DEVELOPMENT OF SPECTRA AND BROADBAND CLOUD OPTICAL DEPTH CALIBRATION CONSTANT AT NEAR- SEA- LEVEL BY USING GROUND BASED SPECTROMETER

NUR HASINAH NAJIAH BINTI MAIZAN

THIS DISSERTATION IS PRESENTED TO FULFILL THE REQUIREMENT FOR OBTAINING A BACHELOR DEGREE OF SCIENCE WITH HONOURS

PHYSICS WITH ELECTRONICS PROGRAMME
FACULTY OF SCIENCE AND NATURAL RESOURCES
UNIVERSITI MALAYSIA SABAH

2014

257280

UNIVERSITI MALAYSIA SABAH

BORANG PENGESAHAN STATUS TESIS

JUDUL: DEVELOPMENT OF CLOUD OPTICAL DEPTH CALIBRATION CONSTAN AT NEAR SEA-LEVEL BY USING GROUND BASED SPECTROMETER.

IJAZAH: PHYSICS WITH ELECTRONIC

SAYA: NUR HASINAH NAJIAH BINTI MAIZAN (HURUF BESAR) SESI PENGAJIAN: 2011 / 2014

Mengaku membenarkan tesis *(LPSM/Sarjana/Doktor Falsafah) ini disimpan di Perpustakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:-

1. Tesis adalah hakmilik Universiti Malaysia Sabah.
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (/)

- [ ] SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di AKTA RAHSIA RASMI 1972)
- [ ] TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana Penyelidikan dijalankan)
- [/] TIDAK TERHAD

Disahkan oleh:

NURULAIN BINTI ISMAIL
LIBRARIAN
UNIVERSITI MALAYSIA SABAH

(TANDATANGAN PENULIS) (TANDATANGAN PUSTAKAWAN)

Alamat tetap: JB 5384, TAMAN JUS PERDANA, 77500 SELANDAR, MELAKA.

NAMA PENYELIA

Tarikh: 2nd JULY 2014

Tarikh:

Catatan :- * Potong yang tidak berkenaan.
*Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT dan TERHAD.
*Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana Secara penyelidikan atau disertai bagi pengajian secara kerja kursus dan Laporan Projek Sarjana Muda (LPSM)

DECLARATION

I hereby declare that this thesis is my own work except for all information obtained from sources which have been declared as reference.

NUR HASINAH NAJIAH BINTI MAIZAN

(BS11110476)

23th JUNE 2014

CERTIFICATION BY

1. **SUPERVISOR**

   (ASSOC. PROF. DR. JEDOL DAYOU)

ACKNOWLEDGEMENT

My first and sincere appreciation goes to my supervisor, Associate Professor Dr. Jedol Dayou for all I have learned from him and for his continuous help and support in all stage to complete this dissertation. I would like to thank him for being a very good supervisor, and for encouraging and helping me to shape my interest and ideas in this research. Without his kind and patient instruction, it is impossible for me to finish this thesis.

In addition, I would like to express my deep gratitude to all the members of club Energy, Vibration and Sound Research Group (e-Vibs) especially to Jackson Chang because willing to help me by giving much knowledge, guidance and advice from the start. His advices always inspired me and bring me to a higher level of thinking.

Finally, a very big thank you goes to my family especially my mother for their endless love. Their loves inspired me and give me strength to accomplish this research. Last but not least, I would like to appreciate all my course mate for helping me by giving very good opinions and encouragement for all this while.

