Author replies are shown in blue
New text is shown in red

Anonymous Referee #3

Wagner et al. describe methods for characterization of instrumental effects on DOAS retrievals. The analysis uses a novel long-term record (30 years) of spectra from the Kiruna station in northern Sweden. The manuscript is well written and describes important instrumental effects that should be considered for retrievals of trace gas slant columns from ultraviolet absorption measurements. The manuscript fits well into AMT and I would recommend publication. Below are some general comments on the novelty of key findings, a few topics that the authors should consider, and some small technical fixes.

The manuscript shows that:
The Ring effect (atmospheric Raman scattering filling intensity dips in solar spectra) broadens the instrument spectral response function (ISRF) as measured by fitting of observed solar spectra.
As the Ring effect is enhanced by clouds, the authors suggest cloudy spectra should not be used to determine the instrument spectral response function (ISRF). Authors also show that there is a seasonal variation due to albedo, which enhances ring effect in winter at this high latitude location.
Interestingly, for retrievals of trace gas slant columns of primarily stratospheric absorbers, such as BrO (at this inland location), convolution with the Ring-effect-broadened ISRF appears better because the Raman scattering happens after the absorption by BrO in the stratosphere. However, retrievals lower in the atmosphere may be affected.
The use of convoluted high resolution solar spectra as "Frauenhofer" reference spectra (FRS) is used to develop methods to determine instrumental light throughput and its wavelength dependence, which can improve trace gas retrievals.
The authors make good suggestions for how future researchers can use this information, assisting the DOAS community in consideration of bandwidth effects in DOAS retrievals.

Many thanks for the positive assessment and helpful comments, which we all addressed as outlined below.

Broader points for consideration:
Lines 326-328. In this section, the authors argume that the filling in of the spectral dips by Raman scattering happens after trace gas absorption in the stratosphere and before detection, therefore, the appropriate ISRF is the one including the added width from Raman scattering. This is reasonable, but one point of evidence is that the retrieved BrO summertime values are "unrealistically low". Can there be a citation or more explanation of why the higher summertime BrO values should be accepted?
We changed the text to: 'In contrast, for the analyses using the ISRF from the Raman-corrected spectrum, inconsistent results are found. Moreover, during summer, the BrO dSCDs are found to be very low, not in agreement with model results (e.g. Sinnhuber et al., 2002).'

Also in this section it was not clear if single values of the FWHM used for the full year in the Figure A6 analysis. Can the authors improve clarity on how the ISRF is used in this analysis?
We added the information to the text that the ISRF used for the analyses were derived from the KFs of the spectrum from 06 September 2002. And that these sets of reference spectra were used for the analysis of the whole year.

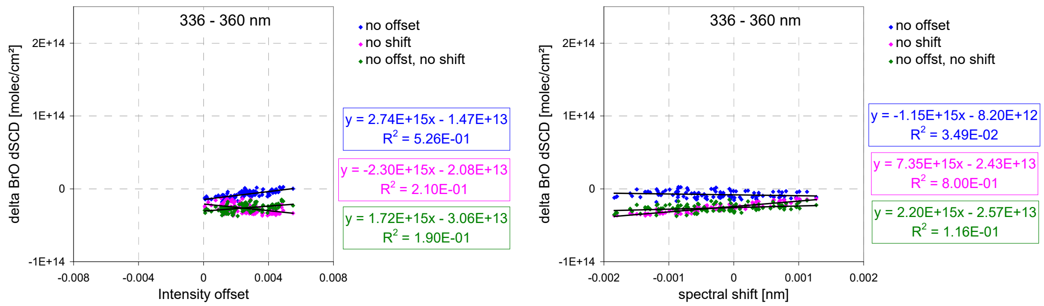
Line 341. The authors say "varying ISRF gives the more exact results". Do they mean more "accurate" (closer to truth) or more "precise" (smaller variability)?
We replaced 'exact' by 'accurate'

Line 393. The first sentence seems to describe the RSP, but it is not clear. Can "the values" be more clearly defined in this sentence?
'the values' was replaced by 'the values of the fitted intensity offset and the RSP'

