Uncertainty Analysis of Satellite Retrieved Aerosol Optical Properties: Implications for Semi-arid Regions

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Highlights

- Aim to understand the physical processes impacting aerosol optical depth (AOD) remote sensing uncertainties.
- Use a conceptual model to diagnose and assess satellite AOD retrieval uncertainties.
- Develop a simplified radiative transfer model with a propagation of error approach.
- Identify critical values associated with surface albedo and aerosol properties.
- Analyze large errors in satellite AOD retrievals in terms of critical values.

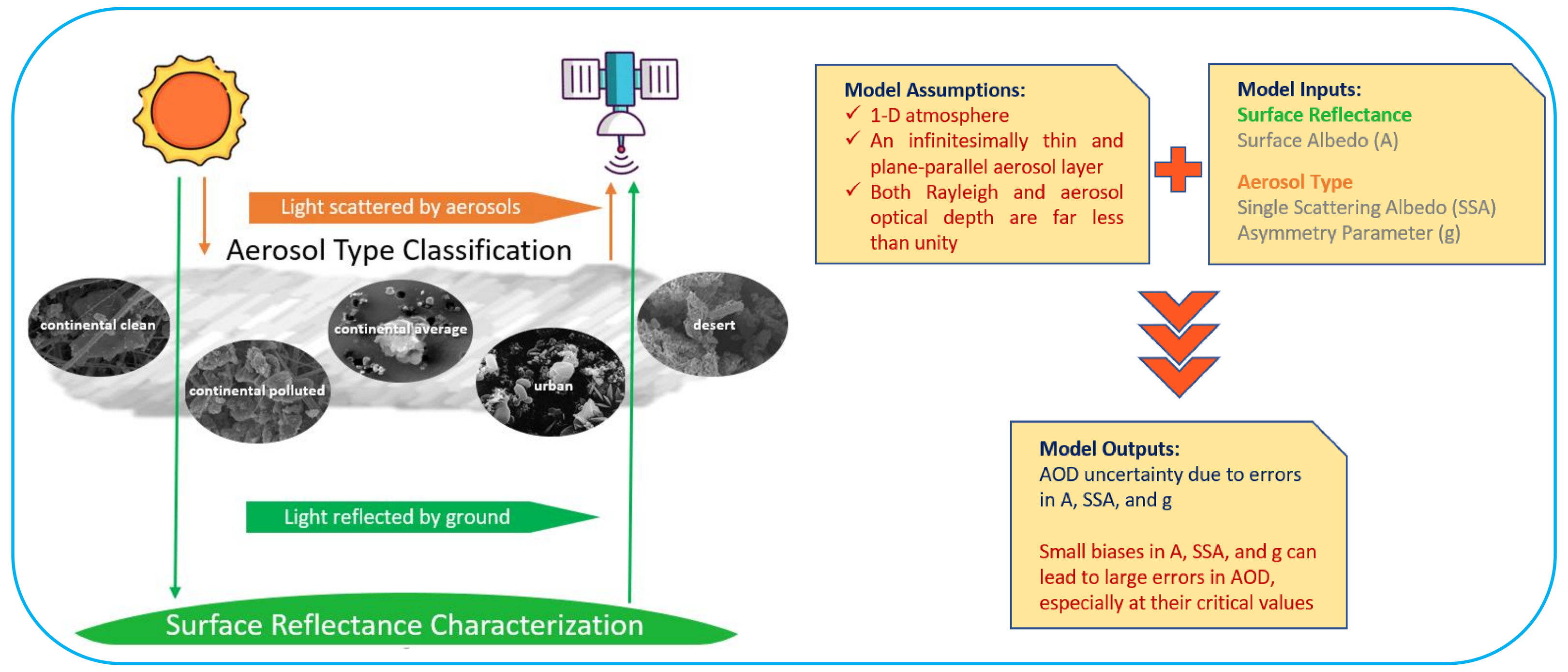
Motivation

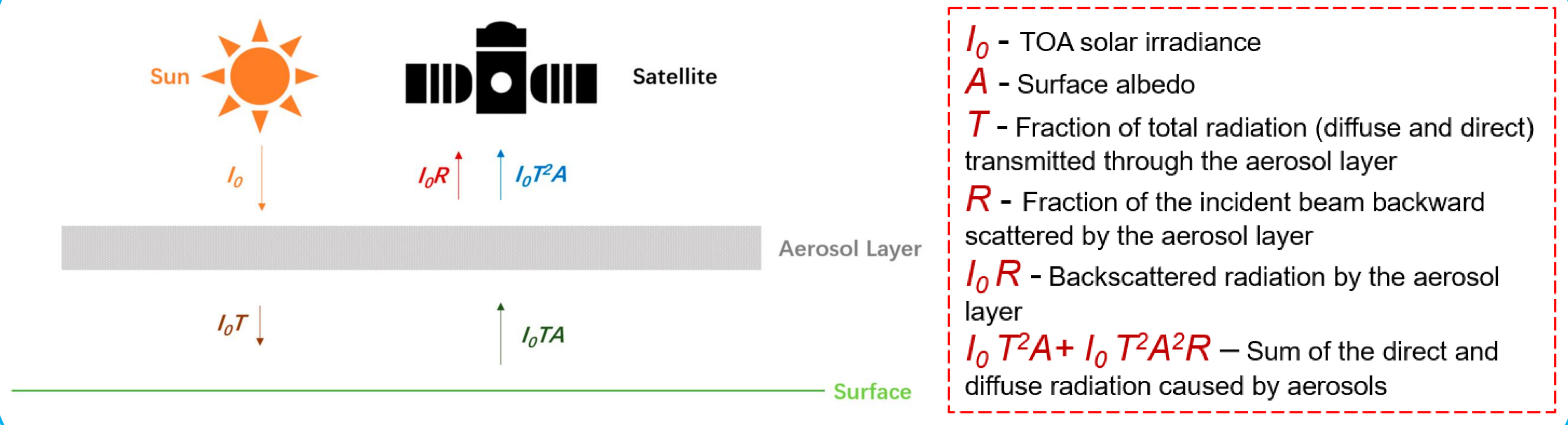
- Difficult to parameterize fundamental aerosol optical properties effectively for use in radiative transfer models (RTMs) due to the spatiotemporal variability.
- About 1% surface albedo uncertainty generally translates to approximately 100% AOD retrieval uncertainty [1].
- Critical surface albedo (CSA) in uncertainty estimates of satellite AOD is defined as the surface albedo where the top-of-atmosphere (TOA) reflectance is insensitive to significant variability in AOD [2].
