Assessment of aerosol models to AOD retrieval from HJ1 Satellites

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Abstract. The Chinese environmental satellites HJ1 A and B can play a significant role in the aerosol retrieval due to their high spatial and temporal resolution. The current Aerosol Optical Depth (AOD) retrieval methods from HJ1-CCD are almost based on the LUT (Look-Up Table), by selecting the best fitting result to determine the AOD. However, aerosol model selection has an important impact on the retrieval results when creating the lookup table; inappropriate choice of aerosol model will significantly affect the accuracy and applicability of the method. This paper determined the local aerosol physical properties (such as complex refractive index, and size distribution) based on the observational data, thus we defined the aerosol type and retrieved the AOD of the local aerosol. Furthermore we compared the results retrieved from the measurement aerosol model with those retrieved from the inherent aerosol model in the radiative transfer model and then evaluate its effect on the aerosol type.

Keywords: Aerosol model, Assessment, AOD retrieval, HJ1

1. Introduction
Aerosol has the variability in spatial and temporal, so the aerosol model parameters are difficult to obtain accurately. The aerosol model which used most widely is get from cluster analysis results based on long time AERONET sits measurements data [1]. Levy used the statistics of the global aerosol parameters data from AERONET sites, and divided the aerosol models into four categories, which included three spherical (neutral, absorbing, and non-absorbing) fine models and the one spheroid coarse aerosol (dust) model, and gives the details of these aerosol model parameters, he considered the field aerosol can be described by a linear combination of a spherical fine mode and a non-spherical coarse mode, MODIS aerosol retrieval algorithm was improved based on these aerosol models[2,3]. Lee used 20 AERONET sits data in Asia, and divided the aerosol distribution into six bimodal distributions, each of which consist of one fine model and one coarse model, and then used these models in AOD retrieval based on MODIS data [4]. Tianhai Cheng used Lee’s aerosol models to retrieval aerosol proprieties based on POLDER data, he took out each of the coarse mode and fine mode in 6 aerosol models and combined them freely, considering 36 combinations, and the retrieval...
method was based on determining which one from the 36 combinations of fine and coarse aerosol models is the best [3].

However, the AOD retrieval method which can get aerosol model based on satellite data independently is rarely, most of the retrieval algorithms need the typical aerosol models according to the target areas as default input, then the aerosol optical and physical properties of the study area in satellite transit time was retrieved through a look-up table (LUT). Many radiative transfer models have default aerosol models, such as continental, marine, urban, rural aerosol models in 6S (Second Simulation of Satellite Signal in the Solar Spectrum) [6,7], which is widely used in aerosol retrieval. In this paper, we determine the local aerosol physical properties based on ground-based sun photometer measurements, and define the aerosol model to retrieve the aerosol optical depth. Then compare the results that retrieval from the measurement and inherent aerosol models, and evaluate the effect of the aerosol type on retrieval results.

2. Methodology

2.1. AOD retrieval method

The AOD retrieval algorithm was applied to data from the CCD cameras of China HJ1 A/B. The algorithm based on the two following assumptions [3]: (1) Aerosol optical properties vary quickly with time but slowly with location. (2) Surface reflectance varies quickly with location but slowly with time. For images of two adjacent phases, the difference of apparent radiances is mostly from the change caused by aerosol. Using a constant aerosol model with an aerosol optical depth (AOD) that varies from 0.1 to 2, we can get the correlation between surface reflectance and TOA radiance by LUT, the caused by aerosol. Using a constant aerosol model with an aerosol optical depth (AOD) that varies from 0.1 to 2, we can get the correlation between surface reflectance and TOA radiance by LUT, the AOD retrieval method is based on the minimization of the following cost function, and we consider that the surface reflectance and AOD are actual value when the cost function is minimized. However, if the aerosol difference is little in two days, it may introduce significant errors to the AOD results, so we added the initial surface reflectance for control. The cost function is defined as follows [8]:

\[
\text{Cost} = k \sum_{i,j,d} \left( \text{atm}_{\text{cor}}(L_{\text{cor}}(i, j, \lambda, D1), AOD(D1)) - \text{atm}_{\text{cor}}(L_{\text{cor}}(i, j, \lambda, D2), AOD(D2)) \right)^2
\]

