Reply to referee 1 for: The impact of parameterizing light penetration into snow on the photochemical production of NOx and OH radicals in snow

We thanks the reviewers for their reviews and recommendation to publish. We have considered every point and corrected the paper to include their points.

General Comments to the Authors

1. However, for the ze method, where will e-folding depths and surface actinic flux values come from going forward? Surface direct and diffuse downwelling irradiance from global chemical transport models and global chemical transport models can be used to calculate the surface actinic flux, but these models will not be able to calculate e-folding depth in snow. Please address this topic in the manuscript.
   Revised text P8626 (Conclusions)
   "The values of e-folding depth used in some of the previous modelling studies were based on field measurements (Thomas et al., 2011; Simpson et al., 2002). Recently research groups have studied to develop new algorithms to estimate optical properties of snowpack, such as grain size and level of pollutants, from satellite measurements (Zege et al., 2011; Malinka , 2014; Khokanovsky, 2015). These measurements and algorithms can be integrated into large scale chemical transport models in the future to estimate e-folding depth and photolysis rate coefficient.
   An important approximation of the e-folding depth (ze) method is that snowpack is optically thick, i.e. assuming the snowpacks are semi-infinite. For shallow snowpacks the exact RT method should be used. It is unlikely a robust parameterization could be developed to correct the ze method for shallow snowpacks over a range of light absorbing snowpack, solar zenith angles and underlying terrains for the thin snowpack, i.e. soil or sea ice. For shallow snowpacks (< 2-3 e-folding depths) the RT method is recommended."

2. Towards the end of the paper, the importance of nonBC absorbers in the UV wavelength region is acknowledged. If this parameterization is ultimately going to be incorporated into large scale models, it is worth making sure that this parameterization can successfully calculate photolysis rates in snowpacks with nonBC absorbers. If it is not possible to perform sensitivity studies with nonBC absorption in this study, please outline plan to perform these sensitivity studies before the parameterization is included in global chemical/ climate models.
   Two extra sensitivity cases, I) snowpack containing HULIS only and II) snowpack containing both black carbon and HULIS as the light-absorbing impurity, been included in this study
   Text P8615 (Modelling procedure) has been added
   "Other common pollutants found in snow samples include HULIS, which represent an important fraction of biomass-buring, biogenic and marine aerosol etc. (e.g. Voisin et al., 2012). HULIS absorb most effectively in the UV region of the solar spectrum and the absorption cross-section decreases towards the visible (Hoffer et al., 2006). Concentrations of HULIS measured in polar snow vary between 1 to 1000 ng g^{-1} and depend on the measurement method (Voisin et al., 2012, France et al., 2012),

which is taken into account by the range of values used in Case 4. In natural snow, it is rare that HULIS would be the only light absorbing impurity within snow as shown in France et al., 2011; France and King, 2012, therefore, in Case 5 a combination of both black carbon and HULIS were used and varied"

3. Also, will this parameterization only be valid for deep snowpacks found in polar regions? It would be very useful to develop this parameterization for shallow snowpacks as well for incorporation in large-scale models.
   An important approximation of the ze method is that snowpack is optically thick (see Warren, 1982). The ze method cannot be used for shallow snowpacks. The following text has been added to Introduction P8611 :
   "In the asymptotic zone radiation is diffused, and provided that the snowpack is semi-infinite, i.e. the albedo of the surface underlying the snow does not affect the calculation of the actinic flux within the snowpack and France et al., 2011 define semi-infinite as 3-4 e-folding depths, the radiation decreases exponentially according to Beer–Lambert law."

   Text also has been added to conclusions:
   "An important approximation of the e-folding depth (z_e) method is that snowpack is optically thick, i.e. assuming the snowpacks are semi-infinite. For shallow snowpacks the exact RT method should be used. It is unlikely a robust simple parameterization could be developed to correct the z_e method for shallow snowpacks over a range of light absorbing snowpack, solar zenith angles and underlying terrains for the thin snowpack, i.e. soil or sea ice. For shallow snowpacks (< 2-3 e-folding depths) the RT method is recommended."

