232.7	24.4	12:56:20	13:03:24
42 Times	Underground	105.9	10.2	13:07:32	13:14:32
34 Penn	Underground	125.7	13.1	13:15:33	13:24:36
14th St.	Underground	109.2	26.9	13:26:41	13:36:31
Chambers	Underground	143.3	13.1	13:40:47	13:48:30
Park Place	Underground	111.7	11.0	13:50:07	13:57:44
Fulton St.	Underground	157.2	34.1	13:59:49	14:05:37
Wall St.	Underground	199.3	43.4	14:06:48	14:15:33
Borough H	Underground	311.0	41.4	14:19:16	14:24:37
Hoyt St.	Underground	219.7	12.0	14:25:59	14:33:54
Nevins St.	Underground	123.8	28.6	14:35:43	14:48:42
Atlantic	Underground	152.7	9.9	14:49:59	14:57:49
Bergen St.	Underground	87.8	11.4	14:59:36	15:12:38
Grand Pl	Underground	137.2	14.5	15:14:21	15:18:19
Eastern P	Underground	144.2	34.1	15:20:11	15:25:36
Franklin	Underground	114.9	10.1	15:28:00	15:41:47
Nostrand	Underground	104.5	4.4	15:44:53	15:49:54
Kingston	Underground	108.0	20.4	15:51:23	16:00:44
Crown Hts	Underground	163.4	15.6	16:03:04	16:10:04
Sutter	Aboveground	96.5	39.9	16:12:33	16:17:45
Saratoga	Aboveground	90.2	23.1	16:19:27	16:25:28
Rockaway	Aboveground	110.7	84.6	16:26:51	16:37:40
Junius St.	Aboveground	58.4	9.7	16:39:24	16:46:44
Pennsylv	Aboveground	44.2	9.8	16:48:22	16:54:42
Van Siclen	Aboveground	34.5	3.4	16:55:51	17:00:20

Line #5

Samples for line #3 were collected on 11th October 2021. The on-train and on-platform measurements were initiated from Flatbush and Eastchester Dyre Avenue, respectively. This line has a total of thirty-six stations, thirteen of which are elevated stations (from Jackson Avenue to Eastchester Dyre Avenue station), and the rest twenty-three are underground stations (from Flatbush Avenue to 3 Av-149 Street station) (figure S3). The average $PM_{2.5}$ concentration for the elevated stations is $16 \pm 5 \mu\text{g}/\text{m}^3$, but for the underground stations, the average is $162 \pm 28 \mu\text{g}/\text{m}^3$. Among the stations, the Bowling Green was found to be the most polluted, with an average concentration of $384 \pm 43 \mu\text{g}/\text{m}^3$. Other polluted stations include 125th Street ($256 \pm 20 \mu\text{g}/\text{m}^3$) and 149th Street ($237 \pm 31 \mu\text{g}/\text{m}^3$). For a Bronx-bound #5 train, the onboard concentration starts to elevate after it crosses Atlantic Avenue station, and it remains high until the train reaches the aboveground stations in the Bronx. The average onboard concentration for an end-to-end trip is $50 \pm 5 \mu\text{g}/\text{m}^3$.

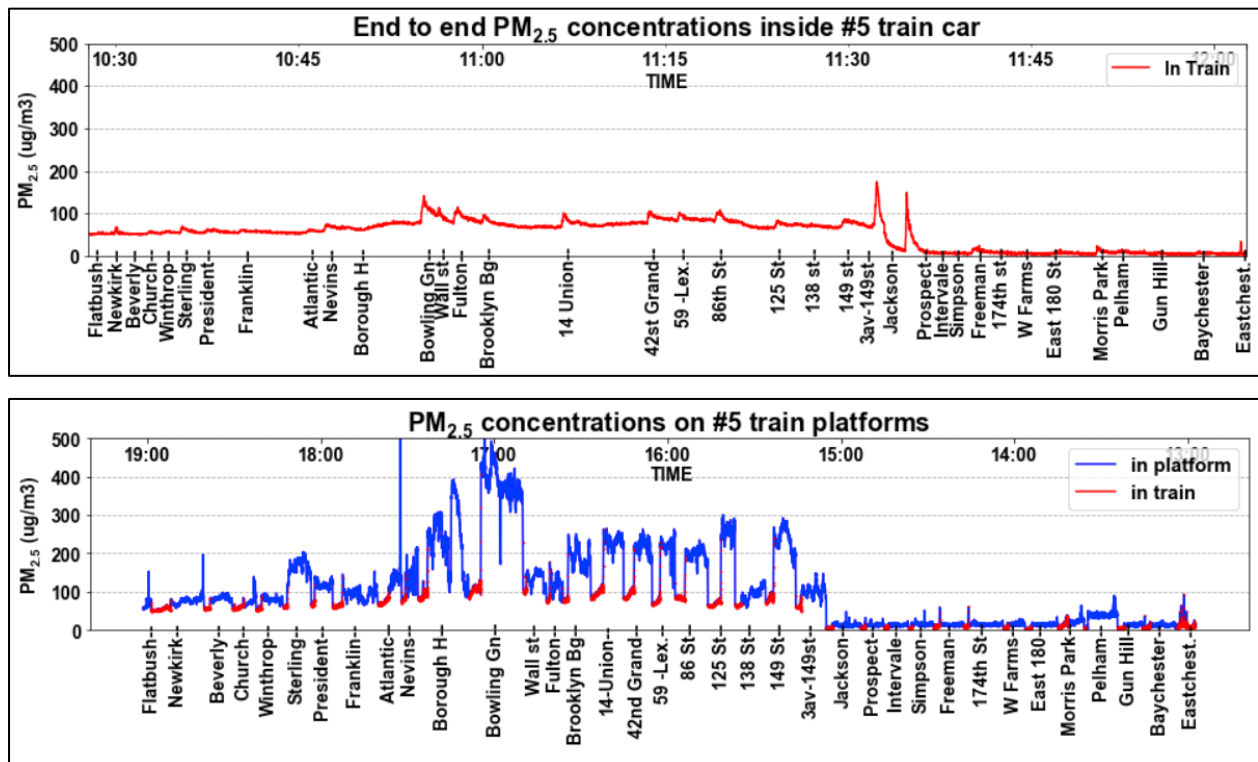


Figure S3: (top) $PM_{2.5}$ concentration inside train car for the end-to-end trip of a #5 train. Measurements started from Flatbush Avenue station at 10:30 AM. (bottom) $PM_{2.5}$ concentration on the platforms (blue color) of the #5 train. The red color in the plot represents the on-train samples while traveling between the stations. Sampling started from Eastchester – Dyre Avenue at 1:00 PM.

