Quantitative retrieval of aerosol optical thickness from FY-2 VISSR data

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ABSTRACT

Atmospheric aerosol, as particulate matter suspended in the air, exists in a variety of forms such as dust, fume and mist. It deeply affects climate and land surface environment in both regional and global scales, and furthermore, lead to be hugely much influence on human health. For the sake of effectively monitoring it, many atmospheric aerosol observation networks are set up and provide associated informational services in the wide world, as well-known Aerosol robotic network (AERONET), Canadian Sunphotometer Network (AeroCan) and so forth. Given large-scale atmospheric aerosol monitoring, that satellite remote sensing data are used to inverse aerosol optical depth is one of available and effective approaches. Nowadays, special types of instruments aboard running satellites are applied to obtain related remote sensing data of retrieving atmospheric aerosol. However, atmospheric aerosol real-timely or near real-timely monitoring hasn’t been accomplished. Nevertheless, retrievals, using Fengyun-2 VISSR data, are carried out and the above problem resolved to certain extent, especially over China. In this paper, the authors have developed a new retrieving model/mode to retrieve aerosol optical depth, using Fengyun-2 satellite data that were obtained by the VISSR aboard FY-2C and FY-2D. A series of the aerosol optical depth distribution maps with high time resolution were able to obtained, is helpful for understanding the forming mechanism, transport, influence and controlling approach of atmospheric aerosol.

Keywords: Geostationary; Aerosol Optical Thickness; Fenyun-2; Land

1. INTRODUCTION

Atmosphere aerosols have profound effects at a variety of scales, exerting myriad influences on the Earth climate, environment and on human health. They influence the present climate and affect future climate change by changing the planetary energy budget. They do this both directly, by scattering and absorbing solar radiation [1], and indirectly, by changing cloud properties, rain, snow, and atmospheric mixing [2, 3]. Some particles can also dissolve in the atmosphere creating acid rain [4, 5], or on the ocean surface, modifying its chemical composition [6]. Furthermore, the resent research has show that aerosol in troposphere have many adverse influences on human health. Ambient aerosol particles originating from the emissions of fossil-fuel-burning power plants may be transported to the respiratory system of the human organism. This particulate matter may contain harmful toxic elements and may cause adverse health effects [7].
To understand atmospheric aerosols effects, information on the spatial and temporal distribution of these aerosols are needed. The only data that allow the assessment of the variability of aerosols in both space and time is satellite remote sensing. Qualitative detection of aerosols using satellite remote sensing data over land dates back to the first Advanced Technology Satellite (ATS-1) in monitoring of pollution in the Los Angeles area [8]. Since then, satellite instruments have been launched which are designed to sense aerosol over land, and many approaches are developed to retrieval aerosol optical thickness (AOT). These include the AVHRR [9], MERIS [10], AATSR [11], SCLAMACHY [12], MISR [13, 14], MODIS [15, 16, 17], and so on.

In spite of advances in aerosol remote sensing [18], most retrieval are limited to twice per day, by using the morning and afternoon passes of the orbiting polar satellites. While aerosols may not exhibit a systematic diurnal trend [19], the continuous measurements during the day can improve characterization of aerosols contents. Since this frequency is not available from polar orbiting satellites, it is prudent to look to geostationary instruments.

Aerosol research from geostationary satellites measurements already have a long history, but slowly building toward routine AOT retrieval processing. While studies have shown the ability of sensing aerosols over ocean [20, 21], Lyons et al. [22] recognize the importance of geostationary imagery in qualitatively analyzing pollutant transport over the eastern United States. Fraser et al. [23] further this research by quantitatively estimating the aerosol mass and transport over the United States using GOES. Later, Tsonis and Leaitch [24] estimated the minimum detectable aerosol optical depth over central Ontario, Canada, to be 0.065. Also, it has been shown that aerosols over desert regions can be sensed using infrared wavelengths [25].

More recently, Pinty et al. [26, 27] exploited the frequent (every 30 min) Meteosat observations to estimate the surface albedo and the aerosol optical depth (held constant throughout the day) simultaneously. Knapp [28] estimated the surface albedo from a series of consecutive GOES-8 images, quantified the aerosol signal in GOES 8 visible imagery over the United States, and analysis the uncertainty. Zhang et al. [29] and Christopher et al. [30] and Laszlo et al. [31] estimated the surface albedo and retrieved the AOD from high temporal resolution GOES-8 imager radiances and detailed radiative transfer calculations. And Wang [32] estimated the AOT over the west Pacific Ocean by using GMS5 imager.

