10.6 AN ASSESSMENT OF AIR QUALITY IN THE HOUSTON REGION: INVESTIGATING THE ABILITY TO INFER SURFACE $PM_{2.5}$ FROM REMOTE SENSING MEASUREMENTS AND EXAMINING POSSIBLE AEROSOL SOURCES

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1. ABSTRACT

Increased concentrations of aerosols, specifically those 2.5 micrometers in diameter or less ($PM_{2.5}$), are detrimental to the health of a community. Houston, Texas lies in a region susceptible to high concentrations of $PM_{2.5}$ due to increasing pollution from sources including large petrochemical plants and natural sources like Saharan dust. Ground based observations of these aerosols are accurate; however the network of stations does not cover a wide area and therefore accurate aerosol forecasts are difficult. Satellite applications were developed with instruments such as MODIS on Terra and Aqua to potentially provide a method to infer $PM_{2.5}$ over a wide area. This project examined satellite, aircraft, and surface aerosol observations to investigate the ability to gather surface $PM_{2.5}$ from satellite Aerosol Optical Depth (AOD) measurements. These issues were addressed in an air quality case study of the Houston region (-93°W to -97° W and 28° N to 32° N) from August to September 2006 to take advantage of measurements acquired during the 2006 TexAQS/GoMACCS study. Peak aerosol events were identified and possible sources of the events were investigated. Comparing Terra MODIS AOD with surface station $PM_{2.5}$ displayed an r-squared value of 0.7191 on high aerosol concentration days. When Terra AOD measurements were divided by the Planetary Boundary Layer (PBL) height, correlations on high aerosol concentration days improved to 0.8075. CALIPSO curtain plots and HYSPLIT back trajectories were utilized to track aerosol sources and indicated the presence of Saharan dust over the Houston area on August 28, 2006.

2. INTRODUCTION

As air quality continues to be at the forefront of community concerns in areas across the United States, scientists continue to determine improved methods for measuring aerosols and predicting poor air quality. The Houston metropolitan area is one of the communities of concern as it rivals Los Angeles, California for the worst air pollution in the nation (TERC annual report 2003-2005). A main contributor in this region is fine particulate matter of size 2.5 micrometers or less in diameter ($PM_{2.5}$). This particulate matter is of such a small size that it is able to enter deep into human lungs, which can in turn cause asthma, bronchitis, and other chronic conditions. Children, the elderly, and individuals with preexisting health conditions are most likely to be affected by higher concentrations of $PM_{2.5}$ (EPA, 2008). Sources of $PM_{2.5}$ include exhaust from vehicles, power plant and industrial emissions, and also smoke from wildfires. It is also possible that long distance transport of desert dust from Asia or Africa could impact local $PM_{2.5}$ levels (Al-Saadi, 2005). According to the Environmental Protection Agency (EPA), visibility can be reduced by up to 70% in polluted areas of the United States, and can also contribute to the production of acid rain ($PM_{2.5}$, 2008). For these reasons, it is necessary for local officials to have accurate forecasts of air quality conditions to protect the health of citizens living in areas with high $PM_{2.5}$ levels.

In 2003, a group consisting of National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), and EPA scientists joined together to work on the Infusing Satellite Data into Environmental Applications (IDEA) project. This study generated a single database for forecasting national air quality by combining satellite, surface, and wildfire sources into a single resource. During the project, researchers found cases in which moderate correlations were apparent between aerosol measurements, confirming the value of the satellite resources (Al-Saadi, 2005). Further research was completed in 2007 by Al-Saadi in the California San Joaquin Valley. During this study aerosol measurements and planetary boundary layer (PBL) heights were derived from an airborne High Spectral Resolution Lidar (HSRL) and compared with surface PM2.5 measurements. This analysis it determined that the correlation between surface PM2.5 values and aircraft HSRL AOD measurements improved when AOD was divided by PBL height, possibly owing to the theory that most aerosols are trapped within the PBL (Al-Saadi, presentation, 2007).

