Aerosol Properties over “Bright-Reflecting Source Regions”: The Deep Blue Algorithm and its Applicability to MODIS

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Asian Dust (+ microbes?): Long Range Transport

"2001 Perfect Dust Storm"

TOMS Aerosol Index - time series

Airborne Dusts

Suspected Asian Dust Layer

Dust layer

Lidar Profiling

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UMBC/NASA GSFC
Rationale

• **Climate Forcing**: requires aerosol properties near source regions to achieve a complete picture of aerosol information from source to sink;

• **Carbon Cycle**: tracks iron sources from windblown dust for stimulating plankton growth in the open ocean;

• **Aerosol Transport Modeling**: needs accurate and realistic dust source locations; and

• **Visibility and Adverse Health Effects**: demands timely atmospheric turbidity information over affected regions.
Percentage of Area Retrieved by Current MODIS Aerosol Algorithm

[Chu et al., JGR, 2003]

Global Coverage for Surface Reflectance (2.1μm) >0.25

~15% ≤ f(season) ≤ ~25%

[Moody et al., 2004, in submission to IEEE TGRS]
The dashed lines denote the critical values of surface reflectance where the presence of aerosol CANNOT be detected by that particular spectral wavelength.

- Simulated apparent 490 nm reflectance (atmosphere + $\tau_{aerosol} = 1 + surface$) at the top of the atmosphere, as a function of surface reflectance.
- Non-absorbing aerosols make contrast apparent reflectance diminished faster for brighter surface.
- Absorbing aerosols make apparent reflectance brighter (or darker) for darker (or brighter) surface.

*Hsu, Tsay, King, and Herman, 2004: Aerosol properties over bright-reflecting source regions, IEEE TGRS, 42, 557-569.
MODIS Visible & NIR Bands: superimposed on the GOME spectral reflectance taken over the Sahara
**Inner Mongolia**
then-farmland/grassland
(over-grazing and cultivation)

**Coarse-size gravel**

**Gobi/Taklimakan**
age deserts
Flowchart for Deep Blue Algorithm

1. **Radiance**
   - 412, 490, 670 nm

2. **3x3 Pixels Spatial Variance at 412 nm**

3. **412/490 Absorbing Aerosol Index**

4. **NO RETRIEVAL**

5. **Cloudy?**
   - Yes
     - **412 nm Surface Reflectivity (0.1° x 0.1°)**
     - Dust Model
   - No
     - **Surface Reflectance Determination**
     - **Aerosol Type**
       - Mixed Aerosols
       - Maximum Likelihood Method
       - **Aerosol Optical Thickness** + **Ångström Exponent**

7. **490, 670... nm Surface Reflectivity (0.1° x 0.1°)**

8. **Smoke Model**
Phase Function for Dust Model

- Used in our dust model
- Retrieved from AERONET
- Mie, m=1.55, alpha=10

Phase Function

Scattering Angle (degree)
Deep Blue Algorithm for SeaWiFS/MODIS

- Utilize solar reflectance at $\lambda = 412$, 490, and 670 nm to retrieve aerosol optical thickness ($\tau_a$) and single scattering albedo ($\omega_o$).

- Less sensitive to aerosol height, compared to UV methods.

- Works well on retrieving aerosol properties over various types of surfaces, including very bright desert.
Asian Dust Outbreak
6 April 2001

Deep Blue Algorithm:
- Cloud mask works very well
- Aerosol retrievals indicate dust storms originated from Gobi and Inner Mongolia regions
- Single scattering albedos are quite different between these two regions
\[ \tau_\lambda \propto \lambda^{-\alpha}, \quad (\text{Ångström 1961}) \]
\[ \alpha = \ln \left[ \frac{\tau_1}{\tau_2} \right] \sqrt{\ln \left[ \frac{\lambda_2}{\lambda_1} \right]} \]
Perfect Dust Storm
7 April 2001
Comparisons with AOT from Sun Photometers in China during ACE-Asia
Aerosol Optical Thickness Retrieved from Deep Blue Algorithm:
Dust plumes in Africa

Feb 25, 2000

Feb 26, 2000

Feb 27, 2000

Cloud

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Validation: Comparisons with AERONET
Aerosol Optical Thickness

North Africa
February 2000

Arabian Peninsula
June - July 2000
1st Case: 6 April 2001

MODIS Red-Green-Blue with Rayleigh scattering removed

Current MODIS
Aerosol Optical Thickness

MODIS Deep Blue
Aerosol Index

Rayleigh scattering removed
Summary

• **It works!**
  – *Deep-Blue Algorithm* well for SeaWiFS measurements
  – Compared *well* with surface/aircraft products
  – Separate dust *well* from other anthropogenic sources

• **We expect:**
  – Implement *Deep-Blue Algorithm* *soon* for MODIS
  – Produce new MODIS products over bright-reflecting surfaces, and integrate into operational MODIS products
Backup Slides
Aerosol retrievals use an Aerosol Index:

Defined in a manner similar to the aerosol index for TOMS to distinguish between absorbing and non-absorbing aerosols:

\[ AI = -100 \cdot \left[ \log_{10} \left( \frac{I_{412}}{I_{490}} \right)_{\text{meas}} - \log_{10} \left( \frac{I_{412}}{I_{490}} \right)_{\text{calc}} \right] \]

- \( I_{\text{meas}} \) = Radiance measured by the satellite at 412 or 490 nm
- \( I_{\text{calc}} \) = Radiance calculated using a radiative transfer model

Large AI’s are caused by high AOT or by highly absorbing aerosols. As with UV wavelengths, the visible AI is also a function of altitude.
The dependence of Al with both AOT and absorption is confirmed by simulations we performed using aerosols of different types.

*The properties of blue water were assumed in this simulation*
The aerosol characteristics used to generate the simulated radiances in these two figures are shown below

<table>
<thead>
<tr>
<th>Aerosol Model</th>
<th>$\tau_{412}$</th>
<th>$\tau_{490}$</th>
<th>$\tau_{470}$</th>
<th>$\tau_{470}$</th>
<th>Refractive Index 412 nm</th>
<th>Refractive Index 490 nm</th>
<th>$\omega_0$ 412 nm</th>
<th>$\omega_0$ 490 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.91</td>
<td>0.96</td>
</tr>
<tr>
<td>Smoke</td>
<td>1.30</td>
<td>0.92</td>
<td></td>
<td></td>
<td>1.55 – 0.020i</td>
<td>1.55 – 0.008i</td>
<td>0.90</td>
<td>0.89</td>
</tr>
</tbody>
</table>

In areas of mixed aerosol types, we linearly mix radiances from the dust aerosol model, $R_{dust}$, with those from the smoke aerosol model, $R_{smoke}$, with a peak at 3 km and a width of 1 km assumed.

$$R_{smoke} = aR_{dust} + (1-a)R_{smoke}$$