Correlation of AIRS CO and MODIS AOD over the Northern Hemisphere from June-August 2008

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Abstract.

This study focuses on the summertime (June-August 2008) when boreal biomass burning is most intensive. The purpose is to better estimate emission ratio of aerosol number density to CO concentration for model simulations. The instruments used for this research are Moderate Resolution Imaging Spectroradiometer (MODIS), which measures aerosol optical depth (AOD) and Atmospheric Infrared Sounder (AIRS), which measures carbon monoxide (CO) mixing ratio at 500 mb. This paper examines the correlation between AOD and CO from satellite measurements and Goddard Earth Observing System Model, Version 5(GEOS-5) model results. Satellite products reflect to the real-time measurements with significant cloud coverage while the GEOS-5 model outputs are continuous in space and time. This analysis shows discrepancies between measured and modeled results possibly due to (1) coarser resolution (0.5° x 0.67°) of GEOS-5 as opposed to MODIS AOD (10 km) and AIRS, (2) uncertainties of satellite measurements, (30 km) and (3) CO vertical distribution governed by pluming rising mechanism in GEOS-5.

1. Introduction

Satellite remote sensing obtains global measurements of tropospheric gases and aerosols over extended periods of time. Aerosols are solid particles or liquid droplets suspended in atmosphere**.** Two types of aerosols include coarse and fine mode aerosols. Coarse mode aerosols are comprised of dust or sea particles. These particles are primarily natural. Fine mode aerosols are composed mainly of sulfate and carbonaceous particles, organic carbon and black carbon. Fine mode aerosols are formed by both anthropogenic (human activity) and wildfire processes that are the same processes that lead to the emission of CO in the atmosphere [*Edwards et al.*, 2004]. Aerosol optical depth is the measure of light extinction due to absorption and scattering by aerosols. Carbon monoxide is a primary product resulted from anthropogenic industrial emissions [*Olivier et al.*, 1996], and biomass burning and wildfires [*Andreae and Merlet*, 2001]. This paper examines the correlation derived between AOD and CO from satellite measurements and GEOS-5 (Goddard Earth Observing System Model, Version 5) model results.

2. Aerosols

Aerosols are tiny particles suspended in the atmosphere. Aerosols can be solid and liquid, which are suspected to influence global climate change. Dust, smoke from wildfires, volcanic ash, and pollution from factories are all examples of aerosols.

Aerosols as a result of human activity can affect agricultural productivity and water quality [*Chameides et al.*, 1999;*Adriano and Johnson*, 1989]. Poor air quality is also harmful to human health and if inhaled, various aerosols can be harmful.

One important ecological issue concerning our planet is the change in the climate. Depending upon their size, type, and location, aerosols can either cool the surface, or warm it. Depending on type, they either absorb sunlight and produce a warming, or reflect sunlight back to space producing a cooling of the Earth's surface and changes in cloud microphysics that increase cloud solar reflection [*Edwards et al.*, 2004]. Aerosols can also enhance the formation of clouds by acting as cloud condensation nuclei.

3. Carbon Monoxide

CO is generally higher in the northern hemisphere than in the southern hemisphere because the northern hemisphere has more human activity. The average lifetime of CO is about 3 months. An increase in atmospheric CO concentrations could reduce the self-cleansing ability of the atmosphere and thus modify its chemical, physical, and climatological properties [*Edwards et al.*, 2004].

4. Instrumentation

MODIS is used to measure AOD in the atmosphere and AIRS is used to measure the CO mixing ratio in the atmosphere. MODIS is onboard both the Aqua and Terra satellite. This research utilizes MODIS and AIRS measurements which are both onboard the Aqua satellite.

4.1 MODIS

Spectral radiation measured by MODIS is used to retrieve the aerosol optical thickness, effective particle radius and ratio between the submicron and micron size particle [*Remer et al.*, 2002]. MODIS retrieves aerosol loading and the fraction of fine mode particle. Aerosol measurements have been recorded since the late 1970s using satellite remote sensing but most of which were derived over the ocean. MODIS provides the spectral information of aerosol optical properties and underlying surfaces from visible to shortwave infrared wavelength [*Chu et al.*, 2003]. MODIS is the first instrument to derive aerosol optical depth over vegetated and partially vegetated land at 0.47 and 0.66μm. MODIS has a 2330-km wide viewing swath, which allows it

to cover the entire globe in 1-2 days [*Edwards et al*., 2004]. MODIS obtains daily global measurements with 36 spectral bands at three different spatial resolutions [*Chu et al*., 2002].

4.2 AIRS

The Atmospheric Infrared Sounder (AIRS) launched into Earth-orbit on May 4, 2002. AIRS sensor is onboard the Aqua satellite. Together both AIRS and Advanced Microwave Sounding Unit (AMSU-A) observe the global water and energy cycles, climate variation and trends, and the response of the climate system to increased greenhouse gases [*Aumann et al*., 2003].

AIRS uses infrared technology to create 3-dimensional maps of air and surface temperature, water vapor, and cloud properties. AIRS can measure gases such as ozone, carbon monoxide, carbon dioxide, and methane. AIRS measurements provide information on the vertical profiles of atmospheric temperature and moisture better than previous IR sounders due to the fact that AIRS has a resolution over a hundred times greater [*Aumann et al*., 2003]. AIRS provided the CO concentrations between June-August 2008 used in this study. AIRS CO has a resolution of 30 km.

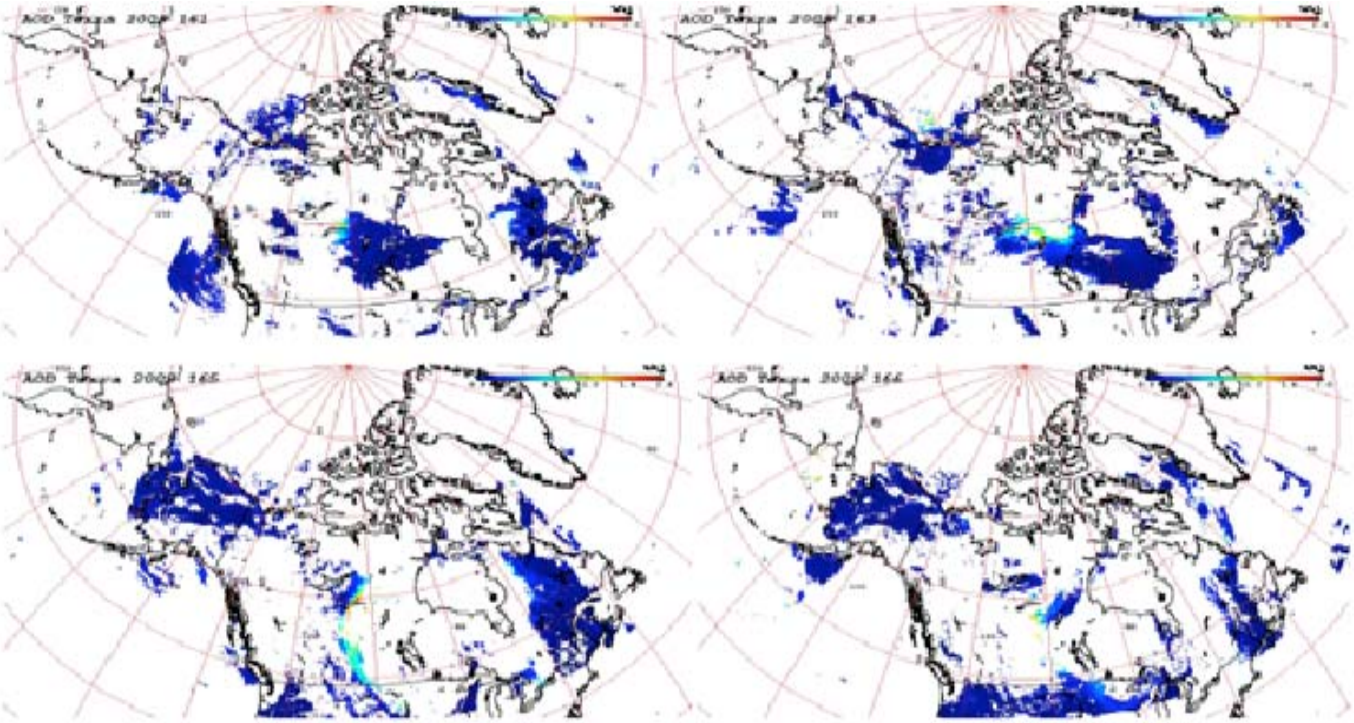
This paper continues to show the correlation of aerosol optical depth and CO concentration using MODIS and AIRS data for June-August 2008 when boreal biomass burning is most intensive. Using the MODIS AOD images we readjusted the broad data given to a smaller range where the AOD was the most intense. After concentrating on a smaller range we plotted the MODIS AOD and AIRS CO mixing ratio in the x-axis and y-axis, respectively. Next we obtained linear regression for the best fit between AOD and CO. Table 1 shows the R-squared values and linear regression equations for the days with a significant amount of AOD (>0.4). Table 2 shows the linear regression and correlation for the days with R greater than 0.7 (or R-squared >0.5). Figure 1 shows the MODIS AOD images followed by the linear regression plots for the days with (R>0.7).