Specific comments:
P8610, L12: I think that the transfer velocity should be referred to as the "depth-integrated photolysis rate constant" throughout the text. It helps the reader understand what this term physically represents.
The term "transfer velocity" had been replaced by "depth-integrated photolysis rate" throughout the text.

P8610, L16: Mention that RT is short for radiative transfer
Fixed, Abstract, line 11-12, now reads "… calculated (a) explicitly with an RT model (TUV), v_{TUV} and (b) with a simple parameterisation …"

P8610, L24: reduces instead of reduce
Fixed, "reduces" changed to "reduce"

P8611, L8: Mention that OH is the hydroxyl radical.

Fixed, now reads ",Snow photochemical processes drive production of chemical trace gases, including nitrogen oxides (NO_x = NO + NO_2), and hydrogen oxide radical (HO_x = OH + HO_2), in snowpacks which are then released to the lower atmosphere."

P8611, L11-12: add "the" before atmosphere and "a" before source and also before sink.
Fixed, now reads "The exchange between snowpack and overlying atmosphere depends on dry and wet deposition, transport (including wind-pumping and diffusion) and snow microphysics (e.g. Bartels-Rausch et al., 2014). Thus snow can act as both a source and a sink of atmospheric chemical species as summarised in Bartels- Rausch et al., 2014 and Grannas et al., 2007.

P8611, L15: the "to be" is not needed before preserved
Deleted "to be" in the sentence.

P8611, L15: Mention that NO_x is nitrogen oxides
The sentence had been removed and NO_x defined in the introduction.

P8611, L17: Add that "photochemically-active" species (e.g. NO^-_3) are the proxies to be more specific
Fixed, now reads
"chemical preserved in ice cores, and potential paleo-climate proxies, may be altered by reactions with OH radicals, photolysis or physical uptake and release (Wolff and Bales, 1996). "

P8612, L15-16: The enhancement in actinic flux in the top few cm is only for certain solar zenith angles (SZA), less than ~50 degrees.
Fixed, now reads " The enhancement in actinic flux occurs for solar zenith angles < 50°."

P8612, L25: check tense of 'providing'. I'm not sure if 'provided' would be better
Fixed for grammar and added definition of "semi-infinite" , now reads
"In the asymptotic zone radiation is diffused, and provided that the snowpack is semi-infinite, i.e. the albedo of the surface underlying the snow does not affect the calculation of the actinic flux within the snowpack an the radiation decreases exponentially according to Beer–Lambert law. (France et al., 2011 define semi-infinite as 3-4 e-folding depths)"

P8614, L6: Provide the range of wavelengths that these reactions each occur over
The wavelengths of the peak of action spectrum are now listed together with the chemical reaction R1, 2,3,4 & 7.

P8614, L13: Provide range of quantum yield and also absorption spectrum
Values of quantum yield and references for all the absorption spectrum are listed in Table 3.

P8614, L16: How deep in the snow is it expected that NO2 would produce O3 by R4 and R5?
The referee's question is not part of work described in the submitted manuscript and relates to work that will follow this submission. The submitted manuscript is an assessment of the different methods for photolysis within the snowpack. The question is for a full chemical snowpack model and unrelated to the questions/aims of this work.

P8615, L5-8: This sentence needs to be ended with something like "are calculated in this study, with and without an algorithm designed to improve X".
The paragraph now reads "The ratio of the depth-integrated photolysis rate coefficients, $Q = v_{TUV}/v_{ze}$, determined from the two methods - the RT model and e-folding depth parameterisation were calculated for the photolysis of NO^-_3 , NO^-_2 , NO_2 and H_2O_2 in snow. Reactions rate coefficients for reactions R1–R4 and R7, will be determined for hypothetical snowpacks with different physical and optical properties and under different environmental conditions, e.g. total column ozone."