Table S3: Sampling time and PM_{2.5} concentration of each station of line #5

Station name	Location	PM _{2.5} Concentration (µg/m ³)		sample start (hh:mm:ss)	sample end (hh:mm:ss)
		Mean	SD		
Eastchest.	Aboveground	10.7	2.9	12:57:17	12:57:37
Baychester	Aboveground	12.5	2.9	13:03:56	13:13:11
Gun Hill	Aboveground	13.1	2.9	13:15:54	13:22:10
Pelham	Aboveground	36.2	11.0	13:24:24	13:35:37
Morris Park	Aboveground	23.5	10.6	13:36:02	13:41:37
East 180	Aboveground	13.4	2.6	13:45:07	13:54:12
W Farms	Aboveground	15.2	3.2	13:56:23	14:02:23
174th St	Aboveground	14.9	4.6	14:04:01	14:15:59
Freeman	Aboveground	14.1	4.9	14:17:40	14:25:54
Simpson	Aboveground	15.3	3.6	14:28:02	14:35:37
Intervale	Aboveground	12.4	2.4	14:36:44	14:43:50
Prospect	Aboveground	13.9	4.0	14:45:12	14:51:38
Jackson	Aboveground	13.4	4.4	14:53:10	15:02:58
3av-149st	Underground	100.9	17.0	15:05:07	15:13:38
149 St	Underground	237.3	31.7	15:15:41	15:23:17
138 St	Underground	95.3	17.6	15:26:07	15:34:32
125 St	Underground	256.3	20.5	15:36:41	15:41:28
86 St	Underground	196.1	16.7	15:46:03	15:53:53
59 -Lex.	Underground	210.0	30.5	15:57:27	16:02:25
42nd Grand	Underground	214.2	21.2	16:05:21	16:11:28
14-Union	Underground	229.2	21.4	16:15:12	16:22:08
Brooklyn Bg	Underground	186.2	29.1	16:26:34	16:34:23
Fulton	Underground	115.4	27.0	16:36:14	16:40:40
Wall st	Underground	134.0	19.6	16:41:55	16:48:44
Bowling Gn	Underground	384.1	42.9	16:50:01	17:04:30
Borough H	Underground	237.1	80.5	17:08:51	17:22:58
Nevins	Underground	135.4	38.3	17:26:21	17:30:35
Atlantic	Underground	149.8	121.7	17:32:00	17:36:22
Franklin	Underground	91.4	13.8	17:40:17	17:52:22
President	Underground	118.6	9.5	17:55:50	18:01:59
Sterling	Underground	163.3	20.7	18:03:13	18:11:31
Winthrop	Underground	79.6	6.3	18:13:03	18:20:19
Church	Underground	75.1	12.6	18:22:17	18:26:43
Beverly	Underground	82.6	6.1	18:30:34	18:38:08
Newkirk	Underground	76.3	12.6	18:40:21	18:51:51

Line #6

For line #6, samples were collected in two days (7th and 8th December 2021), where both on-train and on-platform measurements show the concentration during morning rush hours. Measurements were initiated from Brooklyn Bridge City Hall station (figure S4). This line has ten aboveground stations (from Whitlock Avenue station to Pelham Bay Park), with an average concentration of $12 \pm 6 \mu\text{g}/\text{m}^3$. Compared to the aboveground stations, this line's twenty-seven underground stations, from Brooklyn Bridge City Hall in Lower Manhattan and Hunts Point in Bronx, has significantly high concentration averaging $159 \pm 19 \mu\text{g}/\text{m}^3$. The highest concentration was found in Bleecker Street station ($282 \pm 20 \mu\text{g}/\text{m}^3$), followed by 42nd Street Grand Central ($253 \pm 23 \mu\text{g}/\text{m}^3$), Canal Street ($246 \pm 29 \mu\text{g}/\text{m}^3$), 14th Street Union Square ($241 \pm 31 \mu\text{g}/\text{m}^3$). The average onboard concentration during train running underground is ($89 \pm 7 \mu\text{g}/\text{m}^3$), and

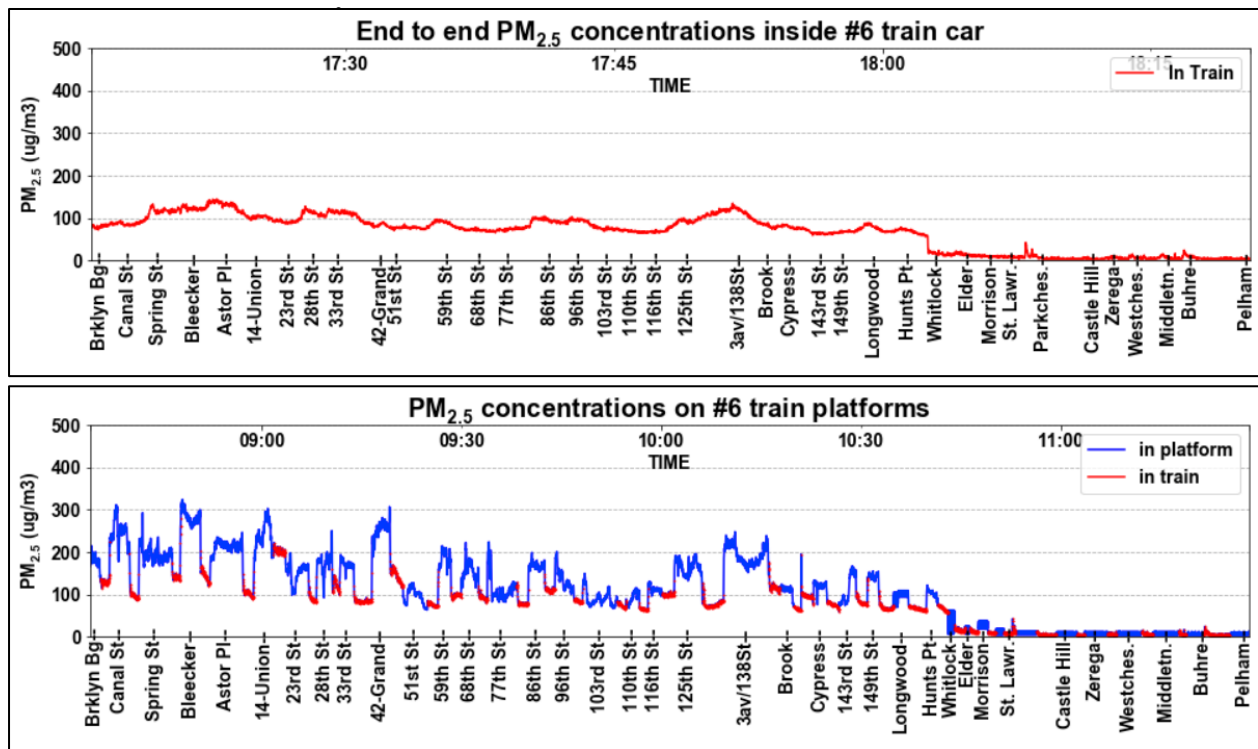


Figure S4: For #6 train, samples were collected in two days, where both on-train and on-platform measurements show the concentration during morning rush hours. (top) the On-train PM_{2.5} concentration for end-to-end trip of #6 train. Measurements were initiated from Brooklyn Bridge City Hall station. (bottom) PM_{2.5} concentration on the platforms (blue color) of the #6 train. Sampling was done on the following day from Brooklyn Bridge Station at 8:30 AM.

