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Discussions

Interactive comment on "An online aerosol retrieval algorithm using OMI near-UV observations based on the optimal estimation method" *by* U. Jeong et al.

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Referee: 2

We reflected all the comments by the reviewer. The criticism and suggestions by the reviewer were appropriate and improved the quality of our manuscript. We appreciate such efforts.

This manuscript describes an OE-based approach to retrieve AOT and SSA using OMI near-UV channels. Conceptually, it is a good idea to take into consideration the inherent measurement/retrieval uncertainties and a priori knowledge; however, it is not

convincing that this approach is superior and has the potential to replace the current operational algorithm. My general comments are the followings:

1. This OE-based approach doesn't address the root of the retrieval problems by improving the cloud screening, using more accurate surface reïňĆectance, vertical proïňĄle, and aerosol models. It appears that, in terms of retrieval, other than introducing a statistically based cost function, the basics are the same as the operational algorithm. If this new cost function (Eq. 2) is dominated by the difference from the measurement which I assumed the operational algorithm tries to minimize, then it is not surprise that the OE retrievals are not quite different from the operational results. Figures 6 and 7 show the similar results from the operational and OE-based algorithms other than some outliers are eliminated by the latter. Ans) The near UV aerosol retrieval algorithm has been developed during last few decades through multidirectional efforts. However, improvements of aerosol inversion products using hyperspectral sensors such as OMI and GOME are quite challenging due to the relatively large ground pixel size compared to typical imagers. However, the decadal aerosol information derived using the near UV channel since TOMS is unique, thus valuable, so that it has potential to be used at various field including climatology and air quality. The main purpose of this study is to suggest an alternative inversion method which provides additional information (error estimates, degrees of freedom, cost function, etc.) on the retrievals to optimize the applicability. However, authors agree that the manuscript did not state the purpose of the study clearly as the referee indicated. Several sentences were inserted/modified to emphasize the advantage of this study. The manuscript was revised as follows: Following sentences were inserted in the introduction of the revised manuscript at pages 3, lines 9-11: "The inversion products from such measurements provide various parameters of aerosols at diverse channels. Thus, appropriate sources of aerosol information needs to be employed for relevant studies." At pages 3 lines 23 – pages 4 lines 29: "However, deriving information on aerosol using available hyperspectral measurements such as OMI is quite challenging due to the relatively low spatial resolution compared to typical imagers. Thus, the error estimates of retrievals using such sensors are particularly

important to understand the reliability of the information, so that it can be used appropriately. The main objective of this study is to improve the applicability of the aerosol inversion products of OMI by providing the reliable error estimates of the retrievals." At pages 21 lines 444 – lines 449: "Note that the relative significances of the ε_fs of retrievals depend on their condition. It is additional merit of the error analysis using OE method that it provides specific error estimates of individual target event retrieval (e.g., dust or biomass burning event). While analysis studies using satellite inversion products have often suffered from the statistic reliabilities, more accurate error estimates in this study are expected to contribute to the assessment of the significances of the analysis." In order to emphasize the advantage of the iterative inversion method, following sentence was inserted in the revised manuscript at pages 4, lines 39-41: "In addition, iterative inversion methods such as OE provide additional retrieval masking parameters (e.g., cost function and convergence criteria)." Also, please see the answer of comment 3 for advantage of online inversion method. 2. For the error characterization, the merit of this OE-based approach should be a more accurate estimation of error for individual retrievals, i.e., the points on Figure 8b should be more or less along the dotted lines. More than 80% of retrievals falling between the dotted lines actually indicate a general overestimation of retrieval errors. It is disappointing that the OE-estimated errors are interpreted as the upper limit (envelope curve) instead of actual retrieval uncertainties; Also the claim of better performance of this error estimation is a little misleading since the error range is actually wider than the operational uncertainty envelope ($\pm$30% or 0.1). Based on Figure 8b, the estimated error for AOT of 1.5 is about 0.6 which gives an uncertainty range of about 40% of retrieved AOT. Ans) Evaluation of the actual radiometric calibration error is still challenging since the calibration methods also have their uncertainties. The 2% of the BSDF error estimation also includes the calibration method and it represents the typical error at whole wavelength domain of OMI (Jaross, 2015, personal communication). For those reasons, the 2% of BSDF uncertainty leads to general overestimates of the error and it is still challenging to evaluate. In our experience, assuming BSDF calibration error as 1% was appropriate at 354 and

388 nm for the retrieval algorithm. Thus, authors regarded the BSDF error as 1% in the revised manuscript. Following sentences were revised in the revised manuscript at pages 11, lines 205-209: "However, the reported BSDF uncertainty includes the errors in the calibration method and it represents whole wavelength domain. Thus, actual BSDF uncertainty at 354 and 388 nm would be less than 2% (Jaross, 2015). In our experience, 2% of BSDF uncertainty leads to the overestimates of the error and it is still challenging to evaluate. According to multiple retrieval tests, the BSDF uncertainty was assumed to be 1% in this study." As the measurement error covariance matrix was changed, all retrieval process in the manuscript was re-performed with the latter error covariance matrix, which was reflected throughout the manuscript. The change slightly affects the retrieval values and validation results except the error estimates. The Figure 4-9 was revised in the revised manuscript. The estimated error of the retrieval has been reduced as shown in Figure 5 and 8 as follows:

" Figure 5. Estimated solution error of (a) OE-based 388 nm AOT and (b) SSA. Panels (c) and (d) show the degrees of freedom and cost function of the retrieval, respectively.

