Aerosol Measurements from the VIIRS Instrument During NPOESS

John M. Jackson[1] , Eric Vermote[2] and Eric P. Shettle[3]

[1]Northrop Grumman Space Technology, [2]Dept. of Geography, University of MD, [3]Remote Sensing Division, NRL

Introduction

Abstract:

The National Polar-orbiting Operational Environmental Satellite System [NPOESS] is being developed to replace the current NOAA Polar Orbiting Environmental Satellite (POES) and the DoD Defense Meteorological Satellite Program (DMSP) systems. The instruments generally will represent significant improvements over the current operational sensors. For example the Visible-IR Imager Radiometer Suite [VIIRS] with 22 channels will be replacing the 6-channel Advanced Very High Resolution [AVHRR] on the POES system and the 2-channel Operational Linescan System [OLS] on the DMSP system. Measurements of the atmospheric aerosols from NPOESS, will come from the VIIRS instrument. VIIRS has 22 spectral bands including 16 radiometric bands plus 5 imaging bands and a day-night band. The aerosol related Environmental Data Records (EDRs) will be derived primarily from the radiometric channels covering the visible through the short-wave infrared spectral regions (412 to 2250 nm). The primary aerosol products will be the aerosol optical thickness, the aerosol particle size parameter, and the identification of suspended matter. These aerosol products and their derivation will be described including recent updates to the retrieval algorithms due to changes in the NPOESS System Specification. Pre-launch estimations of on orbit performance have been derived using MODIS measurements to simulate the radiances measured by VIIRS, comparing the retrieved aerosol properties with AERONET match-up data. Results over both land and ocean will be included.

AOT Requirements:

Aerosol optical thickness (AOT), for this EDR, is defined as the extinction (scattering + absorption) optical thickness of the vertical column above the geolocation of the horizontal cell in a narrow band about the specified wavelength. Optical thickness (tau) is related to transmission by t = exp (-tau).

Paragraph	Subject	Specified Value
	a. Horizontal Cell Size	
40.3.1.1-1b 40.3.1.1-1c 40.3.1.1-1d	2. Over Land and Ocean Nadir Edge of Scan	 6 km 12.8 km
40.3.1.1-2	b. Horizontal Reporting Interval	HCS
40.3.1.1-3	c. Vertical Cell Size	Total Column
40.3.1.1-7	d. Vertical Reporting Interval	Vertical Cell Size
40.3.1.1-8	e. Horizontal Coverage	Global
40.3.1.1-9	f. Vertical Coverage	0 – 50 km
	g. Measurement Range	
40.3.1.1-10	1. Operational	0 .0 to 2.0 units of Tau
	h. Measurement Uncertainty	
40.3.1.1-11b	2. Operational, Over Ocean	0.03 + 0.05 Tau
40.3.1.1-12b	5. Operational, Over Land	0.05 + 0.15 Tau
	i. Measurement Precision	
40.3.1.1-13b	2. Operational, Over Ocean	0.02 + 0.03 Tau
40.3.1.1-13c	3. Operational, Over Land	0.04 + 0.1 Tau
40.3.1.1-14	j. Long Term Stability	0.01
40.3.1.1-15	k. Mapping Uncertainty, 3 Sigma	1.5 km
40.3.1.1-16	l. Maximum Local Average Revisit Time, Operational	24 hrs (Daytime Only)
40.3.1.1-27	p. Latency	NPP - 140 min. NPOESS - 28 min.
	n. Measurement Degradation Conditions:	
40.3.1.1-26b	2. Measurement Precision If Solar Zenith Angle 65 to 80 deg	Degrade by 50% (TBR)
40.3.1.1-26c	3. Measurement Uncertainty If Solar Zenith Angle 65 to 80 deg	Degrade by 50% (TBR)
	o. Excluded Measurement Conditions	
40.3.1.1-25a	1. Solar Zenith Angle > 80 deg	
40.3.1.1-25b	2. Over Ocean With Sun Glint < 36 deg	
40.3.1.1-25c	3. Over Land Without Dense Vegetation (i.e., Without Dark Pixel in 2.25 micrometer Band)	
40.3.1.1-25d	4. Over ocean with the ratio of the atmospherically-corrected radiance of Band M3 to Band M5 is greater than or equal to 0.95 (TBR).	
40.3.1.1-25e	5. Regions of Ice and Snow Cover	
40.3.1.1-25f	6. Inland Water	
40.3.1.1-25g	7. Turbid Water, mass loading > 60 mg/l	

Overview of the AOT Algorithm

Data Screening:

The following conditions are screened out using information provided by the VIIRS Cloud Mask and internal tests in the AOT code.