Table S4: Sampling time and PM_{2.5} concentration of each station of line #6

Station name	Location	PM _{2.5} Concentration (µg/m ³)		sample start (hh:mm:ss)	sample end (hh:mm:ss)
		Mean	SD		
Brklyn Bg	Underground	179.6	16.4	8:34:13	8:35:45
Canal St	Underground	246.0	29.3	8:37:09	8:40:06
Spring St	Underground	195.1	17.9	8:41:32	8:46:29
Bleecker	Underground	282.4	19.6	8:47:50	8:50:45
Astor Pl	Underground	212.2	15.3	8:52:12	8:57:06
14-Union	Underground	240.7	30.7	8:58:48	9:01:40
23rd St	Underground	151.2	23.1	9:03:31	9:06:59
28th St	Underground	172.9	24.5	9:08:14	9:10:31
33rd St	Underground	169.7	10.4	9:11:42	9:13:47
42-Grand	Underground	252.5	22.8	9:16:32	9:19:13
51st St	Underground	95.8	18.4	9:21:12	9:24:49
59th St	Underground	184.7	19.0	9:26:32	9:28:22
68th St	Underground	154.3	22.2	9:29:55	9:32:29
77th St	Underground	115.3	32.8	9:33:51	9:38:11
86th St	Underground	166.8	9.3	9:40:01	9:42:26
96th St	Underground	134.6	25.1	9:44:00	9:46:50
103rd St	Underground	90.5	18.1	9:48:12	9:53:20
110th St	Underground	91.6	12.8	9:54:42	9:56:39
116th St	Underground	112.1	8.1	9:58:01	10:00:03
125th St	Underground	164.3	16.0	10:01:57	10:06:05
3av/138St	Underground	192.1	21.9	10:09:21	10:16:03
Brook	Underground	109.4	10.2	10:17:47	10:19:50
Cypress	Underground	120.0	10.1	10:22:52	10:24:50
143rd St	Underground	111.8	33.5	10:26:41	10:29:12
149th St	Underground	142.5	9.2	10:31:01	10:32:36
Longwood	Underground	96.0	10.8	10:34:52	10:37:04
Hunts Pt	Underground	100.8	12.7	10:39:48	10:41:29
Whitlock	Aboveground	27.5	22.3	10:43:04	10:43:57
Elder	Aboveground	11.4	7.0	10:45:39	10:46:14
Morrison	Aboveground	28.2	7.5	10:47:35	10:48:59
St. Lawr.	Aboveground	8.4	4.1	10:50:13	10:56:19
Castle Hill	Aboveground	7.4	2.4	10:59:16	11:02:22
Zerega	Aboveground	7.4	2.5	11:03:31	11:06:56
Westches.	Aboveground	7.4	2.5	11:08:18	11:12:06
Middletn.	Aboveground	7.4	2.5	11:13:48	11:17:36
Buhre	Aboveground	5.3	2.2	11:18:49	11:27:26

Line B

Samples for line B were collected on 7th December 2021. Line B operates between Brighton Beach in Brooklyn (starting point for on-train samples) and Bedford Park Boulevard in Bronx (starting point for on-station samples). This line has five aboveground stations from Brighton Beach to Church Avenue. Similar to other lines, the average on-train concentration of $PM_{2.5}$ is $20 \pm 5 \mu\text{g}/\text{m}^3$ for aboveground, and $84 \pm 8 \mu\text{g}/\text{m}^3$ when the train runs underground (figure S5). However, extraordinary spikes in onboard concentration ($205 \pm 28 \mu\text{g}/\text{m}^3$) were found when the train passed the tunnel between W4 Street Washington Square and 42nd Street–Bryant Park stations. Looking at the on-platform measurements, we find the concentrations on the B train platforms are considerably lower than its counterparts, averaging $110 \pm 18 \mu\text{g}/\text{m}^3$ (only underground stations = $119 \pm 17 \mu\text{g}/\text{m}^3$). The highest concentration was found in Broadway–Lafayette station ($367 \pm 75 \mu\text{g}/\text{m}^3$), followed by 34th Street–Herald Square ($279 \pm 30 \mu\text{g}/\text{m}^3$), 42nd Street–Bryant Park ($176 \pm 19 \mu\text{g}/\text{m}^3$), 7th Avenue 53rd Street ($173 \pm 12 \mu\text{g}/\text{m}^3$).

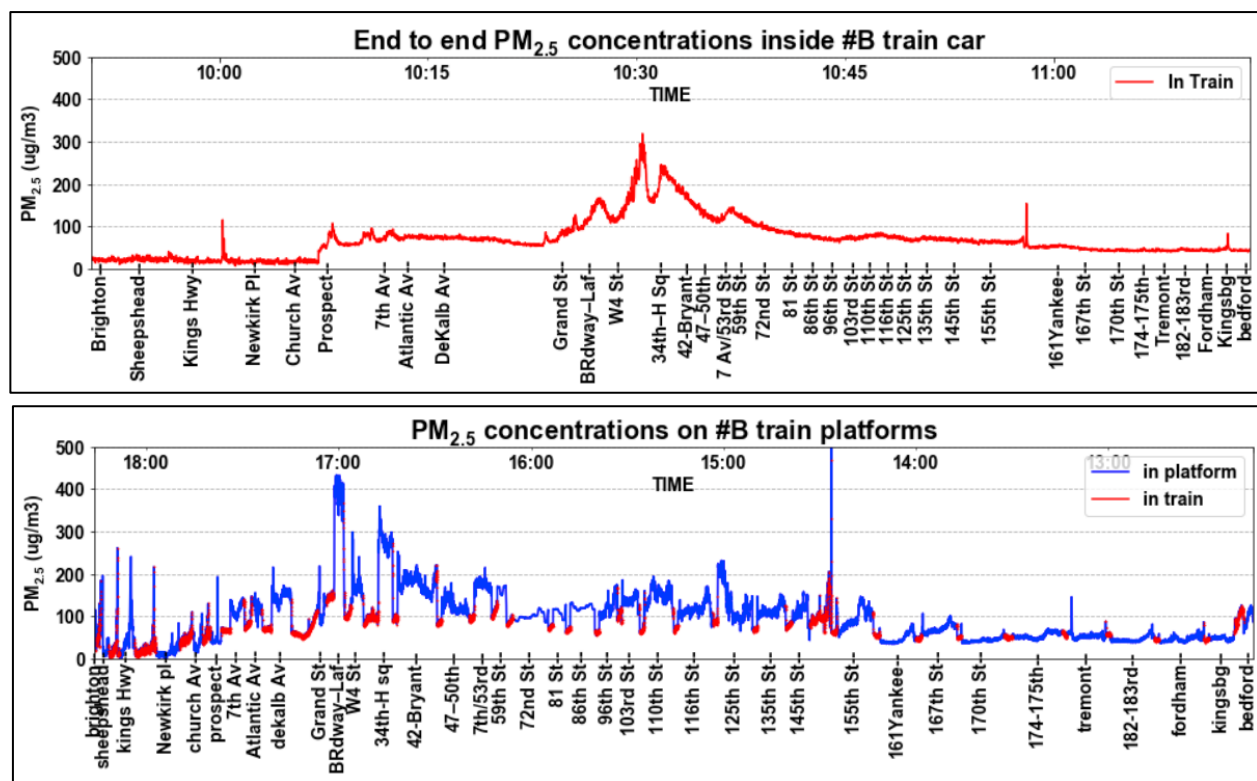


Figure S5: (top) $PM_{2.5}$ concentration inside train car for the end-to-end trip of a B train. Measurements started from Brighton Beach in Brooklyn at 9:45 AM. (bottom) $PM_{2.5}$ concentration on the platforms (blue color) of the B train. The red color in the plot represents the on-train samples while traveling between stations. Sampling started from Bedford Park Boulevard in Bronx at 1:00 PM.

