Proposal submitted to Dr. (Insert advisor name here) for ESS 499 CAPSTONE PROJECT

Particulate Matter Air Quality Assessment over Continental United States and Global Mega-Cities using Satellite and Ground Measurements

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Executive Summary

The major goal of this proposal is to build an integrated analysis system using satellite and ground-based aerosol datasets and model derived meteorological fields to estimate and monitor particulate matter air quality over several locations in the United States and mega cities of the world. This study will enable air quality assessment in remote areas where ground based pollution measurements are not available. We propose to develop air quality indices over large spatial scales that are not available currently because ground based information cannot provide adequate coverage. This proposal will utilize NASA's new space based sensors such as MODIS, MISR, and CALIPSO (see acronym descriptions in Appendix A) that have tremendous potential to support federal and state agencies involved in monitoring and forecasting of air quality. This study will also explore the use of GEOS-CHEM model derived vertical information to build the air quality system. Satellite remote sensing of surface level pollution is an innovative and a promising area of research, which has immediate practical applications and possible long-term benefits.

1. Statement of the problem

Urban air quality has gained critical public health concern in many parts of the globe as urbanization and industrialization have amplified many folds during the last few decades. Almost, half of the world's population now lives in the urban areas and their number will increase to four billion by the end of this decade. Particulate matter (PM) (or aerosols) and ozone are the two major pollutants affecting the air quality in urban areas of the United States (US) and throughout the world. Particulate matter is a complex mixture of solid and liquid particles that vary in size and composition and remain suspended in the air. Many chemical, physical, and biological components of atmospheric aerosols are identified as being potentially harmful to respiratory and cardiopulmonary human health effects. Aerosols have many sources from both natural and anthropogenic activities, naturally occurring processes such wind blown dust and episodic activities such as forest fires/agricultural burning (mostly anthropogenic), dust storms and volcanic eruptions. Increasing human activities also contribute to combustion from automobiles, industries and emission from power plants. Apart from direct emissions, PM is also produced by other processes such as gas to particle conversion in the atmosphere.

1.1 Aerosols and Human Health

Atmospheric aerosols are one of the most important components of the earth-atmosphere system and play important role in climate and weather related processes [*Kaufman et al.,* 2002 *and Ramanathan et al.,* 2001]. Air pollution has both short-term and long-term effects. Short term impacts include, respiratory infections, irritation to the eyes, nose and throat, headaches, nausea, and allergic reactions. Short-term air pollution can intensify the medical conditions of individuals with asthma and emphysema. In 1952 London experienced one of the worst smog disasters, which killed more than four thousand people in few days due to very high concentration of particulate matter in the air [*Scarrow,* 1972]. Long-term effects include lung cancer, heart disease, chronic respiratory disease, and even damage to the brain, nerves, liver, or kidneys. Continual contact to air pollution affects the lungs of growing children and may worsen or complicate medical conditions in the elderly.

Particulate matter with aerodynamic diameters less than 2.5 µm ($PM_{2.5}$) can cause respiratory and lung disease and even premature death [*Krewski et al.,* 2000]. The World Health Organization (WHO) estimates that 4.6 million people die each year from causes directly attributable to air pollution. Worldwide more deaths per year are linked to air pollution than to automobile accidents. Some examples from all around the world: approximately 310,000 Europeans die from air pollution annually [*van Leeuwen van,* 2002], The Tata Energy Research Institute (TERI) in India estimated 18,600 premature deaths per year associated with poor air quality in the Delhi region [*TERI, 2001*], increased PM was associated with 2400 deaths per year in Australia with an associated health cost of $17.2 billion [*Morgan et al.,* 1998*, Simpson et al.,* 2000] and Sydney experiences around 400 premature mortalities each year due to increased levels of pollution, and asthma is also common in this area [*Barusch, 1997*]. Similar mortality deaths are associated with air pollution in other parts of the world. Direct causes of air pollution related deaths include aggravated asthma, bronchitis, emphysema, lung and heart diseases, and respiratory allergies. A medical study by [*Pope III et al., 2002*] concludes that fine particles and sulfur oxide related pollution are associated with all-cause, lung cancer and cardiopulmonary mortality. The same study also states that an increase of 10 μgm^{-3} in fine particulate can cause approximately a 4%, 6% and 8% increased risk of all cause, cardiopulmonary, and lung cancer mortality, respectively. Using statistical data collected in twenty big cities, *Samet et al.* [2000] showed that the daily mortality within a metropolitan area is associated with concurrent or lagged daily fluctuations in ambient PM concentrations. Apart from impact on human health, poor air quality also affects the health of animals and plants. Poor air quality conditions are also associated with damaging buildings and monuments around the world. Indirectly air pollution significantly affects the economy by increasing medical expenditures and expenditure for preserving the surrounding environment.