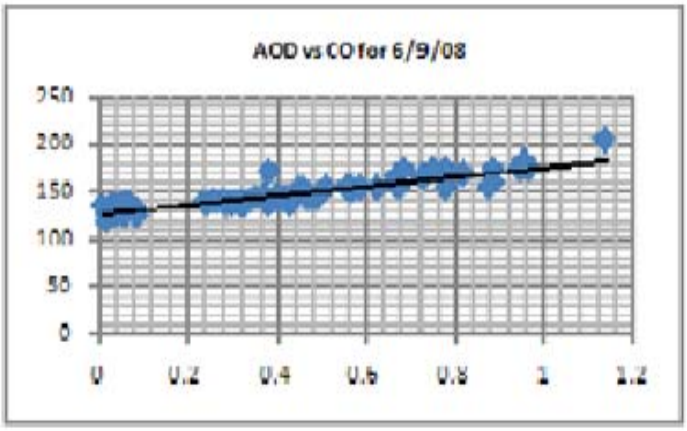
The slope of the linear regression represents the ratio of CO/AOD. The change in slope from day to day reflects the height of the smoke plume. MODIS AOD resolution is 10 km and AIRS resolution is 30 km. The differences of slope from day to day could be due to measurement uncertainties of MODIS and AIRS. We also concluded that the variation of the slope could be due to the variation in CO smoke plume height. Figure 2 combines all the plots from Figure 1 onto one plot. The change is slope from day to day is easier to see in Figure 2. Table 2 lists the correlation (R-squared) and linear regression derived slopes for those days in Figure 2.

The intercepts of the linear regressions vary between 100 and 140 ppbv (part per billion by volume). CO has a lifetime of up to three months where as AOD has an average lifetime of a couple weeks [*Edwards et al*., 2004]. Thus the values of intercepts derived from linear regression represent the range of background CO mixing ratio as AOD decreases to zero.

Julian Day	Date	Linear reg formula	Correlation R^2
161	6/9/08	49.74x + 126.9	0.844
162	6/10/08	36.24x + 136.3	0.395
163	6/11/08	36.51x + 130.4	0.705
164	6/12/08	40.32x + 128.2	0.34
165	6/13/08	49.56x + 127.6	0.723
166	6/14/08	55.55x + 140.8	0.743
180	6/28/08	69.19x + 101.7	0.645
181	6/29/08	19.87x + 108.4	0.353
182	6/30/08	29.96x + 108.0	0.226
183	7/1/08	57.45x + 112.3	0.645
185	7/3/08	81.04x + 111.0	0.655
186	7/4/08	41.29x + 132.0	0.817
187	7/5/08	92.42x + 92.84	0.803
191	7/9/08	25.65x + 120.9	0.44
193	7/11/08	52.24x +101.6	0.556
200	7/18/08	32.21x + 114.8	0.458
201	7/19/08	51.49x +117.4	0.526
202	7/20/08	55.13x + 116.0	0.524
205	7/23/08	45.69x + 100.0	0.35
206	7/24/08	27.07x + 119.7	0.113
207	7/25/08	70.69x + 118.7	0.751
208	7/26/08	39.32x + 118.5	0.766
209	7/27/08	41.12x +110.0	0.544
210	7/28/08	34.54x + 129.8	0.57
211	7/29/08	64.28x +111.3	0.648
212	7/30/08	85.46x + 122.2	0.596
213	7/31/08	43.76x + 118.9	0.439
222	8/9/08	39.46x + 108	0.651
223	8/10/08	34.82x + 127.8	0.282
229	8/16/08	28.76x + 86.65	0.409
232	8/19/08	48.08x + 106.8	0.368
233	8/20/08	16.14x + 106.8	0.13
235	8/22/08	-6.267x +101.7	0.015

Table 1. Table 1 shows the correlation (R^2) and linear regression point slope formula for the days with a significant amount of AOD between the months of June-August 2008




