

RETRIEVAL OF AEROSOL OPTICAL DEPTH OVER URBAN AREAS USING TERRA/MODIS DATA

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ABSTRACT:

Satellite remote sensing retrieval has shown excellent competence at retrieving the aerosol distribution and properties comparing with traditional detection. The extended dark dense vegetation (DDV) algorithm for MODIS data was used widely all over the world. However, whether this algorithm can be transferred to high reflectivity areas of China is not known yet, especially in urban area and its surroundings. In this paper, we attempt to derive Aerosol Optical Depths (AOD) by exploiting the extended dense vegetation algorithm and TERRA/MODIS data. Preliminary validation results by comparing with in situ measured data show good accuracy and promising potential in different seasons of China urban areas.

1. INTRODUCTION

Atmospheric aerosols play an important role in the Earth's radiation balance and global climate change (Charlson et al., 1991; D'Almeida et al., 1991). Aerosol Optical Depth (AOD) is one of the most important key parameters which can not only reflect the characterization of atmospheric turbidity (Charlson, 1991; Sokolik et al, 1996; Twohy et al, 1995; Boucher et al, 1995), but also identify the climate effects of aerosols (Twohy et al, 1995; Rosenfeld et al, 2000; Toon et al, 2000). So the precise detection of AOD is indispensable. As a way of acquiring AOD, satellite remote sensing retrieval has many advantages comparing with the traditional detection, such as wide area coverage, fast accessing cycle, lower cost, etc.

The aerosol retrieval accuracy has already been improved since the first global aerosols maps were derived from the Advanced Very High Radiometer/National Oceanic and Atmospheric Administration (AVHRR/NOAA) (Higurashi and Nakajima, 1999; Holben et al., 1993), due to a series of new sensitive instruments like the Moderate Resolution Imaging Spectroradiometer (MODIS) (Chu et al., 2002), the Polarization and Directionally of Earth's Reflectance (POLDER) (Claquin et al., 1999), and the Along Track Scanning Radiometer (ATSR) (North et al., 1999).

However, remote sensing over land still remains a difficult task (Kaufman et al., 1997), especially in urban areas, because higher ground reflectance makes urban aerosols not sensitive to its changes, and thus the retrieval of AOD becomes much more difficult.

To address the accuracy of retrieval AOD from satellite data over urban areas, the extended dense dark vegetation algorithm (DDV) (Kaufman et al., 2002) was applied to retrieve AOD using the 6S radiative transfer model based on TERRA/MODIS data over urban areas and its surroundings (Lanzhou city, China), and in situ measurement by a multi-band sun photometers (L97) was made at Lanzhou University from May

2005 to April 2006 to obtain the measured AOD at the wavelength of 550 nm to evaluate the accuracy.

2. RETRIEVAL ALGORITHMS

Many algorithms have been applied to satellite data to retrieve AOD. For instance, MODIS retrievals of aerosol over land (Kaufman et al., 1997; Remer et al., 2005) are based on the correlation of reflectances in the visible and shortwave infrared (SWIR). In essence, the algorithm assumes that the influence of aerosols on the top-of-atmosphere (TOA) reflectance in the SWIR is negligible. Therefore, the ground surface reflectance can be found at these wavelengths, (e.g., at 2.1 μ m for MODIS) by only correcting for Rayleigh scattering and gaseous absorption in the atmosphere. One can then exploit the correlation between the SWIR ground reflectances with those in the visible channels where aerosol scattering is significant. The derived surface reflectance is used for constraining the aerosol retrievals (Kaufman et al., 1997).

The extended dark dense vegetation algorithm developed by Dr.Kaufman in 2002, has been used widely. By taking lots of flight experiments, he summarized the relationship between the near infrared band's apparent reflectance and blue, red band's ground reflectance, and eventually got an empirical formula which could be extended to high reflectivity areas. Formula one and two explain the relationships among them here.

$$\rho_R' = \rho_{2.1}^* / 2 \quad (1)$$

$$\rho_B' = \rho_{2.1}^* / 4 \quad (2)$$

Where ρ_R' = the reflectance of red band (B1)

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ρ_B = the reflectance of blue band (B3)
 $\rho_{2.1}^*$ = the apparent reflectance of near infrared band which the wavelength is 2.1 μ m (B7).

