Comparative Study on Satellite Base Air Monitoring System

Norsyuhaimy Abdul Shukor
Faculty of Electrical Engineering
Universiti Teknologi MARA
40450 Shah Alam

Abstract **- The air quality indicator approximated by satellite measurements is known as atmospheric particulate loading, which is evaluated in terms of columnar optical thickness of aerosol scattering. The effect brought by particulate pollution has gained interest after recent evidence on health effects of small particles. This study uses an empirical model, based on actual air quality of particulate matters of size less than 10 micron (PM10) measurements from to predict PM10 based on optical properties of satellite digital imagery. The digital image was separated into three bands assigned as red, green and blue for multispectral algorithm regression. The digital numbers were extracted corresponding to the ground-truth locations for each band and then converted to radiance and reflectance values. The digital numbers of the three bands were converted into irradiance and then reflectance. The atmospheric reflectance value was extracted from the satellite observation reflectance values subtracted by the amount given by the surface reflectance. The atmospheric reflectance values were later used for PM10 mapping using the calibrated algorithm. The PM10 map was color-coded and geometrically corrected for visual interpretation. This study indicates that PM10 mapping can be carried out using remote sensing technique.**

KEYWORDS: Air Quality, PM10

I. INTRODUCTION

Air is essential for all life. All organic material depends on its existence; without it nothing breathes or lives. For these reasons, the monitoring of air quality should be one of our top priorities. Recognizing that air quality has such a great impact on quality of life, the European Union has placed air quality at the top of its thirteen quality of life indicators list. Air monitoring is a greater importance to urban populations, because urban areas have been a source of major pollutants in the past and they support a vast number of people in concentrated areas. Air quality monitoring has typically been done using ground based instrumentation, which has severely restricted the area of land that can be monitored. The ground instruments are designed to monitor specific pollutants (e.g., carbon dioxide) and many of these instruments cannot provide an accurate description of the total concentration of all pollutants at a citywide level. For these two reasons, remote sensing satellites have been used to assist in air quality monitoring of urban areas. Remote sensing satellites have many advantages of monitoring air quality on a citywide scale. Satellite observations can provide a complete survey of the city; show the major sources of pollution and the distribution pattern; assist in determining where the effort should be focused to decrease the level of pollution; and determine any relationship between the city features and the air pollution distribution.

II. METHODOLOGY

For this study, there are several methods that done by USA, Hong Kong, Canada and Italy. Methods that regularly used by these 4 countries are:

i. Image Pre-Processing
ii. Estimation of Surface Reflectance
iii. Data Pre-Processing
iv. Remote Sensing

A. Image Pre- Processing

This method used for the rectification of satellite imagery and the enhancement and normalization of digital number values in all bands to permit inter-scene comparisons. Minimal pre-processing is necessary when conducting a one-time analysis of satellite imagery for land cover within a particular area.

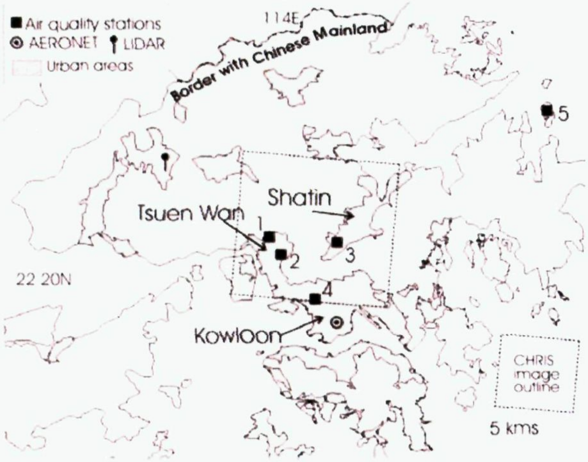


Fig. 1. Example of Image Pre Processing

Urban areas in Hong Kong in relation to the area covered by the CHRIS image on 27-Sep-2006, and locations of AERONET, Lidar, and four urban air quality stations: 1.Tsuen Wan, 2. Kwai Chung, 3. Sham Shui Po, 4. Shatin, and 5. Tap Mun (rural station).

B. *Estimation of Surface Reflectance*

Surface reflectance ratios between visible and infrared bands are determined for land areas by satellite image and from the ground-measured aerosol optical thickness (AOT). For validation, the resulting ratios are used to retrieve the AOT from the satellite image, leading to satisfactory agreement between the satellite-retrieved and ground-measured aerosol optical thickness values.