Land: Clouds, cloud edges, cloud shadows, snow / ice, arid surfaces and sub-pixel water

Ocean: Clouds, cloud edges, cloud shadows, sea ice and shallow / turbid water

Core Land AOT Inversion:

Following the MODIS approach for retrieval of aerosol over Land, the surface reflectance in the red (672 nm) and blue (488 nm) bands is estimated from the TOA reflectance in the 2.25 μm band, enabling simultaneous retrieval of the AOT and aerosol model. First, solve the Lambertian surface reflectance equation for AOT using TOA reflectance in 488 nm band:

$$\rho_{toa}(\tau_A) = Tg_{og}Tg_{O_3}\left[\begin{array}{l}(\rho_{R+A}(\tau_A)-\rho_R(P_0))Tg_{H_2O}(U_{H_2O}/2)+\rho_R(P)\\ +Tg_{H_2O}(U_{H_2O})T_{R+A}(\tau_A,\theta_s)T_{R+A}(\tau_A,\theta_v)\dfrac{\rho_{surf}}{1-S_{R+A}\rho_{surf}}\end{array}\right]$$

Then, for each aerosol model, solve for TOA reflectance at 672 nm using AOT derived from 488 nm band. Select the model with best match to observe TOA 672 nm reflectance.

Core Ocean AOT Inversion:

Following the MODIS approach, TOA reflectance is modeled as the sum of the TOA reflectances from the fine mode and coarse mode aerosols:

$$\rho^c_{toa}(\tau_a) = \eta\rho^s_{toa}(\tau_a) + (1-\eta)\rho^l_{toa}(\tau_a)$$

Then, solve the bi-directional surface reflectance equation for AOT (6S approximation) using the TOA reflectance in the 12.4 μm band

$$\rho_{toa} = Tg_{og}Tg_{O_3}\left[\begin{array}{l}(\rho_{R+A}-\rho_R(P_0))Tg_{H_2O}(U_{H_2O}/2)+\rho_R(P)\\ +Tg_{H_2O}(U_{H_2O})\left[\begin{array}{l}T_{R+A}(\theta_s)T_{R+A}(\theta_v)\dfrac{\rho_{w+wc}}{1-S_{R+A}\rho_{w+wc}}+e^{-\tau_{R+A}m}\rho_G\\ +t^d_{R+A}(\theta_s)e^{-\tau_{R+A}/\cos(\theta_v)}\overline{\rho_G}+t^d_{R+A}(\theta_v)e^{-\tau_{R+A}/\cos(\theta_s)}\overline{\rho_G}'\\ +t^d_{R+A}(\theta_s)t^d_{R+A}(\theta_v)\overline{\overline{\rho_G}}+\dfrac{T_{R+A}(\theta_s)T_{R+A}(\theta_v)S_{R+A}\overline{\overline{\rho_G}}^2}{1-S_{R+A}\overline{\overline{\rho_G}}}\end{array}\right]\end{array}\right]$$

For each ocean model combination solve for the TOA reflectances in the .672, .865, 1.61 and 2.25 μm bands using the AOT derived from the 1.24 μm band and compute the residual:

Select ocean model combination with the lowest residual.

$$\mathrm{Residual}^c = \sum_{i=1}^{n}\left(\rho^c_{toa}(\tau^{inv}_a)^i - \rho^i_{obs}\right)^2$$

Recent Enhancements to the AOT Algorithm

Horizontal Cell Size changed to 6 km (nadir)
- 8x8 moderate resolution pixel aggregation
- Same HCS over both land and ocean
- Improved spatial resolution compared to MODIS

Screen outliers prior to aggregation of EDR
All quality flags have been updated to reflect the new logic