In this paper, an algorithm is developed which retrieves the diurnal change of AOT by using FY-2D satellite visible channel data. To test the performance of the algorithm, it has been applied to a number of aerosol events during Jun 2007.

2. MATERIALS

2.1 VISSR

Visible and Infra-Red Spin Scan Radiometer (VISSR) aboard on FY-2C/D/E provide frequent (15-30min) images at five different wavelengths, including a visible channel and four infrared channels over the Asia, Oceania and Pacific Ocean. The characteristics of each channel are shown in Table 1. The study area is between 60N and 80E and 25N and 150E with the city Beijing, our validation site, located at 39N/118E. Full radiometric resolution images have been ordered and processed. The data are stored on an array of 9152 columns, 9156 lines for visible channel and 2288 columns and 2288 lines for the infrared channels. The images span the period from 23rd of May and 12th of Jun 2007, with a frequency of 11 images per day, every half hour between 03:15 and 07:15 (UTC).

<table>
<thead>
<tr>
<th>Channel</th>
<th>Wavelength Range (μm)</th>
<th>Nadir Spatial Resolution (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.55-0.90</td>
<td>1.25</td>
</tr>
<tr>
<td>2</td>
<td>10.3-11.3</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>11.5-12.5</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>6.3-7.6</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>3.5-4.0</td>
<td>5</td>
</tr>
</tbody>
</table>
2.2 The radiative transfer model 6S

The radiative transfer model 6S (second simulation of the satellite signal in the solar spectrum) has been documented by Vermote et al. [33] and is available from the laboratory d’Optique Atmosphérique, Université des Science et Techniques de Lille, France. This radiative transfer model computes the reflectance at satellite due to backscattering of solar light in the ground-atmosphere system, assuming a cloudless atmosphere. The reflectance calculated is a function of the satellite viewing conditions and the solar geometry. The model includes analytical description of the absorption by aerosol particles and atmospheric gases (H2O, O3, O2 and CO2), describes the scattering by gas molecules (Rayleigh scattering) and aerosols (Mie scattering).

2.3 AERONET

The test sites were selected to coincide with the sites if permanent AERONET (Aerosol Robotic Network) ground-based sun-photometer instruments. AERONET is a global aerosol monitoring network of ground based sun photometer measures solar and sky radiance from which AOT, single-scattering albedo, and particle-size distribution and other aerosol properties can be derived. Cloud screened and quality-assured level 2.0 data is used to validate retrieved AOTs. The accuracy of level 2.0 data is expected to be around 0.02 [34]. To allow direct comparison with the satellite-derived aerosol estimates, the sun-photometer measurements were interpolated to the reference wavelength at 0.55μm.

2.4 VISSR cloud classification product

Operational cloud classification product of VISSR obtained using visible and infrared channels. Cloud classification product has the same spatial and temporal resolution with VISSR infrared channel. In this product pixels were marked as 8 different kinds, as shown in table 2. Only the pixels marked as clear lands were used in this paper.

<table>
<thead>
<tr>
<th>contents</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Clear Oceans</td>
</tr>
<tr>
<td>1</td>
<td>Clear Lands</td>
</tr>
<tr>
<td>11</td>
<td>Mixed Pixels</td>
</tr>
<tr>
<td>12</td>
<td>Altostratus or Nimbostratus</td>
</tr>
<tr>
<td>13</td>
<td>Cirrostratus</td>
</tr>
<tr>
<td>14</td>
<td>Cirrus Dens</td>
</tr>
<tr>
<td>15</td>
<td>Cumulonimbus</td>
</tr>
<tr>
<td>21</td>
<td>Stratocumulus or Altocumulus</td>
</tr>
</tbody>
</table>

3. MODES

The VISSR-AOD retrieval method uses the visible channel of the VISSR Imager instrument to retrieve aerosol information. Our retrieval method is based on a lookup table (LUT) approach. The aerosol optical thickness retrieval is carried out in two steps; in the first step, the surface reflectance of the target pixel of each image is calculated from the satellite reflectance by background mosaic; in the second step, using the inferred reflectance, the at-satellite reflectance relates directly to aerosol optical thickness (s)