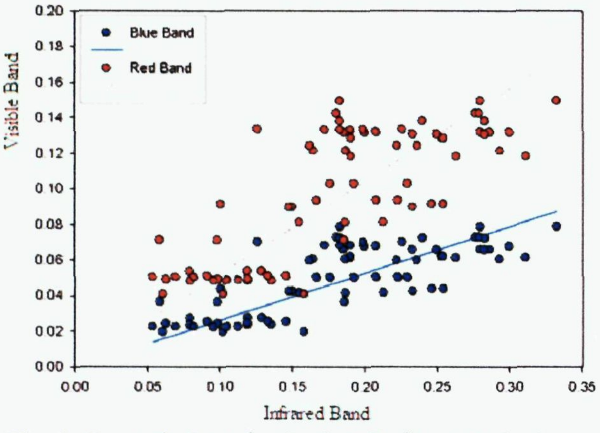


Fig. 2. Example Data for Surface Reflectance in Area Tsuen Wan

C. *Data Pre-Processing*

Satellite data base that been captured by satellite stored in DN (digital number). To prepare these datasets for data processing, the raw data were converted to reflectance and brightness temperature respectively. Image processing was carried out using digital image processing system at the Centre for Remote Sensing It was assumed that the API measurements of each station represented area coverage. A computer program was adopted to discriminate clouds from haze and to produce haze-intensity maps of the individual components the API measurements.

D. *Remote Sensing*

There are currently four major satellite remote sensing techniques used to determine air quality in resident areas and Industrial area. The methods are:

1. Measuring The Aerosol Thickness In The Atmosphere
2. Black Particle Measurement
3. Visual Inspection Of Satellite Imagery
4. Use/Land-Cover Change Analysis.

This paper will focus on the first technique, but will comment briefly on the other techniques.

1. *Aerosol Thickness Measurement*

A basic understanding of how aerosol thickness can be measured is required before any case studies can be reviewed. Aerosol thickness is an indicator of the overall pollution of an area. There have been many methods used over the past 30 years to monitor aerosol thickness, the major four of which are (1) ocean method, (2) brightness method, (3) contrast-reduction method, and (4) dark vegetation method [1].

When a remote sensing satellite distributes a signal towards the earth, the signal will come into contact with the atmosphere and will become modified by the interaction between the radiation and the atmospheric components. The sensor on the satellite will then record the modified signal, and will determine both the geometric and radiometric change in the signal.

The change in the signal is due to the particle absorption and the elastic scattering. By adding the scattering and absorption components, and integrating these components along the path between the earth's surface and the satellites altitude, the particulate optical thickness can be calculated.

Additional corrections may be made to the particulate optical thickness. These corrections consist of solar elevation, solar irradiance, and observations angle variations. Since the satellite observations could be mismatch due to the variation of seasons, another algorithm is often used to screen the results for different variations of chlorophyll activity. The particulate optical thickness can be used in monitoring pollution, because the presence of particles in the atmosphere always causes a reduction in the optical thickness [1].
A major factor that must be predetermined when monitoring air quality using remote sensing satellites is the wavelengths of the signals that will be emitted. By determining the correct wavelength, the absorption and scattering will occur, and the pollution can be monitored. When using Landsat TM data, the correct interval on the wavelength spectrum is the thermal infrared. The UV spectral is practically unclear due to scattering and absorption which the near-infrared is too transparent, the visible domain is useful for manual evaluation but not for scattering or absorption, and the mid-infrared is used to distinguish hot pollution sources, such as fires. Other satellites such as SPOT will use other wavelengths to determine the aerosol thickness. SPOT uses the visible bands to determine the absorption and scattering, which leads to particulate optical thickness [2].