ABSTRACT

One of the requirements to predict earth climate change over a long time is by monitoring thin ice cloud microphysical properties such as cloud optical depth (COD) accurately. COD τ, is measurement of cloud transparency and it depends on the cloud thickness of vertical depth and moisture density. Previously, Langley calibration method was widely used to calibrate ground based instrument, but this calibration method have to take place at high altitude for stable atmosphere. For long time COD monitoring purpose, this calibration method is not efficient in terms of accessibility and economic prospect. Therefore, the purpose of this study is to develop spectra COD calibration constant at near- sea- level by using Perez Du- Mortier model and selected wavelengths is 470nm, 500nm, and 550nm. Data collection for calibration constant development has been conducted on April and May 2012 from 0640 to 0830 with every 3 minute time interval. After all required data was obtained, filtration process is conducted using PDM to select only clear data to form Langley plot for each wavelengths in order to obtain calibration constant k. Measurement data for COD retrieval was conducted on February 2014 from 0900 to 1400 with every 10 minute time interval in 5 days. Calibrated COD reading for these 5 days is obtained by applied calibration constant k, within COD algorithm and results for COD measurement for these 3 wavelength fall within 0.56 until 1.70. Validation process was conducted by comparing broadband COD values measured by spectrometer and pyranometer. Data collection for validation purpose was collected on February 2014 from 0900 to 1400 with every 10 minute time interval in 5 days for entire wavelength and using same method like spectra COD retrieval. Results show minimum and maximum reading for calibrated broadband COD measured by spectrometer is 0.61 and 1.67 respectively. Meanwhile, minimum and maximum reading for pyranometer is 0.36 and 1.68 respectively. Broadband COD reading between these two instruments has slightly differences but their reading still close to spectra COD. It can be concluded that this proposed calibration method is feasible in calibrating ground instrument to measure cloud optical depth at low altitude because it gave a positive result as the reading for spectra and broadband COD after using calibrated instrument fall within the average scale for thin ice cloud optical depth in tropical area which is below than 2 and this results is supported by previous research.

ABSTRAK

Salah satu keperluan untuk meramal perubahan iklim bumi untuk jangka panjang ialah dengan memantau ciri- ciri fizikal mikro awan nipis berais seperti kedalaman optik awannya. Kedalaman optik awan (COD) τ, adalah transperansi sesuatu awan dan bergantung kepada ketebalan vertikal awan dan densiti kelembapan atmosphera. kaedah penentukuran Langley telah banyak digunakan untuk menentukur pelbagai instrument. Tetapi, untuk pemantauan kedalaman optik awan bagi jangka masa panjang, kaedah Langley ini tidak sesuai digunakan kerana ia perlu dilakukan di kawasan tanah tinggi dan hal ini mendatangkan masalah dari segi kemudahan dan ekonomi. Oleh itu, tujuan kajian ini dijalankan adalah untuk membentuk algoritma penentukuran untuk mengira ketebalan optik awan spektra di kawasan paras laut menggunakan spektrometer. Pembentukan algoritma penentukuran didalam kajian ini akan menggunakan model Perez Du- Mortier (PDM) dan jarak gelombang dipilih ialah 470nm, 500nm, 550nm. Pengumpulan data untuk algorithma penentukuran telah dijalankan pada April dan Mei 2012 jam 0640-0830 dengan setiap selang masa 3 minit. Selepas semua data yang diperlukan diperolehi, proses penapisan menggunakan PDM dijalankan untuk memilih data yang cerah untuk membentuk Langley plot bagi setiap jarak gelombang bagi mendapatkan algorithma penentukuran k. Data pengukuran COD telah dijalankan pada bulan Februari 2014 pada 0900-1400 dengan selang masa 10 minit selama 5 hari. Algorithma penentukuran k telah digunakan didalam penggiraan COD dan keputusan menunjukan bacaan diantara 0.56 hingga 1.70. Proses pengesahan telah dijalankan dengan membandingkan nilai COD jalur lebar yang diukur oleh spektrometer dan pyranometer. Pengumpulan data untuk proses ini dijalankan di bulan Februari 2014, jam 0900-1400 dengan selang masa 10 minit untuk 5 hari bagi keseluruhan panjang gelombang. Keputusan menunjukkan jalur lebar COD yang diukur dengan spektrometer berada diantara 0.61 dan 1.67. Sementara nilai yang ditunjukan pyranometer adalah diantara 0.36 dan 1.68. Bacaan jalur lebar COD antara kedua-dua instrumen mempunyai sedikit perbezaan tetapi bacaan mereka masih hampir dengan COD spektra. Ringkasnya, keputusan kajian ini menunjukkan PDM sesuai digunakan untuk membentuk algoritma penentukuran Langley pada kawasan paras laut kerana nilai COD yang telah dihasilkan berada dalam skala purata awan nipis berais di kawasan tropika iaitu bawah daripada 2 dan keputusan ini disokong oleh kajian sebelum ini.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOL

