Aerosol Single Scattering Albedo and Layer Height using VIIRS and OMPS-NM

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Motivation: Large Variability in Annual Mean vertical distribution of Absorbing Aerosols in Models

- Aerosol Absorption (AA) is one of the outstanding challenges in aerosol research and climate applications.
- Forcing and heating rate computations are critically linked to aerosol single scattering albedo (SSA) and layer height (Z).

There is a need to improve global observations of Aerosol Absorption and Height.
Another Motivation: Better AA information will benefit Current Aerosol Algorithms

Recent Studies Highlight biases in AOD retrievals because lack of aerosol absorption and height information

3.2. Seasonal Analysis of MODIS and MISR AOD Retrievals

Any consistent seasonal shift in SSA has the potential to impact satellite AOD retrievals and thus result in a seasonally varying bias which could be perceived as random noise in a large verification study. Retrieval of AOD from the standard MODIS algorithms, for example, is dependent on the a priori assumption of a value of aerosol absorption [Remer et al., 2005; Levy et al., 2007a, 2007b]. Deviation from the assumed values has a compounding effect on retrieval bias as AODs increase into multiple scattering environments. AERONET measured AOD is highly accurate (~0.01 in the visible and near infrared) and therefore comparison to satellite retrievals allows for analysis of the likely reasons for potential biases, primarily either from errors in characterizing surface reflectance or in allowing for a realistic enough aerosol model. Given the high AODs found in the southern Africa smoke plume, the seasonal variation in AERONET inverted SSA provides a natural laboratory to test the impact of SSA on satellite AOD retrieval error.

Indeed, as we found no systematic seasonal microphysical changes in the retrievals other than absorption, the Mongu site allows the examination of a rarely occurring "partial derivative" of satellite retrieval microphysical models.

To begin, comparisons of AOD retrievals from both Terra and Aqua satellite MODIS sensors against the Mongu AERONET site are presented in Figures 11a and 11b, respectively. Comparisons of AOD are shown for 550 nm with the AERONET data being interpolated to 550 nm. This matchup was described in section 2. To observe the influence of seasonal variation of SSA, data are divided into the three core months of burning, August, September, and October.

Figure 11. Comparison of MODIS retrievals (dark target algorithm) from both (a) Terra 2001–2010 and (b) Aqua 2003–2010 of AOD at 550 nm to AERONET measurements at Mongu, Zambia, with data separated for the primary burning season months of August, September, and October. Figures 11c and 11d are the same as Figures 11a and 11b but for the NRL data assimilation grade MODIS product of Hyer et al. [2011].

Deviation found in SSA assumption

Similarly by a customized aerosol layer

(Eck et al., 2013)

(Wu et al., 2017)
Atmospheric Radiance is distinctively different in the UV

Visible to Near-IR

\[ I_{TOA} = I_{ATM} + I_{SURF} \]

- Surface: difficult to model or assume
- Significant Surface contribution
- Minor Sensitivity to Aerosol absorption
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\[ I_{\text{TOA}} = I_{\text{ATM}} + I_{\text{SURF}} \]

\[ I_{\text{ATM}} \sim I_{\text{RAY}} + I_{\text{AEROSOL}} \]

- Atmospheric Signal is dominated by Rayleigh scattering (easy to model)
- Minor Surface contribution
- Significant Sensitivity to Aerosol Absorption

Example from the Cloud Aerosol Imager

Visible to Near-IR

UV
It’s been a long way to achieve UV to near-IR aerosol retrievals

Past missions did not have the right features

80’s and 90’s : AVHRR/GOES and TOMS
It’s been a long way to achieve UV to near-IR aerosol retrievals

Past missions did not have the right features

80’s and 90’s : AVHRR/GOES and TOMS

2000’s : Aqua and Aura

Simultaneous Spatial Resolution UV-Near IR
The Present is good and the Future bodes very well

VIIRS & OMPS-NM

0.5 km

~50x50 km

Simultaneous Spatial Resolution
UV-Near IR

PACE

~1 km

380 500 2100
Near-UV Vis Near-IR

✓ Simultaneous
✓ Spatial Resolution
✓ UV-Near IR
Aerosol UV Top-of-atmosphere Radiance is an Unconstrained Retrieval

In the UV, aerosol $\tau$, $\omega_o$ and $Z$ modulate the atmospheric path radiance

$$I_{TOA} = I_{ATM}(\tau, \omega_o, Z)$$

Aerosol UV retrievals rely on observations at two bands and the $I_{TOA}$ is modulated by 3 parameters ($\tau, \omega_o, Z$)
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Aerosol UV retrievals rely on observations at two bands and the $I_{\text{TOA}}$ is modulated by 3 parameters ($\tau$, $\omega_0$, $z$)

Derive Aerosol Optical Depth with a VIS sensor (MODIS/VIIRS) and use it to constrain the UV retrieval (2 obs and 2 unknowns, $\omega_0$ and $z$)

All these scenarios have same upwelling radiance
**Existing Methodology using MODIS and OMI synergy**

- **Input**
  \[ \tau_{NUV} = f(\tau_{VIS}, \tau_{NIR}) \]

- **OMI**: Derive SSA and Z
- **MODIS**: Dark Target
- **Outputs**
  \[ \tau_{VIS}, \tau_{NIR} \]

**Aerosol models w/ fixed mode conc. & variable SSA**

**Extrapolate MODIS \(\tau\) to the near-UV**

**Outputs**

- \(Z, \tau_{UV}, \omega_{UV}\)

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\[ \tau_{\text{VIS}}, \tau_{\text{NIR}} \]
\[ z, \tau_{\text{UV}}, \omega_{\text{UV}} \]

Extrapolate MODIS \( \tau \) to the near-UV

**Satheesh et al.**, *Improved assessment of aerosol absorption using OMI-MODIS joint retrieval* (2009)

**Gassó and Torres**, *The role of cloud contamination, aerosol layer height and aerosol model in the assessment of the OMI near-UV retrievals over the ocean* (2016)

Satisfactory results when compared with Lidar
However, OMI and MODIS overlaps are not quite adequate for a systematic retrieval approach.