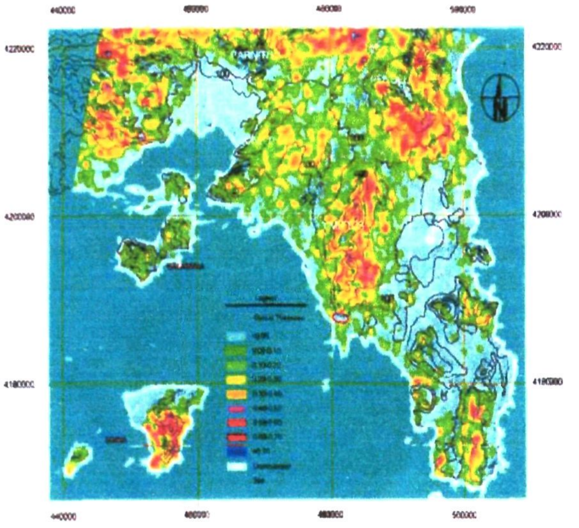


Fig. 3. Aerosol Thickness in the Greater Athens Area, Greece on April 26, 1994

2. Black Particle Measurement

Another technique used to detect pollution in the atmosphere is black particle measurement. Black particles have a very high negative correlation (-0.97) with the temperature of the atmosphere. One theory regarding pollution is that the more pollution buildup in the atmosphere, the more interception the pollution particles have with the sun light, and the atmosphere will have a lower temperature. It should be kept in mind that this is just a theory, and there are no experimental results to back it up. The reduction in temperature is usually in the 0.5EC range, which is very hard to detect. Also, since the temperature fluctuates a great deal on a daily basis, deriving the pollution quantity from mapping the temperature would not provide accurate results. If the black particle content was mapped, however, the temperature of the atmosphere could be derived, which would be a better indicator of the pollution particle content.

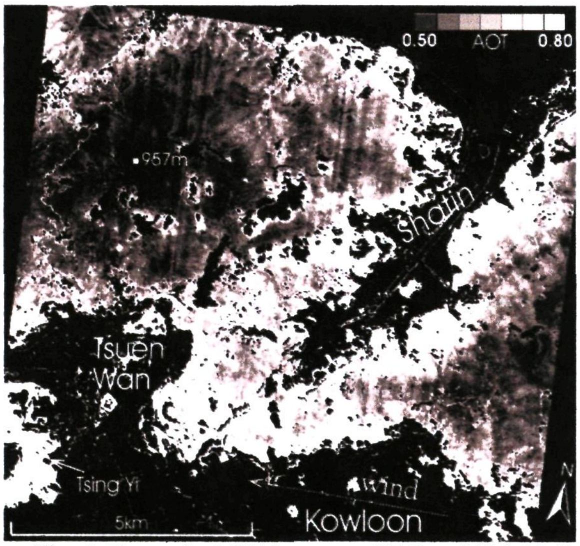


Fig. 4. Example AOT image on 27-Sep-2006. Null values (black) are given for non-DDV areas.

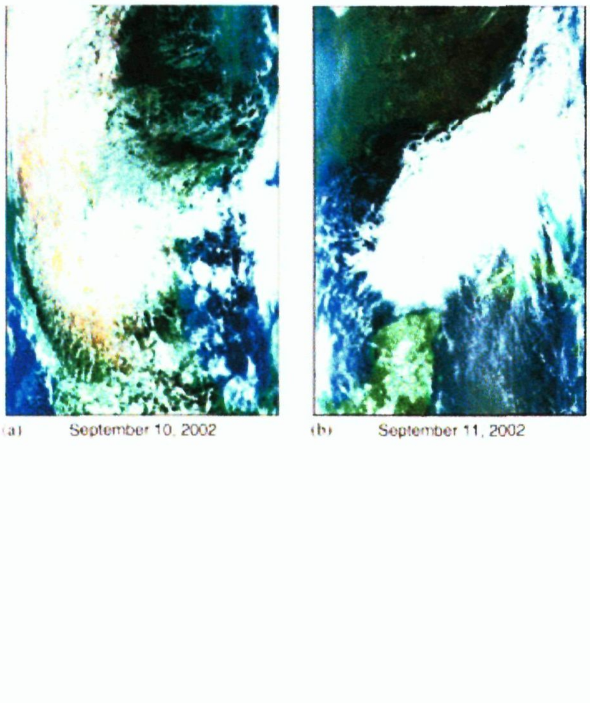
3. Visual Inspection

The third technique used to determine the quantity of air pollution is visual inspection. The existing system in Austin and Houston was two GOES satellites and 200 ground monitoring stations. This system lacked the ability to retrieve information about aerosol products. The TCEQ was looking to improve its monitoring in three pollution divisions: haze, sand particles, and smoke from seasonal fires. The TCEQ also identified three success criteria upon which the use of MODIS would be 850 Environmental Informatics Archives, Volume 2 (2004), based. The first criterion was that MODIS would make manual detection of pollution easier. MODIS would also provide better insight to the severity of the pollution, and would also improve monitoring areas that could not be monitored before because of the limited coverage of ground stations.

