Trend analysis of the aerosol optical depth from fusion of MISR and MODIS retrievals over China

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Abstract. Atmospheric aerosol plays an important role in the climate change though direct and indirect processes. In order to evaluate the effects of aerosols on climate, it is necessary to have a research on their spatial and temporal distributions. Satellite aerosol remote sensing is a developing technology that may provide good temporal sampling and superior spatial coverage to study aerosols. The Moderate Resolution Imaging Spectroradiometer (MODIS) and Multi-angle Imaging Spectroradiometer (MISR) have provided aerosol observations since 2000, with large coverage and high accuracy. However, due to the complex surface, cloud contamination, and aerosol models used in the retrieving process, the uncertainties still exist in current satellite aerosol products. There are several observed differences in comparing the MISR and MODIS AOD data with the AERONET AOD. Combing multiple sensors could reduce uncertainties and improve observational accuracy. The validation results reveal that a better agreement between fusion AOD and AERONET AOD. The results confirm that the fusion AOD values are more accurate than single sensor. We have researched the trend analysis of the aerosol properties over China based on nine-year (2002-2010) fusion data. Compared with trend analysis in Jingjintang and Yangtze River Delta, the accuracy has increased by 5% and 3%, respectively. It is obvious that the increasing trend of the AOD occurred in Yangtze River Delta, where human activities may be the main source of the increasing AOD.

1. Introduction

Atmospheric aerosols, ubiquitous particles suspended in the atmosphere, play an important role in the climate system. They affects climate by scattering and absorbing radiation (the “direct effect”) and by modifying amounts and microphysical and radiative properties of clouds (the “indirect effects”) [1]. The effects of aerosols are thought to partially counterbalance global warming caused by greenhouse gases [2]. Consequently, they affect global surface air temperatures, photochemistry, and ecosystems [3]. However, the quantification of these effects is very difficult because they are relatively short-lived in the atmosphere, with an average residence time of a few days, and are heterogeneous in space and time. Therefore, continuous monitoring of aerosol properties is essential.

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The Moderate Resolution Imaging Spectroradiometer (MODIS) and Multiangle Imaging SpectroRadiometer have provided aerosol observations since 2000, with large coverage and high accuracy. However, some studies have shown that uncertainties still exist in current satellite aerosol products attributable to the complex surface, cloud contamination, and aerosol models used in the retrieving process [4]. As the limitations of single satellite sensor, to merge the MODIS aerosol data and MISR aerosol data is meaningful. The least square is used to merge multi-sensor aerosol data in this article, in order to produce higher degree of coverage of AOD dataset.

Our study region covers the China (70º-135ºE, 5º-50ºN) using MODIS and MISR and fusion AOD (2002-2010). In section 2 a brief description of the aerosol data used in the study is given, including MODIS AOD data and MISR AOD data, and the fusion method. In section 3, we used AERONET station to validate fusion AOD products. Then we used fusion AOD, MODIS and MISR retrievals to analyze trend of aerosols. Finally, the conclusions are in section 4.

2. Descriptions of Aerosol Data and Fusion Approach

2.1. Aerosol Data

The MODIS and MISR, launched on 18 December 1999 aboard the Terra spacecraft, are making global observations of top-of-atmosphere (TOA) radiances [5].

MODIS observes the same point in a single direction but in 36 channels covering a wide spectral range. It has the ability to monitor aerosols with a cloud mask producing satisfactory separation between clouds and aerosols for nearly all aerosols and cloud types [6]. MISR observers the earth and atmosphere with nine different viewing angles, and at 4 spectral bands: 0.446, 0.558, 0.672, and 0.866 µm, with a relatively narrower swath of 360km comparing with MODIS.

The data we studied are level 3 monthly aerosol products at 0.55 and 0.558 µm for MODIS and MISR respectively, which are available at 1°and 0.5°spatial resolution respectively. Near-global coverage is obtained in 2 days for MODIS and 9 days for MISR. The AERONET program is a ground based remote sensing aerosol network that provide long term continuous measurements of aerosol optical, microphysical, and radiative properties for aerosol research as well as validation of satellite retrievals [7][8].

