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Aerosol Optical Thickness and PM10 Mapping over Penang by using Handheld Spectroradiometer

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Abstract: Atmospheric components (aerosol and molecules) scatter and absorb solar radiation. The massive forest fire in 2004 affected the Penang Island region. The Environment of Department of Malaysia notified that the Prai area as unhealthy air quality level on 21 June 2004. This study investigated the used of a handheld spectroradiometer for the retrieval of Atmospheric Optical Thickness (AOT) values over Penang Island. The transmittance values were measured using a handheld spectroradiometer over Penang Island on 11th April 2004. The transmittance values were measured in spectral region from 350 to 1050 nm at the earth surface. We selected the values at 550 nm for the present analysis. This study introduces an economical and a simple technique for retrieval of AOT for remote sensing application. The transmittance values were measured around the Penang Island. The concentrations of particulate matter of less than 10 micron (PM10) were measured simultaneously with the measurements of the transmittance data. The locations were determined with a Global Positioning System (GPS) receiver. The relationship between AOT and PM10 were investigated and we obtained a linear relationship between these two parameters. Finally, an interpolating technique was used to generate AOT and PM10 maps over Penang Island.

Key words: Air quality, spectroradiometer, transmittance, AOT, PM10

INTRODUCTION

Environmental pollution become more and more serious due to today's development all around the world. In order to ensure this situation is under control, Malaysia's government has already established a network throughout Malaysia to monitor this situation. Aerosols scatter and absorb solar radiation. The scattering and absorption features depend on their chemical and physical properties (Guzzi *et al*., 2001). AOT, τ, is a measure of aerosol loading in the atmosphere (Christopher *et al*., 2002). Many studies have been carried out to retrieve AOT values (Nemuc *et al*., 2010; Jiang *et al*., 2010; Guo *et al*., 2009). For this purpose, we used a handheld spectroradiometer to measure the transmittance values at the surface. The transmittance is related to the AOT according to Angstrom expression. So we retrieved the AOT value from these measurements. AOT, τ, is a measure of aerosol loading in the atmosphere (Christopher *et al*., 2002). Retrieval of Aerosol Optical Thickness (AOT) over land from satellite platforms has been limited in comparison to the number of retrievals over oceanic areas (Knapp and Stowe, 2000). The objective of this study was to retrieval AOT values over land using atmospheric radiation measurements. Besides, we also to explore the relationship between Aerosol Optical Thickness (AOT) derived from the spectroradiometer transmittance measurements and the correlation of particulate matter less than 10 micron (PM10).

Many researchers have conducted satellite monitoring of the AOT (Husar *et al*., 1997; Liu *et al*., 2002). In this study, we present a method for air quality mapping from ground-based measurements. Typically, ground based measurements were made with a device of sun photometer. In this study, our purpose is to generate AOT and PM10 maps over Penang Island, Malaysia by using a handheld spectroradiometer. The study area of Penang Island, Malaysia is located in equatorial region and enjoys a warm equatorial weather the whole year, within latitudes 5° 9′ N to 5° 33″ N and longitudes 100° 09′ E to 100° 30′ E. The transmittance values were measured using a handheld spectraradiometer between 9 a.m. to 11 p.m. on 11th April 2004. The sampling locations were determined using a handheld GPS. The sensitivity of this type of spectroradiometer is between the spectral wavelengths from 350 to 1050 nm. In order to derive AOT from spectroradiometer readings, we use the Beer-Lambert-Bouguer law. In this method, the sky radiance values in the first directly to be retrieval. Then the sky

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transmittance values were retrieved from the sky radiance values. A total of 32-point transmittance measurements were measured around Penang Island, Malaysia. The PM10 measurements were taken simultaneously with the acquired transmittance measurements. Generally, a higher AOT value indicates higher column of aerosol loading and therefore low visibility (Wang and Christopher, 2003). The aim of this study carried out at the Penang Island, Malaysia is to a set of measurements of sky transmittance. An AOT and PM10 maps were generated using Kriging interpolating model. Interpolation methods were used here to calculate the unknown value of interested points by referring to the neighboring points within the same area or region. A linear relationship between AOT and PM10 was found in this study. Finally, AOT was compute from the atmospheric transmittance values. PM10 values were collected simultaneously with the atmospheric transmittance using a DustTrak Aerosol Monitor 8520. This study showed that there was a good correlation between the derived AOT and the measured PM10.

MATERIALS AND METHODS

Study area and data acquisition: The study area is the Penang Island, Malaysia, located within latitudes 5° 9' N to 5° 33' N and longitudes 100° 09' E to 100° 30' E (Fig. 1). The map of the study area is shown in Fig. 1. Penang Island is located in equatorial region and enjoys a warm equatorial weather the whole year. Therefore, it is impossible to get the 100% cloud free satellite image over Penang Island. But, the satellite image chosen is less than 10% of cloud coverage over the study area. Penang Island located on the northwest coast of Peninsular Malaysia.