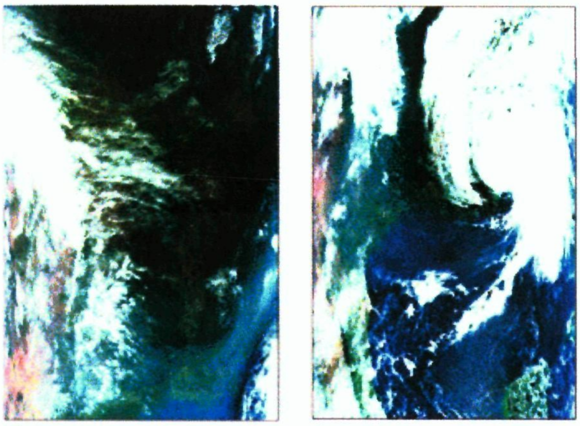
The study was carried out September 11-15, 2002. Observations were collected at five-minute intervals and were then used to evaluate a one-hour average. The TCEQ regulates that the level of pollution harmful to the residents of Austin and Houston is 0.12 ppm over a one-hour interval, or 0.08 ppm over an eight-hour interval. The observations gathered by MODIS were used to establish if any of those two tolerances had been broken. The imagery collected by MODIS should be oriented, so that it is convenient for manual processing. This can be done using GOES data.

4. Land-Use / Land-Cover Change

The last technique for detecting air pollution that will be discussed is land-use/land-cover change method. The University of Athens conducted a study using this technology on the Greater Athens Area, Greece. Two Landsat TM images with the band (0.45 – 0.52 μm) were compared. When using this technology, it is important that the two images are limited to a short time interval, so that the only change in the imagery is the pollution content. It is also important to capture these images at low observation angles to reduce the effect of electromagnetic radiation. Each image was registered according to collected ground control points and each image was also converted into sub-regions of 15 x 15 pixels, and a digital number was assigned. By comparing the two images, a third image was created showing the difference in pollution content between the two days. This technique is useful if one of the images is relatively pollution free, and can be used as a reference, but that scenario does not always exist.



(a) September 10, 2002 (b) September 11, 2002



(c) September 12, 2002 (d) September 14, 2002

Fig. 5. shows the results for the study of Athens (retails et al., 1999).

III. RESULTS AND DISCUSSION

This study suggests that remote sensing techniques can monitor, observing, determine air quality and more important to shows the phenomenon of air pollution. The industrial area and resident areas are the major places to be mark. By strong relationship that can we take from the 4 methods that include in remote sensing, this project is reasonable and can be trusted. The measurements of the criteria pollutants which include the geography can be monitor and calculate.

Based on the algorithm discussed in methodology part, the program was particularly run for one of the place in Penang Island with longitude 100° 15' E and latitude 5° 24' N referring to what have been done by previous work of H. S. Lim et. all. (2006). The time of measuring is at 1:22pm on 9th March 2006. While the set of value of both aerosol and molecule thickness also given by H. S. Lim et. all. At this point, the color reported by remote sensor is blue (Fig. 6).

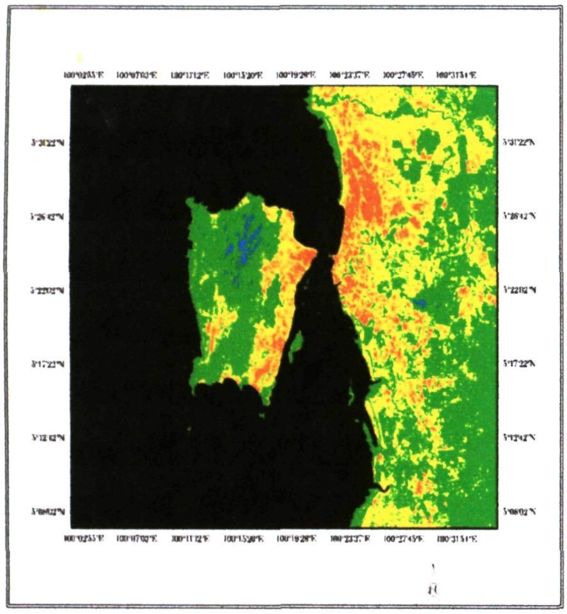
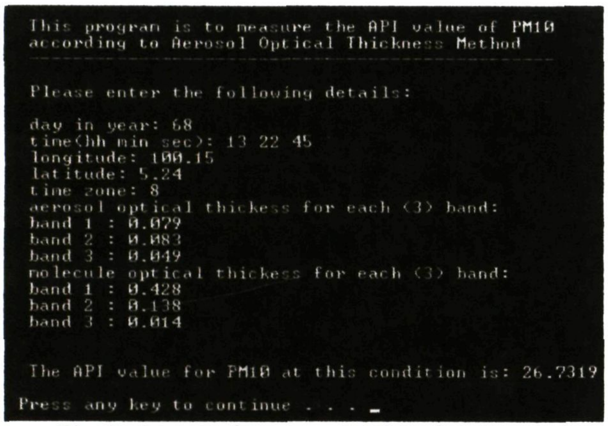


