Corrigendum

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ABSTRACT

An error in a recent analysis of the sensitivity of retrievals of Cloud–Aerosol Lidar with Orthogonal Polarization (CALIOP) particulate optical properties to errors in various input parameters is described. This error was in the specification of an intermediate variable that was used to write a general equation for the sensitivities to errors in either the renormalization (calibration) factor or in the lidar ratio used in the retrieval, or both. The result of this incorrect substitution (an additional multiplicative factor to the exponent of the particulate transmittance) was then copied to some intermediate equations; the corrected versions of which are presented here. Fortunately, however, all of the final equations for the specific cases of renormalization and lidar ratio errors are correct, as are all of the figures and approximations, because these were derived directly from equations for the specific errors and not from the equation for the general case. All of the other sections, including the uncertainty analyses and the analyses of sensitivities to low signal-to-noise ratios and errors in constrained retrievals, and the presentations of errors and uncertainties in simulated and actual data are unaffected.

1. Introduction

The Cloud–Aerosol Lidar with Orthogonal Polarization (CALIOP) on board the *Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)* satellite has been making near-global measurements of the vertical and horizontal locations and optical properties of clouds and aerosols since mid-June 2006 (Winker et al. 2010). To retrieve these properties of interest from the raw measurements made by CALIOP, a complex set of algorithms is employed (Winker et al. 2009). The final step in that processing chain is the Hybrid Extinction Retrieval Algorithm (HERA) (Young and Vaughan 2009), which retrieves profiles of particulate backscatter, extinction, and optical depth in regions identified

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by the preceding algorithms as containing cloud or aerosol features (nonmolecular signals). The retrieval process begins at the top of the atmosphere, retrieving extinction and two-way transmittance profiles for the topmost features first, correcting the attenuated backscatter signals of underlying features for the attenuation caused by this overlying transmittance factor, then repeating the retrieval process in the lower features until the surface or the lowest altitude at which a signal is detected is reached. The retrieval algorithms require the use of either an independently determined layer transmittance constraint or, if a transmittance constraint is not available, an a priori estimate of lidar ratio appropriate to the type of feature being analyzed. As a consequence, errors in either of these parameters, or in the calibration or renormalization of the lidar signal beneath features that have already been analyzed, will lead to errors in the retrieved quantities. [As in Young et al. (2013, hereafter YEA13), we use the term *renormalization* to describe the correction of the measured attenuated backscatter profile for the combined effects of instrumental calibration and attenuation by the overlying atmosphere. The calibration process is itself a normalization of the measured signal to a modeled molecular atmosphere.] The sensitivity of the retrievals to errors in signal renormalization, lidar ratio, or layer transmittance constraint is one of the areas discussed in detail in YEA13.

In the original manuscript submitted by YEA13, the sensitivities of the retrieved particulate profiles to errors in renormalization, lidar ratio, or layer transmittance constraint were presented in separate sections of the main body of the manuscript. In each of these sections, the problem was simplified by assuming that the scattering ratio (i.e., the ratio of total to molecular backscatter) is constant with height throughout the layers being analyzed. There were, however, numerous other sections that addressed topics such as the analyses of uncertainties, the effects of the signal-to-noise ratio, and a presentation of typical results, and this multisection arrangement led to a very long paper containing a very large number of equations.

To reduce the length of the paper and the number of equations, the mathematical derivations of the error sensitivities were moved into an appendix in the revised version of the manuscript, which was subsequently published. In addition, the separate sensitivity analyses for the renormalization and lidar ratio errors were merged into a new section of the appendix that presented general equations for the errors resulting from errors in either or both of these sources. This merging was accomplished by deriving some substitutions, which could be modified as required, to permit the calculation of errors for the specific cases of renormalization or lidar ratio errors. Regrettably, one of the substitution equations was not correct for one of the cases, and the result of the incorrect substitution was then carried over into several subsequent equations. In this incorrect substitution, the exponent of the particulate transmittance was multiplied by an additional factor. For the case where the output errors result from errors in the renormalization, this factor is unity and the results are correct. In the case where output errors are produced by errors in the lidar ratio, however, the factor is not unity and the results are not correct. Corrections to these equations are presented in the next section.

Fortunately, the only equations affected are those to which the incorrect substitutions were copied, and these are limited mainly to the case of sensitivity of unconstrained retrievals to errors in the lidar ratio. All of the final equations for the specific cases of renormalization and lidar ratio errors, all of the equations for the approximations for the constant scattering ratio layers, low optical depths, and high scattering ratios, and all of the related figures are unaffected because they were derived directly from the equations for the specific cases and not from the equation for the general case.

