# Appendix J - Nephelometer Collocation Data

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## Nephelometer Collocation

Collocation consists of placing both nephelometers in the same location to test whether the instruments give close to the same results under the same conditions. It is assumed that when both nephelometers are placed side by side either indoors or outdoors they are being exposed to the same meteorological conditions (air temperature/room temperature, relative humidity, pressure) as well as the same air quality.

Collocation data is the key to knowing whether the instruments are working properly in inert conditions and gives more confidence that they are working properly in the field. When differences in the results occur, it is important to understand why this may be occurring and if the data signals in the data which may predict whether these are taking place in the field as well. It is important to investigate whether the differences in results may be triggered after being on for a certain amount of time, by certain air quality conditions or meteorological conditions etc... If differences in results occur an adjustment may need to be made on the data, from one or both of the instruments.

In most cases, collocation data was collected at locations with TEOMs. TEOMs, which stands for Tapered Element Oscillating Microbalance, are monitors used by the provincial government of BC to measure different types of air quality including PM2.5. TEOMS are calibrated on a monthly basis and audited biannually. Past research such as Larson (2007) and Millar (2010) has found fairly good correlations between nephelometers and TEOMS.

Generally, the provincial government looks at hourly and 24 hour averages for TEOMS. One minute data is available in the archives, however, oscillations are present at this resolution. The oscillations, caused by pressure differences produced by the instrument, cause data at this low a time resolution not to be considered as accurate. Data at such a low time resolution is also known to be biased to very local sources which are only reflective of what is going on in a very small radius.

The nephelometers were protected with enclosures made from plastic garbage containers as well as rain hats provided by the manufacturer whenever they were outside. This ensured that the instruments did not get wet. Also, heating pads were used on a low setting to keep the instruments from getting too cold.

The nephelometers were able to store 1 minute instantaneous values or 5 minute averages. Therefore, the collocation data taken was generally 5 minute averages.

The amount of time the two nephelometers were taking collocation data was a bit random. Sometimes collocation periods were15 hours, other times they lasted several weeks or months. When there was concern over data quality, collocations were taken frequently, and times when there was less concern the nephelometers were shut off.

To distinguish the two nephelometers in this report we will call them nephelometer "A" and Nephelometer "B". Nephelometer A corresponds to the nephelometer which was in a "fixed" spot during the Millar study and nephelometer B the nephelometer which was "mobile".

Nephelometer values are not supposed to be directly dependent on meteorological parameters, however, they seem to be influenced by them during periods where meteorological parameters are changing quickly (this will come up again with the data in the elevator room).

### 1. Collocation Data - Gladstone School Roof

Both Nephelometers were set up on the roof of Gladstone School between December 21 2009 and January 3 2010. Figure J-1 shows the nephelometer scattering data as well as other meteorological parameters available from the two nephelometers during this time. Overall, the correlation does not seem to be too bad; however the relationship between the two nephelometers does not seem to be as desired: a constant one. Instead, there seems to be periods where one nephelometer is higher than the other and other periods where they are close to equal.

There are many interesting things to notice about the meteorological data. Firstly, the relative humanities are significantly different, roughly about 10%. This could be due to snow or water being present inside the plastic casing. Snow inside the plastic casing may also explain air temperature and cell temperature difference. Figure J-2

shows how the nephelometer scattering compares to the Gladstone PM2.5 TEOM.

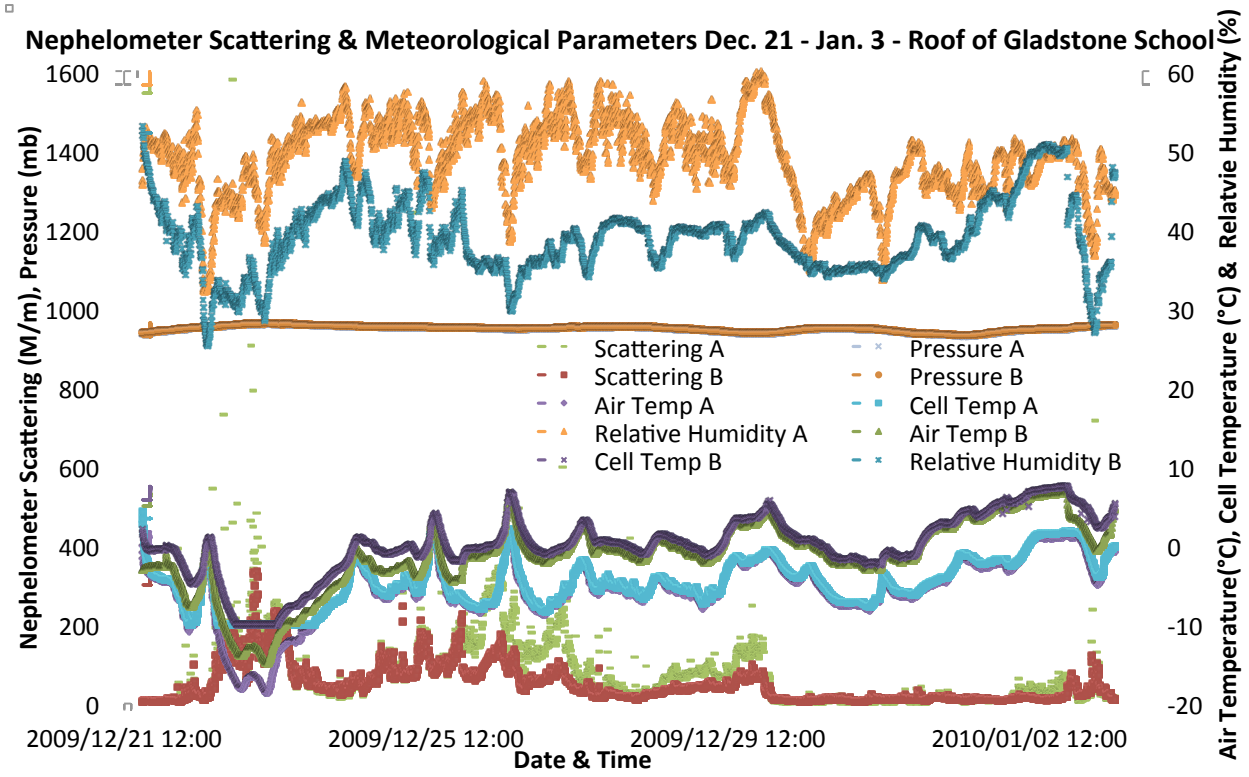


Figure J-1: Nephelometer Scattering & Meteorological Variables – Dec 21 – Jan 3 – Roof of Gladstone School, College Heights

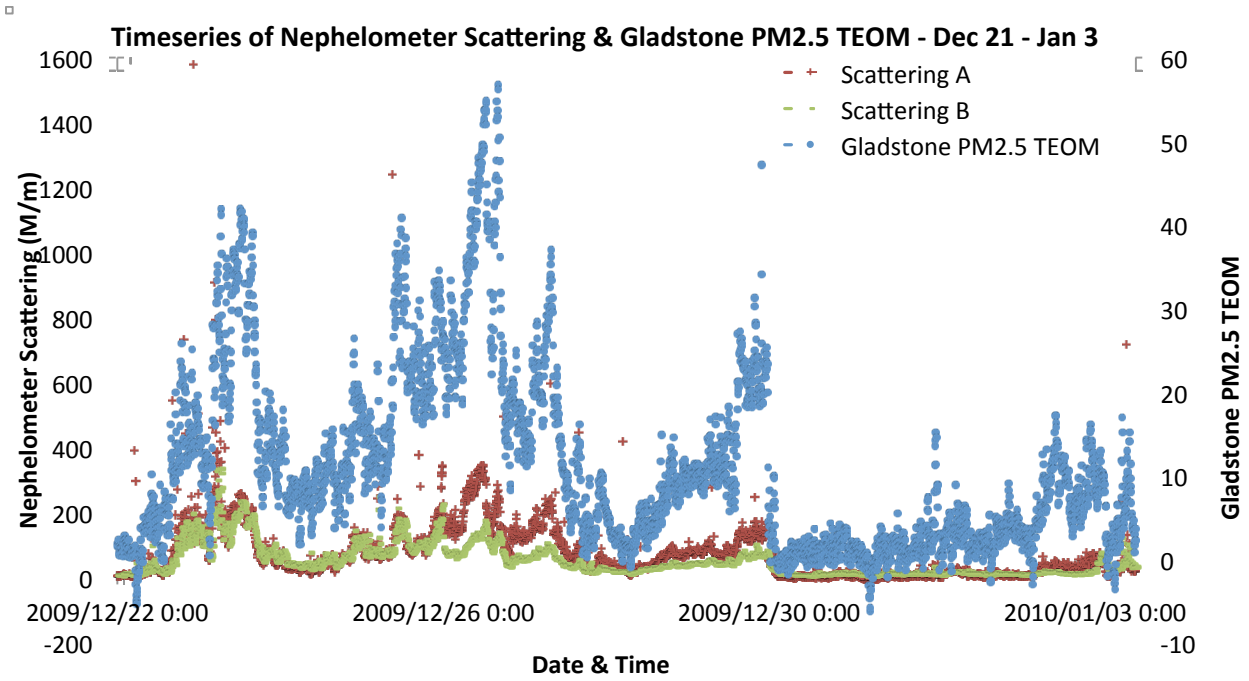


Figure J-2: Timeseries of Nephelometer Scattering & Gladstone PM2.5 TEOM – Dec. 21 – Jan 3 – Gladstone School Roof, College Heights

During the first 4 days, the values were very close, with nephelometer A having higher values than nephelometer B during periods where the values are high and lower values than B when the values are low. Around 11:15pm on December 25th a shift seems to occur in one of the two nephelometers. The shift that occurs is visible up close in Figure J-3. For the next five days differences between the monitors tend to be more pronounced, nephelometer A being significantly higher. This situation comes to an end when the period of high levels comes to an end.

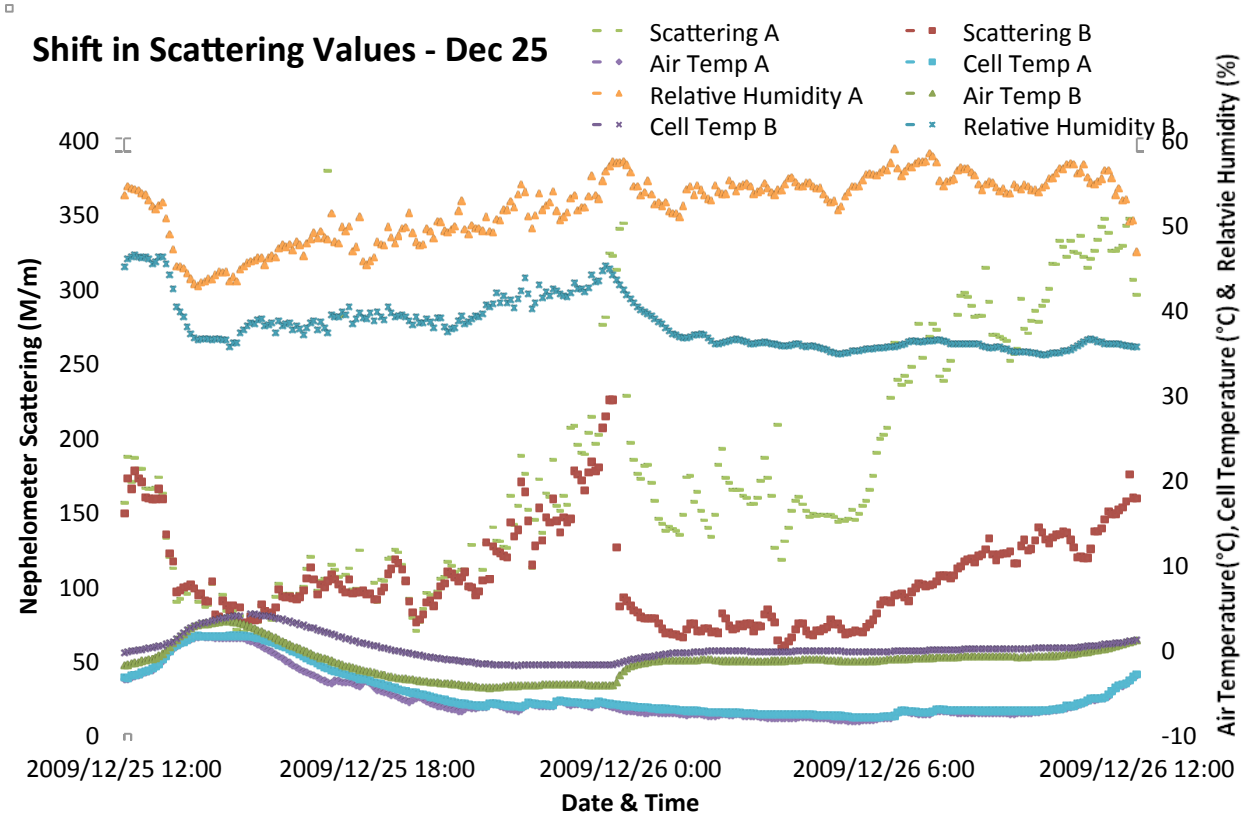


**Figure J-3: Nephelometer Scattering & Meteorological Variables – Dec. 25 "Shift" – Roof of Gladstone School, College Heights**

At the time of the "shift" in scattering values, nephelometer B's temperature values change by about 2 degrees in the span of half an hour where as Nephelometer A's temperature values do not change as well. A two degree change in less than half an hour could be realistic if a warm front was coming through. Environment Canada hourly weather report available in Table J-1 for the night shows slowly decreasing temperatures, fairly constant relative humidity and pressure as well as low wind speeds. This data shows cold calm conditions, the ones are expected to accompany high levels of PM2.5 and no evidence of a front. Another change that seems to happen at the time of the shift is that the series of relative humidity B values (shown in Figure J-2) change textures from being somewhat bumpy to smooth. A possible explanation for this shift is that the heating blanket moved, however, this is thought

not to be the case, because this type of shift was observed later on in the elevator room when no heating blanket was present. It seems likely that there was a shift in the inner working of the nephelometer at this time. Notice from Figure J-1&J-2 that the other meteorological variables, pressure and RH, are not unusually high/low or changing at an unusually fast rate.

**Table J-1: Environment Canada Hourly Data Report for Night of December 25/26, 2009**

| Hour (h) | Temp (°C) | Dew Point (°C) | RH (%) | Wind Dir. (10s of deg.) | Wind Speed (km/h) | Standard Pressure (kPa) | Wind Chill |
|---|---|---|---|---|---|---|---|
| 20:00 | -15.5 | -17.0 | 88 | 18 | 4 | 94.30 | -18 |
| 21:00 | -16.3 | -18.0 | 87 | 35 | 4 | 94.31 | -19 |
| 22:00 | -16.9 | -18.6 | 87 | 3 | 2 | 94.32 | -18 |
| 23:00 | -17.5 | -19.2 | 87 | | 0 | 94.31 | |
| 00:00 | -18.0 | -19.8 | 86 | 6 | 2 | 94.30 | -20 |
| 01:00 | -16.9 | -18.5 | 87 | | 0 | 94.25 | |
| 02:00 | -17.8 | -19.6 | 86 | | 0 | 94.27 | |

Nephelometer B returns to similar values as nephelometer A's late on December 29 which coincides with the end of the high PM level period. This is visible in Figure J-1. There does not appear to be any unusually high/low or quickly changing meteorological variables at this time.

Notice that on the morning of January 2, nephelometer A shows decreasing relative humidity where as nephelometer B shows increasing relative humidity. Environment Canada's Hourly Data Report for that morning, presented here as Table J-2, shows increasing relative humidity. At exactly midnight on the night of January 2 the relative humidity on nephelometer B dropped dramatically and rose quickly around 2pm on January 3. Environment Canada weather, shown in Tables J-3&J-4, shows the relative humidity to staying constant at values of approximately 92%. Perhaps the nephelometers are being influenced by snow getting into their enclosures or moisture condensing close to the sensors.

Table J-2: Environment Canada Hourly Data Report for Morning of January 2, 2010

| Hour (h) | Temp (°C) | Dew Point (°C) | RH (%) | Wind Dir. (10s of deg.) | Wind Speed (km/h) | Standard Pressure (kPa) | Wind Chill |
|---|---|---|---|---|---|---|---|
| 05:00 | -12.8 | -13.5 | 94 | 17 | 2 | 93.42 | -14 |
| 06:00 | -12.6 | -13.8 | 91 | 4 | 2 | 93.50 | -14 |
| 07:00 | -11.5 | -12.7 | 91 | 3 | 4 | 93.57 | -14 |
| 08:00 | -11.1 | -12.3 | 91 | 5 | 2 | 93.61 | -12 |
| 09:00 | -10.7 | -12.0 | 90 | 36 | 4 | 93.69 | -13 |
| 10:00 | -10.4 | -11.8 | 89 | 36 | 2 | 93.77 | -12 |
| 11:00 | -10.3 | -11.5 | 91 | 1 | 4 | 93.78 | -13 |
| 12:00 | -9.4 | -10.6 | 91 | 7 | 4 | 93.82 | -12 |

Table J-3: Environment Canada Hourly Data Report for Night of January 2/3, 2010

| Hour (h) | Temp (°C) | Dew Point (°C) | RH (%) | Wind Dir. (10s of deg.) | Wind Speed (km/h) | Standard Pressure (kPa) | Wind Chill |
|---|---|---|---|---|---|---|---|
| 22:00 | -8.6 | -9.5 | 93 | 2 | 4 | 93.95 | -11 |
| 23:00 | -7.8 | -8.6 | 94 | 1 | 6 | 94.00 | -11 |
| 00:00 | -7.6 | -8.5 | 93 | 32 | 7 | 94.05 | -11 |
| 01:00 | -7.3 | -8.2 | 93 | 2 | 7 | 94.16 | -11 |
| 02:00 | -7.3 | -8.4 | 92 | 34 | 6 | 94.27 | -10 |

Table J-4: Environment Canada Hourly Data Report for the afternoon of January 3, 2010

| Hour (h) | Temp (°C) | Dew Point (°C) | RH (%) | Wind Dir. (10s of deg.) | Wind Speed (km/h) | Standard Pressure (kPa) | Wind Chill |
|---|---|---|---|---|---|---|---|
| 12:00 | -11.3 | -12.4 | 92 | 1 | 9 | 94.85 | -16 |
| 13:00 | -11.1 | -12.2 | 92 | 2 | 9 | 94.86 | -16 |
| 14:00 | -11.0 | -12.1 | 92 | 4 | 7 | 94.87 | -15 |
| 15:00 | -11.0 | -12.1 | 92 | 3 | 7 | 94.90 | -15 |
| 16:00 | -11.2 | -12.3 | 92 | 4 | 7 | 94.90 | -15 |

Figure J-5 shows a plot of Nephelometer A vs. B. Over the entire period, the correlation between the nephelometers is R=0.784. Figure J-6 shows a plot of Nephelometer A vs. the Gladstone PM2.5 TEOM and Figure J-7 shows a plot of Nephelometer B vs. the Gladstone PM2.5 TEOM.

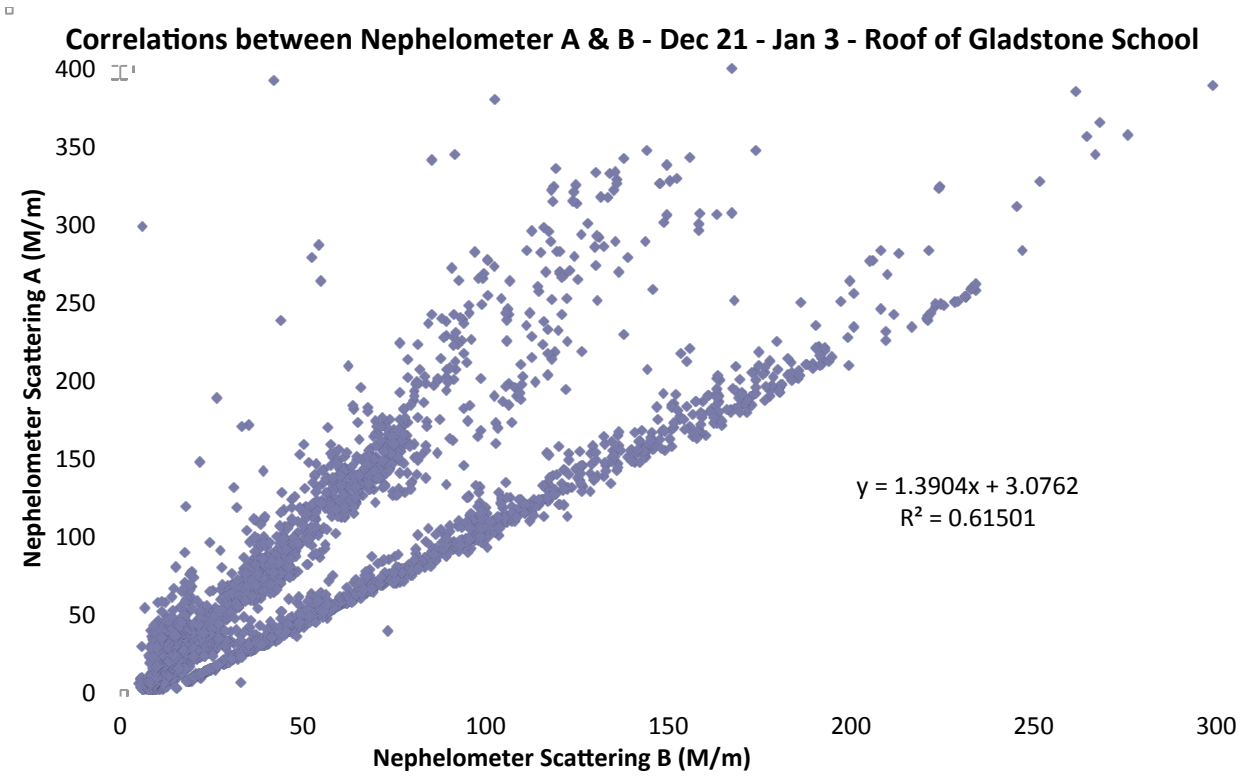


Figure J-4: Correlations between Nephelometer A&B – Dec 21 – Jan 3 – Roof of Gladstone School, College Heights

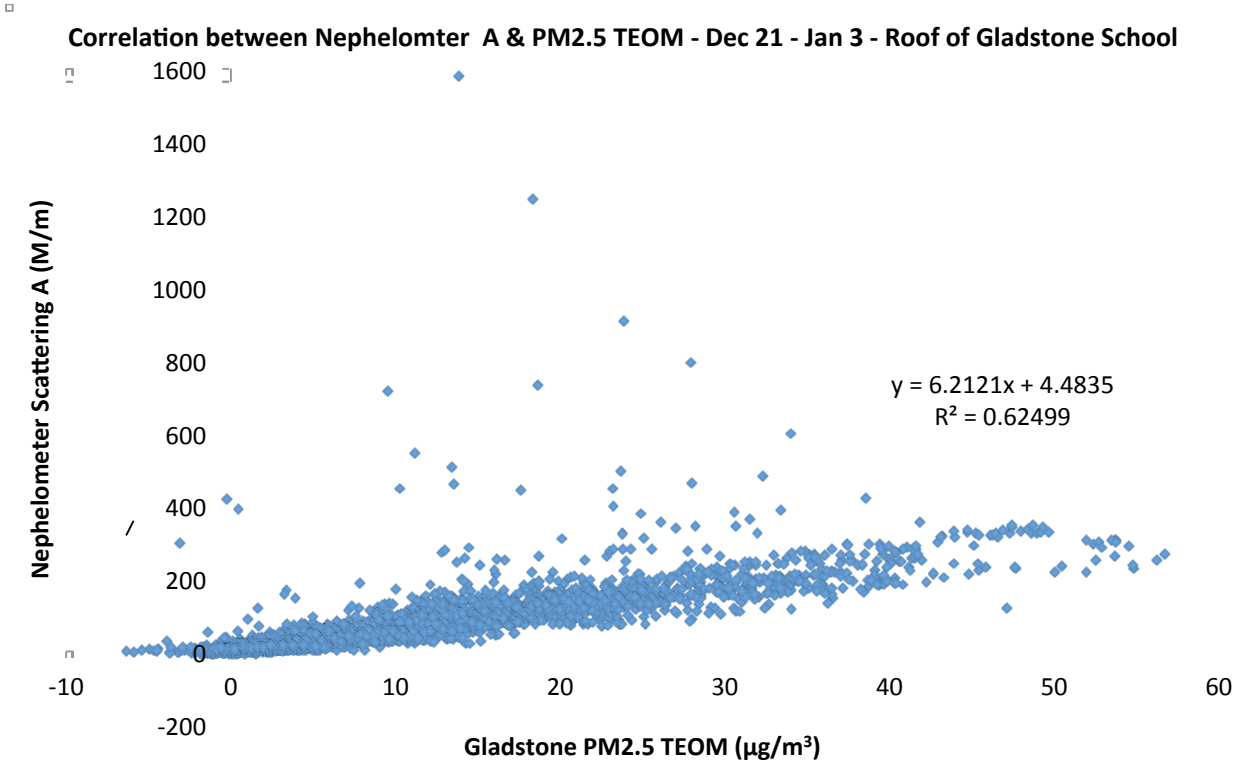


Figure J-5: Correlation between Nephelometer Scattering A & Gladstone PM2.5 TEOM – Dec. 21 – Jan 3 – Roof of Gladstone School, College Heights

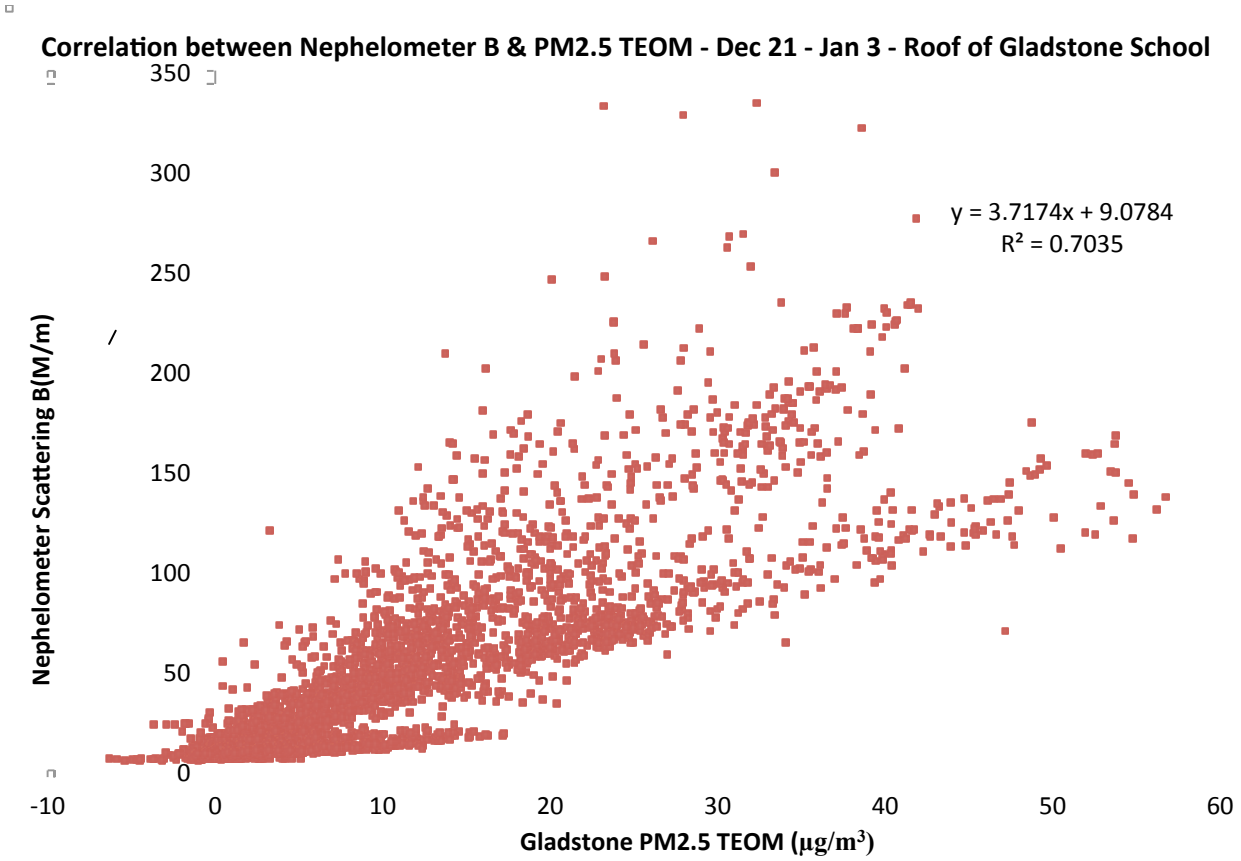


**Figure J-6: Correlation between Nephelometer Scattering B & PM2.5 TEOM – Dec. 21 – Jan. 3 – Roof of Gladstone School, College Heights**

Correlations are not as high as in previous studies. There are several plausible reasons for this.

The first reason for this is the severity of the episode days during this period. Table J-2 shows the daily average PM2.5 levels each day during the period the nephelometers were set up. BC's daily objective is 25µg/m$^3$ for 24 hours, therefore Dec 26 was at the air quality advisory level and Dec. 23 and 25 were very close to that level. Along with the two previous days mentioned and Dec. 29 are all in the fair category. As can be seen from Figures J-6&J-7, there seems to be a higher correlation between instruments when pollution levels are lower.

Table J-5: Average TEOM PM2.5 level for each day at Gladstone

| Day | Gladstone Average TEOM value ($\mu g/m^3$) |
|---|---|
| Dec. 21, 2009 | 1.65* |
| Dec. 22, 2009 | 6.88 |
| Dec. 23, 2009 | 21.69 |
| Dec. 24, 2009 | 10.26 |
| Dec. 25, 2009 | 20.94 |
| Dec. 26, 2009 | 29.68 |
| Dec. 27, 2009 | 13.05 |
| Dec. 28, 2009 | 5.19 |
| Dec. 29, 2009 | 15.25 |
| Dec. 30, 2009 | 1.11 |
| Dec. 31, 2009 | 0.85 |
| Jan. 1, 2010 | 2.97 |
| Jan. 2, 2010 | 6.94 |
| Jan. 3, 2010 | 5.06* |

*Only data for hours where the nephelometers were set up are considered.

