Determination of Aerosol Optical Properties for Retrieval of Water-Leaving Radiance at Roodeplaat Dam Relating to Calibration and Validation of Sentinel 2 And 3

Zimbini Faniso, Derek Griffith, Mark Matthews and Jeremy Kravitz

Abstract**—**Remote sensing of inland water quality is challenging satellite Earth observation application. Inland water bodies are small, optically complex and dark targets compared to surrounding land. Signal reaching satellites is dominated by light scattered in the atmosphere. Aerosols are the strongest variables in the atmosphere by playing a major role in generating unwanted signal. Field campaign took place at Roodeplaat dam (pretoria) relating to calibration and validation of Sentinel 2 and Sentinel 3 satellites. Results were simultaneously taken with the satellite overpass in quantitative method. The Radiative Transfer Modelling for the atmosphere is required. Aerosol models have been evaluated to improve retrieval accuracy of water-leaving radiance. A retrieval algorithm for $\boldsymbol{L_w}$and remote-sensing reflectance Rrs is developed to analyse the sensitivity of the retrieval to aerosol optical properties. Sensitivities and proposals for enhanced retrieval methods are presented. Measurements of aerosol optical thickness, water vapour and other optical properties are presented.

Keywords—A Keywords: Earth Observation, inland water bodies , remote sensing.

I. Introduction

Satellite systems are an important and growing source of measurements for EO. The launch of the European Space Agency’s (ESA) Sentinel 2 and Sentinel 3 satellites in 2015 Donlon (2012) has created a requirement for quality assessment of the resulting data products. Calibration and data product validation (calval) is a lifecycle process addressing product quality. The study has conducted a campaign relating to calval of Sentinel 2 & 3 in the water quality application at Roodeplaat dam near Pretoria. It is observed that the atmosphere has a very significant effect on satellite EO of the surface. Aerosols and water vapour are the most variable atmospheric constituents and these have optical effects which must be understood in order to utilise satellite observations of the surface in an accurate, quantitative mode.

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II. Theory of Satellite Image Data Collection in Relatrion to Eutrophication Study

Many of South Africa’s inland water bodies are in danger of eutrophication due to the growing influx of pollutants (van Ginkel 2011, Harding 2015). These influxes can be due to human activities that include the use of fertilizers which then over flow to inland water bodies during heavy rainfall through surface run-off. Fig.1 shows previous studies taken with satellite sensors. Satellites use a process called remote sensing to record the information about the Earth surface without physical contact.

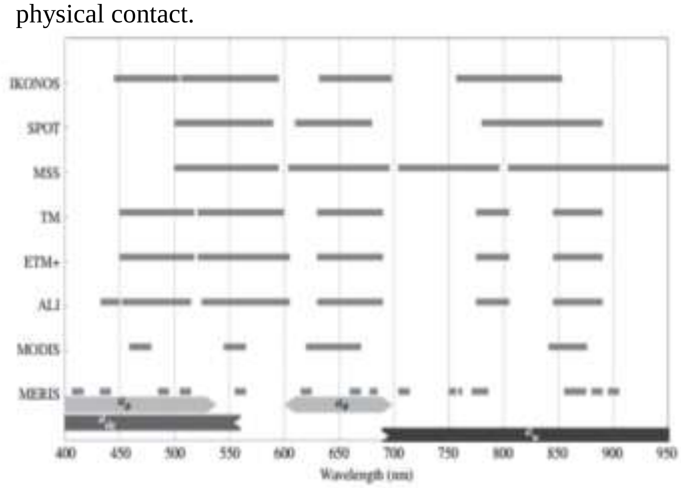

Fig 1: The spectral position of various satellite instruments in relation to the location of the maximum influence of absorption by phytoplankton, a, detritus and gelbstoff, adg, and water, aw.

They use optical sensors to obtain information in the form of images or data. Satellite sensors are passive remote sensors since they obtain the reflected energy signal from an object. These results were taken from inland water bodies to show maximum influence and absorption. Passive remote-sensing instruments, whether handheld or mounted on aircraft or satellites, measuring the light in the visible and near-infrared (NIR) part of the electromagnetic spectrum (400–1000 nm) are most often used for water-related applications. The study shows that there are factors that contribute on accelerating the process of Eutrophication, they include phytoplankton, tripton (made up detritus and minerals) CDOM (also called gelbstoff or

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yellow substance) and water itself all are said to have an impact on the optical sign of water in visible wavelengths Mark (2011).

Eutrophication can be monitored across many water bodies using carefully applied satellite observations Matthews (2011).