To address air quality concerns for the Houston region, this assessment took place in two phases. The first is the verification of aerosols over the region of interest (Latitude: 28° to 32°N, Longitude: 97° to 93°W), for the timeframe of August through September 2006. During this phase, data was analyzed from three satellites: Aqua, Terra, and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO). The Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on both Terra and Aqua and the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument on CALIPSO will provide AOD data. AOD measurements from the High Spectral Resolution Lidar (HSRL) instrument onboard the NASA KingAir B200 aircraft was also used. The final aerosol measurement source was the Texas Commission on Environmental Quality (TCEQ) ground monitoring sites

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which observe surface $PM_{2.5}$ measurements. These parameters were verified in MATLAB and Microsoft Excel to observe correlations, and an analysis was performed to investigate the ability to infer surface PM2.5 from satellite observations following conclusions made by J. Al-Saadi in a 2006 study. The second phase of the project involved an analysis of peak aerosol events, and their sources. Back trajectories of peak aerosol events were analyzed utilizing the HYSPLIT model and primary target sources to be investigated include: Saharan dust, wildfire smoke plumes, and pollution emission events in the Houston metropolitan area.

3. METHODOLOGY

3.1 Correlating Satellite, Airborne, and Surface Data

MODIS is an instrument aboard the Aqua and Terra Satellites that analyzes various features of the Earth. AOD data at 550 nm from collection 5 of MODIS was used. This particular wavelength was used because it is the closest to the actual size of the particles, and therefore has the most accuracy in picking up the backscatter from the aerosols. These data were placed into and revised through both MATLAB and Microsoft Excel. The revision process included the removal of null values, the configuration of the axis to specify the region of interest and the conversion of AOD values to match $PM_{2.5}$ measurements for comparison. Both satellites provide one swathe of data over the Houston region one to two times per day. Longitude, latitude and AOD values were plotted in MATLAB.

The HSRL is an instrument onboard the NASA KingAir B200 aircraft. The HSRL instrument collected AOD data during the Texas Air Quality Study (TexAQS) and Gulf of Mexico Atmospheric and Climate Composition Study (GoMACCS). The aircraft measurements were organized in .hdf files. These were downloaded from the project website and opened in MATLAB. Before the data set could be analyzed, the null values were removed, and the HSRL AOD data was overlaid onto the background of MODIS datasets for qualitative analysis.

Dr. Jim Szykman of the EPA provided surface measurements of $PM_{2.5}$ to prove ground-truth to the satellite AOD data. Surface measurements were imported into Excel where null values were removed. In order to later compare surface measurements to MODIS data, another spreadsheet was created which included only surface measurements from the time of Aqua and Terra's swathe of the Houston region. In addition, all surface stations for every hour of every day were averaged to compare them to HSRL and CALIPSO datasets.

Ground based AOD profiles were gathered using the AERONET site at the University of Houston. Level two data was downloaded for the peak days of interest, 29 and 31 August, and 3, 7, and 14 September. Data was put into an Excel spreadsheet and values were recorded to correspond with MODIS overpasses and HSRL flights. All values of surface AOD for the days of interest were compared to surface $PM_{2.5}$ measurements at the closest relative station.

2.2 Emission Events- Wildfires and Saharan dust

The TCEQ maintains a record of every emission event that occurrs in the state of Texas. The TCEQ website was used to retrieve the data for the months of August and September 2006 for the Houston and Beaumont stations. The data were moved into an Excel spreadsheet to be more easily manipulated. Recorded from the website were the event numbers, site name and location (including latitude and longitude), date and time of beginning and ending emission, and pounds of nitrous oxides (NO_x) and sulfurous oxides (SO_x) emitted. NO_x and SO_x were chosen because they are contributing factors in producing $PM_{2.5}$. NO_x also contributes to ozone production. The data was sorted into date and time order and totals of NO_x and SO_x were obtained both monthly and for the entire time period. This data was used to help pinpoint peak days of emissions.

Wildfire data for Texas, which included size and location parameters, was gathered from the Texas National Park Service (NPS) and can be seen in Table 1. The locations of the seven wildfires were pinpointed in Google Earth. Using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model, forward trajectories of 72 hours, beginning at the wildfires' dates, times, and locations, were viewed at altitudes of 0.5, 1.0, and 2.0 km respectively. The HYSPLIT trajectories were input into Google Earth, and studied to determine whether they intersected the Houston area.

After showing correlations between $PM_{2.5}$ and AOD, the data were analyzed to make assessments regarding the source of the poor air quality. Saharan dust in and around the Houston area was researched and found to occur from 1-3 August and from 27-29 August 2006, based on the TCEQ web database. Lag correlations were done on 28 and 29 August 2006, dates with exceedingly poor air quality in Texas. A lag correlation is a comparative analysis between multiple sets of data in order to validate the accuracy of the additional data and the assumptions inferred from its examination. Given that Saharan dust may have traveled into southern Texas during these days, lag correlations could provide further evidence to support the assumption that dust was present on these days. HYSPLIT back trajectories of air parcels over Houston on 28 and 29 August were compared with images of CALIPSO AOD. A CALIPSO curtain plot was analyzed using the closest swathe to Texas. The latitude and longitude of the potential Saharan dust and the HYSPLIT back trajectories were plotted in Google Earth to observe how closely they matched.