General comment: Are you taking into account the fact that R6 and R7 occur in the condensed phase while R4 and R5 occur in the gas phase?
The rate of photolysis of the gas-phase species and condensed phase species are calculated by modelling the intensity of light within the snowpack as a weakly absorbing, very scattering, homogeneous media. The Simpson et al, 2002 and Lee-Taylor and Madronich, 2002, have compared such calculation with measurements and gained good agreement. The chemistry of the species produced by photolysis will depend strongly on the phase within it is constrained, but not its generation by photolysis.

General comment: Is it possible to include non-black carbon species in this analysis (e.g. insoluble organics (HULIS), dust, brown carbon).
Yes, this has been done and see reply in General comment above.

P8615, L15: Are these all polar studies, or are some mid-latitude studies as well? The semi-infinite snowpacks are most commonly found in polar regions, so will this parameterization be limited to deep snowpack (e.g. > 3 meter depth) regions? It would be really useful to make the parameterization valid for shallower snowpacks as well.
Values considering measurements made in polar, alpine and mid latitude snow have been in used in the production of the values in table 1 (see also Marks and King, 2014).
Semi-infinite snowpacks can be found in polar, alpine, and mid-latitude snowpacks. As shown by France et al., 2011 a snowpack can be considered semi-infinite when its depth exceeds 3-4 e-folding depth which except for very clean snow is significantly smaller than 1 m and hypothetically 30 cm.

P8616, L10: Although black carbon is the most effective absorber by mass, non-black carbon species (e.g. HULIS) dominate the ultraviolet absorption (e.g. nonBC material absorbs 89% of radiation at 307 nm) – see Zatko et al. [2013], likely because there is much more nonBC material in the snow. The

parameterization would be most realistic if nonBC absorbers were also included, but perhaps this can be included in the future.
See reply for P8615, L5-8 general comment.
See also studies from Barrow and Dome C (France et. al., 2011, 2012) where they show dominant absorber is black carbon based on field data and not modelling studies.

P8616, L18: Zatko et al. [2013]
Correction made.

P8616, L20: remove "a" after has. Also, add reference for this sentence.
Fixed, now reads "In Case 2, values of σ_{scatt} were selected to cover a wide range of snow types (Table 2). The values og scattering cross-section are assumed to be independent of wavelength (Lee-Taylor and Madronich, 2002)."

P8616, L24: stratosphere does not need a capital
Fixed, changed "Stratosphere" to "stratosphere"

P8617, L24: add "an" before ice
Fixed, "an" is added before ice

P8618, L4: what is the vertical resolution from the snow surface to 20cm? Is it also 1 cm?
The description of the TUV snow vertical mesh is given in detials in Section 2.1 (P8617, L16 – 19). The top 20 cm of the snowpack is excluded when determining the e-folding depth.

P8618, L6: Going forward, will the e-folding depth always be obtained from TUV? Or is the goal to always use field measurements of e-folding depth? If the goal is to use field e-folding depths, a robust study of field e-folding depths compared to TUV model output should be performed, similar to the Appendix in Zatko et al. [2013].
e-folding depths may be calculated from TUV using values of scattering and absorption cross-section from field data or from measured e-folding depth. It is not for these authors to dictate one or the other when either may be appropriate. Since 2002 there are few studies using a combined field and TUV modelling study have been performed (Simpson et. al., 2002; King et. al., 2005; France et. al., 2007). A sentence for that effect has been included in the paper conclusion, see above.