Table S5: Sampling time and PM_{2.5} concentration of each station of line B

Station name	Location	PM _{2.5} Concentration (µg/m ³)		sample start (hh:mm:ss)	sample end (hh:mm:ss)
		Mean	SD		
bedford	Underground	96.7	17.3	12:14:58	12:17:51
kingsbg	Underground	47.9	3.8	12:20:48	12:28:46
fordham	Underground	46.1	6.2	12:30:20	12:44:17
182-183rd	Underground	45.5	6.7	12:45:49	12:59:25
tremont	Underground	54.0	10.3	13:00:51	13:13:01
174-175th	Underground	53.8	6.8	13:14:34	13:29:56
170th St	Underground	43.7	5.2	13:32:31	13:45:57
167th St	Underground	70.5	10.0	13:47:22	13:58:16
161Yankee	Underground	47.1	12.3	14:00:03	14:11:22
155th St	Underground	94.8	23.4	14:13:31	14:24:41
145th St	Underground	107.9	18.0	14:33:08	14:38:46
135th St	Underground	114.3	13.2	14:40:46	14:49:29
125th St	Underground	130.9	42.5	14:50:51	15:01:44
116th St	Underground	116.6	17.3	15:03:25	15:14:13
110th St	Underground	148.2	17.6	15:15:47	15:24:38
103rd St	Underground	137.8	12.6	15:26:14	15:31:38
96th St	Underground	121.3	21.1	15:33:10	15:38:39
86th St	Underground	121.7	5.3	15:40:09	15:47:44
81 St	Underground	108.1	10.0	15:49:08	15:53:06
72nd St	Underground	99.2	8.3	15:54:41	16:05:39
59th St	Underground	161.7	10.9	16:07:38	16:10:30
7th/53rd	Underground	173.2	11.8	16:12:15	16:17:42
47-50th	Underground	124.9	15.8	16:19:23	16:27:52
42-Bryant	Underground	176.5	19.0	16:29:42	16:41:36
34th-H sq	Underground	279.1	29.6	16:43:13	16:47:36
W4 St	Underground	167.8	30.7	16:52:18	16:56:06
BRdway-Laf	Underground	367.2	74.5	16:58:27	17:01:36
Grand St	Underground	115.2	24.2	17:03:49	17:06:39
dekalb Av	Underground	145.9	15.2	17:14:47	17:20:54
Atlantic Av	Underground	121.1	14.8	17:23:55	17:27:06
7th Av	Underground	114.5	14.2	17:29:43	17:33:46
prospect	Underground	43.2	14.0	17:36:38	17:39:56
church Av	Aboveground	40.4	19.3	17:42:28	17:45:36
Newkirk pl	Aboveground	15.8	11.5	17:49:38	17:56:56
kings Hwy	Aboveground	50.4	49.2	18:03:34	18:08:15
sheepshead	Aboveground	45.3	42.1	18:11:39	18:16:00

Line C

Line C runs fully underground from Euclid Avenue in Brooklyn to 168th Street in upper Manhattan (figure S6). Measurements for this line are done in two days. On the first day (7th December 2021), starting at noon, on-platform measurement was conducted from 168th Street station. On the following day (8th December 2021), onboard concentration was measured during the evening rush starting from Euclid Avenue. For the on-train measurement, the highest concentration inside the train was found when the train moved through the tunnels between Jay Street MetroTech and Fulton Street. During this period, the average onboard concentration was $154 \pm 8 \mu\text{g}/\text{m}^3$. The average on-platform concentration of C line is $146 \pm 23 \mu\text{g}/\text{m}^3$. The top five stations of C line with the highest PM_{2.5} concentrations are: High Street ($360 \pm 131 \mu\text{g}/\text{m}^3$), Lafayette Avenue ($295 \pm 47 \mu\text{g}/\text{m}^3$), Fulton Street ($290 \pm 108 \mu\text{g}/\text{m}^3$), 59th Street ($204 \pm 6 \mu\text{g}/\text{m}^3$), and Jay Street MetroTech ($204 \pm 55 \mu\text{g}/\text{m}^3$).