1.2 Monitoring Particulate Matter Pollution

The US Environment Protection Agency (EPA) monitors air quality by measuring PM and ozone concentration at thousands of ground based monitoring stations across the country. The $PM_{2.5}$ is measured using a Tapered-Element Oscillating Microbalance (TEOM) instrument with an accuracy of ±1.5 μgm^{-3} for hourly averages. TEOM first collects the particles (<2.5 µm in diameter) on Teflon coated glass fiber filter surface by passing them through a cyclone inlet, which removes the bigger size particles from the sample of air. The inlet is heated to 50°C prior to particles being deposited onto the filter in order to eliminate the effect of condensation or evaporation of particle water. The filter is attached to a vibrating hollow tapered glass tube. In the mass transducer unit, as the filter progressively load $PM_{2.5}$ particles, oscillation frequency of glass tube changes proportionally. The change in frequency of oscillation is directly related to the mass of particles on element (filter), which can be measure using computer controlled unit and hence the mass of $PM_{2.5}$ is obtained in the unit of μgm^{-3} [*Charron et al., 2004*].

The United States Environmental Agency (EPA) issues National Ambient Air Quality Standards (NAAQS) for six criteria pollutants namely ozone, particulate matter, carbon monoxide, sulfur dioxide, lead and nitrogen oxides. Standards for particulate matter were first issued in 1971 then revised in 1987 and 1997 by EPA. Recently (September 2006), EPA revised 1997 standards to tighten the criteria. The 2006 standards reduced the 24-hour mean $PM_{2.5}$ mass concentration standard from 65 μgm^{-3} to 35 μgm^{-3}, and retained the current annual $PM_{2.5}$ standard at 15 μgm^{-3} (http://www.epa.gov/pm/naaqsrev2006.html). The EPA reports an Air Quality Index (AQI) based on the ratio between 24-hour averages of the measured dry particulate mass and NAAQS, and it can range from nearly zero in a very clean atmosphere to 500 in very hazy condition. Table 1 gives details on $PM_{2.5}$ mass, air quality categories and possible health effects. Currently USEPA provides particulate matter air quality forecast over more than 200 cities on daily basis. In recent years, other countries in Europe, Australia, Japan, and China have also started monitoring $PM_{2.5}$ mass as measure of air quality conditions. However these EPA and other agencies monitoring stations are only point locations and do not have the spatial resolution to map the regional to global distributions of aerosols.

Satellite data have tremendous potential for mapping the global distribution of aerosols and their properties [*Chu et al., 2002*]. However, several outstanding issues remain in using satellite data because most satellite data provide column information whereas air pollution near the ground is the most important parameter affecting human health. Several studies have demonstrated the potential of monitoring air quality using high resolution data from space based sensors over regional to global scales. The next section provides summary and key conclusions from these studies.

