Inter-Comparison and Synergy Between the Two Long-Term Global Aerosol Products Derived from AVHRR and TOMS

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Introduction

Eighteen years of satellite-based monthly aerosol products have been derived from the advanced very high resolution radiometer (AVHRR) and total ozone mapping experiment spectrometer (TOMS) sensors. The two products differ in many regards rendering a great potential for developing an integrated product for climate studies. Presented here are some preliminary results of inter-comparison and synergy analyses.

Global Aerosol Climatology

Satellite-based long-term aerosol climatology shows considerable spatial and temporal variability, but distinct regional and seasonal distribution features are clearly seen. They are useful for climate studies such as the earth's radiation budget. In general, satellite-based aerosol retrievals suffer from much larger uncertainties for instantaneous values than long-term means due to compensating errors from various sources (Mishchenko et al. 1999). These long-term dataset can be further improved by rescaling through comparisons with estimates from current and future satellites designed specifically for aerosol retrieval by reducing some biases, which were not removed by averaging.

Several regions were selected in light of their distinct characteristics for further analysis. Figure 1 shows time series of monthly mean values of AVHRR aerosol optical thickness (AOT), Angstrom exponent, and TOMS AOT over the oceans covering the latitudinal bands of 30S~30N, 30S~EQ, and EQ~30N. As shown, seasonal variations are clear for all the variables, and decadal variations also exist. Decadal variations of AOTs are related with two major volcanic eruptions (Mt. El Chichon in 1982; Mt. Pinatubo in 1991). No visually discernable trend was found. It is hard to differentiate any subtle trend from uncertainties due to sensor calibration, cloud contamination, etc. It has been reported that any gentle linear trends of the global mean derived must be construed in the context of potential long-term drift in ISCCP calibration (Brest et al. 1997; Rossow and Schiffer 1999). The very low-frequency