I_d	diffuse irradiance
I	global irradiance
I_{dir}	direct irradiance
R	Earth-Sun distance
ϕ_H	zenith angle
ε	clearness index
NI	nebulosity index
CR	cloud ratio
$I_{d,cl}$	clear sky illuminance
α	solar altitude
m	optical air mass
$I_{o,\lambda}$	extraterrestrial irradiance at the top of atmosphere
T	total irradiance
τ	cloud optical depth
A	surface albedo
g	cloud asymmetry factor
μ_0	zenith angle
C	clear sky irradiance
πF	extraterrestial irradiance
$\pm$	plus minus sign
W/m^2	Watt per meter square
$k_{oz(\lambda)}$	ozone absorption cross section
I_λ	direct normal irradiance at the ground at wavelength λ
$\tau_{\lambda,i}$	total optical depth of the ith scatter or absorber
m_i	air mass of the i-th scatter or absorber through the atmosphere
$\tau_{R,\lambda,i}$	Rayleigh scattering optical depth
$\tau_{o,i}$	ozone optical depth

$\tau_{a,i}$	aerosol optical depth
$\tau_{g,i}$	gas optical depth
k_{Ray}	Rayleigh scattering coefficient
H	altitude from sea in meter
Z	ozone concentration

CHAPTER 1

INTRODUCTION

1.1 PREFACE

A cloud is made up of water drops or ice crystals floating in the atmosphere at altitudes ranging up to several miles above the sea. Knowledge about cloud is quite important because cloud play an essential role in establish earth climate system as it involved in earth radiation balance for both visible and infrared spectra. Clouds cool the earth by reflecting incoming sunlight and warm the earth by absorbing infrared radiation emitted from earth surface, and reradiating it back down. This redistribution of the radiant energy in the atmosphere depends on three factors. First, the presence of clouds second is the fraction of the sky covered by clouds and third is cloud phase and its optical depth (Turner, 2008). Basically, formation of clouds occur in the earth's atmosphere when water and moist from earth's land surface is evaporates into vapour and rises up into colder areas of atmosphere by convection process. Next, the water vapour will condense onto condensation nuclei which are made up from dust or microscopic particles. Cloud become visible after the water vapour has been cooled to saturation.

Clouds are classified into four basic categories and this classification is made based on the altitudes above ground. Cirrus clouds are high- level clouds and can reach heights from 5000m to 13,000m, it typically thin, has wispy strands with white or grey colour and it was made up from ice. Presence of this cloud indicates fair weather. "Alto-" is a mid-level clouds form between 2000 m to 7000 m feet and they frequently indicate an approaching storm. Low level clouds lay below 2000 m and they also known as stratus cloud. They are often dense, dark and sometimes look like cottony white clumps in the sky. Next is cumulus and cumulonimbus or thunderheads cloud or also known as vertical growth cloud and they can be found at the surface and up to 13,000 m. Cumulus clouds are fair- weather clouds and when it become big enough to produce thunderstorms, they are called cumulonimbus.

Cloud influence earth energy balance in different ways depending on their height and characteristics. A cloud that is higher in the atmosphere will emit less heat to the space compare to cloud at lower altitude. In particular, thin ice cloud (cirrus cloud) play it role in warming our earth by regulate longwave radiative energy transfer. Therefore, one of the requirement to predict earth climate change over a long time is by accurately monitor thin ice cloud microphysical properties such as cloud optical depth. Cloud optical depth τ, is measurement of cloud transparency and it depends on the cloud thickness of vertical depth and moisture density. Plus, it also describes how much the cloud modifies light passing through it. Many researches have been developed to understand the role of cloud in climate change but research how optical depth influences the climatic changes is still lacking (Min *et. al.*, 2004).

Many algorithms have been developed to measure cloud optical depth but development of calibration constant algorithm for ground based instrument is still lacking. So this research is conducted to develop a calibration constant before cloud optical depth can be retrieved. By developing this algorithm, accuracy of cloud optical depth can be increased and underestimation of cloud optical depth influence by data uncertainties can be avoided thus it may help in other research conducted in the future especially about the relation between cloud optical depth and climatic changes.