2.2. Fusion Approach

The multi-sensor measurement model is analyzed. A multi-sensor information fusion model is constructed for the parameter estimation, which is based on least squares technique.
The idea is to model by a linear combination of n basis functions:

$$y_i = H_i x + V_i, i = 1, 2, ..., n \tag{1}$$

The minimum of the sum of squares is found by setting the gradient to zero, that is:

$$J = V_i^T V_i = [y_i - H_i x]^T [y_i - H_i x] \tag{2}$$

$$\frac{\partial J}{\partial x} = -2\sum (y_i - V_i - H_i x) = 0 \tag{3}$$

The least square estimate can be written as:

$$\hat{x} = (x^T x)^{-1} x^T y \tag{4}$$

The values of fusion AOD is given by：

$$\hat{y}(k) = \beta_1 \sum_{i=1}^{n} y_i + \beta_2 \sum_{i=1}^{n} i \bullet y_i \tag{5}$$

3. Results

3.1. Validation

This work we validate the fusion AOD, MISR AOD and MODIS AOD from AERONET Beijing and Hongkong station, in order to find which sensor is more accurate over China.

The results are shown in Figures 1a and b, respectively. Results show fusion data are better correlated with the AEROENT measurements than are either alone. The overall correlation coefficients (R) of MODIS AOD and MISR AOD were reduced 7.7% and 3.4% at Beijing site, and 5. 3% and 3.9% at Hongkong site respectively by fusion model. The results confirm the fusion data was more accurate over China.

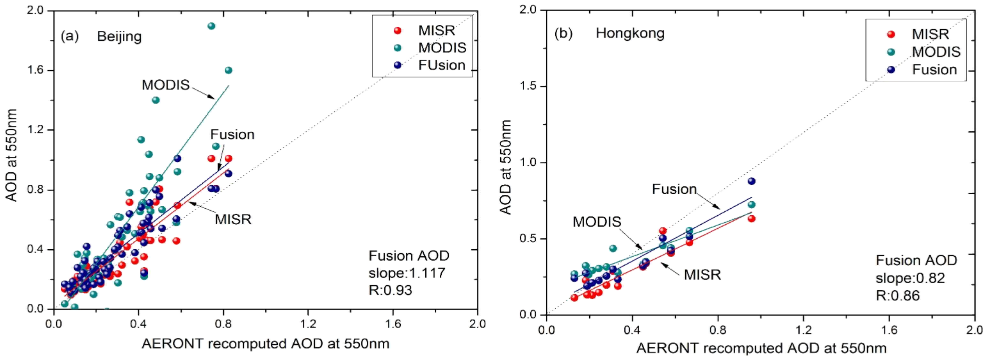

Figure 1. Comparisons between AEROENT AOD data and AOD from fusion data, MODIS data and MISR data at (a) Beijing site and (b) Hongkong sites.

3.2. Results

The MODIS are combined with the MISR AOD data on August 16, 2009. The spatial distribution characteristics of fusion AOD and satellite AOD over China is shown in Figures 2a, b and c. The merged AOD image clearly shows the improvement in spatial coverage.

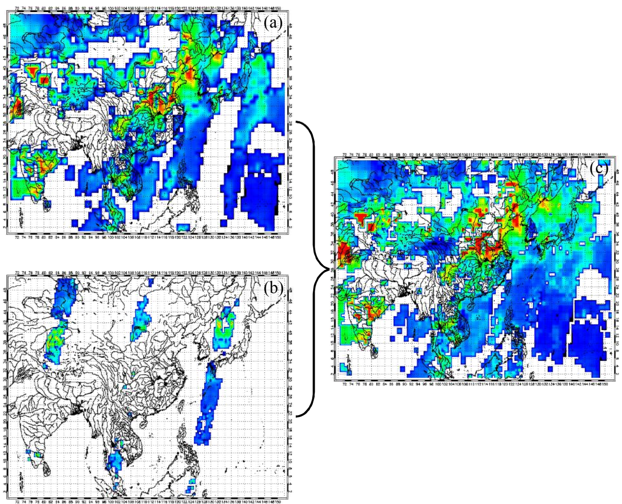

Figure 2. Distributions of (a) fusion AOD, (b) MODIS AOD and (c) MISR AOD in August 16, 2009.