3. DATA USED

MODIS is one of the sensors on board EOS-AM1/TERRA and EOS-PM1/AQUA, which are both sun-synchronous polar orbiting satellites. TERRA was launched on Dec. 12, 1999 and flies northward pass the equator at about local time 10:30 AM. AQUA, launched on May 4, 2002, flies southward pass the equator at about local time 1:30 PM. The time interval of their overpass at the same area is usually less than 3 h. MODIS is a new generation Imaging Spectroradiometer, which has moderate spectral resolution with 36 spectral bands that cover the wavelength range from 0.4 to 14 μ m, and three spatial resolutions of 250, 500, and 1000 m, respectively, and a swath of 2330 km. In this paper, MODIS 1 B HDF data (NASA Goddard Space Flight Center Level 1 and Atmosphere Archive and Distribution System) was employed to retrieve the AOD of study area. SRTM DEM data (CGIAR Consortium for Spatial Information Database) which spatial resolution is 90 m was also used as auxiliary data. In situ measured data by multi-band sun photometers (L97) was used for accuracy evaluation.

4. METHODS

The blue and red band's ground reflectance files were used as input with other parameters to the 6S radiative transfer model, comparing with a look up table, and finally the AOD of corresponding pixel was obtained. Figure 1 shows the flowchart of AOD retrieval using TERRA/MODIS data in details. Input parameters can also be seen from Table 1.

| Codes of parameter | Meaning of parameters |
|--------------------|--|
| 0 | User define conditions |
| 2 | Midlatitude summer mode |
| 1 | Continental aerosols model |
| 0 | Target is at the sea level |
| - 1000 | Sensor on board of satellite |
| 44 | Third band of MODIS |
| 0 | Homogeneous case |
| 0 | No directional effects |
| 0 | User define ground reflectance |
| - 2 | No atmospheric correction is performed |

Table1. Input parameters in 6S radiative transfer model

5. RESULTS AND DISCUSSION

We can know from the distribution map of AOD over Lanzhou city and its surroundings that there are two high-value zones of AOD, which are located in Xigu and Chengguan districts.

Qilihe district will also appear a high-value area in some cases, and the maximum AOD value usually appears in Xigu district, which is consistent with the actual distribution of pollution sources.

The spring weather is usually influenced by dust and sand aerosols, so that the spatial distribution of AOD changes largely, mainly due to the effects of dust and sand particles. Especially on March 9, 2006, a serious of dust storms occurred. From the distribution map of AOD, we observed clearly a high-value zone from west to east over urban areas which was different from its surroundings. At Lanzhou University Measurement Site (LZUMS), the measured AOD is 0.334, and the retrieved AOD is 0.421 (see Figure 2).

In summer, the spatial distribution of AOD is relatively stable, mainly because of high speed wind, which is beneficial to spread of aerosol. At the center of urban, the high value indicates the main industrial pollution. On May 8, 2005, at LZUMS, the measured AOD is 0.406, and the retrieved AOD is 0.671 (see Figure 3).

From September to October in autumn, owing to harvesting of crops, increasing of bare soil, and combining with the soot emissions, the AOD of surroundings increased clearly than urban. On September 2, 2005, at LZUMS, the retrieved AOD is 0.687, and the measured AOD is 0.584 (see Figure 4).

The results showed that the urban AOD was lager than those in its surroundings in winter, because of increasing in emissions of air pollutants, the spread of adverse conditions, and winter heating. It was consistent with actual circumstances that winter air pollution was very serious. On December 8, 2005, at LZUMS, the measured AOD is 0.633, and the corresponding retrieved AOD is 0.796 (see Figure 5).