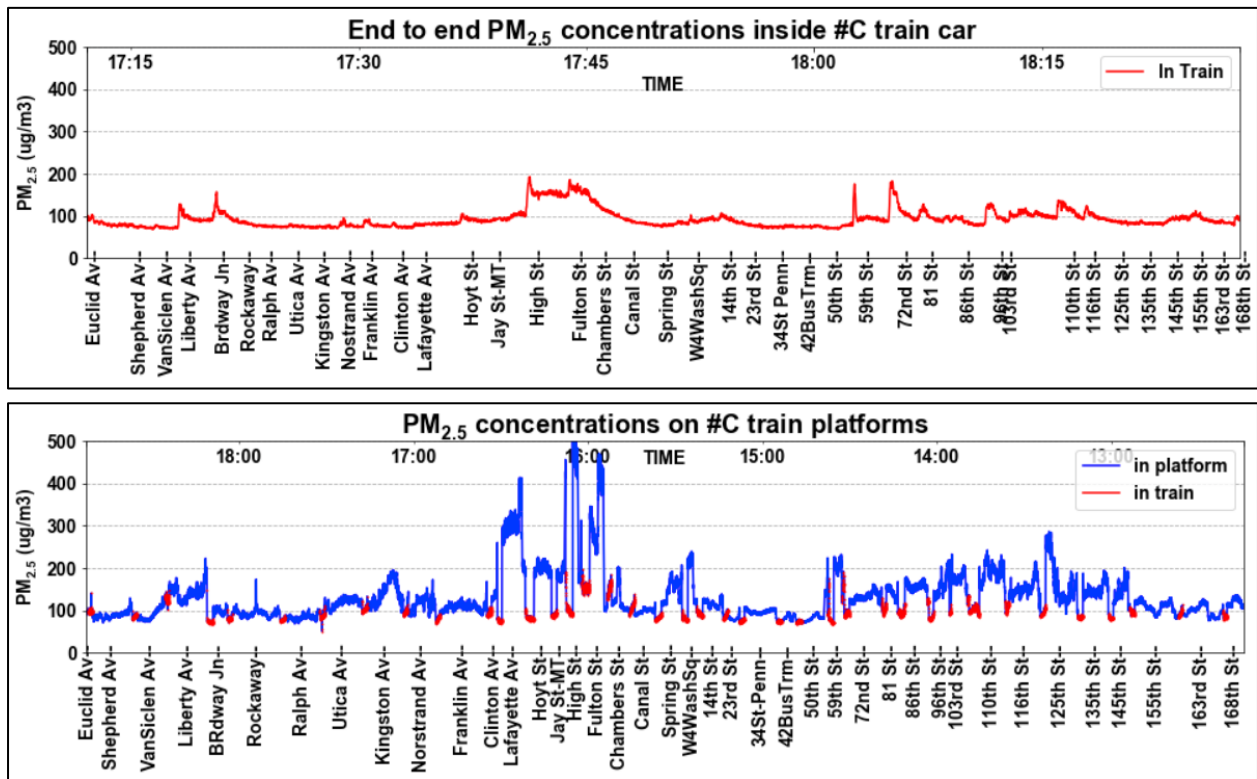


Figure S6: Measurements for C line are done in two days. On the first day, onboard concentration was measured during the evening rush starting from Euclid Avenue. On the following day, starting at noon, on-platform measurement was conducted from 168th Street station. (top) shows the on-train and (bottom) shows the on-platform measurements

Table S6: Sampling time and PM_{2.5} concentration of each station of line C

Station name	Location	PM _{2.5} Concentration (µg/m ³)		sample start (hh:mm:ss)	sample end (hh:mm:ss)
		Mean	SD		
168th St	Underground	119.4	8.6	12:14:31	12:20:10
163rd St	Underground	97.2	12.8	12:21:35	12:35:32
155th St	Underground	107.9	13.2	12:36:59	12:51:57
145th St	Underground	142	20.3	12:53:38	12:59:14
135th St	Underground	149.1	15.4	13:01:02	13:09:45
125th St	Underground	168.4	49.6	13:11:38	13:22:31
116th St	Underground	151.8	20.2	13:24:22	13:35:10
110th St	Underground	188.6	20.6	13:36:33	13:45:24
103rd St	Underground	176.5	14.7	13:49:36	13:55:00
96th St	Underground	157.3	24.7	13:55:39	14:01:07
86th St	Underground	157.6	8.5	14:03:22	14:10:57
81 St	Underground	142.3	12.9	14:13:22	14:17:20
72nd St	Underground	131.4	10.4	14:19:02	14:30:00
59th St	Underground	204.6	14.2	14:32:35	14:35:27
50th St	Underground	89.8	24.9	14:37:33	14:46:31
42BusTrm	Underground	83.2	6.7	14:48:22	14:53:20
34St-Penn	Underground	97	4.9	14:55:09	15:06:07
23rd St	Underground	80.6	5	15:07:56	15:11:54
14th St	Underground	115.9	8.9	15:13:31	15:20:29
W4WashSq	Underground	180.7	45.1	15:22:38	15:25:36
Spring St	Underground	145.9	24.1	15:27:41	15:34:39
Canal St	Underground	98	5.6	15:36:55	15:43:53
Chambers St	Underground	123.8	29.4	15:45:49	15:51:47
Fulton St	Underground	290.1	108.1	15:53:24	15:59:22
High St	Underground	360.2	131.5	16:02:13	16:05:11
Jay St-MT	Underground	203.9	55.2	16:07:44	16:10:42
Hoyt St	Underground	198.3	11	16:12:33	16:18:31
Lafayette Av	Underground	294.6	46.8	16:21:34	16:29:32
Clinton Av	Underground	143.8	31.2	16:31:08	16:33:06
Franklin Av	Underground	107.1	9.2	16:34:44	16:50:55
Norstrand Av	Underground	115.8	16.5	16:52:21	17:02:07
Kingston Av	Underground	139.6	26.9	17:03:33	17:15:55
Utica Av	Underground	117.5	10.1	17:17:49	17:30:27
Ralph Av	Underground	83.6	6.7	17:32:15	17:44:09
Rockaway	Underground	92.5	8.7	17:45:53	18:02:25
BRdway Jn	Underground	99.3	8.3	18:04:01	18:08:56
Liberty Av	Underground	143.2	17.5	18:11:01	18:24:02
VanSiclen Av	Underground	90	14.2	18:25:34	18:35:07
Shepherd Av	Underground	88.6	8.5	18:36:49	18:50:18

Line F

On 11th October 2021, we started the on-train measurements from Coney Island in Brooklyn at 10:00 am and on-platform samples from 169th Street station in Queens from around 1:30 pm of the same day (figure S7). There are 15 aboveground stations and 30 underground stations on this line. One complete run from start to end station takes around 110 minutes, where passengers are exposed to an average of $53 \pm 7 \mu\text{g}/\text{m}^3$ $\text{PM}_{2.5}$ inside train cars. Onboard concentration is much higher when the train moves underground stations between East Broadway station and 47-50 street station. Again, we have observed substantial variation in concentration for different stations during on-platform measurements. Like other lines, the aboveground stations of F have low $\text{PM}_{2.5}$ with an average of $23 \pm 6 \mu\text{g}/\text{m}^3$. However, the average concentration for underground stations is $123 \pm 28 \mu\text{g}/\text{m}^3$. Among all stations of the F train, the platform of the 2nd Avenue station provided the highest concentration value of $273 \pm 32 \mu\text{g}/\text{m}^3$. Several stations also showed high concentrations, such as, East Broadway ($253 \pm 65 \mu\text{g}/\text{m}^3$), York Street ($246 \pm 41 \mu\text{g}/\text{m}^3$), W4 Street-Washington Square ($194 \pm 45 \mu\text{g}/\text{m}^3$).