Figure 3 compares the monthly averaged of aerosol optical depths over Jingjintang and Yangtze River Delta from 2002 to 2010, with the assimilated (blue), Terra MODIS (red) and MISR (green) AOD values, respectively.

From Figures 3a and b, the trends of both fusion data and MISR data are similar with each other, which are lower than that of the MODIS. Remer et al. (2008) suggested the reason for the differences between Terra and Aqua MODIS AOD values is caused by radiometric calibration [4][9].The results

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from linear regression fits show that the merged AOD is generally in better agreement with the MISR retrievals than MODIS AOD, and an trend in AOD of about -0.019 and 0.001per 9-year was found over Jingjintang and Yangtze River Delta, respectively.

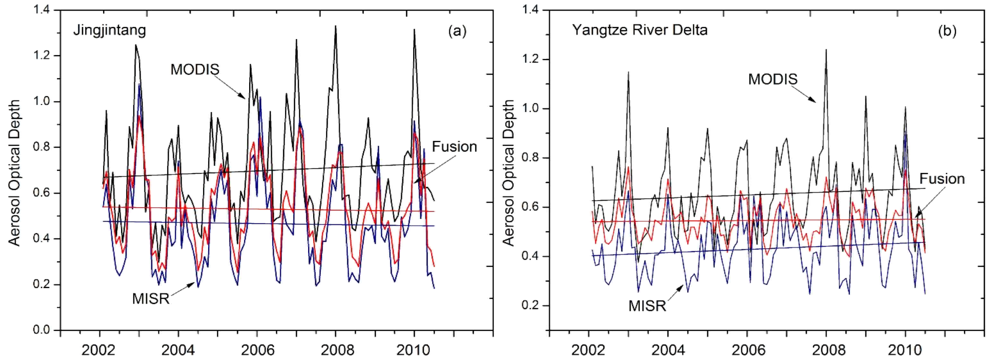

Figure 3. Nine-year(2002-2010) AOD trend analysis for monthly mean MODIS (black), MISR (blue) and fusion (red) over (a) Jingjingtang and (b) Yangtze River Delta.

To better understand the factors leading to the AOD change, analysis of inter-annual variation of AOD on seasonal basis are shown in Figures 4 and 5 [10]. The positive trend is only observed in summer of Yangtze River Delta using fusion AOD data. The trends of fusion AOD differs greatly from MODIS AOD, as the trends in fusion AOD are in better agreement with corresponding MISR AOD trends.

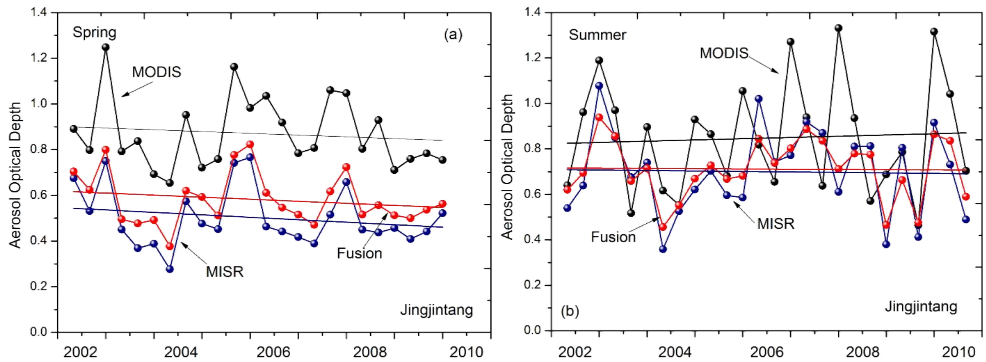

Figure 4. Time series (2002-2010) of monthly MODIS AOD, MISR AOD and fusion AOD during (a) spring (March to May) and (b) summer (June to August) for Jingjingtang.