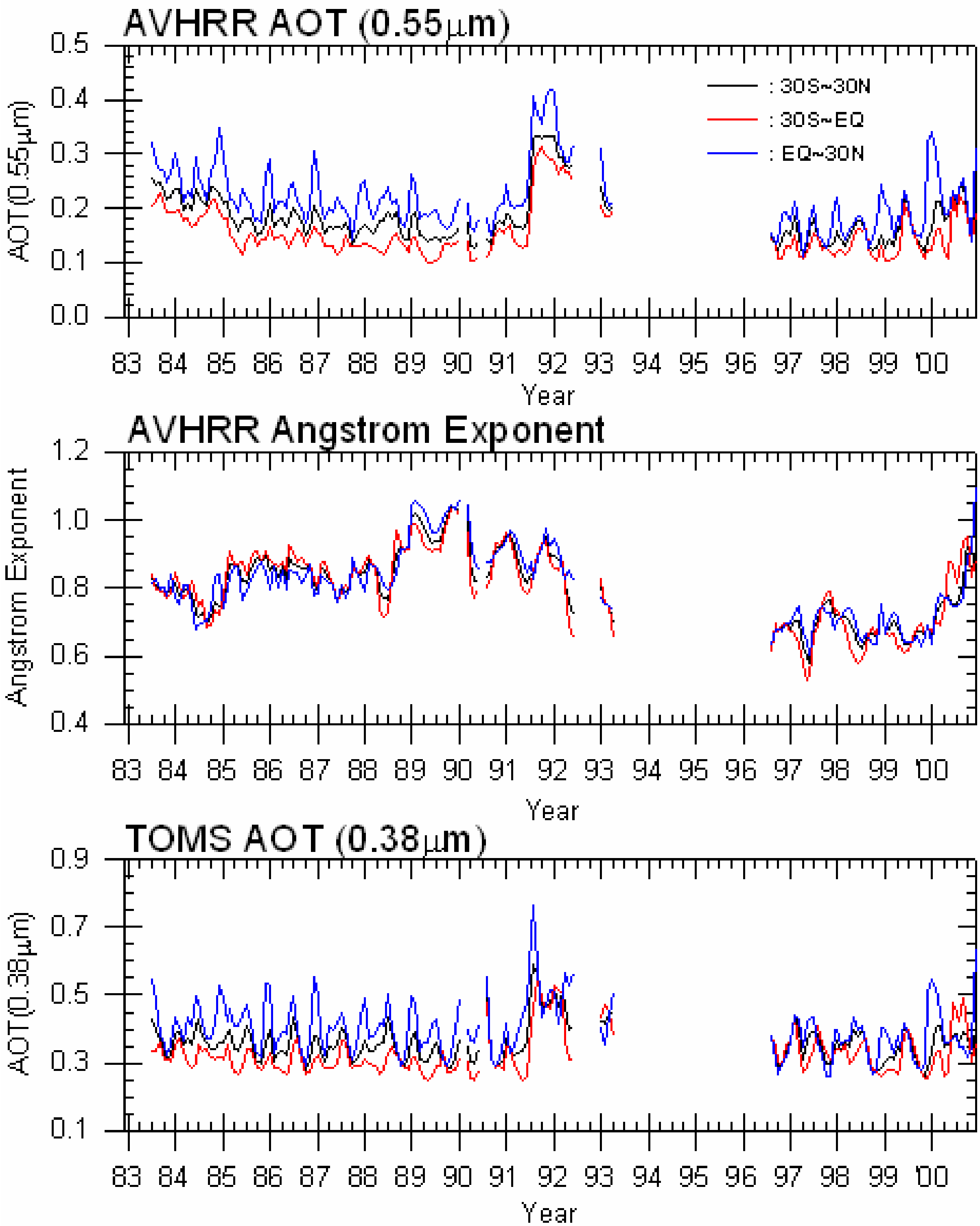

Figure 1. Time series of monthly AVHRR AOT, Angstrom exponent, and TOMS AOT averaged over latitude bands of 30S~30N, 30S~EQ, and EQ~30N.

change of Angstrom exponent is also likely an artifact in response to small residual errors in measured radiance. Note that its direction of change discords with anticipated influences of volcanic eruptions (Geogdzhayev et al. 2002).

Possibility of Synergy

TOMS and AVHRR, which were not designed for aerosol monitoring, do a reasonable job in generating long-term aerosol climatology despite numerous instrument limitations and inversion difficulties. While both sensors have global coverage, limitations in the inversion algorithms often lead to large gaps. The AVHRR retrievals are confined to dark oceans, while TOMS is insensitive to aerosols in low altitudes and affected significantly by sub-pixel cloud contamination (Herman 1997; Torres et al. 1998 and 2002). Cloud screening is the most serious problem for both retrievals. The datasets have different advantages and shortcomings. One may develop a synergetic product that could be produced by combining the two long-term satellites observations.

To gain insight into their pros and cons, each satellite product is compared against AERONET measurements as shown in Figure 2. The large sampling errors in point specific measurements (Kinne et al. 2002) are responsible for much of the scattering seen in Figure 2. Nevertheless, the two datasets are correlated to each other. AOT tends to be overestimated by TOMS and underestimated by AVHRR relative to AERONET measurements at this location. It is notable that the discrepancy is greater for higher aerosol loadings related to dust events in the region. This may be caused by differences in retrieval algorithms or different types of aerosol models employed.

As a diagnosis tool to examine consistency between the two datasets, Angstrom exponent was calculated from TOMS and AVHRR AOTs. The Angstrom exponent is not an absolute measure for checking spectral consistency because it depends on aerosol size distributions and their optical properties (Eck et al. 1999) and it is known to be subject to error when derived from smaller AOTs (Geogdzhayev et al. 2002). However, if it resides within a certain range of values (normally 0.5~2; Kinne et al. 2001) with reasonable temporal/regional variability, it might be linked to the variability in aerosol size and types. Figure 3 shows the seasonal maps of the derived Angstrom exponent. In general, the distributing patterns tend to be roughly similar to those of AVHRR Angstrom exponent, and those are in accordance with what they are supposed to be in reference to the aerosol types that we can expect according to the corresponding source regions nearby. However, the magnitude of derived Angstrom exponent is rather exaggerated. For most regions (esp., South-East Pacific, South Atlantic nearby Brazil [in all seasons], and off the west coast of Africa [MAM, JJA]), it is higher than AVHRR Angstrom exponent while for some other regions (e.g., eastern side of Central America [in all seasons] and North Indian Ocean [in DJF]), are rather lower. There are several factors that could cause this result: aerosol layer height and optical property dependencies of TOMS AOT (Herman et al. 1997; Torres et al. 2002), lack of common days in monthly averages between AVHRR and TOMS AOTs (Cakmur et al. 2001), and systematic errors in each AOT in conjunction with the sensitiveness of Angstrom exponent to the errors of smaller AOT (Ignatov et al. 1998; Geogdzhayev et al. 2002). The anomalous high values of derived Angstrom exponent in most regions seem to be mainly caused by the sensitiveness of Angstrom exponent to the smaller errors of AOTs since they are located very lower AOT regions centered at the high-pressure regions. The directions of errors (over-/underestimation) of the two AOTs cannot be verified from Angstrom exponent calculation; moreover, this is unlikely to be verified from other observations

