

# Responses to Referee 1 (Christopher Sioris) on Behalf of the Authors

We would like to thank the referee for their helpful comments and suggestions. Included below is each of the referee's comments (italics) followed by our reply.

## General Comments

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*Even though this is a difficult topic, the paper is very well written and understandable. I recommend it for publication after the following minor corrections. This long paper could be made shorter by dropping the timing section. I didn't find it that interesting, particularly since apples-to-apples comparisons were difficult, particularly for the Monte Carlo models. Perhaps that section could be condensed, if it is not eliminated.*

**Reply:** We thank the reviewer for the positive comments on the paper. The point about the timing section does not fall on deaf ears, however we think it does add value to the manuscript. Having the timings presented indicates to the reader that every model in the study used "reasonable" settings, i.e., no RTM was executed with settings that could not be used in practice. The timing also highlights a few of the practical differences between the different MC techniques used by SASKTRAN-MC/Siro and SMART-G/MYSTIC, and demonstrates an important result in that the "forced single scatter only" method of SMART-G is very efficient. The referee's point that this is not an "apples-to-apples" comparison is very valid, and this is the reason why the section may be considered verbose in a few places. We wanted to be clear and precise in how the results should and should not be interpreted which makes it difficult to shorten the section.

## Specific Comments

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**L36** *BrO reference should not be McLinden and Bourassa, 2010. It should be McLinden et al.,2010*

**Reply:** Thank you, this has been fixed.

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**L48** *“at most” → “, at most,”*

**Reply:** Changed.

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**L75** *“built-in” → “a built-in”*

**Reply:** Changed.

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**L79** *With the previous sentence mentioning polarization, it should be clear here whether Sasktran HR is a vector model or not.*

**Reply:** Good point, we have added the descriptor “polarized”.

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**L105** *“the multiple scatter source function is calculated at” → “at which the multiple scatter source function is calculated”*

**Reply:** Added.

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**L106** *In what sense are the weighting functions “approximate”? Is this related to the pseudo-spherical multiple scattering?*

**Reply:** The weighting functions are “approximate” in that the contribution from single scatter terms is handled exactly, but the contribution from multiple scatter has to be handled approximately. This is not related to how well the RTM itself calculates the multiple scattering solution, it is something specific to the weighting functions and more of a computational approximation. Since weighting functions are not a focus of the paper we think it is okay to leave the wording as is since the next line refers to two other papers where

more information can be found.

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**L140** (*and elsewhere*) *approximate* → *approximately*

**Reply:** We see the grammar point, but “approximate spherical” has become the standard term for describing this type of solution so we prefer to leave it.

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**L146** *SCIATRANs* → *SCIATRAN’s*

**Reply:** Changed.

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**L172** *The last part of this sentence is repetitive: “and is capable of simulating the effects of a fully three-dimensional atmosphere”.*

**Reply:** We have changed this to read “and is capable of handling atmospheres where the parameters vary in three-dimensions (not just in altitude)”.

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**L180** (*and elsewhere*) *A comma should follow a leading prepositional phrase. See L76, L77 for good examples.*

**Reply:** Added .

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**L186** *Was the surface 3-d (i.e. varying terrain elevation) or is 2-d meant?*

**Reply:** You are correct, 2-D is meant and this has been changed.

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**L206** *The two sentences starting here are irrelevant to this paper. Maybe they should be deleted.*

**Reply:** We understand the referees point that the distinction between the two different MC techniques is not particularly relevant for the presented radiance comparisons, however, the

difference is very important for the timing section.

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**L207** “higher wavelengths” → “longer wavelengths” ?

**Reply:** Thank you, longer is better.

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**L214** “force-scatter” What is this? Never heard of such a term. It becomes clear later (L432), but I suggest a rewording here.

**Reply:** This has been reworded to “Siro and SASKTRAN-MC both use the same technique where every photon traced is forced to scatter”

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**L237** Reword or remove “when the incident source is unpolarized”. This is not correct. The incident source could be, for example, partially polarized and the statement would be true.

**Reply:** We have changed the statement “polarization only affects  $I$  through multiple scattering when the incident source is unpolarized.” to read “the single scatter  $I$  is unaffected by polarization when the incident source is unpolarized”. The intended message is that in the scattering plane,  $I_{out} \sim P_{11}I_{in} + P_{12}Q_{in}$ , and if the incident source is unpolarized then  $Q_{in}$  is 0 thus the output radiance is unaffected by polariation. This would also be true for a circularly polarized input source, but here we aren’t claiming it is a necessary condition, only a sufficient condition.