III. THEORY OF THE STUDY AND METHOD ON OBTAINING RESULTS

During the process of taking measurements by the satellite the relative amount and spectrum of light emerging from the water surface under specific conditions which is called the water-leaving radiance Lw has to be obtained. This is the quantity which must be retrieved from satellite observations and ground calibrated instruments like the Analytical Spectral Device (ASD). The Lw is generally small such that light scattering and absorption in the atmosphere are the two major optical properties of this spurious signal reaching the satellite at top-of-atmosphere (TOA). The relationship between the down welling irradiance at the water surface (at bottom-of-atmosphere, BOA) E_λ and L_w is

$$L_w = R_{rs} \times E_\lambda \tag{1}$$

Where R_{rs} is the spectral remote sensing reflectance of the water body. Remote sensing reflectance is ratio of the water leaving radiance per down welling radiance, R_{rs} is measured at the dam using an ASD spectroradiometer together with a white reference reflectance standard according to a specific measurement protocol (Mobley 1999, Lee 2010) executed closer to the dam edge. While R_{rs} depends on water state, E_λ depends on a number of factors including solar zenith angle (which depends on date and time), atmospheric composition, notably aerosol optical properties/thickness and water vapour column. Through scattering in the atmosphere, E_λ also depends on the spectral reflectance of the land area surrounding the water body. The latter influence is known as the "adjacency effect" at BOA.

The atmospheric radiative transfer code, MODTRAN® 5 (Berk 2005), was used to model E_λ on the basis of measured AOT and aerosol spectral single-scattering albedo (SSA) as well as adjacent land spectral reflectance. The SSA expresses the probability that a photon will be scattered rather than absorbed when interacting with an aerosol particle.

While MODTRAN offers several canned aerosol types, including "urban", "rural", "maritime", "tropospheric" and "desert", none of these options were found to be appropriate in this case, probably due to the fact that the aerosols for this location and season are dominated by biomass burning. Biomass burning aerosols tend to have smaller particles and higher carbon content causing lower Single Scattering Albedo (SSA) than other aerosol classes.

IV. INSTRUMENTATION

The AOT or AOD is an important determinant of the amount of sunlight reaching the Earth surface and reflected back up to the satellite. The AOT was measured at wavelengths of 440 nm, 500 nm, 675 nm and 870 nm using a Micro TOPS II handheld sun photometer. The instrument also estimates the total water vapour column using an additional optical thickness measurement at 936 nm and also shows altitude depending on the area of measurements. Two Micro TOPS units were used at Roodeplaat dam on the 5th, 6th and 24th June 2016 to measure AOT at the times of Sentinel 3 overpasses. An Analytical Spectral Device (ASD) Field spec 3 spectroradiometer with a remote cosine receptor was used to measure global and diffuse down welling spectral irradiance. A second Analytical Spectral Device (ASD) Field spec 3 was used in radiance mode to measure the remote-sensing reflectance of the dam itself. In addition, the Cimel CE318 robotic sun photometer at the CSIR Pretoria campus was used as a reference instrument for the micro tops II sun photometer AOT. This instrument is a node in the AERONET Holben (1998) network.

V. RETRIEVAL ALGORITHM

The total spectral radiance signal reaching the satellite sensor is computed using MODTRAN with the following procedure. The atmospheric model is compiled in MODTRAN using available Micro TOPS and Aeronet data. The mean area-averaged land/water surface spectral reflectance is retrieved from the Sentinel 2/3 image and input to MODTRAN. The total down welling spectral irradiance at BOA is computed using MODTRAN. The water leaving radiance L_w is computed from the in-situ measurement of R_{rs} using Equation (1). MODTRAN is used to calculate the radiance of the sky seen by reflection from the water surface. The total upwelling radiance at BOA is propagated to TOA by multiplying by the atmospheric path transmittance provided by MODTRAN. The atmospheric path radiance (due to light scattering in the atmosphere) is added to radiance from the previous step to obtain the total spectral radiance seen by the satellite at TOA. The channel radiances for the satellite in question are computed by weighting with the spectral response functions (SRF) of the satellite sensor. These can be compared to the actual values provided by the satellite data product. In order to retrieve the water-leaving radiance at BOA, the same process as above is used, neglecting the (supposed unknown) water-leaving radiance, but including all other radiance components. The shortfall in channel radiance at TOA compared to the satellite measurement is then assumed to be residual water-leaving radiance at TOA, which is then back-propagated to BOA by dividing by the (channel averaged) path transmittance.

VI. RADIATIVE TRANSFERE MODELLING

Radiative Transfer Models (RTM) and software code implementations can be used for quantifying atmospheric effects in the reflective and scattering signal that is sent to the satellite.