A second reason for less accuracy is that the instruments were set up outside to collect collocation data whereas in other studies such as Millar(2010) the instruments were inside. The Vancouver and Victoria study by Larson et al. did collect collocation with one of the nephelometers and the TEOM outside, finding an $R^2$=0.76. Detail beyond the slope and intercept of the nephelometer-TEOM correlation was not published. However, Vancouver and Victoria are known to have better air quality than Prince George (see Figure J-2 in the interim report) and this should be especially true during the winter due to a lower density in woodstoves, therefore, the higher correlation may be partially due to lower values. Collocation results between both nephelometers seem to be unpublished. This again relates to the data values being higher than they would be had they been taken inside because inside air is generally filtered before it enters.

A third reason is that, especially in the case of nephelometer A, a few very high points on the nephelometer which are tremendously off the slope of TEOM vs. Nephelometer have a major effect on bringing down the correlation. When Nephelometer data points over 400 are substituted with 145 for Nephelometer A, than $R^2$ = 0.8458. This is a very dramatic difference especially since these only accounts for changing 17 out of the 3715 data points. For Nephelometer B when data points over 145 are substituted with 145, $R^2$ improves a little bit to 0.7489. Note that 145 and 150 were not chosen arbitrarily but were chosen to optimize $R^2$. When the optimized Nephelometer data sets are compared, $R^2$ = 0.7632. It would be interesting to do further analysis on how many "outliers" (2 standard deviations away from the mean) exist in the data set and how taking them out would affect the

correlation. These are very close to or higher than the Nephelometer-TEOM correlation for the Vancouver and Victoria based mobile monitoring study.

A heat vent for Gladstone School was located within a few meters of where the nephelometers were located. It is possible that this may explain some of the particularly high results.

Yet another possible reason for lower than expected correlations are the low temperature during the period of December 21-January 3(see Table J-7). Perhaps, under these difficult conditions the nephelometers which are made in Australia, are not able to operate properly. These temperatures are certain below temperatures Vancouver or Victoria normally experiences.

**Table J-6: Meteorological Conditions at the Prince George Airport during the collocation period at Gladstone (Environment Canada)**

| Date | Max Temp °C | Min Temp °C | Mean Temp °C | Heat Deg Days °C | Cool Deg Days °C | Total Precip mm | Spd of Max Gust km/h |
|---|---|---|---|---|---|---|---|
| Dec. 21 | -7.5 | -11.5 | -9.5 | 27.5 | 0.0 | 2.4 | 37 |
| Dec. 22 | -7.5 | -26.4 | -17.0 | 35.0 | 0.0 | 0.5 | <31 |
| Dec. 23 | -18.1 | -30.5 | -24.3 | 42.3 | 0.0 | 0.0 | <31 |
| Dec. 24 | -11.0 | -18.2 | -14.6 | 32.6 | 0.0 | 0.0 | <31 |
| Dec. 25 | -8.8 | -17.4 | -13.1 | 31.1 | 0.0 | 0.0 | <31 |
| Dec. 26 | -8.8 | -20.3 | -14.6 | 32.6 | 0.0 | 0.0 | <31 |
| Dec. 27 | -9.7 | -17.9 | -13.8 | 31.8 | 0.0 | 0.0 | <31 |
| Dec. 28 | -12.8 | -15.6 | -14.2 | 32.2 | 0.0 | 0.0 | <31 |
| Dec. 29 | -8.0 | -16.5 | -12.3 | 30.3 | 0.0 | 0.8 | <31 |
| Dec. 30 | -7.8 | -16.4 | -12.1 | 30.1 | 0.0 | 2.5 | 32 |
| Dec. 31 | -14.2 | -17.9 | -16.1 | 34.1 | 0.0 | 0.0 | <31 |
| Jan. 01 | -10.7 | -15.0 | -12.9 | 30.9 | 0.0 | 4.4 | <31 |
| Jan. 02 | -8.3 | -13.8 | -11.1 | 29.1 | 0.0 | 1.6 | <31 |
| Jan. 03 | -7.1 | -18.2 | -12.7 | 30.7 | 0.0 | 0.3 | <31 |

Figure J-4 shows an unusually shaped correlation. The hypothesis is that nephelometer B which also shows a divergence in high values plotted against the Gladstone PM2.5 TEOM in Figure J-5 is responsible for the divergence in the correlation between the two nephelometers. This hypothesis was tested by replotting the TEOM vs. Nephelometer B into five sections: the first section corresponding to the section on Figure J-4 before the differences occurred, the second section corresponding to the area where large differences between the two nephelometers occurred, the third section corresponding to the area following where the values are low, the fourth section corresponds to the area where the values are a bit higher again and the fifth section corresponds to a few last points near the end where the

nephelometer B has higher values than nephelometer A. Figure J-7 shows with different sections represented by different colors that shifts in the nephelometer's functioning clearly occur. Notice, that data from section 1 and 4 may be along the same line and may have the same equation.

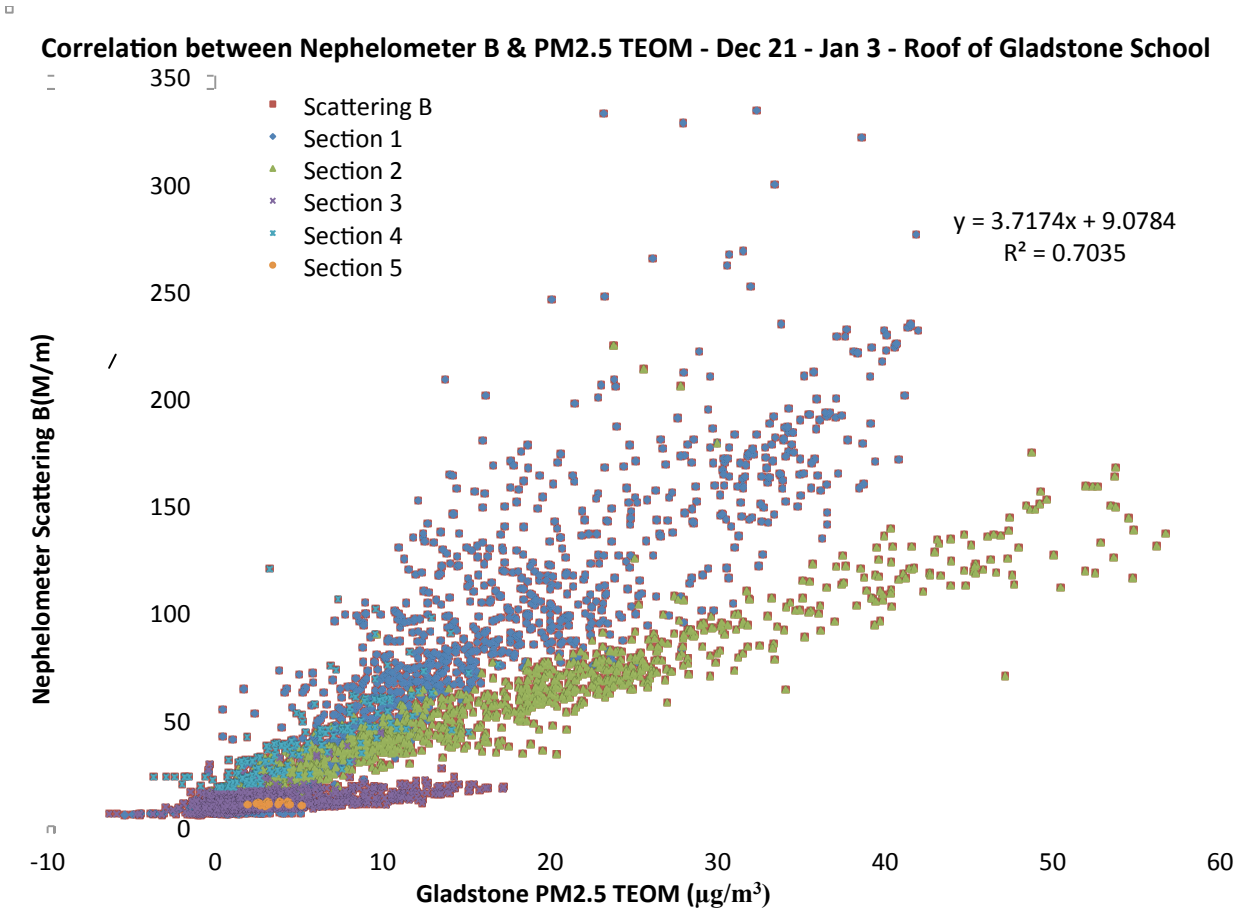


**Figure J-7: Correlation between Nephelometer Scattering B & PM2.5 TEOM – Dec 21 – Jan 3 – Roof of Gladstone School, College Heights. Sections as defined above are represented in different colors.**

## 2. Collocation Data – Plaza Building Roof

Both nephelometers were set up on the roof of the Plaza Building between January 15 and 22 2010 close to where the Partisols are located. The Plaza is a four story building located in Downtown Prince George. PM2.5 & PM10 TEOMs as well as other air quality monitors are located there. Because of the elevation on top of the building, the monitoring station is known to be less sensitive to local sources than other monitoring stations such as Gladstone School. Pollution levels are also known to be less high at this elevation than at ground level.

Figure J-8 shows plots of scattering and meteorological variables from the two nephelometers over the entire time period. The two sets of scattering values seem to be closest between Jan. 15 and 19, with nephelometer B having relatively higher

results. Figure J-9 shows the time series of nephelometer scattering values as well as Plaza PM2.5 values.

Between 2-4pm on Jan. 19 a very high period, visible in Figures J-8 & J-9 as well as up close in Figure J-10 is recorded on both nephelometers. During this period, scattering values on nephelometer A peak at 700M/m where as nephelometer B values at 200M/m. It is strange that both nephelometers record this high period, yet the TEOM, which seems to mimic the nephelometers patterns during the rest of the period does not. None of the other air quality monitors at the Plaza monitoring site such as $SO_2$, TRS, $PM_{10}$, $NO_2$, CO, $O_3$ & NO recorded particularly high values during this time.

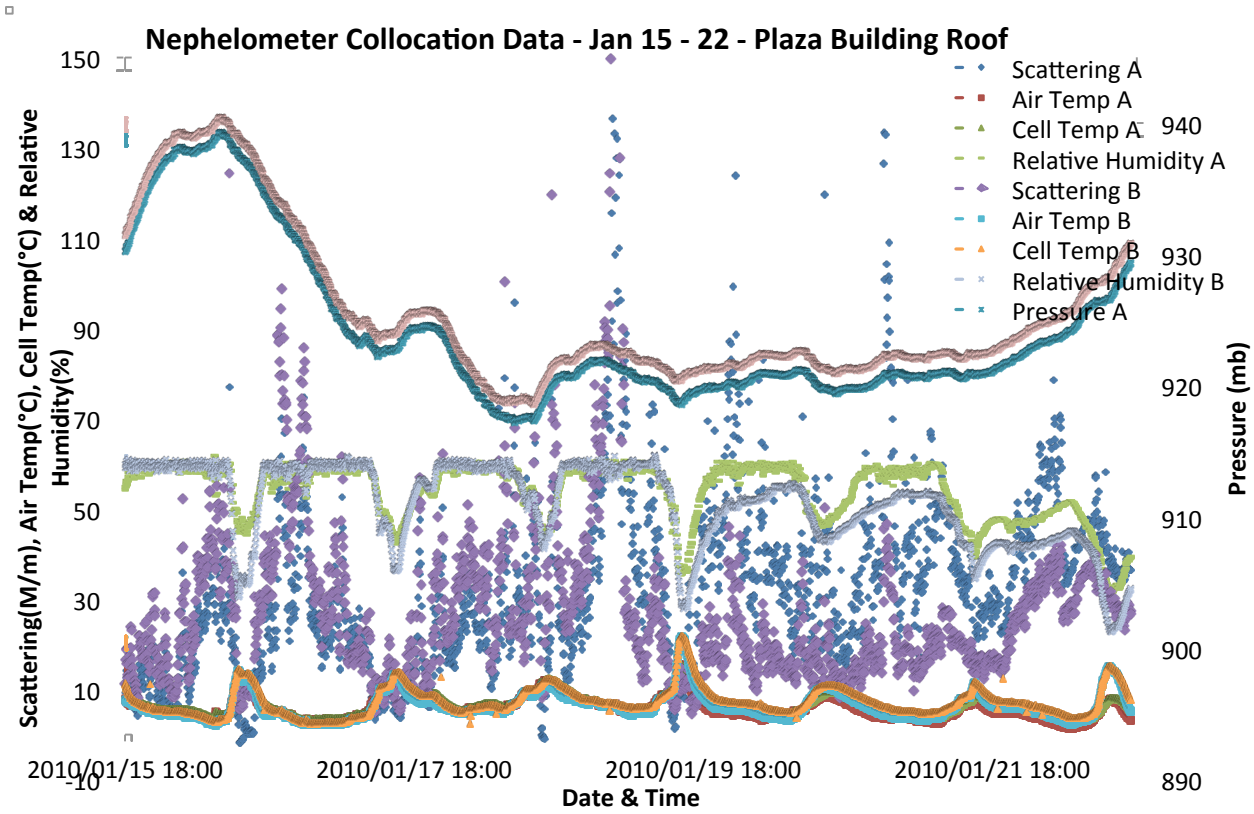


Figure J-8: Nephelometer Collocation Data – Jan. 15 – Jan. 22 – Plaza Building Roof

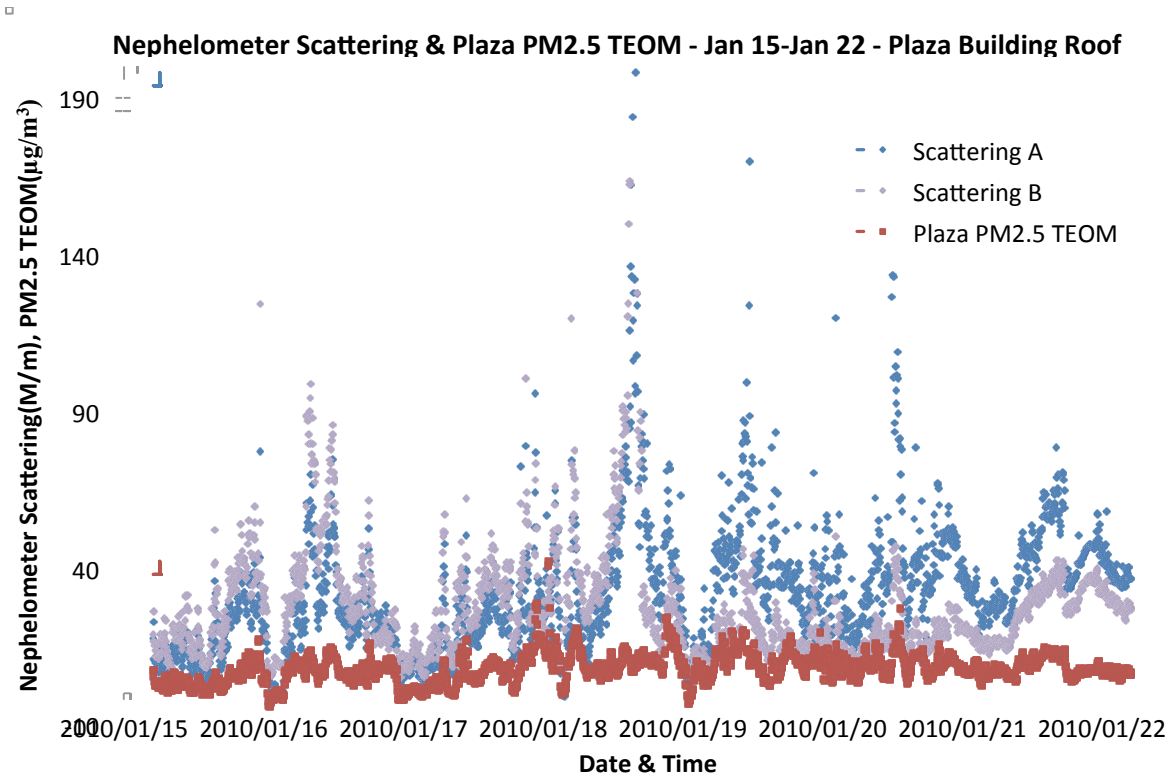


Figure J-9: Nephelometer Scattering & Plaza PM2.5 TEOM – Jan. 15 – Jan. 22 – Plaza Building Roof

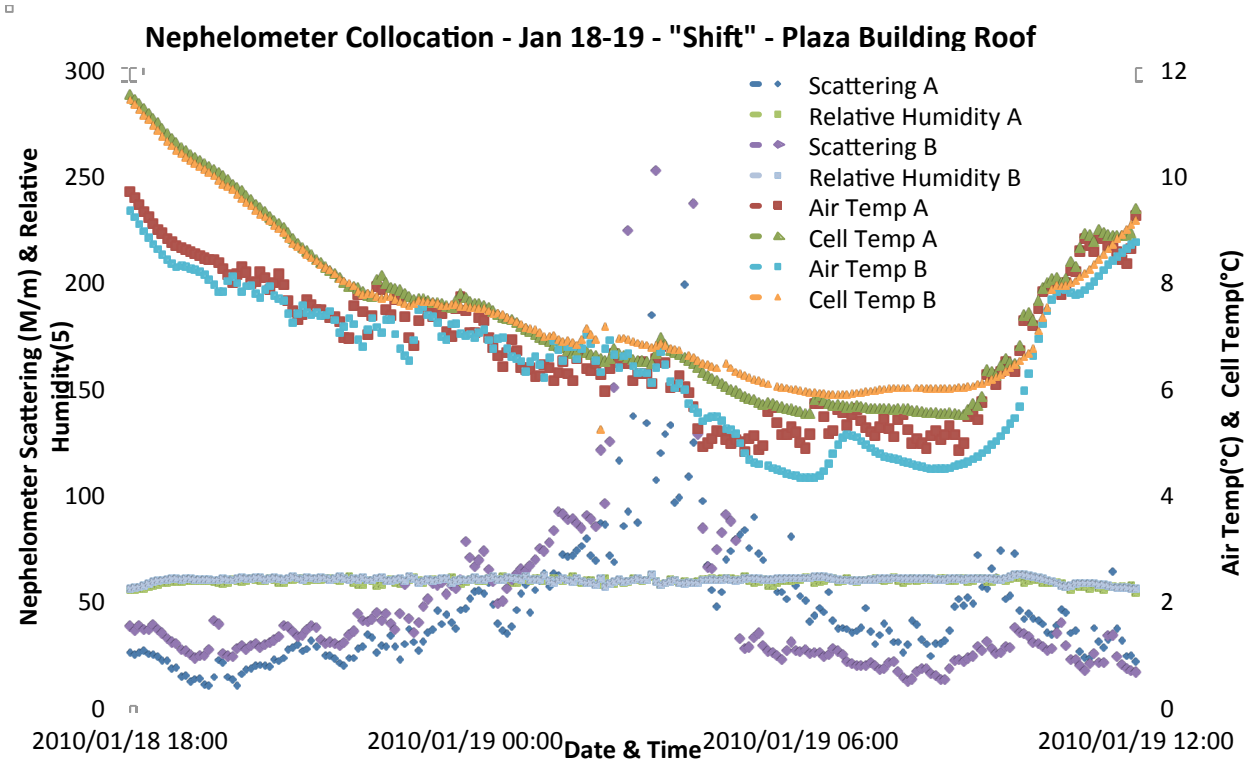


Figure J-10: Nephelometer collocation – January 18-19 – "Shift" – Plaza Building Roof

The heated inlet warms incoming air when the relative humidity was over 60%. In the field, the relative humidity never reached 60% mainly because nights with precipitation were not considered good conditions for sampling. Also the nephelometers were in cars where the relative humidity was lower than outdoors.

When the heated inlet comes on, meteorological parameters such as relative humidity and air temperature seem to oscillate as well as nephelometer scattering. This is visible in Figure J-10.

Oscillations have wavelengths of about 15- 20 minute. Oscillations have amplitudes of: less than one degree Celsius for temperature, 1-2 % for RH and scattering of 15-20 M/m which is significant.

Correlations are quite high between the two nephelometers up until the spike in values/shift occurs $R^2 = 0.8362$, after the shift/high values $R^2 = 0.2919$ significantly lower. $R^2$ for the entire period including the high values is 0.4779. See Figure J-11. On the three different linear regression equations the linear intercept does not change much (less than 2), however the slopes significantly change from 1.1584 for the first section to 0.4021 for the second section.

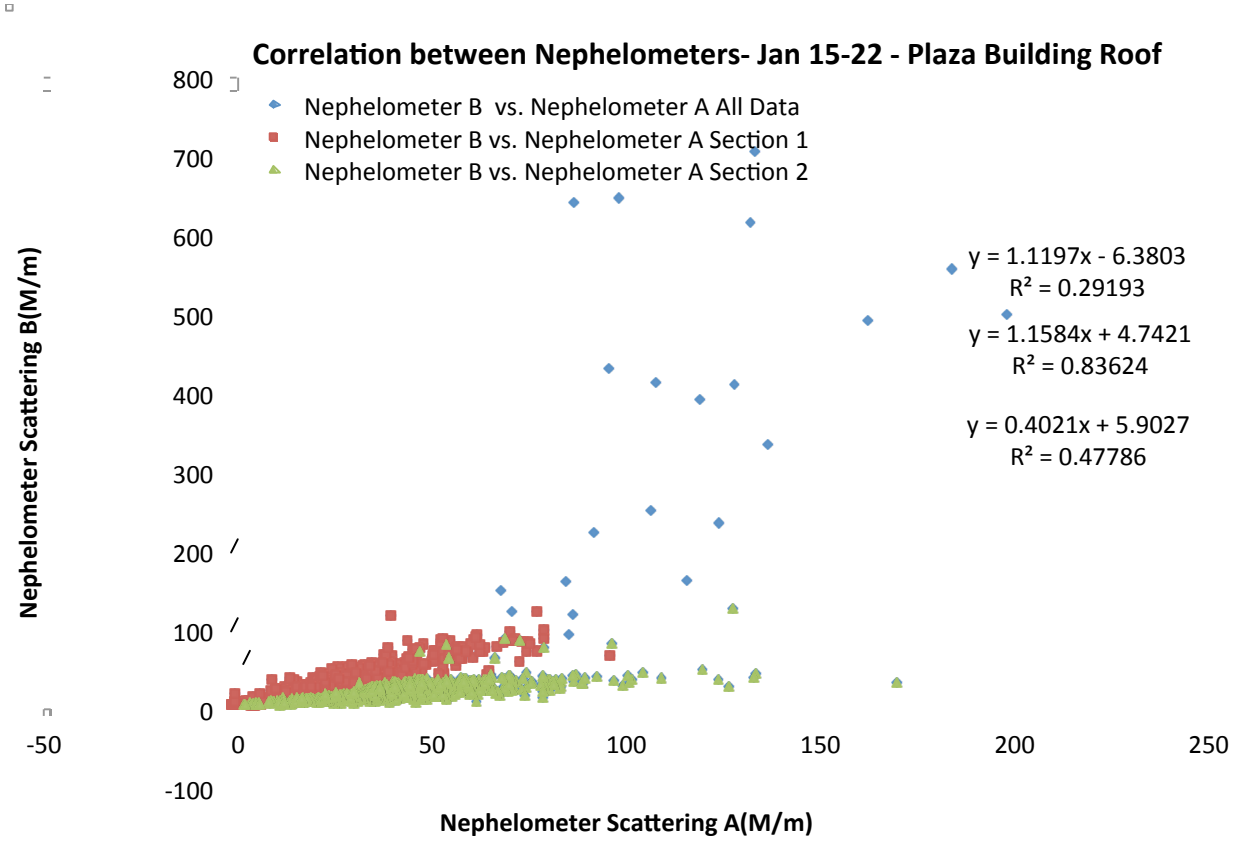


Figure J-11: Correlation between Nephelometers A & B– Jan 15-22 – Plaza Building Roof

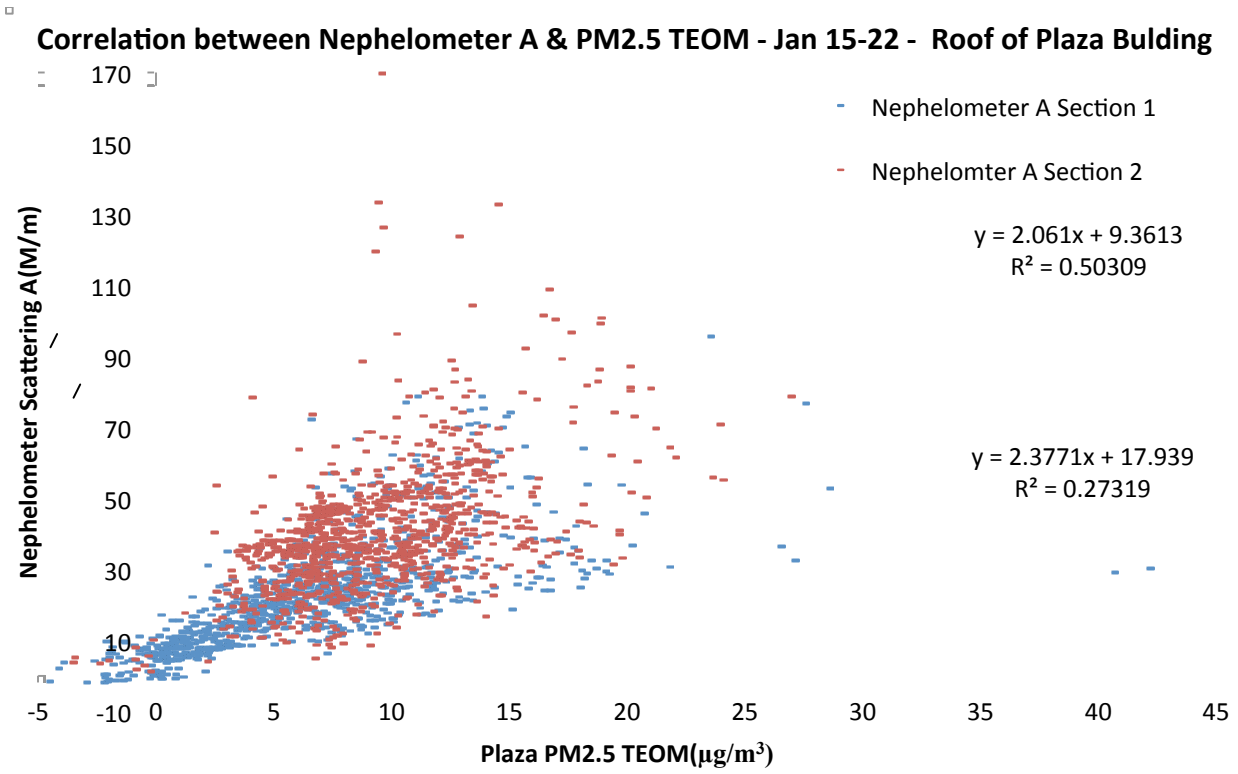


Figure J-12: Correlation between Nephelometer A & Plaza PM2.5 TEOM – Jan 15-22 2010 – Roof of the Plaza Building

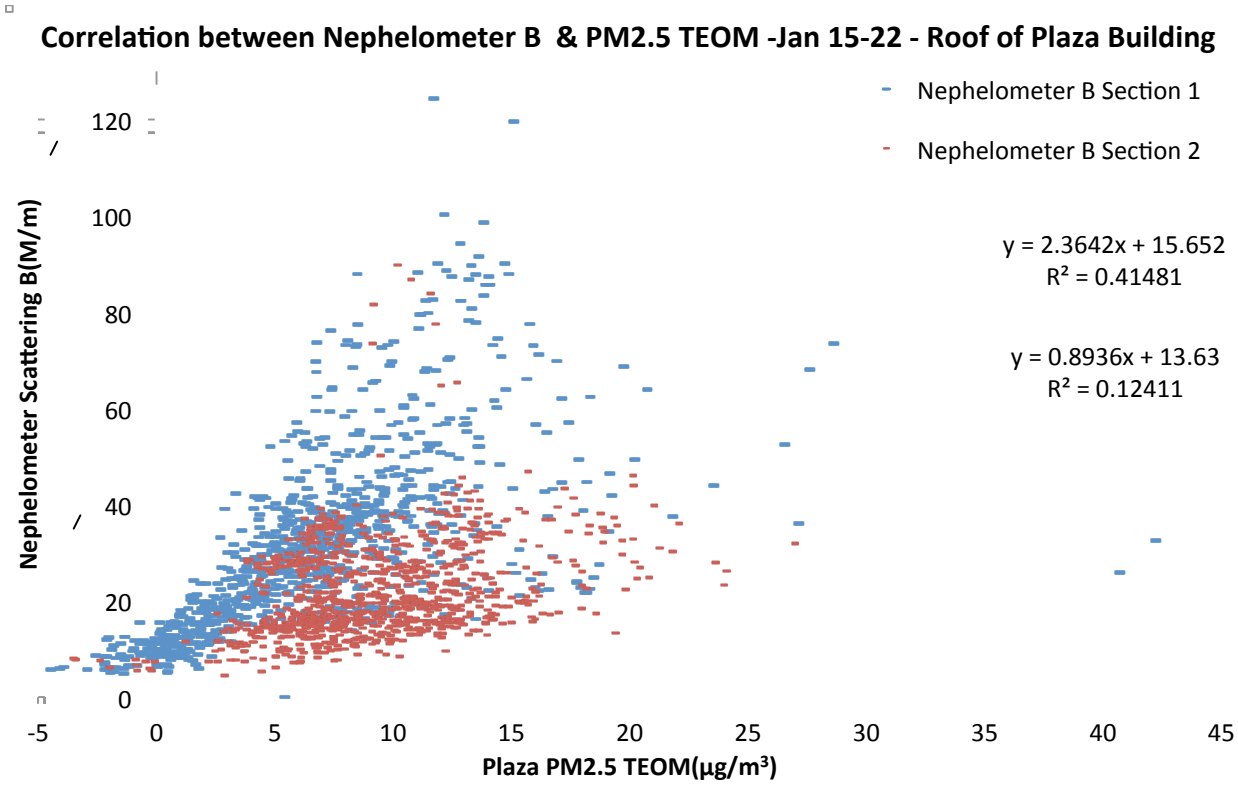


Figure J-13: Correlation between Nephelometer B & Plaza PM2.5 TEOM – Jan 15-22 – Roof of the Plaza Building

Figure J-12 shows correlations between Nephelometer A & the Plaza PM2.5 TEOM. for both the section before the "shift" (section 1) and the section after the "shift" (section 2) . The correlation is better during section 1 than section 2. The two slopes show a difference of roughly 0.4 and intercepts show a difference of 12M/m. These differences may be due to different levels of PM2.5 present during the two different sections. The second section does not have as many low values recorded on either the TEOM or the nephelometer – perhaps if it had the equations would have looked more similar.