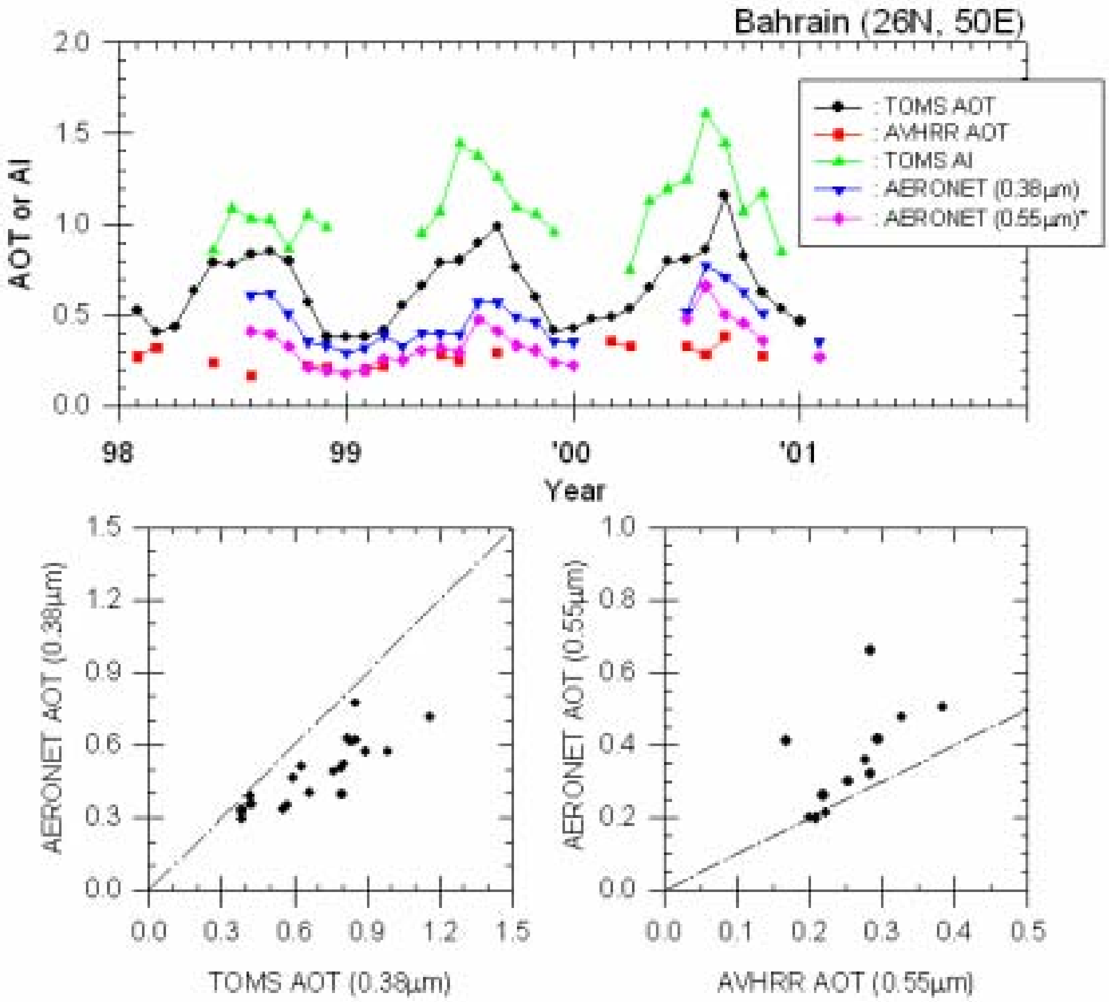

Figure 2. A sample comparison of satellites products (AVHRR AOT, TOMS AOT, and AI) against AERONET measurements (Bahrain, 26N, 50E; 1998-2001). *AERONET AOT at 0.55μm was interpolated using Angstrom exponent.

because there rarely exists in situ measurements over those regions. However, if we assume that the both products can more or less reasonably represent the distribution of aerosols TOMS should a little bit overestimate whereas AVHRR underestimate AOTs for those regions. Otherwise, at least one product could be significantly misestimating. This idea is indirectly supported by Figure 4. The figure provides a comparison of the scatter plot of TOMS and AVHRR AOTs to that of AERONET AOTs at the wavelengths compatible to those of TOMS and AVHRR products. The slopes are related to Angstrom exponent, and the dots with different colors and shape represent different regions where it is expected to be predominant by specific types of aerosols. In the left panel for AERONET measurements at various aerosol regimes, one can find that Angstrom exponent (or slope) ranges from 0 to 2 depending on regions (thus, aerosol type/size). On the other hand, Angstrom exponent derived from AVHRR and TOMS AOTs showed more dispersion ranged from -1 to 4, and regional characteristics are not clear. The large dispersion in satellite-based AOT can be attributed to the convoluted effects of lack of common data in monthly means and aerosol layer height/optical property dependency of TOMS data.

