ANALYSIS ON THE QUALITY OF AEROSOL OPTICAL THICKNESS DATA DERIVED FROM NPP VIIRS AND AQUA MODIS OVER WESTERN REGION OF INDONESIA

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Abstract. Preliminary analysis on quality data of Aerosol Optical Thickness/Depth or AOT/AOD derived from NPP VIIRS EDR (Environmental Data Record) has been done in previous work. Qualitative analysis of the previous work revealed that AOT data of VIIRS had insufficient quality due to some factors such as sun glint and cloud cover. However the accuracy of AOT VIIRS data over western area of Indonesia has not been investigated. Therefore this paper describes further analysis on AOT VIIRS data quality and accuracy. Comparison with AOT derived from Aqua MODIS data was implemented since AOT of MODIS has verified well with AOT data from field observation. Examination on cloud masking intermediate product of VIIRS was done for its importance in AOT data processing and persistent cloud cover obstacle over Indonesia. We used VIIRS and MODIS data archieved by LAPAN ground station. Further analysis on sun glint and cloud masking images indicates that these two intermediate products predominantly affect the quality of AOT from VIIRS and MODIS over the study areas. Compared with AOT of MODIS, AOT of VIIRS seems to result more pixels consisting AOT information over the same area and date. The statistical results showed that AOT values of VIIRS highly correlated with AOT values of MODIS with R^2 of 78%. The accuracy of AOT derived from VIIRS was adequate as indicated by RMSE of 0.0977 or less than 0.5 for the samples over Sumatra, Borneo, and Java islands. Visual comparison of AOT images indicates that VIIRS data could result more detailed AOT values than MODIS data. Therefore the AOT of VIIRS data could be recommended for further applications in western area of Indonesia.

Keywords: *aerosol optical thickness, NPP VIIRS EDR, Aqua MODIS, sun glint, cloud masking*

1 INTRODUCTION

Data sensor Visible Infrared Imaging Radiometer Suite (VIIRS) on the satellite Suomi National Polar-Orbiting Partnership (NPP) can be processed to produce various data products. NPP-VIIRS sensor has similar capabilities to MODIS sensor on Terra and Aqua satellites, but it has a wider coverage of 3,000 km compared with 2,330 km on MODIS. Thus, the observation coverage VIIRS for further utilization is also expected better. In addition, VIIRS sensor has a higher spatial resolution, especially at the edges of the coverage. Based on LAPAN's experience in using MODIS data, NPP-VIIRS data products can be developed and operated in the future for natural resources and environment observations.

VIIRS data products which has been developed or operationalized include geobiophysical parameters for land areas such as land surface temperature, vegetation index, and hotspots, while for the sea area are sea surface temperature (SST), as well as for the atmosphere as Aerosol Optical Depth (AOD). Aerosol Optical Depth (AOD) or also called Aerosol Optical Thickness (AOT) denoted by τ is the extinction coefficient over vertical atmospheric column at horizontal line unit. Extinction coefficient is a fractional decimation of radiance per unit of line length (it is also called as attenuation in the radar signal). AOT data is used to the satellite data atmospheric correction in medium and high resolution, air quality observations, air visibility, monitoring sources and sinks (source and sink) aerosol, health, monitoring volcanic eruptions and forest fires, the earth radiation balance, and climate change.

AOT data processing from VIIRS is basically developed from the successful AOT processing from AVHRR and MODIS data (Retalis *et al.*, 2010). AVHRR data has resulted the recording of long term aerosol climate data from 1981 to 2009. The climatology of aerosol data is the longest data records that can be used for climate studies as well as ancillary data sources for AOT processing (Chan *et al.*, 2013). There are three options of AOT data processing algorithms derived from MODIS radiance. One of them is AOT algorithm over ocean developed by Remer *et al.*, (2005). The other two algorithms are AOT over land which is called Dark algorithm-Target by Levy *et al.*, (2007) and the Deep-Blue algorithms for surface brighter by Hsu *et al.*, (2004). In addition, AOT over land can also be derived from SeaWiFS data which is based on top of atmosphere (TOA) radiance processing (Von Hoyningen-Huene *et al.*, 2003).

AOT data products from MODIS have been validated with in-situ data using sun-photometer and the result showed a significant correlation (r = 0.83) (Retalis *et al.*, 2010). Research on AOT data quality data products at 550 nm derived from MODIS data was carried out and validated by the data aerosol measurements of the Earth's surface at observation stations AERONET and generate an error average of 0.03 or 17% relative to the AOT data average based on observation field. Research on the effect of data level on the AOT processing from MODIS has been done by analyzing the role of the count pixels on the spatial aggregation from the Level 2 to Level 3 products as well as the effect of AOT uncertainty at Level-3 of horizontal global irradiance (Ruiz-Arias *et al.*, 2013).