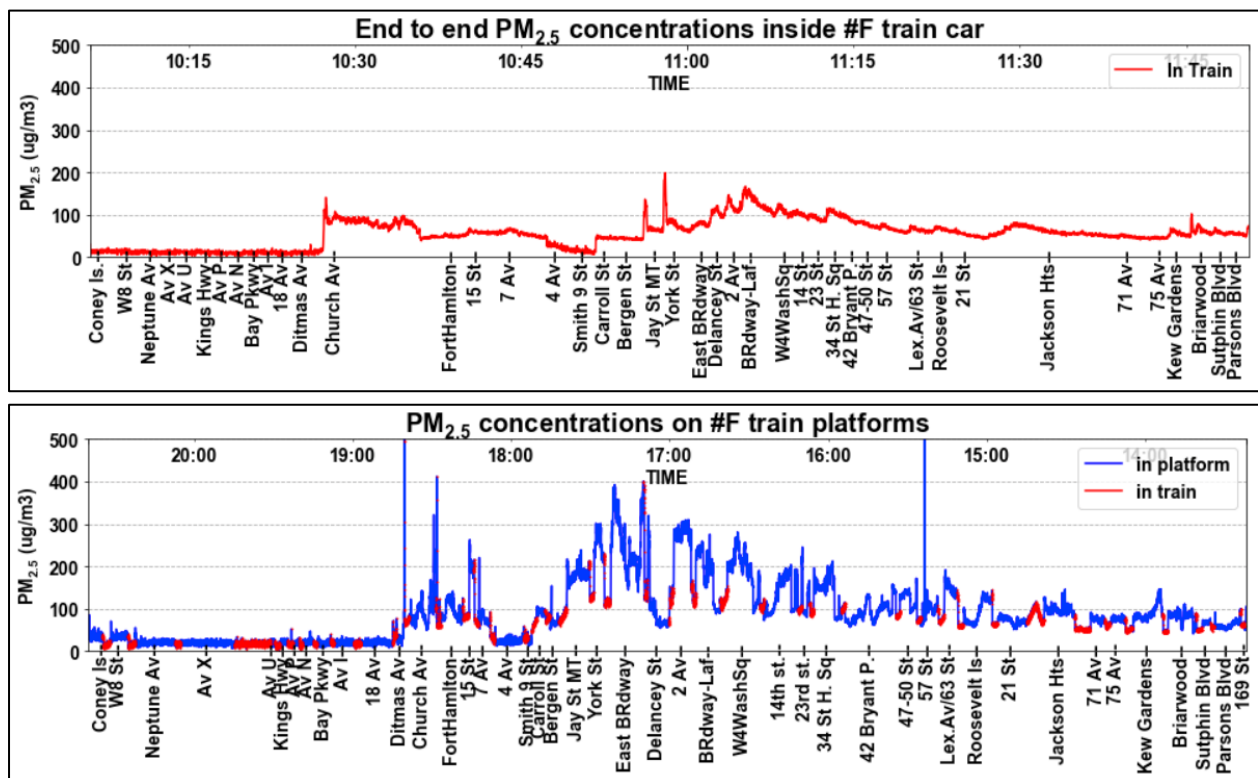


Figure S7: (top) $\text{PM}_{2.5}$ concentration inside train car for the end-to-end trip of a F train. Measurements started from Coney Island in Brooklyn at 10:00 AM. (bottom) $\text{PM}_{2.5}$ concentration on the platforms (blue color) of the #F train. The red color in the plot represents the on-train samples while traveling between stations. Sampling started from 169th Street station in Queens at 1:30 PM.

Table S7: Sampling time and PM_{2.5} concentration of each station of line F

Station name	Location	PM _{2.5} Concentration (µg/m ³)		sample start (hh:mm:ss)	sample end (hh:mm:ss)
		Mean	SD		
169 St	Underground	61.2	10.7	13:21:48	13:22:23
Parsons Blvd	Underground	61.5	7.4	13:24:04	13:33:45
Sutphin Blvd	Underground	66.8	5.7	13:35:15	13:38:31
Briarwood	Underground	80.9	15	13:40:52	13:51:34
Kew Gardens	Underground	90.1	19.3	13:53:28	14:04:50
75 Av	Underground	74.6	5.1	14:07:41	14:13:25
71 Av	Underground	73.8	7.7	14:15:23	14:20:52
Jackson Hts	Underground	98.2	9.8	14:26:49	14:38:23
21 St	Underground	71.7	7.8	14:44:49	14:56:03
Roosevelt Is	Underground	91.6	26.8	14:58:08	15:08:56
Lex.Av/63 St	Underground	144.4	19.8	15:11:11	15:16:13
57 St	Underground	101.8	79.8	15:18:31	15:25:00
47-50 St	Underground	125.1	19.2	15:26:22	15:32:48
42 Bryant P.	Underground	92.7	22.2	15:34:25	15:53:35
34 St H. Sq	Underground	143.8	38.3	15:55:04	16:05:27
23rd st.	Underground	125	47	16:07:06	16:10:03
14th st.	Underground	134.6	39.8	16:11:28	16:24:19
W4WashSq	Underground	194	45.3	16:25:53	16:38:08
BRdway-Laf	Underground	179	56.7	16:40:55	16:50:06
2 Av	Underground	273.4	32	16:51:56	16:58:44
Delancey St	Underground	97.8	60.6	17:00:20	17:08:34
East BRdway	Underground	253.3	65.3	17:09:53	17:22:33
York St	Underground	246.1	40.7	17:25:02	17:28:54
Jay St MT	Underground	180.1	19.6	17:30:36	17:39:08
Bergen St	Underground	70	13.2	17:41:59	17:45:30
Carroll St	Underground	91.5	7.5	17:47:15	17:50:26
Smith 9 St	Aboveground	25.2	7.1	17:52:16	17:53:46
4 Av	Aboveground	23.8	5.7	17:55:28	18:06:17
7 Av	Underground	77.1	19.7	18:08:08	18:12:30
15 St	Underground	189.1	42.9	18:14:17	18:16:09
FortHamilton	Underground	95.4	20.8	18:18:35	18:26:43
Church Av	Underground	94	31	18:28:39	18:38:39
Ditmas Av	Aboveground	33	13.4	18:40:37	18:43:29
18 Av	Aboveground	20.7	4.4	18:45:05	18:56:59
Av I	Aboveground	20.1	4.1	18:59:43	19:07:07
Bay Pkwy	Aboveground	18.7	4.2	19:08:31	19:13:31
Av N	Aboveground	21.1	4.7	19:15:01	19:18:59
Av P	Aboveground	19.4	4.2	19:20:25	19:22:45
Kings Hwy	Aboveground	20.9	4.7	19:24:47	19:27:33
Av U	Aboveground	19.1	4.2	19:29:31	19:31:10
Av X	Aboveground	19.2	3.9	19:44:46	20:05:15
Neptune Av	Aboveground	20.7	4.9	20:07:15	20:22:24
W8 St	Aboveground	34.7	6.5	20:25:18	20:31:57

Line R

Samples for line R were collected on 10th December 2021. We sampled both the on-train (starting from Bay Ridge 95th Street) and the on-station (from Forest Hills) measurements on a single day (figure S8). R line operates completely underground, and we observed a constant level of PM_{2.5} concentration for on-train measurements. The average concentration inside the train car was $83 \pm 5 \mu\text{g}/\text{m}^3$. On the contrary, the average concentration on R train station platforms was found to be $121 \pm 18 \mu\text{g}/\text{m}^3$.