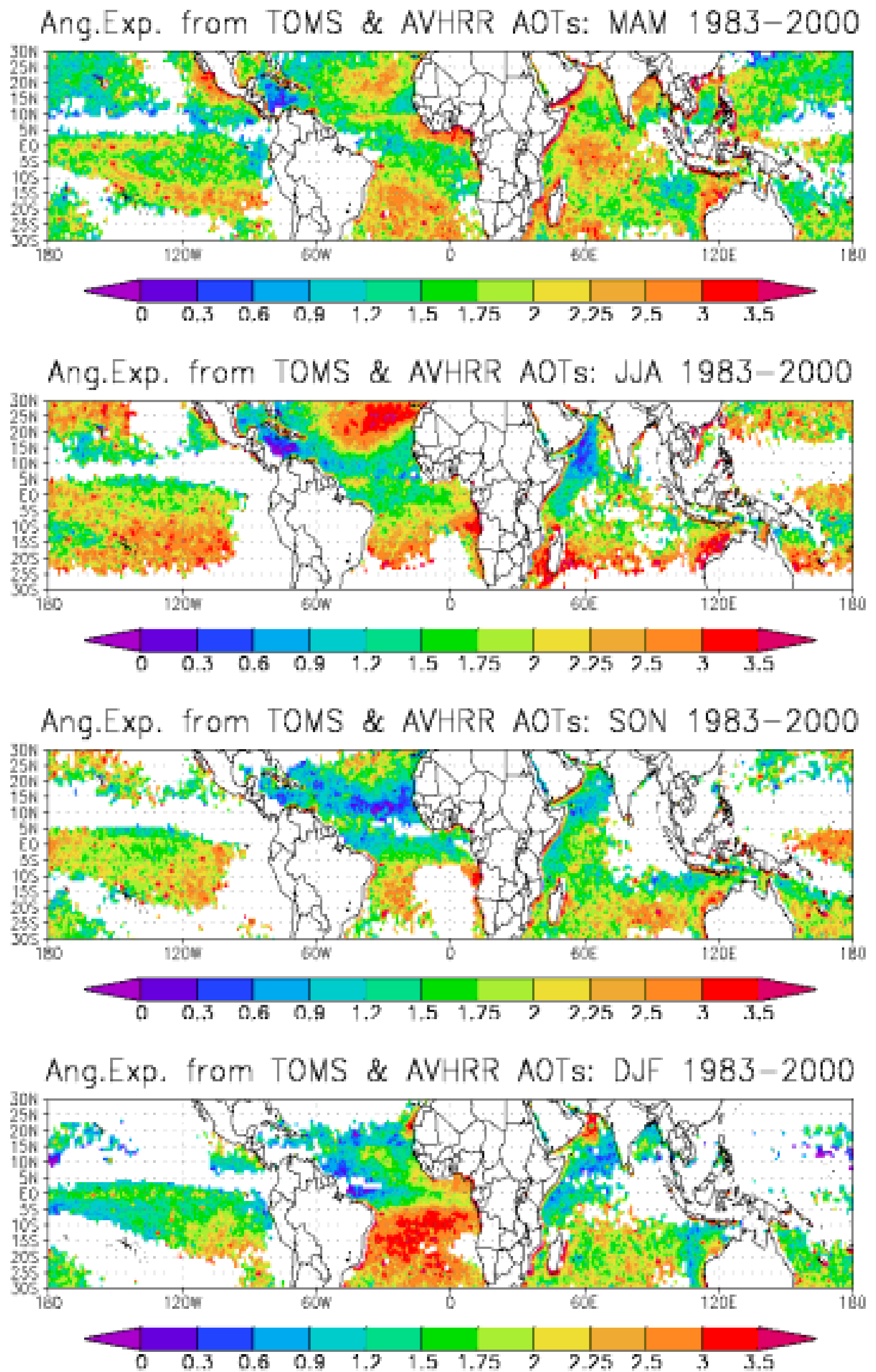

Figure 3. Seasonal mean Angstrom exponent derived from TOMS and AVHRR AOTs.