6. CONCLUSIONS

This study presents a retrieval and accuracy verification experiment in China's urban city, using the extended dark dense vegetation algorithm, 6S radiative transfer model, and MODIS data. By comparison, retrieved AOD was overestimated probably due to the selection of aerosol model, atmospheric model, geometric parameters, and BRDF, all of which were predefined in the 6S model. Although the Aerosol Robotic Network (AERONET) can provide globally distributed observations of AOD, there are only few sites in China. We need more accuracy verification sites.

REFERENCES

Boucher. O., T.L. Anderson, 1995. General Circulation Model Assessment of the sensitivity of direct climate forcing by anthropogenic sulfate aerosols to aerosol size and chemistry. *Journal of Geophysical Research*, 100(12), pp. 26117-26134.

Charlson, R.J., J.Langner, H.Rodhe, C.B. Leovy, and S.G. Warren., 1991. Perturbation of the northern hemisphere radiative balance by backscattering from anthropogenic sulfate aerosols. *Tellus*, 43AB (4), pp. 152-163.

Chu, D.A., Kaufman, Y.J., Ichoku, C., Remer, L.A., Tanré, D., Holben, B.N., 2002. Validation of MODIS aerosol optical depth

- retrieval overland. *Geophysical Research Letter*, 29. Doi: 10.1029/2001GL013205.
- Claquin, T., Schulz, M., & Balkanski, Y. J., 1999. Modeling the mineralogy of atmospheric dust source. *Journal of Geophysical Research*, 104, pp. 22243–22256.
- D’Almeida, G.A., P. Koepke, and E. P. Shettle, 1991. Atmospheric aerosols, global climatology and radiative characteristics. Deepak Publ., pp.561.
- Dubovik O., Smirnow A., Holben B.N., et al, 2000. Accuracy assessments of aerosol optical properties retrieved from AERONET sun and sky-radiance measurements. *Journal of Geophysical Research*, 105, pp. 9791-9806.
- Durkee, P.A., D.R.Jensen, E.E.Hindman, and T.H.Vonder Haar., 1986. The Relationship between Marine Aerosols and Satellite Detected Radiance. *Journal of Geophysical Research*, 91, pp. 4063-4072.
- Higurashi, A., & Nakajima, T., 1999. Development of a two-channel aerosol retrieval algorithm on a global scale using NOAA AVHRR. *Journal of Atmospheric Sciences*, 56, pp. 924– 941.
- Holben, B. N., Vermote, E., Kaufman, Y. J., Tanre, D., and Kalb, V., 1992. Aerosol retrieval over land from AVHRR data-application for atmospheric correction. *IEEE Transactions on Geoscience and Remote Sensing*, 30(2), pp. 212– 222.
- Liang S.L., Zhong B., Fang H.L., 2006. Improved estimation of aerosol optical depth from MODIS imagery over land surfaces. *Remote Sensing of Environment*, 104, pp. 416-425.
- Kaufman Y.J. and J.H. Joseph, 1982. Determination of surface albedos and aerosol extinction characteristics from satellite imagery. *Journal of Geophysical Research*, 87, pp. 1287-1299.
- Kaufman Y.J. and C.Sendra, 1988. Algorithms for automatic atmospheric corrections to visible and near-IR satellite imagery. *International Journal of Remote Sens*, 9, pp. 1357-1381.
- Kaufman Y.J. and L.A. Remer, 1994. Remote sensing of vegetation in the near IR from EOS MODIS. *IEEE Transactions on Geoscience and Remote Sensing*, 32, pp. 672-683.
- Kaufman, Y. J., Tanre, D., Nakajima, T., Lenoble, J., Frouin, R., Grassl, H., et al., 1997. Passive remote sensing of tropospheric aerosol and atmospheric correction for the aerosol effect. *Journal of Geophysical Research*, 102, 16815–16830.
- Kaufman, Y.J., D.Tanre, L.Remer, et al, 2002. MODIS semi-annual report.
- Remer, L.A., Kaufman, Y.J., Tanre, D., et al., 2005. The MODIS aerosol algorithm, products and validation. *Journal of Atmospheric Sciences*, 62, pp. 947 – 973.
- Rosenfeld, D., 2000 Suppression of rain and snow by urban and industrial pollution. *Science*, 287, pp. 1793-1796.
- Sokolik, et al., 1996. Direct radiative forcing by anthropogenic airborne mineral aerosols. *Nature*, 381, pp. 681-683.
- Toon, O.B., 2000. How Pollution Suppresses Rain. *Science*, 287, pp. 1763-1764.
- Twohy, C.H., P.A. Durkee, B.J. Huebert, R.J. Charlson, 1995. Effects of aerosol particles on the microphysics of coastal stratiform clouds. *Journal of Climate*, 8, pp. 773-783.