Penang is one of the 13 states of the Malaysia and the second smallest state in Malaysia after Perlis. The state is geographically divided into two different entities - Penang Island (or Pulau Pinang in Malay Language) and a portion of mainland called Seberang Perai in Malay Language. Penang Island is an island of 293 square kilometres located in the Straits of Malacca and Seberang Perai is a narrow hinterland of 753 square kilometres

Fig. 1: The location of the study area

(Penang-Wikipedia, 2009). The island and the mainland are linked by the 13.5 km long Penang Bridge and ferry.

Penang Island is predominantly hilly terrain, the highest point being Western Hill (part of Penang Hill) at 830 metres above sea level. The terrain consists of coastal plains, hills and mountains. The coastal plains are narrow, the most extensive of which is in the northeast which forms a triangular promontory where George Town, the state capital, is situated. The topography of Seberang Perai is mostly flat. Butterworth, the main town in Seberang Perai, lies along the Perai River estuary and faces George Town at a distance of 3 km (2 miles) across the channel to the east (Penang-Wikipedia, 2009).

The Penang Island climate is tropical and it is hot and humid throughout the year. with the average mean daily temperature of about 27°C and mean daily maximum and minimum temperature ranging between 31.4 and 23.5°C respectively. However, the individual extremes are 35.7 and 23.5°C, respectively. The mean daily humidity varies between 60.9 and 96.8%. The average annual rainfall is about 267 cm and can be as high as 624 cm (Ahmad *et al.*, 2006). The corresponding transmittance and PM10 measurements were collected at the several selected locations around the Penang Island between 9.00 to 11.00 a.m.

A handheld spectroradiometer was used to collect the sky transmittance data over Penang Island, Malaysia campus on 11th April 2004 from 32 stations in the USM campus (Fig. 2). The AOT was calculated based on the Beer-Lambert-Bouguer law.

Methodology: The transmittance data over Penang Island on 11th April 2004 was used in this study. The observation site is located in the northern region of the Peninsular Malaysia. The spectroradiometer measure the atmospheric transmittance from 350 to 1050 nm. The data that have been used in this study were collected at 32 locations in Penang, Malaysia.

The AOT is calculated based on the Beer-Lambert-Bouguer law. The AOT is related to the transmission by the expression (Vermote *et al.*, 1997):

$$T_{d\lambda} = e^{-\frac{\tau_\lambda}{u_s}} \quad (1)$$

Where:
$T_{d\lambda}$ = transmittance for direct irradiance at wavelength, λ
u_s = cosines (θ), θ is the zenith angle

AOT values were obtained after performing the sequence of the following calculations:

- First, we measured the total solar irradiance. This was done by measuring the radiance reflected from a Spectralon panel placed perpendicular to the direction of the Sun. The measured radiance was converted into irradiance by multiplying by Π and then divided by the reflectance of the Spectralon panel
- Second, we measured the diffuse irradiance. This step was performed with the same Spectralon panel maintained in the same orientation as in step 1. The panel was shaded from direct sunlight using a disk of

Fig. 2: The handheld spectroradiometer

black painted cardboard mounted on a stick. The size of the disk and distance to the panel should be such that the shadow of the disk on the panel is just sufficient to fully shade the area viewed by the FieldSpec HH. As in step 1, we measured the reflected radiance. Again, the measured radiance is converted to irradiance by multiplying by Π and then dividing by the reflectance of the Spectralon panel

- Third, we computed the direct solar irradiance by subtracting the diffuse irradiance from the measured total solar irradiance
- Fourth, we computed the top-of-atmosphere (TOA) solar irradiance values corresponding to the wavelengths of the spectra measured by the FieldSpec HH. In this study, Wehrli 1985 AM0 Spectrum was chosen to calculate the TOA spectra and interpolate it to the FieldSpec HH wavelengths, multiplying by cosines solar angle and then correct for the exact Earth-Sun distance factor, D, given by Spancer (1971) as:

$$D = 1.00011 + 0.034221\cos\phi + 0.00128\sin\phi + 0.000719\cos 2\phi + 0.000077\sin 2\phi \quad (2)$$

The day angle, φ, in radians is represented by:

$$\phi = 2\pi(d-1)/365 \quad (3)$$

where, d is the day number of a year (1-365)

- Finally, we computed the atmospheric transmission by dividing the direct solar irradiance computed in step 3 by the top of atmosphere values calculated in the fourth step. This was done by first exporting the FieldSpec HH spectrum to a text file, importing the text file into a program like MS Excel and then performing the calculations in Excel. Then the AOT values were computed using Eq. 1

RESULTS AND DISCUSSION

In this study, we derived AOT values in the 550 nm only (Fig. 3). The AOT and PM10 maps over Penang Islands were created using a Kriging interpolation technique for estimating aerosol values to be associated to their distribution patterns (Fig. 4). PM10 was used as an aerosol concentration in this study. We obtained a linear relationship between PM10 and AOT and correlation coefficient (R) of 0.81 and root-mean-squares error (RMS) of 0.0544 μg m^{-3} (Fig. 5). The linear correlation coefficient (R) is 0.81 which suggests that the PM10 concentration measured at the earth surface is still linearly related with the AOT data (Fig. 5). It seems that the AOT values above the sampling sites increased as PM10 increased. Several studies also found this linear relationship (Wang and Christopher, 2003).

