Aerosol Optical Depth Retrieval from Satellite Data over Land

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Multi-scale quantitative retrieval of Aerosol optical depth (AOD) over land

• Spatial resolution: 10km, 1km, 100m
  • for researches of global AOD variation, especially the spatial and temporal AOD evolution and air pollution researches in urban regions over China

• Temporal resolution: polar-orbit satellites V.S. geostationary satellites
  • for studies on extreme weather cases e.g. dust storms
Satellite and data:

**Himawari-8 and AHI**:

A geostationary satellite, aboard a new payload called the Advanced Himawari Imager (AHI).

- 16 Channels: 3 Vis bands, 3 NIR bands, 10 IR bands.
- Observation area and periodicity:
  
  In each 10-minute period, the AHI will scan the Full Disk once, the Japan Area and Target Area four times, and the two Landmark Areas twenty times.

<table>
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<th>Band Number</th>
<th>Spatial Resolution at SSP (km)</th>
<th>Central Wave Length (µm)</th>
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Forward Modeling

◆ Atmospheric radiative transfer equation

\[ \rho_{TOA}(\lambda, \theta_s, \theta_v, \phi) = \rho_{Aeo}(\lambda, \theta_s, \theta_v, \phi) + \rho_{Ray}(\lambda, \theta_s, \theta_v, \phi) + \frac{T(\lambda, \theta_s, \theta_v, \phi)\rho_s(\lambda, \theta_s, \theta_v, \phi)}{1 - R_s(\lambda)S(\lambda)} \]

◆ Surface BRF/albedo model - Ross-Thick-Li-Sparse kernel Model

The basic assumption of the Ross–Li BRF model is that the land surface reflectance can be modeled as the sum of three kernels representing basic scattering types:

\[ \rho(\theta_s, \theta_v, \phi, \Lambda) = f_{iso}(\Lambda)K_{iso} + f_{vol}(\Lambda)K_{vol}(\theta_s, \theta_v, \phi) + f_{geo}(\Lambda)K_{geo}(\theta_s, \theta_v, \phi) \]

\( K_{iso} = 1 \)

\( K_{vol} = \frac{(\pi / 2 - \xi) \cos(\xi) + \sin(\xi)}{\cos(\theta_s) + \cos(\theta_v)} - \frac{\pi}{4} \)

\( K_{geo} = O(\theta_s, \theta_v, \phi) - \sec(\theta_s) - \sec(\theta_v) + \frac{1}{2}[1 + \cos(\xi)]\sec(\theta_s)\sec(\theta_v) \)

\( f_{iso}, f_{vol}, \) and \( f_{geo} \) are the coefficients for those kernels, they are all wavelength dependent;

Lu She, Yong Xue, Xihua Yang, John Leys, Jie Guang, Yahui Che, Cheng Fan, Yanqing Xie, Ying Li, 2018, Joint Retrieval of Aerosol Optical Depth and Surface Reflectance over Land Using Geostationary Satellite Data. IEEE Transactions on Geoscience and Remote Sensing. (DOI: 10.1109/TGRS.2018.2867000)
Aerosol retrieval Algorithm

◆ Aerosol Retrieval based on multiple observations and optimal estimation

① Non-Lambertian forward model coupled with BRDF model

\[ \rho_{TOA}^\text{sim} = \rho_a + \frac{\rho \cdot \rho_{BHR} - \rho \cdot \rho_{HDR} \cdot \rho_{DHR}}{1 - \rho_{BHR} \cdot S} \cdot \frac{e^{-\tau/\mu_s} \cdot e^{-\tau/\mu_v} \cdot T(\mu_s) \cdot \bar{R}(\mu_v) - e^{-\tau/\mu_v} \cdot T(\mu_v)}{1} \]

② Joint retrieval- Optimal estimation

\[ x_{i+1} = x_i - (J'(x_i) + \gamma S_a)^{-1} \cdot J(x_i) \]

Two fundamental assumptions (Lyapustin et al., 2011; Dubovik et al., 2012):
- the surface reflective property changes little during the observation period
- assume one aerosol type for a grid of 1° × 1° (g and SSA do not vary over the region of 1° × 1°)

③ Aerosol models
Results and analysis

Hourly AOD Comparison between AHI and Japan Meteorological Agency (JMA) product on May 5, 2017

01:00 – 08:00 UTC- retrieved AOD

01:00 – 08:00 UTC- JMA L2 AOD
Results and analysis

◆ Comparison of retrieved AOD between DB, DT, AHI and JMA on May 5, 2017

<table>
<thead>
<tr>
<th>MOD-DT</th>
<th>MOD-DB</th>
<th>03:00 UTC-AHI</th>
<th>03:00 UTC-JMA</th>
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<tbody>
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<td>MYD-DB</td>
<td>06:00 UTC-AHI</td>
<td>06:00 UTC-JMA</td>
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</table>

JMA: AOD from JMA L2 aerosol product
AHI: AOD retrieved with this presented algorithm

MOD: Terra
MYD: Aqua
DT: Dark Target
DB: Deep Blue
Results and analysis

Validation

- Comparison with AERONET measurements, MODIS C6 product, and JMA L2 product
Results and analysis

◆ Cross comparison

➢ Comparison with MODIS C6 product, and JMA L2 product

AHI vs MODIS

JMA vs MODIS

AHI vs JMA

Retrieved AOD and JMA AOD at 05:00 UTC on 4 May 2017 were compared, also compared with MODIS C6 product, respectively.
Time Series Retrieval

**Time Series (TS)** technique makes use of the two visible bands at 0.6 µm and 0.8 µm (with support of 1.6 µm) in three orderly scan.