Figure 8. Comparison between estimated uncertainties of the 388 nm AOT (x-axis) and biases of retrieved AOT from AERONET measurements (y-axis). The panels (a) and (b) are based on the operational and OE-based retrieval/error-estimation algorithm, respectively.

As shown in Figure 8 (b), the OE-based retrieval error better represents the variances of the actual biases (r=0.93, MB=0.08) than operational error estimation method (Figure 8 (a), r=0.52, MB=0.11). Furthermore, the ratio of error falling within the estimated error of OE method (Qsol= 65.9%) was higher than that of operational method (Qomi = 64.8%), despite that the mean estimated error of OE method (0.20) was lower than that of operational method (0.21). Also, the mean systematic biases from the AERONET was smaller (0.08) than the operational method (0.11) when cost-function cut-off was applied. Following sentences was added in revised manuscript at pages 18-19, lines 370-383 as: "The estimated retrieval uncertainties of the AOT at 388 nm from the operational algorithm (ε_omi, $\pm$30% or 0.1) and estimated ε_sol were plotted against the biases relative to AERONET measurements as shown in Figure 8. The percentages of AOT retrieval biases from AERONET falling within the estimated retrieval errors of operational (Qomi) and OE-based method (Qsol) were 64.8% and 65.9%, respectively. The Qsol was higher than Qomi despite of the lower mean value of ε_sol (0.20) than that of ε_omi (0.21). The error bars and black squares in Figure 8 represent the moving σ and average value of the retrieval biases from AERONET as a function of estimated error, respectively. As shown in Figure 8 (b), ε_sol better explained the moving σ of the actual biases (r=0.93) than ε_omi in Figure 8 (a) (r=0.52). Fisher's z-value between the correlation coefficients was 2.33 with two-tailed p-value of 0.02. The systematic biases of ε_sol and ε_omi (represented by the moving average of each error estimates) are typically related to other error sources, including forward model parameters and sub-pixel cloud contaminations. Since the ε_sol of retrieved AOT considers the theoretical sensitivity of the retrieval biases to associated parameters, it explained the retrieval uncertainties better than the ε_omi, which only considers the retrieved AOT values."

3. For the online radiative transfer calculations, it is not clear how signiïňĄcant the improvements (eliminate interpolation errors and improve stability) are than using the traditional lookup tables. I hope the authors can have a discussion about the tradeoff between increase of accuracy and loss of efïňĄciency, and whether it is recommended to use this method in operational retrieval. Ans) We agree that it was not clear how significant the improvements were. However, interpolation error of LUT method typically depends on the interpolation method, resolution of the nodal points, and analytic characteristics of the parameters in LUT, which is hard to evaluate due to such dependency, thus depends on individual algorithm design preference. Therefore, rather than suggesting quantitative significances of the accuracy improvements of the online calculations, more detailed discussions were added in the revised manuscript. Following sentences of discussion about online calculation method were added in the revised manuscript at pages 8-9 at lines 145-165 as: "Such interpolation error typically depends on the interpolation method, number of the nodal points, and analytic

characteristics of the parameters in LUT. In order to reduce the interpolation error, higher resolution of LUT nodal points is necessary which requires larger amount of numerical computation. Furthermore, in order to modify the retrieval algorithm, whole LUT should be re-calculated even for the few number of target retrievals. The errors from the interpolation are also hard to evaluate as the LUT becomes more complicated. On the contrary, online retrieval methods can reduce such errors from the interpolation and numerically efficient particularly for the smaller number of target retrievals. Thus, online retrieval method is appropriate for the research purposes since retrieval sensitivity study typically use smaller number of sample compared to the operational purposes and prefer rapid and accurate results. In our experience, the online retrieval method was numerically more efficient compared to the LUT-based retrieval method by order of 1 or 2 for less than few thousands of retrievals. Furthermore, the online retrieval methods are optimized to avoid local minima by employing additional constraints to find more reliable and stable solutions (Kalman, 1960;Phillips, 1962;Tikhonov, 1963;Twomey, 1963;Chahine, 1968). However, employing online calculation as operational retrieval method requires large computation cost. Thus, using the online calculation as a benchmark results for the LUT-based algorithm is recommended to develop the optimized LUT for the operational purposes. Recent efforts to minimize the numerical cost of radiative transfer model and to increased calculation speed are expected to make the online calculation more practical even for the operational purposes." We also concluded that the advantage of this study is to provide more accurate error estimates by OE method as mentioned in general comments #1 rather than the online calculation. In addition, the OE method is one of the online calculation methods. Thus the title of this study was revised as follows: "An optimal estimation based aerosol retrieval algorithm using OMI near-UV observations"