3.1 Compilation of the composite background

In non-cloudy conditions, the reflectance at the top of atmosphere (TOA) in the visible spectrum mainly is a function of Sun-satellite geometries (i.e., solar zenith angle $\theta_{sun}$, solar azimuth $\varphi_{sun}$, satellite zenith angle $\theta_{sat}$, and satellite azimuth $\varphi_{sat}$), surface reflectance $\rho_{surf}$, AOT $\tau$, and aerosol optical properties (AOP). Since the Sun-satellite geometry is known for each satellite pixel, and the reflectance of the TOA reflectance can be obtained through analysis of satellite data, the key aspect is surface reflectance.
The backbone of this approach is the creation of a background image from a time series of satellite images. A background image is created for each satellite observation time. The background mosaic method is based on the unique capabilities of the VISSR measurements. We take advantage of the high temporal resolution and fixed viewing geometry of VISSR. We can reasonably assume that for given acquisition times (i.e. 8/00 UTC) within a period of 15 days:

- The solar zenith angle and the relative azimuth angle do not vary significantly. So for one pixel, the viewing geometry is stable.
- The surface properties do not change (except for particular and exceptional cases such as floods, fires and snowfall).

Measurements that are made every day for the same pixel at the same time can then be easily compared. After screening the clouds/water and assuming no change in surface reflectivity, the minimum value of pixel represents the surface reflectance. We use VISSR cloud classification product to identify the cloud/water pixels.

### 3.2 Retrieval of aerosol optical depth

The different steps to calculate the AOT using visible channel of VISSR are shown in Fig.1. The aerosol optical thickness retrieval algorithm applies only to cloud and water free scenes over the ocean. On each satellite image, clouds and water are eliminated according the VISSR cloud classification product. The retrieval algorithm to estimate the aerosols optical depth is based on the two LUTs derived from the 6S model. The LUTs are seven dimensional, relating geometric conditions, the surface reflectance and the aerosol optical thickness \( s \) to the at-satellite level reflectance. The LUTs were populated for specific steps (given in Table 3) using the known boundary conditions of the images and the target, allowing subsequent values to be retrieved using interpolation.

![Flowchart for aerosol AOT retrieval over land](image)

**Fig. 1.** Flowchart for aerosol AOT retrieval over land

### 4. RESULT AND DISCUSSION

For the series of FY2D images from 1st to 12th of June 2007 we have calculated the optical thickness of aerosols over

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Range</th>
<th>Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \theta_{sun} )</td>
<td>0-60 (Degree)</td>
<td>5 (Degree)</td>
</tr>
<tr>
<td>( \varphi_{sun} )</td>
<td>90-270 (Degree)</td>
<td>20 (Degree)</td>
</tr>
<tr>
<td>( \theta_{sate} )</td>
<td>0-60 (Degree)</td>
<td>5 (Degree)</td>
</tr>
<tr>
<td>( \varphi_{sate} )</td>
<td>90-270 (Degree)</td>
<td>20 (Degree)</td>
</tr>
<tr>
<td>( \rho_{surf} )</td>
<td>0-0.4</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Table 3 Range and step fixed for the parameters in the LUTs

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Asia. Fig. 2 shows a set of AOTs over Asia, the time resolution is 1 hour. We note that there are two areas with thick AOT. One is north-east of China and another one is South of the Himalayas. In the day, AOT values rise firstly, and reach the peak about noon, and then reducing.
Fig. 2. Aerosol optical thickness at 550nm over Asia from 03:15 UTC till 07:15 UTC the 8th June 2007.

Fig. 3 shows the temporal sequence of the sun photometer derived aerosol optical thickness. For validation, we compare the sun photometer data of aerosol thickness taken on Guadeloupe with those of a 5x5 average of GOES pixels for a point 10 km east of the island derived from the images shows in Fig. 2. The results seem to be in good agreement with the ground based values.

Fig. 3. Aerosol optical thickness at 550 nm
5. RESULT AND DISCUSSION

In addition to their impact on climate, aerosols have significant health and aviation impacts, which are particularly sensitive to large concentrations of aerosols. Observing aerosols from FY2 would allow high temporal sampling important in these cases. In this paper, a methodology to estimate the aerosol optical thickness from the FY2/VISSR data and the radiative transfer model 6S has been developed. A series of the aerosol optical depth distribution maps with high time resolution were able to obtained. A background composite is compiled for each satellite observation time from imagery during the course of 15 days and is then corrected for atmospheric extinction to obtain a surface reflectance, firstly. And then, optical depths are then retrieved using a radiative transfer model. For validation, the FY-22 AOT retrieval was correlated with AREONET site in China, and the result shows a good agreement between retrieval values and the ground based values. This study is helpful for understanding the forming mechanism, transport, influence and controlling approach of atmospheric aerosol.

Further research work mainly includes validations using more data, exploration of grid computing technology applications to aerosol retrieval, and considerations of the effects of the factors such as ground surface bidirectional properties, aerosol and water vapour spectral absorbing, etc., to promote the accuracy of AOT retrieval in the future research.

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