Fig. 6. Map of PM10 around Penang Island, Malaysia [Blue < 40 µg/m3, Green = (40-80) µg/m3, Yellow = (80-120) µg/m3, Orange = (120-160) µg/m3, Red = (>160) µg/m3) and Black = Land]

By using C++ programming language, Fig. 7 shows the output of the program. As what is displayed, the calculated value of API is 26.7319 µg/m3. The result is exactly within the range of blue color (i.e. less than 40 µg/m3). Hence, the program is considered to be successfully implemented to find the API value of PM10 based on Aerosol Optical Thickness (AOT) method.



```
This program is to measure the API value of PM10
according to Aerosol Optical Thickness Method
------------------------------------------------

Please enter the following details:

day in year: 68
time(hh min sec): 13 22 45
longitude: 100.15
latitude: 5.24
time zone: 8
aerosol optical thickess for each (3) band:
band 1 : 0.079
band 2 : 0.083
band 3 : 0.049
molecule optical thickess for each (3) band:
band 1 : 0.428
band 2 : 0.138
band 3 : 0.014

The API value for PM10 at this condition is: 26.7319

Press any key to continue . . . _
```

Fig. 7: Output of Program Designed Based On Algorithm of AOT Method

However, due to limited source of data, this program can only be designed for 3 bands (blue, green and red only) and hence the accuracy of the program is limited. If other remote sensor is used, which require more than 3 bands, the program is probably not suitable to produce the accurate API value of PM10. Therefore, further study may come out with more flexible program to measure the API value of PM10 with various option of band number

One sign whether a city has an advanced understanding of the importance of air quality monitoring is if it has passed regulations to help mitigate pollution sources and assist in the reduction of pollution levels. Satellite observations can ensure that these regulations are necessary and effective; assist in timely enforcement of these regulations, and help in creating public awareness and participation (Hutchison, 2003).

Another advantage of satellite remote sensing technology is that it can monitor many pollutants simultaneously, and it has the capability to monitor in near real-time, and provides continuously rapid monitoring. These are major improvements on most ground monitoring instruments.

However, there are drawbacks associated with satellite remote sensing technology. One of the major limitations is spectral interference caused by other atmospheric inhabitances that are not pollution. Satellite observations are restricted to wavelength ranges of atmospheric windows; the results of the observations are subject to the atmospheric conditions. Any pollutant with a low concentration will not be detected. A second drawback is that the remote sensing technology has to be supervised with a highly qualified staff, and the process is very expensive (Szczurek et al., 1998). These factors should be weighed according to the benefits that the remote sensing technology brings. Namely, the potential to improve air quality monitoring, which provides more accurate information to assess the implications associated with the quality of the air, and the impact that it will have on human life.

This technique is useful if one of the images is relatively pollution free, and can be used as a reference. The geometric and radiometric change in the signal can be change. The use of remote sensor improved estimate of surface conditions in regions the important meteorological variables considered such as wind speed, temperature, relative humidity, atmospheric pressure, and atmospheric stability class can be measure, calculate and monitor by using all method considering in remote sensing. The present study shows how the remote sensing can help to monitoring the air pollution, and the ideas strongly achieve the objectives.

IV. CONCLUSION

The purpose of this paper was to determine which technique of air quality monitoring would be best for the Malaysia. An overview of the four techniques is presented with respect to the capabilities to be implemented in Malaysia.

The first technique discussed was aerosol thickness. This method is the most popular of the four, and has been studied throughout the world with sufficient and adequate results. This technique can be used to map both the aerosol thickness and the pollution distribution of the Malaysia. This method is also useful in determining the pollution sources in the city. For both these reasons this technique is the best choice for monitoring air quality in Malaysia.

The second technique discussed was the measurement of black particles. Thought this study determined that there is a high correlation between black particles and the pollution content in the atmosphere, the method is unreliable at this time. There is no proof that the decrease in temperature in the atmosphere is directly correlated to the pollution content, and it is for this reason that this method is not advised for the Malaysia.

