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Evaluation of the Moderate Resolution Imaging Spectroradiometer aerosol products at two Aerosol Robotic Network stations in China

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[1] Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol products have been used to address aerosol climatic issues in many parts of the world, but their quality has yet to be determined over China. This paper presents a thorough evaluation of aerosol optical depth (AOD) data retrieved from MODIS collections 4 (C004) and 5 (C005) at two AERONET sites in northern and southeastern China. Established under the aegis of the East Asian Study of Tropospheric Aerosols: An International Regional Experiment (EAST-AIRE) project, the two sites, Xianghe and Taihu, have distinct ecosystems and climate regimes, resulting in differences in retrieval performance. At the rural northeastern site (Xianghe), MODIS C004 retrievals generally overestimate AOD at 550 nm during clean days, with the largest errors occurring during winter. In the warm and humid regions of southeastern China (Taihu), MODIS C004 retrievals overestimate AOD throughout the year. The systematic error at Xianghe is primarily due to the fixed surface reflectance ratio, while as the error at Taihu is mainly caused by the choice of the single scattering albedo (SSA) for the fine model aerosols. Both problems are alleviated considerably in the C005. The comparisons between C005 retrievals and AERONET data show much higher correlation coefficient, lower offset and a slope closer to unity. Also, the variability of AOD retrieval among neighboring pixels is reduced by several factors. The strong overestimation problem at small AOD values was fixed by using dynamic reflectance ratios that vary with the vegetation index and scattering angle. However, significant uncertainties remain because of the use of highly simplified aerosol models.

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1. Introduction

[2] Fast economic growth in China over the past two decades has resulted in rapid increases in energy consumption and atmospheric emissions [*Streets and Waldhoff*, 2000]. Ground observations [*Hu et al.*, 2003; *Liang and Xia*, 2005; *Qian et al.*, 2006] revealed decreases in visibility and surface solar radiation. Abrupt changes in the atmospheric environment may have contributed toward a tendency of increasing summer flooding in southern China and drought in northern China [*Qian and Giorgi*, 2000; *Xu*, 2001; *Menon et al.*, 2002], because of the heating effect of absorbing aerosols that can alter the atmospheric circulation [*Ramanathan et al.*, 2001, 2005; *Feichter et al.*, 2004]. A positive feedback between the reduction in precipitation and the increase in aerosols over eastern China was proposed [*Zhao et al.*, 2006] from analysis of precipitation data on the ground and the fine-mode aerosol optical depth (AOD) retrieved from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite sensor.

[3] Daily global aerosol products have been generated from the MODIS onboard the Terra platform since 2000 and the Aqua platform since 2002 [*Kaufman et al.*, 1997; *Remer et al.*, 2005]. Publications on the use of MODIS aerosol products have grown nearly exponentially. A handful of MODIS aerosol validation studies [e.g., *Chu et al.*, 2002; *Xia et al.*, 2004; *Levy et al.*, 2005; *Ichoku et al.*, 2002; *Remer et al.*, 2005] have been carried out using ground Sun photometer measurements, especially those from the international Aerosol Robotic Network (AERONET) [*Holben et al.*, 1998]. Although AOD retrievals from the MODIS agree with AERONET AOD measurements within the expected error range, AOD is generally overestimated on clean days

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and underestimated for high aerosol loading events. To remedy the problem, *Levy et al.* [2007a, 2007b] recently proposed a substantially revised algorithm (collection 5) that attempts to reduce the systematic errors incurred by improper treatments of surface reflectance and aerosol models. The revisions were based on analyses of global AERONET data, which included very few data from China. The AOD is generally too high over China so that no data is used for deriving surface reflectance parameterization, and only data from Beijing site was included in aerosol model derivation. Given the distinct surface conditions and aerosol properties in China [*Xia et al.*, 2006; Z. Li et al., An overview of the East Asian Study of Tropospheric Aerosols: An International Regional Experiment (EAST-AIRE), submitted to *Journal of Geophysical Research*, 2007, hereinafter referred to as Li et al., submitted manuscript, 2007], the quality of the MODIS aerosol products in this region need to be thoroughly evaluated.