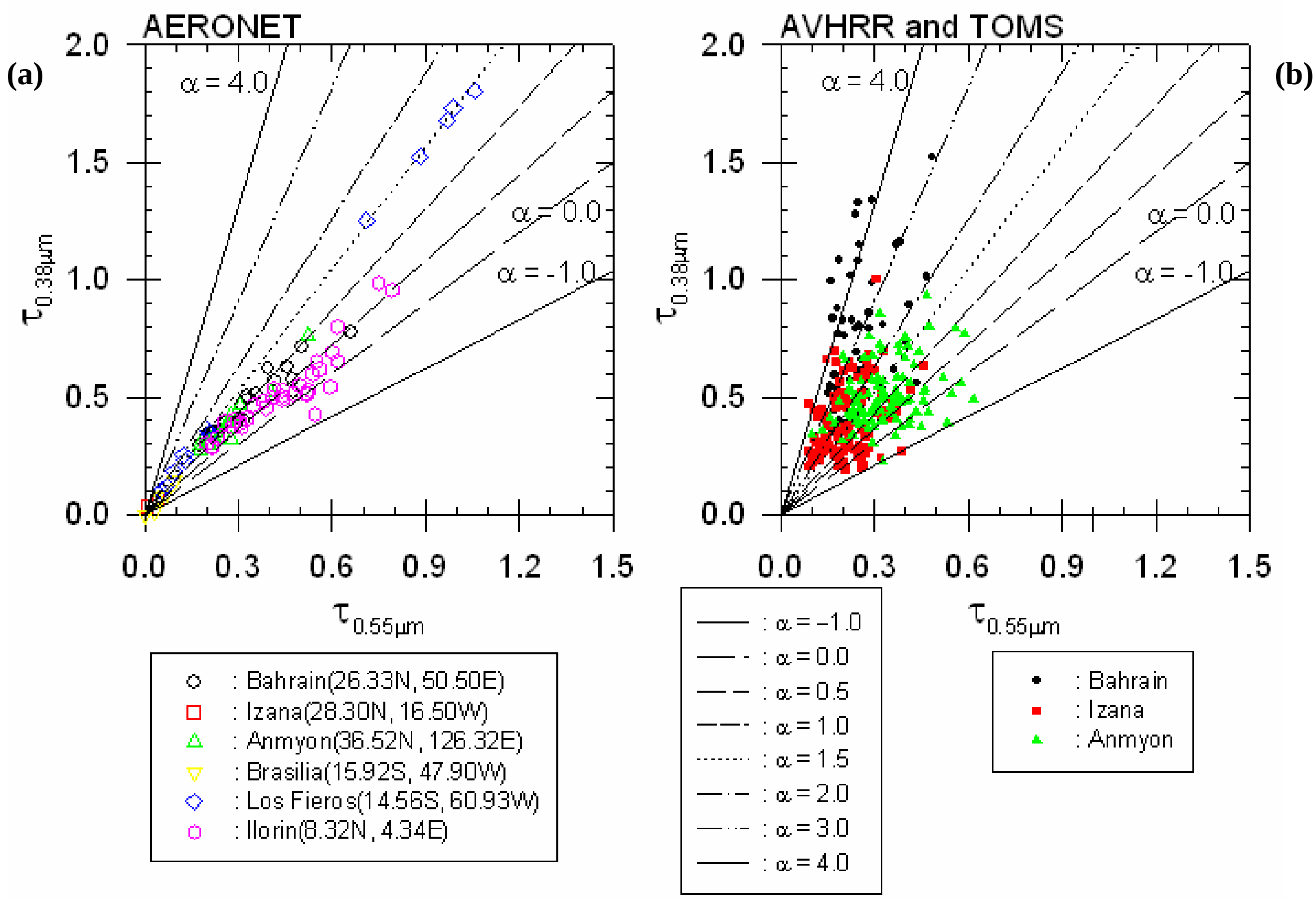

Figure 4. (a) Scatter plot of monthly mean AOTs measured at 0.38µm and 0.55µm from several AERONET sites, some of which tend to be dominated by different types of aerosols: dust (Izana and Ilorin), biomass burning (Brasilia and Los Fieros), dust+pollution (Bahrain and Anmyon). (b) Scatter plot of TOMS and AVHRR AOTs (at 0.38µm and 0.55µm, respectively). Lines of constant Angstrom exponent at the two wavelengths are also presented. Again, AERONET AOT at 0.55µm was interpolated using Angstrom exponent