4. RESULTS

4.1 Satellite, Airborne, and Surface Correlations

Satellite AOD Correlations

MODIS area-averaged AOD measurements from Aqua and Terra were compared over the two month case study to determine the initial correlation coefficient of 0.2146 over the area of interest (Figure 1). The AOD measurements for this analysis were obtained by averaging the daily AOD measurements across the region of interest (93° to 97°W and 28° to 32°N).

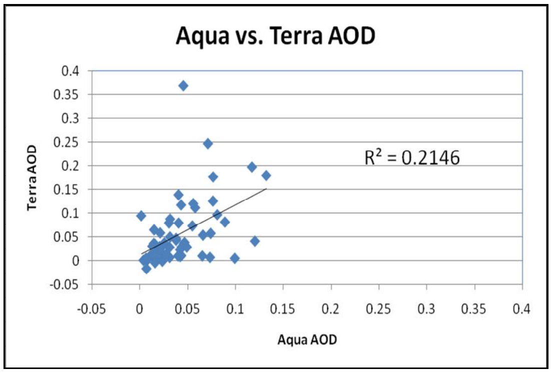
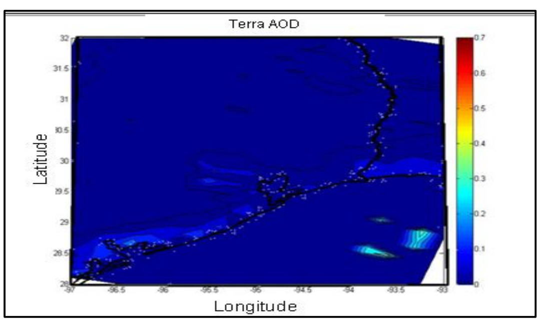


Figure 1: Correlation between surface $PM_{2.5}$ vs. Terra MODIS AOD over region of interest for August and September 2006

MODIS AOD values obtained from Terra and Aqua were compared visually for each case study day to determine if measurements were matching on low and high aerosol days. Figure 2 displays an example of a low aerosol event day and figure 3 shows a high aerosol event day. A comparison was performed over three clean aerosol days to understand the correlation within the grid, specifically at the University of Houston (UH) AERONET site, which resulted in an r-squared value of 0.9965. The UH AERONET site AOD measurements were also utilized to verify Terra AOD measurements on five high aerosol days and found an r-squared value of 0.931.



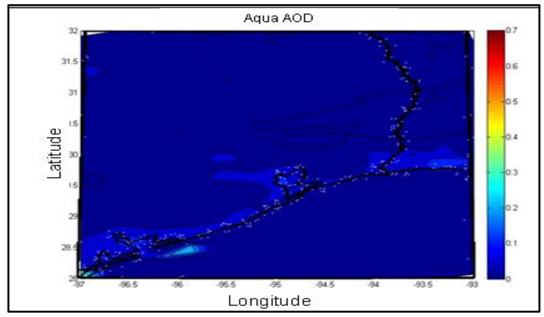


Figure 2: Low aerosol event day (19 September 2006) comparison with Terra (bottom left) and Aqua (top right)

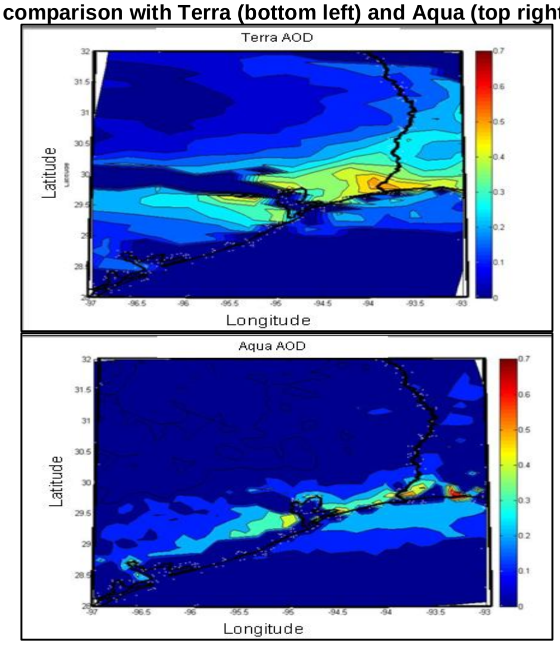


Figure 3: High aerosol event day (13 September 2006) comparison with Terra (top) and Aqua (bottom)