Figure J-12 shows the correlation between nephelometer B & the Plaza PM2.5 TEOM. Sections are defined as in the previous paragraph. Again, section 1 shows a higher correlation than section 2. Slopes are pretty different between the two data sets. Note that the very high values were not plotted in Figures J-12&J-13.

There are several hypotheses on why correlations are not as high as in previous studies. Firstly, in this case, there is thought to be something wrong with the internal functioning of at least one of the nephelometers, most likely in Nephelometer B. This explains why a gap exists between the two sets of values after January 19. An alternate explanation is that the placement of the heating pad interfered with the instrument's internal workings and that this caused the shift on January 19.

### 3. Collocation Data – Plaza Building Elevator & Furnace Rooms

To improve correlations, the nephelometers were brought inside and used in the Plaza Building's furnace and elevator rooms. In the elevator room, the nephelometers were attached to a vacuum line containing outdoor air. The PM2.5 TEOM and other air monitoring equipment attach to the same vacuum line which the nephelometers were able to attach to as well. This room provided what is thought to be an ideal location for collecting collocation data because the nephelometers could remain at room temperature in this indoor location while still monitoring outdoor air through the vacuum line. Special knobs were bought to seal gaps between the vacuum line and the nephelometers. When the nephelometers were not being used for mobile monitoring they spent numerous amounts of time collecting collocation data in the furnace and elevator room of the Plaza Building. The elevator room is on the 6$^{th}$ floor of the Plaza Building.

#### A. January 29- February 1 2010 – Plaza Building Elevator Room

The time series of scattering and meteorological variables between January 29 and February 1 is shown in Figure J-14. Both sets of scattering values seem to show a similar pattern with an average difference of 15.81M/m. The relative humidities, air temperatures & cell temperatures appear to be almost exact between the two series. Pressures show a gap of on average 1.27mb. This small difference in pressures appears to be emphasized in Figure J-14 due to the detailed right hand scale. There

does not appear to be any "shifts" in scattering or meteorological parameters during the period.

Figure J-15 shows the time series of nephelometer and PM2.5 TEOM values for the period. The correlations between the nephelometers and the TEOM looks quite good. Also noticeable is the fact that the TEOM seems to show an oscillation of approximately 5µg/m$^3$.

Figure J-16 shows that the correlation between the nephelometers is high with $R^2$=0.9398. The equation describing the correlation shows an intercept of 17.38M/m which is a significant difference. Figure J-17&J-18 show the Neph/TEOM correlations predicted from Figures J-13 & J-14. For nephelometer A and the Plaza PM2.5 TEOM $R^2$=0.8455, likewise, for Nephelometer B and the Plaza PM2.5 TEOM, $R^2$=0.8264. All of these correlations are in the realm of what correlations for previous studies have been including Larson (2007) and Millar (2010).

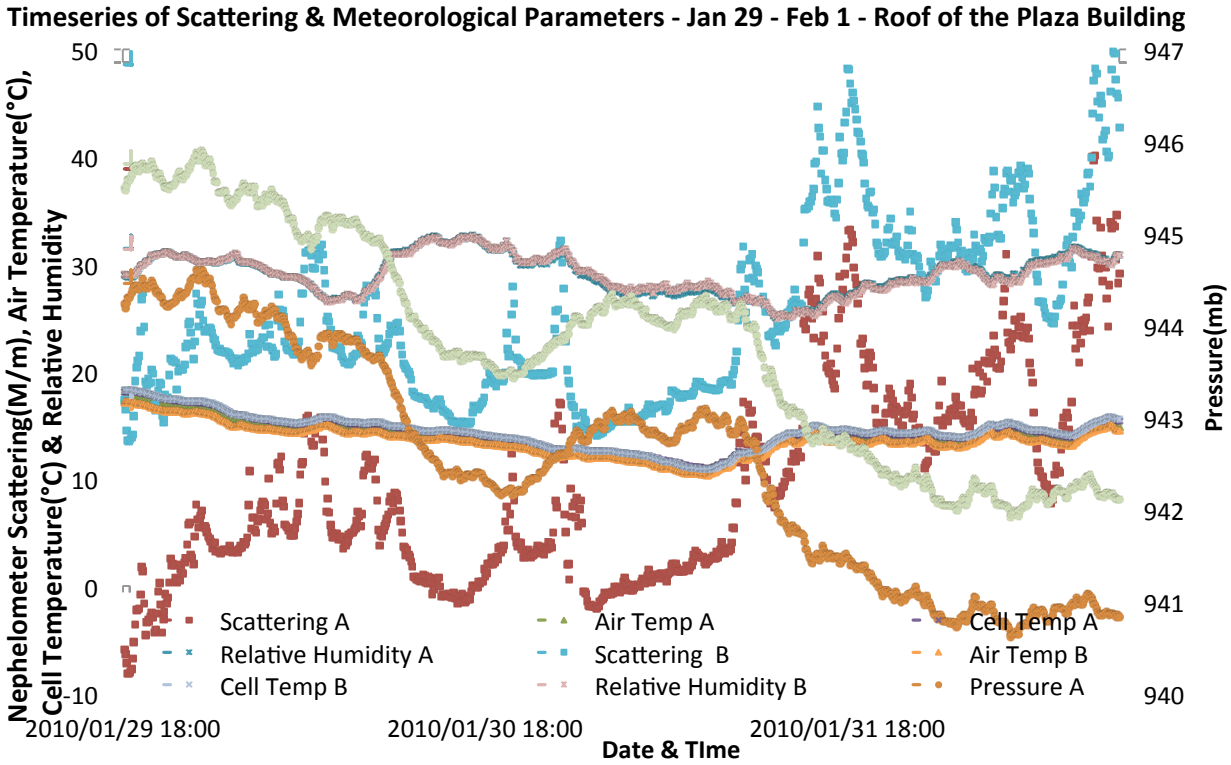


Figure J-14: Nephelometer Correlation Data between January 29 and February 1 2010 on the Roof of the Plaza Building

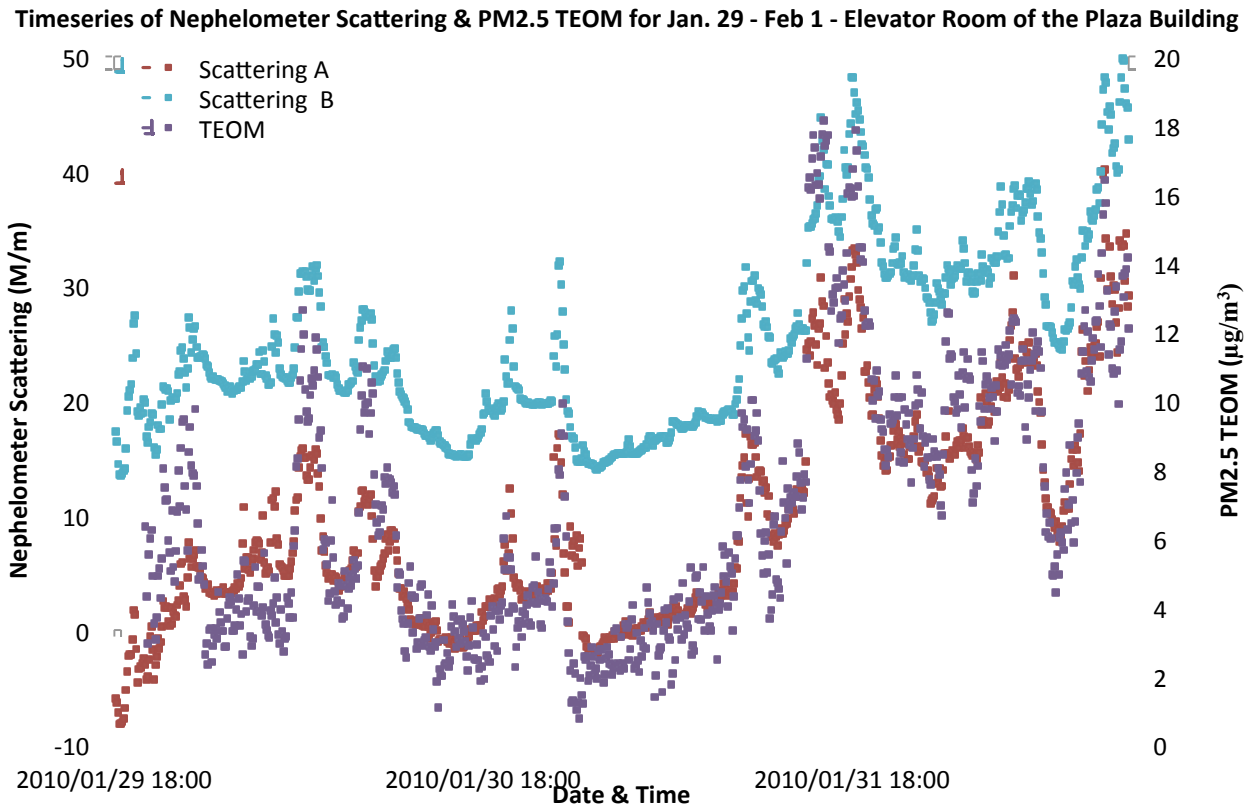


Figure J-15: Nephelometer Scattering & Plaza PM2.5 TEOM for January 29-Febuary 1 2010 in the Elevator Room of the Plaza Building

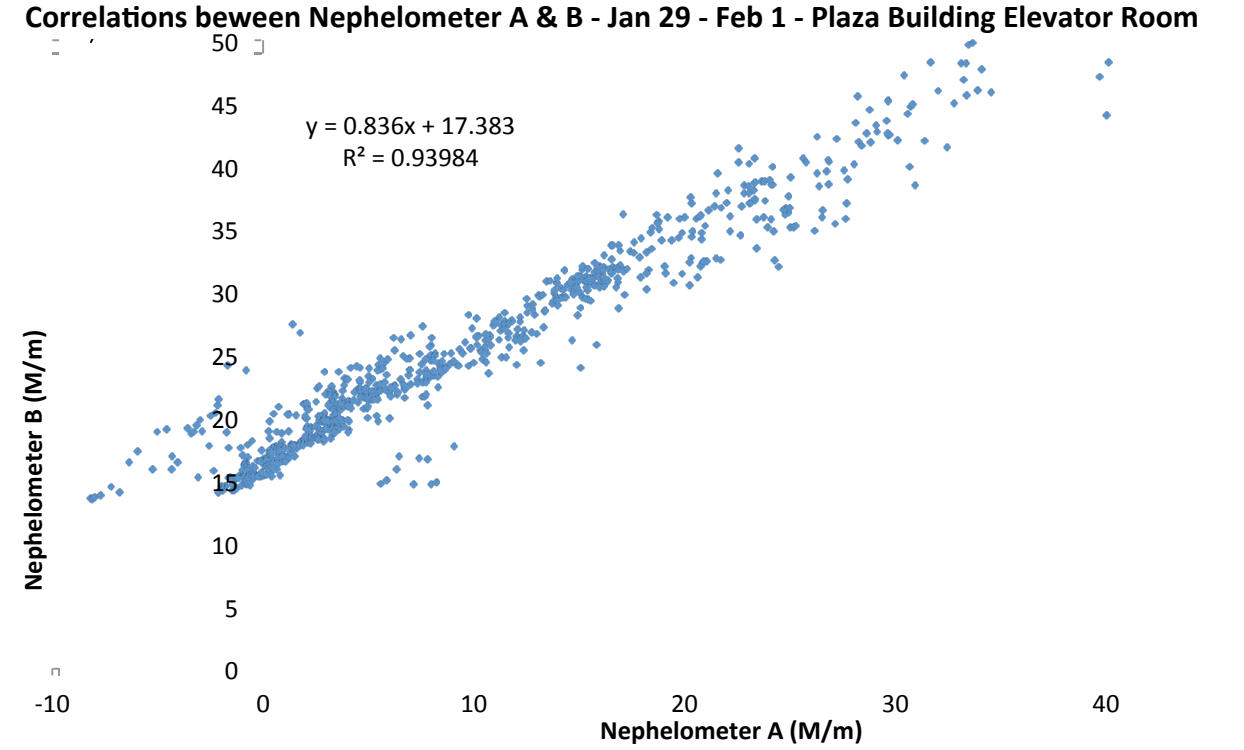


Figure J-16: Correlation between Nephelometer A & B – January 29 – February1 2010 – Plaza Building Elevator Room

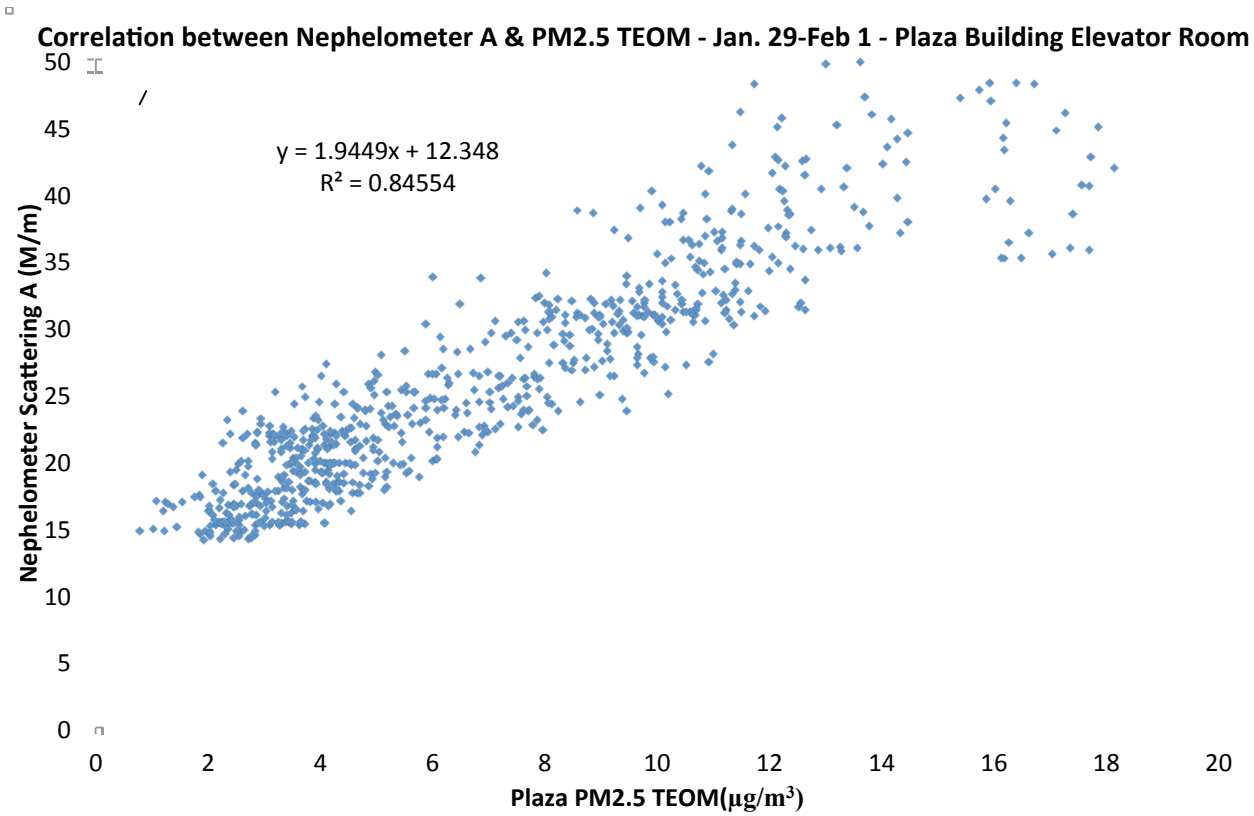


Figure J-17: Correlation between Nephelometer A & PM2.5 TEOM - January 29 to February 1 2010 in the Plaza Building Elevator Room

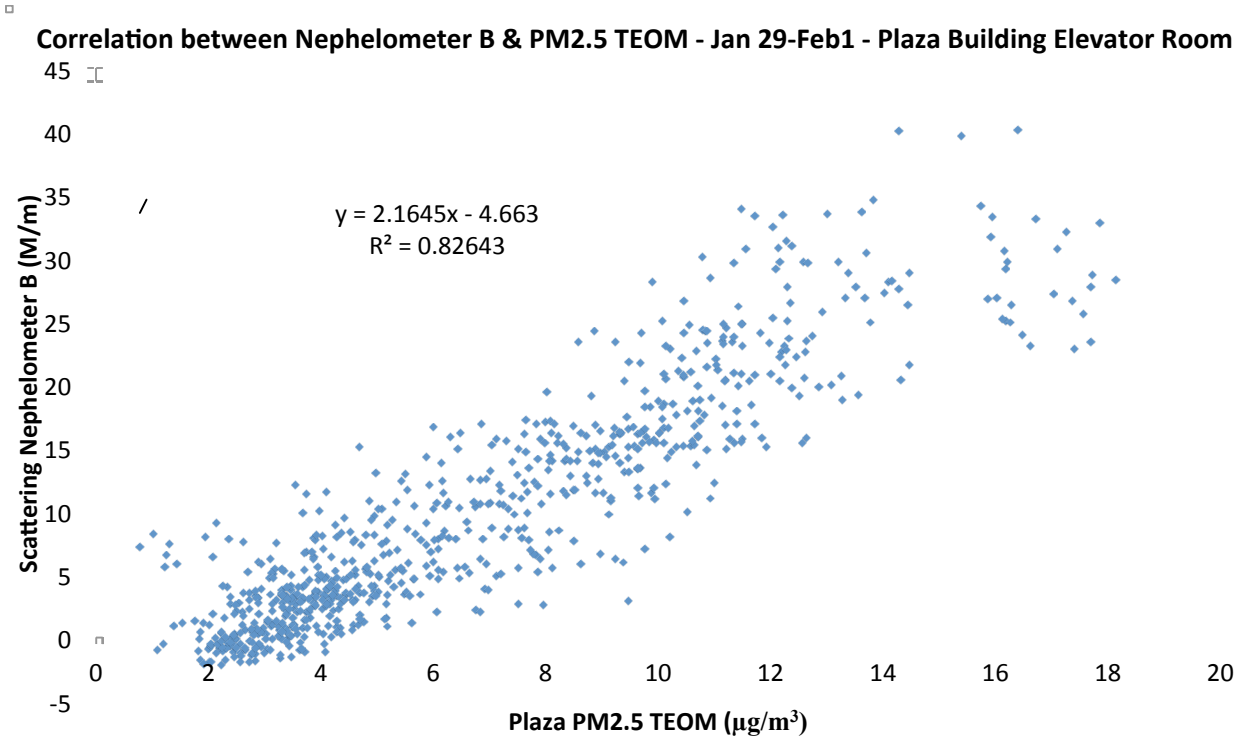


Figure J-18: Correlation between Nephelometer B & the Plaza PM2.5 TEOM for January 29 to February 1 in the Plaza Building Elevator Room

## B. February 3-5 2010

The time series of the nephelometer data for the collocation period is visible in Figure J-19. One of the peculiar things about this data set is that all of the data appears to be oscillating. Ministry of Environment Prince George has found equipment in this room to give oscillating results before, specifically a TEOM many years ago. When the TEOM was moved behind a type of curtain the oscillating stopped. One possible explanation for the oscillations is a fan located nearby. Another possible explanation is the heating/cooling system. Later on an external thermometer was placed in the room to see if it recorded the same oscillations as well. These results will be discussed later on.

As seems to be the fashion trend in nephelometer data, a "shift" in scattering data occurs in the afternoon of February 4 around 15:40. The shift is shown up close in Figure J-20. Before the shift the air and cell temperatures were almost identical whereas they diverge slightly afterwards. Pressure tends to show an average difference of 1.7mb.

The shift is different from earlier shifts in that no sudden jumps in meteorological parameters occur and the shift does not occur proceeded by very high scattering values.

Figure J-22 shows the correlation between the two nephelometers. Section 1 comprises the data before the shift at 15:40 February 4 and section 2 comprises the data after this time. The correlation changes from 99% to 1%, obviously quite a dramatic change!

The correlations between the Nephelometers and the Plaza PM2.5 TEOM are shown if Figures J-23&J-24. The correlations are divided up into two sections as defined above. Again, the differences in correlations before and after the shift are fairly large. The correlations before the shift are only $R^2$=53 for both Nephelometers, however, this is most likely due to the oscillations in scattering.

One interesting thing is that when the nephelometers were working properly for the first 18 hours there was no correlation between temperature and scattering Figure J-24. However, when nephelometer B shows no correlation with the TEOM, there appears to be a strong correlation between scattering and temperature. See Figure J-25.

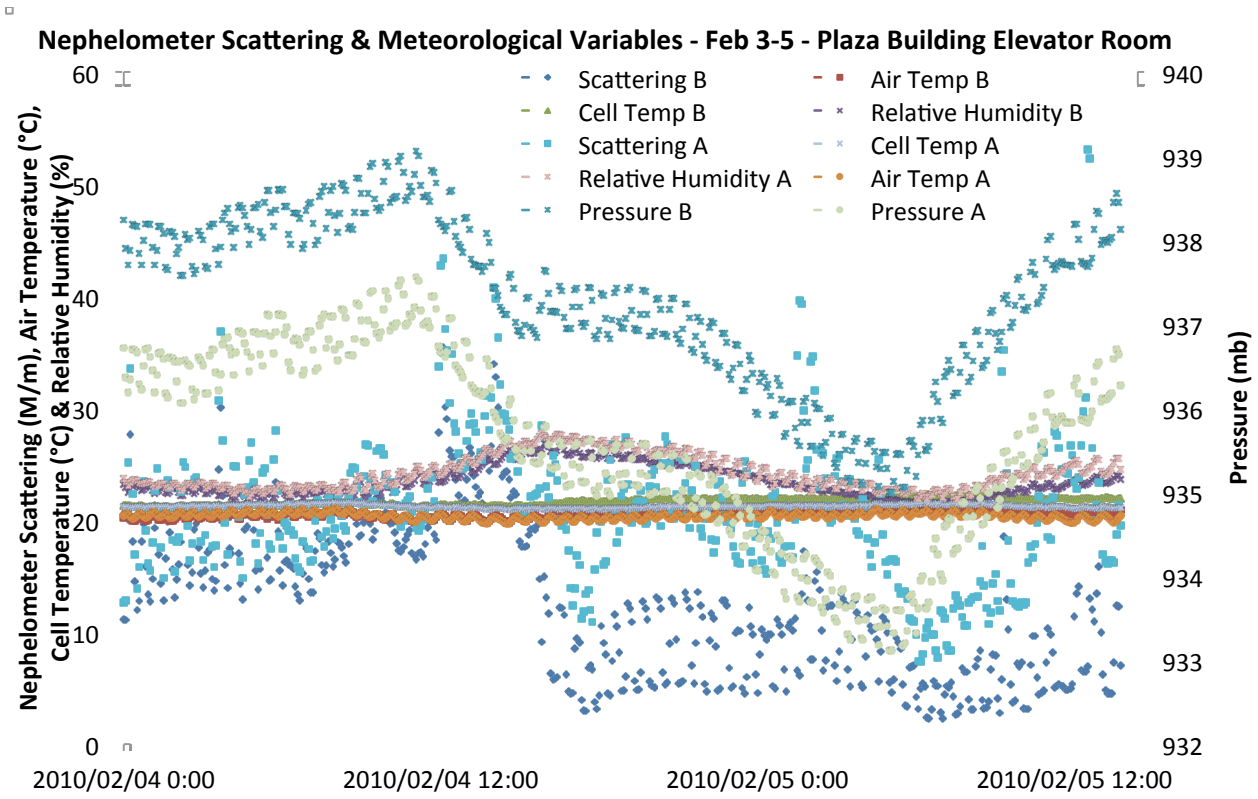


Figure J-19 Nephelometer Scattering & Meteorological Variables February 3-5 2010– Plaza Building Elevator Room

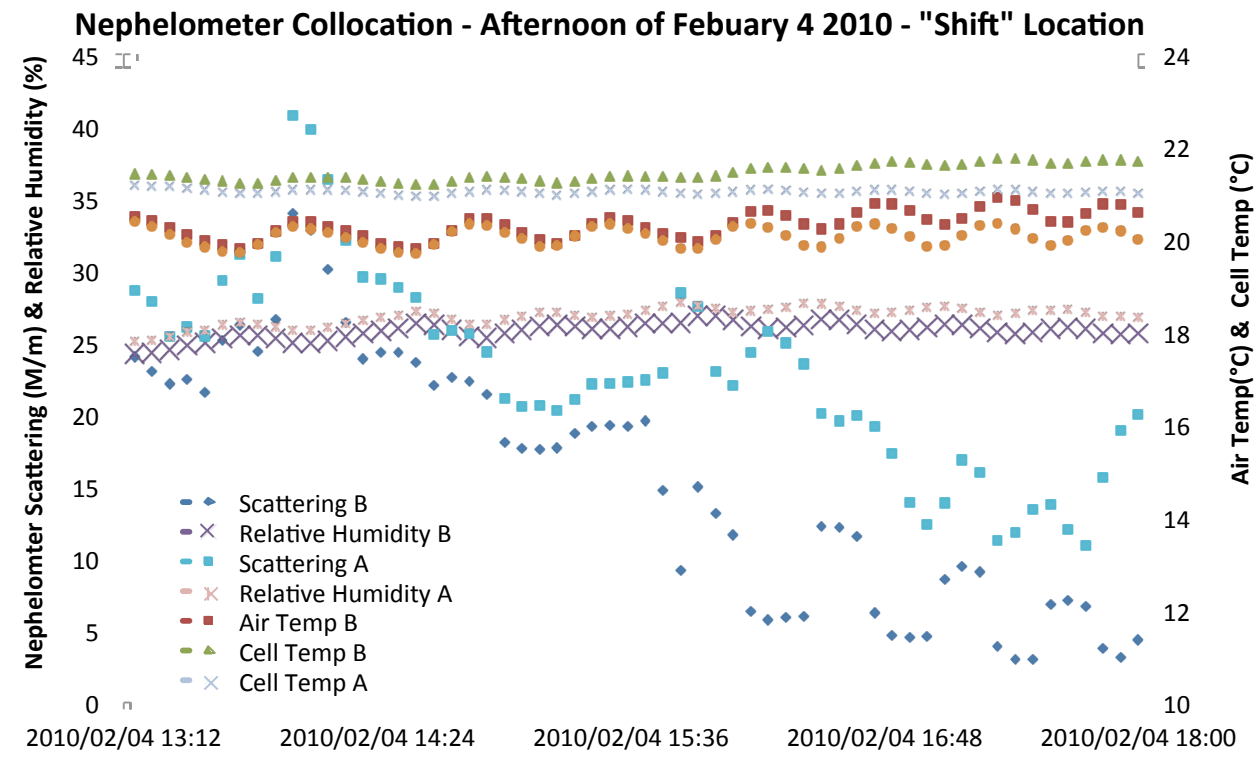


Figure J-20: Up close "Shift" in scattering values – February 4 2010 – Plaza Building Elevator Room

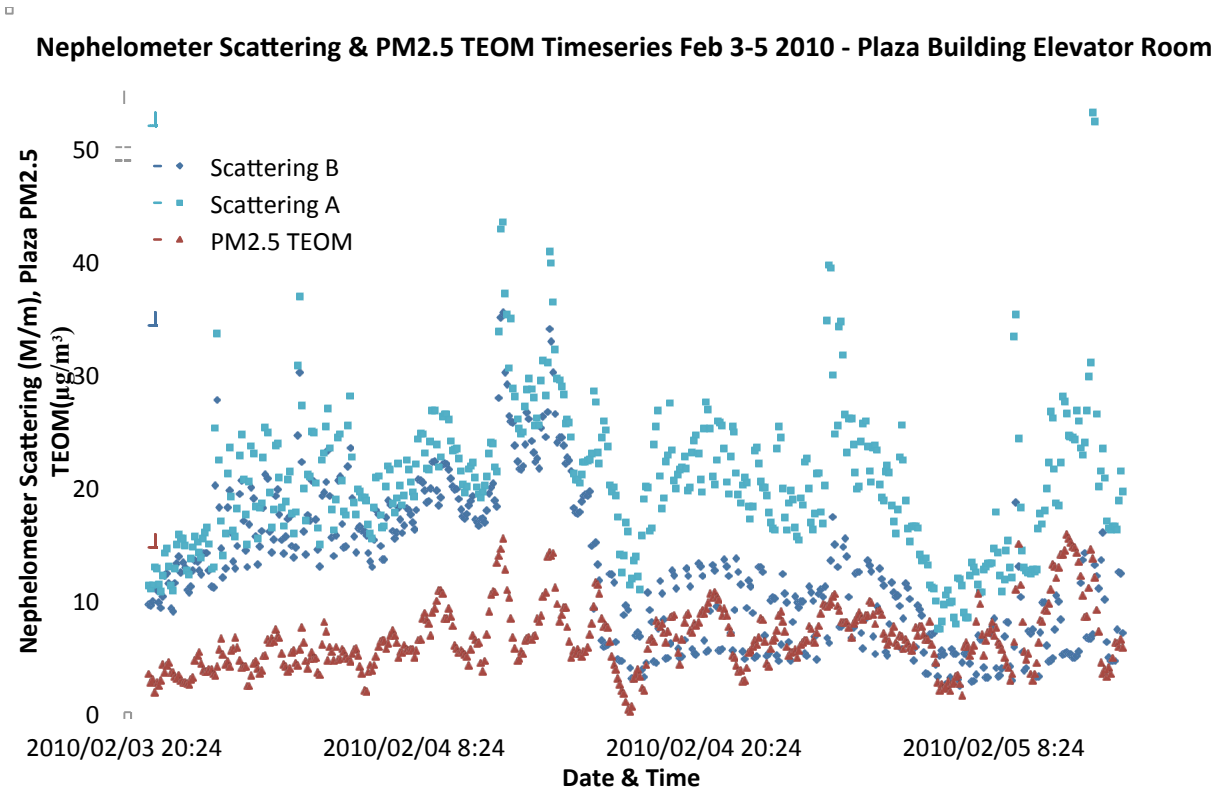


Figure J-21: Time series of Plaza PM2.5 TEOM & Nephelometer Scattering in Plaza Building Elevator Room for February 3-5, 2010