[4] A large number of published studies employed the collection 4 (C004) aerosol products whose quality deserves further evaluation, especially over understudied regions like China. Taking advantage of data collected from two AERONET sites recently established in northeastern and southeastern China, this study is devoted to the validation of MODIS aerosol AOD products and comparison between collection 4 (C004) and collection 5 (C005) algorithm. In addition to analyses of matched satellite and ground data, some modeling work was done to investigate the sources of retrieval errors and to sort them in terms of contributions due to assumptions of surface reflectance and aerosol models.

[5] The data sets and algorithms used in the study are described in the next section. The newly derived surface reflectance ratios are presented in section 3. The seasonal change in surface reflectance and the relationship with MODIS retrievals are also discussed in this section. Section 4 presents the results from validation and sensitivity tests. Conclusions are given in section 5.

5. Summary

[44] Satellite retrievals of aerosol properties are a major challenge over land, due primarily to high surface reflectance and variable aerosol type. As a result, development of satellite retrieval algorithms requires ground-truth information. Thanks to the extensive global aerosol measurements made by AERONET, the MODIS retrieval algorithm can be easily validated, and has undergone a series of revisions, resulting in the widely used C004 aerosol product and the newest C005 aerosol product. The performance of the algorithm hinges upon prior knowledge gained through in situ or ground-based observations. There exist a large number (192) of AERONET stations around the world, but very few sites over China (4), a vast territory where there is generally heavy aerosol loading and complex aerosol properties.

[45] In this study, we take advantage of the AERONET data acquired in China to evaluate the two most recent MODIS aerosol products, C004 and C005. The AERONET data have been acquired continuously since 2004 and 2005 in northeastern (Xianghe) and southeastern (Taihu) China under the aegis of the EAST-AIRE project (Li et al., submitted manuscript, 2007). While both sites are heavily loaded with anthropogenic aerosols, Xianghe is much more susceptible to mineral dust transport than Taihu. In addition the two sites display very different climate regimes and ecosystems. After performing atmospheric corrections using AERONET data, observed relationships were established between surface reflectance in the visible and SWIR channels. Together with these newly derived relationships, aerosol optical properties retrieved from AERONET are employed to evaluate the MODIS products and quantify various uncertainties.

[46] In northeastern China, MODIS C004 retrievals have the largest error around February and the smallest error during the summer. The overestimation of AOD under low aerosol loading conditions is primarily due to the use of biased surface reflectance ratios in winter and early spring. The fixed reflectance ratio assumed in the C004 algorithm cannot properly account for strong seasonal changes in the surface condition, namely barren soil with little vegetation in the dry and cold winter season and green vegetation in the humid summer season. The quality of MODIS C005 retrievals has been significantly improved, as indicated by the high correlation coefficient (0.93), low offset (0.02) and a slope close to unity (1.03). As compared to AERONET, the strong overestimation problem at small AOD values was fixed by using dynamic reflectance relationships that vary with the vegetation index and scattering angle. The improvement also benefits from a change in coarse aerosol particle shape from spheres to spheroids.

[47] On the other hand, the inferior retrieval quality of the C004 algorithm over southeastern China is mostly caused by the inaccurate assumption in aerosol models rather than the surface reflectance. The seasonal variation of the surface reflectance at the Taihu site is much weaker because of its consistently warmer and more humid climate. Both C004 and C005 algorithms systematically overestimate AOD year-round. Most of the aerosols come from industrial pollution, which are highly scattering sulfate aerosols with small particle size. Compared with AERONET-measured SSA, the assumed SSA in the C004 algorithm (equal to 0.85) is too low. The MODIS C005 algorithm corrected this oversight by assuming a more realistic ''moderately absorbing'' aerosol with a SSA equal to 0.9.

[48] The new C005 algorithm can also reduce the possibility of artificial variation of AOD retrievals in pixel scale due to the improved strategy in surface reflectance estimation. However, more accurate observations of the surface condition in China are needed to further optimize the algorithm and make it possible to retrieve AOD with higher resolution.