Using MODIS to retrieve the AOT over the region of Baikal

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Abstract: The aerosol optical thickness (AOT) over the region of Baikal was retrieved using the MODIS data and the V5.2 algorithm developed by NASA. The results were validated by the CE-318 observations. Though the R² is not that high, the result could display the spatial distribution of aerosol. The AOT characteristics of spatial and temporal variation over the region of Baikal were analyzed: The mean AOTs in spring and summer are higher, with the highest value of 0.26 in May; and the mean AOTs in autumn and winter are lower and steady.

1 Introduction

The aerosol refers to a multiphase system, consisting solid or liquid particles suspended in the gas, and the particles have a diameter between 0.001 to 10 μm. Scattered in the atmosphere, fungi, viruses, carcinogens, polycyclic aromatic hydrocarbons and other harmful substances contained in the aerosol particles can lead to air pollution and have a great harm to human health. Also, the increasing mortality rate has great relationship with the increasing of the aerosol particles’ concentration[1-3].

Using satellite to observe the global aerosol distribution and the change is very important, because of the few days of life period and the diversity of spatial distribution of the aerosol particles[4,5]. The NASA provides 10 km global aerosol products, however, higher resolution aerosol products become an urgent need to study regional aerosol optical properties, because of the spatial variation of aerosol. Using the MODIS images, Li et al. retrieved 1 km aerosol data of places such as Beijing, Hong Kong and others, and the retrieval results reflect the spatial variation of the aerosol in the region[6-7,14].

Trace gases, coming from biomass combustion emissions, have great influence on global atmosphere, due to its important geographical and environmental signification, the river of Baikal has...
got more attentions. Using the MODIS data and the NASA V5.2 aerosol retrieval method, the AOT was retrieved with the resolution of 500 m over the region of Baikal in 2000 and 2010.

2 Research Region and Data Processing

2.1. Study Area
The Lake Baikal is the world’s deepest freshwater lake, and have the largest storage. The vicinity of the it is a continental climate, the temperature there varies big. In January, the average temperature ranges from -33 °C to -26 °C, while 17 °C~21 °C in July. The lake plays an important role in regulate the climate of the lakefront, and has a special eco-hydrological characteristics. Surround the lake, there are four first-tier cities: Angarsk, Ulan-Ude, Chita, Irkutsk, which is the biggest industrial city, traffic and trading hub in Siberia. Covered by large forest, the aerosol and biomass combustion emission of trace gases have influence on the atmosphere, which got especially attention [8].

2.2. Data
MODIS is an important sensor equipped on Terra and Aqua. The resolution of the sub-satellite point is 250 m, 500 m, 1000 m, and the scanning width is 2330 km. It takes only one day to cover the word. Radiometric calibration and geometric correction has been conducted before retrieving the AOT.

The CE-318 observation is downloaded from the AERONET, which is builded by NASA using 900 CE-318 layed around the world, and the data is used to monitoring global AOT, spectral distribution and water vapour. The data has been processed, and can be used for validation. To validate the accuracy of MODIS AOT, the author downloaded the CE-318 observation of Irkutsk (103.087° E, 51.800° N) [15,16].

2.3. Retrieval Method
Due to the spectral resolution, high time and spatial resolution, MODIS has great signification on monitoring resources, environment, disasters and global climate change. Using a large number of aircraft testing, Kaufman found that on conditions of clean atmospheric, the apparent reflection in red, blue and short wave infrared 2.1 μm is linear dependence over region covered by dense vegetation or low reflection area. Meanwhile, the monitoring of short wave infrared is essentially not the effects of aerosol. And they apply this for retrieving AOT by MODIS data. Basic on Kaufman dark-target method, Levy and Remer developed NASA’s V5.2 aerosol retrieval method, and conduct global AOT retrieval operation to provide global aerosol product (MOD04) with resolution of 10 km [9-13].