1.2 PROBLEM STATEMENT

As time passed by, many algorithms has been developed from the complicated to the simplest but sometimes, due to several factors, these algorithm failed to measure cloud optical depth accurately. Some of factor that contributes to this inaccuracy is unwanted scattered radiance which can cause an overestimate of the cloud transmission and further lead to underestimation of the cloud optical depth value and Min *et.al.* (2004) already fixed this problem by develop a technique that can remove the contamination of the measured direct transmittance and do a correction for forward scattering radiance before estimation of cloud optical depth value is take place. Beside that, uncalibrated instrument also lead to inaccuracy in cloud optical depth value.

Previously, calibration for radiometric instrument is performed by using standard laboratory lamp. Calibration constant is obtained by determine the absolute response of a spectrometer for a given spectral irradiance incident of the instrument (Chang *et. al*, 2013). However, this method have a few disadvantages, these lamp are not user friendly as they are quite fragile and a bit costly because it has very limited lifetime about 50 hours (Slusser *et. al.*, 2000). In addition, this method is not accurate and precise enough because these lamps have inconsistent uncertainty about 1 to 4% in the wavelength from 400 to 1070nm (Kiedron, 1999).

To improve this conventional method, a passive calibration is then develop and known as Langley method. Basically, this method use solar radiation as a light sources which is more stable than labolatory lamp and calibration process have to takes place at the high altitude for clear and stable atmosphere. However, regular access to high altitude altitude to get calibration constant for Cloud Optical Depth become a problem now because it is not efficient in accessibility and economical prospect because recalibration for almost reference instrument used in monitoring network need to recalibrate for every 2 to 3 month cycle (Chang *et. al.*, 2013). So, the key to this research is to develop a calibration constant for cloud optical depth for near- sea-level area without going to high altitude.

1.3 RESEARCH OBJECTIVE

The objective of this research is to investigate the feasibility of Perez-Du Mortier (PDM) algorithm in calibrating instrument for cloud optical depth measurement for a few wavelengths and for the total global irradiance at near- sea- level.

This research is divided into two parts; first part is the measurement of spectra Cloud Optical Depth by using global irradiance for a few wavelengths by using spectrometer and for this measurement part, there are three wavelengths used, which are 470, 500, and 550 nm. As this is only initial study, only three wavelengths is selected to study the dependence of cloud optical depth with wavelength. Calibration constant for each wavelength is determined by using PDM algorithm before the measurement process of cloud optical depth for a specific wavelength is take place.

Part two is the validation process for the cloud optical depth measurement and the validation is made by using pyranometer. This validation process is done by comparing the broadband Cloud Optical Depth, τ_{pre} measured by spectrometer with broadband Cloud Optical Depth, τ_{ref} measured by pyranometer. The spectra cloud optical depth was assumed to be true if the predicted Cloud Optical Depth, τ_{pre} is close to the Cloud Optical Depth reference value, τ_{ref}.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

For further knowledge about cloud optical depth field, some information should be understood first such as specifics term about solar radiation and explanation about these specifics term will be focus more on definition, how it occurs and example. Review about three clouds optical depth retrieval method and derivation of cloud optical depth algorithm will be included as well for better understanding.

2.2 SOLAR RADIATION

Solar energy received at the Earth's surface can be separated into two basic components: direct solar energy and diffuse solar energy. Direct solar energy can be defined as energy that arrived at the Earth's surface with the Sun's beam and diffuse solar energy is energy that is a result of atmosphere attenuating, or reducing the magnitude of the Sun's beam by scattering. Some of the energy removed from beam is redirected or scattered towards the ground. The remaining energy from the beam is either scattered back into space, or absorbed by the atmosphere (ABM, 2012). The sum of diffuse and direct solar energy incident on a horizontal plane at the Earth's surface is referred as global solar energy and all three quantities (specifically their rate or irradiance) are linked mathematically by the following expression (Paulescu *et. al.*, 2013):

$$G = G_d + G_b \cos\theta_z \quad (2.1)$$

Where, G = global irradiance on a horizontal surface, G_d = diffuse irradiance, G_b = direct beam irradiance on a surface perpendicular to the direct beam, and θ_z = Sun's zenith angle. Radiation quantities are generally expressed in terms of either irradiance or radiant exposure. Irradiance is a measure of the rate of energy received per unit area, and has units of watts per square metre (W/m^2).