AOD vs CO for 6/9/08
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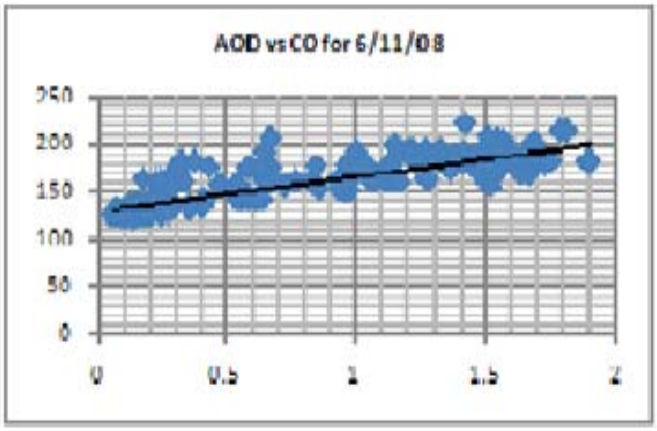
AOD vs CO for 6/11/08
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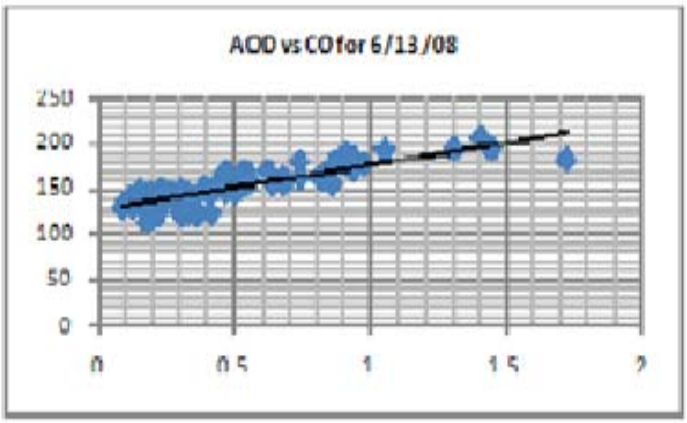
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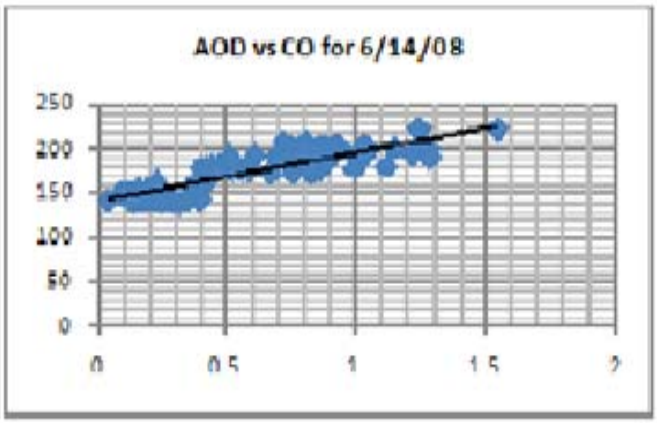
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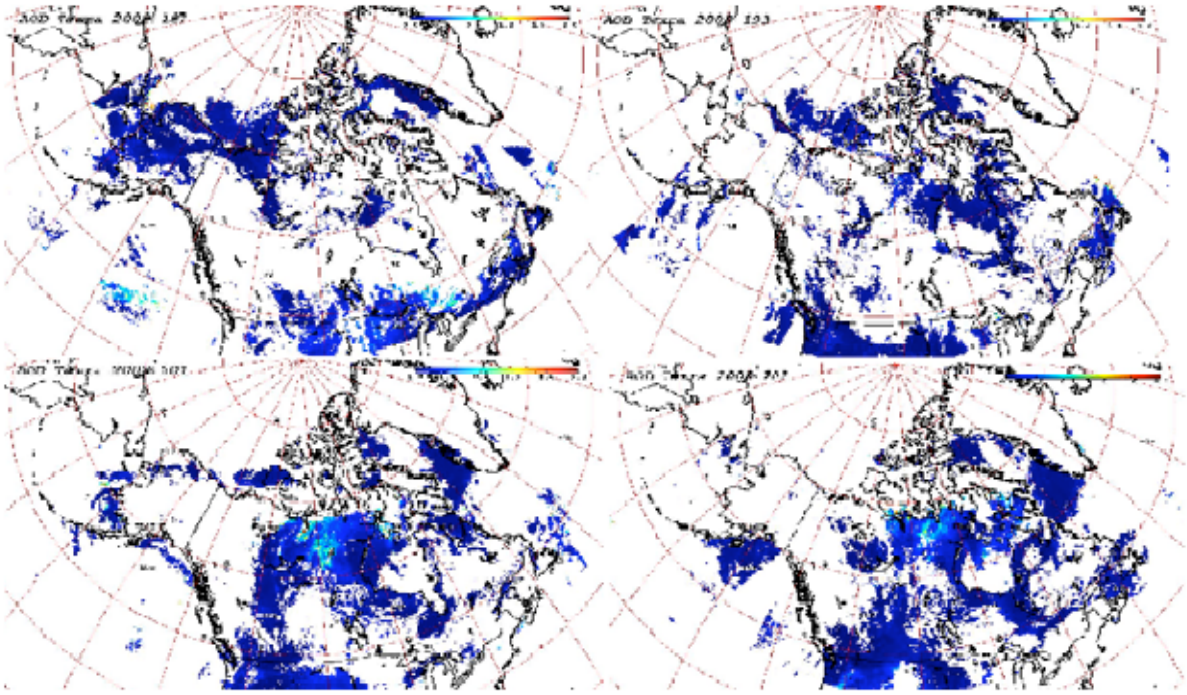
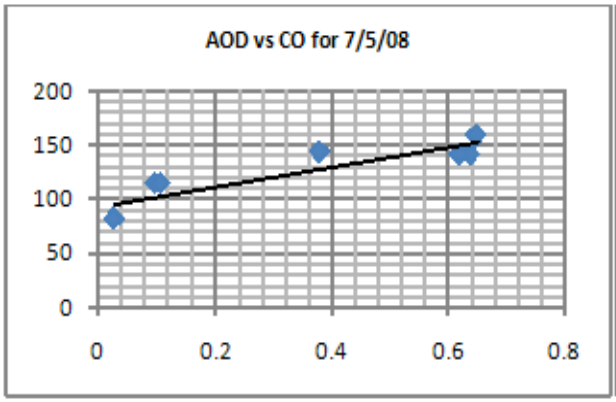
1
1.5
2




AOD vs CO for 7/5/08
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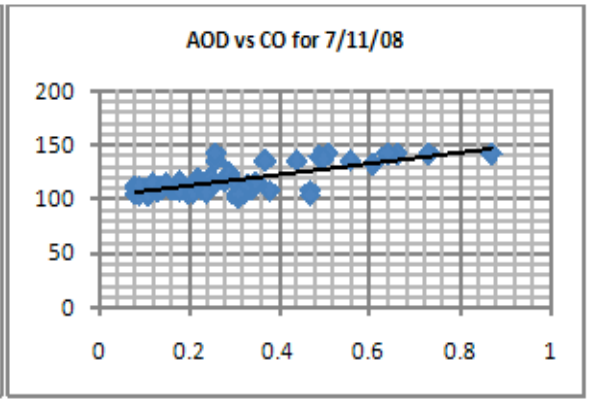
AOD vs CO for 7/11/08
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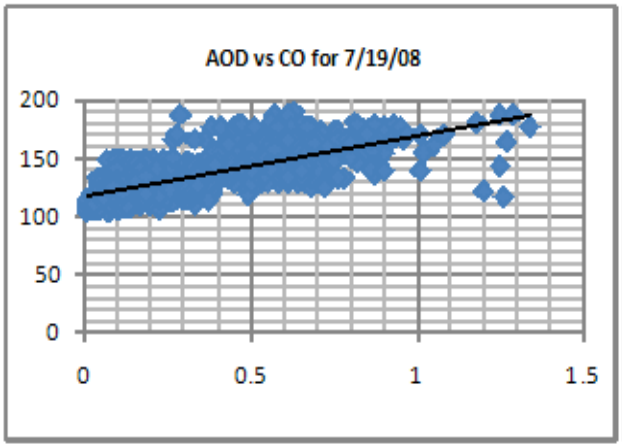
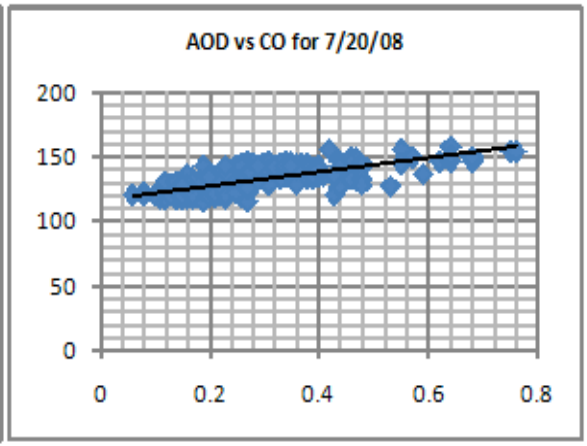
0.8
1


