Communications

Note on "An Improved Model of Surface BRDF-Atmospheric Coupled Radiation"

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***Abstract*—A recent paper compared approximate radiative transfer results for top-of-atmosphere (TOA) radiance, using various algorithms published in the literature. We show that one of the algorithms was used incorrectly, resulting in its poor performance as stated in that paper. Correct usage produces results with errors typically less than 3%, which compares favorably to the other tested algorithms.**

***Index Terms*—Algorithms, radiative transfer.**

I. Introduction

An algorithm to compute the top-of-atmosphere (TOA) radiance in an efficient but approximate manner was described in [1]. It was developed to facilitate the retrieval of atmospheric aerosol properties when viewing dense, green vegetation with the Multi-Angle Imaging SpectroRadiometer (MISR) instrument on board the Terra space platform [2]. As such, it was designed to be used with a lookup table (LUT) containing precalculated, model-dependent atmospheric functions on grids of view and solar angle values. Also required was the specification of a parameterized BRF model to describe the reflectance characteristics of vegetated surfaces. The three-parameter Rahman–Pinty–Verstraete (RPV) model [3] was selected, with two of the parameters preset and the third one allowed to vary. Multiple scattering was fully accounted for, both within the atmosphere and at the atmosphere–surface boundary, but the emerging TOA radiance was approximated by limiting the expansion of its azimuthal dependence to the first two Fourier terms. The results delivered by this algorithm were found to be in excellent agreement with those from an algorithm implementing a very rigorous calculation of the multiple-scattering component [1]. For an analysis of Meteosat data, the algorithm was generalized in [4], allowing all three RPV model parameters to vary, in order to accommodate the wide range of surface types found globally. A comparison of TOA radiances from this algorithm with those from the *second simulation of the satellite signal in the solar spectrum* (6S) algorithm [5] again showed excellent agreement [4].

Recently, Qiu [6] introduced a modified version of the 6S algorithm with supposed improved accuracy. TOA radiances from this algorithm were then compared to the radiances from the original 6S algorithm, the algorithm of Wanner *et al.* [7], and the algorithm of Martonchik *et al.* [1] and Pinty *et al.* [4] (denoted as M+P), described above. In particular, Qiu noted that the M+P algorithm performed the poorest, stating errors of over 25% for certain cases studies, and in contradiction to the study results of [1] and [4]. Qiu then modified the apparently poorly performing algorithm and claimed to reach accuracies comparable to or better than those of the other algorithms being tested.

We want to point out in this paper that the M+P algorithm was incorrectly used by Qiu, resulting in the gross errors stated in his paper [6], and that correct usage of the original algorithm produces results comparable to his "modified" version.

II. Analysis

Since the algorithm equations in [1] were to be used in an operational capacity, they were expressed strictly in terms of atmospheric functions whose values were to be stored in an LUT. Both the upward and downward diffuse transmittance functions are intrinsically present in the equations, but the use of their reciprocal relationship requires that only one of these transmittance functions needs to be stored. Thus, the downward diffuse transmittance function $\bar{T}$ was chosen to be replaced in the equations by the corresponding upward diffuse transmittance function T, via the reciprocity relation

$$\mu_0 \cdot T(-\mu_0, -\mu, \phi_0 - \phi) = \mu \cdot \bar{T}(\mu, \mu_0, \phi - \phi_0) \qquad (1)$$

where μ_0, μ are the cosines of the zenith angle of the radiance direction and ϕ_0, ϕ are the associated azimuth angles. The first argument in both functions describes the direction of the transmitted radiance and the second argument the direction of the incident radiance. It is also important to note that for the upward diffuse transmittance, the cosines of the transmittance and incidence zenith angles are defined to be negative. When T and $\bar{T}$ are expanded in a Fourier series in $\phi - \phi_0$, a similar expression holds for the expansion coefficients T_n and $\bar{T}_n$ of the nth term, namely

$$\mu_0 \cdot T_n(-\mu_0, -\mu) = \mu \cdot \bar{T}_n(\mu, \mu_0). \qquad (2)$$

When performing calculations with the algorithm equations (limited to the first two Fourier terms), it appears that Qiu [6] misinterpreted the upward diffuse transmittance functions $T_0(-\mu_0, -\mu)$ and $T_1(-\mu_0, -\mu)$ by incorrectly assuming that the arguments $-\mu_0$ and $-\mu$ pertained to the incident and transmitted directions, respectively, for these functions. We tested this hypothesis by comparing results from the algorithm, when using both the correct and incorrect (interchanged arguments) forms of these transmittance functions. Table I shows the percentage error in the algorithm TOA radiances when compared to results from a more rigorous multiple-scattering algorithm [8]. The atmospheric and surface conditions used in the comparison calculations are the same as those used for Figs. 4–6 in [6], illustrating results for solar illumination zenith angles $\theta_0 = 0^\circ$, 60°, and 75°, respectively. First, it is clear that when the algorithm is used correctly, the errors are small, less than 2% (columns labeled "Correct" in Table I) for the three cases studied. Second, when the algorithm is used with the incident and transmitted directions interchanged in both T_0 and T_1 (columns labeled "Incorrect" in Table I), the errors can be quite large, exceeding 20%. The magnitude and angular variation of these errors are in very good agreement with those reported in Figs. 4 and 5 in [6], indicating that Qiu had probably inappropriately interchanged the incident and transmitted directions in T_0 and T_1. For the case $\theta_0 = 75^\circ$ in Fig. 6 of [6], however, the errors produced by Qiu are in the range of -1% to -8%, far larger than -1% to -2% listed in the "Incorrect" column of Table I. The reason for this is uncertain but may be due to a difference in the Junge aerosol phase function in the two analyses, caused