P8618, L19: species instead of specie
Fixed, "specie" is changed to "species"

P8618, L16: Similar to my e-folding depth comment, will the surface J value ultimately be obtained using actinic flux values from the field?
Please refer to reply to P8618, L6. Either field or calculated may be used. Indeed it is possible to use a combination of the two. (See barrow paper by France et. al., 2011 in Dome C, Antarctica and France et. al. 2011 b in Ny-Alesund, Svalbard)

P8619, L8: coefficient should be plural
Fixed, “coefficient” changed to “coefficients”

P8619, L13: parentheses around ‘i.e. total column ozone’
Fixed, now reads as “ environment conditions, i.e. total column ozone. ”

P8619, L19-21: By how much do the ze differ across that wavelength range and solar zenith angle range for all the different snowpack types? If nonBC absorbers were included, there would be a distinct wavelength dependence on e-folding depth even from 321 to 375 nm. The snowpack types included likely have different density profiles, which should influence ze (Figure 2a).
The range of variation coefficients for ze across wavelength and solar zenith angle are now listed in Section 3.1, The response of e-folding depth to solar zenith angle and wavelength.
“Table 3 has listed the averaged e-folding depth across seven solar zenith angles for all Cases. For the Base Case, Case 1-3, 6 & 7, the e-folding depths listed were not only averaged across solar zenith angles but also across three wavelengths (321, 345 & 375 nm). There are no significant difference between the calculated e-folding depths, of which the variation coefficients are between 0.002 and 2%. For snowpacks in Case 4 and 5, the e-folding depths were at a single wavelength (321 nm) only and the variation coefficients are ranging from 0.007-0.16 %.”

General comment: Will this parameterization be able to account for varying amounts of direct and diffuse radiation? Please specify the fraction of direct to diffuse incoming solar radiation in TUV.
The parameterisation is effectively correcting for the fact that the ze method does not accurately consider direct radiation illumination within the snowpack. The e-folding depth used in this study and all other studies is the asymptotic e-folding depth which is independent of solar zenith angle and direct/diffused ratio as it is calculated or measured in the snowpack below the near surface layer of the snowpack, where all direct light is effectively converted to diffuse light. The amount of direct to diffuse was calculated by TUV for clear sky i.e. with no cloud and aerosol and a large surface albedo.

P8620, L4-5: Increased scattering leads to increased chance of absorption by black carbon and other absorbers
Fixed, now reads “A larger scattering cross-section will typically reduce the path length of a photon through the snowpack and reduce the possibility for absorption by ice or light absorbing impurities.”

P 8620, L22: Please include which SZA that the purple line represents in the text. Also, which figures in Figure 4 show that the purple line (sza=76) overestimates relative to the RT method? In the figures on the left (top and bottom), the purple dashed and solid lines are similar; it’s hard to see that the ze method overestimates relative to the RT method in this case. In the figures on the right (top and bottom) the purple line is in the middle of the other lines, so it seems like the purple line shouldn’t stand out.
Figure 4 has now taken out of the manuscript.

General comment: The discussion switches back from Figure 3 and Figure 4 throughout this section. Please try to discuss all of Figure 3 first and then discuss Figure 4 so that the reader doesn't need to keep switching back and forth between figures.
Manuscript should now improved by the removal of Figure 4.

P8621, L5: The sentence about anthropogenic pollution is interesting, but out of place. Please move it to a section that is more relevant (3.2.3?).
The sentence is now removed.

P8621, L19-20: add "and" and remove comma between fluxes and photochemical
Fixed.

P8621 (bottom) and P8622 (top): Refer to the figures that are relevant to each statement.
Also, NO3-, H2O2, and NO2 disagreements are given in percent but for NO2-, the disagreement is expressed in factor form. Change NO2- to percent to be consistent.
All the disagreements are now given in factor form.
Now reads

"The value of the ratio Q for the photolysis of the NO^-_3 anion and H_2O_2 are very similar in terms of their response to changing solar zenith angle (Fig. 3a & b). The maximum and minimum values of Q is ~1.27 (underestimation of solar radiation by z_e method), at direct overhead sun, and ~0.92 (overestimation of solar radiation by z_e method), at solar zenith angles between ~66-70°. The disagreement between the two methods for the photolysis of NO^-_2 is slightly larger, the ratio Q ranging between 0.88–1.28 (Fig. 3c). The approximation with z_e method is the most inaccurate for the photolysis of NO_2 within snowpack interstitial air, having Q values range between 0.82 and 1.35 (Fig. 3d)."