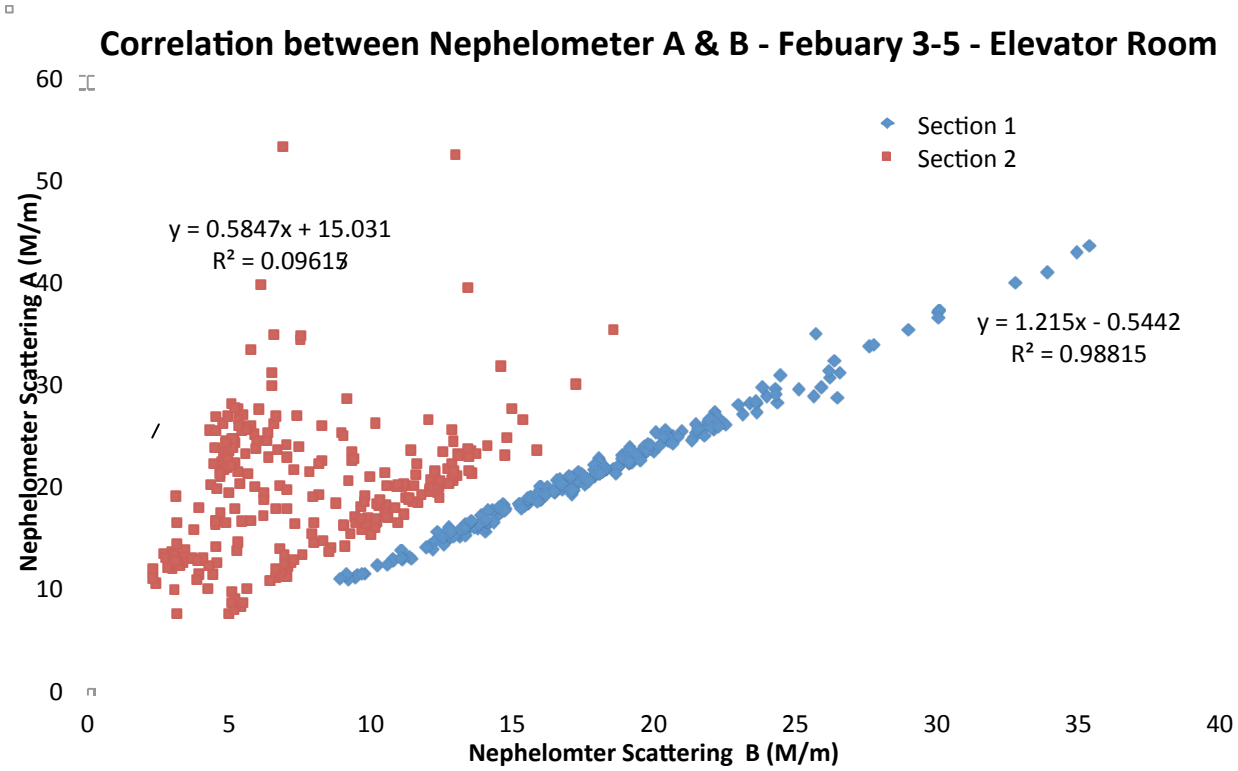


Figure J-22: Correlation between Nephelometers A&B – February 3-5 – Plaza Building Elevator Room

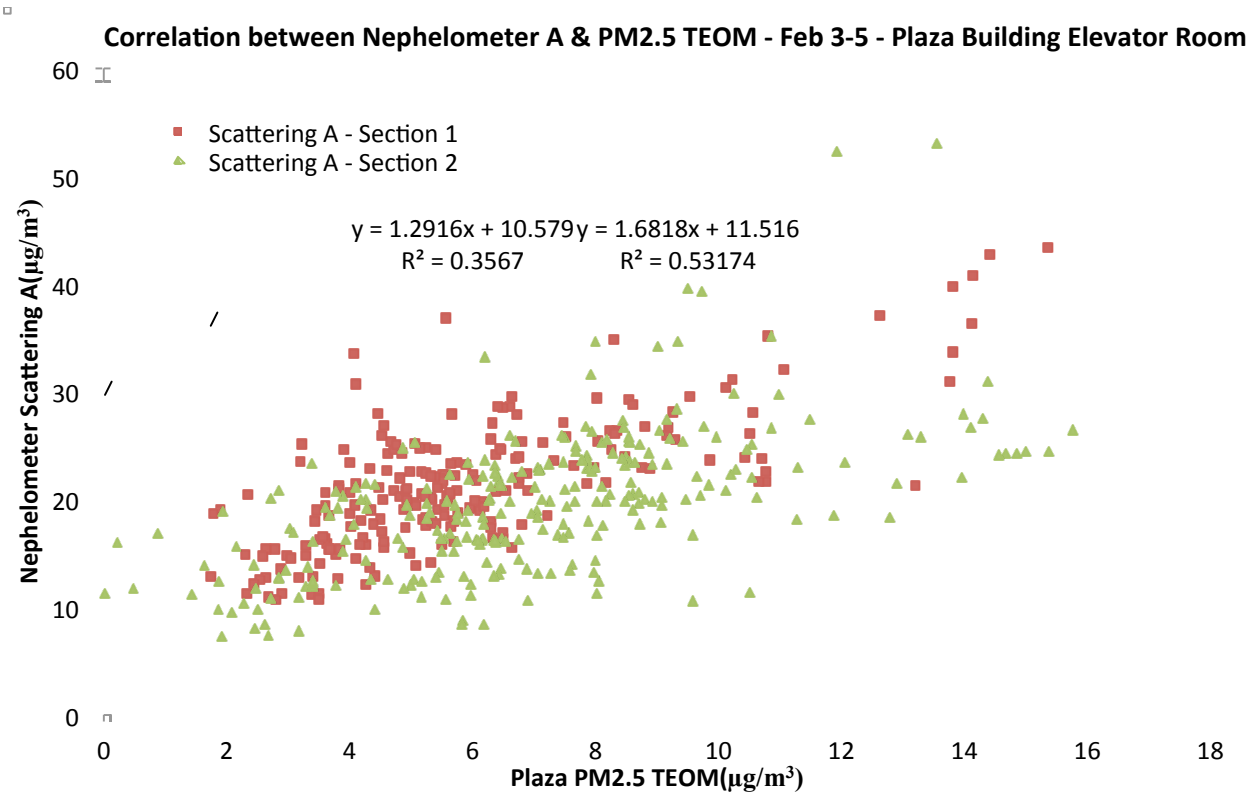


**Figure J-23: Correlation between Nephelometer A & Plaza PM2.5 TEOM – February 3-5 – Plaza Building Elevator Room**

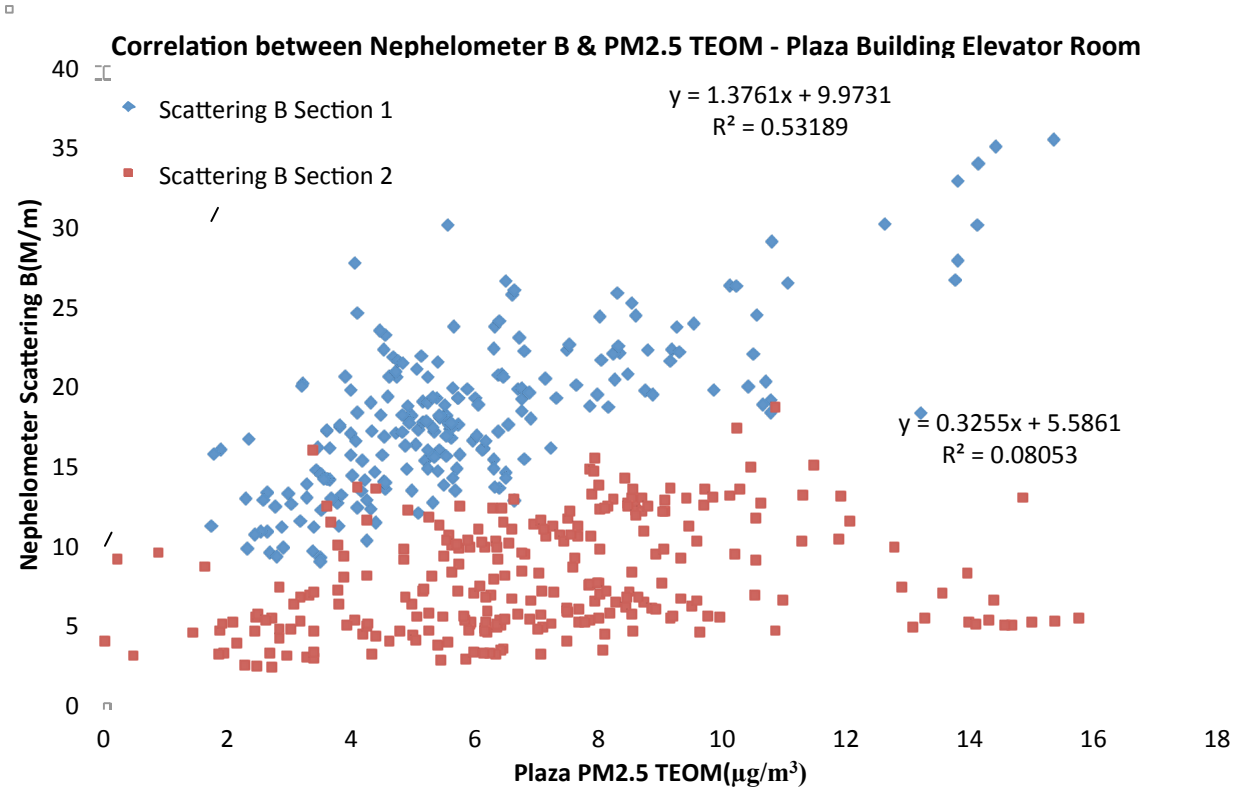


**Figure J-24: Correlation between Nephelometer B & Plaza PM2.5 TEOM – February 3-5 – Plaza Building Elevator Room**

## C. February 10-12 2010

Figure J-25 shows the timeseries of Nephelometer Scattering & meteorological parameters for February 10-12. Figure J-26 is the same but does not include pressure, this allows for air temperature, cell temperature and relative humidity to be more visible on the graph. Overall, the data looks a lot like the data from the previous section. The parameters are all oscillating like before. Near the beginning, there is an interesting kink in the Scattering B values. During the time where the scattering values seems to dive the values seem to not show oscillations, however, the meteorological parameters still oscillate. At the very end of the timeseries, neither the scattering values nor the meteorological parameters oscillate. It seems to be a coincidence that oscillations stop when scattering values are low because in the previous timeseries (Feb. 3-5) this did not take place.

Figure J-27 shows the timeseries of nephelometer scattering and Plaza PM2.5 TEOM. Despite a couple of blunder areas, the two sets of instruments seem to follow the same pattern pretty well.

Figure J-28 shows the correlation between the two nephelometers for the timeperiod which shows $R^2$=0.5118. This $R^2$ value seems quite a bit lower than expected from

the similar patterns shown in Figure J-25 & J-26. Is this because of the oscillations? In previous sections (notably in the February 3-5 section), even though oscillations were taking place, the correlation remained high.

Figure J-29 & J-30 show the correlations between the nephelometers and Plaza PM2.5 TEOM for the period of February 10-12. What seems strange is that because the Neph/Neph correlations was lower than for the previous period, Feb 3-5 and the data series is still oscillating, one would have expected that the Neph/TEOM correlations to be lower than the Feb. 3-5 correlations. However, this is not the case, for Nephelometer A and B and the TEOM $R^2$=0.65 and $R^2$=0.5165 respectively.

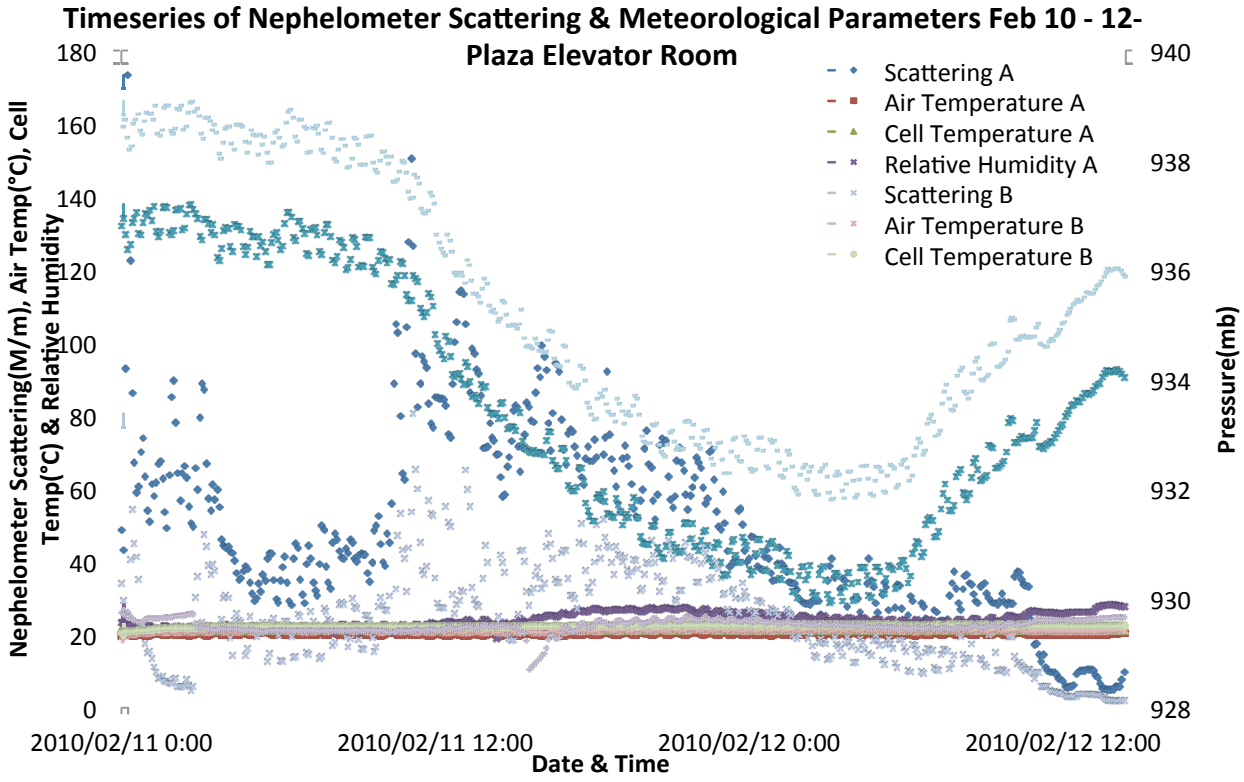


**Figure J-25: Time Series of Nephelometer Scattering & Meteorological Parameters – Feb 10-12, 2010 – Plaza Building Elevator Room**

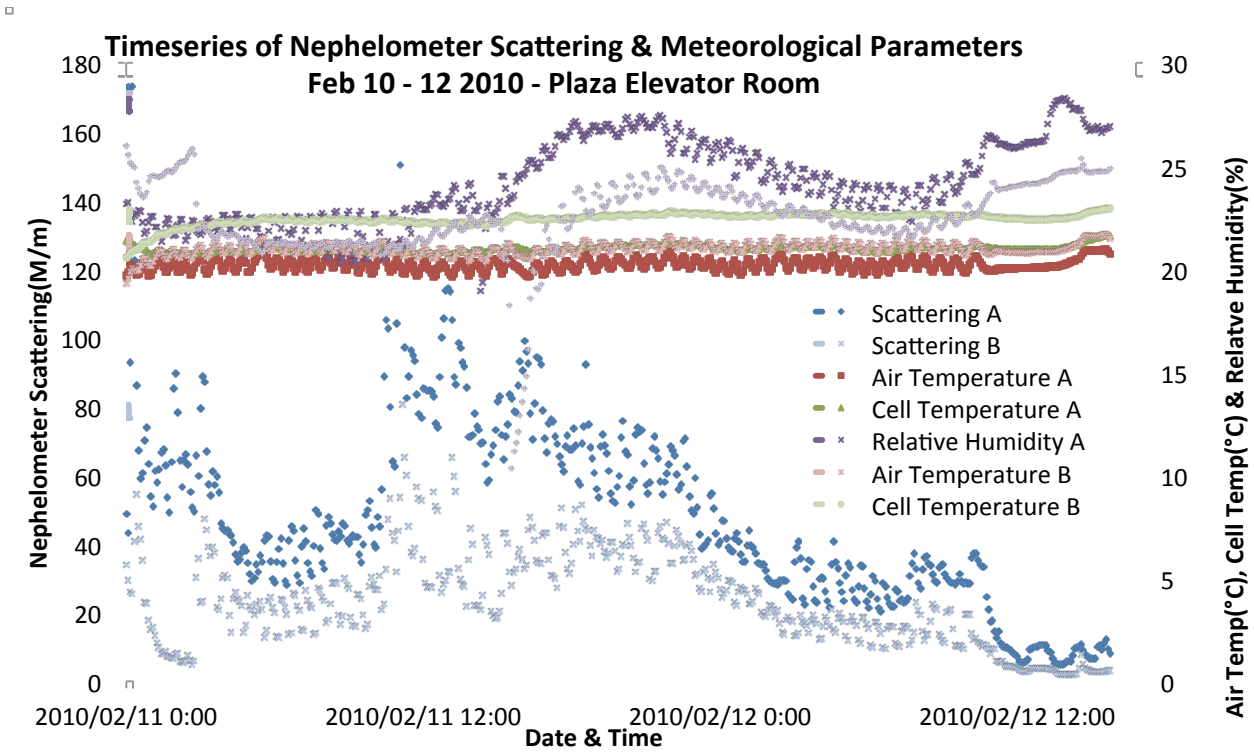


Figure J-26: Time Series of Nephelometer Scattering & Meteorological Parameters Feb 10 - 12 2010 - Plaza Elevator Room – layout shows air temperature, cell temperature and relative humidity up close.

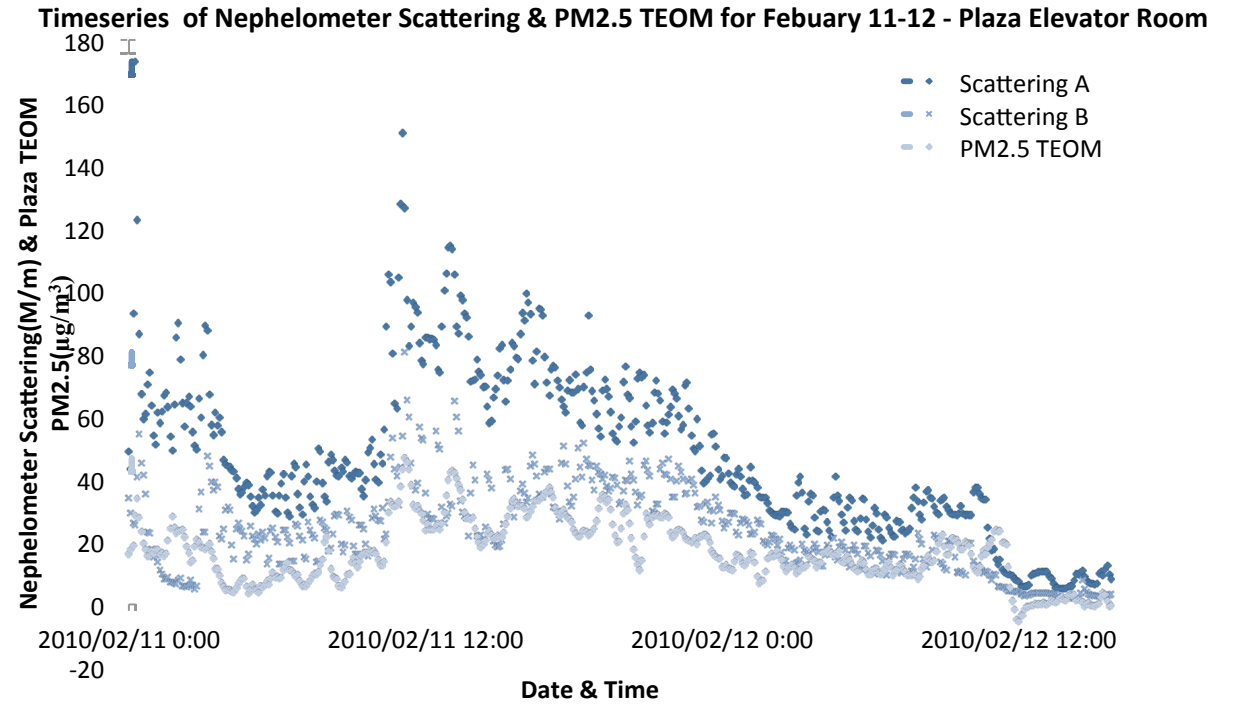


Figure J-27: Time series of Nephelometer Scattering & Plaza PM2.5 TEOM for February 11-12 – Plaza Building Elevator Room

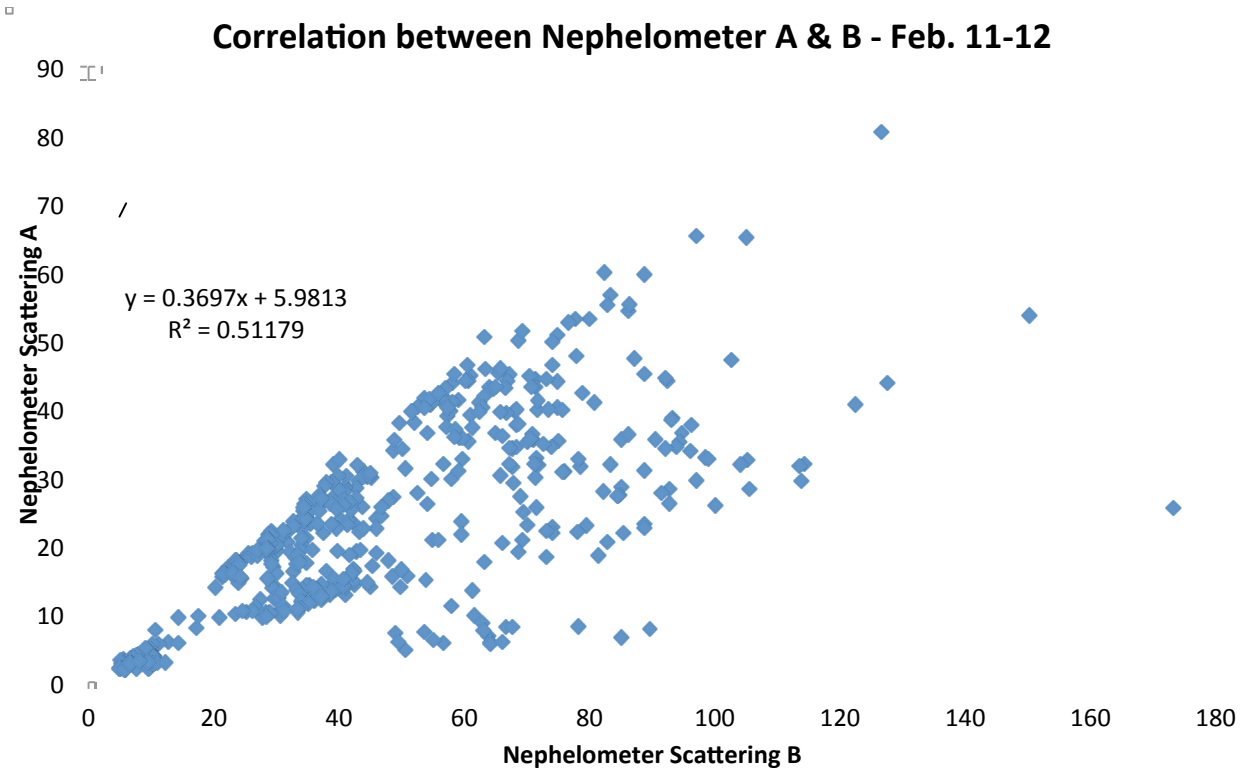


Figure J-28: Correlations between Nephelometers A&B – February 11-12, 2010 – Plaza Building Elevator Room

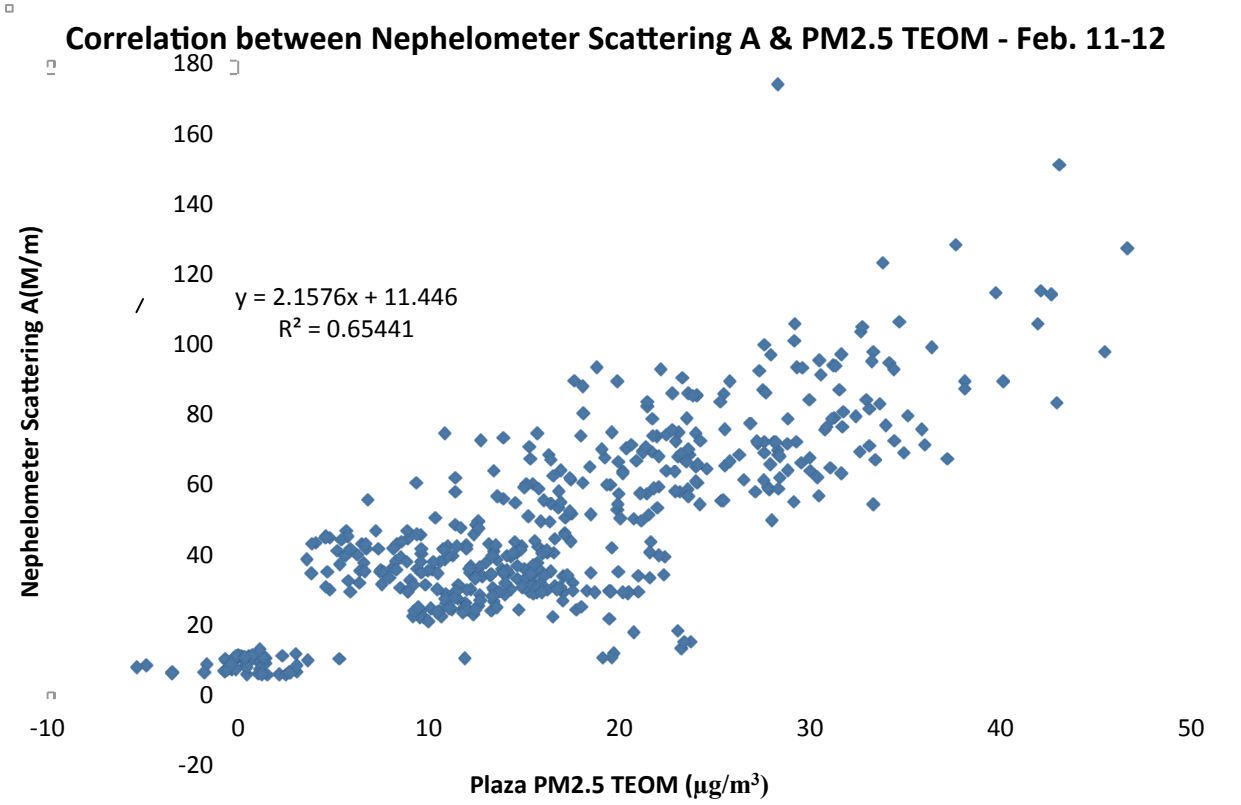


Figure J-29: Correlation between Nephelometer Scattering A & PM2.5 TEOM – Feb. 11-12, 2010 – Plaza Building Elevator Room

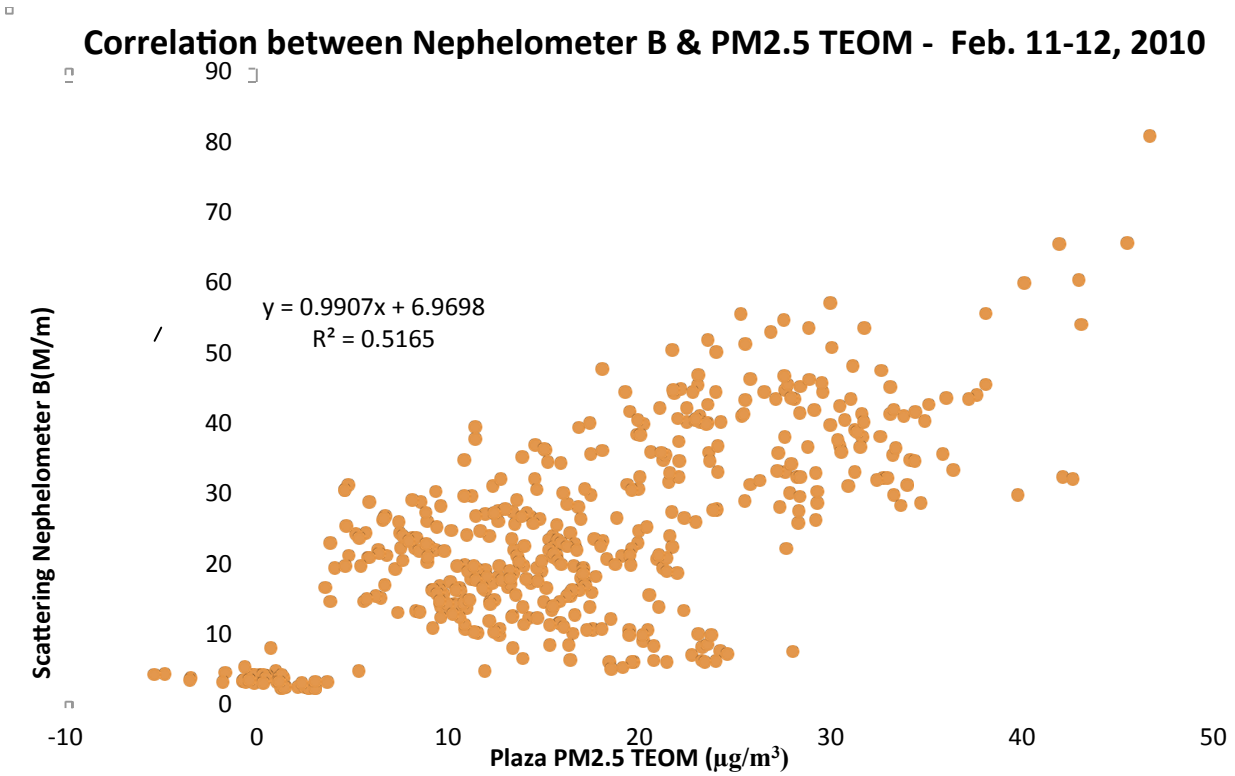


**Figure J-30: Correlation between Nephelometer B & Plaza PM2.5 TEOM – February 11-12 2010 – Plaza Building Elevator Room**

## D. February 22-23, 2010

Figure J-31 shows the timeseries of nephelometer scattering and meteorological parameters over February 22-23. Obviously noticeable is the very high oscillations in Relative Humidity B at the beginning of the timeseries. The nephelometers had been out right before this collocation period began. While the nephelometers were out often ice would form the part of the nephelometer which was outside. Before bringing the nephelometers in this ice would be taken off. Perhaps, water or ice got into nephelometer B and is responsible for causing such strongly fluctuating values in Relative Humidity.