AOD vs CO for 7/19/08
200
150
100
50
0
0
0.5
1
1.5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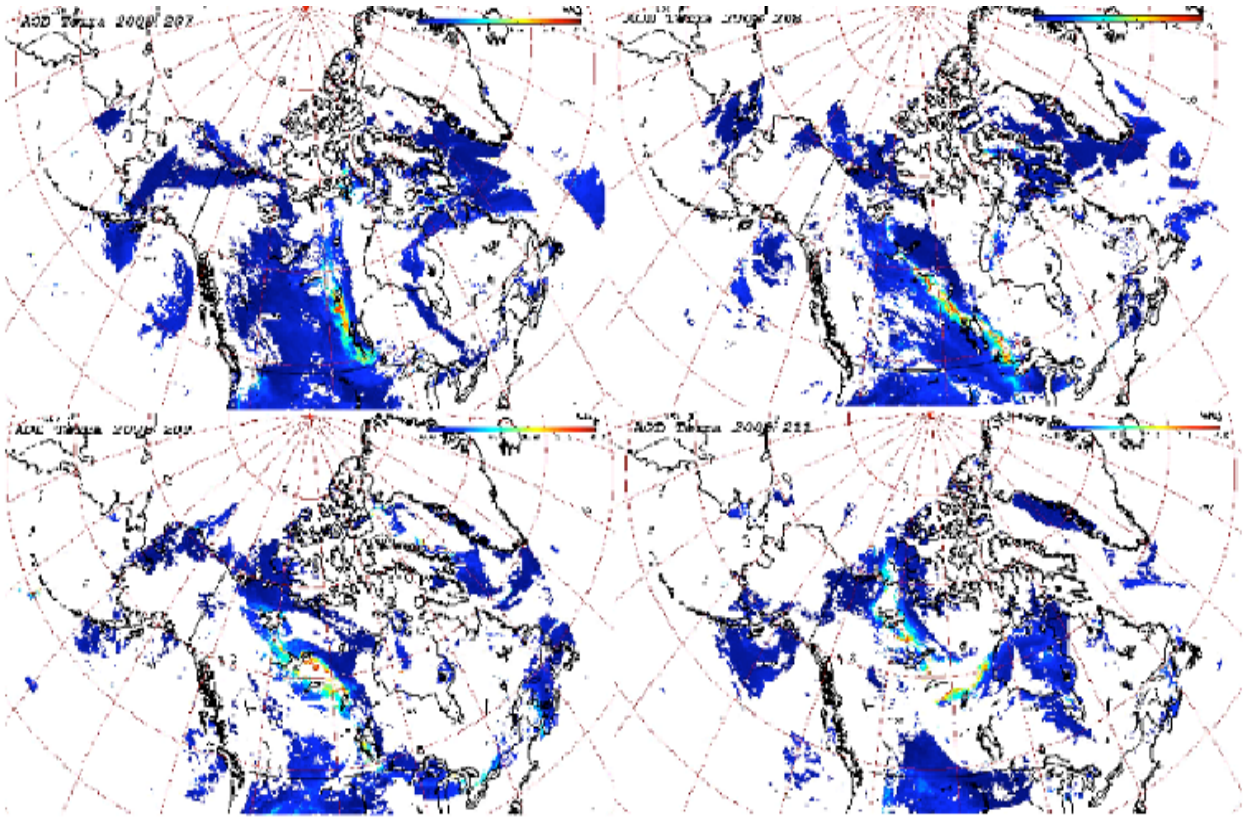

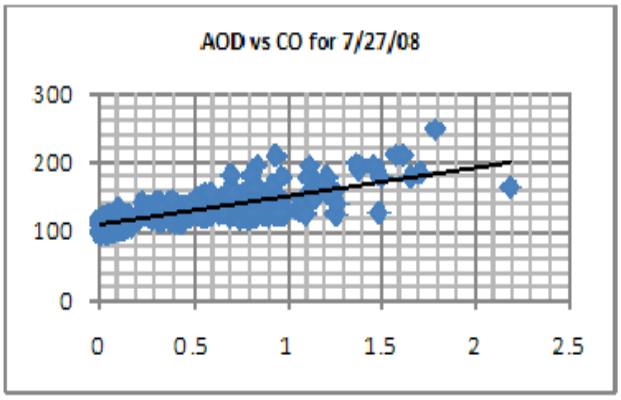
AOD vs CO for 7/27/08
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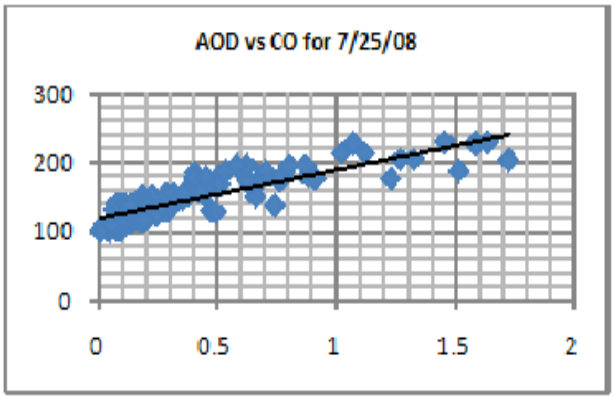
2
2.5


AOD vs CO for 7/25/08
300
200
100
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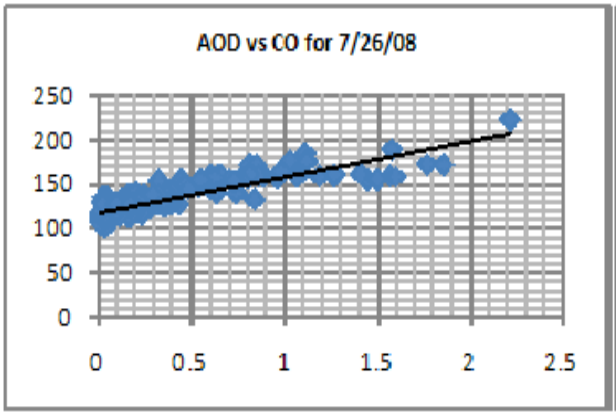
0
0.5
1
1.5
2


AOD vs CO for 7/26/08
250
200
150
100
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0
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0.5
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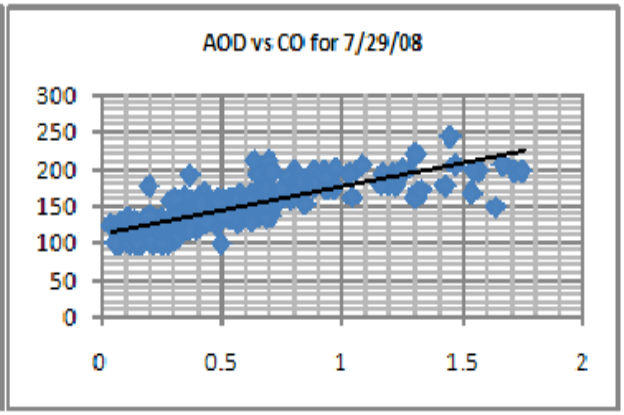
1.5
2
2.5


AOD vs CO for 7/29/08
300
250
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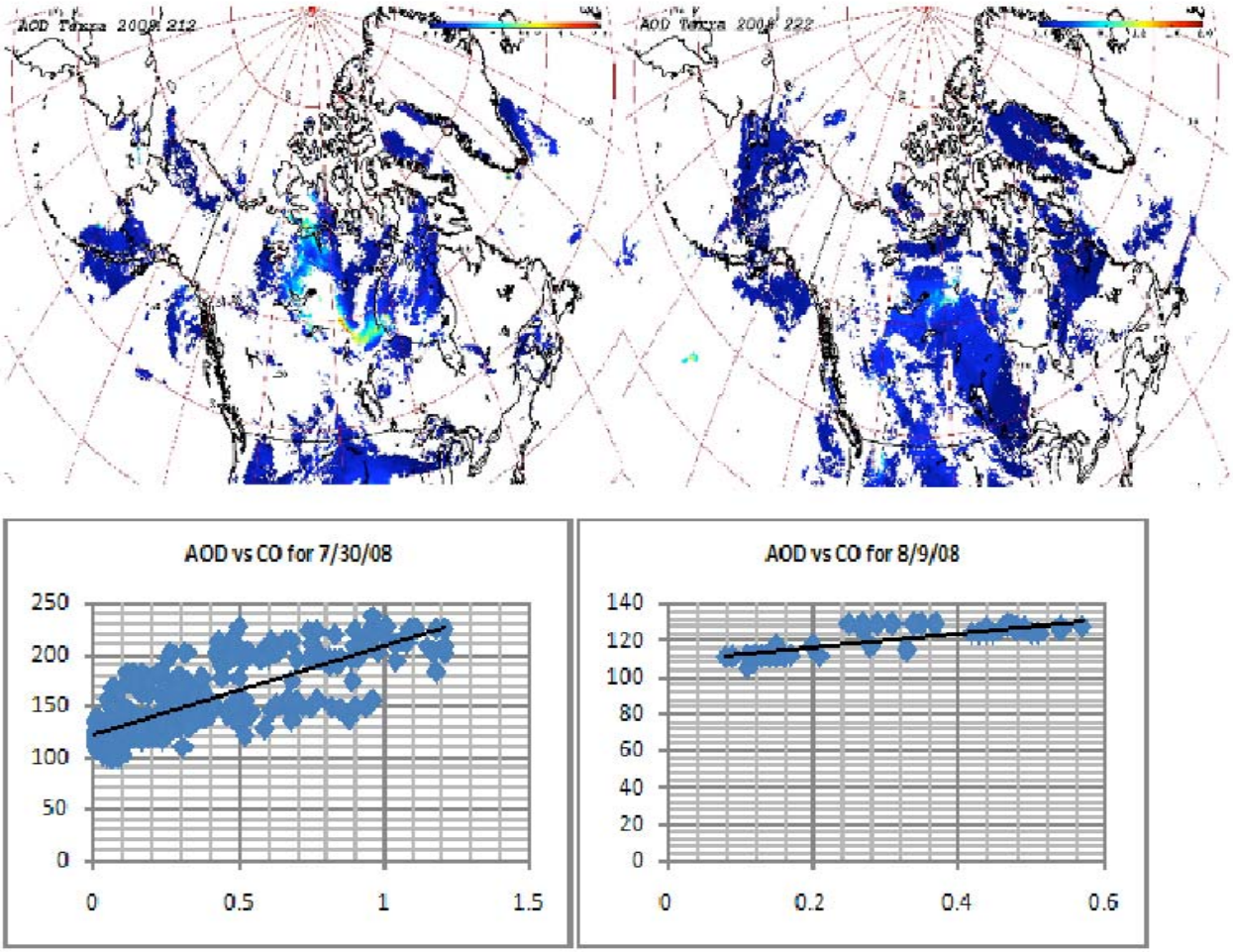