Satellite AOD Correlations with Surface Station $PM_{2.5}$

MODIS daily area-averaged AOD measurements were compared with TCEQ ground monitoring station $PM_{2.5}$ measurements for a qualitative analysis of aerosol events (Figures 4 and 5). The $PM_{2.5}$ measurements are the resulting average of the 16 TCEQ surface stations located within the area of interest. On certain days, such as 29 August, a peak aerosol event was identified by both satellite and surface observations. On other days events were picked up by only one source.

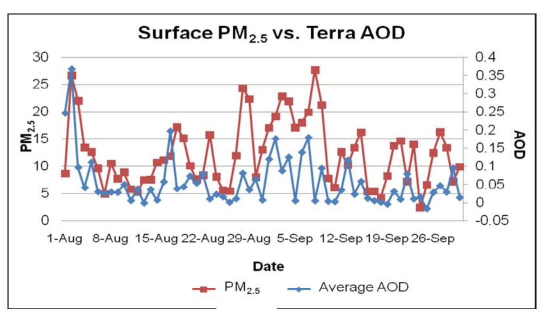


Figure 4: Correlations between surface $PM_{2.5}$ vs. Terra MODIS AOD over region of interest for August and September 2006

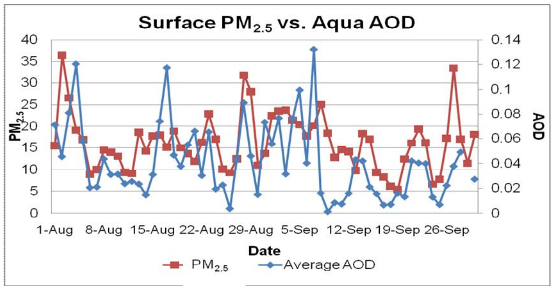


Figure 5: Correlations between surface $PM_{2.5}$ vs. Aqua MODIS AOD over region of interest for August and September 2006

Calculations were performed to determine if PBL height effected the correlation with satellite AOD measurements (Table 1). Resulting r-squared values improved for both low and high aerosol days; however, there was a much greater improvement for higher aerosol days. Terra AOD measurements obtained within +/- 0.2° latitude and longitude of the UH AERONET station (95.3419°W, 29.7178°N). These were compared with $PM_{2.5}$ measurements obtained from three surrounding surface stations (3, 5, and 8 miles from the AERONET site) and within +/- 1 hour of Terra observations.

	R^2 on low aerosol day	R^2 on high aerosol day
Terra AOD vs. $PM_{2.5}$	.9784	.7191
Terra AOD/ PBL vs. $PM_{2.5}$	.995	.8075

Table 1: Correlations between Terra and surface $PM_{2.5}$ on high and low aerosol concentration days are shown

HSRL AOD Correlations

HSRL AOD measurements taken aboard the KingAir B200 aircraft were overlaid on MODIS AOD measurements involving the region of interest for each flight during the case study. Figure 6 displays an example of the flight path AOD measurements (outlined in white) overlaid on Aqua MODIS AOD for August 31, 2006.

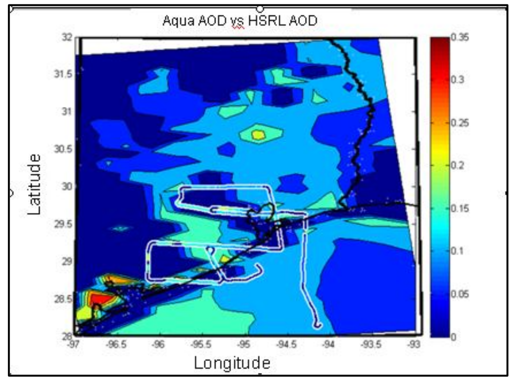


Figure 6: August 31, 2006 Aqua MODIS AOD on low aerosol day with HSRL AOD outlined in white

Further analysis was performed to determine how HSRL corresponded with surface $PM_{2.5}$ on low and high aerosol days (Table 2). HSRL AOD measurements were taken within +/- 0.2° latitude and longitude of the AERONET site, and surface $PM_{2.5}$ measurements were obtained from three surrounding surface stations (3, 5, and 8 miles from the AERONET site) within +/- 1 hour of HSRL observations.