When using scalar method to retrieve AOT, in the condition of the surface is Lambert reflector and the atmosphere is uniform in horizontal direction, the reflectance of the atmospheric top (ρ_{TOA}) observed by satellite is expressed as:

\[
\rho_{TOA}(\mu_s, \mu_v, \varphi) = \rho_0(\mu_s, \mu_v, \varphi) + \frac{T(\mu_s)T(\mu_v)\rho_s(\mu_s, \mu_v, \varphi)}{[1-\rho_s(\mu_s, \mu_v, \varphi)S]}
\]  

(2.1)

Here: $\mu_s = \cos{\theta_s}$, $\mu_v = \cos{\theta_v}$, $\theta_s$ and $\theta_v$ means solar zenith angle and observed zenith angle;$\rho_0$ means equivalent reflectivity of the atmospheric path radiation in the observed direction; $\rho_s$ means BRDF; S means hemisphere reflectivity of the atmospheric lower bound; T means atmospheric transmittance;$\varphi$ means relative azimuth angle.
People often assume different aerosol model and observation geometry in the practical retrieval, use the radiation transfer model to calculate the corresponding relation between the AOT and the three parameters – $S$, $\rho_0$ and $T(\mu_s) \cdot T(\mu_v)$, and set up a look up table according to the corresponding relation. Thus the AOT can be required by the look up table.

To remove the surface reflection noise, the dark-target method is used to eliminate the contribution to the Earth's surface. The principles are: for surface covered by dense vegetation and has lower reflectivity (that is, dark pixel), near-infrared reflectivity and reflectivity of the red and blue channels has a good linear correlation; relative to visible light, the influence of the short wave infrared on the aerosol can be neglected. Therefore, the apparent reflectance of the red and blue channels can be required from the near-infrared apparent reflectance, thus the surface reflect can be removed and the atmospheric parameters, $S$, $\rho_0$ and $T(\mu_s) \cdot T(\mu_v)$ can be required, and then the AOT.

The dark pixels are needed to be ascertained, as well as the relationship between the reflectivity of the red and blue channels and near-infrared reflectivity, and this plays an important role. A pixel is identified as a dark pixel, when it’s apparent reflectance at the wavelength of 2.1 $\mu$m is greater than 0.1 and less than 0.4. Gatebe and Remer find that, the relationship between the reflectivity at 2.1 $\mu$m and the reflectivity at 0.47 $\mu$m and 0.66 $\mu$m over dense vegetation is not only determined by the scattering angle, but also determined by the density of the vegetation\[18,19\].

Generally, the NDVI is used to indicate the density of vegetation, but the NDVI calculated from red band and near-infrared band is impacted by the aerosol\[20\]. Considering the aerosol has less influence on the short wave infrared band, the NDVI$_{SWIR}$ can be calculated like this:

$$\text{NDVI}_{SWIR} = (\rho_{1.24}^m - \rho_{2.1}^m)/(\rho_{1.24}^m + \rho_{2.1}^m)$$

Here: $\rho_{1.24}^m$ and $\rho_{2.1}^m$ means apparent reflectance of 1.24 $\mu$m and 2.1 $\mu$m.

According to the function relationship between the surface reflectance in 2.1 $\mu$m, 0.47 $\mu$m and 0.66 $\mu$m of the dense vegetation($\rho_{2.1}$, $\rho_{0.47}$ and $\rho_{0.66}$) and NDVI$_{SWIR}$ and scattering angle, the surface reflectance in 0.47 $\mu$m and 0.66 $\mu$m can be calculated by the surface reflectance in 2.1 $\mu$m:

$$\rho_{0.66} = \rho_{2.1} \times a_{0.66/2.1} + b_{0.66/2.1}$$
$$\rho_{0.47} = \rho_{0.66} \times a_{0.47/0.66} + b_{0.47/0.66}$$

Here: $a$ and $b$ is determined by scattering and NDVI$_{SWIR}$.

3 Result

3.1. Validation

There are many advantages of satellite remote sensing, but also many uncertainly for the complicated character of aerosol, therefore, the result should be validated. To validate the results, the author compared the results with the CE-318 observations. The V5.2 algorithm is great influenced by weather, there are less retrieval AOT over this area, so the CE-318 observations and MODIS data that are observed at the same time are chosen. Due to the result and the CE-318 observations are different in central wavelength and temporal and spatial scales, so the time and space matching and wavelength matching are needed. For time matching, the CE-318 AOT observations in the set time are selected to calculate an average, and the time is no more than half hour than the satellite transmit time (the local time 10:30 am), that is 10:00 ~ 11:00 am; for space matching, the average of the MODIS retrieval AOT in a window ($3 \times 3$), which is the CE-318’s coordinate centered, is selected. Because there is no
data on 550 nm, which is the central wavelength of the MODIS retrieval AOT, the CE-318 AOT at 550 nm need to be calculated by the Angstrom equation ($\tau_\lambda = \beta \lambda^{-\alpha}$).