2. Previous Work

Satellite remote sensing of particulate matter (PM) air quality is a relatively new area of research in the field of atmospheric science. As presented in Table 2, many research studies have shown the potential of using satellite derived aerosol optical thickness information as surrogate for air quality conditions. Table 2 presents relevant published research in this field. The two main conclusions from Table 2 are very clear; 1) Most of studies have used MODIS derived AOT products except a few studies by *Liu et al.* [2004, 2005, 2007], and *van Donkelaar et al,* [2006], which used AOTs from both MISR and MODIS. 2) Area of study for most of the studies have been in some part of United States except studies by *Gupta et al., 2006, Koelemeijer et al.* [2006] and *van Donkelaar et al.* [2006]. One of the reasons is that MODIS gives much better spatial and temporal coverage as compared to MISR and measurements of $PM_{2.5}$ mass concentration in other parts of the world are limited. The first study by *Wang and Christopher* [2003] used $PM_{2.5}$ mass and MODIS AOT data over seven stations in Alabama and presented very good correlation (>0.7) between these two parameters. This study also concluded that although deriving exact $PM_{2.5}$ mass from satellites could have larger error; satellites can provide daily air quality condition as calculated by EPA with sufficient accuracies. It also shows the potential of satellite monitoring of transport of air pollution from source to near and far urban areas. *Hutchison et al.* [2004, 2005], mainly focus on air quality over Texas and Eastern United States and use of satellite imaginary in detecting and tracing the pollution. The first comprehensive study by *Engel-Cox, et al.* [2004] presented a thorough correlation analysis between MODIS AOT and $PM_{2.5}$ mass over entire United States. The correlation pattern shows high values in Eastern and Midwest portion of the United States whereas correlations are low in Western United States. The authors also states that '*This variability is likely due to a combination of the differences between ground-based and column average datasets, regression artifacts, variability of terrain, and MODIS cloud mask and aerosol optical depth algorithms.'* This study also concludes that high space and time resolved observations from satellites can provide synoptic information, visualization of the pollution, and validation of ground based air quality data and estimations from models. *Engel-Cox* and other co-authors also published other studies in 2004, 2005 and 2006 which further emphasizes the use of satellite derived aerosol products in day to day air quality monitoring and even in policy related decision making. One of these papers [*Engel-Cox, et al., 2006*] also presented the application of LIDAR derived vertical aerosol profiles to improve $PM_{2.5}$ -AOT relationship. MODIS aerosols and clouds data are now being used in the IDEA (Infusing satellite Data into Environmental Applications) program to monitor air quality over United States. IDEA is a joint effort from NASA, NOAA and EPA to improve air quality assessment, management, and prediction by infusing satellite measurements into analysis for public benefit [*Al-Saadi et al., 2005*]. MISR derived aerosol products were first used by *Liu et al.* [*2004*], which shows similar potential for air quality applications. This study also used GOCART and GEOS-CHEM models derived meteorological fields to examine their relative effects on $PM_{2.5}$ -AOT relationships. *Liu et al.* [*2007*] also compared MISR and MODIS over few sites around St. Louis area, which shows better performance of MISR than MODIS for air quality application. *Gupta et al.* [*2006*] compared $PM_{2.5}$ -AOT relationship in different parts of the world such as Europe, Australia, USA, and Asia. This study shows applications of satellite derived air quality products at global scales and in the regions where surface $PM_{2.5}$ measurements are not available. Correlations analysis varies in different parts of the world depending on accuracies of MODIS retrieval, cloud contamination in AOT and height of aerosol layer in the atmosphere. Results from this study are presented in preliminary result section. van *Donkelaar et al,* [2006] used GEOS-CHEM derived vertical extinction profiles and basic mass formula to calculate mass of fine particles and compared the results over several locations in USA and Canada. This study also presented global picture of MODIS and MISR derived $PM_{2.5}$ mass concentration and results looks more promising.