	R^2 on low aerosol day	R^2 on high aerosol day
HSRL AOD vs. $PM_{2.5}$	.0193	.5521
HSRL AOD/ PBL vs. $PM_{2.5}$	.117	.5391

Table 2: Correlations are shown between HSRL and surface $PM_{2.5}$

4.2 Emission Events Analysis

Wildfire Smoke Plume Analysis

Wildfire data for Texas during the case study were received from the Texas National Park Service (Table 3). The locations of the seven wildfires were pinpointed in Google Earth, and forward trajectories were generated with a 72 hours run of the HYSPLIT model. The trajectories were analyzed at altitudes of 0.5-, 1-, and 2- km (Figure 7), and showed wildfire smoke plumes did not enter the study region of interest during the case study timeframe.

Fire Name	Latitude	Longitude	Start Time (UTC)	Control Acres
Green	29.2942	-103.263	7/31/2006 19:45	0.1
Rosillos	29.5344	-103.252	8/1/2006 12:00	5
Avery Ridge	29.4003	-103.17	8/4/2006 18:30	0.1

Woodson	29.0058	-103.297	8/17/2006 14:00	4
Espada Acequia	29.3383	-98.4597	8/26/2006 13:44	0.4
Espada Dam Fire	29.3436	-98.4611	9/2/2006 14:00	3.2
Pitcher Plant Bog RX	30.5889	-94.335	9/15/2006 10:00	111

Table 3: Wildfire data used provided by Texas NPS.

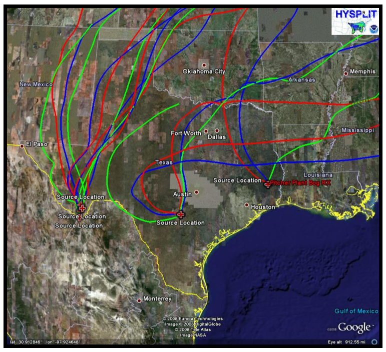


Figure 7: Image showing forward trajectories over Texas from wildfire sites.

Saharan Dust Analysis

The TCEQ database indicated there was possible Saharan dust located within our region of interest 28-29 August 2006. Terra MODIS displayed higher aerosol concentrations on 28 August with AOD values up to 0.4. HSRL AOD measurements in the region displayed possible dust signatures in the aerosol backscatter and aerosol depolarization plots (Figure 8) as well on 28 August. The HYSPLIT model was utilized to generate back trajectories from peak AOD values in the region to determine where the air mass originated (Figure 9). This was further investigated with CALIPSO which indicated a possible dust signature in the curtain plot intersecting the back trajectory at approximately 8 UTC on 27 August (Figure 9). Figure 10 displays the CALIPSO Depolarization plot for 27 August 8 UTC indicating higher depolarization for the aerosols located over southeastern Texas and the Gulf of Mexico; these higher values of depolarization are associated with non-spherical dust aerosols.

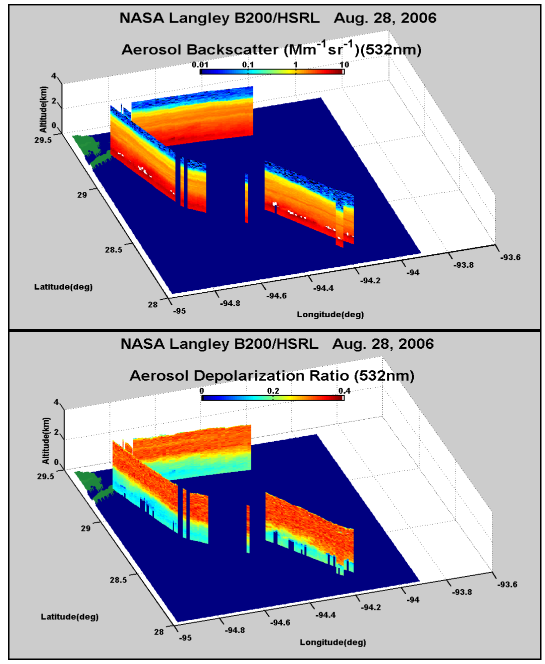


Figure 8: HSRL Aerosol Backscatter (top) and Aerosol Depolarization Ratio (bottom) both indicate a dust signature