Direct solar irradiance or also known as direct normal irradiance is a measure of the rate of solar energy arriving at the Earth's surface from the Sun's direct beam, on a plane perpendicular to the beam and diffuse solar irradiance is a measure of the rate of incoming solar energy on a horizontal plane at the Earth's surface resulting from scattering of the Sun's beam due to atmospheric constituents. As diffuse solar irradiance is a component of global irradiance, therefore, diffuse solar irradiance should be less than or equal to global irradiance measured at the same time. Global and diffuse irradiance will have equal value when there is no direct solar irradiance, which is when the Sun is blurred by thick cloud, or the Sun is below the horizon.

Global solar irradiance is a measure of the rate of total incoming solar energy (both direct and diffuse) on a horizontal plane at the Earth's surface and the most accurate measurement of global solar irradiance can be obtained by summing the diffuse and horizontal component of the direct irradiance.

2.3 SOLAR RADIATION PATHWAYS

Reasons that cause variations in the solar irradiance is a pathways they had to past once entering the atmosphere and basically, there are five pathways for solar radiation to past. They are scattering, transmission, refraction, absorption and the final pathways is reflection (Briney, 2013). As the shortwave solar radiations enter the atmosphere, this energy will refers as insolation and insolation can be direct or diffuse radiation. Solar radiation received on Earth's surface after undergo scattering process by atmosphere is known as diffused radiation and solar radiation that has not been altered by atmospheric scattering is known as direct irradiance. Scattering occur when insolation is deflected or redirected after entering the atmosphere by dust, gas, ice, and water vapour present there. If the energy waves have a shorter wavelength, they are scattered more than those with longer wavelengths (Ahrens *et. al.,* 2012).

Transmission take place when both shortwave and longwave energy pass through the atmosphere and water instead of scattering interacting with gases and other particle in the atmosphere. Refraction also occurs when solar radiations enter the atmosphere and this pathway happens when energy moves from one type of space to another, such as from air into water. As the energy moving from one space to another, it speed and direction is changing because of the interaction between particles present there. Absorption is conversion of energy from one form to another. For example, when solar radiation is absorbed by water, its energy shifts to the water and raises its temperature. The last pathway is reflection. This is occur when portion of energy bounces directly back to the space without being scattered, transmitted, refracted, or absorbed.

2.4 ALBEDO

Another important term relating with solar radiation is albedo. Albedo is defined as the ratio of reflected solar shortwave radiation from a surface to that incident upon it (Strugnell and Lucht, 2001). It is expresses as a percentage of reflected insolation to incoming insolation and zero percent is total absorption while 100% is total reflection. In term of visible colours, darker colours have a lower albedo that is they absorb more insolation, and lighter colours have high albedo, or higher rates of reflection (Briney, 2013). For example, snow reflects 85-90% of insolation, whereas asphalt reflects only 5-10%. Another factor that influences albedo value is sun angle and lower sun angle create greater reflection because the energy coming from a low sun angle is not strong as that arriving from a high sun angle. Smoothness of surface also gives impact to albedo value as smooth surface will have higher albedo than rough surface.

In general, albedo values also vary across the globe with latitude but Earth's average albedo is around 31% (Bryan, 2004). For surfaces between the tropics (23.5° N to 23.5° S) the average albedo is 19-38%. At the poles it can reach about 80% in some area.

2.5 REVIEWS ABOUT CLOUD OPTICAL DEPTH RETRIEVAL METHOD

Different approach have been developed to measure cloud optical depth by using three popular method which is, retrieval with satellite data, Lidar, and ground based instrument. Different approach can be selected by depending on the researcher target.

Satellite is the most accurate option for retrieve cloud optical depth because it can estimate solar radiation better than ground based instrument. A simple model has been developed by Perez *et. al.* (2002) to measure global and diffuse irradiance by using geostationary satellite visible image and this new model is particularly efficient at correcting possible distortions for global and diffuse irradiance measure by ground based instrument. Satellites also have the ability to retrieve cloud optical depth for snow area. This method is newly developed and it uses the sensitivity of top-of-atmosphere (TOA) reflectance in the oxygen A- band to the cloud optical thickness (Schlundt *et. al.,* 2013). The Cloud optical thickness Retrieval Over Snow (CROS) is applies forward simulations for clouds over snow using the radiative transfer model SCIATRAN in order to find the cloud optical thickness representing the measured TOA radiance for a given cloud top height and solar zenith angle. This algorithm is capable to retrieve simultaneously cloud optical depth, cloud bottom height, and the effective albedo of snow by using optimal estimation approach.