AOT data processing from VIIRS is generally adopted from AOT models that have been developed by Dubovik *et al.*, (2001). Initial evaluation and validation of AOT VIIRS data was done using global aerosol data from AERONET (Kennedy *et al.*, 2013). The results showed that the bias of AOT data compared with the AERONET data was about 0.02 with 0.05 standard error over ocean and 0.12 over land. The use of AERONET data for AOT estimation was done and resulted determinant coefficient (R2) 68% and the results was validated by LIDAR data (Tan *et al.*, 2014). Although the testing of MODIS AOT data quality had been done in several places, but the data quality has not been evaluated for Southeast Asian region, particularly for Indonesia (Adiningsih *et al.*, 2015).

This research was done for selected areas in Sumatra and Borneo to represent western region of Indonesia, since information about aerosol over these areas is needed to determine the level of air pollution and visibility. Another reason is associated with the spread of smog (smoke fog) from forest and land fires that often occur in these two areas. According to Podgorny *et al.*, (2003) and Graf et al. (2009), during smog episode from fires in Indonesia in 1997, there was a significant increase of aerosol that ultimately affects the clouds and rainfall.

This research was conducted to further develop the results from the previous studies which have been presented at the National Seminar on Remote Sensing in 2015 (Adiningsih *et al.*, 2015). The previous study reviewed the quality of AOT data from VIIRS based on qualitative analysis. AOT data at several wavelengths were tested by Cesnulyte et al., (2014) which showed that AOT at 500 ~ 550 nm was significantly correlated with AOT data of field observation. Therefore, this research was focused on the AOT data of 550 nm wavelength. AOT data from field measurements over a large area in Indonesia is very difficult to obtain. Meanwhile, AOT accuracy of MODIS data was successfully investigated by Retalis et al (2010) with good results for the Cyprus island. Therefore AOT of MODIS data can be used to compare the quality and accuracy of AOT VIIRS data. The objective of this research was to analyze the quality and accuracy of AOT VIIRS data at 550 nm wavelength which was compared with AOT data from Aqua MODIS at 550 nm for western region of Indonesia.

2 MATERIALS AND METHODOLOGY

2.1 Data

NPP VIIRS and Aqua MODIS data for this research was obtained on August 11, 2013, August 5, 2014, and August 11, 2015 over western region of Indonesia. Data acquisition time was between 05:39 am to 06:48 am UTC in accordance with the satellite path line over western region of Indonesia. This period was chosen since there were many forest and land fires in Sumatera and Borneo, which produced smog and could increase the aerosol content in the atmosphere.

2.2. Methods

As it has been done in the initial analysis (Adiningsih *et al.*, 2015), AOT VIIRS data extraction refers to Algorithm Theoretical Basis Document (ATBD) published by the Joint Polar Satellite System (JPSS) on NASA (Goddard Space Flight Center, 2013) with a model developed by Dubovik *et al.*, (2001). Data processing was done using an open source software namely Community Satellite Processing Package (CSPP) published by the University of Wisconsin. We used ENVI for further data processing and visualization.

Furthermore, the estimated AOT values was calculated by the following equation (2-1) and (2-2) below (Jackson *et al.*, 2013), with τ_A is AOT, θ_S is the solar incidence angle, θ_A is the zenith angle, P is the air pressure surface, and ρ is the atmospheric reflectance due to Raleigh scattering and aerosol scattering. The extraction of AOT values from VIIRS data includes three main stages as follows (Goddard Flight Center, 2013; Jackson *et al.*, 2013):

a) Raw data processing to generate Sensor Data Record (SDR) using data of band M1, M2, M3, M5, M6, M7, M8, M10, M11 from VIIRS sensor that works on a range of 0.412 to 2.25 µm to fit with lookup table (LUT) to obtain aerosol data. Then, we did the masking and pixels selection for internal filter test stage to determine the characteristics of the surface conditions using data of band M4, M9, M12, M15, M16. Data from the band M4, M9, M12 were used for internal testing over land area, masking and selecting pixels (shallow water, cirrus clouds). Data of band M15, M16 were used for internal testing over land and sea surface.