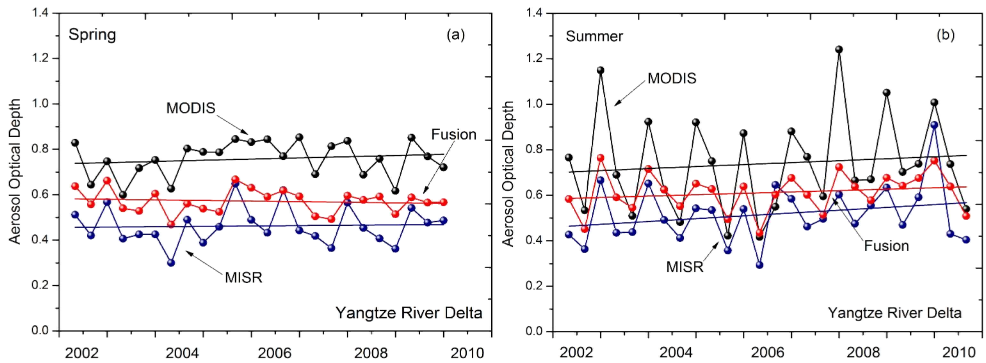

Figure 5. Similar to Figure 4, but for Yangtze River Delta.

4. Conclusions

In this paper, spatial and temporal distribution and the long-term trend of AOD have been researched by using aerosol products from MODIS, MISR and fusion data. This research shows that the spatial and temporal resolution of AOD data has been improved by merging satellite AOD with least square method, which has more details and accuracy than original AOD data. The finding from this paper, fusion AOD performs better than either individual aerosol product and is in better agreement with MISR AOD.

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References

[1] B. Adhikary, S. Kulkarni, A. Dallura, Y.Tang, T. Chai, L.R. Leung, Y. Qian, C.E. Chung, V. Ramanathan, G.R. Carmichael 2008 *Atmospheric Environment* **42** 8600-8615.

[2] Charlson, R. J, S. E. Schwartz, J. H. Hales, R. D. Cess, J. A. Coakley Jr, J. E. Hansen and D. J. Hofmann 1992 *Science* **255** 423– 430

[3] Chameides, W. L, et al. 1999 *Proc. Natl. Acad. Sci.* **96(24)** 13,626–13,633

[4] Zhang, J., and Reid, J.S. 2010 *Atmospheric Chemistry and Physics* **10** 10949–10963

[5] Wedad A., David J. Diner, John V. Martonchik, Carol J. Bruegge, Ralph A. Kahn,Barbara J. Gaitley, and Kathleen A. Crean 2005 *J. Geophys. Res*. **110** D10S07

[6] Martins, J. V., D. Tanre´, L. Remer, Y. Kaufman, S. Matoo, and R. Levy 2002 *Geophys.Res.Lett.* **29(12)** 8009

[7] Holben, B. N., et al. 1998 *Remote Sensing of Environment.* **66** 1– 16

[8] Holben, B. N., et al. 2001 *J. Geophys. Res*. **106** 12.067–12.097

[9] Remer, L. A., Kleidman, R. G., Levy, R. C., Kaufman, Y. J., Tanr´ e, D., Mattoo, S, Martins, J. V., Ichoku, C., Koren, I., Yu, H., and Holben, B. 2008 *J. Geophys. Res*. **113** 14S07

[10] C. D. Papadimas, N. Hatzianastassiou, N. Mihalopoulos, X. Querol, and I. Vardavas 2008 *J. Geophys. Res*. **113** 11205