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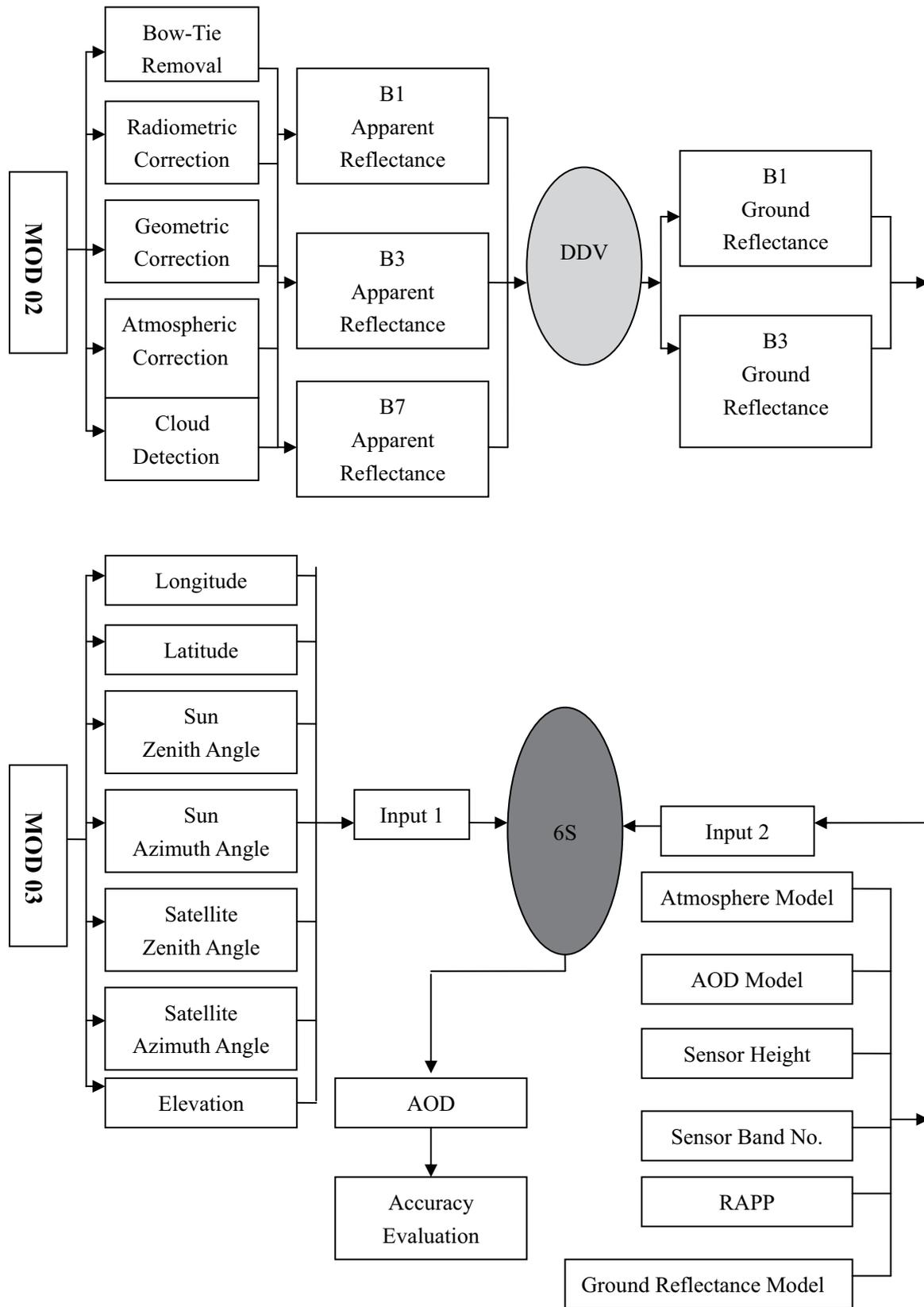


