PRIOR INFORMATION SUPPORTED POST-PROCESSING IN AEROSOL OPTICAL DEPTH RETRIEVAL

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ABSTRACT: It is essential to provide high-accuracy Aerosol Optical Depth (AOD) dataset to evaluate radiative forcing effect of aerosol on climate. However, AOD retrieved from satellite data are generally “contaminated” by a host of discrete outliers due to uncertainties in instrument calibration, variety of underlying surface, assumptions on the aerosol model and incompleteness of retrieval model. This is incongruous with the inherent homogeneity of AOD in time and space, whose variability has a scale of many kilometers. It is neither possible nor necessary to remove noise from root source. Instead, we could reduce its influence by filtering AOD retrieval result.

In this paper, a noise detecting and removing method based on a prior knowledge is proposed and proved to be effective for AOD post-processing. The algorithm consists of three steps: 1) Firstly, AOD results are divided into several blocks as basic units of noise detection; 2) secondly, a 3×3 window is slid pixel by pixel. Prior knowledge is used to determine whether the central pixel is noise; and 3) thirdly, a certain filtering method is applied to remove and “pad” the noise detected.

The study area is located in Shandong province (114-123°E, 34-40°N) and the AOD result is retrieved using Synergistic Retrieval of Aerosol Properties (SRAP-MODIS) algorithm. The correlation coefficient of SRAP-MODIS retrieval result with MODIS aerosol product are improved from 0.6092 originally to 0.7063, 0.7146, and 0.7825 after geometric mean filtering, median filtering and adaptive median filtering respectively, thus proving the effectiveness of the above methods and the superiority of adaptive median filtering over the other two, a superiority owing to selecting window size adaptively based on the degree of noise interference and replacing the corrupted pixel with a weighted average rather than simply with median of the window.

1. INTRODUCTION

Atmospheric remote sensing offers us a view to estimate air quality in describing the aerosol distribution either for a local or global coverage. Aerosols are important components of the earth-atmosphere-ocean system, affecting climate through direct or indirect climate forcing (King et al. 1999). Since Aerosol Optical Depth (AOD) is a significant feature of aerosol, it is very important to provide high-accuracy as well as large-coverage AOD dataset to evaluate effects of aerosol on climate.

A host of approaches have been developed to retrieve AOD, but due to some reasons such as uncertainties in instrument calibration, variety of underlying surface, assumptions on the aerosol model and incompleteness of retrieval model (Kaufman et al. 1997), the retrieval results may contain many discrete outliers. These outliers not only contradict with the widely recognized fact that AOD is relatively homogeneous within kilometers (Holzer-Popp et al. 2009), but also reduce the overall accuracy and impede further application of the model.

In this paper, an interpolation and smoothing procedure is applied based on prior information. A series of tests are made and validation results show that this procedure is quite effective.

2. METHOD

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2.1 Noise Detection

Identifying noise accurately is a prerequisite for removing noise effectively. Balancing time cost and probability of mistake and omitting, a new method (Zhang et al. 2005) is put forward based on the difference between the central pixel and peripheral pixels.

Firstly, the image is divided into several blocks as basic units. Let MAX be the maximum of the block, MIN be the minimum of the block, and MED be medium of the block. Secondly, a 3×3 window is slid pixel by pixel. If AOD of the central pixel equals MAX or MIN, and the difference between the central pixel and MED is greater than a given threshold T, then the central pixel is classified as a noise. The threshold T should be relevant with image: the more serious noise is, the greater T should be. After many contrast experiments, 0.08×(MAX-MIN) proved to be appropriate for most cases.

2.2 Filtering

After noise points are accurately detected, several filters, including geometric mean filter, median filter and adaptive median filter, are applied respectively only to those noise points.

Geometric mean filter smoothes noise by replacing the noise point with geometric mean of the window, while median filter replace it with median of the window. These two filters lost some original information when repressing noise. Adaptive median filter (Zhang et al. 2005) performs better in this respect. It evaluate the noise level by calculating noise points within this block; then filter window size is determined according to noise level; finally, the noise is replaced by a weighted average in four directions as shown in Figure 1 (take 3×3 window for example). Let $M_0(m,n), M_1(m,n), M_2(m,n), M_3(m,n)$ be median of the four sub-windows respectively, namely $M_k(m,n) = med[M_k(m,n)], k = 0,1,2,3$. The filtered result is $g(m,n) = \sum_{k=0}^{3} c_k M_k(m,n)$, where $c_k = \frac{M_k(m,n)}{\sum_{i=0}^{3} M_i(m,n)}$. Filter window size is determined by Equation 1. Experiments found that best effect can be achieved when w_1, w_2, w_3 equals 0.2%, 25%, 45% respectively.