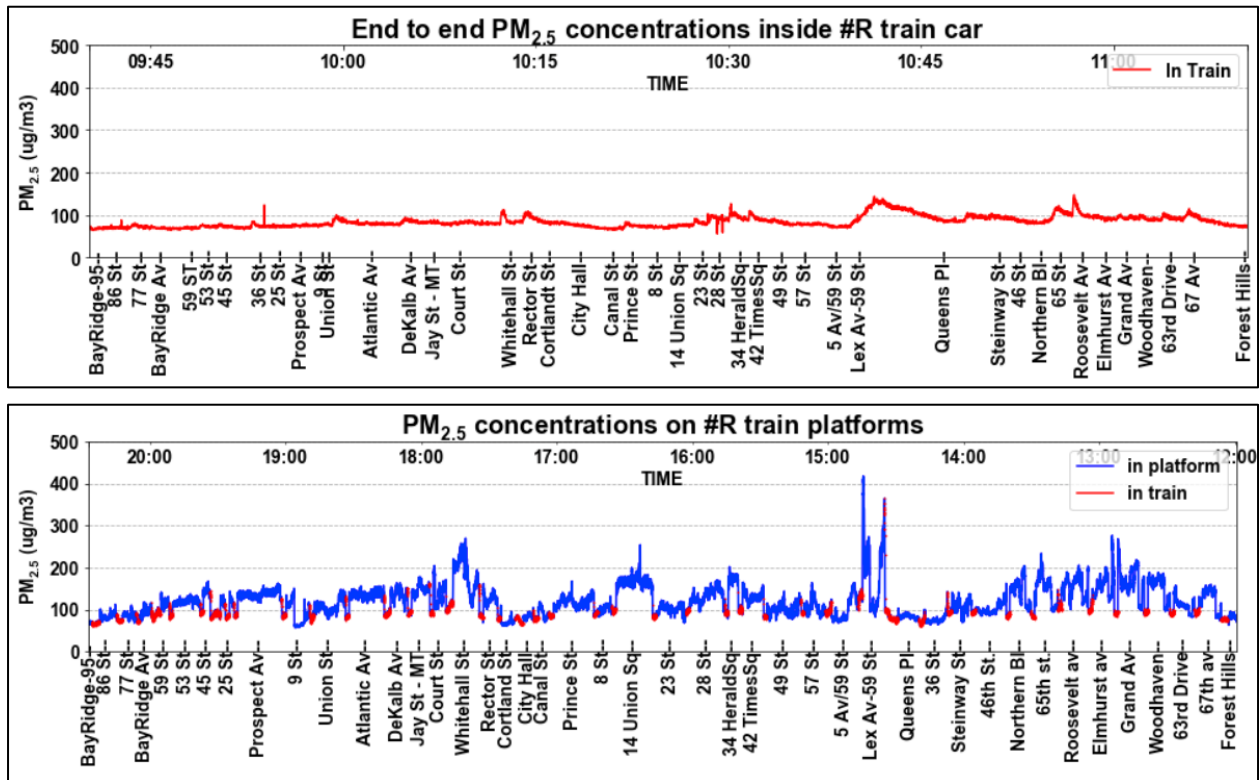


Figure S8: (top) PM_{2.5} concentration inside train car for the end-to-end trip of a R train. Measurements started from Bay Ridge 95th Street in Brooklyn at 9:40 AM. (bottom) PM_{2.5} concentration on the platforms (blue color) of the #R train. The red color in the plot represents the on-train samples while traveling between stations. Sampling started from Forest Hills Street station in Queens at 1:30 PM.

Table S8: Sampling time and PM_{2.5} concentration of each station of line R

Station name	Location	PM _{2.5} Concentration (µg/m ³)		sample start (hh:mm:ss)	sample end (hh:mm:ss)
		Mean	SD		
Forest Hills	Underground	81.8	7.2	11:59:33	12:03:34
67th av	Underground	125	25.6	12:06:12	12:16:05
63rd Drive	Underground	110.8	15	12:17:59	12:27:02
Woodhaven	Underground	153.3	27	12:28:52	12:38:34
Grand Av	Underground	169.4	36.8	12:40:16	12:51:53
Elmhurst av	Underground	158.9	28.9	12:53:30	13:03:12
Roosevelt av	Underground	154.3	24.5	13:05:01	13:16:50
65th st.	Underground	148.9	33.1	13:18:37	13:28:43
Northern Bl	Underground	143.3	29.6	13:30:19	13:39:40
46th St.	Underground	101.6	12.4	13:41:14	13:54:59
Steinway St	Underground	107.3	16.4	13:56:40	14:05:34
36 St	Underground	75.8	7.5	14:07:33	14:17:30
Queens Pl	Underground	83.7	10.1	14:19:53	14:29:12
Lex Av-59 St	Underground	185.6	79.8	14:35:10	14:45:00
5 Av/59 St	Underground	99.7	27.9	14:46:53	14:58:39
57 St	Underground	105.1	17.5	15:01:13	15:10:42
49 St	Underground	100.9	13.7	15:12:06	15:27:17
42 TimesSq	Underground	130.2	12.9	15:28:28	15:38:02
34 HeraldSq	Underground	167.5	20.3	15:39:45	15:44:21
28 St	Underground	132.8	16.7	15:45:52	16:01:32
23 St	Underground	99.8	10.1	16:02:55	16:16:14
14 Union Sq	Underground	164.3	16.3	16:17:37	16:34:06
8 St	Underground	101.9	8	16:35:38	16:41:59
Prince St	Underground	117.1	12.6	16:43:32	17:01:39
Canal St	Underground	91.8	13.3	17:03:30	17:08:15
City Hall	Underground	82.4	6.5	17:10:20	17:15:03
Cortland St	Underground	71.8	9.1	17:18:17	17:25:00
Rector St	Underground	122.8	14.7	17:26:09	17:32:36
Whitehall St	Underground	183.7	41.9	17:34:28	17:46:04
Court St	Underground	140	27.7	17:48:55	17:54:46
Jay St - MT	Underground	145.5	14.2	17:56:22	18:04:21
DeKalb Av	Underground	135.2	14.3	18:06:11	18:13:43
Atlantic Av	Underground	134.2	10.6	18:16:31	18:32:04
Union St	Underground	106.3	15.1	18:33:34	18:47:29
9 St	Underground	88.8	26.6	18:49:16	18:59:49
Prospect Av	Underground	135.7	10.2	19:01:46	19:21:24
25 St	Underground	116.2	13.6	19:22:49	19:28:53
45 St	Underground	139.8	15.5	19:33:23	19:36:27
53 St	Underground	118	6.9	19:37:52	19:50:00
59 St	Underground	113.1	11.2	19:51:31	19:55:21
BayRidge Av	Underground	90.7	9.4	19:59:29	20:04:39
77 St	Underground	85.9	6.7	20:05:56	20:12:13
86 St	Underground	82.6	8	20:14:37	20:26:10