Figure1. Flowchart of AOD retrieval using TERRA/MODIS data

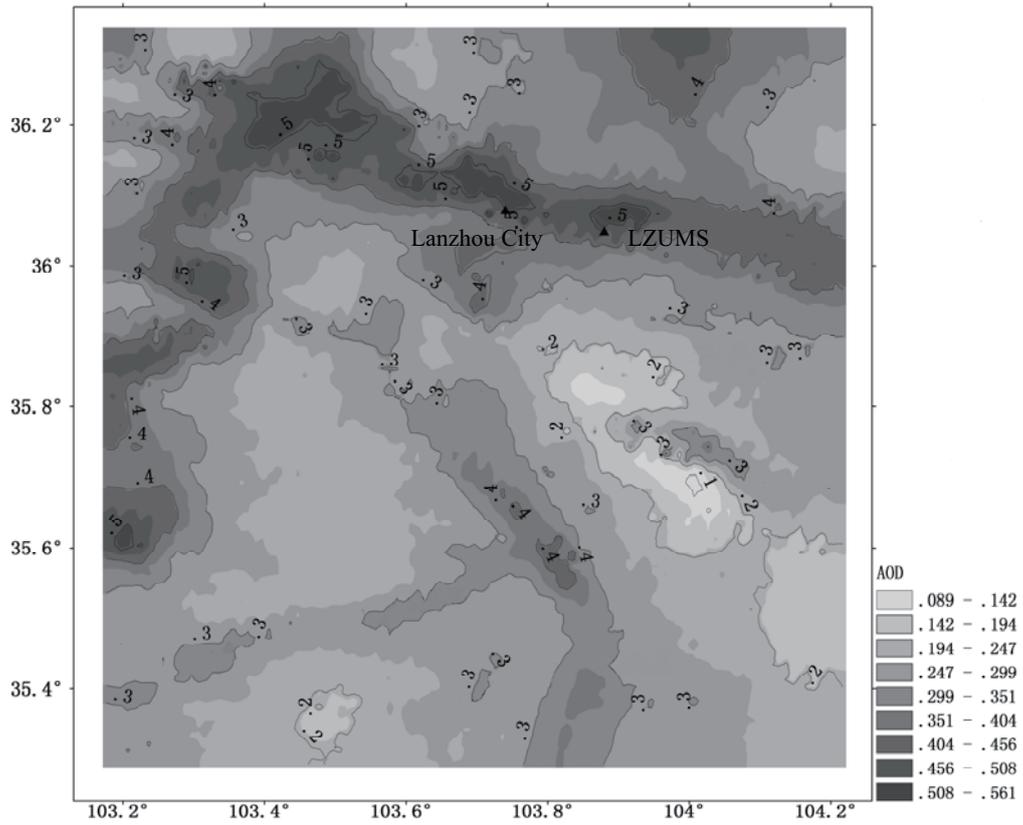


Figure 2. Distribution map of AOD on March 9, 2006 at LZUMS (spring)