General comment: Please add letters to all multipanel plots (e.g. a, b, c, d)
Letters are added to Figure 3, 4, 6, 7 & 8

P8622, L5: change 'negligible' to 'negligibly'
Fixed, "negligible" to "negligibly"

P8622, L6-7: There are some missing words in this sentence.
Fixed, now reads "Solar radiation in the UV region is less intense and more diffuse relative to the UV-A and visible radiation at the snow surface as 1) the ozone layer absorbs strongly in the UV-B & C while relatively weakly in the UV-A and almost negligibly in the visible region and 2) the Rayleigh scattering of photons by air molecules increases as the wavelength decreases.."

P8622, L9-10: Remind readers what the action spectrum for each species is.
The wavelength of the action spectrum peaks are listed together with the reaction equations.

P8622, L15: coefficients
Fixed, change "coefficient" to "coefficients"

P8622, L16: add "that" before have
Fixed, "that" is added

P8622, L13-22: Please include figures that show changes in J when the ozone column is changed.
The changes in photolysis rate coefficient profile of nitrate and nitrogen dioxide under different column ozone are now plotted as Figure 5.

General comment: Section 3.2.2. should be split up into two separate sections, or at least include the discussion of how different chemical species are influenced by SZA in the previous section about SZA. The ozone sensitivity studies should be its own section.
These two sections were originally separate and merged at the request of the editor.

P8623, L1-6: This paragraph needs to be moved to an earlier section where Figure 3 is first described.
The first paragraph is highlighting result in Figure 3, specifically, the variation in the depth-integrated photolysis rate with various physical and optical properties. To clarify, the texts had been edited as such
"Figure 3 highlights three results in terms of various physical properties of the snowpacks: ..."

Figure 3 should somehow be color-coded so that these key points stand out clearly in the figure (see Figure 3 comment below).
Colour code had been adopted. Base Case, Base C in Magenta; Case 1 in red, Case 2 in blue, Case 3 in black, Case 4 in Green & purple.

P8623, L10-11: State the depth where the maximum in J occurs for clean snowpacks and describe why the J maximum depth varies for each different snowpack type.
The value for the maximum J is, at the very least, sensitive to solar zenith angle, snowpack impurity and scattering cross-section. This would be an extremely large amount of data and table – several journal pages and for no apparent useful reason. A good description of the enhancement can be found in Lee-Taylor and Madronich, 2002 with good example. The authors cannot imagine what use these data could be useful for. It would be a poor metric as it is so sensitive to external conditions

P8623, L15-16: Please describe what would happen to the agreement with RT and ze when the density is lowered. The agreement between the RT and ze approaches is important and it would help the reader understand these concepts better.

Additional explanation on how changing density impacts the e-folding depth is added in Section 3.1. As long as the snowpack is semi-infinite there should be no significant change in Q with density.

"A denser snowpack implies more scattering or absorption events per unit length."

P8623, L24: compounds
Fixed, changed to "compounds"

General comment: Section 3.2.3. should be renamed "variations in snow physical properties" and then you should add a section after that titled "variations in optical properties" and include the "variation of asymmetry factor section" into it. In the "physical property" section, describe Figure 6 (it isn't described anywhere else in the text). In the optical section, include the direct vs. diffuse discussion from section 3.2.2.
Figure 6 has now been discussed in details within Section 3.2.3
"Scattering cross-section of the snowpack: Lower values of the scattering cross-section implies longer path length of the photon between individual scattering events. Hence, the maximum photolysis rate coefficient tend to occur deeper into the snowpacks, as shown in blue in Fig. 6 (Scatt2, i.e. melting snow), compared with snowpacks that have a larger scattering cross-section (magenta in Fig. 6, BaseC, i.e. cold polar snow). Thus for snow- packs with a small scattering cross-section the agreement between the RT and z_e methods is likely to be poor as the z_e method will not capture the behaviour in the near-surface layer accurately."