4. Another general comment is about the comparison between the operational and OE-based retrieval results. Since this manuscript has so much focus on statistics, it is a bit disappointing to see the comparison is not examined in terms of statistical signiïňĄcance, it would be more convincing that "the OE method showed better results"

if the difference is statistically signiïňĄcant. Ans) As the referee suggested, Fisher's z-values and Student's t-values were provided to evaluate the significances of the improvements. Following sentences were revised in the manuscript at pages 17, lines 340-344: "The Fisher's z-value between the correlation coefficients (Fisher, 1921) was 3.04 corresponding to two-tailed p-value of 0.0024. The Student's t-value for the difference between the two slopes is 2.10 with 512 degrees of freedom with two-tailed p-value of 0.04. The statistical values show that the difference between two correlation coefficients and slopes are significant (p-value < 0.05)." And at pages 18, lines 358-366: "The retrieved 388 nm SSA from both the operational and OE-based algorithms showed similar correlation with the AERONET (r = 0.27 and 0.26 for operational and OE-based algorithms, respectively. Fisher's z-value is 0.1 with two-tailed p-value of 0.92). The retrieved SSA at 388 nm from the operational and OE-based algorithms showed slightly higher correlation with the converted 388 nm SSA from AERONET (r = 0.34 and 0.33 for the operational and OE-based algorithm, respectively) than with the 440 nm SSA from AERONET. However, the significances of the differences in r between converted and unconverted SSA comparisons were low (Fisher's z-values were 0.71 and 0.67 with two-tailed p-values of 0.48 and 0.50 for operational algorithm and OE-based algorithm, respectively)."

My speciïňĄc comments: 1. Line 65, delete "(2013)" Ans) Following sentence was modified in the revised manuscript at pages 7, lines 116-117 as: "The overall concept and design of the improved OMAERUV algorithm is well described by Torres et al. (2013)."

2. Line 119, "and spectral contrast, I354/I388, for the measurement vector" Ans) Following sentence was modified at revised manuscript at pages 10, lines 190-192 as: "As described above, the OMI near-UV algorithm uses radiance (I388) and spectral contrast (I354/I388) for the measurement vector, where I354 and I388 are the normalized radiances at 354 nm and 388 nm, respectively."

3. Line 133-160, in this section, there is confusion about the terms of "uncertainty"

and "error" and symbols of σ and ε. For example line 138 says $\varepsilon\lambda$ is "the absolute uncertainty" which is the "square root of the sum of squared radiometric random noise and calibration accuracy" (line 133), while Eq. 6 indicates it is the sum of "the random and system components radiometric error" (line 145). Ans) Sorry for the confusion. As the referee suggested, the definition of the symbols and terminology of error, uncertainty, and accuracy are clarified at the revised manuscript at pages 11, lines 209 – pages 12, lines 222 as follows: "The radiometric error covariance at each wavelength was calculated from the square root of the sum of squared radiometric uncertainty and calibration accuracy. The error covariance matrix can be written as:

S_Ïţ=[σ(Ïţ_388)ˆ2 (Ïţ_388, Ïţ_(354/388))ˆ2] [σ(Ïţ_388, Ïţ_(354/388) (Ïţ_(354/388))ˆ2)] (5)

where Ïţ_λ is the total error of the measured radiance at wavelength λ, Ïţ_(354/388) is the error of I_354/I_388 , which is described later in this section, and σ(Ïţ_388, Ïţ_(354/388))ˆ2 is the covariance between the total measurement errors of I_388 and I_354/I_388 . The Ïţ_λ typically includes both random and systematic components and its covariance can be expressed as follows:

σ(Ïţ_λ)ˆ2 = σ(Ïţ_(r,λ))ˆ2 + σ(Ïţ_(s,λ))ˆ2 (6)

where Ïţ_(r,λ) and Ïţ_(s,λ) are the random and systematic components of radiometric error at λ, and σ(Ïţ_(r,λ))ˆ2 and σ(Ïţ_(s,λ))ˆ2 are their covariance values, respectively."

[*** Sorry for the font problem here that I could not resolve. Thus, I included pdf version of this response as Figure 1. ***]

4. Line 211, the references are missing. Ans) Following references were inserted in the revised manuscript: "Spurr, R., Wang, J., Zeng, J., and Mishchenko, M. I.: Linearized T-matrix and Mie scattering computations, J Quant Spectrosc Ra, 113, 425-439, 10.1016/j.jqsrt.2011.11.014, 2012. Spurr, R., and Christi, M.: On the generation of atmospheric property Jacobians from the (V)LIDORT linearized radiative

transfer models, J Quant Spectrosc Ra, 142, 109-115, 10.1016/j.jqsrt.2014.03.011, 2014."

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/15/C8350/2015/acpd-15-C8350-2015-supplement.pdf

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