Another unexpected result is that the oscillations seem to stop especially on Nephelometer A as the values get low. Again, the pattern between nephelometer A & B seems to have blunders but be fairly good overall. There is a noticeable "jolt"close to the middle of the timeseries in scattering A values along with nephelometer A's meteorological parameters. The scattering A timeseries in general seems to show stronger fluctuations than scattering B's.

Figure J-32 shows the timeseries of nephelometer scattering and PM2.5 TEOM values. Overall, they all show similar patterns, theTEOM values looking a little bit more like Nephelometer B's.

Figure J-22 shows the correlation between the two nephelometers. Figure J-34 and J-35 show the correlations between the nephelometers and the TEOM. The correlation between the two nephelometers is $R^2$=0.8331, and the correlation between nephelometers A&B with the TEOM is $R^2$=0.6809 and $R^2$=0.6689 respectively. These two last correlations are higher than expected considering the timeseries are oscillating. The TEOM timeseries seems to be almost oscillating slightly as well – could this be why the correlations are higher than expected?

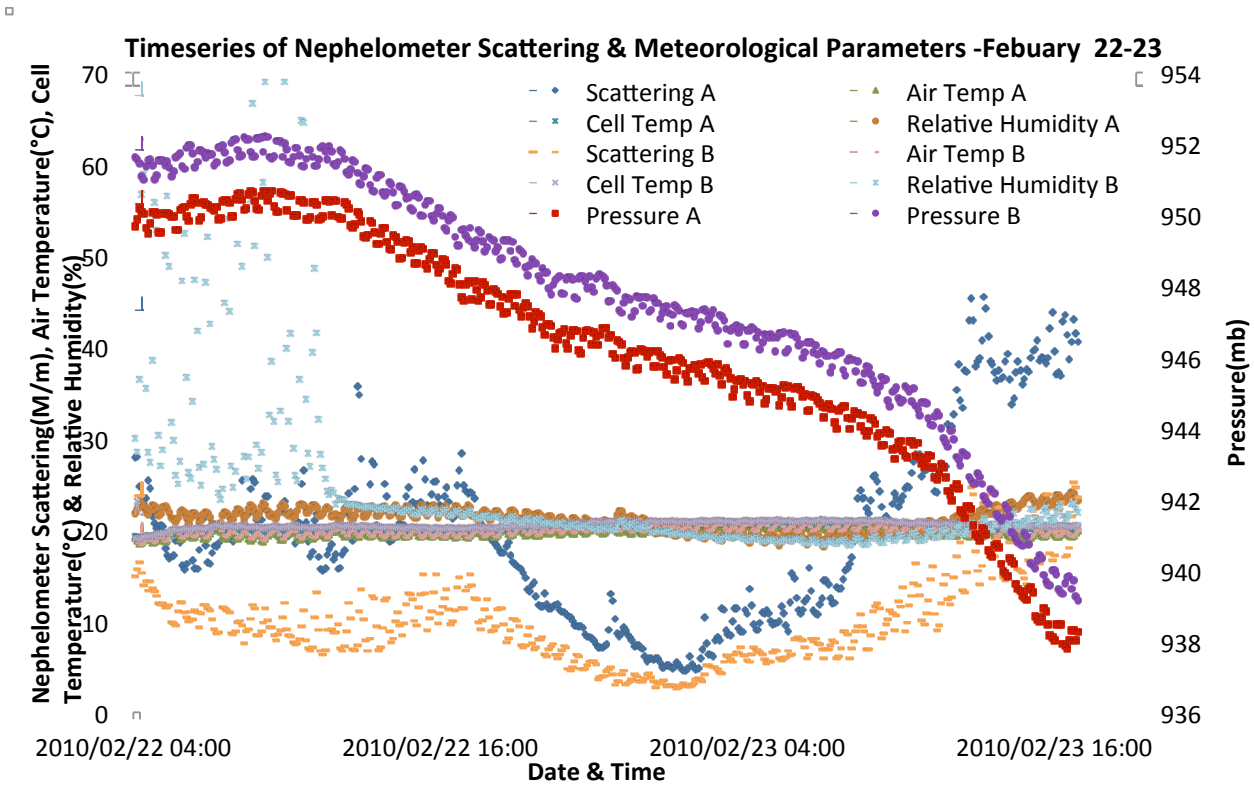


Figure J-31: Time series of Nephelometer Scattering & Meteorological Parameters – February 22-23

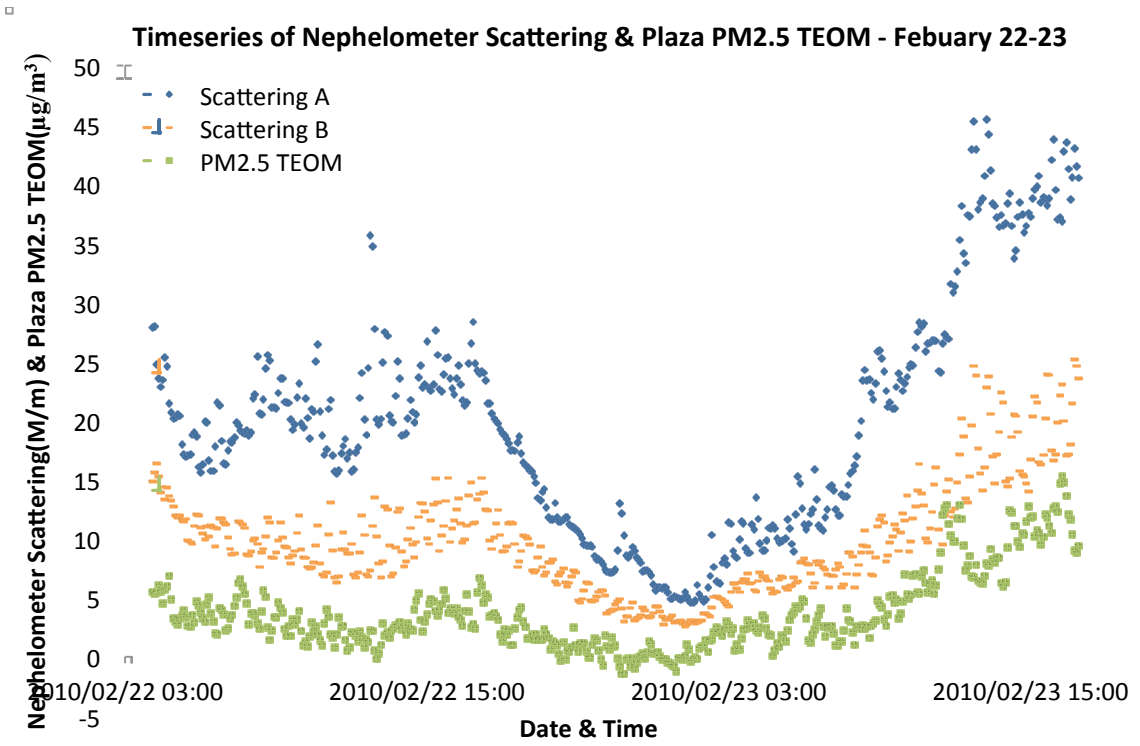


Figure J-32: Time series of Nephelometer Scattering & Plaza PM2.5 TEOM – February 22-23- Plaza Building Elevator Room

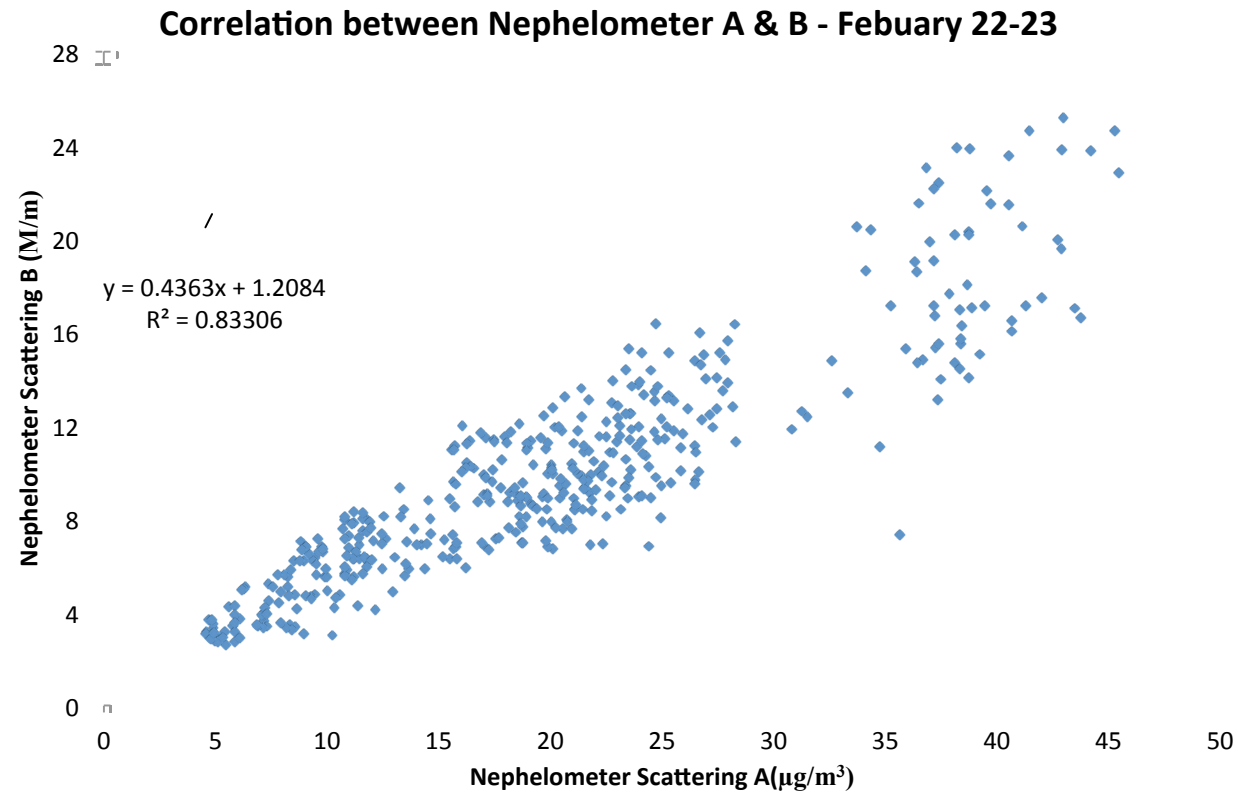


Figure J-33: Correlation between Nephelometer A&B – February 22-23, 2010 - Plaza Building Elevator Room

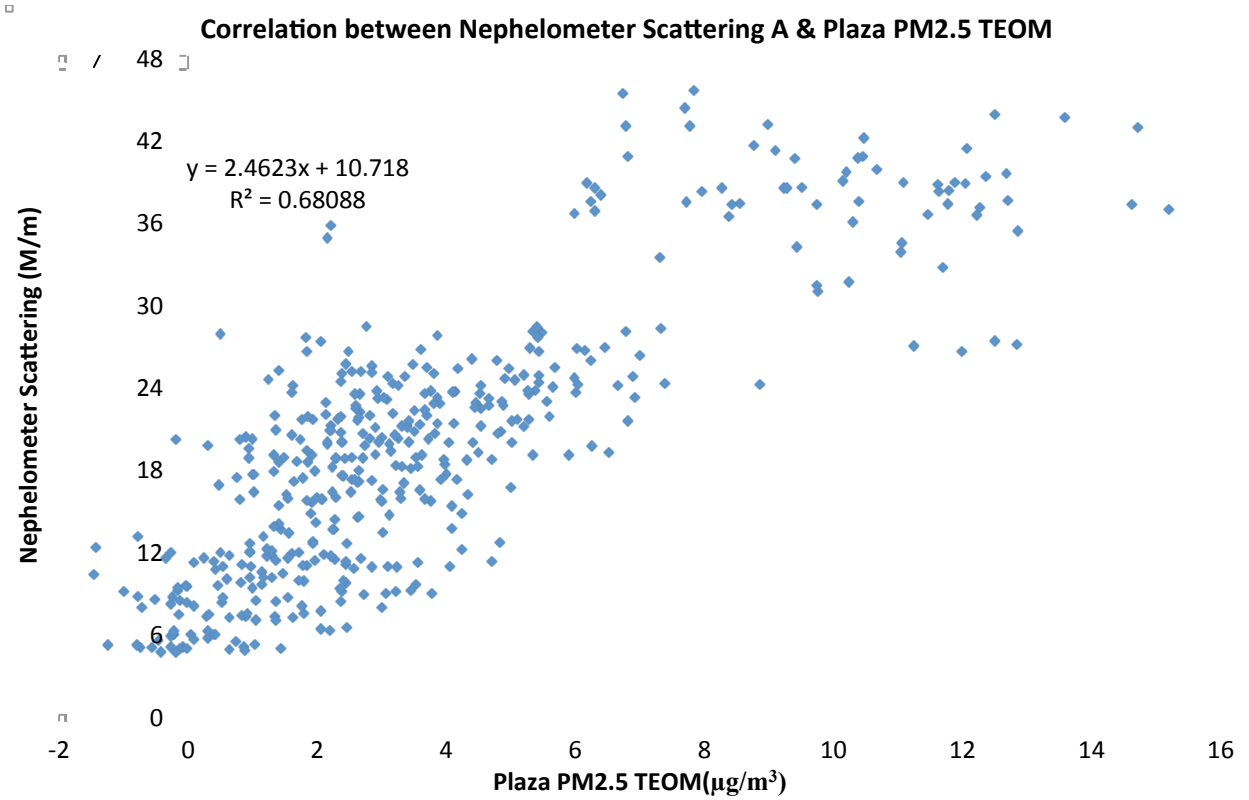


Figure J-34: Correlation between Nephelometer A & Plaza PM2.5 TEOM – February 22-23, 2010 – Plaza Building Elevator Room

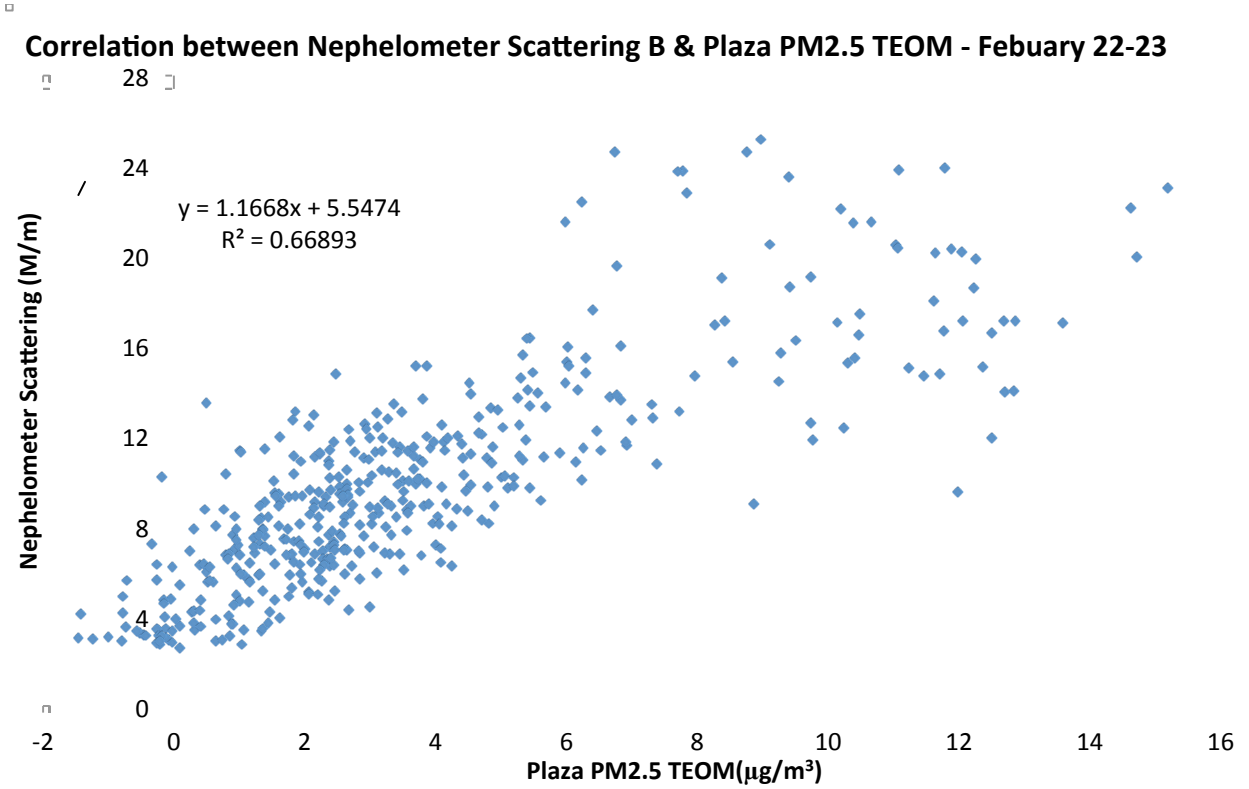


Figure J-35: Correlation between Nephelometer Scattering B & Plaza PM2.5 TEOM – February 22-23, 2010 – Plaza Building Elevator Room

## E. February 23-25 – Plaza Building Elevator and Furnace Room

Due to concern over the nephelometer's oscillations, one nephelometer was placed in furnace room and one placed in elevator room. The hope was that one of the nephelometer in the elevator room would oscillate but not the nephelometer in the furnace room. This would shed light on the mysterious oscillations – providing proof that the oscillations were likely due to the environment or room the instruments are operating in.

The furnace is also located on the 6$^{th}$ floor of the Plaza Building. The room has receives filtered air from outside. Figure J-36, showing timeseries of the two sets of scattering values and meteorological parameters shows that our hypothesis worked. Nephelometer B's scattering and meteorological parameters are oscillating where as nephelometer A's are not. Figure J-37 shows how the two nephelometers compare to the TEOM.

One observation of interest is that that the timeseries of scattering A's values are all larger those of scattering B's. This information could possibly be used when trying to interpret how high oscillating scattering values really are. Previously it was thought that taking the middle of the serious as the real amplitude would be the best approache.

Figure J-38, J-39 & J-40 are the correlations between the two nephelometers, nephelometer A and the TEOM and nephelometer B and the TEOM respectively. The correlation between the two nephelometers, $R^2$= 0.9132, seems surprisingly high considering the instruments were in different rooms and one was oscillating and the other was not. The correlation between nephelometer A &B and the TEOM are $R^2$=0.7895 and $R^2$=0.7988 respectively.

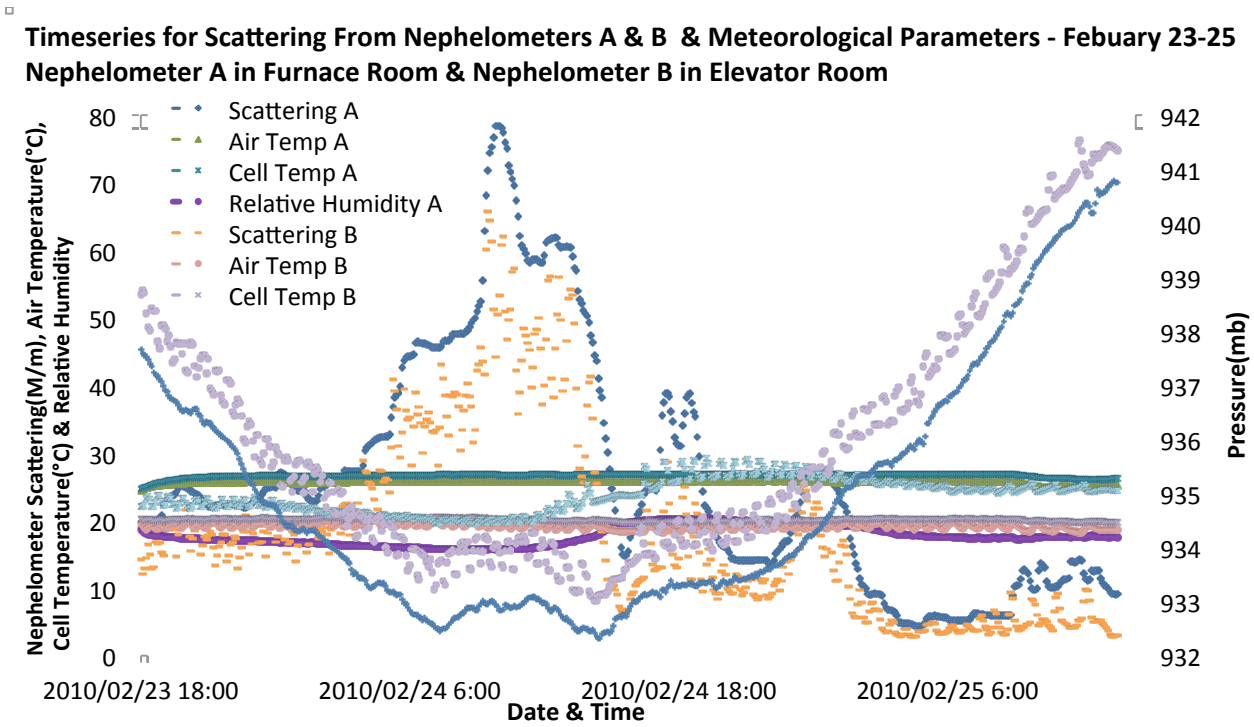


Figure J-36: Time series for scattering from Nephelometer A & B & Meteorological Parameters – February 24-25, 2010 – Nephelometer A in Furnace Room, Nephelometer B in Elevator Room

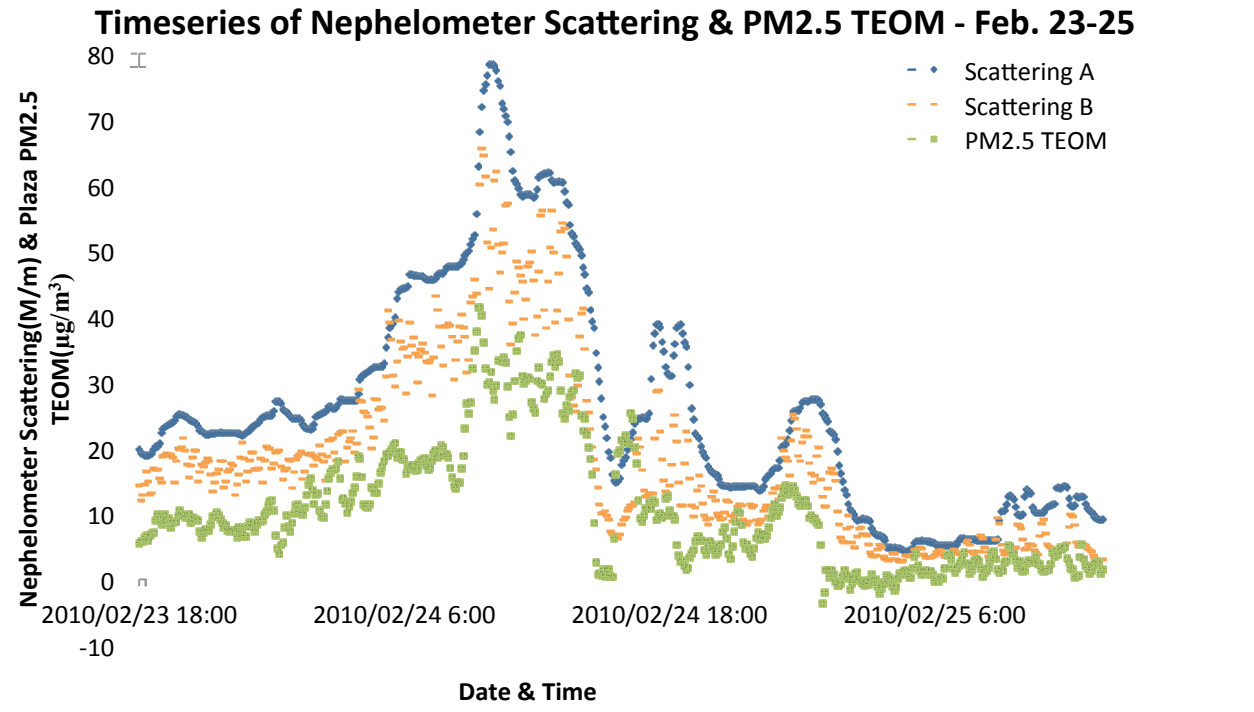


Figure J-37: Time series of Nephelometer Scattering & PM2.5 TEOM – Feb. 23-25, 2010 – Nephelometer A in Elevator Room, Nephelometer B in Furnace Room

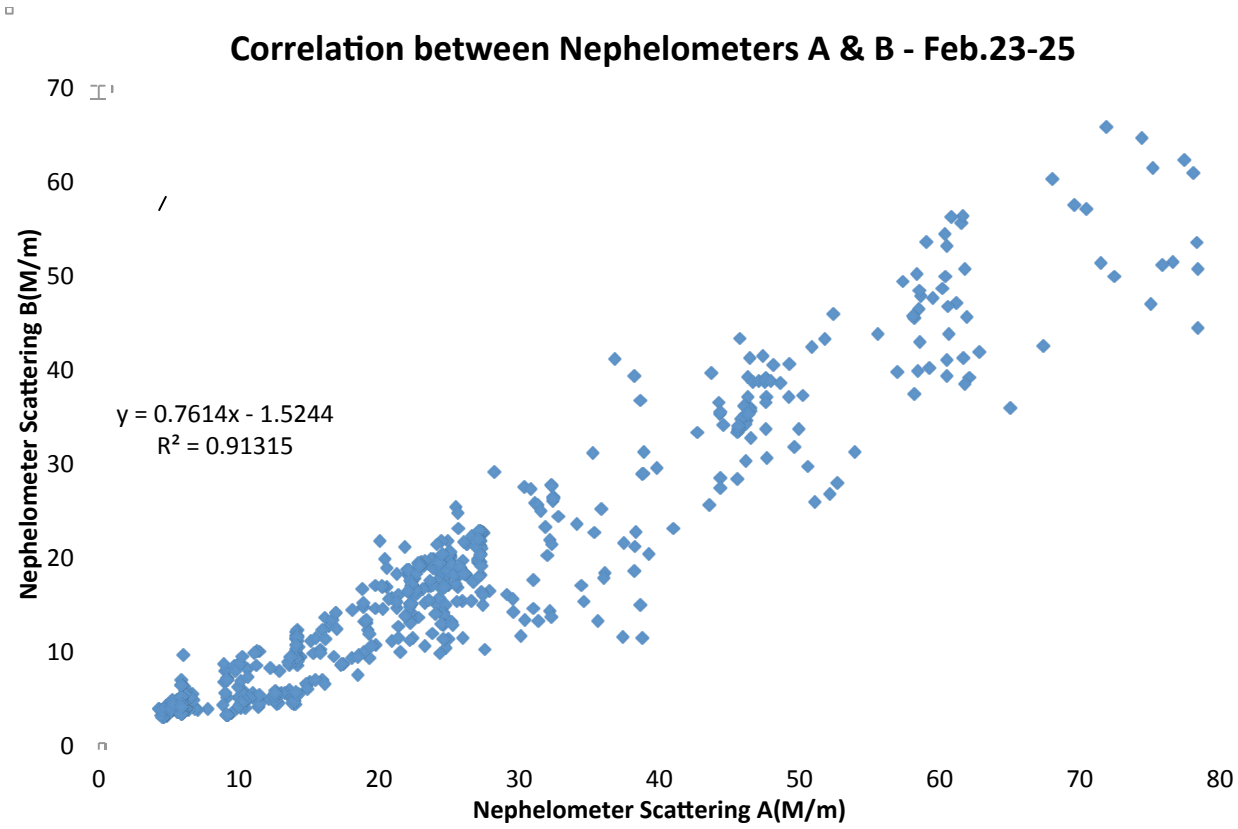


Figure J-38: Correlation between Nephelometers A & B – Feb 23-25, 2010 – Nephelometer A in Plaza Building Furnace Room, Nephelometer B in Plaza Building Elevator Room.