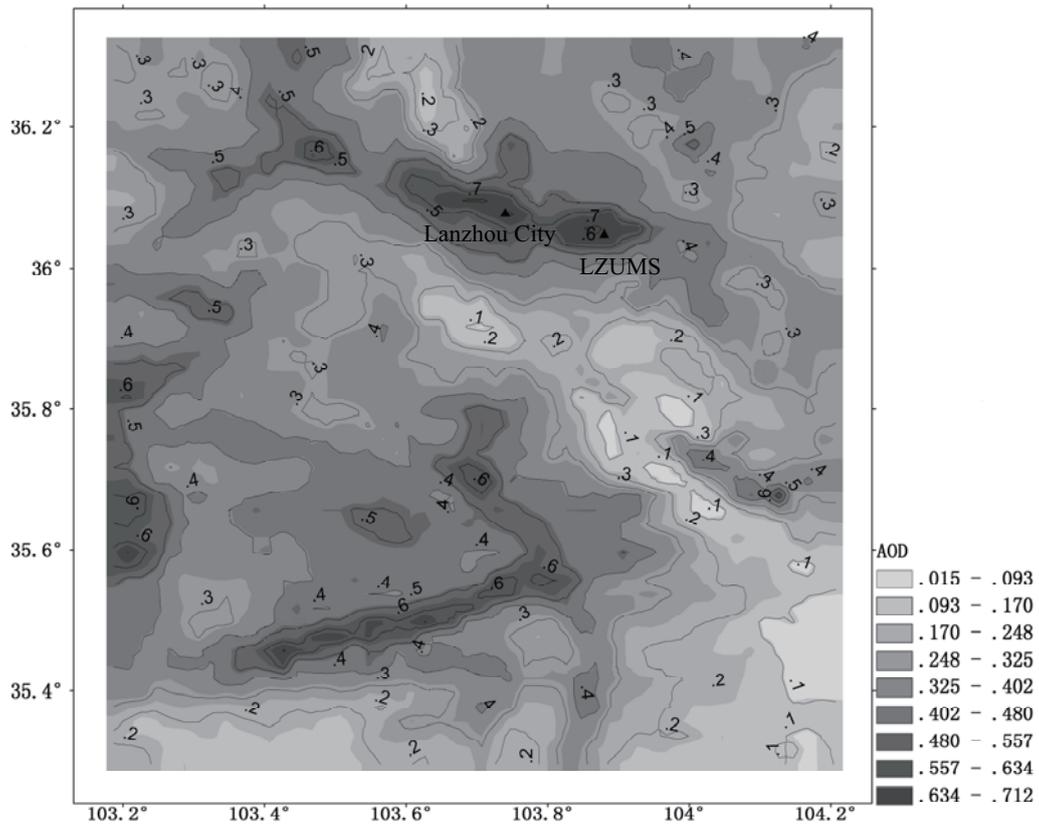


Figure 3. Distribution map of AOD on May 8, 2005 at LZUMS (summer)