The equation to calculate the AOT was (Jackson *et al.*, 2013): ….. (2-1)

$$\rho_{\text{toa}}(\tau_A) = Tg_{og}\, Tg_{O_3} \begin{bmatrix} \rho_A(\tau_A)\, Tg_{H_2O}(U_{H_2O}/2) + \rho_R(P) \\ +Tg_{H_2O}(U_{H_2O}) \begin{pmatrix} T_{R+A}(\tau_A, \theta_s)\, T_{R+A}(\tau_A, \theta_v) \dfrac{\rho_{\text{surf}}}{1 - S_{R+A}\rho_{\text{surf}}} \\ +(\text{non-Lambertian terms}) \end{pmatrix} \end{bmatrix}$$

$$\rho_A(\tau_A) = \rho_{R+A}(\tau_A) - \rho_R(P_0)$$

….. (2-2)

b) Input intermediate products, especially cloud mask IP (Intermediate Product) into the process. Cloud Mask IP consists of cloud identification and cloud avoidance stages. The next stage is sun glint avoiding over the sea, by calculating the glint based on the geometry and recognizing pixels which have specular reflectance more than 36°. The next stage is fire avoidance over land. In this case, the pixel is detected as ire if the value of Middle Infrared Anomaly (MIRA) is greater than 0.1. The next stage is brighter surface avoidance over land, and the last stage is snow/ice avoidance.
c) Calculation of AOT values and saved as EDR level data. In this process, we used ancillary data consisting of perceptible Water (cm), Surface Temperature (K), Wind speed (m/s), Wind direction, Ozone (atm-cm), and Surface Pressure (hPa).

The results of AOT processing from VIIRS were then compared with AOT from Aqua MODIS. AOT image analysis was conducted qualitatively. To determine the accuracy of AOT VIIRS data, we took AOT value samples of 30 points for the three-date data over Sumatra, Borneo, and Java. Hence, we obtained 90 AOT value samples varied from 0.2 to 0.9. Determinant coefficient (R2) and the mean error (Root Mean Square Error or RMSE) were calculated to determine the correlation and accuracy of AOT data from VIIRS compared with AOT data from the MODIS.

3 RESULTS AND DISCUSSION

3.1 Image Analysis of VIIRS AOT and MODIS AOT

The results of daily VIIRS data processing in August 2013, 2014, and 2015 presented in AOT images of VIIRS and MODIS are shown in Figure 3-1, 3-2, and 3-3. Figure 3-1, 3-2, and 3-3 show that AOT values over western region of Indonesia, especially Sumatera and Borneo, are relatively high compared to other regions. The resulted imageries appear to be less "smooth". As described in the method, AOT data processing, both for land and sea, used LUT and ancillary data derived from in-situ measurements and aerosol climatology data recording. The use of LUT and ancillary data is very critical related to dynamic atmospheric condition over Indonesia. Since AOT climatology data sources used were obtained from AERONET data and the observation stations in Indonesia was still very limited, so the update was lacking.

Besides, we found large blank areas over nadir area of the daily imageries which did not contain AOT data. If we traced from RGB imageries resulted by the previous study (Adiningsih *et al.*, 2015), the surface conditions with excessive brightness always appeared in the central part of VIIRS data which was acquired by the Ground Station in Parepare, South Sulawesi. The condition was also caused by the implementation of algorithms and data processing stages, in which the area was classified as a "brighter surface". Since the algorithm used the principle of "brighter surface avoidance" from the effects of sun glint at nadir area, the daily AOT data products always produce the blank area in the central of data scope. The result ofAOT data products derived from VIIRS and Aqua MODIS are shown in Figure 3-1, 3-2, and 3-3. Outside the blank area, generally the AOT values of VIIRS tends to be higher than AOT values of MODIS.

Other factor that has been identified from AOT of VIIRS data in the previous study (Adiningsih *et al.*, 2015) is related to the cloud classification in cloud mask product. The atmosphere over western region of Indonesia is frequently covered by clouds. The accuracy of satellite derived AOT was studied for AVHRR and MODIS data which showed uncertainty in errors related to aerosol optical characteristics, particle distribution, and form of aerosol particles around nadir area. Meanwhile, the error is relatively smaller for larger viewing angle (off nadir) (Chylek *et al.*, 2003). The results of previous studies (Chylek *et al.*, 2003; Adiningsih et al. 2015) resulted AOT imageries of VIIRS data with blank area around nadir due to sun glint effect. In this study, the AOT imageries resulted from Aqua MODIS data (Figure 3-1b, 3-2b and 3-3b) are consistent with the previous studies.

