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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Divergence of sun-rays by atmospheric refraction at large solar zenith angles" *by* R. Uhl and T. Reddmann

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(A) First, for the sake of clarity, we point out a mistake on page 2042 line 4: the unit of alpha is 1/km, not km (this originates from the EGU Production Office).

(B) Response to both referees concerning the part of the spectrum

As will be noted in the final revised version we focus on the visual part of the spectrum, according to DeMajistre et al. (1995) and Trentmann et al. (2003); important absorbers here are for example O3 and NO3. 550 nm is representative for refraction in this range. Moreover, we will add Fig. 9 which is the same as Fig. 7 but for 400 nm. For even smaller wavelengths the portion of the diffusive part of the radiation field increases in the lower stratosphere, and the refractive effects become less important.

(C) Response to both referees concerning the extension of the solar disc

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Both referees rise the question if the finite size of the solar disc and its oblateness for the deep sun could influence the results. First, one must separate the two effects: divergence and altered optical thickness. For the last effect, it is obvious that for large taus there will be also a large delta tau. Everebody can realize how the sun is absorbed at her lower limb when she is setting. But the maximum effect will be of the order of an offset of 0.25 deg lower SZA (half) the solar apparent diameter) compared to the center of the disc. Despite this question obviously should be of primary concern for all calculations considering refractive effects by differential absorption (and not just ours) we think that this maximum difference is tolerable for most applications. Nevertheless, the last paragraph of Sec. 4 has been extended to give bounds for the changes in Figures 6, 7 by including the sun's size.

For the divergence effect we first state that the assumption of a punctiform sun (not withstanding the averaging error over the disc) should generally be sufficient to describe geometrical optical effects. Our treatment is also valid for star occultations. We add that the divergence is also the reason for stellar scintillation. The speculation of Referee#1 that there may be a focussing effect, which changes the apparent intensity (W/sterad/mˆ2) of the solar disc, contradicts the well-known "conservation of etendue"; see for example M. Bass (ed.), Handbook of Optics 2nd ed., Optical Society of America, 1995 (Section 1.6).

Thus a formulation by means of the apparent size and shape of the (small) solar disc is equivalent to our representation.

(D) Additional response to Referee#1

In the final revised version the other specific points will be taken into account as follows:

2. The explanation to Eq. (1) has been extended, and we justify that the constant a is the distance of earth's centre to the unrefracted ray. The main part of our calculations is to solve the initial value problem and the fixed point equation in 2.3. Since both numerical problems are very common, we have left out further details. However, our

ray tracing calculations can be checked by means of Fig. 3 showing the refraction induced decrease of altitude. At Fig. 3 we will note in addition that refraction increases the solar zenith angle of the terminater by epsilon = epsilon_max / 2. This can be considered as another check as this gives the very well known numerical value of about 0.6°.

3. The explanations of Figures 3, 4, 6 has been extended.

4. The description of divergence has been extended, using the phrase "direct (normal) irradiance", and the reference to Born and Wolf (1980) (3.1 Eq. 31) has been inserted.

5. The data for extinction at other wavelenghs has been inserted.

Interactive comment on Atmos. Chem. Phys. Discuss., 4, 2037, 2004.