"In Fig. 6, black lines representing the extreme polluted case - BC128, the photolysis rate co- efficient calculated by the two methods matches at around 2 cm depth for the NO^-_3 anion, but ~4 and ~5 cm for the NO^-_2 and NO_2 respectively."

P8624, L11: I think the transfer velocity should be referred to as the "depth-integrated photolysis rate" throughout the document. This will make more sense to the reader. Also, change the axis labels in Figure 7 and Figure 8 accordingly.
Fixed, the term "transfer velocity" is changed to "depth-integrated photolysis rate" within this manuscript as stated earlier.

P8625, L2: velocities to velocity
The term "transfer velocity" is changed to "depth-integrated photolysis rate" and so now changed to "depth-integrated photolysis rates"

8625, L8 and L10: factor should be factors, or add 'a' in front of factor
Fixed, changed "factor" to "factors"

P8625, L11: snowpack to snowpacks
Fixed, changed "snowpack" to "snowpacks"

General comment: In section 3.3., Figures 7 and 8 need to be introduced and described in more detail.

Introduced Fig 7 & 8 in Section 3.3.

"The correction was evaluated by comparing the depth-integrated photolysis rate coefficients computed by the RT method, vTUV, to depth-integrated photolysis rate coefficient approximated by ze method, v_{ze} , and the corrected depth-integrated photolysis rate coefficient by ze method, v^{Corr}_{ze} , for all four species at twenty different solar zenith angles of snowpack BaseC (Table 3) using "windpack and cold polar" snowpack correction factors and results are shown in Fig 7. For evaluating the "melting and clean" snowpack correction factors, snowpack Scatt2 (Table 3) was used and results are shown in Fig. 8. The corrections factors for the NO-3 photolysis rate coefficient were also tested against snowpacks HULIS1, HULIS8 and Comb (Table 3) too."

Tables and Figures:

Table 2: Meusinger et al., 2014] and Zhu et al., 2010 also report quantum yields for NO3- photolysis. The use of the Chu and Anastasio, 2003 quantum yield should be justified or additionally sensitivity studies should be performed using the reported quantum yields from these two studies.
The quantum yields of the chemical species discussed here are all independent of wavelength and thus Q is independent of quantum yield used, i.e.

$$Q = \frac{\int J(z)\, dz}{J(z_0) \int e^{-z/z_e}\, dz}$$

$$Q = \frac{\iint \sigma \Phi I\, d\lambda\, dz}{\int \sigma \Phi I\, d\lambda \int e^{-z/z_e}\, dz} = \frac{\Phi \iint \sigma I\, d\lambda\, dz}{\Phi \int \sigma I\, d\lambda \int e^{-z/z_e}\, dz} = \frac{\iint \sigma I\, d\lambda\, dz}{\int \sigma I\, d\lambda \int e^{-z/z_e}\, dz}$$

A sentence has been included in the paper
" The quantum yield used in the study presented here are independent of wavelength, λ, and depth, z. Thus the values of Anastasio, 2003 could be replaced by values of Meusinger et al. , 2014 or Zhu et al. , 2010 and it would make no difference to the results presented in this work."

Table 3 and 4: Why doesn't H2O2 have a, b, and c coefficients?
The parameterization of nitrate and hydrogen peroxide were considered together as the peak in the action spectrum for both species is the same, 321 nm. For clarification, new coefficients for nitrate and hydrogen peroxide were calculated separately and listed in Table 3 & 4. However, the R^2 remain the same with the newfound coefficients compared to previous calculated coefficients.