All these studies mainly concluded that the MODIS and MISR AOTs are important to define air quality over large spatial domains and to track and monitor aerosol sources and transport. These studies are based on correlation and linear and multi-variant regression between MODIS AOT, ground based $PM_{2.5}$ mass and model derived meteorological parameters. The MODIS derived AOT which is measure of column aerosol loading cannot be used alone to derive $PM_{2.5}$ mass concentration, which is an indicator of the mass of the dry $PM_{2.5}$ near the surface [*Wang and Christopher, 2003*]. Meteorological factors such as surface temperature (T_s), relative humidity (rh), wind speed (WS) and direction (WD), variations in sunlight due to clouds and seasons are important parameters which affect the relationship between the two parameters. Changes in these processes, which affects the variability in pollution, is primarily governed by the movement of large-scale high and low-pressure systems, the diurnal heating and cooling cycle, and local and regional topography. The vertical profile of aerosol mass extinction ($\square_{ext}$), which determines effective scale height (H_{eff}) and hygroscopic growth factor (a function of rh) are also very important parameters that must be accounted for while deriving relationships between $PM_{2.5}$ and AOT [*Wang & Christopher, 2003, Gupta et al., 2006)*. Strong winds of 6 ms^{-1} or more can cause dust to become airborne and many factors influence the amount of $PM_{2.5}$ produced by windblown dust including vegetation cover, soil moisture, soil particle size distribution, surface roughness, and changes in wind direction (*Saxton et al., 2000*). Easterly trade winds can transport Saharan dust to the eastern and southeastern US [*Prospero, 1999*] and can increase $PM_{2.5}$ concentrations at the surface and degrade visibility. Also the western US can be affected by dust transported from Asia [*Falke et al., 2001*]. Air quality modeling actually requires a system of models and observations including satellite and ground-based data that work together to simulate the emission, transport, diffusion, transformation, and removal of air pollution and these models include meteorological models, emission models and air quality models.

4. Data and Methods

This section will list and describe different data sets and the methods, which will be used for research.

4.1 MOD04 and MYD04

The Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA's Terra (morning satellite with equatorial over cross time is 10:30 AM) and Aqua (afternoon satellite with equatorial over cross time is 1:30 PM) satellites give systematic retrieval of cloud and aerosol properties over land [*King et al., 1999*]. MODIS provides the spectral information on aerosol optical properties in seven different wavelengths with good accuracy [*Kaufman et al., 1997, Remer et al., 2002 and 2005*]. Aerosol optical thickness (AOT) is an important aerosol parameter retrieved from satellite observations representing columnar loading of aerosols in the atmosphere along with the fraction of fine mode aerosol which is an indicator of anthropogenic pollution which correlates well with $PM_{2.5}$ mass. Several validation studies conducted over land reveal that 57% MODIS AOT retrievals are within expected uncertainty levels of ± 0.05 ± 0.15 AOT [*Remer et al., 2005*]. Preliminary results from validation exercise of MODIS collection 5 shows increase in the number from 57% to 67%. Depending on availability, MISR derived AOT will also be used to inter-compare the results from two different sensors. As an example Figure 1 presents the aerosol optical thickness observed by MODIS (Terra) and estimated air quality conditions during August 20-26, 2006 over EPA region 4.

4.2 $PM_{2.5}$ Mass Concentration

The United Stated Environment Protection Agency and its state partners maintain several air quality monitoring networks in the United States. The networks monitor the mass concentration and speciation (some of the sites) of gaseous and particulate air pollutants at the ground level. $PM_{2.5}$ data from these networks include 24-h average (daily) concentration data, typically taken every 3 days, and continuous (hourly) $PM_{2.5}$ concentration measurements. Most relevant for present study is $PM_{2.5}$ mass concentration measure in μgm^{-3}. This study will use both hourly and daily mean $PM_{2.5}$ mass data sets from several ground stations in different area of interest as shown in figure 4.

4.3 RUC20 Meteorological Fields

The Rapid Update Cycle (RUC) is an operational atmospheric prediction system comprised primarily of a numerical forecast model and an analysis system to initialize that model. The RUC has been developed to serve users needing short-range weather forecasts. RUC runs operationally at the National Centers for Environmental Prediction (NCEP). A new version of the RUC has been implemented at the NCEP with a improved horizontal resolution (20km), increased number of vertical computational levels (40 to 50), and improvements in the analysis and model physical parameterizations. A primary goal in development of the 20-km RUC (or RUC20) has been improvement in warm-season and cold-season quantitative precipitation forecasts. Improvements in near-surface forecasts and cloud forecasts have also been targeted. The RUC20 provides improved forecasts for these variables, as well as for wind, temperature, and moisture above the surface [*Benjamin et al., 2002*]. Hourly data of relative humidity, wind speed, wind direction, and height of planetary boundary layer (PBL) from RUC20 will be used in the proposed study.