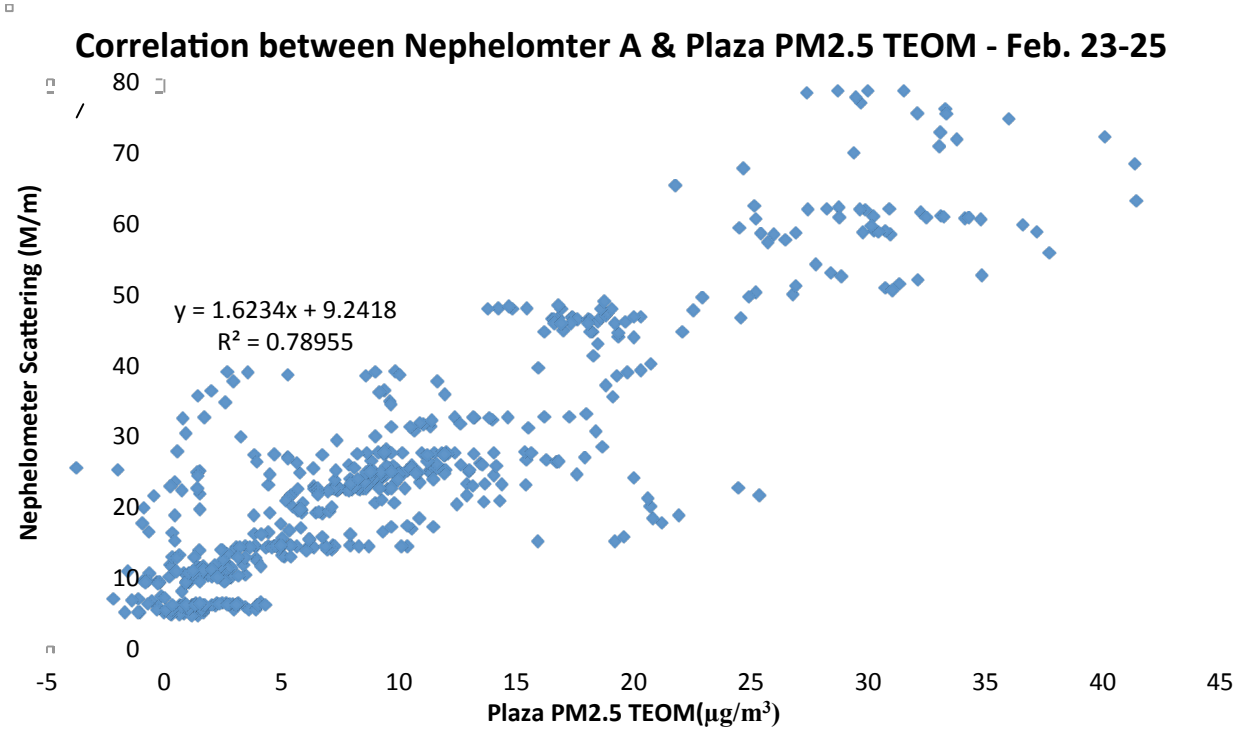


Figure J-39: Correlation between Nephelometer A & Plaza PM2.5 TEOM – Feb. 23-25, 2010 – Nephelometer A in Plaza Building Elevator Room

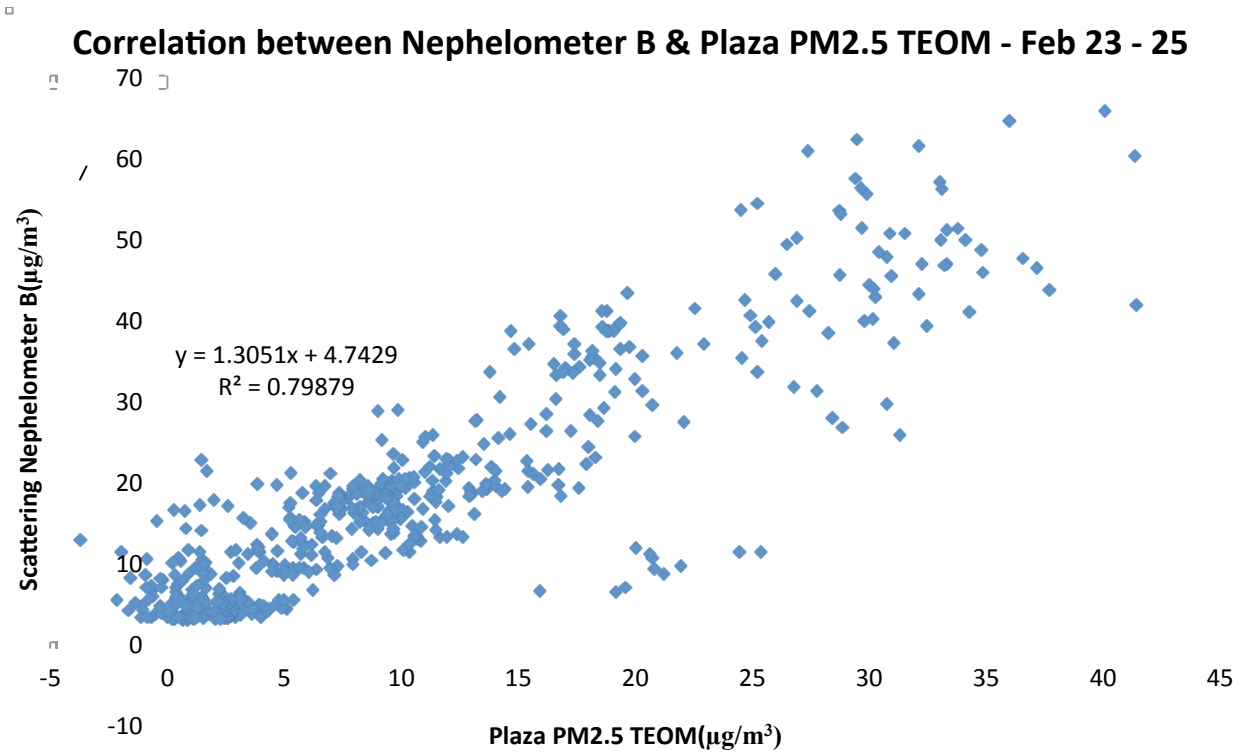


**Figure J-40: Correlation between Nephelometer B & Plaza PM2.5 TEOM – Feb. 23-25, 2010 – Nephelometer B in Plaza Building Furnace Room**

## F. March 9-10 2010 –Plaza Building Elevator Room

For March 9 and 10, the interesting thing was that the nephelometer was taking 1minute instantaneous values instead of the usual 5min averages. Figure J-41 shows the timeseries of nephelometer scattering and meteorological variables during the time period. The variables seem to be oscillating differently than usual. The pressure timeseries shows almost box shaped waves. This tells us that the interference causing the oscillations, has a more robust form than previously thought and is probably something that changes pretty instantaneously. What is also interesting about this timeseries is that the shape of the two scattering patterns are fairly different. Scattering A seems to have the more robust form like the pressures where as Scattering B seems to have small, non-sea metrically shaped oscillations. Perhaps this is caused by one of the position of the two nephelometers. The two air temperatures and relative humidities have almost identical values which oscillate. The two cell temperatures are similar but do not oscillate.

Figure J-42 shows the timeseries of the nephelometer and PM2.5 TEOM over March 9 and 10. Figure J-43 shows the correlation between the two nephelometer to be $R^2$=0.4757. A lower correlation like this one was expected both because the values are 1 minute instantaneous and not 5 minute averages and because of the differently shaped oscillating scattering patterns.

Figure J-44 shows the correlations between nephelometer A and the TEOM and nephelometer B and the TEOM. Placing both correlations on the same graph makes the difference in intercept between the two serious obvious. For nephelometer A and the TEOM $R^2$=0.5465 and for nephelometer B and the TEOM $R^2$=0.2163. Looking at the graph, one would not have assumed such a large difference in correlations.

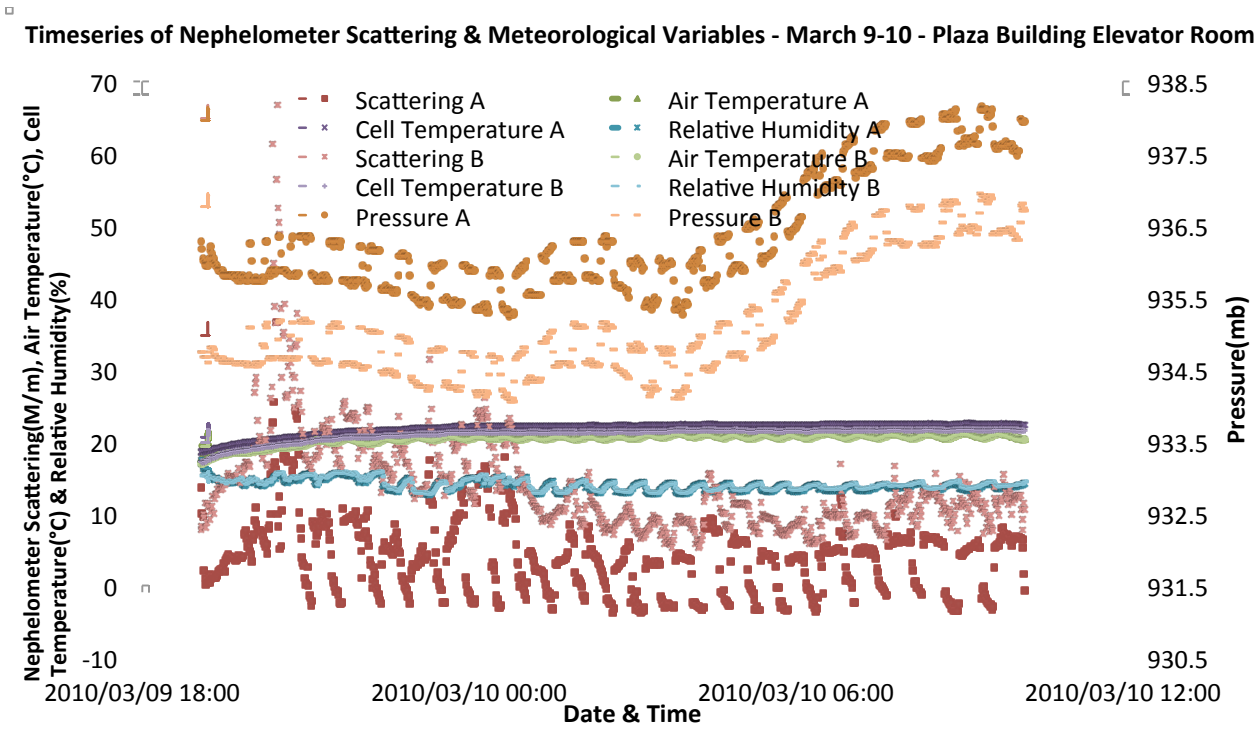


Figure J-41: Time series of Nephelometer Scattering & Meteorological Variables – March 9-10, 2010 – Plaza Building Elevator Room

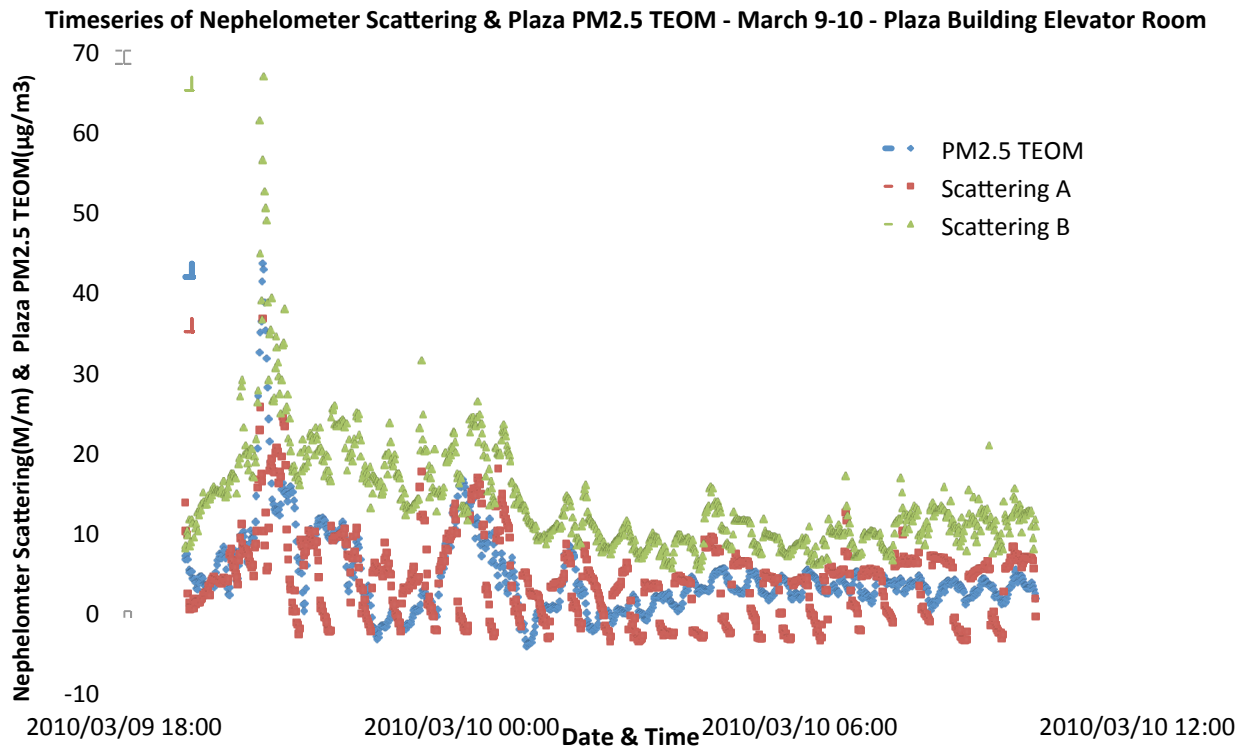


Figure J-42: Time series of Nephelometer Scattering & Plaza PM2.5 TEOM – March 9-10, 2010 – Plaza Building Elevator Room

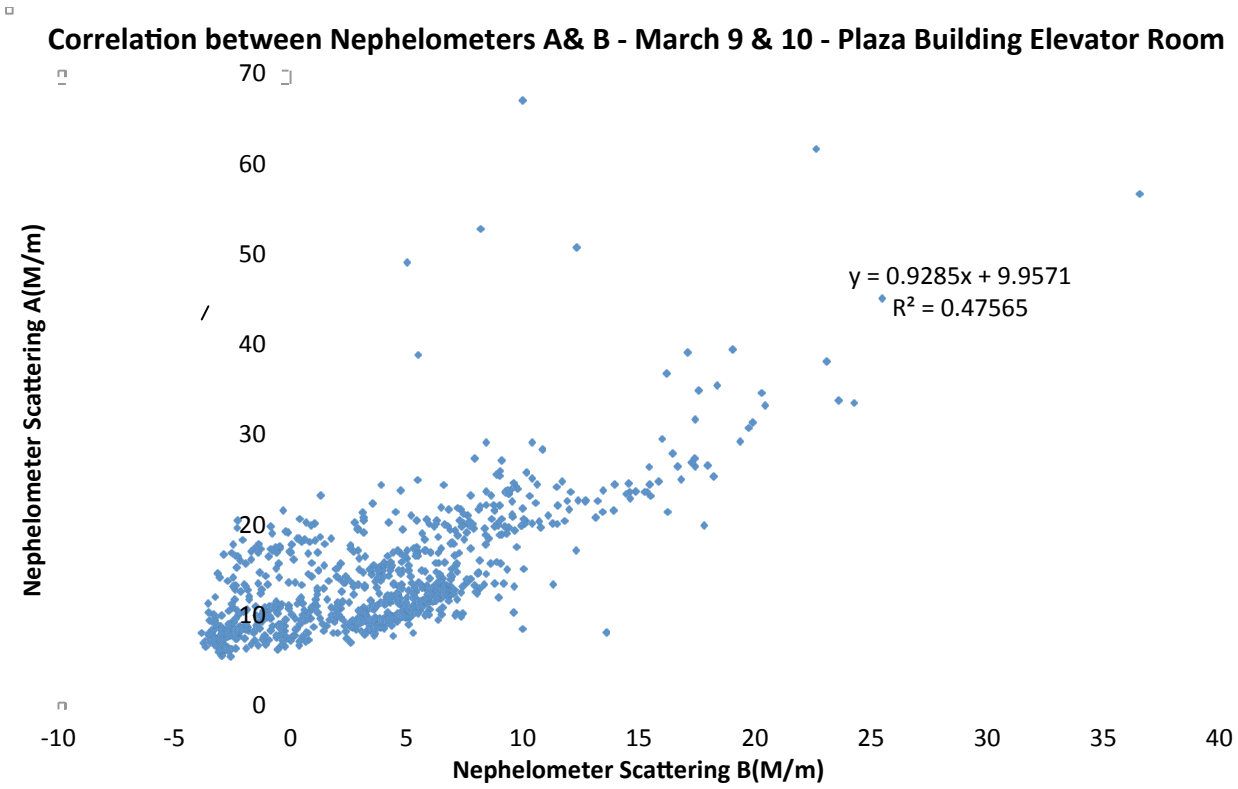


Figure J-43: Correlation between Nephelometer A&B – March 9-10, 2010 – Plaza Building Elevator Room

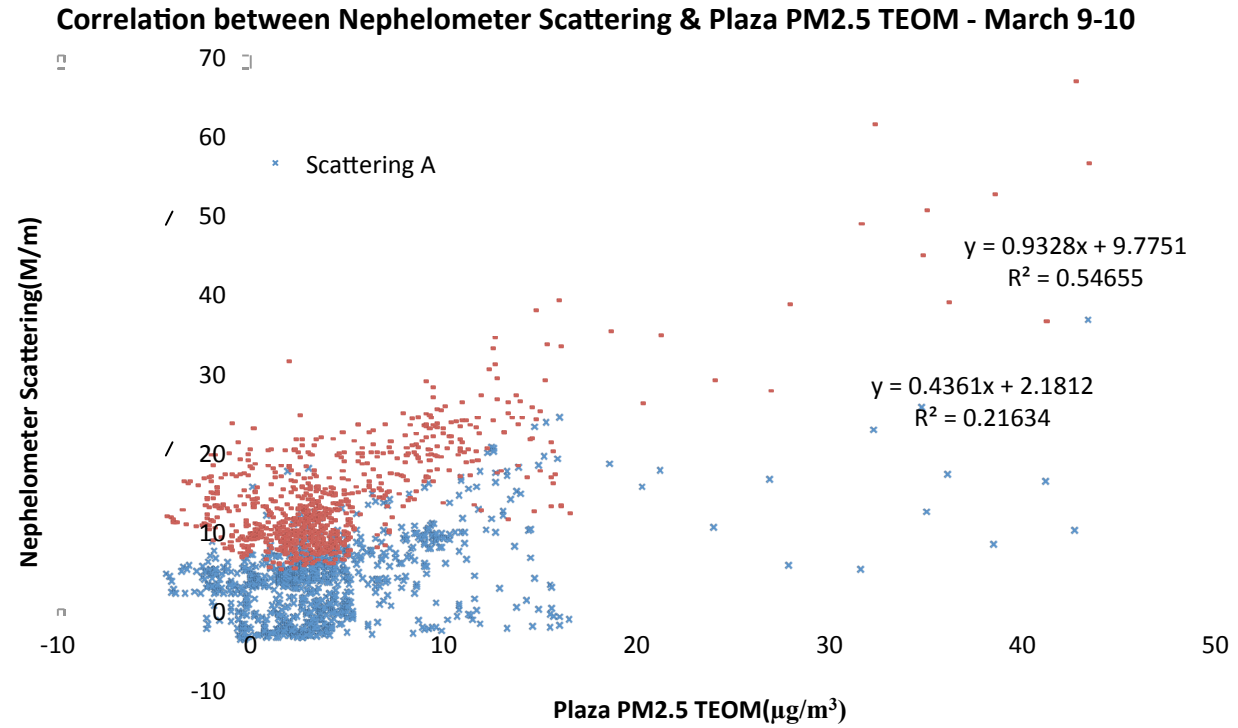


Figure J-44: Correlation between Nephelometer Scattering & Plaza PM2.5 TEOM – March 9-10, 2010 – Plaza Building Elevator Room

## G. March 16-22, 2010 Plaza Building Furnace Room

Figure J-45 illustrates the timeseries of scattering and meteorological parameters for March 16-22. The meteorological parameters between the two nephelometers all seem pretty close for this timeseries. The scattering values also look amazingly close. Again, these are 1min instantaneous values and not 5min averages. Figure J-46 shows the timeseries of the two nephelometers and the Plaza PM2.5 TEOM. It seems as if sometimes the nephelometer 's response is

The correlation between the two nephelometers is quite amazing! Figure J-47 shows it to be $R^2$=0.9877. Originally correlations between the nephelometer and TEOMS were not made on this time series because the nephelometers were in the furnace room and not the elevator room. Remember that the furnace room does get its air from outside but how the filtration system works in that room is a bit of an unknown. However, because of the excellent correlation between the two nephelometers it was decided that at least looking at the Neph/TEOM might be interesting.

Figures J-48 and J-49 show the correlations between nephelometers A & B respectively and the Plaza PM2.5 TEOM. The correlations using all of the data are $R^2$=0.3763 and R2=0.3573 for nephelometers A&B respectively. It was very surprising that these correlations were so low when the correlation between the nephelometers was so high. On both of the graphs there are a number of very high points on the nephelometers where the TEOM is recording very low values (close to 0). This seems very suspicious. It's also interesting that this time of maximum peak happens when the pressures are at their lowest. All of these points were recorded on the nephelometer around 6pm on March 16 and is visible on Figure J-45 as a spike. One theory on this is that it may have been caused by someone entering the furnace room at this time. The furnace room tended to be very dusty and perhaps someone walking in would stir the dust, causing the high values. Correlations were done again with this spike removed from both scattering series. These are also visible in Figures J-48 and J-49 and are $R^2$=0.5057 and $R^2$=0.5051 for nephelometers A&B respectively. This one spike seems to have an effect on the correlation but does not seem to be wholly responsible for it.

It seems funny that the Feb 23-25 timseseries, where one neph was in the furnace room, had a very high correlations between Neph A & Neph B had correlations of 0.78-0.79 where as the correlations between the two Nephs during this period was even higher however, the Neph/TEOM correlations significantly lower. Could the fact that there is a larger amount of spread in nephelometer values 0-80M/m during Feb 23-25 mean that the TEOM oscillations have less of an influence? If the TEOM oscillations are the influence, why is it that the non-oscillating and oscillating scattering series on Feb 23-25 have similar correlations with the TEOM?

To answer some of these questions correlations of the hourly averages were computed. Figure J-50 shows the correlation between the hourly averages of the nephelometers vs. the TEOM. There is a correlation of $R^2$=0.9628 and $R^2$=0.8793 for nephelometers A&B respectively.

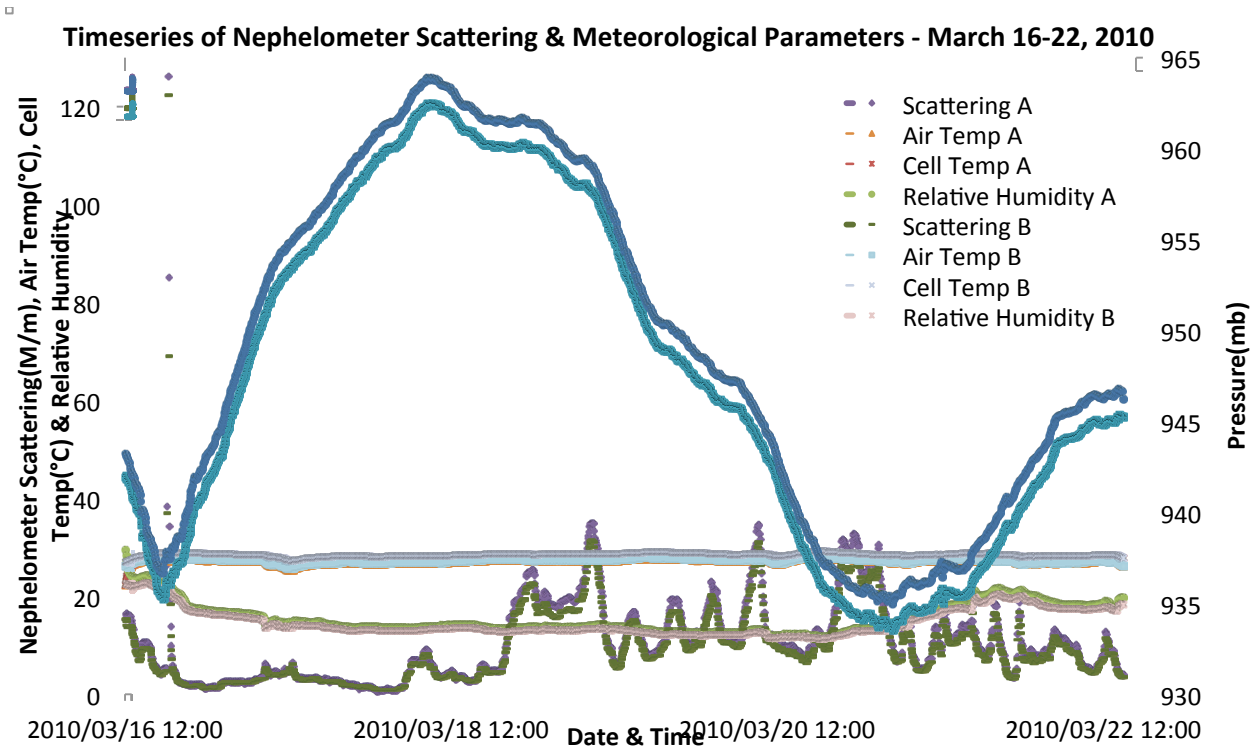


**Figure J-45: Time series of Nephelometer Scattering & Meteorological Parameters – March 16-22, 2010 – Plaza Building Furnace Room**

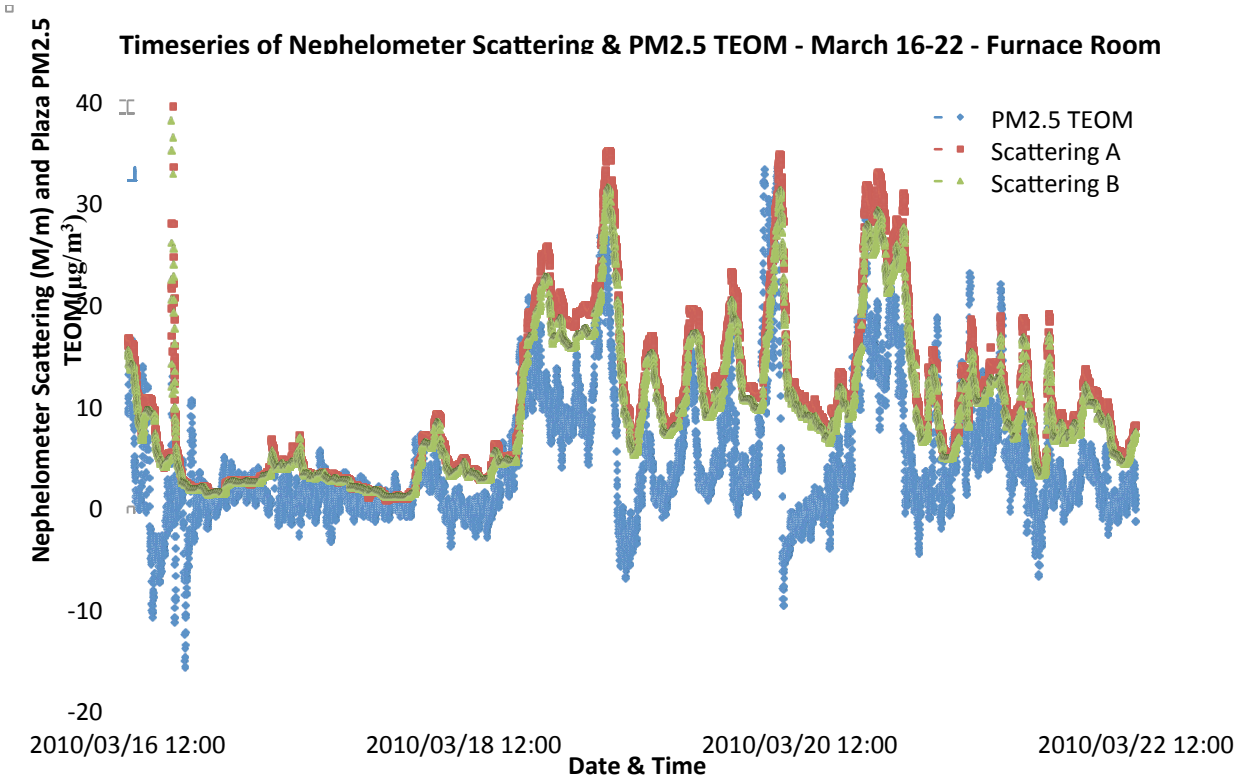


Figure J-46: Time series of Nephelometer Scattering & PM2.5 TEPM – March 16-22, 2010 – Nephelometers are inside Furnace Room

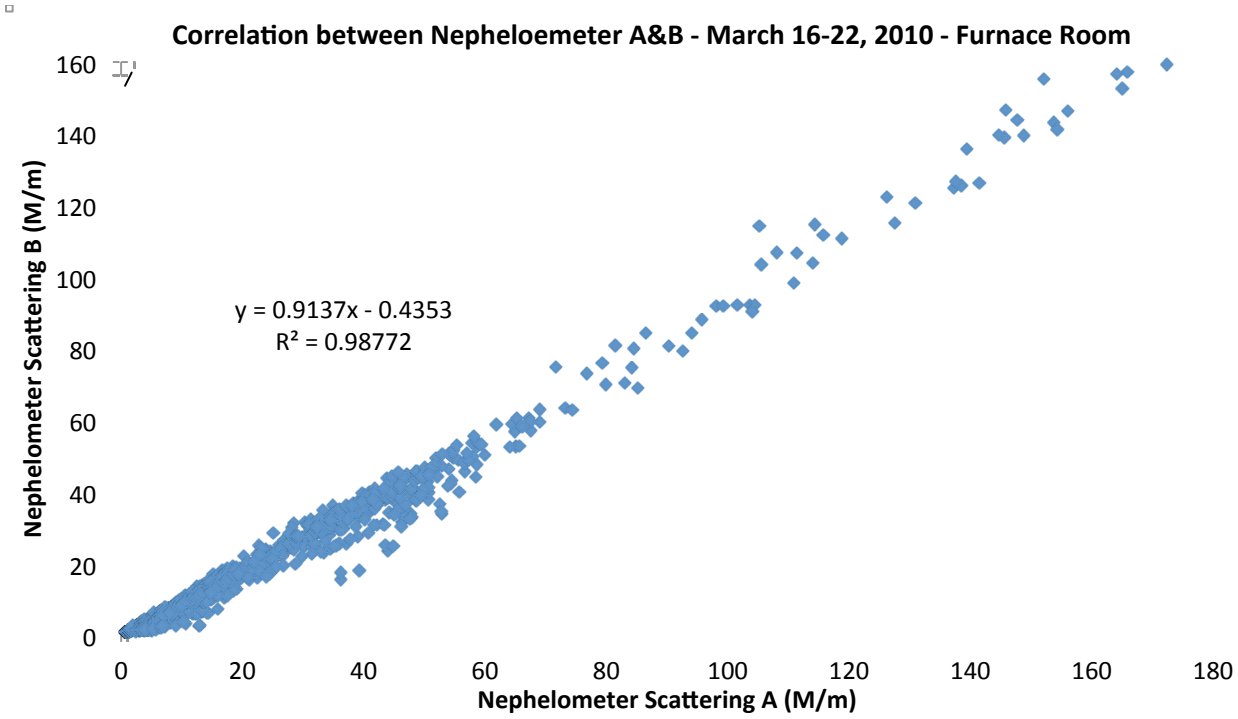


Figure J-47: Correlation between Nephelometer A&B – March 16-22, 2010 – Plaza Building Furnace Room