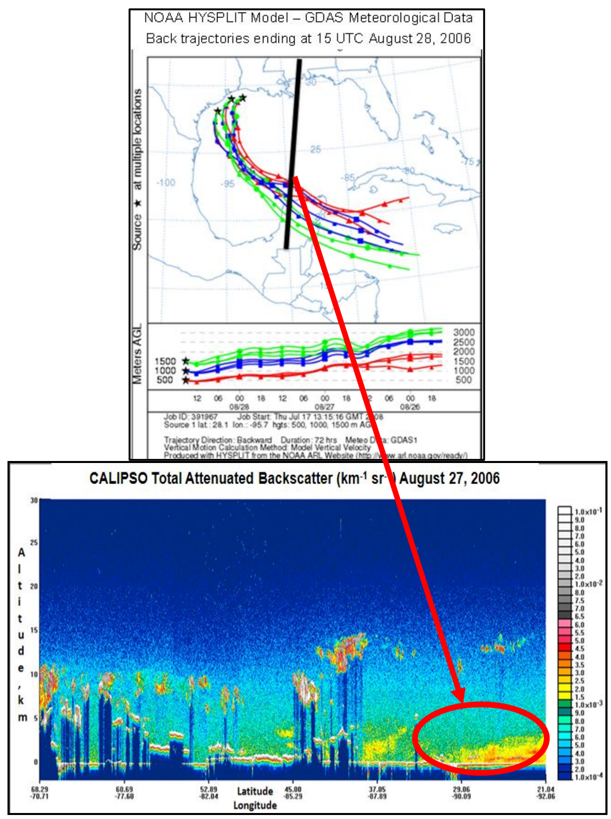


Figure 9: HYSPLIT back trajectory from peak points on 28 August AOD (left) and CALIPSO backscatter curtain intersecting back trajectory (black line) on 27 August at 8 UTC

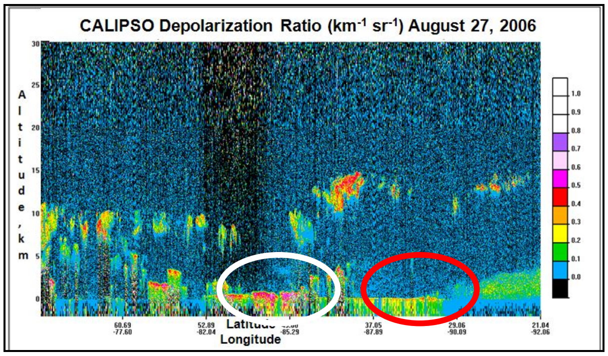


Figure 10: Depolarization plot showing the low depolarization associated with pollution aerosols (white circle) and high depolarization associated with dust aerosols (red circle)

Surface Station Analysis

Each surface station on the days of interest was graphed by hour. The Excel graphs show that trends in surface $PM_{2.5}$ are very inconsistent and data for many times do not exist. Figure 10 shows an example for 29 August 2006 which confirmed the late evening and early morning measurements were more closely correlated, however as the day continues the measurements become widely spread out.

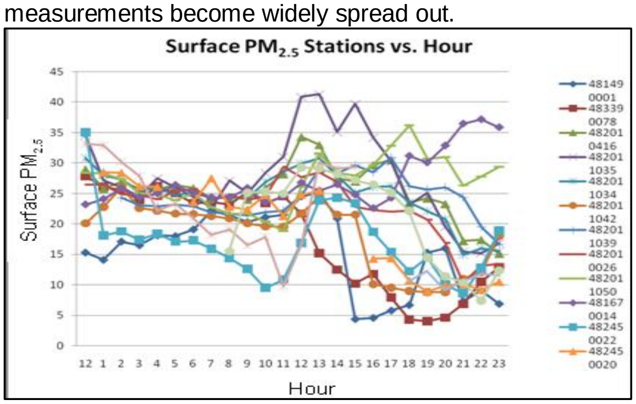


Figure 11: Line graph showing variability of surface $PM_{2.5}$ on 29 August 2006.

5. DISCUSSION

5.1 Satellite, Airborne, and Surface Analysis

The initial analysis of Terra versus Aqua AOD indicated a very low correlation (r-squared of .2146) when averaged over the entire region of interest. This may be attributed, as shown in Figures 2 and 3, to evaluation of too large an area, the time difference between the measurements, as well as the variability in the regions were AOD was derived. By narrowing the field of view, the correlations between the two values of AOD are greatly increased. This verified an area average was not effective for comparing AOD, as the values vary significantly over a large region.

Comparisons of surface $PM_{2.5}$ and AOD values from Terra and Aqua were staggered. They indicated AOD sometimes infers surface $PM_{2.5}$ concentrations, but can also show opposite values. A variable in this analysis is the PBL height and, as seen in Table 1, values for correlations improved when AOD levels were divided by the PBL height, showing the effect of mixing and variability of winds in the atmosphere.