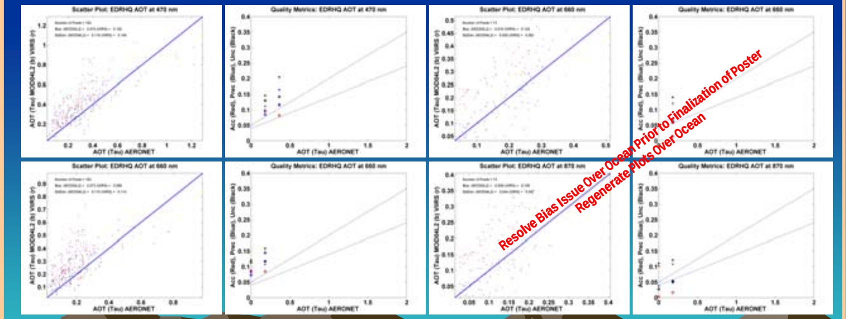
Incorporated MODIS turbid water test over ocean
Using VIIRS Cloud Mask Heavy Aerosol flag to process heavy aerosols previously identified as clouds
Using VIIRS Cloud Mask Volcanic Ash flag to correctly identified volcanic ash for the Suspended Matter EDR

Testing with AERONET Match-up Data

MODIS / AERONET match-up data and analysis methodology provided by the MODIS Aerosol Validation website. High quality MODIS data is aggregated in a 5x5 cell centered on the AERONET site 5 out of 25 valid retrievals are required for a valid match-up. Quality controlled (L1.5) AERONET retrievals are averaged from +/-30 minutes from the MODIS overpass. AERONET retrievals at 440 nm and 870 nm are interpolated linearly in log space to the MODIS AOT retrieval wavelengths (470 nm, 550 nm and 660 nm over land and 470 nm, 550 nm, 660 and 870 nm over ocean). High quality VIIRS AOT EDR retrievals are aggregated to the same 5x5 cell. 5 out of 25 valid retrievals are required for a valid match-up. 55 granules of MODIS data processed through the VIIRS Aerosol algorithm producing 311 valid match-ups over land and 87 valid match-up over ocean.

AERONET Locations

Performance Results from AERONET Match-up Data

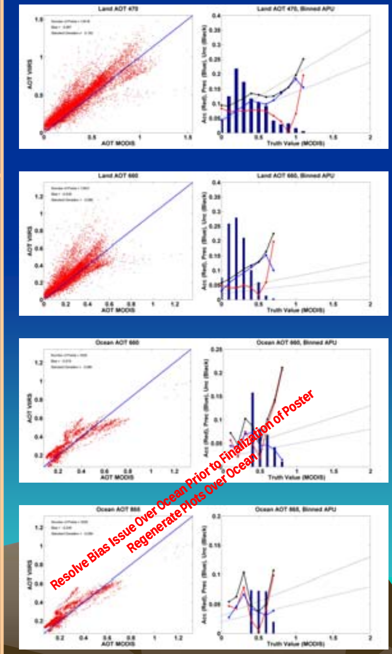


VIIRS AOT Performance over land is comparable to the performance of the MODIS Aerosol Product. Since the NPOESS System Specification requirements are based on MODIS demonstrated performance, it is expected that the VIIRS AOT product has a reasonable probability of achieving requirements.

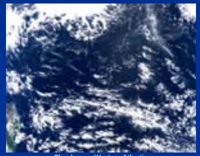
VIIRS AOT Performance over ocean is comparable to the performance of the MODIS Aerosol Product. Since the NPOESS System Specification requirements are based on MODIS demonstrated performance, it is expected that the VIIRS AOT product has a reasonable probability of achieving requirements.

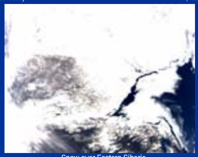
Testing with Selected MODIS Granules

The VIIRS AOT EDR was compared to the MODIS Collection 5 Aerosol Product for a set of five granules. The aggregate statistics were used to generate the following scatter plots and APU plots.



Smoke over Southeastern Africa
(2000.258.0830)


Clouds over Western Atlantic
(2001.213.1220)


Snow over Eastern Siberia
(2002.118.0215)

Dust over Red Sea
(2002.121.0750)

Dust over Arabia
(2003.151.0735)

Conclusions

Comparison of the VIIRS AOT retrievals with AERONET match-up data and the MODIS Collection 5 Aerosol product shows significant agreement. The match is not good enough to conclude with certainty that the VIIRS Aerosol EDR will meet NPOESS System requirements, but the results are encouraging. A number of enhancements that have been implemented in the MODIS Collection 5 Aerosol product (such as a more sophisticated approach to estimating surface reflectance over land) have not yet been implemented in the VIIRS AOT algorithm. Implementing these enhancements for NPOESS should provide performance margin.