$$l = \begin{cases} 0, & p \le w_1 \\ 3, & w_1 < p \le w_2 \\ 5, & w_2 > p \le w_3 \\ 7, & p > w_3 \end{cases} \tag{1}$$

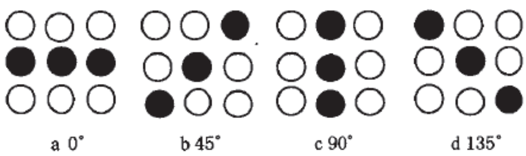


Figure 1. Four Specific Filter Direction (Zhang et al. 2005)

As noise cannot be removed completely by filtering only once, iteration procedure is employed in order to achieve better result. Later experiments show that iteration improve both visual effects and numeral accuracy dramatically.

3. RESULTS AND VALIDATION

3.1 Data and Results

The study area is located in Shandong province (114 - 123°E, 34 - 40°N) where landform varies from mountain to plain. Test data is AOD of that area on 18th of August 2004, retrieved by SRAP-MODIS (Xue and Cracknell 1995, Tang et al. 2005) algorithm as shown in Figure 2. Aerosol product from MODIS data, MOD04, is used as standard in validation, since its well recognized high accuracy. Correlation coefficient between MOD04 and filtered results will be used as an indicator of accuracy in validation work.

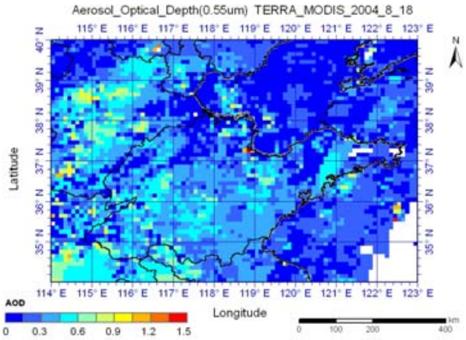
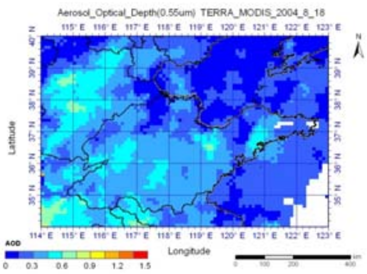
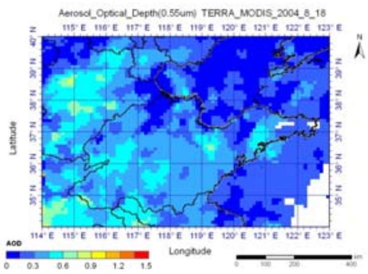


Figure 2. Original AOD Retrieved by SRAP-MODIS Algorithm

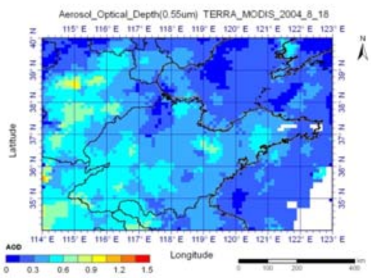
Figure 3 shows AOD filtered by different algorithms. They are results of geometric mean filtering (a), median filtering (b), adaptive median filtering (c), and MOD04 of matched time and space (d). As is shown clearly, all three results are much smoother than original AOD (Figure 2). Adaptive median filter works best on preserving original information, and its result is most similar to MOD04. The high value area (yellow color) in upper left corner decays after filtered by the first two filters, but remains in the result of adaptive median filter.



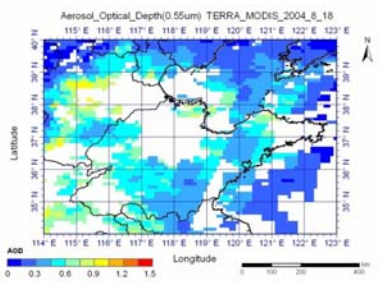
(a)



(b)



(c)



(d)

Figure 3. AOD Filtered by Geometric Mean Filtering, Median Filtering and Adaptive Median Filtering Along with Co-located MODIS Aerosol Product

3.2 Validation

Regression analysis offers us further understanding of the results. In Figure 4, horizontal axis represents MOD04; longitudinal axis represents original, geometric mean filtered, median filtered, adaptive median filtered AOD, in the corresponding order from (a) to (d). Correlation coefficient between each result and MOD04, along with slope and intercept, are shown in Table 1. It can be seen clearly from both graphs and figures in the table that adaptive median filter win out as the most accurate one. It removes noise points that deviate from the ideal line y = x most effectively, thus getting the highest correlation coefficient. The superiority is the result of selecting window size according to noise level and using a weighted average to replace the central pixel.