Lidar is a remote sensing technology that measure distance by illuminating a target with a laser and analyse the reflected light. In the process of retrieval of cloud optical depth for cirrus cloud made by Mitrescu and Stephens (2001), laser have been transmit through the cirrus cloud for where the cloud optical depth want to be retrieved and analyse the back scatters signal using an algorithm. This method has high probability to retrieve accurate cloud optical depth because the principle advantage for this method is the radiatively weaker dependence of scattering phase function during the retrieval process. An advantage using Lidar is, it can detect optically thin cloud layer that may not detected by milimiter cloud radar or ground based instrument and this research already conducted by Lo *et. al.* (2006), they used Micropulsed Lidar (MPL) to retrieve short- wave) cloud optical depth for optically thin cloud. However, Lidar method have disadvantage too which is, it cannot retrieve cloud optical depth for thin cloud if optically thick cloud obstruct the Lidar beam because this optically thick cloud will attenuate the Lidar beam (Lo *et. al.,* 2006).

Retrieval cloud optical depth by using ground instrument will measure cloud optical depth by using solar irradiance whether spectra irradiance or broadband irradiance and this method have been developed over decade ago. Recently, Barnard *et. al* (2003) has proposed a simple empirical equation to calculate cloud optical depth using shortwave broadband measurement and this algorithm has been emphasis on thick cloud (Barnard *et. al.,* 2003)and thin ice cloud (Barnard *et. al.,* 2008). Both of these research used pyranometer for collecting data and this method can produce similar result to those using Min algorithm. Min algorithm is an algorithm proposed by Min and Harrison (1996) and the retrieval process is using data from spectral irradiance and this data have been measure by using Multi- Filter Rotating Shadowband Radiometer (MFRSR). The uses of Min algorithm for wide variety side is limited because it require the total and diffuse component of the spectral irradiance at one wavelength, usually 415 nm and unfortunately, this information is often readily unavailable (Barnard *et. al.,* 2004) and this limitation has been solved by Barnard *et. al.* by using broadband irradiance to retrieve cloud optical depth.

2.6 CALIBRATION METHOD

New Langley calibration method will be used to calibrate spectrometer for this research instead of conventional Langley calibration method and this method has been proposed by Chang *et. al.* This algorithm uses the combination of clear- sky detection model and statistical filter to constrain the Langley extrapolation to get close as possible to the extraterrestrial constant over a wide range of wavelengths. It attempt to produce data set that close to the high altitude atmospheric. Previous research has used this New Langley calibration to calibrate Aerosol Optical Depth measurement for near- sea-level (Chang *et. al.,* 2013) and assess the solar spectrum intensity of solar radiation in Kota Kinabalu (Natalie, 2013). Conventional Langley calibration method also has been widely used before to calibrate UV Filter Radiometers (Slusser *et. al.,* 2000) and Sun Photometer (Adler, 2006).

2.6.1 Conventional Langley Calibration Method

Optical depth can be compute by the progress of the sun's apparent motion that changes the observed path length through the atmosphere (Harrison and Michalky, 1994). Ground- based instrument will measure the sun's irradiance as the sun moves across the sky for significant changes of air mass. Working principle behind this method is, as the solar radiation transmits through the atmosphere, it experiences a series of attenuation either by absorption or scattering due to the air molecules or solid particles suspended in the atmosphere.

Mathematically, the attenuation of the sun's direct- beam of particular wavelength passing through the Earth's atmosphere is described by the Beer-Lambert law as (Thomason *et. al.*, 1983)

$$I_\lambda = R^2 I_{o,\lambda} \exp\left(-\sum \tau_{\lambda,i} m_i\right), \tag{2.2}$$

where I_λ is the direct normal irradiance at the ground (or near-sea-level) at wavelength λ, R is the Earth-to Sun distance in astronomical units (AU), $I_{0,\lambda}$ is the extraterrestrial irradiance at the top of atmosphere (TOA), $\tau_{\lambda,i}$ is the total optical depth of the ith scatter or absorber, and m_i is the air mass of the i-th scatter or absorber through the atmosphere. Taking the natural logarithm of both sides, Eq. (2.2) can be written as

$$\ln I_\lambda = \ln R^2 I_{o,\lambda} - \sum \tau_{\lambda,i} m_i \ . \tag{2.3}$$