2. Details

Following YEA13, we describe the error in the attenuated backscatter profile, $\beta'(r)$, caused by errors in calibration or renormalization, by the multiplicative factor

$$\alpha = \hat{\beta}'(r)/\beta'(r) = 1/(1+\kappa) = 1/[1+\varepsilon(C)/C],$$

where we use a generic $\varepsilon(C)/C$ to represent the fractional (relative) error in either calibration or renormalization. We use the "^" notation to indicate estimated or retrieved quantities that may be in error. Similarly, we describe the ratio of the incorrectly estimated lidar ratio to the correct value, S_P, as

$$\psi = \hat{S}_P/S_P = 1 + \varepsilon(S_P)/S_P.$$

Equation (A13) in YEA13 expresses the ratio of the estimated two-way particulate transmittance to the true value, $u(r) = \hat{T}_P^2(0, r)/T_P^2(0, r)$, in a standard or common form, as follows:

$$u(r) = \exp\left[-\int_0^r w(z)\,dz\right]\exp\left[\int_0^r \nu(z)u^{-1}(z)\,dz\right].$$

Substitutions for the functions $\nu(r)$ and $w(r)$ that include the factors α and ψ are subsequently introduced in order to produce an equation that can describe each of the separate error contributions. Unfortunately, however, as a result of an error in the integrand of Eq. (A12) in YEA13, the substitution for the function $w(r)$ is incorrect. The correct form of their Eq. (A12) is

$$\frac{\hat{T}_P^2(0,r)}{T_P^2(0,r)} = \exp\left\{\int_0^r 2\left[\sigma_P(r) + \left(\frac{\hat{S}_P}{S_M}\right)\sigma_M(r)\right]\right\}\exp\left\{-\int_0^r 2\alpha\psi S_P\beta_T(z)\left[\frac{T_P^2(0,z)}{\hat{T}_P^2(0,z)}\right]dz\right\}. \tag{A12}$$

The correct definition for their function $w(r)$ in their Eq. (A14) should then be

$$w(r) = -2\left[\sigma_P(r) + \psi\left(\frac{S_P}{S_M}\right)\sigma_M(r)\right] = -2\left[\sigma_T(r) + \left(\psi\frac{S_P}{S_M} - 1\right)\sigma_M(r)\right]. \tag{A14}$$

The incorrect version of $w(r)$ was then used in Eqs. (A16) and (A17), which are, as a result, also incorrect. The correct version of Eq. (A16) is

$$\int_0^r w(z)\,dz = -2\int_0^r \sigma_T(z)\,dz - 2\left(\psi\frac{S_P}{S_M} - 1\right)\int_0^r \sigma_M(z)\,dz = -2\tau_T(0,r) - 2\left(\psi\frac{S_P}{S_M} - 1\right)\tau_M(0,r) \tag{A16}$$

and the correct version of Eq. (A17) is

$$\exp\left[\int_0^r w(z)\,dz\right] = T_P^2(0,r)\,T_M^{2\psi(S_P/S_M)}(0,r) = T_T^2(0,r)\,T_M^{2(\psi S_P/S_M - 1)}(0,r). \tag{A17}$$

The only difference between this corrected version of Eq. (A17) and the original in YEA13 is the additional ψ factor in the exponent of the particulate transmittance. Regrettably, this incorrect substitution for the product of the modified particulate and molecular transmittance factors was also copied to Eq. (A22) [reproduced as Eq. (27) in the body of the paper]. The corrected version of Eq. (A22) is

$$\frac{\hat{T}_P^2(0,r)}{T_P^2(0,r)} = \frac{1 - 2\alpha\psi S_P\int_0^r \beta_T(z)T_P^2(0,z)T_M^{2\psi(S_P/S_M)}(0,z)\,dz}{T_P^2(0,r)T_M^{2\psi(S_P/S_M)}(0,r)}. \tag{A22}$$

Note that because ψ (the error in the lidar ratio) is unity for the case where the sensitivity of the retrieval to errors only in calibration or renormalization is considered, all of the equations (except one typographical error) in section a2 in the appendix of YEA13 are correct, as are the subsequent simplifications, approximations, and figures. The typographical error is in Eq. (A23). The product of the transmittances in the denominator should be the same as in the numerator with the subscript of the first factor being T rather than P:

$$\frac{\hat{T}_P^2(0,r)}{T_P^2(0,r)} = \frac{1 - 2\alpha S_P \int_0^r \beta_T(z) T_T^2(0,z) T_M^{2[(S_P/S_M)-1]}(0,z)\,dz}{T_T^2(0,r) T_M^{2(S_P/S_M-1)}(0,r)}. \tag{A23}$$

Alternatively, if T_P^2 is to be used, then the denominator is the same as in Eq. (A22) above.

Where the sensitivity to errors in lidar ratios is considered in section a3 of the appendix in YEA13, ψ is not unity and equations to which the incorrect substitution was copied require correction. The first is Eq. (A42), the correct version of which is

$$\frac{\hat{T}_P^2(0,r)}{T_P^2(0,r)} = \frac{1 - 2\psi S_P \int_0^r \beta_T(z) T_P^2(0,z) T_M^{2\psi(S_P/S_M)}(0,z)\,dz}{T_P^2(0,r) T_M^{2\psi(S_P/S_M)}(0,r)}. \tag{A42}$$

The incorrect substitution for the transmittance product was also copied to Eq. (A45)—the correct version of which is

$$T_P^2(0,r) T_M^{2\psi(S_P/S_M)}(0,r) = \exp\left\{-2\left[\tau_P(0,r) + \psi \frac{S_P}{S_M} \tau_M(0,r)\right]\right\} \tag{A45}$$

—and Eq. (A46), where the exponent for the particulate transmittance should be simply 2:

$$T_P^2(0,r) T_M^{2\psi(S_P/S_M)}(0,r) = \exp[-2\phi\tau_P(0,r)] = T_P^{2\phi}(0,r) \tag{A46}$$

We note that all other equations, results, and figures where sensitivity to lidar ratio errors is considered, and those in sections dealing with constrained retrievals, are unaffected by the incorrect substitution described above.

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