Figure 1. MODIS generated images of AOD for 2008 over North America for June-August 2008 followed by the linear regression plots based upon AOD as x-axis and CO mixing ratio as y-axis for days between June and August 2008 with correlation greater than 0.7.

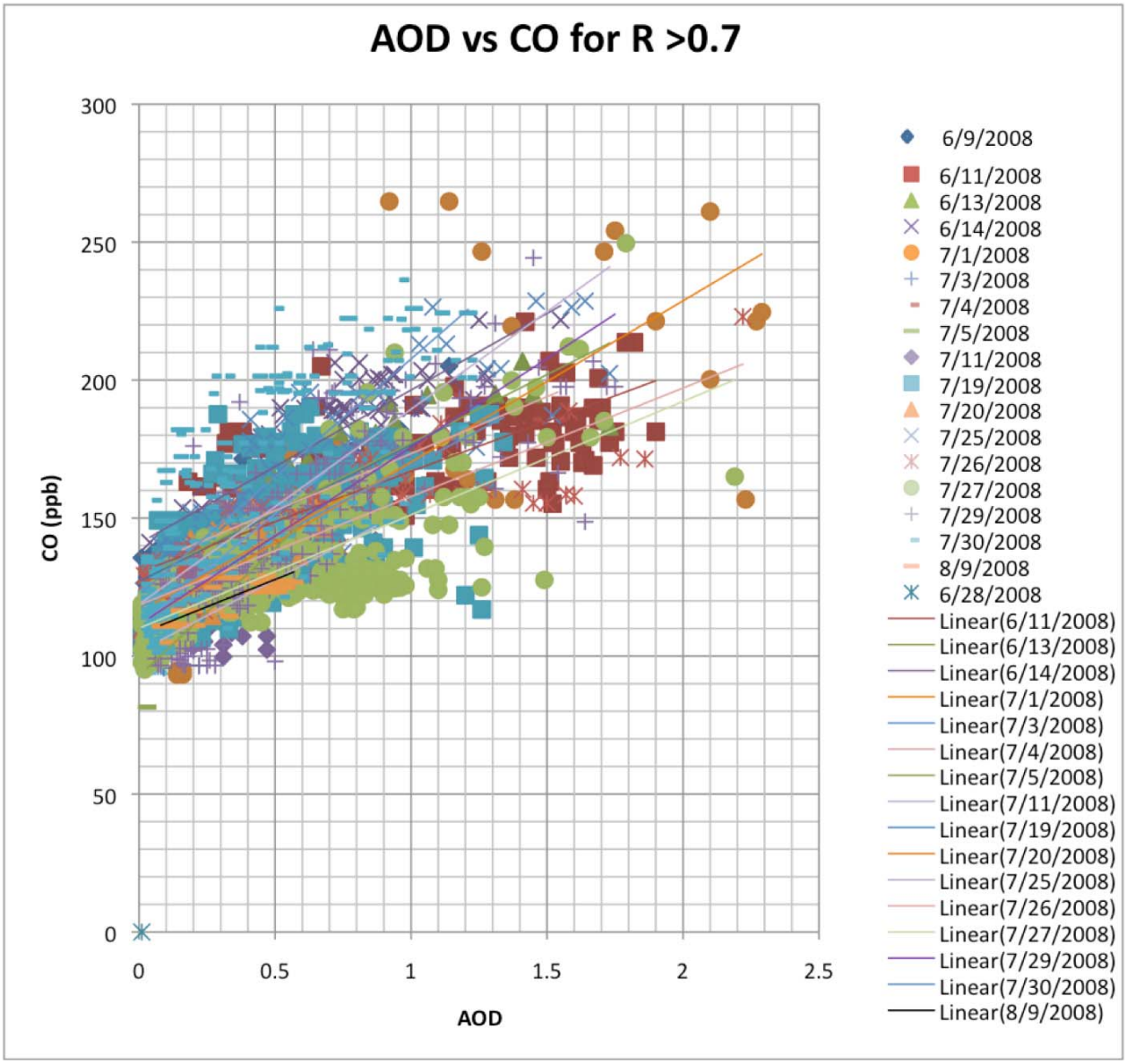


Figure 2. Linear regression of MODIS AOD and AIRS CO data with correlation greater than 0.7 (R>0.7). All the plots are from Figure 1.

Julian Day	Date	Linear reg formula	Correlation R^2
161	6/9/08	49.74x + 126.9	0.844
163	6/11/08	36.51x + 130.4	0.705
165	6/13/08	49.56x + 127.6	0.723
166	6/14/08	55.55x + 140.8	0.743
180	6/28/08	69.19x + 101.7	0.645
183	7/1/08	57.45x + 112.3	0.645
185	7/3/08	81.04x + 111.0	0.655
186	7/4/08	41.29x + 132.0	0.817
187	7/5/08	92.42x + 92.84	0.803
193	7/11/08	52.24x +101.6	0.556
201	7/19/08	51.49x +117.4	0.526
202	7/20/08	55.13x + 116.0	0.524
207	7/25/08	70.69x + 118.7	0.751
208	7/26/08	39.32x + 118.5	0.766
209	7/27/08	41.12x +110.0	0.544
210	7/28/08	34.54x + 129.8	0.57
211	7/29/08	64.28x +111.3	0.648
212	7/30/08	85.46x + 122.2	0.596
222	8/9/08	39.46x + 108	0.651

Table 2. Lists the correlation (R^2) and linear regression point slope formula for the days plotted in Figure 2.

5. GEOS-5 Model results

The Goddard Earth Observing System Model, Version 5 (GEOS-5) is a system of models integrated using the Earth System Modeling Framework (ESMF).

After calculating the correlation for all the days between June and August 2008 with significant amount of AOD (AOD > 0.4) and separating the plots of the days with a correlation greater that 0.7, we compared them to the GEOS-5 model results. Table 3 shows linear regression and correlation derived from modeled AOD and CO. As shown below model results do not agree with MODIS and AIRS measurement results. Figure 3 shows the plots for the model results that had a correlation >0.7, followed by the plots of the same days according to MODIS and AOD measurements.