However, it is also can found that TOMS AOT is larger and AVHRR AOT is rather smaller than AERONET data. In the given scatter plots, AERONET data are based on 1~4 years of observations while satellite data are based on more than 10 years, covering most periods of AERONET data presented here. In statistical sense, it is expected that the more extreme values of AOTs could be shown in longer-term datasets (i.e., AVHRR and TOMS) rather than shorter-term datasets (i.e. AERONET). As can be seen in the Figure 4, TOMS AOT lacks lower values and AVHRR lacks higher values compared to AERONET data, supporting the idea of overestimating TOMS and underestimating AVHRR. Given the above discussions, AVHRR and TOMS AOTs seem to be spectrally inconsistent to each other in terms of Angstrom exponent; therefore, they cannot be combined to estimate aerosol size.

One, however, should note that the above results do not suggest that the two products will not provide any synergy, but the results are just suggesting that TOMS and AVHRR AOT are not consistent enough to provide aerosol size information because of differences in sampling and/or magnitude/direction of errors and so on. In addition, the two satellite data are correlated to each other so that, at least, a statistical method can be applied to combine them. Here is such an example of synergy: to estimate one AOT (AVHRR AOT) from the other AOT (TOMS AOT) wherever one reports missing but the other does not. It would be especially good for AVHRR AOT since it is restricted only over oceans while TOMS AOT can cover both land and oceans. To a first approximation, one can assume that the two products have linear relationship. Then, by further assuming that averaging may compensate errors from both products, long-term (18 years) monthly mean areal averages over the pre-defined regions were used to derive a relationship between TOMS and AVHRR AOTs. By taking this method, one may expect to reduce errors due to sampling difference and random errors in both products while retaining variability due to spatio-temporal characteristics of aerosols. As shown Figure 5a, along with a dependency of the relationship along with magnitude of AOTs, TOMS and AVHRR AOTs seem to reasonably fit to a linear line with the slope of 0.48. This value is applied to estimate AVHRR AOT from TOMS AOT, and the results for the developmental data that were used to derive the relationship are represented in Figure 5b. The estimated error range is ±0.05 ±0.17*AOT. Figure 5c shows the result when the derived relationship is applied to global and hemispheric means, which were not used to derive the relationship. As shown in the figure, all points fall within the estimated error range, suggesting that such an application of the given linear relationship between TOMS and AVHRR AOTs may be valid for a climatological scale. Thus, the derived relation is applied to estimate long-term seasonal mean AOT at 0.55μm over the locations where AVHRR AOT reported missing as given in Figure 6. A visual examination reveals that there is no artificial discontinuity as a trace of patching the two products. Seasonal mean maps for Mach to May (MAM) and December to February (DJF) showed smooth connection between the land source regions and nearby oceans. Please note that rather high gradient around off the west coast of South Africa in the other two seasons is not an artificial effect of combining the two products, but it coincides with the original TOMS AOT distribution over the corresponding regions. This estimation will be validated against AERONET measurements and improved in the near future.

Summary and Future Work

Long-term satellite aerosol estimations based on AVHRR and TOMS show distinct regional and seasonal patterns, superimposed by high-frequency variability. There exist many limitations in the aerosol retrieval estimated from the measurements made by non-aerosol-specific instruments. In the pursuit of generating a synergetic aerosol product from these long-term datasets, we explore the possibility of combining TOMS and AVHRR AOTs in order to compensate for the shortcomings of each and an example was presented. Unfortunately, the two products are not spectrally consistent enough in terms of Angstrom exponent to produce aerosol size information; however, one possibility of synergy can be suggested: estimation of AVHRR AOT over land using TOMS AOT. No artificial discontinuity was found by a visual examination and the current range of estimated errors is ±0.05±0.17*AOT.

Future work will be devoted to improvement of suggested synergism- estimating AVHRR-like AOT over land from TOMS data- and to the efforts to evaluate the method using ground-based climatology that has been constructed at many AERONET sites. Moderate-resolution atmospheric radiance and transmittance model (MODIS) data will be used as a reference against which the synergetic product based on TOMS and AVHRR can be compared. Further, MODIS data can also be utilized to provide another synergy with the two long-term satellite datasets.