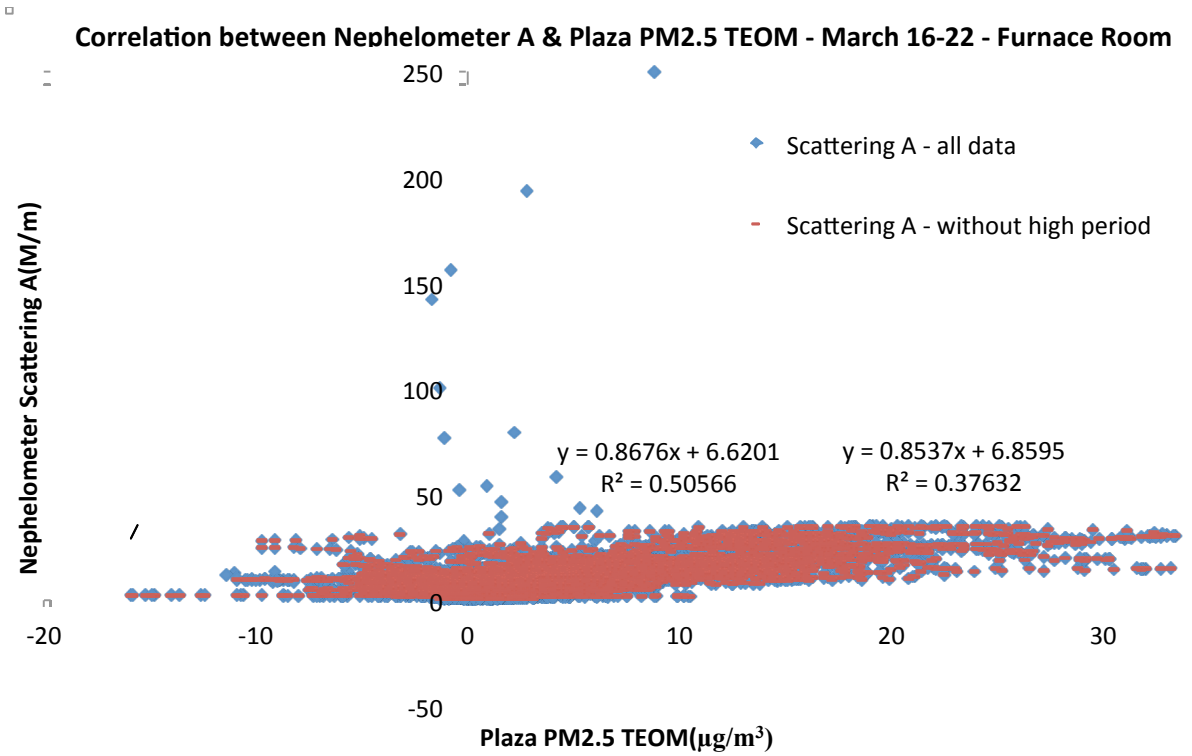


Figure J-48: Correlation between Nephelometer A & Plaza PM2.5 TEOM – March 16-22 – Nephelometers in Furnace Room

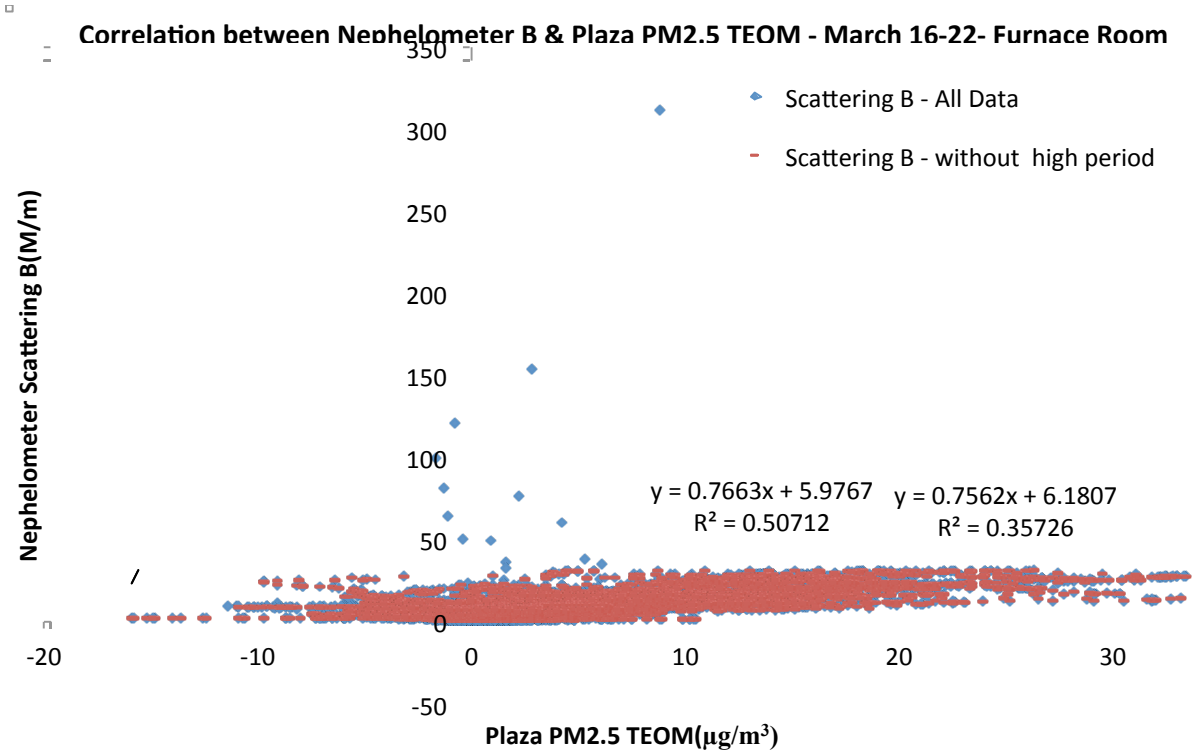


Figure J-49: Correlation between Nephelometer B & Plaza PM2.5 TEOM – March 16- Nephelometers in Furnace Room

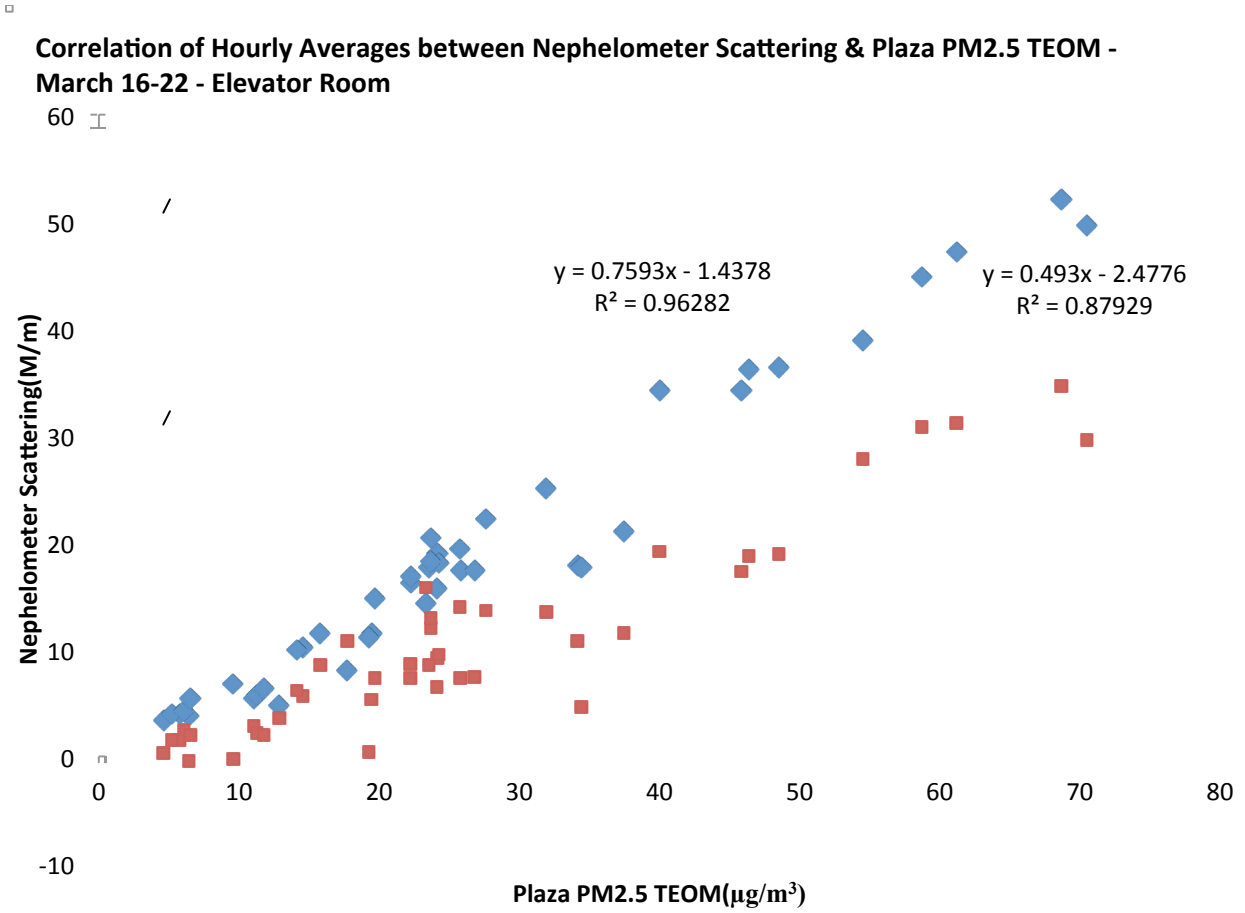


Figure J-50: Correlation of Averages between Nephelometer Scattering & Plaza PM2.5 TEOM – March 16-22 – Elevator Room

## H. March 22-26, 2010 – Elevator Room

The timeseries of nephelometer scattering and meteorological parameters is illustrated in Figure J-51. The timeseries of nephelometer scattering & Plaza PM2.5 TEOM for the period is illustrated in Figure J-52.

Figure J-53 shows the correlation between the two nephelometers to be $R^2$=0.9856, an excellent correlation! Figure J-54 and J-55 show the correlations between Nephelometer A&B respectively and the Plaza PM2.5 TEOM to be $R^2$=0.8139 and $R^2$=0.8439.

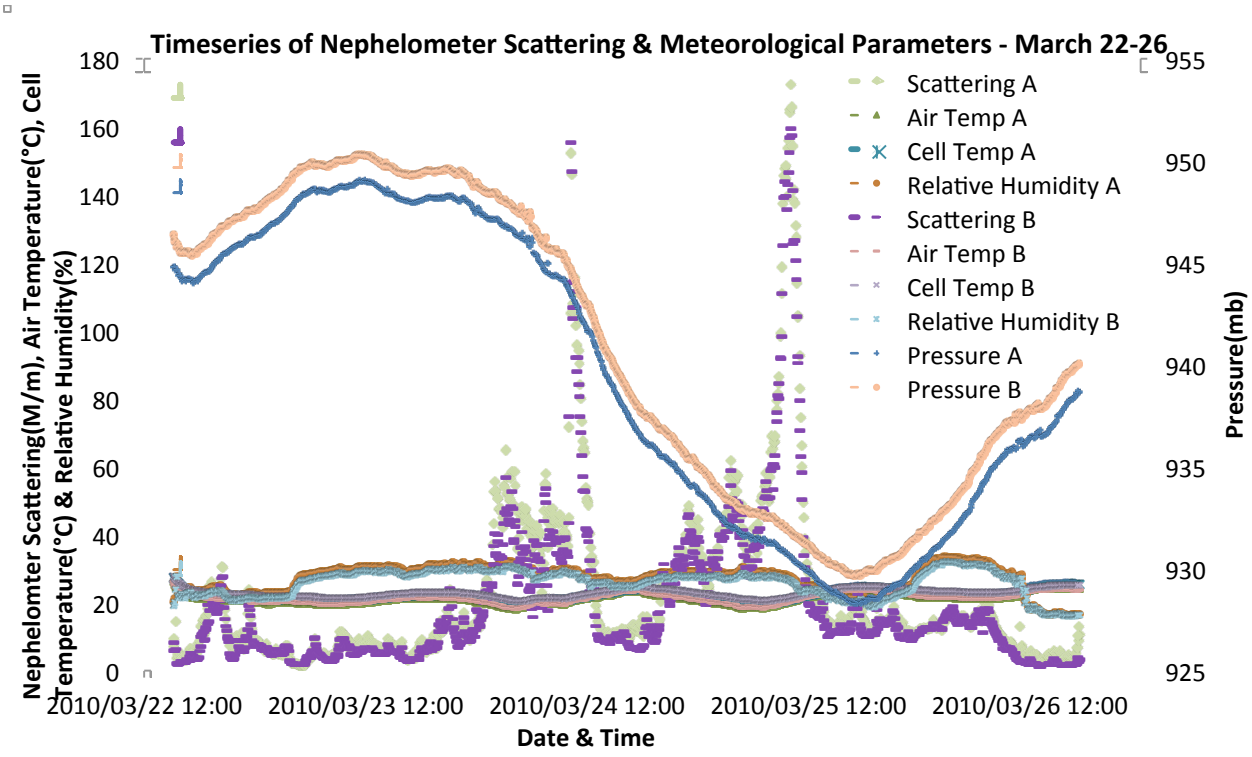


**Figure J-51: Time series of Nephelometer Scattering & Meteorological Parameters – March 22-26, 2010 – Plaza Building Elevator Room**

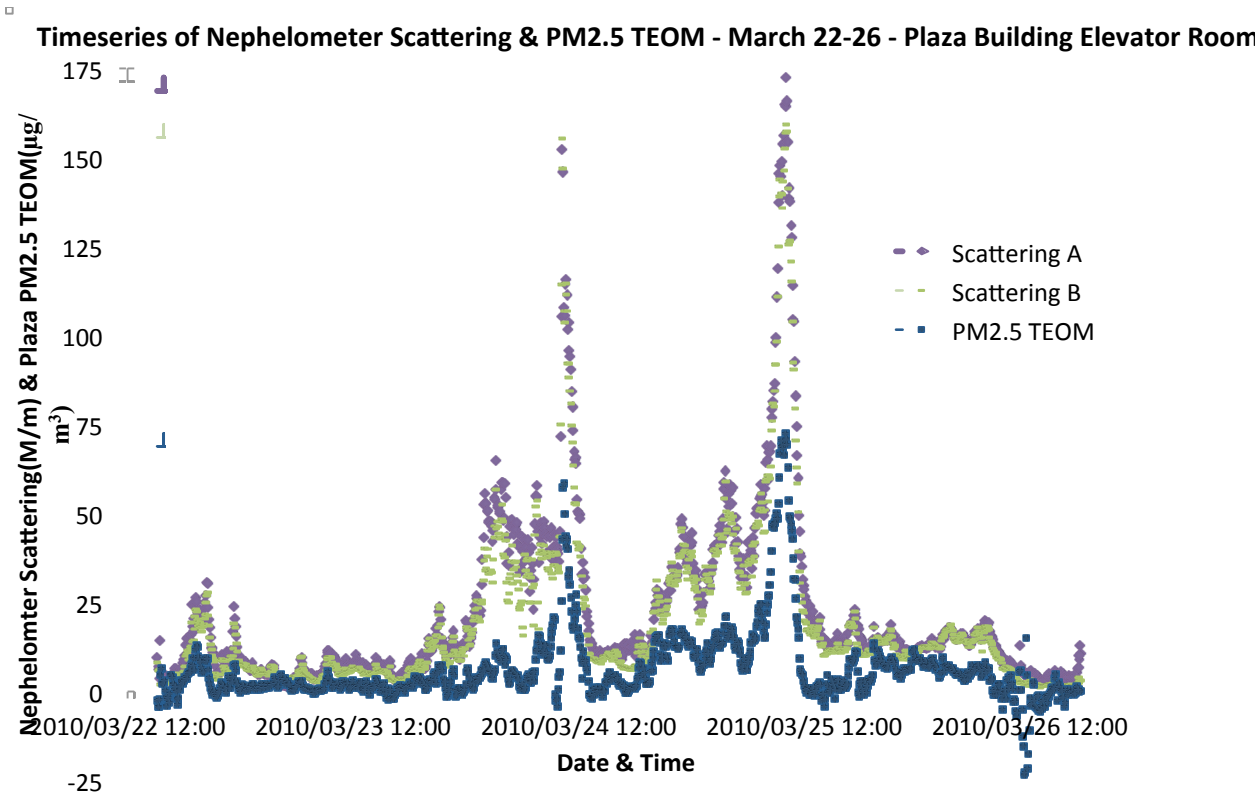


Figure J-52: Timeseries of Nephelometer Scattering & PM2.5 TEOM – March 22-26 – Plaza Building Elevator Room

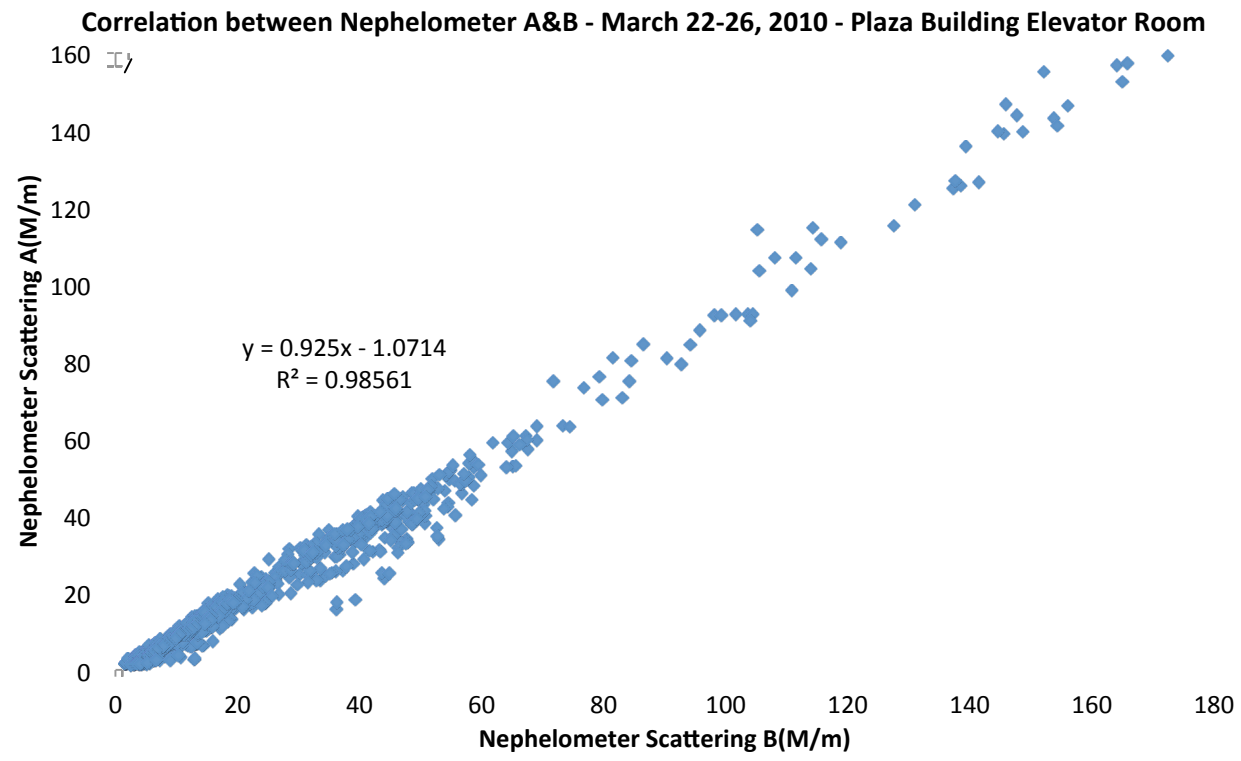


Figure J-53: Correlation between Nephelometers A&B - March 22-26, 2010, - Plaza Building Elevator Room

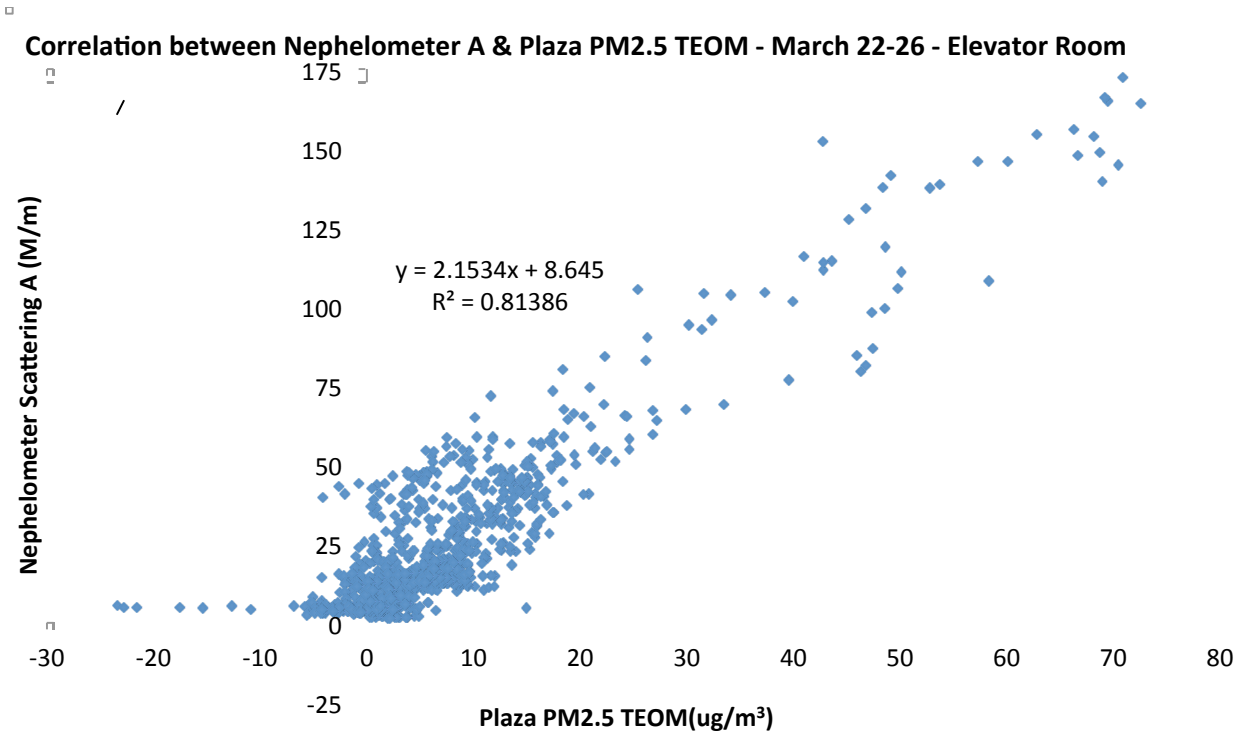


Figure J-54: Correlation between Nephelometer A & Plaza PM2.5 TEOM – March 22-26, 2010 – Plaza Building Elevator Room

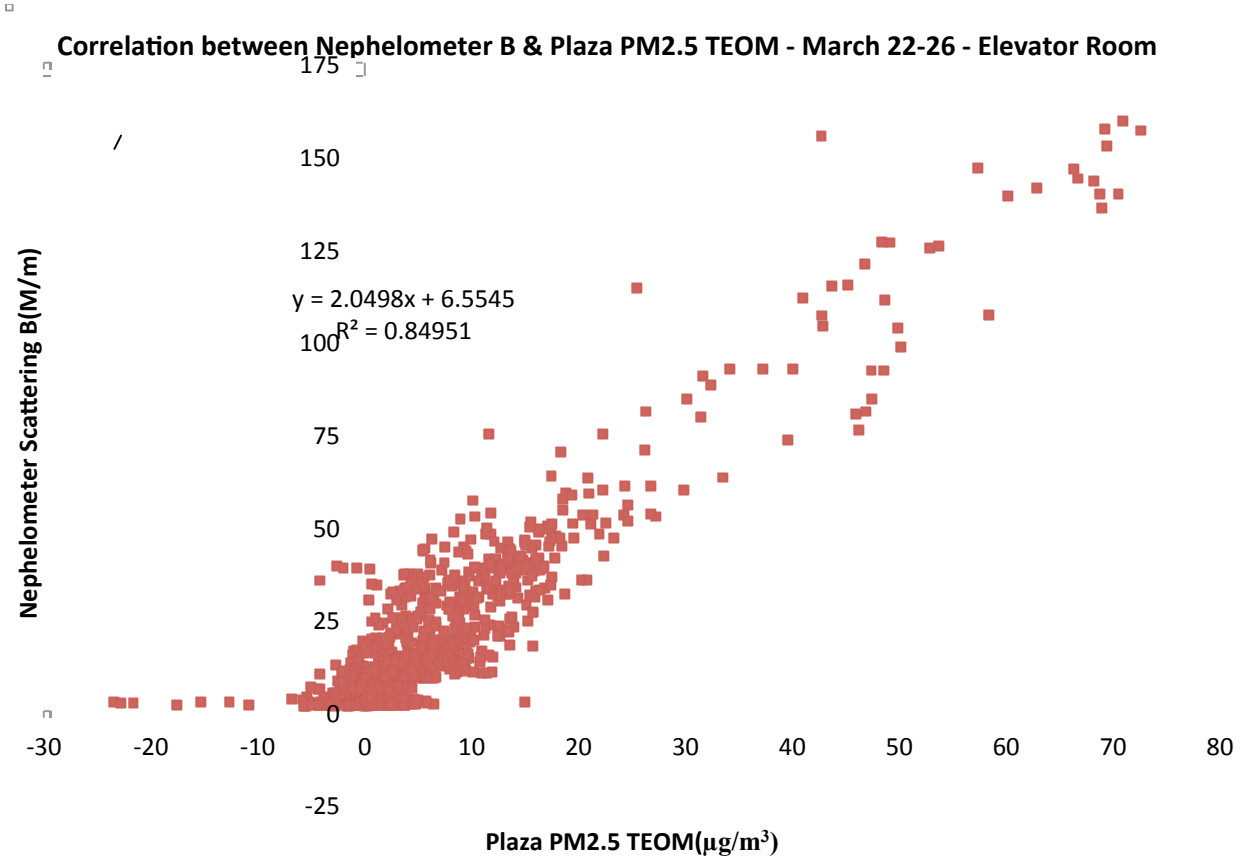


Figure J-55: Correlation between Nephelometer B & Plaza PM2.5 TEOM – March 22-26, 2010 – Plaza Building Elevator Room

## I. April 7-12, 2010 – Elevator Room

Figure J-56 shows the timeseries of nephelometer scattering & meteorological parameters for the two TEOMS. A shift seems to occur on April 10 around 6am. Before this time the two sets of scattering values show very small differences. After this point, differences of about 5M/m is visble in Figure J-56. The shift that occurred on April 10 is visible up close in Figure J-57. The meteorological parameters do not show any shifts at this time.

Figure J-58 shows the timeseries of nephelometer scattering and the Plaza PM2.5 TEOM for the time period noted above. Note that TEOM Data is missing for the first few hours. TEOM was down at this time. Figure J-59 shows the correlation between the two nephelometers to be $R^2$=0.7373. The graph shows two sets of data with different slopes. These separate slopes are most likely caused by the shift that occurred April 10.

Figure J-60 shows the correlation between nephelometer A & the Plaza PM2.5 TEOM to be $R^2$=0.5562 and Figure J-61 shows the correlation between nephelometer B & the Plaza PM2.5 TEOM to be $R^2$=0.5857.

Again hourly averages were done of the nephelometer scattering & PM2.5 TEOM values. Figure J-62 shows a graph of the hourly average PM2.5 nephelometer values vs. PM2.5 values. The correlations are $R^2$=0.6723 for nephelometer A and $R^2$=0.7819 for nephelometer B. This shows that possibly the lower correlations on the 5minute data is due to the oscillations.