Figure 2 hitran molecular simulation web data simulation, molecule Oxygen absorption has a great effect on the atmospheric readings. The hitran data is obtained from (hitran.iao.ru/).The absorption depends on the angle of the incident light and then path length that the light passes through it. An increase in the path length leads to an increase in the oxygen absorption lines. Figure 3 and 4 shows BASS data plotted on the visible light region and near infrared region where the results will be taken. The Bass data shows Fraunhofer lines which known as absorption lines as well as Earth atmosphere. The bass data is obtained from (bass2000.obspm.fr/solar_spect.php)

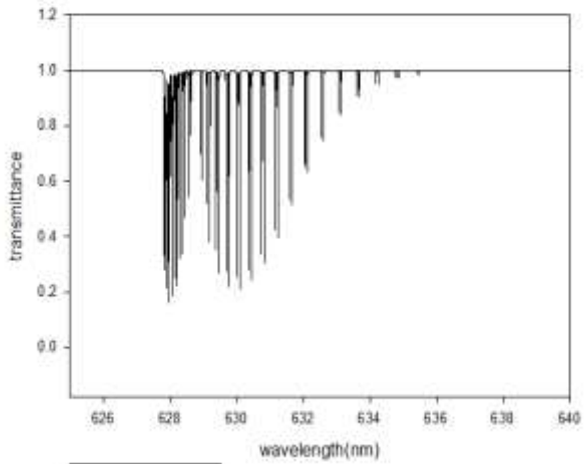

Fig 2: Hitran simulations data with 5000m pathlength for oxygen (visible range region)

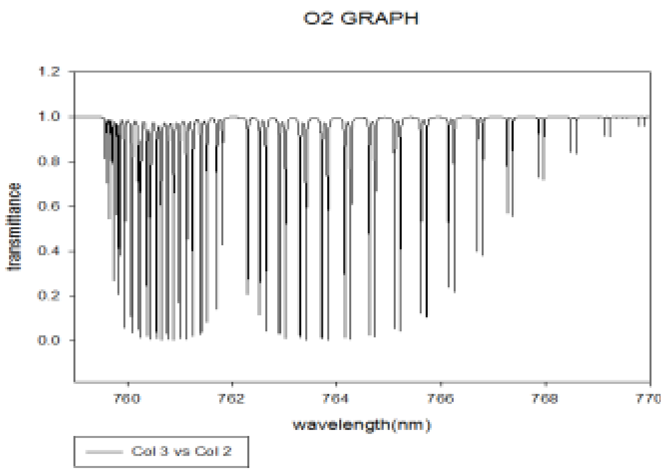

Fig 3: Hitran data for Oxygen (near infrared)