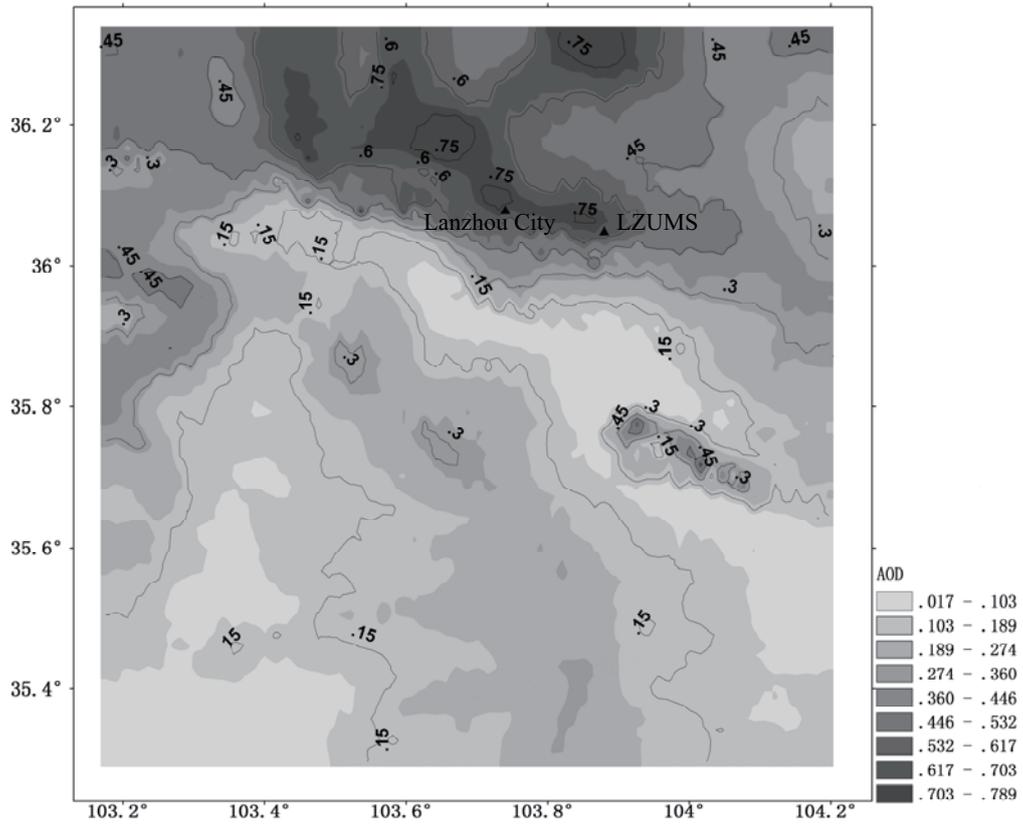


Figure 4. Distribution map of AOD on September 2, 2005 at LZUMS (autumn)

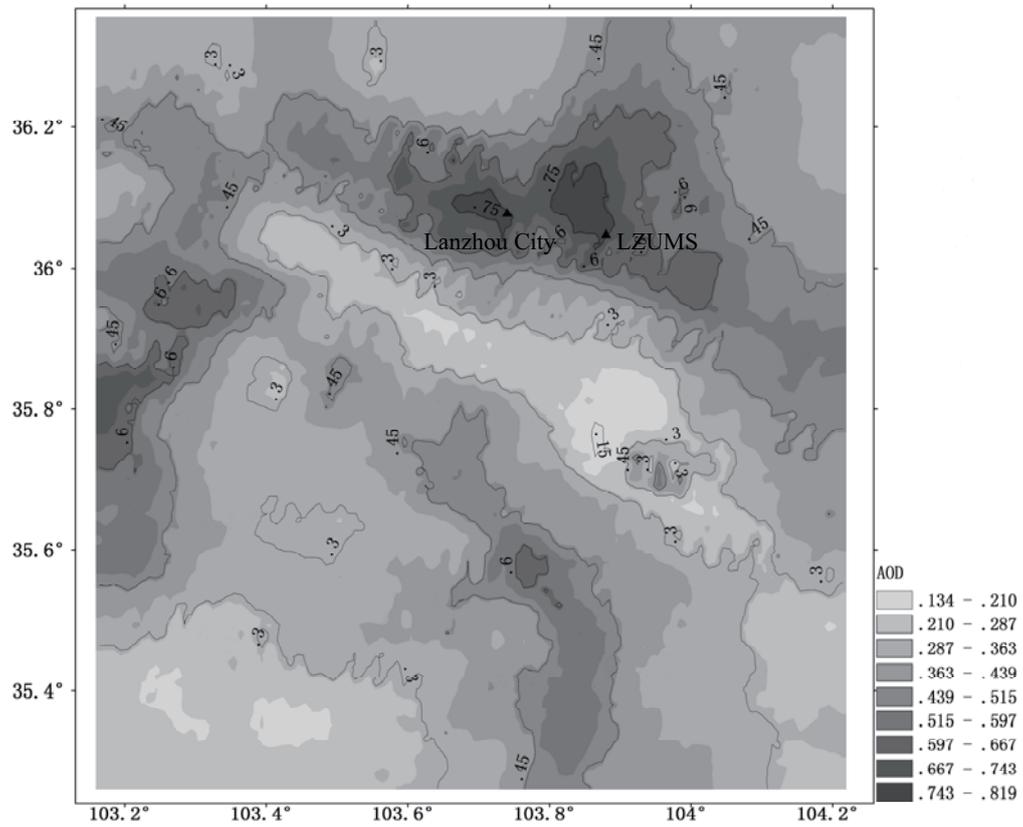


Figure 5. Distribution map of AOD on December 8, 2005 at LZUMS (winter)