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TABLE I
PERCENTAGE ERRORS USING THE TOA RADIANCE ALGORITHM IN [1] CORRECTLY AND INCORRECTLY, AS DESCRIBED IN TEXT

Viewing angle (deg)	Correct $\theta_0 = 0°$	Incorrect $\theta_0 = 0°$	Correct $\theta_0 = 60°$	Incorrect $\theta_0 = 60°$	Correct $\theta_0 = 75°$	Incorrect $\theta_0 = 75°$
-70	-0.59	21.69	-1.07	8.19	-0.68	-0.11
-50	-0.42	21.45	-1.48	12.62	-1.20	-0.51
-30	-0.40	19.73	-1.40	14.80	-1.42	-0.95
-10	-0.26	17.06	-1.28	15.77	-0.91	-0.68
0	-0.24	16.04	-1.24	15.81	-1.61	-1.54
10	-0.26	17.06	-1.32	15.45	-1.72	-1.79
30	-0.40	19.73	-1.58	14.06	-1.90	-2.11
50	-0.42	21.45	-1.98	10.68	-1.90	-1.81
70	-0.59	21.69	-1.88	9.90	-1.53	-0.91

TABLE II
PERCENTAGE ERRORS USING ALGORITHM IN [1] CORRECTLY AND USING THE MODIFIED ALGORITHM AS DESCRIBED IN[6]

Viewing angle (deg)	Correct $\theta_0 = 0°$	Modified $\theta_0 = 0°$	Correct $\theta_0 = 60°$	Modified $\theta_0 = 60°$	Correct $\theta_0 = 75°$	Modified $\theta_0 = 75°$
-70	-0.59	-0.45	-1.07	-1.10	-0.68	-0.75
-50	-0.42	-0.31	-1.48	-1.53	-1.20	-1.31
-30	-0.40	-0.28	-1.40	-1.46	-1.42	-1.61
-10	-0.26	-0.15	-1.28	-1.28	-0.91	-1.71
0	-0.24	-0.14	-1.24	-1.24	-1.61	-1.82
10	-0.26	-0.15	-1.32	-1.32	-1.72	-1.91
30	-0.40	-0.28	-1.58	-1.51	-1.90	-2.06
50	-0.42	-0.31	-1.98	-1.94	-1.90	-1.99
70	-0.59	-0.45	-1.88	-1.77	-1.53	-1.62

by using different minimum and maximum size limits in the particle size distribution. These limits were not explicitly given in [6]. In any event, Qiu's evaluation that the M+P algorithm performed the worst of the algorithms tested is invalid and entirely unwarranted.

We can infer that Qiu also misunderstood the transmission functions in his "modified" version of the M+P algorithm, the equations of which are in the appendix of [6]. Although Qiu did not state how he derived these "modified" equations, it can be easily demonstrated that they are identical to the original M+P algorithm equations [1], before the use of the reciprocity relation described by (2). These original equations, however, contain the downward diffuse transmittance functions $\bar{T}_0(\mu, \mu_0)$ and $\bar{T}_1(\mu, \mu_0)$, not $T_0(-\mu_0, -\mu)$ and $T_1(-\mu_0, -\mu)$, the functions which are explicitly contained in Qiu's "modified" equations. Assuming that T_0 and T_1 represent the upward diffuse transmittance in the "modified" M+P algorithm, because the arguments are explicitly expressed as being negative, Qiu again may have incorrectly interpreted $-\mu_0$ and $-\mu$ as indicating the incident and transmitted directions, respectively, for these functions, an interpretation which is correct only if the functions represent the downward diffuse transmittance. The fact that Qiu's "modified" M+P algorithm was able to achieve very good results, in spite of a probable incorrect argument interchange, implies that it is not particularly sensitive to whether the upward or downward diffuse transmittance is used. That this implication is true is illustrated by the percentage errors of TOA radiance tabulated in Table II when using both the upward (columns labeled "Modified") and the downward (columns labeled "Correct") diffuse transmittance functions. Again, the same atmospheric and surface conditions were used as in Table I. For these particular cases, we find that there is no significant difference between the two interpretations. Thus, the apparently good results from the "modified" M+P algorithm (shown in [6, Figs. 4–6, Table III]) are really indicative of the quality of the results of the original M+P algorithm and not of Qiu's "correction" procedure.

III. CONCLUSIONS

It has been demonstrated that the M+P algorithm [1], [4], when used correctly, produces TOA radiances with an accuracy that is typically better than 3%. As such, it compares favorably with other algorithms, such as [5] and [7], which also employ extensive approximations. We have also demonstrated that Qiu misused this algorithm, which resulted in an inappropriate performance assessment in his algorithm comparison study [6]. Qiu's "modified" algorithm, designed to correct this "poor" performance, is only a reformulation of the M+P approach. When correctly implemented, the M+P algorithm compares favorably to other algorithms using approximations, and no modifications or corrections of the type specified by Qiu are necessary.

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