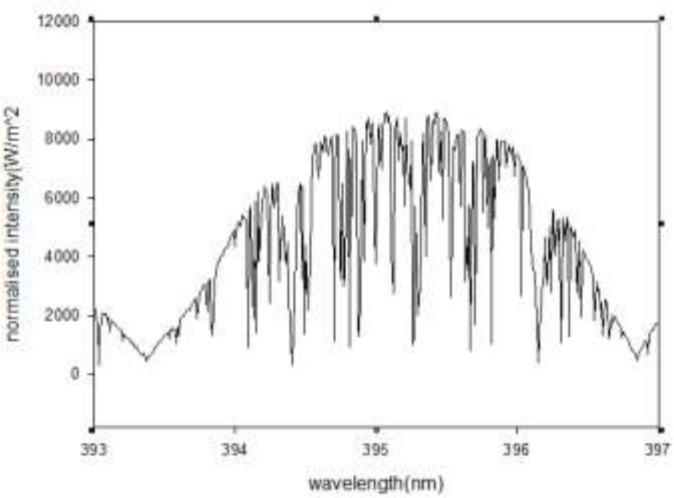

Fig 4: Bass data on the visible infrared region

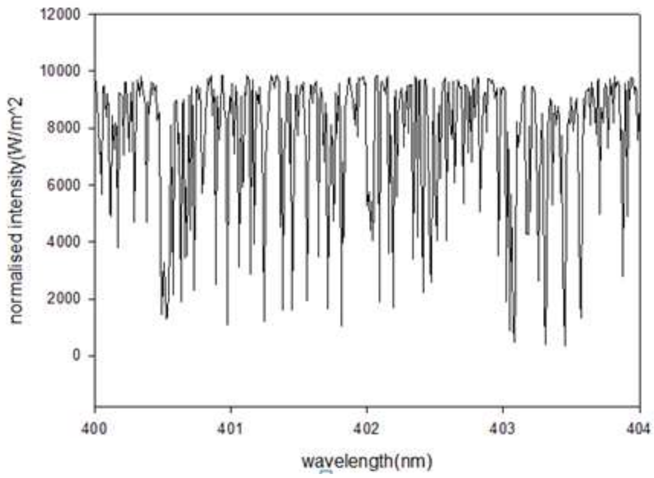

Fig 5: BASS data at near infrared region

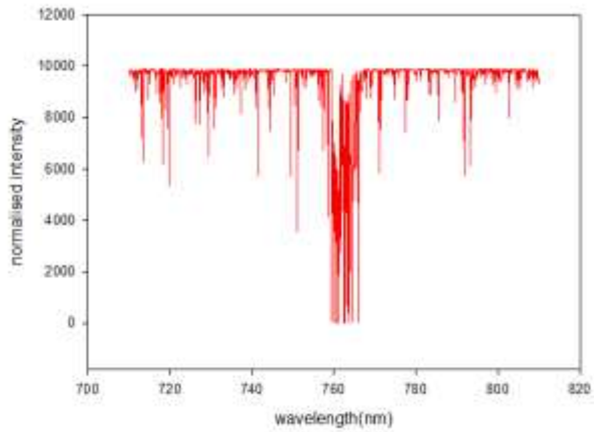

Fig 6: BASS data at visible range

VII. AEROSOL OPTICAL PROPERTIES

The optical properties of aerosol particles and dispersed aerosols can be computed and specified in various ways. The aerosol model input options for MODTRAN 5 include the Modtran canned models, which means models that have the same characters as the field of measurements, where the aerosol loading (total amount) is specified with an optical visibility range or a vertical aerosol optical depth at 550 nm. Other alternatives include Ångstrom law manipulations, spectral Single Scattering Albedo (SSA) inputs, direct inputs of spectral absorption and scattering coefficients as well as spectral phase function inputs. In this case, Ångstrom law manipulations and spectral SSA inputs were provided to MODTRAN on the basis of Micro TOPS measurements at the dam combined with AERONET measurements at CSIR. Aerosol optical property inputs to MODTRAN were fine-tuned to best match the Micro TOPS measurements, AERONET measurements and also the diffuse/global spectral irradiance ratio at Roodeplaat obtained with the ASD.

VIII. FIELD AOT RESULTS AND DISCUSSION

Sensitivity analysis study will be conducted in correction of the possible uncertainties.

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TABLE I: MICRO TOPS SUN II PHOTOMETER DATA FOR ROODEPLAAT DAM AND CSIR AERONET.

INTER-COMPARISON OF THE MICRO TOPS AND THE AERONET

Location/Date	Instruments	AOT (440nm)	AOT (500nm)	AOT(675nm)	Water Vapour (cm)	Altitude(m)
Roodeplaat Dam/	Micro tops	0.67	0.58	0.34	1.05	1.23
CSIR	Aeronet					
05/06/2016		0.59	0.48	0.28	1.06	1.45

Table 1 shows the Roodeplaat dam aerosols having higher atmospheric aerosol optical depth which may be due to several things, such as dust particles, the presence of trees and green veldts around the dam, biomass burning that comes from nearby cities floated by wind since it's the change of the season. This contributes more on the adjacency effect of the dam images. The aerosol optical thickness (AOT) decreases with the altitude meaning there are thicker aerosol particles in the lower part of the Earth surface. The water vapor decreases with the altitude thus Roodeplaat water vapour is lower than the CSIR Aeronet. The micro tops sun II photo meter altitude is detected by the instruments according to the location of the measured in situ data.

Fig 7: Microtops II sun photometer data at Roodeplaat dam .

From figure 2 The AOT shows a slight curvature which decreases with an increase in wavelength. When the light strikes an aerosol particle few properties happen i.e absorption, reflection and scattering. However they depend on the type of aerosol. Dark colored aerosol mostly absorbs the sunlight while bright colored aerosol reflects the sunlight (https://earthobservatory.nasa.gov, 24/08/2017). Roodeplaat dam aerosol is bright because of the partly green layer covering the top of water due to the process of Eutrophication. Aerosol Particles are larger in lower part of the Earth surface meaning the wavelength of the incident light striking the particle is small and results into forward scattering which is the phase-function atmospheric model. The smaller the aerosol particle the higher the light strikes the particle the more the scattering of the light in to different directions.

IX. SATELLITE AND R_{rs} COMPARISON AND SENSITIVITY

The Roodeplaat readings were conducted near the dam water at the satellite sport on figure 11. The study will analyse at visible and near infrared region where it is easy to distinguish the atmospheric noise and gas impacts. Readings were taken on a clear and uncloudy day but due to winter season factors there was a little bit of smoke in the morning but as the satellite passes it was clean and clear. The ASD on figure 8 provides Rrs spectrum and figure 9 and 10 are the two satellite pictures of the Roodeplaat dam.