Line M

Table S9: Sampling time and PM_{2.5} concentration of each station of line M

Station name	Location	PM _{2.5} Concentration (µg/m ³)		sample start (hh:mm:ss)	sample end (hh:mm:ss)
		Mean	SD		
Forest Hills	Underground	80.5	6.5	11:49:53	11:51:59
67th Av	Underground	100	11	11:52:01	12:04:25
63rd Drive	Underground	86.9	11.1	12:06:04	12:15:06
WoodhAvn	Underground	128.8	6.4	12:16:35	12:26:19
Grand Av	Underground	147.8	30.1	12:27:58	12:39:34
Elmhurst Av	Underground	121.1	15.2	12:41:12	12:50:36
Roosevelt Av	Underground	123.1	17.3	12:52:58	13:02:14
65th St	Underground	125.2	20.1	13:06:04	13:13:40
Northern Bl	Underground	119.4	17.1	13:17:32	13:25:47
46th St	Underground	68.5	6.8	13:28:08	13:39:31
Steinway St	Underground	76.8	14.1	13:41:04	13:49:58
36th St	Underground	49.8	6.5	13:51:32	14:01:29
Queens Plaza	Underground	74.3	8.1	14:04:26	14:22:29
CourtSq/23rd	Underground	101.8	14.1	14:25:07	14:41:43
Lex. 53rd St	Underground	205	53.5	14:44:43	14:59:18
5Av-53rd St	Underground	145.5	23.4	15:00:54	15:11:38
47th -50th St	Underground	134.8	5.8	15:13:52	15:18:41
42nd St	Underground	91.3	23.1	15:18:43	15:40:06
34th St	Underground	162.3	17.2	15:41:44	15:51:43
23rd St	Underground	157.2	41	15:53:27	15:56:04
14th St	Underground	138.1	38	15:57:19	16:10:39
W 4th St	Underground	206.9	27	16:11:45	16:23:45
BRdway-Laf	Underground	208.9	29.6	16:26:18	16:35:15
Delancy-Ex	Underground	70.9	24.6	16:36:30	16:54:07
Marcy Av	Aboveground	28.2	5	16:55:53	16:58:47
Hewes St	Aboveground	37.6	15.1	16:59:20	17:12:10
Lormier St	Aboveground	27.1	11.6	17:13:25	17:23:17
Flushing Av	Aboveground	24.1	4.1	17:24:31	17:29:51
Myrtle Av	Aboveground	30.2	6.3	17:31:47	17:47:26
Central Av	Aboveground	23.3	2.7	17:49:33	17:54:49
Knickerbock.	Aboveground	26.9	6.1	17:55:55	18:08:20
Seneca Av	Aboveground	27.8	5.1	18:09:47	18:20:30
Forest Av	Aboveground	29.8	11	18:21:47	18:32:03

Elemental Analysis

Table S10: Normalized trace element concentrations (μg element/ mg $\text{PM}_{2.5}$) for on-train and on-platform measurements of 9 subway lines (#1, #3, #5, #6, B, C, F, M, R)

	5 train ($\mu\text{g}/\text{mg}$)		F train ($\mu\text{g}/\text{mg}$)		M train ($\mu\text{g}/\text{mg}$)		R train ($\mu\text{g}/\text{mg}$)	3 train ($\mu\text{g}/\text{mg}$)		1 train ($\mu\text{g}/\text{mg}$)		6 train ($\mu\text{g}/\text{mg}$)		B train ($\mu\text{g}/\text{mg}$)		C train ($\mu\text{g}/\text{mg}$)		Outdoor
	On train	On platform	On train	On platform	On train	On platform	Both on- train and on-platform	On train	On platform	On train	On platform	On train	On platform	On train	On platform	On train	On platform	
Na	1.9	6.2	0.0	10.1	3.4	5.4	6.7	10.7	6.3	0.0	4.9	10.8	7.8	12.0	6.9	10.4	5.7	8.7
Mg	0.0	1.0	0.0	0.9	0.0	0.2	0.8	0.8	1.3	0.0	0.3	0.0	0.0	1.1	1.2	0.0	0.5	0.6
Al	0.8	5.5	2.7	5.4	0.0	4.9	5.5	2.1	6.3	5.2	7.3	0.7	8.7	0.7	6.4	0.0	6.2	0.0
Si	42.0	15.8	8.2	17.8	6.2	16.4	17.9	10.3	17.3	9.6	20.3	3.1	23.2	10.2	22.5	5.2	20.8	4.6
S	3.4	10.2	2.4	7.0	1.0	6.4	6.1	7.3	12.1	7.3	9.6	2.3	11.3	3.5	8.7	1.9	7.8	9.1
Cl	1.3	4.6	2.3	6.1	0.7	5.3	4.2	2.2	1.4	0.0	1.4	0.0	1.0	2.4	3.7	1.2	4.2	52.6
K	3.4	2.1	0.0	2.0	0.0	3.1	2.3	0.7	2.3	0.0	2.5	0.0	3.2	0.0	2.8	0.0	3.4	7.1
Ca	5.1	11.9	0.0	8.0	0.0	9.6	9.4	0.0	9.1	0.0	7.2	0.0	11.4	0.0	11.2	0.0	12.4	0.0
Ti	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
Cr	0.7	2.9	1.0	1.6	0.5	1.2	1.4	1.6	2.7	1.7	1.9	1.4	3.0	1.3	1.8	0.0	1.4	0.0
Mn	0.6	3.5	2.3	3.7	1.6	3.1	3.5	2.7	3.8	3.7	4.2	1.9	5.1	2.8	4.3	1.5	2.9	0.1
Fe	63.6	423.0	239.0	444	155	360.9	410.4	276.8	441.6	338.2	457.9	171.6	572.8	287.3	452.8	154.8	346.0	3.4
Ni	0.3	0.6	0.1	0.4	0.1	0.4	0.4	0.6	0.5	0.2	0.5	0.0	0.6	0.1	0.5	0.1	0.4	0.1
Cu	0.4	2.0	0.6	1.9	0.6	1.6	1.8	1.1	1.8	1.0	1.9	0.5	2.2	0.9	2.0	0.4	1.6	0.0
Zn	0.5	2.0	0.0	0.7	0.0	1.3	1.1	1.0	1.8	0.0	1.6	0.0	1.5	0.0	1.9	0.0	1.8	0.7
As	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Se	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Br	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Rb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sr	0.2	0.2	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.0	0.1	0.0	0.3	0.0	0.2	0.2	0.2	0.0
Y	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mo	0.0	0.4	0.0	0.7	0.0	0.3	0.0	0.0	1.0	0.0	0.4	0.0	0.7	0.0	0.3	0.0	0.0	0.0
Rh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Te	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
Ba	1.9	11.1	4.1	4.2	1.7	4.3	5.0	6.0	9.9	5.9	7.9	4.7	11.6	5.6	6.5	2.1	4.2	0.0
La	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pr	0.0	3.7	0.0	0.0	0.0	4.3	3.4	0.0	0.0	0.0	0.0	0.0	10.6	0.0	3.7	0.0	0.0	0.0
Eu	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0
Gd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0
Er	1.0	1.6	1.5	1.3	0.8	1.1	1.2	1.2	1.5	1.4	1.5	0.0	1.9	0.0	1.4	1.5	1.3	0.0
Yb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lu	0.8	1.2	0.9	0.8	0.3	0.9	0.9	0.9	1.1	0.5	1.0	0.0	1.4	0.5	1.1	0.6	1.0	0.4
Ir	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Pt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Au	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Hg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Pb	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.8	0.4
OC																		692.7
Sum	128	509.9	265.6	517.0	171.9	431.1	482.1	326.2	522.5	374.8	533.6	202.8	678.4	328.6	540.3	180.0	422.8	783.9
UX**	872	490.1	734.4	483.0	828.1	568.9	517.9	673.8	477.5	625.2	466.4	797.2	321.6	671.4	459.7	820.0	577.2	216.1

UX** = Unexplained, likely iron oxides, carbon and others