+ \sum_{i,j,d} \left( \text{atm}_{\text{cor}}(L_{\text{cor}}(i, j, \lambda, D1), AOD(D1)) - \rho_{\text{surf}}(i, j, \lambda, D1) \right)^2 + \sum_{i,j,d} \left( \text{atm}_{\text{cor}}(L_{\text{cor}}(i, j, \lambda, D2), AOD(D2)) - \rho_{\text{surf}}(i, j, \lambda, D2) \right)^2 (1)

Where \( \lambda \) is the wavelength, (ij) are the coordinates of pixels belonging to a neighbourhood, and the aerosol is constant in this neighbourhood, \( \rho_{\text{surf}} \) is initial surface reflectance, \( \text{atm}_{\text{cor}} \) is the atmospheric model that enables to estimate surface reflectance from TOA reflectance, D1 and D2 represent imaging date. K is a weighting coefficient which is proportional to the average variation of \( L_{\text{TOA}} \) between day D1 and D2.

![Figure 1](image-url)

**Figure 1.** The flowchart of AOD retrieval method.

Figure 1 is the flowchart of the algorithm. In this algorithm, the different AOD considered in LUT is from 0.1 to 2.0, \( L_{1,\text{TOA}}, L_{2,\text{TOA}} \) is apparent radiance. Surface reflectance is determined by the cost function.
2.2. Aerosol model

Three aerosol models were chosen in this paper: continental and urban in 6S \cite{6,7}, and the measurement aerosol model statistics from sun photometer measurement data in Tianjin.

The data from which we get the measurement aerosol model is from sun photometers observation in Tianjin during March in 2012, all data chosen are level 2.0, and the model parameters are get from statics the data which is obtained before and after half an hour of satellite transit time. Figure 2 and figure 3 are the results of measurement aerosol model parameters.

![Figure 2. Refractive index in Tianjin.](image)

![Figure 3. Size distribution in Tianjin.](image)

2.3. Look-up tables

| Parameter                  | value                      |
|----------------------------|----------------------------|
| Spectral band              | HJ1-CCD band 1/band 2      |
| Atmospheric model          | Mid-latitude summer, Mid-latitude winter |
| Aerosol model              | Continental/urban/measurement |
| Solar zenith angle         | 0-66(°)                    |
| View zenith angle          | 0-35 (°)                   |
| Relative azimuth angle     | 0-180(°)                   |
| Aerosol optical depth      | 0.001-2.0                  |
| Surface reflectance        | 0-0.4                      |

The AOD can be determined through solving the radiative transfer (RT) equation. However, because it is time consuming to solve the RT model, we used the look-up table (LUT) method to estimate AOD \cite{9}. This LUT was precalculated for a given aerosol model, location and time using Second Simulation of the Satellite Signal in the Solar Spectrum (6S) RT code.

6S model mainly used for simulate albedo and radiation values measured by space borne or airborne optical sensor which range from 0.25 to 4 micrometer without cloud. The step used for spectral integration is 2.5 nanometers, it calculates Rayleigh scattering of air molecules and aerosol scattering using the state-of-the-art approximate calculation and Consecutive order scattering algorithm \cite{5,6}. If the solar-view geometric, wavelength, altitude is determined, 6S can calculate the relationship between the top of atmosphere radiance and surface reflectance.

We considered the following parameters in constructing the LUT: Geometrical conditions, atmosphere models, aerosol models, spectral conditions, and surface reflectance. Then, we can build
the LUT in specific research areas and Atmospheric models. The details of LUT parameters are set as Table 1.

