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Interactive comment on “On the variability of the Ring effect in the near ultraviolet: understanding the role of aerosols and multiple scattering” by A. O. Langford et al.

A. O. Langford et al.

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Reply to Anonymous Referee 2

We would like to thank the reviewer for his helpful comments on this paper. We have considered his suggestions (shown in *italics*) and have made the indicated revisions (normal type) to the manuscript.

Specific comments:

2. Measurement techniques

It is not easy to visualize the “daisy” pattern. Is this important to one’s understanding of the setup? Perhaps this detail is not necessary.

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P10157, L4: The term “daisy” pattern is clarified in the text. It isn’t necessary to visualize the pattern in order to understand the paper, but the information might be useful to other experimenters familiar with the term.

Is there any internal scattering from the Hg/Ar calibration lamp leading? This could lead to a filling in of Fraunhofer lines. Perhaps the authors could quantify this by measuring the intensity of the lamp at wavelengths far from any lamp emission lines (with no second input from sky or sun).

P10157, L22: The line “Any internal scattering from the Hg/Ar lamp near 350 nm is less than the noise level of the detector.” has been inserted.

A reference for the lack of fluorescence of PTFE at 344 nm should be given since only the direct solar measurements used the plate. Heitz et al. studied the weak visible fluorescence of PTFE with 514 nm excitation [Appl. Phys. A 69 [Suppl.], S467-S470 (1999)].

P10157, L25: The following more applicable reference supporting the lack of PTFE fluorescence has also been added.

Li, Z., Shaw, P.-S., Arp, U., Yoon, H., Saunders, R. D., and Lykke, K. R. (2006), Characterization of integrating spheres for ultraviolet radiometry, paper presented at Sixth Workshop on Ultraviolet Radiation Measurements, Davos, Switzerland, 28 October 2005.

The sentence “Forward scattered light . . . was shown to be negligible by measuring the change in intensity when the telescope tracking was switched off” leaves it up to the reader to figure out how the intensity changed as the sun moved out of the field of view (FOV). I assume the measured intensity dropped off significantly when the sun left the FOV. This should be stated explicitly.

P10157, L28: we have changed the sentence to read: “Forward scattered light from the solar aureole was shown to be negligible by the

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$>10^3$ decrease in intensity when the telescope tracking was switched off and the sun drifted out of the field of view."

ACPD

The term "global component of solar irradiance" is not one with which I was familiar prior to reviewing this paper. I suggest "total irradiance", the term used by Michalsky et al. (2001).

P10158, L10: "Global irradiance" has been replaced by "total irradiance"

3. Measurement results

The SZA range was restricted to <70 deg. Are the measured intensities at SZA=79 deg so small that uncertainties go from being negligible at SZA=70 deg to being non-negligible? Including the SZA range of 70-80 deg would provide an interesting test of the authors' ability to simulate the effects of aerosols.

P10159, L2: Agreed. Unfortunately, measurements were not made at higher SZA to avoid the effects of O₃ and O₄ absorption.

HOW WELL DOES A SCALED SINGLE SCATTERING RING SPECTRUM FIT THE OBSERVATIONS? You are in the position to answer this question and it would be valuable to contrast the single and multiple scattering Ring spectra.

P10159, L? At our resolution, the double scattering Ring spectrum is very similar to the single scattering spectrum but about a factor of two larger. Differences would only become apparent at much higher resolution. The unscaled Ring in Figure 7b is the single scattering spectrum.

"These measurements provide the first explicit demonstration of this phenomenon in radiance spectra that can be directly related to DOAS measurements." The authors have overlooked the work of Karkoschka [Icarus 111: 174, 1994] who clearly showed the filling in of Neptune and Uranus to be greater than Jupiter and Saturn and related it to the stronger contribution by aerosol scattering for the latter planets. That study relied on optical absorption spectroscopy to investigate, for example, the possible existence of water vapour in Jupiter's atmosphere. The authors should remove their claim of a

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"first" here.

P10159, L23: We were unaware of the work by Karkoschka. "First" claims are often problematic, particularly in a field of research as storied as the Ring effect. We had hoped to temper ours by including the admittedly ambiguous word "explicit", and by confining the application to DOAS measurements. In any event, such claims rarely serve any useful purpose and we agree that it is best to remove it entirely.

The authors should add the word "simply" in the blank to "calculated. . . from the Rayleigh phase function normalized" so that the reader is clear that there are no RTMs used up to this point in the paper.

P10160, L3: "calculated . . ." The word "simply" has been added as suggested.

4. Model descriptions

". . . from a forward Monte Carlo model developed by one. . ." - Refer to the model description paragraph which follows later in the section.

P10161, L3: The sentence has been changed as suggested.

"it does not appreciably change the shapes of the Fraunhofer lines. . ." -The shape of the lines are changing, it's the shape of the filling-in which is relatively constant between first and second order scattering.

P10162, L4: Agreed. The line has been modified as suggested.

"Molecular parameters are taken from Sioris and Evans (1999)." -The appropriate reference for molecular parameters is:

Sioris, C. E., The filling in of absorption lines in sky spectra due to rotational Raman scattering, Ph. D. thesis, 135 pp., York Univ., Toronto, May 2001.

and/or

C. E. Sioris and W. F. J. Evans, Impact of rotational Raman scattering in the O₂ A band,

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The second reference has been added to the paper.