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**Land-Atmosphere** (Mei et al., 2011)

\[
\rho = \left[ a + c(\Gamma - \rho_{\text{TOA}}) \right] e^{\Phi} + \left[ b + c(\rho_{\text{TOA}} \Gamma - 1) \right] \Gamma e^{\Phi} + (\Gamma^2 - 1) \frac{G}{\rho_{\text{TOA}}} e^{\Phi}
\]

**A prior knowledge (Multi-Channel)**

\[\tau(\lambda) = \beta \lambda^{-\alpha}\] (Angstrom et al., 1961)

**Land model (Multi-Temporal)**

\[
\frac{\rho(\lambda)}{\rho_{\text{TOA}}} \approx k(\lambda)
\] (Flowerdew et al., 1995)

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**Inputs:** 3 scans/2 bands

**10 Equations = 10 Un-knows**

**Other constraints:**

- Aerosol Type (Govarert et al., 2010)
- Single Scattering Albedo
- Asymmetry factor
- Reflectance (Kim et al., 2008)

\[
\varepsilon = \min \left\{ \sum_{i} \sum_{j \neq i} (4A_{x,i,j}^k - A_{x,i,j}^k)^2 \right\}
\]
Sensitivity: Internal

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\[ R = \frac{\rho_{\text{targ}}^{\text{AVHRR}} \times \cos \theta}{d^2} \]

\[ D_C \leq SC : 100 \times R = S_{\text{inv}} (D_C - Z_C) \]

\[ D_C > SC : 100 \times R = S_{\text{inv}} (D_C - SC) + S_{\text{inv}} (SC - Z_C) \]

\[ S = \sum_{i=0}^{2} C_i \times D_i \]

- \( C_i \): fitted coefficients
- \( D_i \): days since the January 1 of the beginning year with data availability

\[ \text{NOAA-16} \]

\[ \text{TIROS-N} \]

\[ \text{NOAA-6} \]

\[ \text{NOAA-7} \]

\[ \text{NOAA-8} \]

\[ \text{NOAA-9} \]

\[ \text{NOAA-10} \]

\[ \text{NOAA-11} \]

\[ \text{NOAA-12} \]

\[ \text{NOAA-14} \]

\[ \text{NOAA-15} \]

\[ \text{Metop-A} \]

\[ \text{Metop-B} \]

Quadratic fit results of AVHRR calibration slope time series. Note that NOAA-15 and Metop-B are presented with equivalent single gain slopes.
The reflectance at the top-of-atmosphere, including the direct, single-scattered and multiple-scattered components can be written as

\[
\rho_{\text{TOA}}(\theta_s, \theta_v, \phi) = \frac{I_0(0, \Omega_v) + I_1(0, \Omega_v) + I_m(0, \Omega_v)}{F_0' |\mu_s|}
\]

\[
= \rho(\theta_s, \theta_v, \phi) \exp(-G\tau_a) + \frac{\omega P(\Omega_v, \Omega_s)}{4(|\mu_s| + \mu_v)} \left[ 1 - \exp(-G\tau_a) \right] 
+ \frac{1}{2\pi \left[ 1 - g^2(1-|\mu_s|) \right]} \left( 1 - g^2 \right) \left( 1 + 1.5 \mu_v \right) \left[ I_{ms}^+(0) - I_{ss}^+(0) \right] 
+ g^2 \delta(\mu_v - |\mu_s|) \left[ I_{ms}^+(0) - I_{ss}^+(0) \right]
\]

Data Selection
Re-calibrated Level 1B datasets from AVHRR on-board the TIROS-N and the Metop-B satellites to retrieve the AOD over North China and Central Europe.
Validation for Central Europe

For the Central Europe area we compare the retrieved AOD with PFR derived AOD in the ACTRIS network at five ACTRIS sites in Central Europe for which data were available for the period from 1980 to 2015.

### Five ACTRI sites information in Central Europe

<table>
<thead>
<tr>
<th>site_name</th>
<th>Lat ACTRIS</th>
<th>Lon ACTRIS</th>
<th>Elev ACTRIS</th>
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<td>89.0</td>
<td>1994.11-2002.01</td>
</tr>
</tbody>
</table>
China Collection 2.0 & 2.1

Website: www.tgp.ac.cn

- Spatial Resolution: 10km, 1km
- Temporal Scale: from August 2002

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