Beside the sun glint effect that produces "no AOT data" over nadir area, especially over sea, the effects of cloud cover that produces cloud masking needs to be further analyzed. Therefore, in the next section, we described the effect of cloud masking o the AOT data quality.

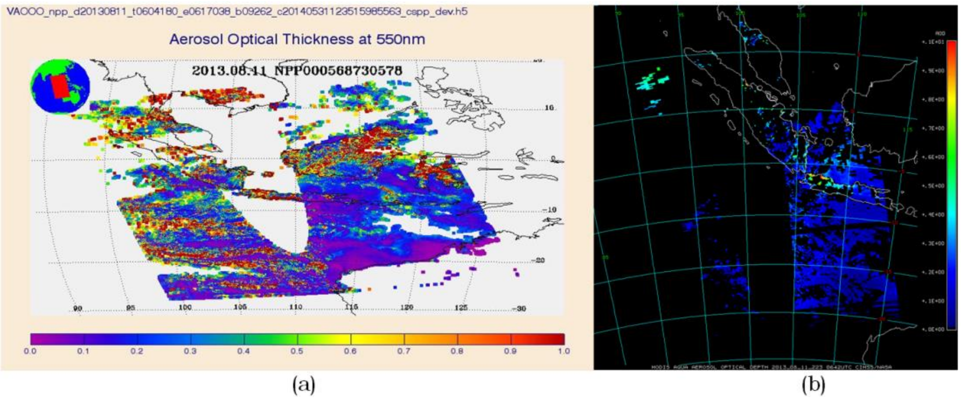


Figure 3-1: AOT over western region of Indonesia on 11 August 2013: (a) derived from VIIRS at 06:04 UTC (Adiningsih *et al.,* 2015); (B) derived from Aqua MODIS at 06:42 UTC

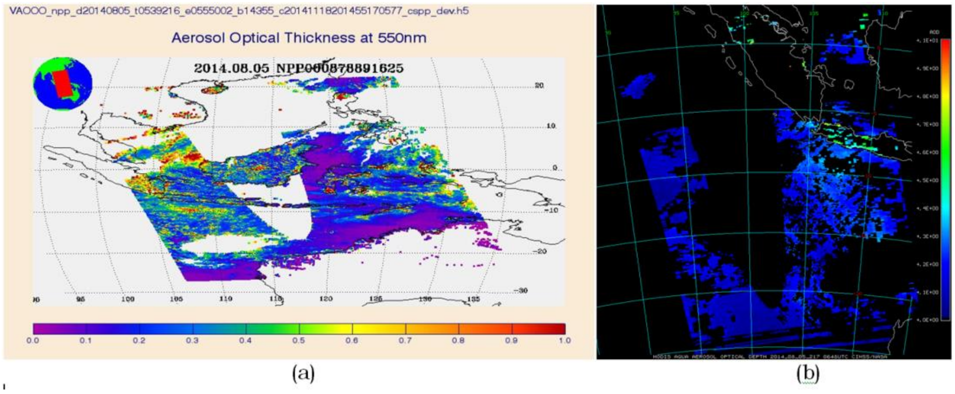


Figure 3-2: AOT over western region of Indonesia on 5 August 2014: (a) derived from VIIRS at 05:39 UTC (Adiningsih et al. 2015); (B) derived from Aqua MODIS at 06:42 UTC