What simplifications have been made in your single scattering model relative to the one using the approach of Sioris et al.? Is it mostly in the way the Raman shifting is handled?

P10161, L2-L8: Our RRS model is very similar to that described by Sioris and Evans (1999) and uses the molecular parameters given in that paper. This has been more explicitly stated in the paper and the reference to Sioris and Evans (2000) has been added.

The description of the RRS model is slightly lacking, forcing most readers to try to understand why binning is done when the spectrum has already been interpolated to the pixel center wavelengths. After the sentence on binning, you could simply add a sentence such as: "The binning is required for the computation of inelastic scattering component to determine the pixel in which the Raman shifted light falls."

P10161, L9: The suggested sentence has been inserted.

"These phase functions are essentially independent of wavelength" -The phase functions listed in Eqns 1-2 are completely independent of wavelength, as they are only a function of scattering angle. Phase functions for Rayleigh scattering that include part or all of the rotational Raman band have a weak wavelength dependence (far from resonant frequencies).

P10161, L22: The word "essentially" has been removed.

"Since only one of the scattering angles is constrained" -Change "constrained" to unconstrained" so that similarity of SZA dependence between single and double scattering intensity is explained.

P10161, L26: The word "constrained" has been changed to "unconstrained" as sug-

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gested.

Citing “Health” is insufficient. The web address should be inserted into the text, according to EGU citation guidelines.

P10163, L6: The cited URL has been inserted into the text.

5. Model results and comparison to measurements

“This expression assumes that scattering orders greater than two are unimportant”. -change to e.g. “. . . that double molecular scattering is sufficient”.

P10164, L12: “This expression assumes. . .”. The sentence is revised as suggested.

“. . . RRS model of Sioris and Evans” The appropriate reference for this model is: C. E. Sioris, W. F. J. Evans, R. L. Gattinger, I. C. McDade, D. Degenstein, E. J., Llewellyn, Ground-based Ring effect measurements with the OSIRIS DM, Can. J. Phys., 80, 483-491, 2002.

P10165, L9: The reference has been appropriately revised.

“The scattering angle dependence of FI2 . . .” A reference to: C. E. Sioris and W. F. J. Evans, Modeling higher order radiation fields using iterated integrals of phase functions, J. Quant. Spectrosc. Radiat. Transfer, 72, 227-236 (2002). and/or a polar plot of the angular dependence of FI2 would be useful here.

P10165, L15: The suggested reference has been added.

6. Implications for DOAS retrievals

It is somewhat surprising that including NO₂ absorption does not improve the fit between 305 and 365 nm.

p10167, L8: The line “The zenith and direct sun spectra were deliberately chosen to minimize the differential absorption by other species in order to emphasize the Ring contribution. . .” has been added to the text.

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Near Eqn. 5, the following work should be cited: Liu, X., K. Chance, C. E. Sioris, R. J. D. Spurr, T. P. Kurosaki, R. V. Martin, and M. J. Newchurch (2005), Ozone profile and tropospheric ozone retrievals from the Global Ozone Monitoring Experiment: Algorithm description and validation, *J. Geophys. Res.*, 110, D20307, doi:10.1029/2005JD006240.

p10168, L3: The suggested reference does not seem appropriate here.

There are at least two previous studies on the impact of clouds on Ring effect. In the final paragraph, you could acknowledge this with a reference to, for example: R. de Beek, M. Vountas, V. V. Rozanov, A. Richter, and J. P. Burrows, "The Ring Effect in the cloudy atmosphere," *Geophys. Res. Lett.*, vol. 28, pp. 721-724, 2001.

P10171, L4: Three references to cloud effects were added here.

Technical corrections

Rotational -> rotational (although others have capitalized as you have)

We seem to have used both capitalized and uncapitalized versions. We have standardized on the former as suggested.

3. Measurement results

"Rayleigh scattering contribution calculated from the Rayleigh phase function" -change "from" to "using"

P10160, L3: This sentence has been changed as noted above.

"The calculated FI are. . ." -> "The FI observations are. . ." "calculated" sounds like a model calculation but you are referring to your measured FI here.

P10159, L9: "The calculated" has been changed to "The measured"

4. Model descriptions

". . .and the average weighted by the level density." -Insert "is" between "average" and "weighted".

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p10161, L14: The sentence has been changed as suggested.

5. Model results and comparison to measurements

“...scattering results from. . .” -> “model results from. . .”

p10164, L14: changed as suggested

“. . .when the aerosol scattering phase function is large.” -> “. . .when aerosol scattering is most intense.”

p10165, L22: changed as suggested

6. Implications for DOAS retrievals

“NE” -> “northeast”

p10169, L8: changed as suggested

Figure captions

Include SZA and indicate am or pm.

Done!

Figures

Figure 2. The colour of the crosses should follow the same day-based colour scheme as is used for FI, so the reader isn't left guessing.

Using the same color instead of black makes the crosses disappear into the FI data points. We added the word “superimposed” to the figure caption instead.

Figure 3a. Exponents on the y-axis are not legible.

The figures have been reformatted to improve legibility and will be made larger in the final published version.

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