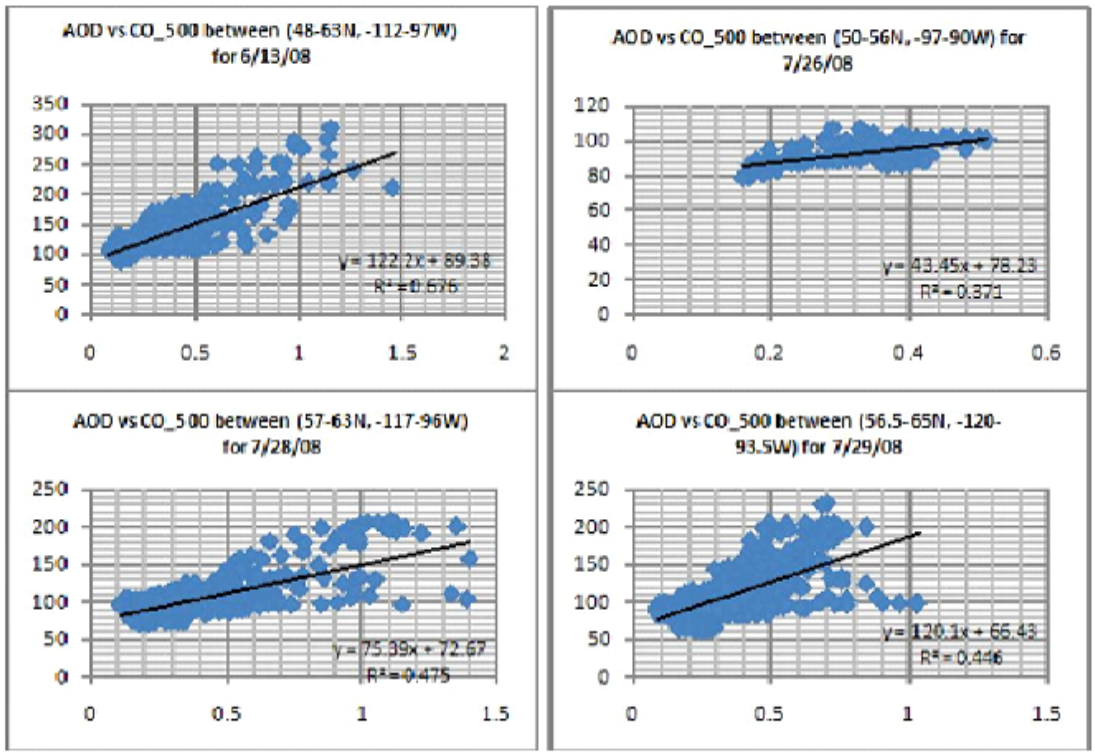
GEOS-5 data are on a resolution of 0.5° X 0.67°. AIRS resolution is 30 km and MODIS AOD resolution is 10 km. Different results could be due to the fact that GEOS-5 cannot resolve small-scale fires that MODIS and AIRS can or it could be due to other mechanical uncertainties.

MODEL DATA

Julian Day	Date	Linear Regression formula	Correlation R^2
163	6/11/08	y = 37.33x + 108.0	0.134
164	6/12/08	y = -6.563x + 118.1	0.037
165	6/13/08	y = 122.2x + 89.38	0.676
166	6/14/08	y = 106.8x + 99.29	0.348
180	6/28/08	y = -30.54x + 92.63	0.204
183	7/1/08	y = -3.685x + 89.84	0.002
185	7/3/08	y = -89.47x + 113.7	0.316
186	7/4/08	y = 22.24x + 84.89	0.099
202	7/20/08	y = -61.88x + 108.4	0.385
207	7/25/08	y = 32.28x + 94.19	0.314
208	7/26/08	y = 43.45x + 78.23	0.371
209	7/27/08	y = -10.82x + 94.79	0.014
210	7/28/08	y = 75.39x + 72.67	0.475
211	7/29/08	y = 120.1x + 66.43	0.446

Table 3. Lists the linear regression and correlation derived using GEOS-5 model results

MODEL GEOS-5 Results With correlation r>0.6



MODIS AOD and AIRS CO Results

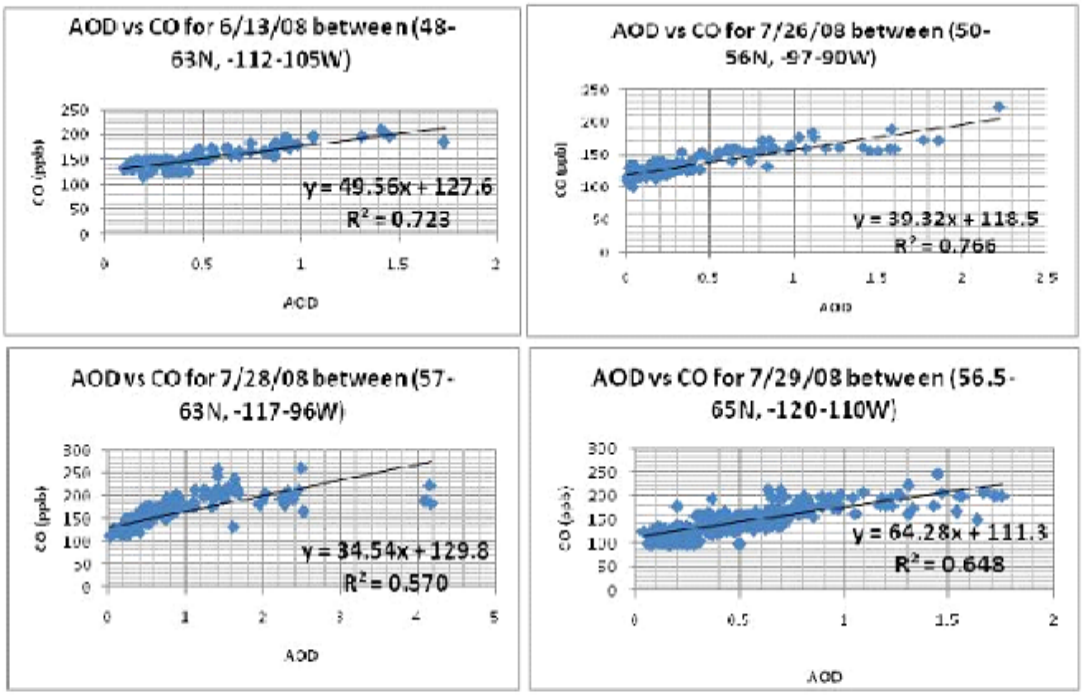


Figure 3. Displays MODEL GEOS-5 results With correlation r>0.6 followed by MODIS AOD and AIRS CO results for the corresponding days

6. RESULTS OF SIGMA FROM LINEARE REGRESSION

Date	Julian Day	Correlation R^2	Linear reg formula	Sigma value for slope	Sigma value for y-intercept	Percentage of points within one sigma
6/9/08	161	0.844	49.74x + 126.9	2.29276	1.02951	35.955%
6/13/08	165	0.723	49.56x + 127.6	3.19361	1.85725	27.660%
6/14/08	166	0.743	55.55x + 140.8	3.06715	2.00722	24.348%
7/1/08	183	0.645	57.45x + 112.3	6.75527	7.0729	39.583%
7/3/08	185	0.655	81.04x + 111.0	7.11816	2.1019	42.857%
7/4/08	186	0.817	41.29x + 132.0	3.56662	1.88652	56.250%
7/5/08	187	0.803	92.42x + 92.84	18.6382	7.75446	37.5%
7/11/08	193	0.556	52.24x +101.6	5.66027	1.77696	41.429%
7/19/08	201	0.526	51.49x +117.4	1.68549	0.66061	8.799%
7/20/08	202	0.524	55.13x + 116.0	3.42035	1.02625	18.908%
7/25/08	207	0.751	70.69x + 118.7	4.04287	2.31487	11.650%
7/26/08	208	0.766	39.32x + 118.5	1.57695	0.830523	7.853%
7/29/08	211	0.648	64.28x +111.3	3.018	1.89109	18.1%
7/30/08	212	0.596	85.46x + 122.2	3.49554	1.51129	10.074%
8/9/08	222	0.651	39.46x + 108	4.0802	1.39071	42.308%

Table 4. Lists the sigma values used for the plots in Figure 4 and the percentage of points within one sigma.