- Satellite sensors are unable to retrieve the correct aerosol signal at the CSA.

Objectives

- Outline the importance of the critical surface albedo (CSA), critical single scattering albedo (CSSA), and critical asymmetry parameter (CAP) concepts in next-generation satellite AOD products to the scientific user community.
- Elaborate on a mathematical and physical framework to compute uncertainties in satellite AOD retrievals using analytical equations.

Model Development





Analytical method to quantify uncertainty

$$\frac{\partial AOD}{\partial A} \cong \frac{1}{\left[2A\left(1 - SSA\frac{1+g}{2}\right) - (1+A^2)SSA\frac{1-g}{2}\right]}$$

$$\frac{\partial AOD}{\partial SSA} \cong -\frac{AOD}{SSA - \frac{2A}{(1+A^2)\frac{1-g}{2} + A(1+g)}}$$

$$\frac{\partial AOD}{\partial g} \cong \frac{AOD}{\frac{(1+A^2)\frac{1-g}{2} + A\left[(1+g) - \frac{2}{SSA}\right]}{\frac{1+A^2}{2} - A}}$$

The 800 nm was picked as a representative wavelength to demonstrate the model results so that the AOD range can be within 0.1 .

$$\frac{\partial AOD}{\partial A}, \frac{\partial AOD}{\partial SSA}, \frac{\partial AOD}{\partial g} \to \infty$$