The total optical depth, $\tau_{\lambda,i}$ in Eq. (2.3) is contributed by Rayleigh, ozone, aerosol, and trace gases, which can be written as

$$\tau_{\lambda,i} = \tau_{R,\lambda,i} + \tau_{o,i} + \tau_{a,i} + \tau_{g,i}. \tag{2.4}$$

The optical depth of Rayleigh scattering is approximated using the relationship (Knobelspiesse *et. al.*, 2004; Djamila *et. al.*, 2011)

$$\tau_{R,\lambda,i} = k_{Ray}(\lambda)\exp(-\frac{H}{7998.9}), \quad (2.5)$$

where $k_{Ray}(\lambda)$ is the Rayleigh scattering coefficient, p is the site's atmosphere pressure, P_0 is the mean atmosphere pressure at sea-level and H is the altitude from sea- level in meter. Optical depth of ozone is calculated using satellite observation of Dobson unit (DU), which is computed by (Knobelspiesse *et. al.*, 2004)

$$\tau_{o,\lambda,i} = Zk_{\alpha(\lambda)}x2.6e16mol/cm^2, \quad (2.6)$$

Where, Z is ozone concentration in DU, and $k_{oz(\lambda)}$ is ozone absorption cross section. By substitute Eq. (2.4- 2.6) into Eq. (2.3), the uncalibrated pixels, P measured by the spectrometer can be written as

$$\ln P_{\lambda} + \tau_{R,i}m_i + \tau_{o,i}m_i = \ln R^2 P_{o,\lambda} - \tau_{a,i}m_i \quad (2.7)$$

On a clear day, a Langley plot gives a stable $P_{o,\lambda}$ for each wavelength when the data are extrapolated to TOA. With sufficient data of $P_{o,\lambda}$ on several clear days, and averaged $P_{o,\lambda(avg)}$ is obtained by

$$P_{o,\lambda(avg)} = \frac{1}{n\sum_{i=n}^{i} P_{o,\lambda,n}}, \quad (2.8)$$

Where, n is the number of Langley plots available for calibration. The calibration factor k is obtained by dividing the averaged extrapolated values with the extratial spectrum which is

$$k = \frac{\int P_{o,\lambda(avg)} F_{\lambda} d\lambda}{I_{o,\lambda} \int F_{\lambda} d\lambda}. \quad (2.9)$$

REFERENCES

Adler, S.M., Golden & Slusser, J.R. 2006. Comparison of Plotting Methods for Solar Radiometer Calibration. *Journal of Atmospheric and Oceanic Technology,* **24**: 935-938.

Ahrens, C.D. & Jackson, P.L. 2012. *Meteorology Today: An Introduction to Weather, Climate, and the Environment.* Nelson Education Ltd, Canada.

Australian Bureau of Meteorology, 2012. http://www.bom.gov.au/

Barnard, J.C. & Long, C.N. 2003. A Simple Empirical Equation to Calculate Cloud Optical Thickness from Shortwave Broadband Measurements.

Barnard, J.C. & Long, C.N. 2004. A Simple Empirical Equation to Calculate. *Journal of Applied Metereology.* **4:** 1057-1066.

Barnard, J.C., Long, C.N., Kassianov, E.I., McFarlane, S.A., Comstock, J.M., Freer, M. & Mc Farquhar, G.M,. 2008. Development and Evaluation of a Simple Algorithm to Find Cloud Optical. *The Open Atmospheric Science Journal,* **2:** 46-55.

Boyou, N.V. 2013. *Assessment of Visible Range Solar Spectrum Intensity in Kota Kinabalu by Using Langley Method.* B. Sc. Dissertation. Universiti Malaysia Sabah.

Bryant, E. 2004. *Climate Process and Change.* Cambridge University Press, Melbourne, Australia.

Chang, J.H.W, Dayou, J. & Sentian, J. 2013. Development of Near-Sea-Level Calibration Algorithm for Aerosol Optical Depth Measurement Using Ground-Based Spectrometer. *Aerosol and Air Quality Research.* **14** (1): 380-395.