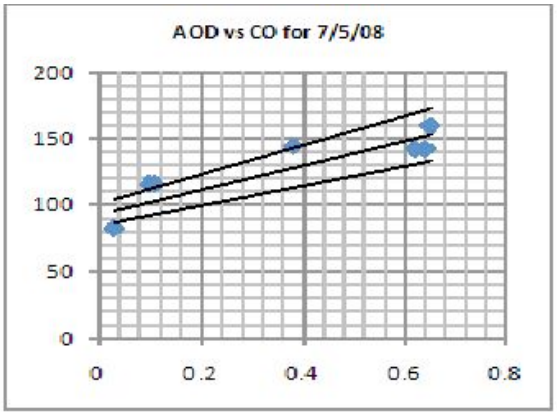
Ideally about 68% of the points on each plot should be within one sigma of the slope. Table 4 lists the percentage of point within one sigma and as shown most of the percentages are not close enough to 68% to be statistically accurate. Figure 4 shows the graphs of each day with sigma incorporated into the plots. As Figure 4 shows a lot of the points are outside the two-sigma lines. This could be due to the fact that the plots are too scattered or the latitude and longitude range is too big. It could also be due to the fact that MODIS and AIRS have different resolutions.

7. Conclusion.

Based upon the correlation and linear regression between MODIS AOD and AIRS CO, we concluded that the variations of the slope were due to the variation smoke plume height and uncertainties of MODIS and AIRS measurements. The variations in intercept reflect to the range of background CO ~100-140 ppbv as AOD decreases to zero.

The lower correlation derived between CO and AOD obtained from GEOS-5 indicates larger uncertainties in the model attributed mainly to coarser resolution of 0.5^{o} x 0.67^{o} compared to 10-km MODIS AOD and 30-km AIRS CO that GEOS-5 might have missed some of the small scale biomass burnings and resulted in the differences between model and measurement results. Mechanism of plume rising used in GEOS-5 model might also have contributed to the uncertainties of vertical distribution of CO and consequently led to the differences between model and measurement.

After incorporating sigma values into linear regression, we concluded that the data is too scattered and not statistically significant. Further research can aid in better understanding of the uncertainties we encountered.


AOD vs CO for 7/5/08
200
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100
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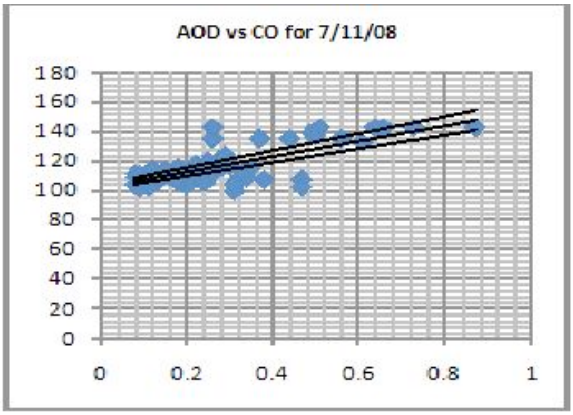
0
0.2
0.4
0.6
0.8


AOD vs CO for 7/11/08
180
160
140
120
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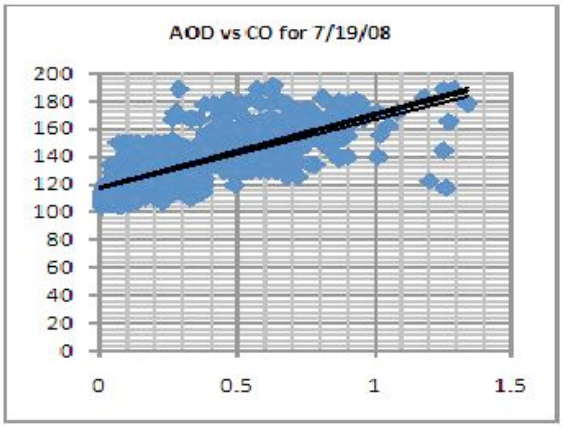
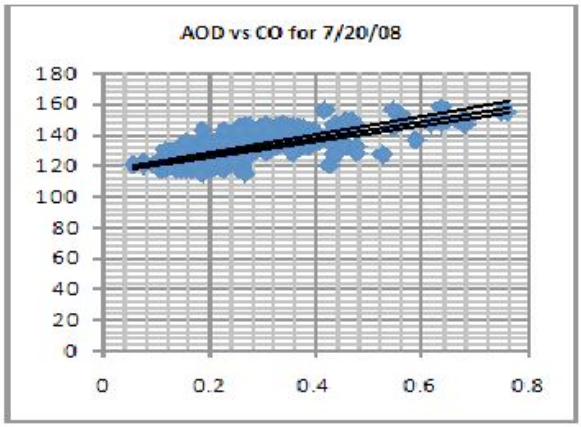
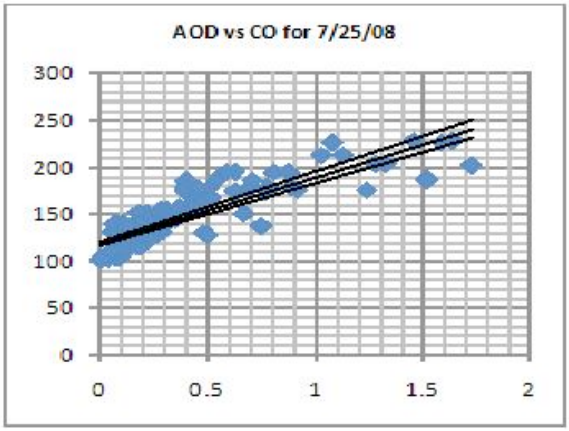
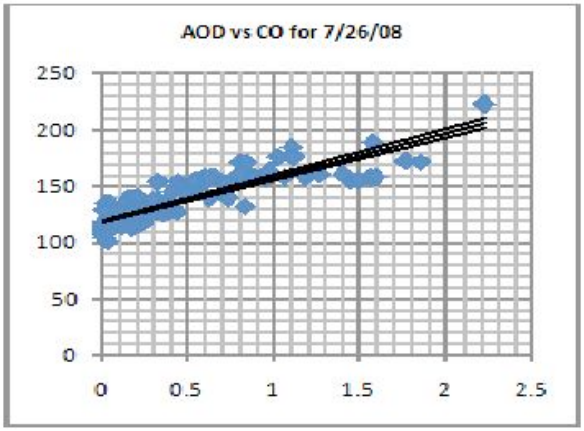
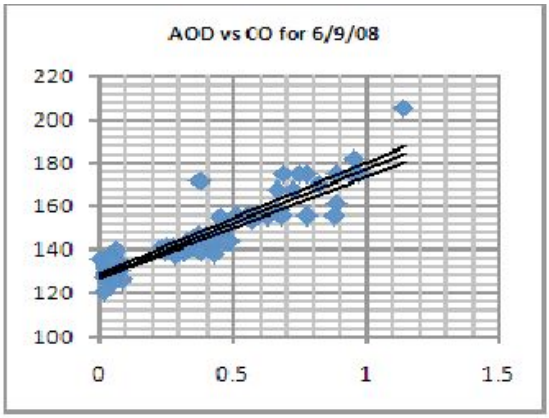
0.4
0.6
0.8
1

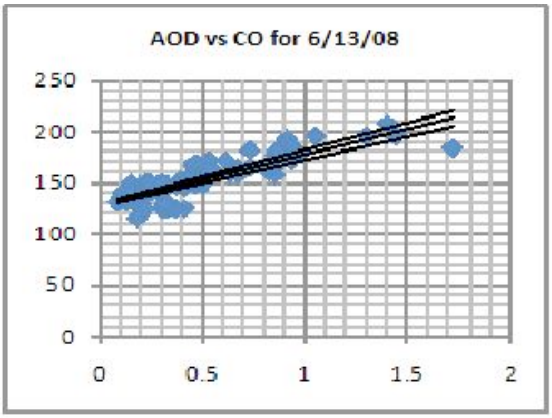

AOD vs CO for 7/19/08
200
180
160
140
120
100
80
60
40
20
0
0
0.5
1
1.5

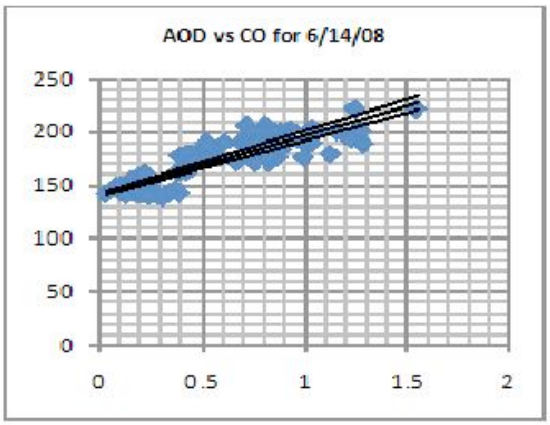

AOD vs CO for 7/20/08
180
160
140
120
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8