4.4 Ancillary Data Sets

In order to build air quality model several supporting data sets will be required These include chemical speciation from IMPROVE network, GEOS-CHEM derived vertical aerosol layer heights and CALIPSO (for case studies in 2006-2007 time periods) derived vertical aerosol optical thickness profiles. To extend the study to other mega cities of the world, similar data sets for all other cities will be collected. For this study, all the cities, where human population is more than ten million are categorized as megacities. Air quality in such cities is mainly governed by anthropogenic activities due to large human population. 20 such megacities are already identified and relevant data sets for each city will be collected.

4.5 Proposed Methods

Initially, the proposed study will use data sets available during year 2005 over different months and seasons. This study will primarily focus on EPA region 4 but other areas as shown in figure 4(a) will also be explored depending on availability of different data sets and time line of the current project. These study areas are selected due to complexity of aerosols (e.g. dust from Saharan, smoke from Central America, anthropogenic urban pollution, emissions from power plants and the ease of data access. Also, it will be important to monitor the accuracies of satellite derived products in different part of the study area. Mega cities (population greater than 4 million) analysis will be done for three year time period starting January 2003 to December 2005.

First we will obtain all data sets and apply quality control processes to all the data sets. For example, MODIS AOT in valid ranges with 'Good' quality flag will be used for only clear sky conditions using reported cloud cover percentages. Different statistical parameters such as mean, median, and standard deviation will also be calculated and by applying different conditions on these values for each data set, qualified data sets will be selected. Using appropriate weighting functions, the MODIS AOT will be collocated in space and time with ground based $PM_{2.5}$ measurements [*Gupta et al., 2006*]. All the $PM_{2.5}$ mass measurements and other meteorological parameters will be averaged within one hour of MODIS observation time. Since RUC derived meteorological fields are available in 20 km horizontal resolution hence a box of 20X20 km centered at air quality stations will be used to average AOT, and meteorological fields. To test the sensitivity of vertical profiles of aerosols, GEOS-CHEM derived coarse resolution monthly means data will be used. Depending on availability, LIDAR profiles as well as observations from CALIPSO will be used. Once quality controlled data sets of hourly averaged $PM_{2.5}$ mass (μgm^{-3}), MODIS AOT (0.55 μm), meteorological parameters such as wind speed, wind direction, relative humidity, and height of planetary boundary layer are ready, the training of ANN system will start.

Several case studies with extreme pollution events such as dust storm and forest fires will be first identified (e.g. the transport of aerosols from biomass burning fires in Central America to South Eastern United States) for analysis. Variability and accuracy of the output $PM_{2.5}$ mass will be tested for different seasons at different geographical locations. The sensitivity studies will be performed to study the role of each input parameter in the model. The model will also be tested against extreme values of input parameters such as very high wind speed, rainy conditions, and extreme low temperatures. Errors will be reported as root mean square values during validation exercise between measured and estimated $PM_{2.5}$ mass concentration. In order to minimize these errors, different exercises will be carried out on the input data sets. This may includes putting constraints on AOT, $PM_{2.5}$ and meteorological fields.

8. Relevance and Outcomes

The major goal of this proposal is to build an integrated analysis system using satellite and ground-based datasets and meteorological data to monitor and predict particulate matter air quality over the several locations in the United States and mega cities of the world. Satellite remote sensing of surface level pollution is an innovative and promising area of research, which has immediate practical applications and long-term benefits. The expected results from this research will enhance our scientific understanding on satellite remote sensing of particulate matter and can be utilized toward operational monitoring of particulate matter air quality over remote areas where point observations are not available.