In the study, the CE-318 observations got from the site in Irkutsk are used for validation. The fig.1 displays the result of the regression analysis. The correlation coefficient is only 0.2226, and it is not precise. Comparing the CE-318 observations with the MOD04 to find that the two data are all less than 1, thus the conclusion can be got that the AOT over Irkutsk is below 1. However, after removing the measurements greater than 1, the result of the regression analysis is still unsatisfactory.

Figure 1. The contrast of MODIS AOT and the sun photometer in situ

Taking into account the Baikal’s high latitude (higher than 50° N), the sunshine duration is short, and the solar radiation is influenced, and thus the retrieval result is influenced. So the retrieval AOT is separated by month and is validated respective. In these result of regression analysis, the result of July is good, the correlation of CE-318 observations and the MODIS retrieval AOT is reach up to 0.9031.

Figure 2. The contrast of MODIS AOT and the sun photometer in situ in July

The retrieval result is not as well as expected, the reason may be: the high latitude, the sunshine duration in winter is short and the Lake Baikal is in the freezing period for long time (every January to May), and this is needed to be further studied. However, MODIS AOT has high spatial resolution, and can show the spatial distribution of aerosol visualized, thus, it could be referenced for the temporal and spatial dynamics analysis.

3.2. Temporal and Spatial of AOT

Because the Lake Baikal locates on high latitude and the sunshine duration is short in winter, the MODIS AOT product and MODIS retrieved AOT of December and January is lacked.

According to the MOD04 during 2000 to 2010, the monthly variation of AOT is showed on fig.3. The monthly average AOT presents a normal distribution, from February to May the AOT is gradually increasing to the highest value and then begins to decrease till November. The maximum is 0.263 in
May, while the minimum is 0.078 in November. In spring and summer the average AOT is larger than it in fall and winter. The average AOT over the region is generally lower, the possible reason is there are less people and less human activities as well as the region is covered by large area dense vegetation, thus the air is more clear\cite{17}. In winter, the snow and ice is melting, and the lake water is thawing, so the air humidity is larger than other season. Hygroscopic particle makes a difference in increasing the AOT, so the AOT is higher in spring.

**Figure 3.** The month average of AOT over the region of Baikal during 2000–2010

In fig.4, the spatial distribution of the MODIS AOT in 2000 and 2010 is displayed on. For there are no data in November and December, the MODIS AOT in the two month is lack. Though the result is not as good as expected, the fig.4 can still be a reference to help for the analysis. In the pictures of spatial distribution, it has more high AOT in spring (March, April, May), and after June there are almost low AOT over the region. Also, it could be found that, the high AOT is almost concentrated in the northern area, while there is more low AOT in the southern region.

**Figure 4.** The month average AOT retrieved using MODIS data over the region of Baikal in 2000 and 2010

According to the meteorological department usual season partition method, March, April and May is defined as spring; June, July and August is definition for the summer; September, October and November is defined as fall; December, January and February is definition for winter. The seasonal variation of AOT over the region is displayed on the fig.5. Similar to the results previous, the average AOT in spring and summer is greater than that in fall and winter. In spring, the highest AOT can reach up to 0.2406, and the lowest AOT is just greater than 0.1 in fall.
According to the MOD04 data during the year 2000 to 2010, the yearly variation of AOT is showed on fig.6. From the year 2000 to 2010, the AOT generally changes like a wave as years go on, and there’s no trend of increasing or decreasing. At the beginning, the average AOT increases generally till 2003, and the highest AOT is 0.371 in 2003; from the year 2004 to 2009, the yearly average AOT over the region of Baikal has a up and down trend, but the change is small and the value is generally steady.

4 Conclusion

1) Using MODIS to retrieve the high spatial resolution (500 m) AOT over the region of Baikal, the accuracy remains need to be further improve. However, satellite remote sensing AOT has any their own advantages which is the ground monitoring lack of: intuition and monitoring the space distribution features in large area.

2) Using the MODIS retrieval AOT and the MODIS aerosol product (MOD04), the characteristics of spatial and temporal distribution over the region of Baikal can be displayed on the result picture. The AOT in spring is higher than others, perhaps is the reason of the lake water is thawing and the moisture content is high. And from the summer, the AOT begins to decrease to a steady condition. However, in winter, the region is covered by snow and ice, and the dark-target method is not applied for this region and season.

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