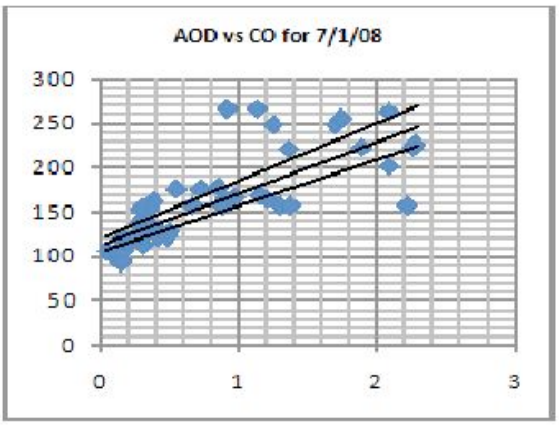

AOD vs CO for 7/25/08
300
250
200
150
100
50
0
0
0.5
1
1.5
2

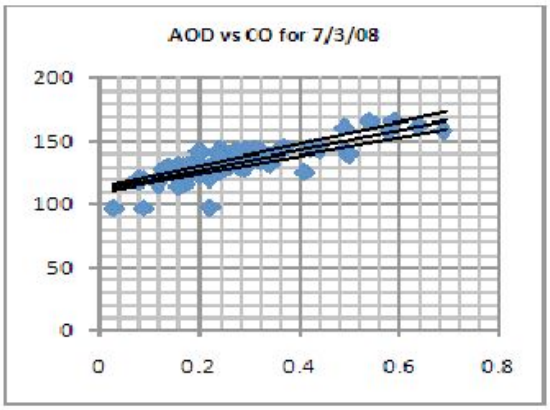

AOD vs CO for 7/26/08
250
200
150
100
50
0
0
0.5
1
1.5
2
2.5

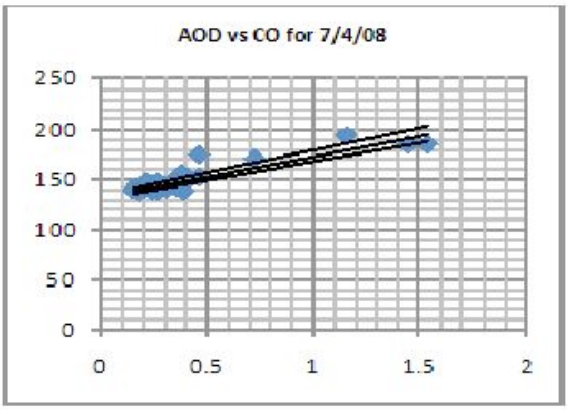

AOD vs CO for 6/9/08
220
200
180
160
140
120
100
0
0.5
1
1.5


AOD vs CO for 6/13/08
250
200
150
100
50
0
0
0.5
1
1.5
2


AOD vs CO for 6/14/08
250
200
150
100
50
0
0
0.5
1
1.5
2


AOD vs CO for 7/1/08
300
250
200
150
100
50
0
0
1
2
3


AOD vs CO for 7/3/08
200
150
100
50
0
0
0.2
0.4
0.6
0.8


AOD vs CO for 7/4/08
250
200
150
100
50
0
0
0.5
1
1.5
2

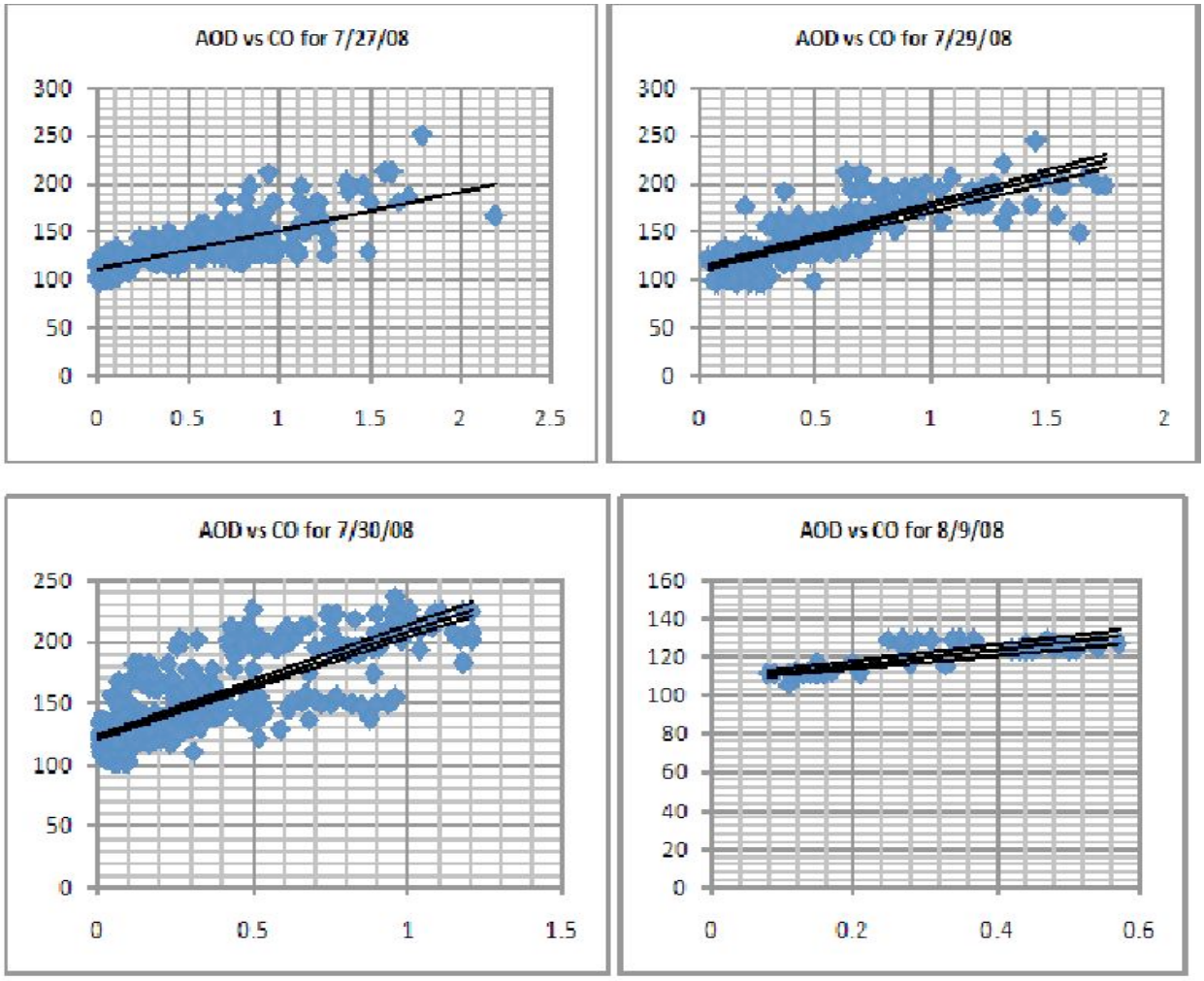


Figure 4. Plots with sigma incorporated into MODIS AOD and AIRS CO measurement original R>0.7 plots.

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