Djamila, H., Ming, C.C. & Kumaresan, S. 2011. Estimation of Exterior Vertical Daylight for the Humid Tropic of Kota Kinabalu City in East Malaysia. *Renewable Energy*, **36:** 9-15.

Harrison, L. & Michalsky, J. 1994. Objective Algorithms for the Retrieval of Optical Depths from Ground-Based Measurements. *Applied Optics.* **33:** 5126-32.

Hu, Y.X. & Stamness, K. 1993. An Accurate Parameterization of the Radiative Properties of Water Clouds Suitable for Use in Climate Models. *AMS Journal Online* **6:** 728-742.

Kiedron, P.W., Michalsky, J.J., Berndt, J.L. & Harrison, L.C. 1999. Comparisons of spectral irradiance standards used to calibrate shortwave radiometers and spectrodiometers. Applied Optics. **38:** 2432-2439.

Knobelspiesse, K.D., Pietras, C., Fargion, G.S., Wang, M., Frouin, R., Miller, M.A., Subramaniam, A. & Balch, W.M. 2004. Maritime aerosol optical thickness measured by handheld sun photometers. *Remote sensing of enviroment*.**93:** 87-106.

Lo, C., Comstock, J.M. & Flynn, C. 2006. An Atmospheric Radiation Measurement Value- Added Product to Retrieve Optically Thin Cloud Visible Optical Depth using Micropulse Lidar. *DOE/SC-ARM/TR-077*, U.S. Dep. of Energy, Washington, D. C.

Marius, P., Eugenia, P., Paul, G. & Viorel, B. 2013. *Weather Modeling and Forecasting of PV Systems Operation.* Springer- Verlag London, New York.

Min, Q. & Harrison, L.C. 1996. Cloud Properties Derived from Surface MFRSR Measurements and Comparison with GOES results at the ARM SGP site. *Geophysical Research Letters.* **23:** 1641-1644.

Min, Q., Joseph, E., & Duan, M,. 2004. Retrievals of Thin Cloud Optical Depth from a Multifilter Rotating Shadowband Radiometer. *Journal of Geophysical Research.* **109:** 1984-2012.

Mitrescu, C. & Stephens, G.L. 2001. A New Method for Determining Cloud Transmittance and Optical Depth Using the. *Journal of Atmospheric and Oceanic Technology.* **19:** 1073–1081.

Piotr, W. & Kiedron, J. J. (1999). Comparison of Spectral Irradiance Standards Used to Calibrate Shortwave Radiometers and Spectroradiometers. *Applied Optic.* **38**: 2432-2439.

Schlundt, C., Kokhanoovsky, A.A., Rozanov, V.V., & Burrows, J.P. 2013. Determination of Cloud Optical Thickness over snow using satelite measurement in the oxygen A-band. *IEEE Geoscience and Remote Sensing Letter.* **10:** 1-5.

Shettle, & EP, W. J. 1970. The Transfer of Solar Irradiance Through Inhomogeneous Turbid Atmosphere Evaluated by Eddington's Approximation. *Journal of The Atmosphere Sciences.* **27:** 1048- 1055.

Slusser, J., Gibson, J., David, B., Kolinski, D., Disterhoft, P., Lantz, K. & Beaubien, A. 2000. Langley Method for Calibrating UV Filter Radiometer. *Journal of Geophysical Research.* **10:** 4841-4849.

Strugnell, Nicholas, C. & Wolfgang, L. 2001. An Algorithm to Infer Continental-Scale Albedo from AVHRR Data, Land Cover Class, and Field Observations of Typical BRDFs. *Journal of climate,* **14:** 1360-1376.

Thomason, L.W., Herman, B.M. & Reagan, J.A. 1983. The Effect of Atmospheric Attenuators with Structured Vertical Distributions on Air Mass Determinations and Langley Plot Analysis. *Journal of the Atmospheric Sciences.* **40:** 1851-1854.

Turner, D.D & Eloranta, E.W. 2008. Validating Mixed- Phase Cloud Optical Depth Retrieved From Infrared Observations With High Spectral Resolution Lidar. *Geoscience and Remote Sensing.* **5:** 285- 288.