The third technique was visual inspection. The study conducted on visual inspection was successfully conducted and met all the criteria used to determine success or failure. One of the conditions of the study was that there had to be personnel both familiar with visual inspection methods and have the adequate skills in interpreting what the imagery was conveying. This technique is not desirable, because the system becomes vulnerable on the reliance of skilled technicians, and it introduces human error to the monitoring system.

The fourth technique was land-use/land-cover change. This was implemented in Athens, Greece, which is a low latitude city. The low altitude means that very little land-change is present during the course of 15 days (or whatever the coverage cycle happens).

Upon determining the technique used to monitor air quality, the choice of satellite must be determined. Each of the three studies on aerosol thickness measurement used a different satellite to monitor air quality: Landsat, Nimbus-7, and SPOT. The studies involving SPOT and Nimbus-7 provided strong and accurate results if any cloud cover imagery was neglected. The majority of the time, however, there will be cloud cover and thus these satellites are inadequate. The Landsat study did not limit its findings to clear days, which is a very big advantage over the other satellites. Therefore, from the three studies reviewed in this report, the Landsat study was the one with the most realistic conditions, and the one that yielded the best results. Therefore, one possible satellite that could be used to monitor the air quality in the Malaysia could be Landsat.

The choice of the satellite will depend on three factors: spatial resolution, coverage cycle, and the bands that will scatter and absorb the aerosol in the atmosphere.

REFFERENCE

[1] Sifakis, N. I., N. A. Soulkellis, and D. K. Paronis, 1998. Quantitative mapping of air pollution density using earths observations: a new process method and application to an urban area, International Journal of Remote Sensing, 19(17):3289-3300.

[2] Liu, G.-R., A. J. Chen, T.-H. Lin, and T.-H. Kuo, 2002. Applying SPOT data to estimate the aerosol optical depth and air quality, Environmental Modelling & Software, 17(2002):3-9.

[3] Sifakis, N. I., N. A. Soulkellis, and D. K. Paronis, 1998. Quantitative mapping of air pollution density using earth's observation.

[4] Hsu, N.C., Tsay, S.C., King, M.D.; Herman, J.R. Aerosol Properties Over Bright Reflecting Source Regions. IEEE Trans. Geosci. Remote Sens. 2004, 42, 557-569.

[5] Li, Z.Q., Niu, F., Lee, K.H., Xin, J.Y., Hao, W.M., Nordgren, B., Wang, Y.S.; Wang, P.C. Validation and understanding of Moderate Resolution Imaging Spectroradiometer aerosol products (C5) using ground-based measurements from the handheld Sun photometer network in China. J. Geophys. Res. 2007, 112, D22S07, doi:10.1029/2007JD008479.

[6] Sifakis, N.I.; Deschamps, P.-Y. Mapping of air pollution using satellite data. Photo. Engin. Remote Sens. 1992, 58, 1433-1437.

[7] Kaufman, Y.J., Tanré, L.A., Remer, L.A.,Vermote, E., Chu, A.; Holben, B.N. Operational remote sensing of tropospheric aerosol over land from EOS moderate resolution imaging spectroradiometer. J. Geophys. Res. 1997a, 102, 17051-17067.

[8] Kaufman, Y. J., Tanr, 1 D. C, Gordon, H. R., Nakajima, T., Lenoble, J. , Frouins, R. Grassl, H., Herman, B. M., King, M. D. and Teillet, P. M. 1997. Passive remote sensing of tropospheric aerosol and atmospheric correction for the aerosol effect. Journal of Geophysical Research, 102 (D14):16,815-16,830.

[9] Camagni, P. and Sandroni, S., 1983, Optical Remote sensing of air pollution, Joint Research Centre, Ispra, Italy, Elsevier Science Publishing Company Inc.

[10] Ung, A., Weber, C., Perron, G., Hirsch, J., Kleinpeter, J., Wald L. and Ranchin, T., Air Pollution Mapping Over a City - Virtual Stations And Morphological Indicators, Proceedings of 10th International Symposium "Transport and Air pollution" September 17-19, 2001 - Boulder, Colorado USA, Online [Available]: http://www.cenerg.cma.fr/Public/themes_de_recherche/teledetection/title_tele_air/title_tele_air_pub/air_pollution_mappin.

[11] Vermote, E., Tanre, D., Deuze, J. L., Herman, M. and Morcrette, J. J., 1997, Second Simulation of the satellite signal in the solar spectrum (6S), [Online] available: http://www.geog.tamu.edu/klein/geog661/handouts/6s/6smanv2.0_P1.pdf.