3. Data processing and results

3.1. Data selection and processing

![Figure 5. AOD results from continental (left) and observational (right) aerosol models.](image)

This study has the validation area in Tianjin, this area is about 60 × 60 km² (Figure 4), in HJ-CCD images is about 2000*2000 pixels. The region has sun photometer measurements during March in 2012, so we can get the actual measurement data to define the aerosol model and compare the results easily. Seven images were selected in this area during the March of 2013. The three quadrangular in red, green and blue colour in figure 4 represent the Tianjin, Tiangang and Tanggu stations.

Geometric correction, radiometric calibration, and calibrate the data. HJ-CCD images are then sub-sampled into 100 m resolution in order to reduce noise and registration errors, and to smooth very
local variation of surface reflectance. Then, we consider the AOD is unchanged in a neighbourhood of \(5 \times 5\) pixels. In equation (1), the max of \(i\) and \(j\) is 5.

Only two HJ1-CCD spectral bands, centered at 483 and 568 nm, are used in the retrieval method, because these bands are very sensitive to aerosol effects, and in most cases, the surface reflectance of these bands varies slowly.

The initial surface reflectance data in the method is get from atmospheric correction the data of the first day of the time series data, the AOD in the atmospheric correction is get from the Sun photometer (CE318) measurement data. Here, we used Level 2.0 optical depth outputs as validation data, the transit time of HJ1 in Beijing is around 2:30 GMT, the HJ1 transit time measured results is get from averaging the CE318 data which is before and half an hour of the transit time. AOD at 550 nm was calculated using the CE318 Ångström exponent \([10]\) and aerosol optical depth at 440 nm and 870 nm. The Ångström exponent satisfies the following formula \([11]\):

\[
\tau_\alpha(\lambda) = b \lambda^{-\alpha} \tag{2}
\]

Where, \(\tau_\alpha(\lambda)\) is aerosol optical depth at \(\lambda\), \(b\) is turbidity factor, and \(\alpha\) is Ångström exponent.

### 3.2. AOD results

![Figure 6](image6.png)  Results from continental and measurement aerosol models in three sites

![Figure 7](image7.png)  AOD results from urban aerosol model.

After building the LUT based on different aerosol models, we retrieved AOD of Tianjin using this method, the resolution of AOD results is 500m. AOD results retrieved from measurement aerosol model and AOD from CE318 sites (Tianjin, Tiangang, Tanggu) are in good agreement, the correlation coefficient is greater than 0.8. AOD results of different aerosol models are shown in figure 5. Comparing the results from the different aerosol models in Tianjin, we can found that the retrieved results from continental aerosol model are higher than that from measurement aerosol model, the Correlation coefficient is 0.91, however in Tiangang and Tanggu, the results are very similar from continental and measurement aerosol model (Figure 6), AODc and AODm is continental and measurement aerosol model respectively. The results from urban aerosol model have great difference compared to continental and measurement aerosol models, the AOD results are significantly lower in...
the March 7, 2012, so the surface reflectance is larger than the true value, and it results of the March 13, 2012 results very low (Figure 7) directly.

4. Conclusion
In this paper, we compared the results retrieved from different aerosol models, and evaluated the impact on retrieval results which based on measurement aerosol model quantitatively. The different AOD results from different aerosol models of Tianjin show that the results from continental aerosol model have better consistency with measurement aerosol model. We can consider that the aerosol type of Tianjin in March 2012 is close to the continental aerosol model. However, measurement aerosol model retrieved results have better sensitivity in areas of higher AOD and lower AOD.

The determination of the atmospheric aerosol model is a very complex work, general radiative transfer calculations and other applications choose from some given aerosol models in radiative transfer program perceptually. Different aerosol models have different impact on the radiative transfer, choosing the appropriate aerosol model is an effective method to improve AOD retrieval precision and using the closest aerosol model can reduce the error of radiative transfer calculations or atmospheric correction in satellite remote sensing.

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