Can be used to find critical values

$$CSA = \frac{2 - SSA(1+g) \pm 2\sqrt{1 + SSA[g(SSA-1) - 1]}}{SSA(1-g)}$$

$$CSSA = \frac{2A}{(1+A^2)\frac{1-g}{2} + A(1+g)}$$

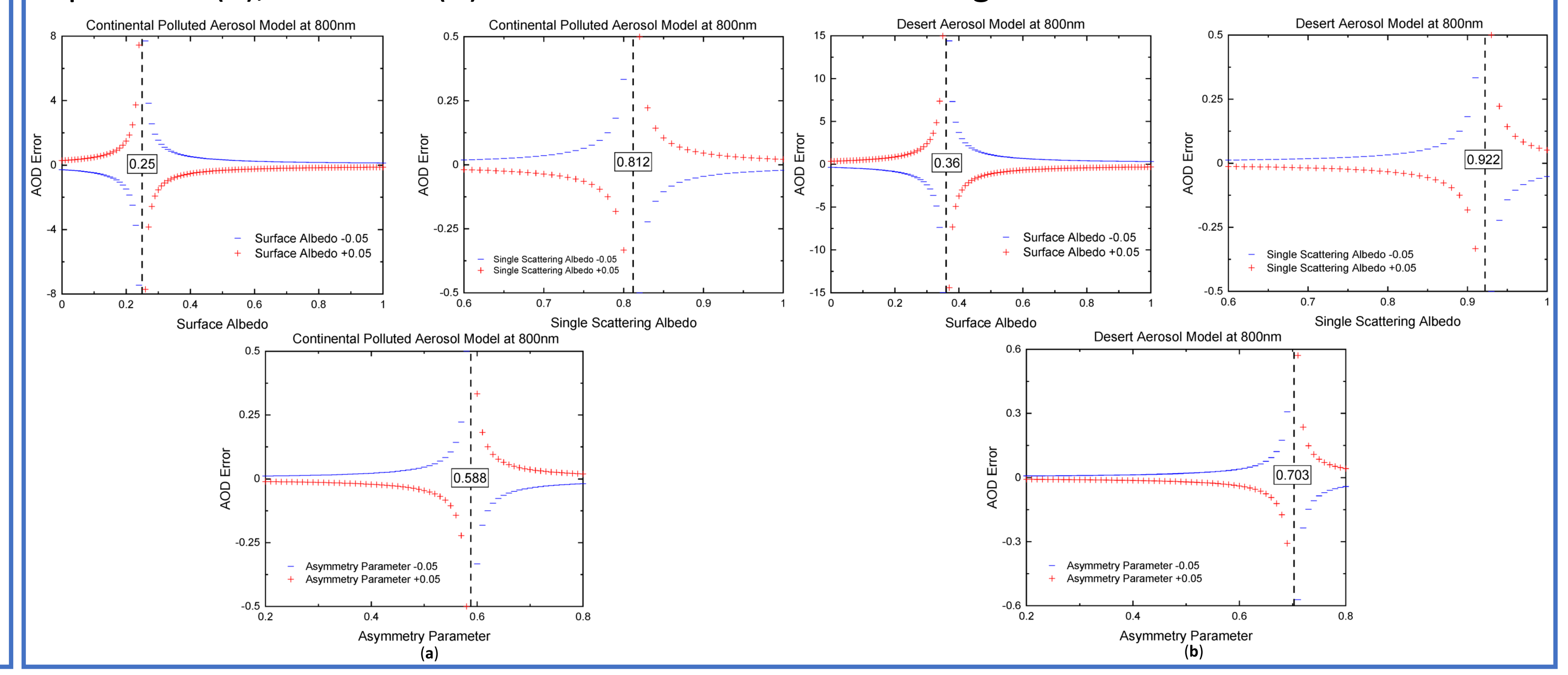
$$CAP = \frac{SSA(1+A)^2 - 4A}{SSA(1-A)^2}$$

Results

Table 1 Summary of CSSA, CAP, CSA values for the five different aerosol types.

Aerosol Type	CSA	CSSA	CAP
Continental clean	0.413	0.933	0.655
Continental average	0.294	0.861	0.62
Continental polluted	0.25	0.812	0.588
Urban	0.186	0.711	0.545
Desert	0.36	0.922	0.703

Figure 1 AOD errors for an AOD of 0.08 as function of surface albedo (top left), single scattering albedo (top right) and asymmetry parameter (bottom) for a continental polluted (**a**), or desert (**b**) aerosol model at the wavelength of 800 nm.



Real World Case Study : Black Rock Desert (BRD)

Figure 2 Monthly average MODIS AOD (550 nm) during October 2017 over the Black Rock Desert in the zoomed image: (a) Terra DB AOD. (b) Aqua DB AOD.