It was expected that the HSRL AOD values would correspond well with surface concentrations of $PM_{2.5}$ as the instrument on the aircraft were much closer to the source of the data, rather than a satellite. However, values for AOD on HSRL were largely inconsistent and did not point to specific conclusions. Comparisons of HRSL AOD to MODIS AOD also resulted in a lack of conclusions. This ambiguity in results can be attributed to high horizontal and temporal variability in the aerosol concentrations; note that the HSRL data were often collected during the middle of the day when PBL heights were rapidly increasing and when there were large variations in the horizontal and vertical distributions of the aerosols.

5.2 Emission Events Analysis

The wildfire data showed no significant impact on the surface or satellite data from smoke plumes over the region of interest during the months of August and September 2006. HYSPLIT forward trajectories from the wildfire sites confirmed winds blowing away from the Houston area during this time.

The combination of CALIPSO and HYSPLIT allowed for a snapshot picture of aerosols in an environment. These two observation systems were used in conjunction to prove the presence of Saharan dust in the Houston area. Specifically it was shown that Saharan dust entered the Houston area on 28 August. The CALIPSO Total Attenuated Backscatter plot shown in Figure 9 indicated the presence of dust which was further confirmed by the CALIPSO Depolarization Ratio Plot showing the difference between aerosols from pollution and aerosols from Saharan dust (Figure 10).

The graph shown in Figure 11 displays potential variability within a 24-hour period in surface $PM_{2.5}$ concentrations. There were many factors that may have contributed to these wide spread values such as meteorology, locations of power plants, and limitations of current measuring equipment. All of these aspects make determining specific aerosol sources very complex and intricate. It was then necessary to evaluate the synoptic scale features in order to make an overall picture and forecast.

6. CONCLUSIONS

With an area of over 1655 square kilometers, the city of Houston could encompass New York City, Washington D.C., Boston, San Francisco, Seattle, Minneapolis, and Miami. The millions of people who reside in this metropolitan area are all affected by the environmental quality of the city in which they live. The reason humans can live on the Earth is due to the protective atmosphere; the air we breathe is vital to our existence. It is therefore vastly important to keep the air clean. Houston suffers from an air quality problem, with many sources of ozone and particulate matter pollutants. Though it has a large problem, the issue of air quality is also one of national importance. Discoveries made for Houston can be applied all around the United States, as well as globally.

The results in this study show that AOD can be an indicator of surface $PM_{2.5}$ levels, however the range of the satellite data that can be used to infer surface PM2.5 must further be determined as averages determined from a large region may not reveal correlations valuable for forecasting.

There is a significant amount to be learned from remote sensing applications in the Houston area. Small scale features greatly affect the validity of a forecast. Possible features to be studied to improve air quality forecasts include sea and land breezes, dust devils, small fires, and local aviation. Correlation studies of surface $PM_{2.5}$ to ozone, relative humidity, and PBL height could be done as well as determining sources of long range transport of aerosols into the Houston area.

The addition of the GOES-R satellite and other upcoming aerosol missions, such as the NASA Glory mission, can provide measurements of such variables as particle size and distribution could be analyzed to determine what type of aerosols are being driven into the atmosphere. The AOD spatial resolution will also be increased from a four by four kilometer resolution to a two by two kilometer resolution.

Taking into account the addition of these variables and those looked at in this study, the forecast models will become more detailed and therefore more accurate. Providing lawmakers with better forecasts and improved scientific data enables them to make informed policy decisions with regard to air quality for Houston as well as the United States.

7. ACKNOWLEGMENTS

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References

Air Quality in Texas. 2008. Texas Environmental Profiles. Retrieved June 19, 2008, from http://www.texasep.org/html/air/air2.html

Al-Saadi, J., Szykman, J., Pierce, R.B., Kittaka, C., Neil, D., Chu, D.A., et al. 2005. Improving National Air Quality Forecasts with Satellite Aerosol Observations. *American Meteorological Society*, 1249-1261.