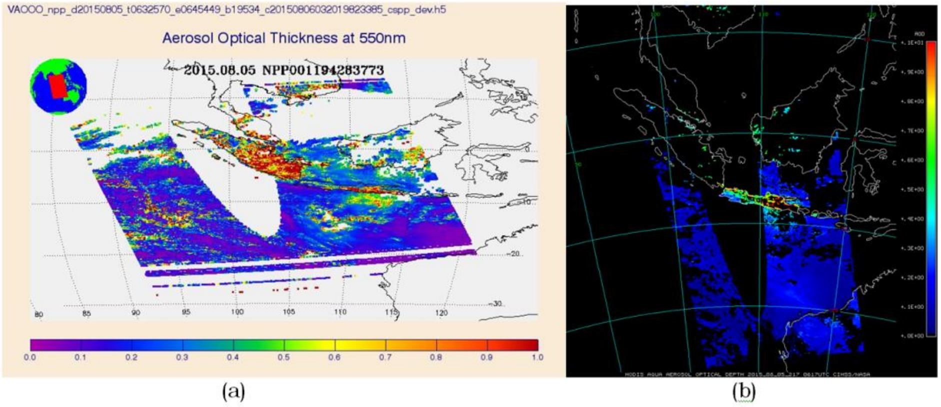
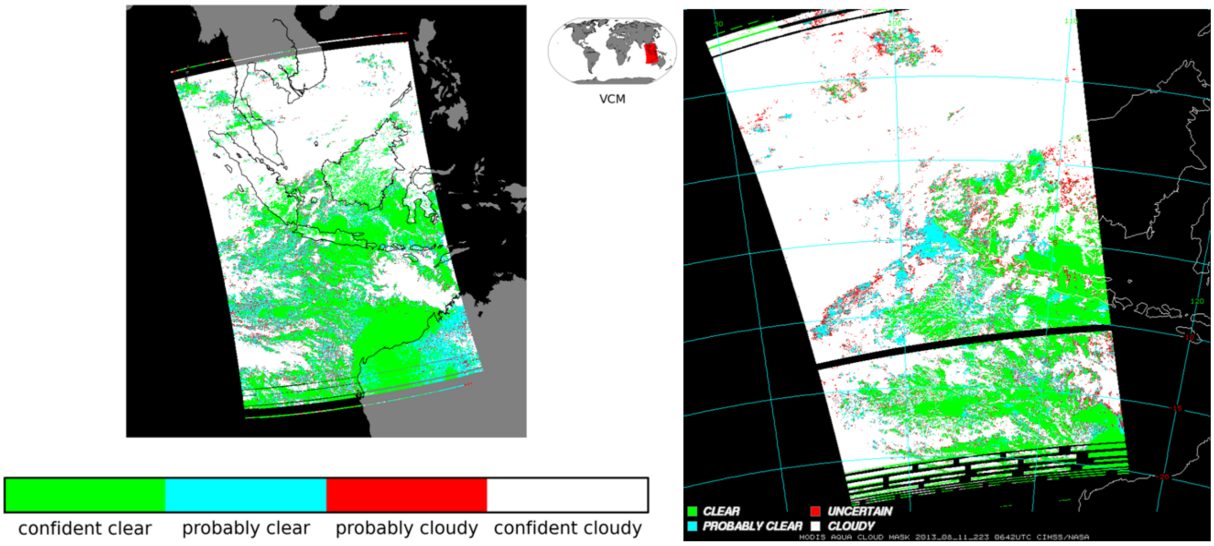


Figure 3-3: AOT over western region of Indonesia on 11 August 2015: (a) derived from VIIRS at 05:39 UTC; (b) derived from Aqua MODIS at 06:42 UTC

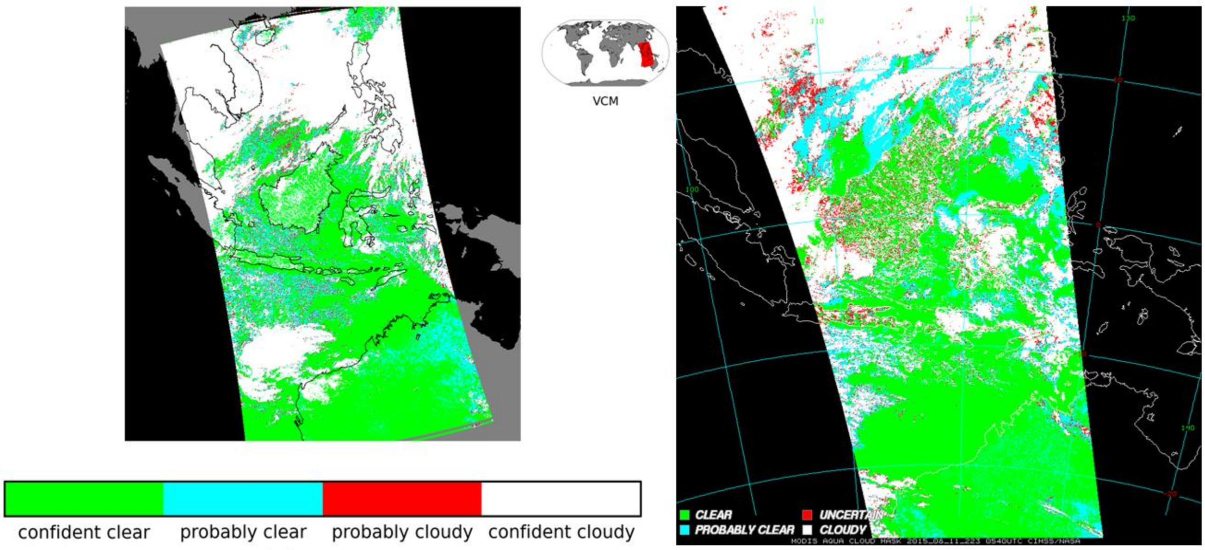
3.2 Analysis of Cloud Masking Effect on the Quality of AOT Data