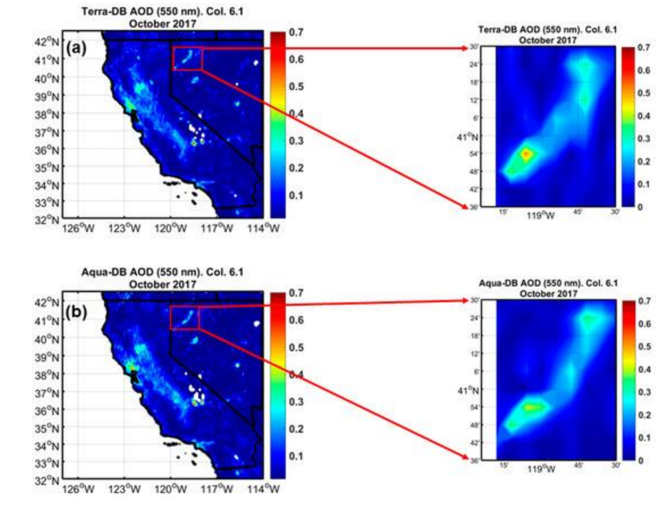


Image Courtesy of Loría-Salazar et al. (2016)

Interesting findings:

- Satellite retrievals always underestimate surface reflectance over bright, semi-arid surfaces, causing abnormally high satellite-retrieved AOD at 550 nm (i.e., negative AOD error) [1], without anthropogenic or wildfire disturbance.
- The sign of the AOD retrieval error depends on the wavelength of the retrieval where it switches from negative to positive due to the actual albedo becoming larger than the CSA at the higher bands (770 – 900 nm).
- The CSA for the polluted scenario is less than the mineral dust because of its more absorbing characteristics that reduce the satellite AOD bias over the deserts.
- Selecting an inaccurate aerosol type over deserts from the look-up table by mistake propagates the errors in SSA and through to the retrieved AOD.

Figure 3 Comparison between albedometer measured and satellite estimated (LANDSAT7 ETM+) surface albedo over Nevada's Black Rock Desert on 5 October 2017.

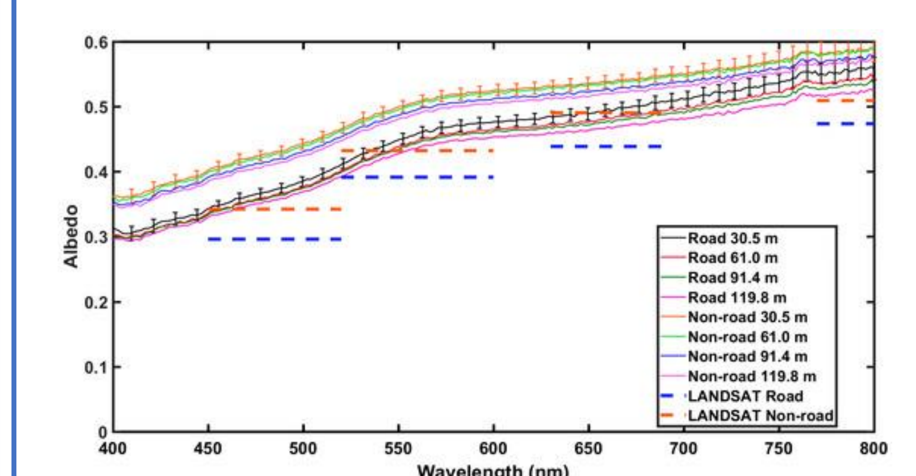


Image Courtesy of Boehmler et al. (2018)

Conclusions

- No sensitivity of the TOA reflectance to AOD at CSA or CSSA or CAP. It is impossible to retrieve AOD from satellite remote sensing under conditions at or close to the critical values because of infinite AOD uncertainty.
- Very bright surfaces are ideal for retrieving AOD of strongly absorbing aerosols (e.g., urban aerosols). High AOD errors are related to desert aerosols over bright surfaces (e.g., BRD) as a result of the closeness of the actual surface albedo to the CSA for desert aerosols.
- Our 1-D RTM provides an initial step to quantify uncertainty estimates in satellite AOD products and captures the underlying physical system behind the overall radiative effects of aerosols.

References [1] Seidel, F.C.; Popp, C. Critical surface albedo and its implications to aerosol remote sensing. Atmos. Meas. Tech. 2012, 5, 1653–1665, doi:10.5194/amt-5-1653-2012. [2] Kaufman, Y.J. Satellite sensing of aerosol absorption. J. Geophys. Res. Atmos. 1987, 92, 4307–4317, doi:10.1029/jd092id04p04307.

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