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**L245** Begin sentence with “The ozone...”

**Reply:** Changed.

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**L247** “simple Rayleigh scattering without” → “elastic and without”

**Reply:** Changed.

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**L279** Remove comma after “attributing”

**Reply:** Removed.

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**L288 (Figure 2 caption)** State the wavelength. Presumably there is a single wavelength

used to generate the figure.

**Reply:** Added.

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**L299** “(MMM).” → “(MMM) for this case.” [see L284]

**Reply:** Changed.

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**L304** *in* → *with* (?)

**Reply:** Changed.

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**L306** “simulation” might be preferable over “calculation”

**Reply:** We agree.

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**L329** *What kind of approximations are made in the ground-to-LOS scatter? How might GSLS be approximating this differently? Since the surface is Lambertian for all models, it does not seem that this should be a source of bias.*

**Reply:** We think our wording here was a little confusing, it is not an approximation in the ground scatter itself since as you point out it should be fairly simple, instead it is more of an approximation in the full process of accounting for ground multiple scattering. The current thought is that it involves

All that being said, this is only the current theory and it needs further investigation, which is why we chose not provide additional details. When we mention this (once in the main text and once in the conclusions) we have made sure to state that it is part of the multiple scattering calculation and still under investigation.

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**L369** *identically* → *exactly*

**Reply:** Changed.

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**L384** “differences” → “differences relative to SMART-G” (?)

**Reply:** We have reworded this entire phrase to be more clear, “The agreement of GSLS

relative to the other models is almost identical in the refracted and unrefracted cases”

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**L388** *“The refraction ratio is larger at longer wavelengths due to the atmosphere being more optically thin”. This explanation is insufficient for me. Is it that refraction is of greater relative importance when scattering is diminished? If so, I think my wording is more to the point.*

**Reply:** Basically at short wavelengths and low altitudes, there is so much scattering (or absorption) that you don’t “see” low altitudes where refraction is actually important. So you are correct that the diminished scattering leads to refraction being more important, but it is not the sole reason. We have split this sentence into two and it now reads “At short wavelengths and low tangent altitudes, the increased extinction causes the atmosphere to be optically thick, reducing the contribution from the lower atmospheric layers where the refractive effects are significant. Therefore the refraction ratio is shown at 1020 nm which is representative of the differences observed between the models at all wavelengths where the atmosphere is optically thin.”

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**L397** *Odd construction with this sentence (suggested change is optional): “There exist various methods” → “Various methods exist”*

**Reply:** Changed

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**L400** *The meaning of “this” is ambiguous. Can you not narrow it down with some single scattering comparisons?*

**Reply:** “this” has been replaced with “solar refraction” to clear up the ambiguity. For sure additional simulations could be performed that could narrow this down, but we are unable to isolate this effect with the simulations that we have already done. We definitely agree that this is interesting and as stated in the manuscript it is a subject for future study.

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**L402 (and L471)** *higher → larger (see L470)*

**Reply:** Changed.

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**L415** *Delete “, solar geometry, and atmospheric composition”*

**Reply:** We think it is important to be clear here. If we only state that this is average time is for a single wavelength the reader could incorrectly infer that this time is the time

to calculate all solar geometries and compositions at that wavelength, when that is not the case.

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**L423** *The → the*

**Reply:** Fixed.

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**L441** *Search the document for polaris\* and replace the 8 occurrences with polariz\**

**Reply:** Thank you, this has all been changed to be consistent.

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**L448** *low → small*

**Reply:** Changed.

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**L455** *Is refraction considered at all altitudes for SMART-G or does it “turn on” when the altitude is low enough (e.g. 11.5 km)?*

**Reply:** It is considered at all altitudes, as you can see in Figure 9 the refraction ratio is not 1 at the higher altitudes. The cause of this is still somewhat of a mystery.

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**L477** *university → University*

**Reply:** Fixed.

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**L720** *No need to provide second website and publisher in this reference and many others, or is this a new convention?*

**Reply:** We are also unsure about this but this is automatically generated from the copernicus AMT bibtex template so I assume if it is not correct it can be fixed during copy-editing.