TOMS Ozone Retrieval Sensitivity to Assumption of Lambertian Cloud Surface (I)

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Abstract. Using a radiative transfer model that treats clouds as scattering medium in the forward simulation, we study the assumption of opaque Lambertian cloud surface and the employed PCM on TOMS ozone retrieval. The assumption of angularly independent cloud reflection is fairly good because the Ozone Retrieval Error (ORE) is within 1.5% of the total ozone when Cloud Optical Depth (COD) ≥ 20. Because of the In-Cloud Ozone Absorption Enhancement (ICOAEN), the assumption of opaque cloudy surface introduces large OREs even for optically thick clouds. For a water cloud of COD 40 at 2-12 km with 20.8 DU ozone homogeneously distributed in the cloud, the ORE is 17.8 DU at nadir view. This ICOAEN effect depends greatly on viewing geometry, ozone amount in the cloud, and ozone distribution in the cloud. The ICOAEN effect for those tropical high-refl ectivity convective clouds (reflectivity > 80% and cloud top pressure ≤ 300 HPa) is typically 5.13 DU over the Atlantic Ocean and Africa, and 1.7 DU over the Pacific Ocean. The TOMS PCM is good because negative errors from the cloud fraction being underestimated partly cancel positive errors, especially for the ICOAEN effect. At COD ≤ 5, the PCM effect nearly offsets the ICOAEN effect, and the TOMS algorithm retrieves the about correct TOC. With increasing COD up to 20-40, the negative PCM effect decreases dramatically than the positive ICOAEN effect, so the overall positive ORE increases.

Motivation and Objectives

• Cloud treatment in operational algorithms is highly idealized. TOMS V7 algorithm assumes clouds as opaque Lambertian surfaces and uses the partial cloud model (PCM) (Minimum Full cloud Reflectivity is 80%). These idealizations may cause ozone retrieval errors.
• The significant ozone excess of 10-15 DU over tropical high-altitude, highly reflecting clouds compared to clear observations motivates to study the TOMS cloud treatment on ozone retrieval.
• Possible sources of ozone retrieval errors are illustrated in Figure 1.
  • Cloud reflection is angularly dependent.
  • Photon penetrate into clouds even below cloud bottom.
  • Cloud optical depth (OD) may be different from the actual.
• We use radiative transfer codes to address the effects of these aspects on TOMS ozone retrieval for thick clouds.

Lambertian and PCM Effects (or Lambertian-PCM effect)

- Figure 2 shows the sum of Lambertian and PCM effects as a function of viewing geometry for a water cloud of COD 40 (left) and 10 (right) at 2-12 km. The cloud fraction in the forward cloud fraction
  - The Lambertian-PCM effect varies with viewing geometry. At COD 40, the error is within ±4.5 DU. The error at COD 10 ranges from -8.9 DU to 4.4 DU.
- Figure 3 separates the Lambertian effect from the PCM effect. The error caused by the Lambertian effect is slightly more scattered for COD 40 than for COD 10. The negative PCM effect is due to mainly to the cloud fraction being underestimated so the added ozone below clouds is reduced.
  - With decreasing COD, the negative PCM effect increases in magnitude because the effective cloud fraction decreases, and the Lambertian-PCM effect becomes dominated by the negative PCM effect.
- Table 1 shows the range and average error due to the Lambertian-PCM effect.
  - The Lambertian-PCM effect varies with cloud optical depth, cloud optical properties (Water Clouds with Henney-Greenstein phase function (WCG), HEXagon ice crystals (HEX), POLyCrystals (POLY)), ozone profiles, and cloud top pressure.

Table 1. The range and average of the Lambertian-PCM effect.

<table>
<thead>
<tr>
<th>COD</th>
<th>2-12 POD</th>
<th>Location</th>
<th>Error Range</th>
<th>Avg. Error</th>
<th>SZA</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>-11.7 – 4.0</td>
<td>50</td>
<td>-5.3 – 1.2</td>
<td>-8.9 ± 1.5</td>
<td>60</td>
</tr>
<tr>
<td>20</td>
<td>-11.7 – 4.0</td>
<td>70</td>
<td>-5.3 – 1.2</td>
<td>-8.9 ± 1.5</td>
<td>80</td>
</tr>
<tr>
<td>10</td>
<td>-11.7 – 4.0</td>
<td>90</td>
<td>-5.3 – 1.2</td>
<td>-8.9 ± 1.5</td>
<td>100</td>
</tr>
</tbody>
</table>

ICOAEN Effect vs. Viewing Geometry

- Figure 4 shows the ICOAEN effect vs. viewing geometry for a water cloud of COD 40 positioned at 2-12 km. There is 20.8 DU ozone in the cloud.
- The ICOAEN effect decreases dramatically with the increase of SZA and VZA and is azimuthally independent. -18 DU at nadir and only 0.15 DU at SZA = 75° and VZA = 7°. The exchange of SZA and VZA does not change ICOAEN.
- The photon path length in clouds decreases with increasing SZA and VZA. Furthermore, the algorithm automatically accounts for the geometrical path length (1/cos[SZA] + 1/cos[VZA]). These two factors lead to the dramatic decrease of enhanced ozone vs. geometrical path length.

Figure 4. ICOAEN effect vs. Viewing Geometry, + indicates the SZA.