9. References

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Table 1: Air quality category and corresponding 24 hourly mean $PM_{2.5}$ mass (μgm^{-3})

Air Quality Category	**Description**	**24 Hour Mean $PM_{2.5}$ mass (μgm^{-3})**
Good	None	0 ~ 15.4
Moderate	Unusually sensitive people should consider reducing prolonged or heavy exertion	15.5 ~ 40.4
Unhealthy for Sensitive Groups	People with heart or lung disease, older adults, and children should reduce prolonged or heavy exertion	40.5 ~ 65.4
Unhealthy	People with heart or lung disease, older adults, and children should avoid prolonged or heavy exertion. Everyone else should reduce prolonged or heavy exertion	65.5 ~ 150.4
Very Unhealthy	People with heart or lung disease, older adults, and children should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion	150.5 ~ 250.4

Table 2: Literature survey on satellite remote sensing of particulate matter air quality

SN	Reference	Data & Study Area	Key conclusions/Remarks
1	*Wang and Christopher, 2003*	MODIS, 7 stations, Alabama	Quantitative Analysis with space and time collocated hourly $PM_{2.5}$ and MODIS AOT. (R=0.7). Demonstrated the potential of satellite data into air quality monitoring.
2	*Chu et al., 2003*	AERONET, MODIS, PM10, 1 station	Show relationship between PM10 and AOT. More qualitative discussion on satellite capabilities to detect and monitor aerosols globally.
3	*Hutchison, 2003*	MODIS AOT MAPS, MODIS Imagery, GEOS Imagery , $PM_{2.5}$, Texas	Show potential of MODIS data in monitoring continental haze over land surface. No correlation analysis
4	*Engel-Cox et al., 2004*	MODIS, $PM_{2.5}$ Continental United States	First study, which present correlation analysis over entire USA and discuss difference in relationship over different regions. Qualitative and qualitative analysis over larger area, demonstrated spatial distribution of correlation.
5	*Hutchison et al., 2004*	MODIS AOT maps, Ozone, Eastern USA	Used few MODIS AOT maps and discussed the hazy conditions, no correlation analysis, more emphasis on ozone pollution. No correlation analysis
6	*Liu et al., 2004*	MISR, GEOS-CHEM GOCART, USA	First used MISR data for air quality study (R=0.78). More emphasis on seasonal and annual mean correlation analysis and forecasting
7	*Engel-Cox et al., 2004*	MODIS	Recommendations to use satellite data into air quality applications. These data sets can add synoptic and geospatial information to ground-based air quality data and modeling.
8	*Liu et al., 2005*	MISR , GEOS-3 Meteorology, USA	Regression Model Development and Forecasting of $PM_{2.5}$, Model generated coarse resolution meteorological fields are used and focused only in Eastern United States. 48% explanation of $PM_{2.5}$ variations.
9	*Al-Saadi, J., et al., 2005*	MODIS, USA	More descriptive paper on IDEA program, which provides online air quality conditions from MODIS and surface measurements over several locations in the USA
10	*Hutchison et al., 2005*	MODIS, Texas	Correlation analysis in Texas. Correlation varies from 0.4 to 0.5 and long time averaging can make correlation greater than 0.9
11	*Engel-Cox et al., 2005*	MODIS, USA	Potential of satellite data for monitoring transport of $PM_{2.5}$ over state boundaries and event specific analysis.
12	*Gupta et al., 2006*	MODIS, Meteorology,	Correlation varies from 0.37 to 0.85 over different part of the world. Cloud fraction, relative humidity and

		Global 21 locations	mixing height information can improve relationship significantly. First study covered several global locations.
13	*Engel-Cox et al., 2006*	MODIS, LIDAR, USA	Weak correlation can be significantly improved by using vertical aerosol information from LIDAR measurements.
14	*Donkelaar et al., 2006*	MODIS, MISR, $PM_{2.5}$, GEOS-CHEM, USA and Global	Inter-comparison between MODIS and MISR over several locations in Canada and USA. R= 0.69 (MODIS) and R= 0.58 (MISR). Different approached used to calculate the fine mass concentration.
15	*Koelemeijer et al., 2006*	MODIS, $PM_{2.5}$ and PM_{10}, Europe	Mainly focused on Europe. Correlation varies from 0.5 for PM_{10} to 0.6 for $PM_{2.5}$. Use of boundary layer height in analysis improved the relationship. MODIS has potential to use for air quality monitoring.
16	*Liu et al., 2006*	MODIS, MISR, RUC	Inter-comparison between MODIS and MISR in St. Louis area. MISR performed slightly better than MODIS in the region.