As described in the methods, one of the important steps in data processing to generate AOT from VIIRS and MODIS data is cloud masking. Figure 3-4 and Figure 3-5 show cloud masking imageries from VIIRS and MODIS which was recorded in the same date in 2013 and 2015. In Figure 3-4b, we can see the cloud masking result from MODIS on August 11, 2013 which shows more "uncertain" (red) class compared to the similar class or "probably clear" from the VIIRS in Figure 3-4a. Similar result is also shown for cloud masking on August 11, 2015 (Figure 3-5).



(a) (b)

Figure 3-4: Cloud masking imageries over western region of Indonesia on 11 August 2013: (a) derived from VIIRS at 06:04 UTC; (b) derived from Aqua MODIS at 06:42 UTC.



(a) (b)

Figure 3-5: Cloud masking imageries over western region of Indonesia on on 11 August 2015: (a) derived from VIIRS at 05:39 UTC; (b) derived from Aqua MODIS at 06:42 UTC

The analysis of cloud masking imageries (Figures 3-4 and 3-5), particularly over West Borneo, South Sumatra and western Java show that MODIS data processing produces more areas of cloudy classes (uncertain and cloudy) than VIIRS data on the same date and location. Besides, for the probably clear class, MODIS data also showed a larger area than the VIIRS data, as seen in South Sumatra. Since AOT value is affected by cloud classification of the cloud masking, so the larger area of clouds in MODIS data causes the larger number of pixels with no AOT values compared with VIIRS data. This result is in line with AOT MODIS imageries which have darker areas (black) or less AOT values as shown in Figure 3-1b, 3-2b and 3-3b. In other words, for the same location and date of data recording, the VIIRS data could produce more AOT information than MODIS data.

3.3 Correlation between AOT of VIIRS with AOT of MODIS

The correlation between AOT from VIIRS with AOT from Aqua MODIS shows a linear relationship between AOT VIIRS with MODIS AOT over Indonesia's western region as seen in Figure 3-6. From the correlation coefficient values, we found the variance was 78%. In addition, the accuracy of AOT derived from VIIRS is categorized better than AOT of MODIS although AOT of MODIS has been widely used and tested in the previous studies (Retalis et al. 2010). This was shown by the RMSE value which was 0.0977 or less than 0.5 for 90 data samples extracted for Sumatra, Borneo, and Java. Based on these results, it can be said that although AOT values derived from VIIRS tend to be overestimated in comparison with AOT from MODIS, but AOT values of VIIRS have better accuracy. Therefore, the AOT data derived from VIIRS can be utilized for further studies and operational observations.

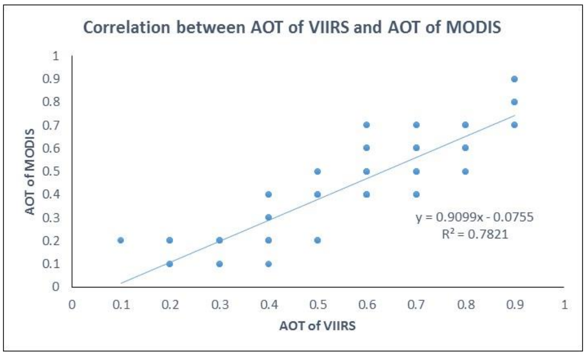


Figure 3-6: Correlation between AOT of VIIRS and AOT of Aqua MODIS on August 2013, 2014, and 2015 over western region of Indonesia

4 CONCLUSION

Based on the analysis on AOT products from VIIRS compared with AOT from MODIS for data records in August 2013, 2014, and 2015, it could be concluded that the quality of AOT derived from VIIRS data is spatially adequate. Cloud masking intermediate product which is used in data processing will influence the quality of AOT imageries resulted from the processing. Cloud masking of the VIIRS data produces fewer cloud pixels, so that VIIRS data could produces more pixels containing AOT data compared with MODIS data. As the variance was 78% and RMSE was 0.0977, AOT of VIIRS data was then considered to have sufficient accuracy and could be used for further applications, particularly over western region of Indonesia.

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