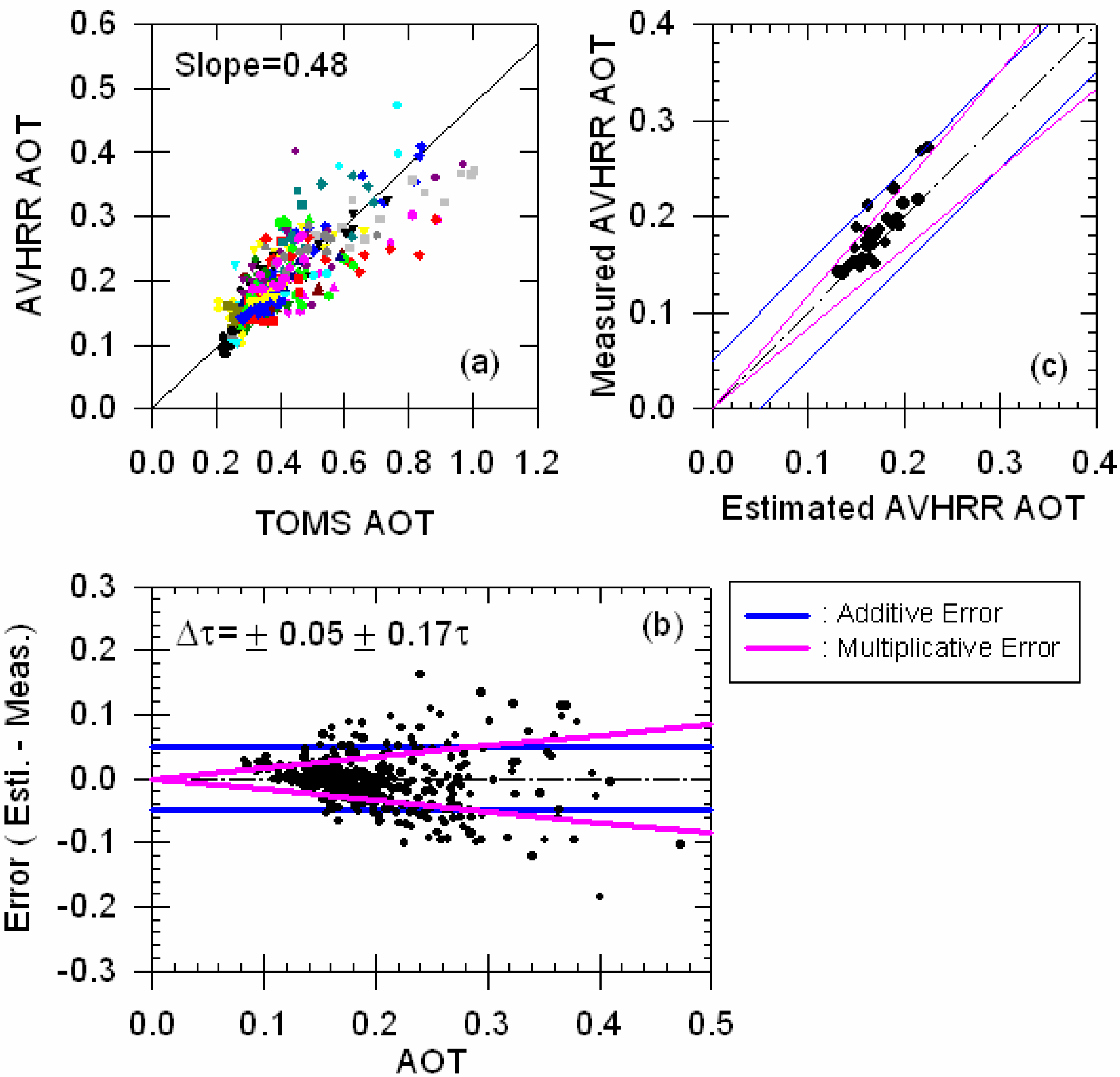

Figure 5. (a) Relationship between TOMS and AVHRR AOTs. Each dot with different colors and shapes stands for different regions. (b) Errors of AVHRR AOT estimated from TOMS AOT by using the linear relationship derived from (a). (c) Results when the relationship is applied to global and hemispherical means, which were not used to derive the relationship.