Both, time difference (cloud formation) and viewing geometry are an impediment for a systematic UV to Near-IR retrieval.

Yellow numbers in grid: Aerosol Index (left)
OMPS-NM High Resolution mode and VIIRS are an improvement.

VIIRS & OMPS-NM

0.5 km

~50x50 km

Simultaneous Spatial Resolution

UV-Near IR

PACE

~1 km

380 500 2100
Near-UV Vis Near-IR

✓ Simultaneous
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OMPS-NM High Resolution Mode and VIIRS are an improvement

- VIIRS & OMPS-NM
  - 0.5 km
  - ~50x50 km

- VIIRS & OMPS-NM High Res Mode
  - ~12x5 km
  - ~12x12 km

- PACE
  - ~1 km
  - 380 500 2100
  - Near-UV Vis Near-IR

Simultaneous Spatial Resolution

UV-Near IR

Simultaneous Spatial Resolution

UV-Near IR

✓ Simultaneous
✓ Spatial Resolution
✓ UV-Near IR
OMPS-NM has two High Resolution Modes

- ~4000 orbits spanning 4 years (1 day / week)
- “High” res ~ 12 x 12 km, similar to OMI
- “Super high” res ~12 x 5 km, Better than OMI!!

~ 12 x 12 km

~ 12 x 5 km
A Synergetic UV to Near-IR Algorithm: Fusion Dark Target – OMAERUV approach

Extrapolate MODIS $\tau$ to the near-UV

Input: $\tau_{\text{NUV}} = f(\tau_{\text{VIS}}, \tau_{\text{NIR}})$

OMPS: Derive SSA and $Z$
- Aerosol models w/fix mode conc. & variable SSA

VIIRS: Dark Target
- Aerosol models w/ variable mode conc. & fixed SSA

Outputs: $\tau_{\text{VIS}}$, $\tau_{\text{NIR}}$

Outputs: $z$, $\omega_{\text{UV}}$

Input: $Z$ & $\omega_{\text{VIS}} = f(\omega_{\text{UV}}, AE)$

Extrapolate MODIS $\omega$ to the VIS

A consistent methodology for retrievals of AOD, SSA and $Z$ using Near-UV to near-IR radiances
A Synergetic UV to Near-IR Algorithm: Fusion Dark Target – OMAERUV approach

Methodology already developed
(Gassó and Torres, 2016)

A consistent methodology for retrievals of AOD, SSA and Z using Near-UV to near-IR radiances

**OMPS**: Derive SSA and Z
Aerosol models w/ fixed mode conc. & variable SSA

**VIIRS**: Dark Target
Aerosol models w/ variable mode conc. & fixed SSA

**Extrapolate MODIS \( \tau \) to the near-UV**

**Extrapolate OMI \( \omega \) to the VIS**

**Input**: \( \tau_{NUV} = f(\tau_{VIS}, \tau_{NIR}) \)

**Outputs**: \( \tau_{VIS}, \tau_{NIR} \)

**Input**: \( Z \& \omega_{VIS} = f(\omega_{UV}, AE) \)

**Outputs**: \( Z, \omega_{UV} \)
Expected Outcome and Summary

• Global Maps of SSA and Z from combined OMPS-NM and VIIRS

• Unified Methodology for Aerosol retrievals of AOD, SSA and Z from the UV to Near IR
Figure 3: Illustration of the standard (or operational, Torres et al., 2013) and hybrid (Satheesh et al., 2009) retrieval schemes. The standard algorithm computes the pair of AOD and SSA at five assumed aerosol heights for the pixel’s viewing geometry (blue solid lines and circles). In a prior step, it selected an aerosol model and surface albedo used in the computation. Each triplet (Z, SSA and AOD) has a corresponding upwelling radiance matching the observed radiance by OMI. To select the final (or retrieved) AOD and SSA for the pixel, the operational algorithm uses a climatological height ($Z_{c-clm}$, red arrow and red dashed lines). The hybrid method uses a VIS AOD (extrapolated to 388nm) as entry point (black arrow and black dashed lines) to determine the Z and SSA using the triplets from the lookup table.
Spatial resolution in near UV sensors has been improving steadily

Example of UV Radiances aggregated at different pixel size over the Nevada Desert (from CAI Band 1)

- **TOMS, OMPS**: 40-60 km x 40-60 km
- **OMI**: 20 km x 13 km
- **CAI-2, PACE, ACE?**: TEMPO, OMPS (JPS1) TropOMI 3-10 km x 3-10 km
- **0.5 - 1 km x 0.5 - 1 km**

- **1970s-1990s**
- **2000s**
- **2017 >**
- **2020s >**