Figure 1: -Why is the wavelength 451 nm used for comparison instead of a more photochemically-relevant wavelength (such as from 298-345nm)?
Actinic flux profile at 451 nm was plotted instead of more photochemically relevant wavelength is to emphasis the enhancement/ faster than exponential decay in the near-surface layer.
-Is the snowpack typically for polar regions or for other regions too?
Added description of the "typical" snowpack, now reads "cold polar snowpack"
-angle should be plural

Fixed, change "angle" to "angles"

Figure2: -The red line description is missing in the figure caption
Fixed, added the missing caption

Figure 3: It might be helpful to give each of these scenarios a name (e.g. like you've done for BC128 on Figure 4). Right now it's hard to extract information from the figure. It would be effective to use the same color but different line style for similar runs that are slightly different. For example, instead of having dark blue, dark green, and black represent different densities but otherwise same BC and scattering, you could have these lines all be dark blue but vary the line style – e.g. one solid, one dashed, one starred.
Fixed.

Figure 4: -Purple doesn't need to be capitalized
-It would be helpful to add a line on the two left plots that distinguishes which SZA leads to the ze method underestimating with respect to the RT method compared to leading to overestimates.
The original Figure 4 has taken out from the manuscript.

Figure 6: -The caption suggests that the transfer velocity is being plotted, but it looks like it is the photolysis rate constant that is being plotted instead. The second sentence should describe what the different colored lines are to orient readers. -I don't understand or see from the plot what the second sentence of the caption is getting at or referring to.
Caption for Fig 6, now reads
"Photolysis rate coefficient for the NO^{-}_{3} anion (a & d), the NO^{-}_{2} anion (b & e) and NO_2 (c & f) computed by TUV (solid line) and z_e method (dashed line) at two different solar zenith angles, θ, at 0° (top row) and 66° (bottom row). Maximum and minimum depth-integrated photolysis rate ratio occurred at $\theta = 0^{\circ}$ and $\theta = \sim 66^{\circ}$ respectively. Blue is the "melting snow", Scatt2, ($\rho = 0.4$ g cm^{-3}, [BC] = 4 ng(C) g^{-1} and $\sigma_{scatt} = 2$ m^2 kg^{-1}); Black is the "heavily black carbon polluted snow", BC128, ($\rho = 0.4$ g cm^{-3}, [BC] = 128 ng(C) g^{-1} and $\sigma_{scatt} = 25$ m^2 kg^{-1}); Magenta is the "BaseCsnow", BaseC,(ρ=0.4gcm^{-3},[BC]=4ng(C)g^{-1} and σ_{scatt}=25m^2kg^{-1});and Green is the "HULIS polluted snow" HULIS8 ($\rho = 0.4$ g cm^{-3}, [HULIS] = 8 ng g^{-1} and $\sigma_{scatt} = 25$ m^2 kg^{-1}). Surface (depth = 0 cm) values of photolysis rate coefficient from "RT method" and "z_e method" are the same (see Eq. 8 for calculation of J_{TUV}).

-For the Scatt2 case, shouldn't the density of melting snow be higher than the standard case? It looks as though you account for changes in grain size though by lowering the scattering cross-section.
In our previous works with TUV we do not explicitly calculate σ_{scatt} based on grain size but fit field data (albedo and e-folding depth) by varying σ_{scatt} and σ_{abs} to find unique match to field measured albedo and e-folding depth. A fine grained snowpack will have a large value of σ_{scatt} and vice versa – this was explored in details in Marks and King, 2014.

-There are several sentences in this caption that describe results of the figure. These sentences belong in the part of the main text where Figure 6 is introduced and described.

The sentences describing the result in the caption has been removed.

Figure 7 and 8: make angle plural. In Figure 7, the last two sentences can go into section 3.3. The R squared sentence can go into section 3.3 instead of the caption in Figure 8.

Fixed. The sentences describing the result in the caption has been removed.

Reference

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