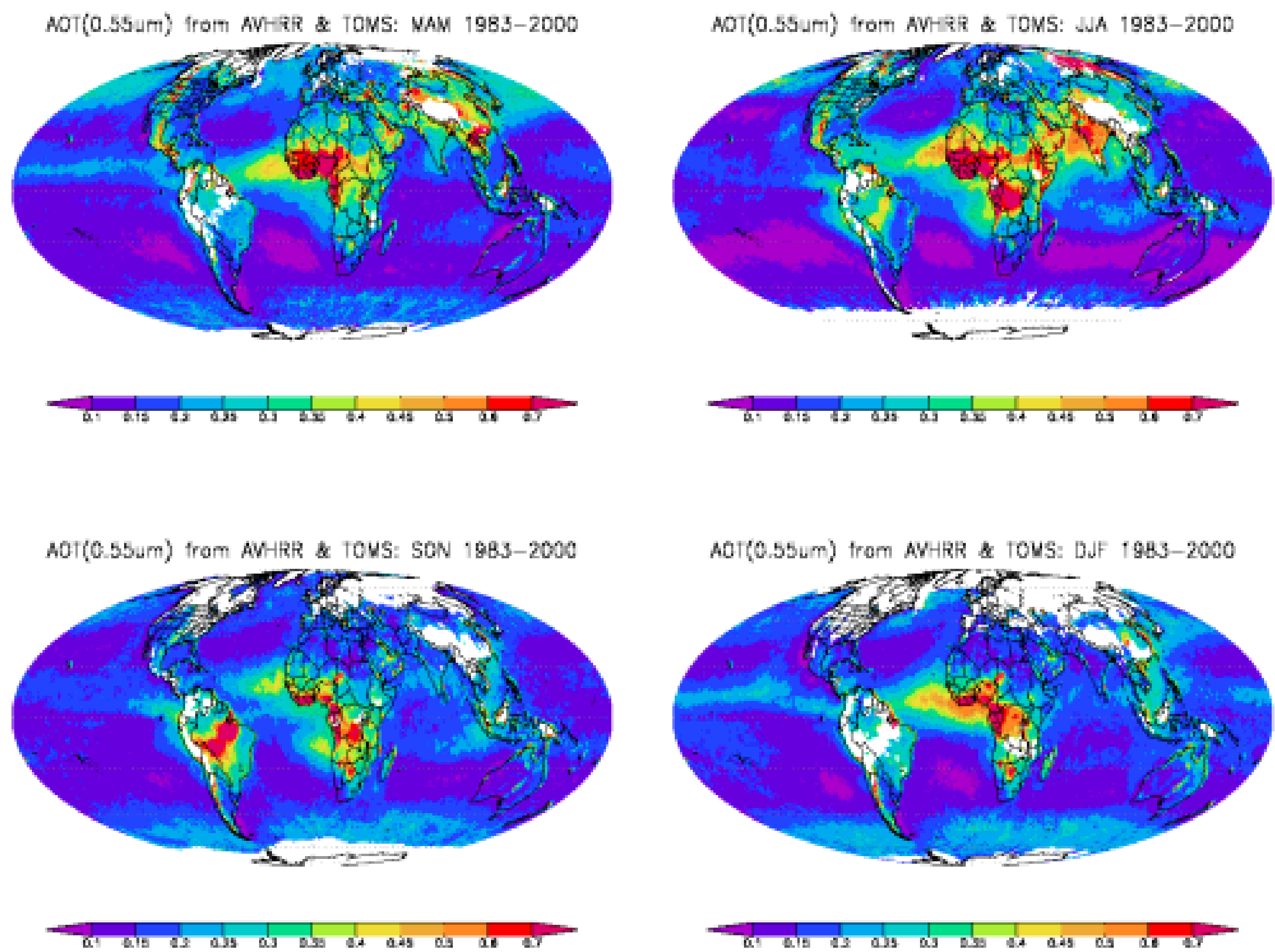

Figure 6. Seasonal mean maps of AVHRR AOT (0.55μm). AVHRR AOT over land was estimated from TOMS AOT (0.38μm) by using the relationship derived from Figure 5a).

Acknowledgement

The datasets under study include AOT and Angstrom exponent (hereinafter referred to as AVHRR aerosol products) derived from AVHRR under the Global Aerosol Climatology Project (GACP; http://gacp.giss.nasa.gov/) by Mishchenko et al.(1999) and Geogdzhayev et al.(2002), and AOT (Torres et al. 1998 and 2002) and Aerosol Index (AI; Herman et al. 1997) from TOMS (http://toms.gsfc.nasa.gov). AERONET (Holben et al. 1998, http://aeronet.gsfc.nasa.gov/) Level 2.0 data and monthly MODIS aerosol products (March 2000~April 2001, version 4) were also used for the comparison of AVHRR aerosol product. We thank them for providing AVHRR, TOMS, and AERONET data and guidance for the use of the datasets.

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