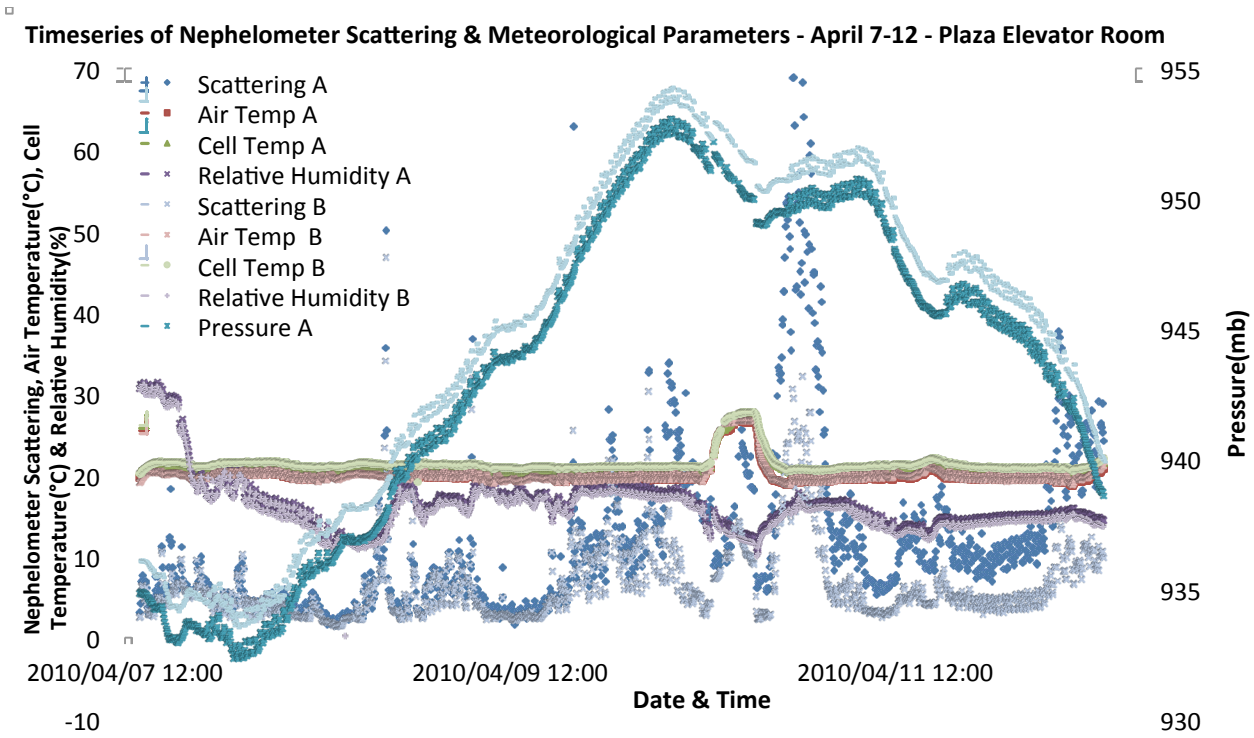


Figure J-56: Timeseries of Nephelometer Scattering & Meteorological Parameters – April 7-12, 2010 – Plaza Building Elevator Room

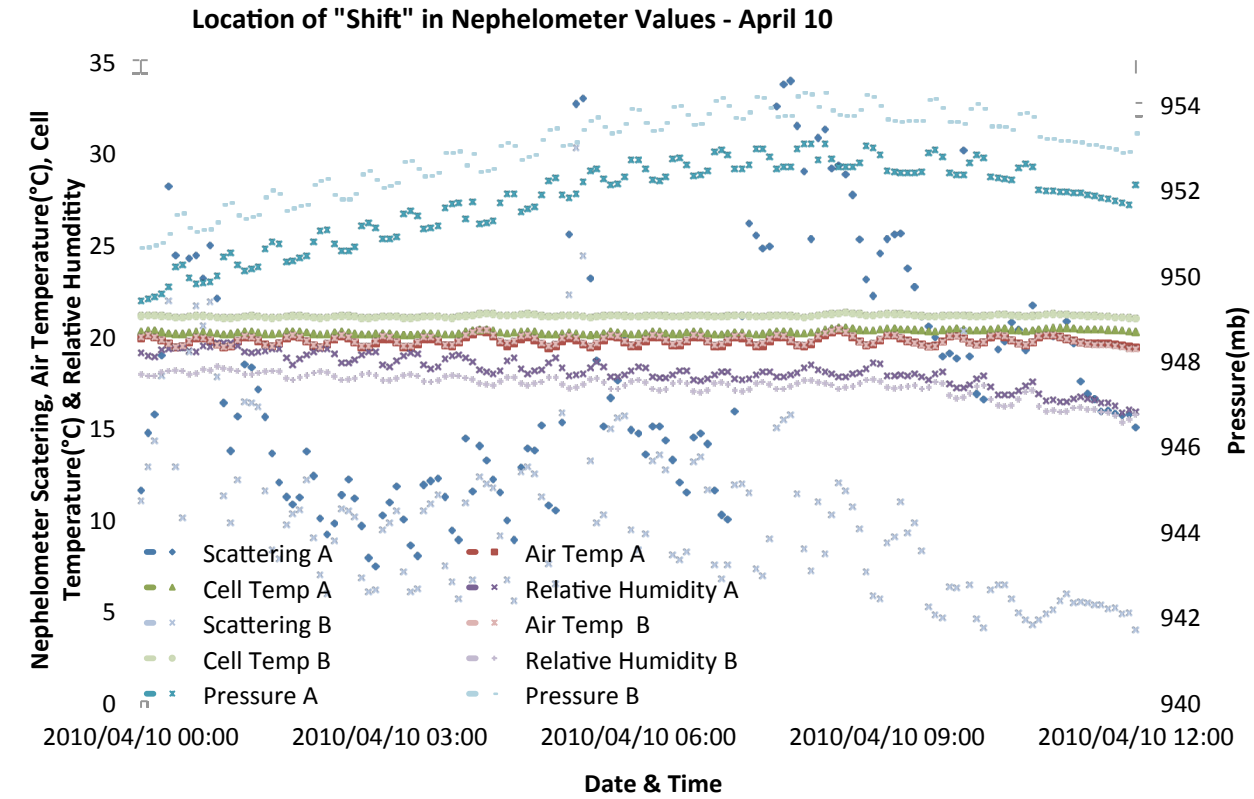


Figure J-57: Location of "Shift" in Nephelometer Values – March 10, 2010 – Plaza Building Elevator Rom

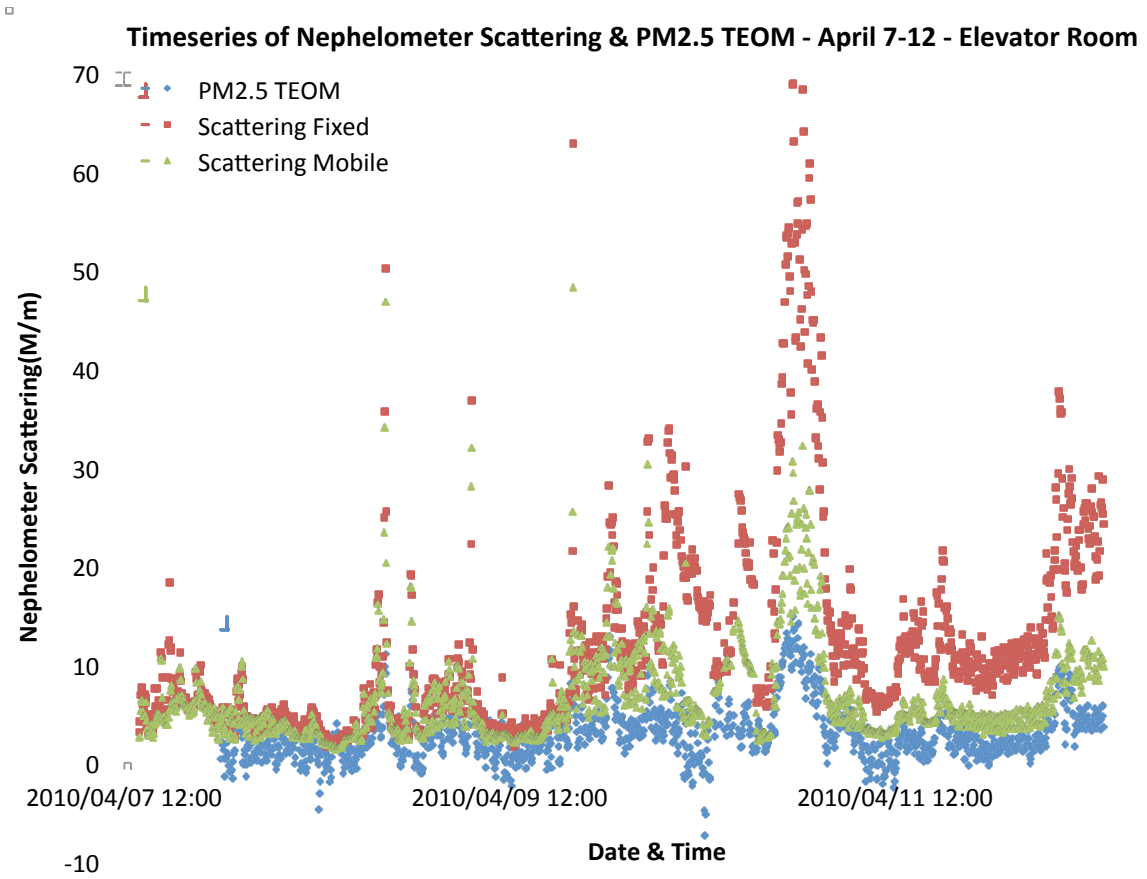


Figure J-58: Time series of Nephelometer Scattering & Plaza PM2.5 TEOM – April 7-12, 2010

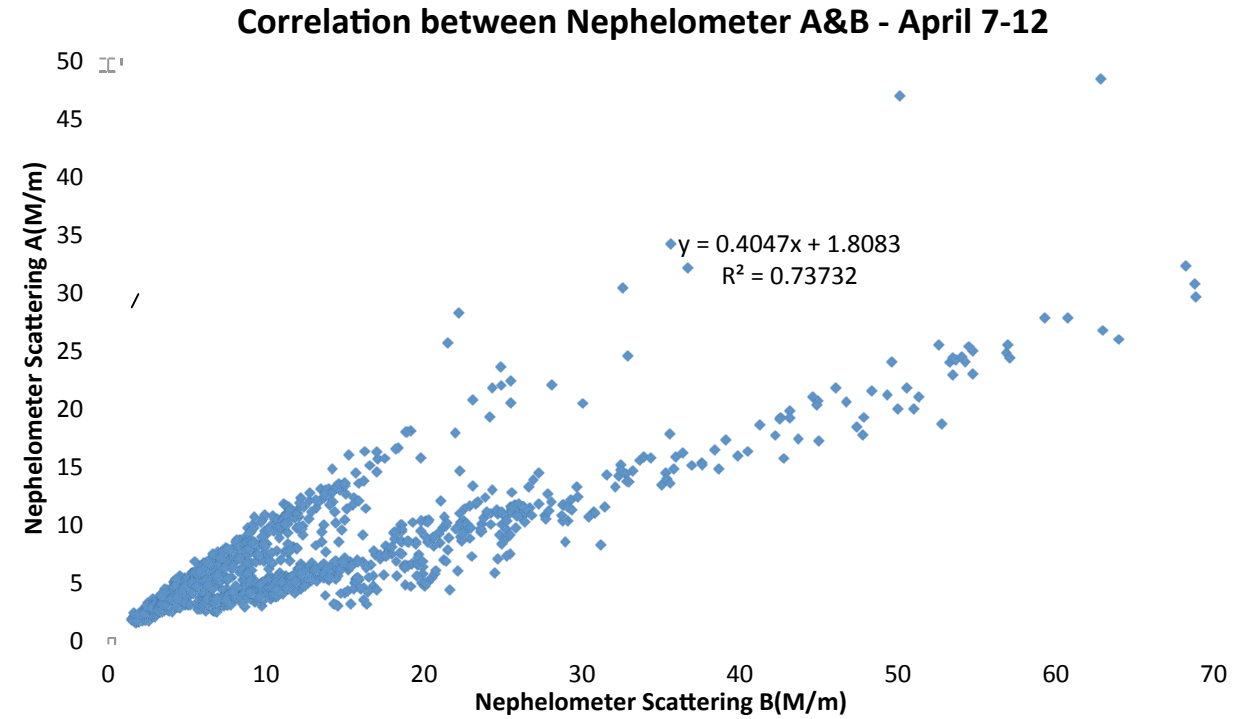


Figure J-59: Correlation between Nephelometers A&B – April 7-12, 2010- Plaza Building Elevator Room

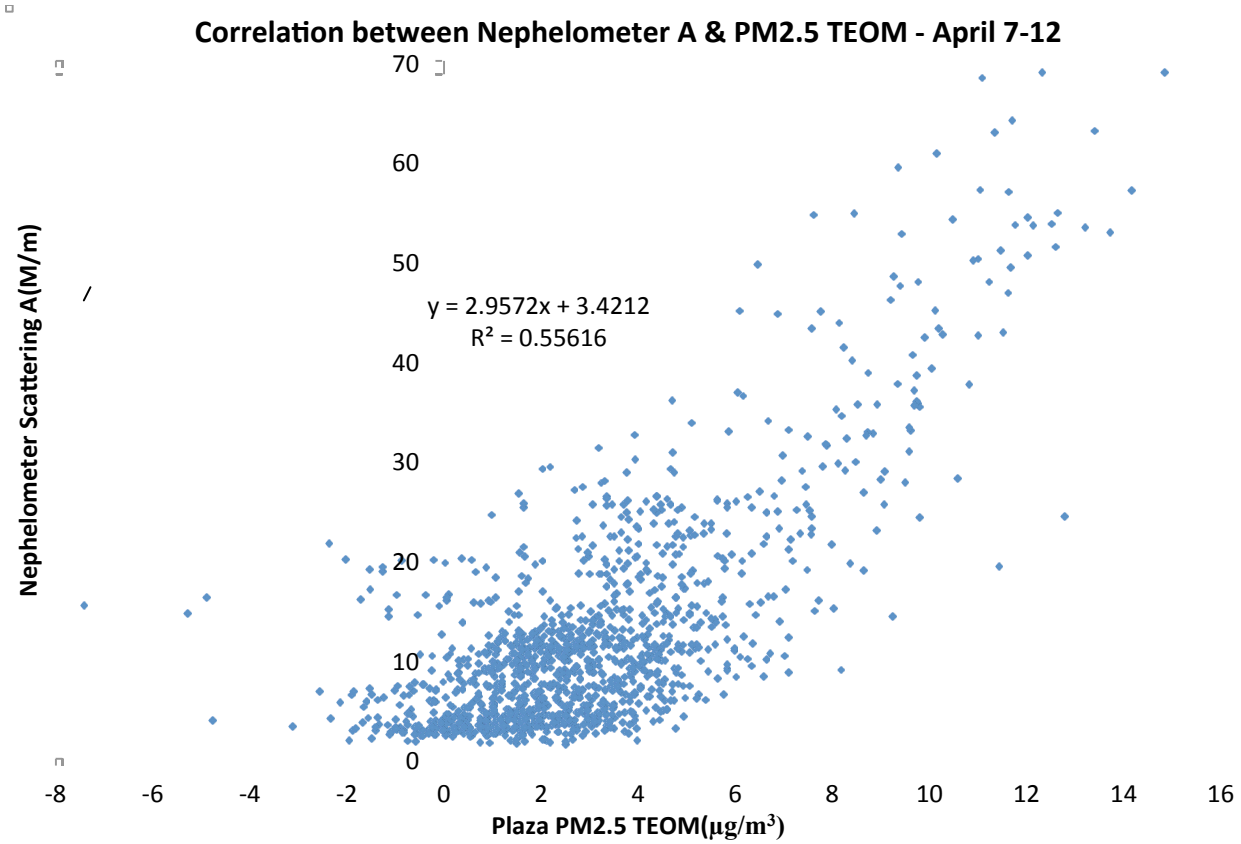


Figure J-60: Correlation between Nephelometer A & PM2.5 TEOM – April 7-12, 2010 – Plaza Building Elevator Room

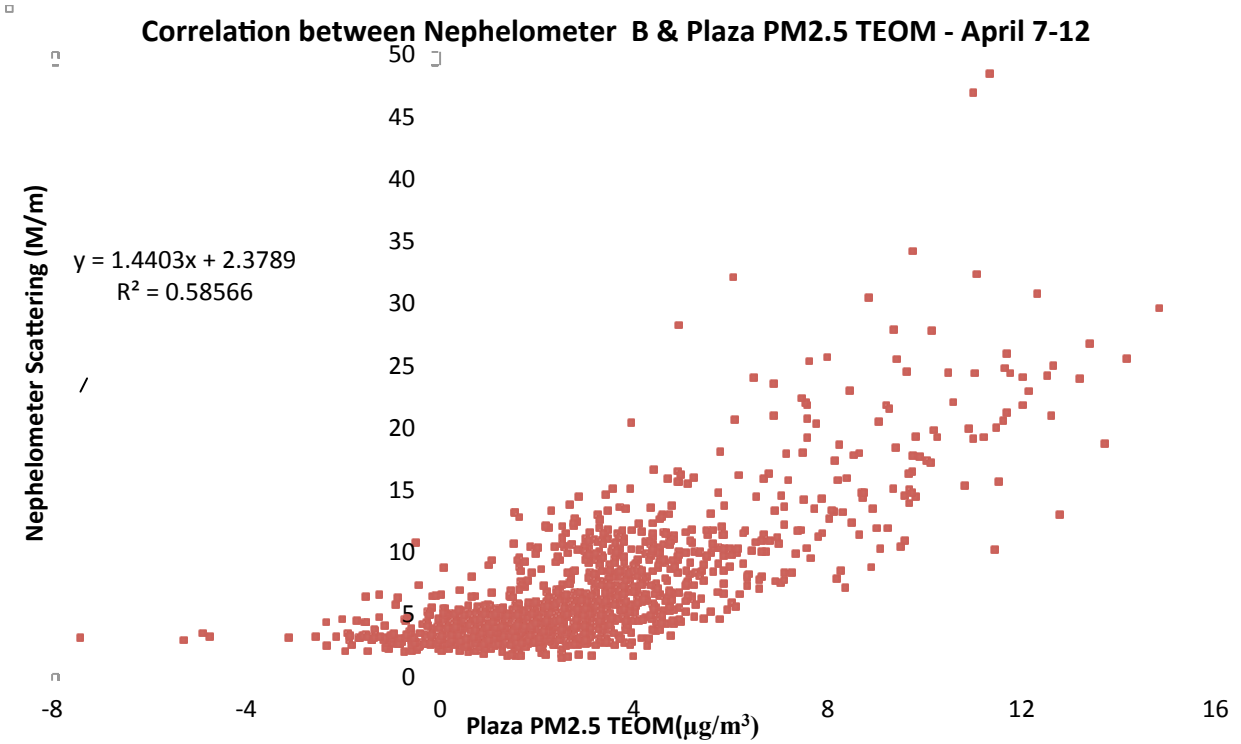


Figure J-61: Correlation between Nephelometer B & Plaza PM2.5 TEOM – April 7-12, 2010 – Plaza Building Elevator Room

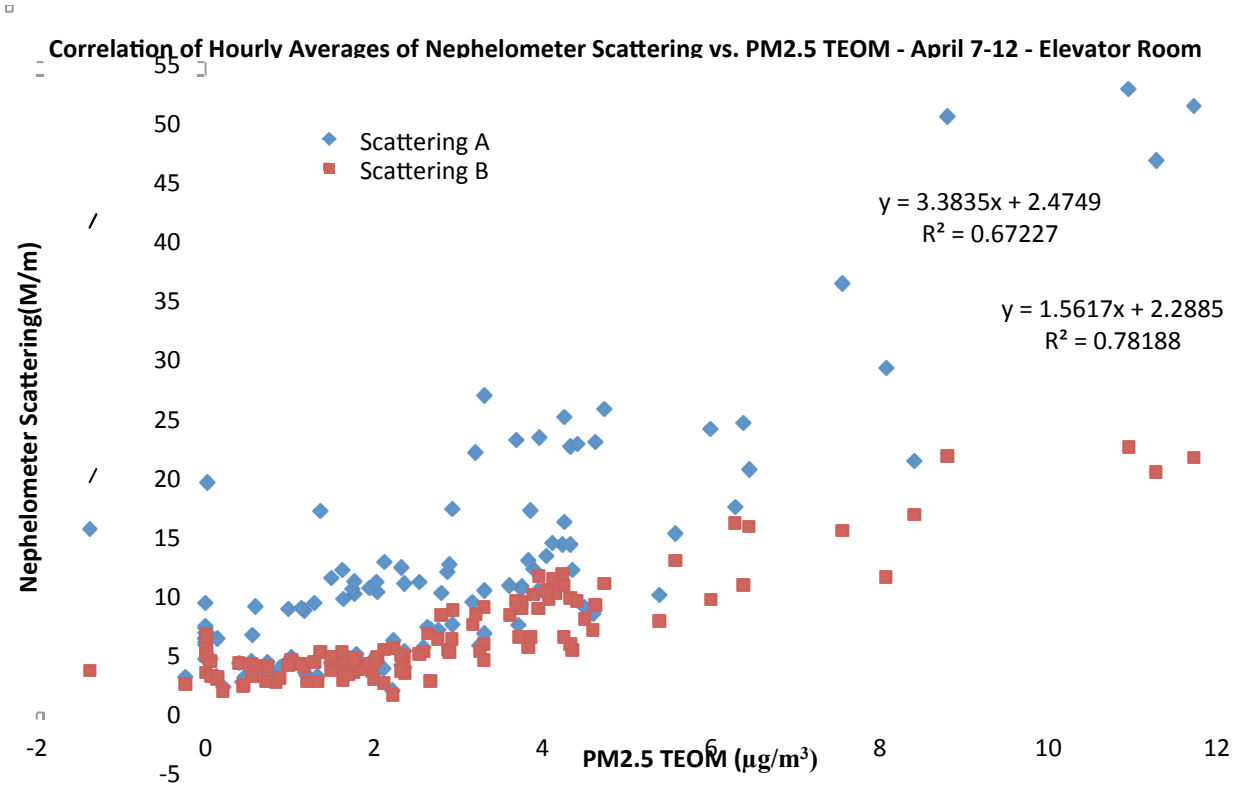


**Figure J-62: Correlation of Hourly Averages of Nephelometer Scattering vs. PM2.5 TEOM – April 7-12, 2010 – Plaza Building Elevator Room**

## J. April 12 – May 21, 2010 – Elevator Room

Note that there was a period where the nephelometers were off between April 14 and April 20. Figure J-63 shows the correlation between the two nephelometers between April 12 & May 21 to be $R^2$=0.9077.

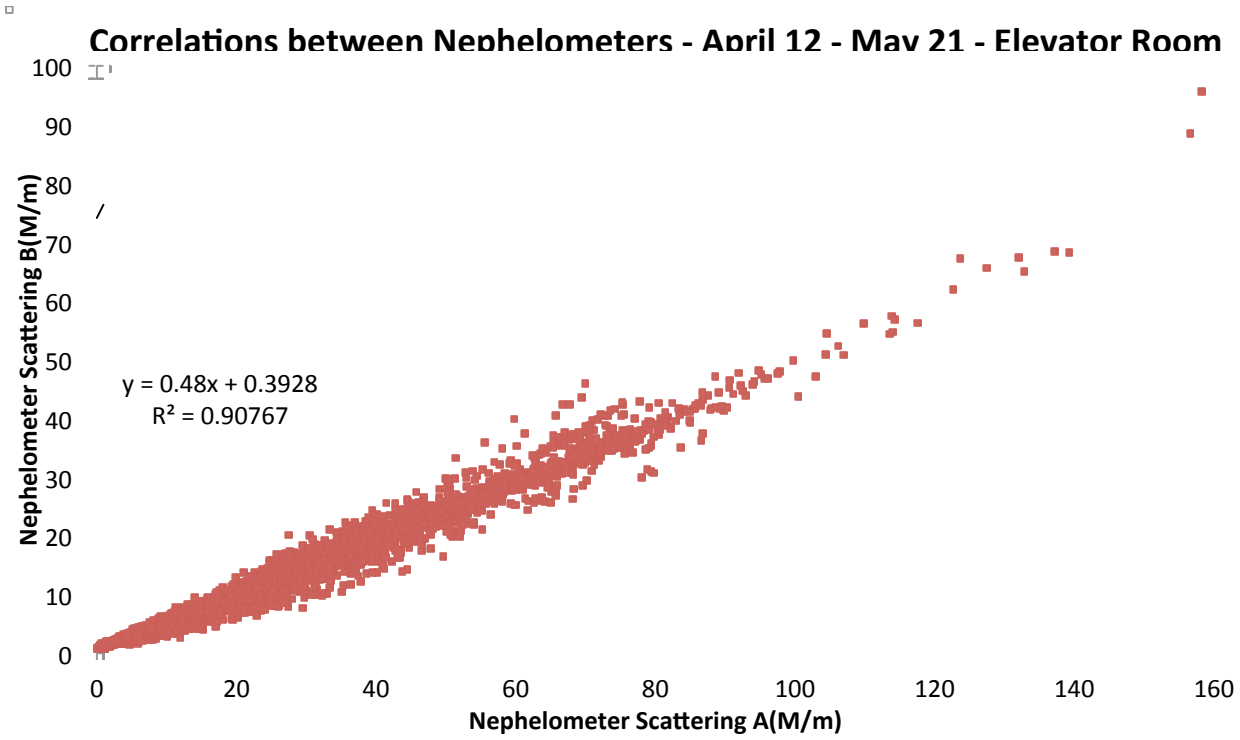


Figure J-63: Correlations between Nephelometers – April 12 – May 21, 2010 – Plaza Building Elevator Room

## 4. Mobile Collocation

On April 12, a cold, calm night meeting the definition of requirements for a night with high PM levels, the team went out with both nephelometers in the same car. One of the nephelometers poked out the left window and the other nephelometer poked out the right window of the car. The route done was mainly in Greater South Fort George which included Trailer parks which tended to have the highest scattering levels.

Figure J-64 shows the correlation between the two nephelometers. The first series on Figure J-64 contains all data points and the second series contains all data points except for the two highest ones on Nephelometer A(over 600M/m). The correlation improves substantially when these two points are removed. It goes from $R^2$=0.3359 to $R^2$=0.7323. Although removing high points may not be deemed scientific, showing the differences in correlations illustrates the questionability in whether the $R^2$ value should be considered representative if it changes by 40% by removing two points. Perhaps more advanced statistics are necessary in this case so not to give such a high weight to two points which stray enormously.

A big source of error for this correlation would be the car's exhaust.

Because of the suspicious changes in Nephelometer A's cell temperature and recognizing that often sudden shifts in meteorological parameters affected collocation results, correlations were done for the section before the first shift in cell temperature, between the two shifts in shifts and after the second shift.

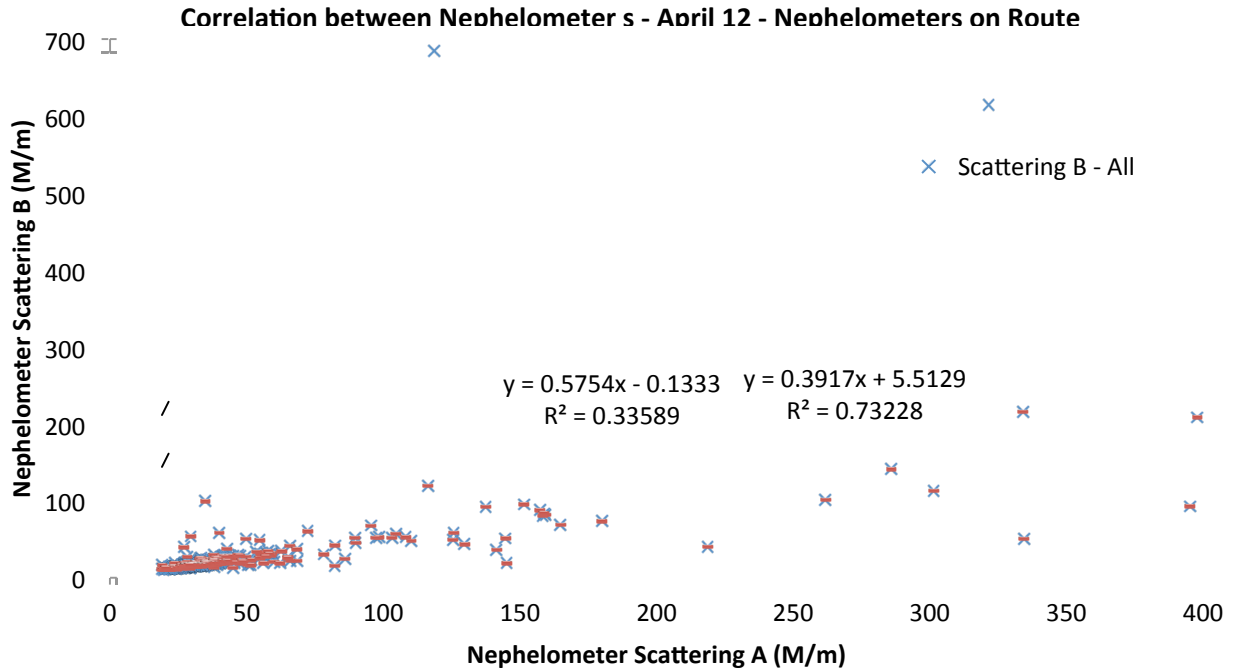


Figure J-64: Correlation between Nephelometers – Night of April 12 – Nephelometers on Route in vehicle

## 5. Summary of Collocation Results

| Dates | Oscilla-tions | $R^2$ of Neph A vs. Neph B | $R^2$ of Neph A vs. TEOM | $R^2$ of Neph B vs. TEOM | Slope of Neph A vs. Neph B | Slope of Neph A vs. TEOM | Slope of Neph B vs. TEOM | Intercept of Neph A vs. Neph B | Intercept of Neph A vs. TEOM | Intercept of Neph B vs. TEOM | Shift Occur? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dec 21 – Jan 3 | No | 0.615 | 0.625 | 0.7035 | 1.3904 | 6.2121 | 3.7174 | 3.0762 | 4.4835 | 9.0784 | Yes, 1 |
| Jan 15-22 | No | 0.2919 | 0.3622 | 0.0233 | 0.8931 | 4.3795 | 1.3872 | 2.6377 | 11.552 | 19.031 | Yes, 1 |
| Jan 29-Feb 1 | No | 0.9398 | 0.8455 | 0.8264 | 1.1962 | 1.9449 | 2.1645 | -20.7931 | 12.348 | -4.663 | No |
| Feb 3-5 | Yes | 0.2698 (0.9881 & 0.0952) | (0.3567 & 0.5317) | (0.5319 & 0.0805) | 0.5001 (0.5847 & 1.215) | (1.2916 & 1.6818) | (1.3761 & 0.3255) | (15.031 & -0.5442) | 14.201 (10.579 & 11.516) | (9.9731 & 5.5861) | Yes, 1 |
| Feb 10-12 | Yes | 0.5118 | 0.6544 | 0.5165 | 0.3697 | 2.1576 | 0.9907 | 5.9813 | 11.446 | 6.9698 | No |
| Feb 22-23 | Yes | 0.8331 | 0.6809 | 0.6689 | 0.4363 | 2.4623 | 1.1668 | 2.7504 | 10.718 | 5.5474 | No |
| Feb 23-25 | A, no B, yes | 0.9132 | 0.7895 | 0.7988 | 1.3133 | 1.6234 | 1.305 | 2.002 | 9.2418 | 4.7429 | No |
| Mar. 9-10 | Yes | 0.4757 | 0.5465 | 0.2163 | 0.9285 | 0.9328 | 0.4361 | 9.9571 | 9.7751 | 2.1812 | No |
| March 16-22 | No | 0.9877 | 0.3763 | 0.3573 | 0.9137 | 0.8595 | 0.7562 | -0.4353 | 6.6201 | 6.1807 | No |
| March 22-26 | No | 0.9856 | 0.8139 | 0.8495 | 0.925 | 2.1534 | 2.0498 | -1.0714 | 8.645 | 6.5545 | No |
| April 7-12 | Yes | 0.7373 | 0.5562 | 0.5857 | 0.4047 | 2.9572 | 1.4403 | 1.8083 | 3.4212 | 2.3789 | Yes |

## 6. Recommendations & Conclusions

Overall, there seems to be a very wide range of correlations in the data, a very wide range of correlation slopes and a very wide range of intercepts. "Shifts" in data as well as the wide ranges in correlations show that the nephelometer was not working as well as it was in previous studies.

Because of the uncertainty these conditions bring, the decision was made not to convert scattering values to PM2.5 concentrations. Also, it was decided that data would be reported in quantiles to minimize uncertainty. See the main report for more information.