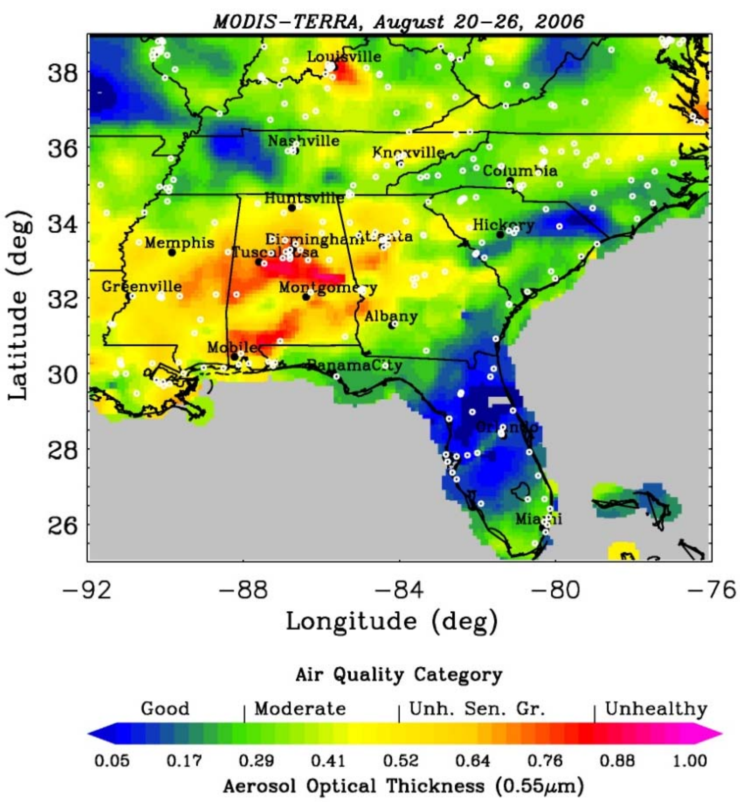

Figure 1: Aerosol optical thickness and color coded air quality based on regression relationship between MODIS AOT and $PM_{2.5}$ mass over EPA region 4 during August 20-26, 2006.

Appendix A

List of acronyms used throughout the proposal

1	**AERONET**	Aerosol Robotic Network
2	**ANN**	Artificial Neural Network
3	**AOT**	Aerosol Optical Thickness
4	**AQI**	Air Quality Index
5	**CALIPSO**	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
6	**EPA**	Environment Protection Agency
7	**GOCART**	Goddard Chemistry Aerosol Radiation and Transport
8	**GEOS-CHEM**	Goddard Earth Observing System-Atmospheric Chemistry Model
9	**IMPROVE**	Interagency Monitoring of Protected Visual Environments
10	**IDEA**	Infusing satellite Data into Environmental Applications
11	**LIDAR**	Light Detection and Ranging
12	**MISR**	Multi-angle Imaging SpectroRadiometer
13	**MODIS**	Moderate Resolution Imaging Spectroradiometer
14	**NAAQS**	National Ambient Air Quality Standards
15	**NAC**	National Academy of Science
16	**NASA**	National Aeronautics and Space Administration
17	**NCEP**	National Center for Environment Prediction
18	**PBL**	Planetary Boundary Layer
19	**PM**	Particulate Matter
20	**PM10**	Particulate Matter less than 10 micro meter in size
21	$PM_{2.5}$	Particulate Matter less than 2.5 micro meter in size
22	**RUC**	Rapid Update Cycle
23	**TEOM**	Tapered-Element Oscillating Microbalance
24	**TERI**	Tata Energy Research Institute
25	**UNEP**	United Nations Environment Protection
26	**US**	United States
27	**WHO**	World Health Organization