remote sensing

MDPI

Supplementary Materials for:

Article

Severe Biomass-Burning Aerosol Pollution during the 2019 Amazon Wildfire and Its Direct Radiative-Forcing Impact: A Space Perspective from MODIS Retrievals

Shuyun Yuan [1,2], Fangwen Bao [2], Xiaochuan Zhang [2] and Ying Li [2,3,*]

[1] School of Environment, Harbin Institute of Technology, Harbin 150059, China; 11749326@mail.sustech.edu.cn
[2] Center for Oceanic and Atmospheric Science at SUSTech (COAST), Department of Ocean Sciences and Engineering, Southern University of Science and Technology, Shenzhen 518055, China; baofw@sustech.edu.cn (F.B.); zhangxc3@mail.sustech.edu.cn (X.Z.)
[3] Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou), Guangzhou 511458, China
* Correspondence: liy66@sustech.edu.cn

This file includes:

Pages S1-S4

Supplementary S1

Supplementary S2

Table S1.

Table S2.

Supplementary S1

The top-of-atmosphere (TOA) reflectance is a function of successive orders of radiation interactions, the surface reflectance can be calculated based on the solar-viewing geometry (θ), BC volume fraction (f_{bc}) , the microphysical properties of BAs, and the AOD (τ):

$$\rho_\lambda^s = \frac{\left[\rho^{TOA}(\lambda)/T_g - \rho_R(\lambda) - \rho_0(\theta, f_{bc}, BA, \tau)\right]}{F_\lambda(\theta, f_{bc}, BA, \tau)T_\lambda(\theta, f_{bc}, BA, \tau) + \left[\rho^{TOA}(\lambda)/T_g - \rho_R(\lambda) - \rho_0(\theta, f_{bc}, BA, \tau)\right] * S_\lambda(\theta, f_{bc}, BA, \tau)} \quad \text{(S1)}$$

where ρ_λ^s is the Lambertian angular spectral surface reflectance at wavelength λ; ρ^{TOA} is the TOA reflectance obtained by sensors; T_g is the total gaseous transmission; ρ_R is the Rayleigh intrinsic reflectance of molecules; F_λ and T_λ are the downward and upward atmospheric transmission, respectively; S_λ is the atmospheric backscattering ratio; and ρ_0 is the normalized aerosol path reflectance.

In this study, f_{bc} and BAs are retrieved depending on the atmospheric correction that best fits the hypothesis of surface reflectance at two visible channels (0.645 μm and 0.469 μm). The constraints of the surface reflectance inherited from the MODIS dark target (DT) aerosol algorithm are applied to select all possible combinations from the LUT. The surface reflectance at visible channels is parameterized as a function of the channel 7 (2.12μm) reflectance, normalized difference vegetation index (NDVI) and scattering angle (sca). Thus, the exact results of f_{bc} and the selected BA can be determined as follows:

$$\varepsilon = \min \sum \left[\rho_i(f_{bc}, BA)/\rho_{2.12} - R_{i/2.12}(\text{NDVI}, sca)\right], \qquad i = 0.645, 0.469\ \mu\text{m} \quad \text{(S2)}$$

where $\rho_i(f_{bc}, BA)$ is the surface reflectance calculated by different combinations of f_{bc} and BAs in wavelength of i; $\rho_{2.12}$ is the TOA reflectance at MODIS channel 7, which features strong aerosol transmission; and $R_{i/2.12}$ is the ratio of the surface reflectance between wavelength i and 2.12 μm inherited from the constraints of the MODIS aerosol algorithm.

Supplementary S2

Our previous study have revealed the main factors contrbuting to the model errors of volume fraction of BC, which is the primary retrieval product in our algorithm. Based on the procedure of our inversion algorithm, the model errors are mainly related to the input AOD, surface reflectance assumptions, and background aerosol properties. Table S1 provides a simple summary of the expected uncertainty of the algorithm in this study.

The error of the MODIS AOD at 0.550 μm over land is expected to be 0.05+0.15×AOD. Significant impacts contributing to the retrieval bias are found under different surface backgrounds and varying AOD levels in the simulations. The retrievals under higher aerosol loadings are less affected by the AOD than those in clear-sky conditions. The uncertainty ranges from -54% to 72% in highly clear-sky conditions (AOD=0.1) but significantly decreases to ±15% under higher aerosol loadings (AOD⩾0.5). Additionally, the uncertainties over dark targets (vegetation) are much lower than those over bright targets (sand), likely due to the more substantial contribution of the AOD to the TOA reflectance over bright surfaces.

For most land covers, the surface reflectance error for the MODIS red channel (0.645 μm) is expected to be ±0.01. The bias of the MODIS red (0.645 μm) vs. blue (0.469 μm) surface relationship is expected to be ±0.2. These uncertainties demonstrate significant biases in excessively high retrievals when the AOD is lower than 1.0. Fortunately, overestimating or underestimating the surface reflectance at the red channel will produce the exact surface reflectance change at the blue channel, which influences final retrievals to the opposite extent. This finding indicates a possible bias lower than 40% for AOD⩾ 0.5 and lower than 20% for AOD⩾1.0.

The variance of the clustering models for the background aerosols also contributes to the uncertainties in the retrieval because the microphysical parameters averaged from these clusters cannot reflect realistic conditions, especially on a daily scale. These AOD-independent uncertainties ranging from -24% to 9% (-15% - 9% when AOD ⩾3.0).

From these analyses, we can see that although the error may be higher when the AOD is low (unavoidable because the satellite can only receive external atmospheric signals at low AOD), it has excellent performance for the pollution case. For Amazonia in this paper, the inversion uncertainties are lower because the AOD performance is better (see Figure.3a). However, the uncertainties of the surface reflectance assumption are lower because our surface model is more applicable to vegetation, and there is a large amount of vegetation cover in Amazonia. The background aerosol is less complex, as the background aerosol changes are not dramatic in the same season, and the clustering results are closer to the actual situation).

The spectral SSA of aerosols are further simulated by inputting the f_{bc} retrievals into the MG-EMA and MIE scattering model. Therefore, the uncertainty of SSA is influenced by the f_{bc} uncertainties. In another study, we have tested the sensitivity between f_{bc} and SSA[59]. We found that under background aerosol conditions with different absorption intensities, f_{bc} with 1% absolute error introduce an 0.05 uncertainty on SSA.

Table S1. Uncertainties of the algorithm under different AODs (τ)

Factors	τ = 0.1	τ = 0.5	τ = 1.0	τ = 3.0
AOD error (Expected to be 0.05 + 0.15 × AOD)	−54%~72%	−15%~15%	−6%~6%	−2%~3%
Surface reflectance error (Expected to be ±0.01 for MODIS Band1/3)	79%~110%	25%~37%	7%~20%	1%~3%
Background Error (Expected to be the variance of the clustering models)	−24%~8%	−21%~7%	−19%~7%	−15%~9%

Table S2. The parameters used in the aerosol components retrievals from AERONET.

Component	**Density (g/cm^3)**	**Mass Absorption Efficiency (m^2/g)**	
		0.67 μm	**0.87 μm**
Black Carbon	2.0	8.14	6.32
Brown Carbon	1.8	0.067	0.05
Dust	2.6	0.045	0.035
Ammonium sulfate	1.76	0	0
Aerosol Water	1	0	0