From our experimental data set, we can see the PM10 increases as the AOT increases. This mean that as the AOT values increases these is a increase of the

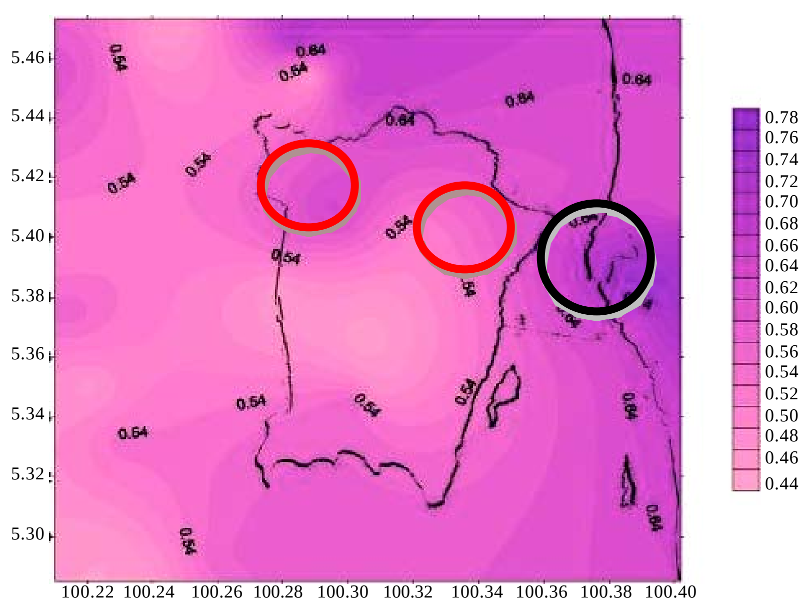

Fig. 3: Extract of a map of AOT

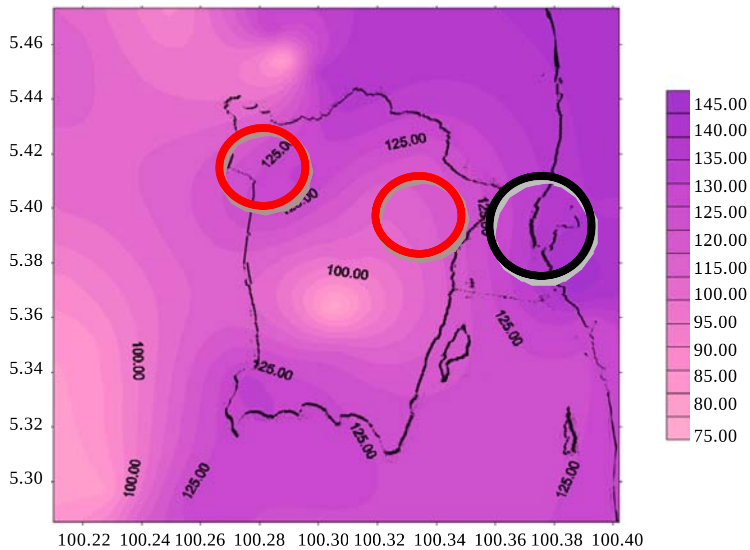

Fig. 4: Extract of a map of PM10 ($\mu g\ m^{-3}$)

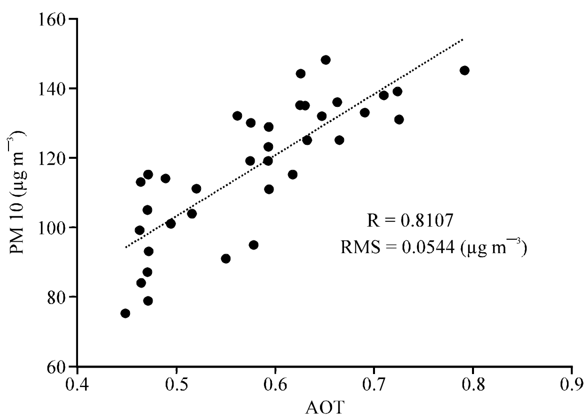

Fig. 5: A linear correlation between AOT and PM10 ($\mu g\ m^{-3}$) values

concentration of PM10. Therefore, we obtained a positive correlation between AOT and PM10.

From the AOT and PM10 maps, we can see that the high concentration of the AOT and PM10 values was located near the Bayan Lepas and Prai industrial areas (Black circle) and Georgetown urban areas (Red circle) (Fig. 3, 4). This was due to the high density of population area and industrial area respectively. The air pollution caused by industry has even more grave effects than vehicle exhaust fumes

CONCLUSIONS

AOT retrieval was produced by the handheld spectroradiometer from the atmospheric transmittance measurements. The measured sky radiance can be re-processed and new results of the AOT values can be obtained. The interpolation PM10 map shown by a visualization tool discloses that spectroradiometer is able to measure AOT values. A linear relationship between PM10 and AOT was found by this study. Findings can be used to analyze the air pollution levels over Penang Island. This indicates that air quality can be retrieved from the spectroradiometer transmittance measurements.

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