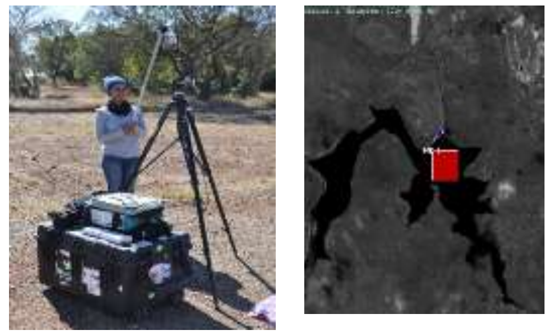

Fig.8(a)Roodeplat dam ASD setup and Fig. 9(b) Roodeplaat dam satellite image

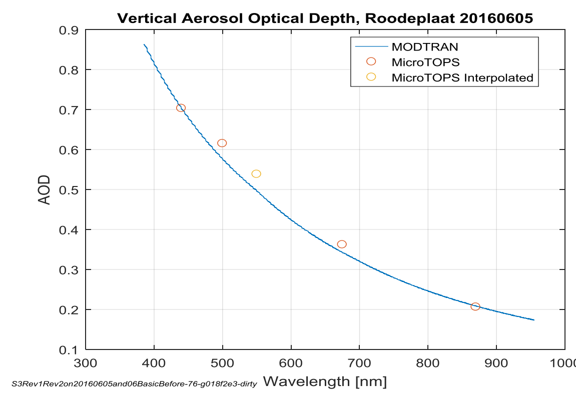

Fig 10: Roodeplaat dm satellite image

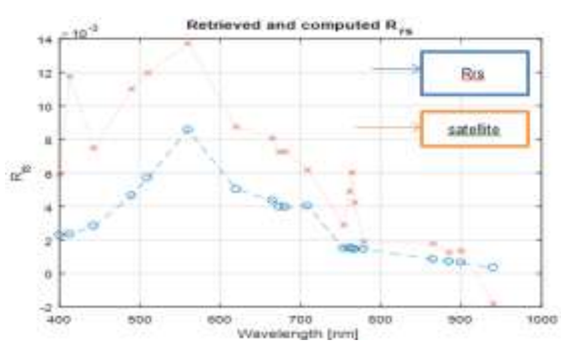

Fig.11 Retrieved Remote sensing reflectance of water leaving radiance versus Retrieved Sentinel3 data. That is possible be of the adjacency effect, the sentinel 3 picked up signal but the Rrs shows absorption.

Both satellite and Rrs show a slight reflection from the wavelength 400nm but the satellite after points 0.011 W/m^2 for satellite a deep absorptions occur to point 0.051 this maybe caused by the atmospheric absorption lines show by the Bass data on the RTM's. After this point both satellite and Rrs have

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nice reflection of the signal in the visible range region. After 550nm a quick absorption is observed from both the instruments, this is the red region of the visible range spectrum where water absorbs more sunlight due to water vapour vibrations (www1.lsbu.ac.uk/water/water_vibrational_spectrum.html). Water absorbs more sun on the infrared region but the satellite picked up some reflection from 750nm until 780nm while Rrs was completely absorbed. The rest absorption of the near infrared since water is completely absorbed in the infrared region those points are also affected.

X. UNCERTANITIES AND ASSUMPTIONS

Figure 11 was ran in modtran at rural area canned modtran model however Roodeplaat dam is situated in Pretoria outskirts, where it is clearly rural environment area but due to atmospheric disturbances at times the results may be affected by the smoke coming from different areas around the dam city through wind. Each year during winter season there is a burning of veldts which is now an urban view environment character.

XI. CONCLUSION

The atmosphere has a very important influence on satellite remote sensing views of the Earth surface. Particularly for dark and small targets such as inland water bodies, it is necessary to perform atmospheric correction/compensation of raw satellite EO data. The effect is increasingly pronounced with increasing off-nadir view angles. Aerosols are the most dynamic atmospheric component in cloud-free views and knowledge of aerosol loading and optical properties is required for accurate retrievals of BOA radiant variables. In this application, this knowledge can only be obtained through integration of satellite and in-situ measurements such as those offered by AERONET. Measurement of the spectral diffuse/global irradiance ratio at BOA provides a more robust way of tuning the aerosol optical model than measurement and use of absolute spectral irradiance. This information can be very useful in resolving the satellite observation.

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