The superiority continues when it comes to iteration. With iteration number increases, there is a sudden drop of accuracy of median filter, as demonstrated in Figure 5. However, the accuracy of adaptive median filter remains at a high level with iteration goes on (Figure 6). This is because when noise level goes down to a certain degree, filter window size would adjust adaptively to be 0, so it would not continue to smooth the image and undermine original information.

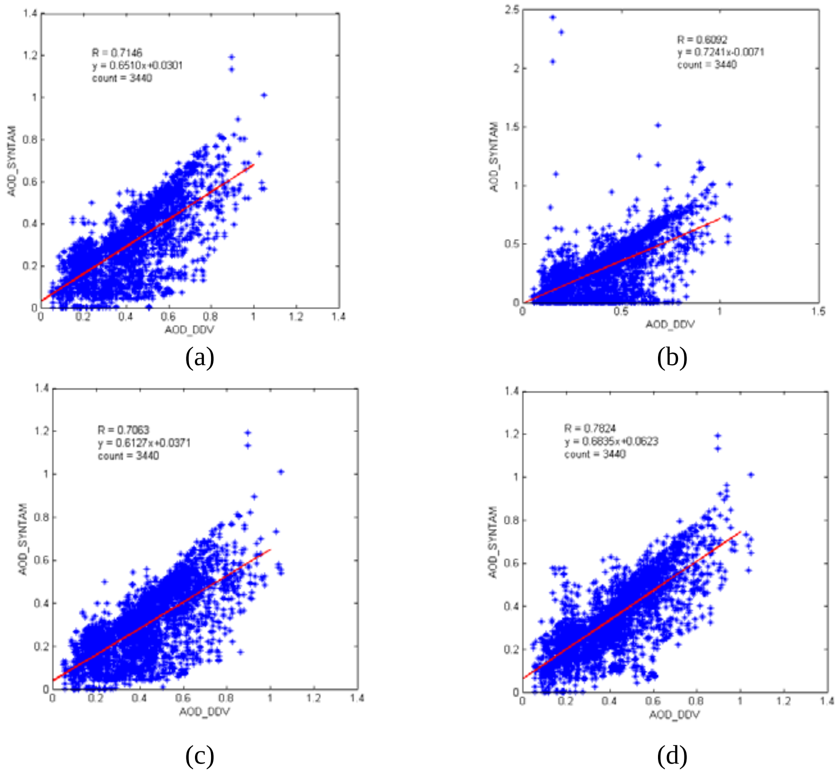


Figure 4. Regression Analysis of Original AOD Result and AOD Filtered by Geometric Mean Filtering, Median Filtering and Adaptive Median Filtering

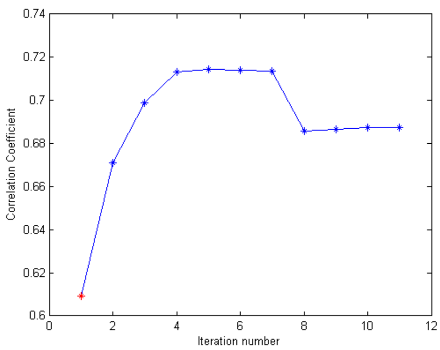


Figure 5. Accuracy of Median Filter Varies with Iteration

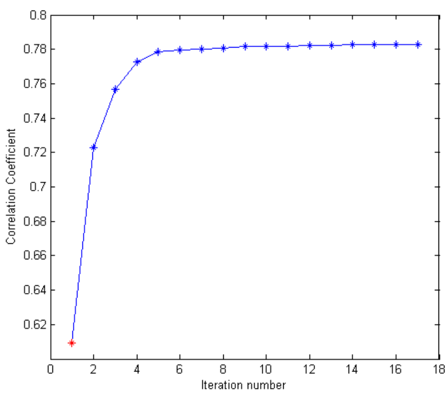


Figure 6. Accuracy of Adaptive Median Filter Varies with Iteration

Table 1. Comparison of Regression Analysis of Three Filtering Methods

Filtering method	Correlation Coefficient	Slope	Intercept
Geometric filtering	0.7063	0.6127	0.0371
Median filtering	0.7146	0.6510	0.0301
Adaptive median filtering	0.7824	0.6835	0.0623

4. CONCLUSION

The method proposed in this paper works very well against noise in AOD. Correlation coefficient between test data and MOD04, which is used as standard, improved greatly after the procedure. Among three filters discussed in this paper, adaptive median filter outperforms other two filters in both effect of removing noise and maintaining accuracy in iteration. All in all, this method is simple and feasible, and could improve accuracy of AOD in a relatively small cost.

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