Analysis of S. 1844, the Clear Skies Act of 2003; S. 843, the Clean Air Planning Act of 2003; and S. 366, the Clean Power Act of 2003. 2004. Energy Information Administration.Retrieved June 19, 2008, from http://www.eia.doe.gov/oiaf/ servicerpt/csa/pdf/ sroiaf(2004)05.pdf

Annual Report January 2007. 2007. Texas Environmental Research Consortium. Retrieved June 19, 2008, from http://files.harc.edu/Sites/TERC/About/AnnualReport200701.pdf

Clean Air Planning Act of 2007. 2007. U.S. Senate. Retrieved June 19, 2008, from http://www.govtrack.us/congress/billtext.xpd?bill=s110-1177

Clean Power Act of 2007. 2007. U.S. Senate. Retrieved June 19, 2008, from http://www.govtrack.us/congress/billtext.xpd?bill=s110-1201

Combining Climate Change and Air Quality Research. 2005. 2006 TEXAQS/GoMACCS Science and Implementation Plan.

Fact Sheet: Clean Air Interstate Rule. Environmental Protection Agency. Retrieved June 19, 2008, from http://www.epa.gov/cair/pdfs/cair_final_fact.pdf

Ford, B., Morris, G.A., Thompson, E., Rappenglueck, B., Lefer, B., Byun, D., et al. The Impact of Residual Layer Ozone on Surface Ozone Levels in Houston, Texas During TexAQS II.

Forecast for Houston: Air Quality Improving. 2008. *Texas Commission on Environmental Quality.* Retrieved June 19, 2008, from http://www.tceq.state.tx.us/comm_exec/ forms_pubs/pubs/pd/020/08-02/forecastforhouston.html

Gupta, P. & Christopher, S.A. 2008. Seven year particulate matter air quality assessment from surface and satellite measurements. *Atmospheric Chemistry and Physics Discussions, 8* (327-365).

Hair, J.W., Hostetler, C.A., Ferrare, R.A., Cook, A.L., & Harper, D.B. The NASA Langley Airborne High Spectral Resolution Lidar for Measurements of Aerosols and Clouds. NASA Langley Research Center.

Heinrich, J. Respiratory Health and Individuals Estimated Exposure to Traffic-Related Air Pollutants in a Cohort of Young Children. 2007. Occupational and Environmental Medicine. Retrieved July 22, 2008 from http://oem.bmj.com/cgi/content/full/64/1/8

Jin, M., Shepherd, J.M. & King, M.D. 2005. Urban aerosols and their variations with clouds and rainfall: A case study for New York and Houston. *Journal of Geophysical Research, 110.*

Kleinman, L. 2006. Atmospheric Science Program Participation in TEXAQS II. Atmospheric Science Program. Retrieved June 19, 2008, from http://www.asp.bnl.gov/Houston.html

Perna, R., Rappenglueck, B., & Zhong, S. An Insight into the Vertical Structure of the Atmosphere During TexAQS-II: Understanding the Effect of the Upper-Level Meteorology on Houston's Surface Ozone Levels.

PM 2.5 Objectives and History. 2008. Region 4: Laboratory and Field Operations – PM 2.5. Retrieved July 22, 2008, from http://www.epa.gov/region4/sesd/pm25/p2.htm#8

Prados, A.I., Kondragunta, S., Ciren, P., Hoff, R., & McCann K. GOES-R Aerosol Products and Applications. Retrieved June 19, 2008, from http://rammb.cira.colostate.edu/corp/Symposium/PostSymposium/presentations/2%20Aerosol%20Applications%20-%20Ana%20Prados_CIRA%20CoRP%20Symposium%20FY06.ppt.

Sarnat, J.A., Schwartz, J., Suh, H.H., Samet, J.M., Dominici, F., & Zeger, S.L. 2001. Fine Particulate Air Pollution and Mortality in 20 U.S. Cities. *New England Journal of Medicine, 344.* Retrieved June 19, 2008, from http://content.nejm.org/cgi/content/short/344/16/1253

Search the Air Emission Even Report Database. 2008. Texas Natural Resource Conservation Commission. Retrieved June 19, 2008, from http://www2.tceq.state.tx.us/eer/main/index.cfm?fuseaction=searchForm

Sexton, K., Linder, S. H., Marko, D., Bethel, H., & Lupo P.J. 2007. Comparative Assessment of Air Pollution: Related Health Risks in Houston. *Environmental Health Perspectives, 115*(10). Retrieved June 19, 2008, from http://www.pubmedcentral.nih.gov/articlerender.fcgi?tool=pubmed&pubmedid=17938725

Sullivant, R. 2007. Satellites Track Human Exposure to Fine Particle Pollution. Retrieved June 19, 2008, from http://www.jpl.nasa.gov/news/news.cfm?release=2008-122a

Texas Air Quality Study 2000. 2000. Retrieved June 23, 2008, from http://www.utexas.edu/research/ceer/texaqs/