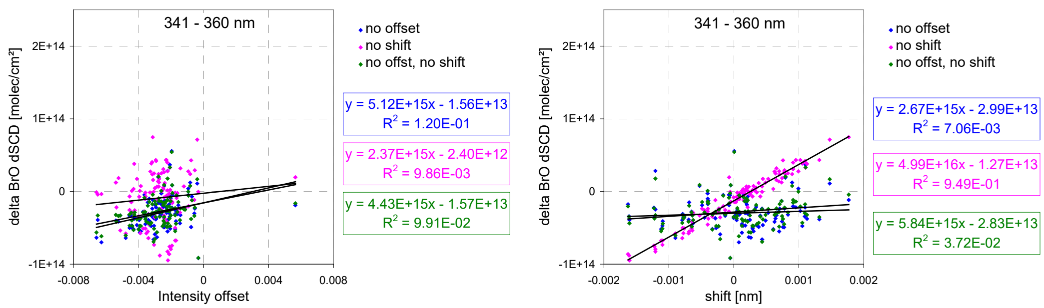
About line 515, it says that the nonlinearity from allowing a shift is the cause of errors in the BrO retrieval. Does giving some constraint on the shift suppress this effect? Is the variation in the dSCD correlated to the fitted shift?
We investigated these dependencies in more detail and added the new Fig. A10 to the Appendix. The following text was added (or original text changed) at the end of Sect. 4.3:
'The effect of excluding the free spectral shift or intensity offset in the DOAS analysis was further investigated. For that purpose, different DOAS analyses of the original spectra (no etalon correction applied) were performed for two weeks in May 1998. BrO dSCDs were retrieved with either no intensity offset allowed, no shift allowed, or no intensity offset and no shift allowed. The corresponding deviations from the results of the standard analyses (with shift and intensity offset allowed) are plotted versus the shift or intensity offset obtained from the standard analysis. The corresponding results are shown in Fig. A10. Systematically different results are found for the different fit windows indicating that each fit window is affected in a specific way by the respective part of the etalon modulation. The smallest deviations are found for the largest fit window, which contains most spectral information. Except for the smallest fit range, the largest differences from the standard analyses are found if no spectral shift is allowed, and these differences are correlated with the spectral shift. Similarly, if no intensity offset is allowed, the differences are correlated with the intensity offset. The systematic dependence on the spectral shift is similar to the so-called tilt effect (e.g. Rozanov et al., 2011; Lampel et a., 2017, and references therein), but the influence of the Fabry–Pérot etalon effect on the DOAS analyses is more complex. In contrast to the monotonic tilt effect, it causes periodic structures affecting different parts of the fit windows in opposite ways.'

Dependence on the intensity offset   Dependence on the spectral shift

336 – 360 nm



341 – 360 nm



345 – 360 nm

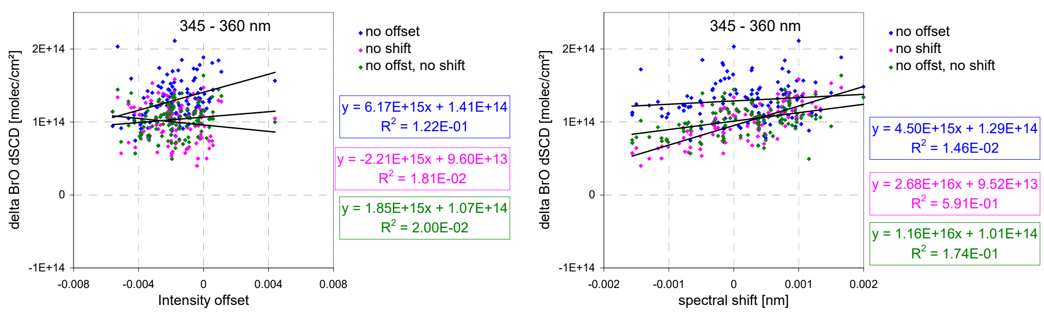


Fig. A10 Correlation plots of the deviations of the BrO dSCDs from those of the standard analyses if the free fitting of a spectral shift, intensity offset, or both is deactivated versus the spectral shift (right) or intensity offset (left) derived from the standard analyses.

The derived shifts are rather small and in the range of typical shifts applied in DOAS analyses (caused e.g. by the tilt effect or instrument effects). But even for such small shifts, the difference to the standard analysis can be rather large. Thus we see no way to constrain the shifts in a meaningful way.

Typographical errors:
Line 61. Replace "ist" with "is"
corrected

Line 87. I'd say "located within the polar vortex"
corrected

p9, line 189. FWHM starts to increase after 2023 -- why is this?
The reason for that change is unclear. Unfortunately, no atomic line lamp measurements during that period are available. We added this information to the text. During the next visit at the measurement site (hopefully in 2026), atomic line lamp measurements will be performed.

Line 207. Has a typo, which should say "On that day of the year..."
corrected

Line 208. Define FRS.
definition was added

Line 252. I think it should say "a similar monotonic increase of..."
corrected

Line 279. Doesn't the RSP vary with wavelength? The figure cited uses 340nm RSP, which should probably be mentioned. Possibly what matters is weaker wavelength dependence of the Raman / Rayliegh ratio. Can the authors comment?
While addressing this comment, we recognised that the wavelength for the RSP simulation stated in the text and the figure (340 nm) was wrong. The wavelength was replaced by the correct value (350 nm).

To illustrate the wavelength dependence of the RSP (together with its dependence on the surface albedo and aerosol load), we added the new Fig. A6 in the Appendix (see below).
The following text was added to the last part of Sect. 3.3: 'The strength of the Ring effect increases with decreasing wavelength (see Fig. A6). Thus, its effect on the FWHM derived from the KF in the visible spectral range is smaller than for the examples discussed in this study.'

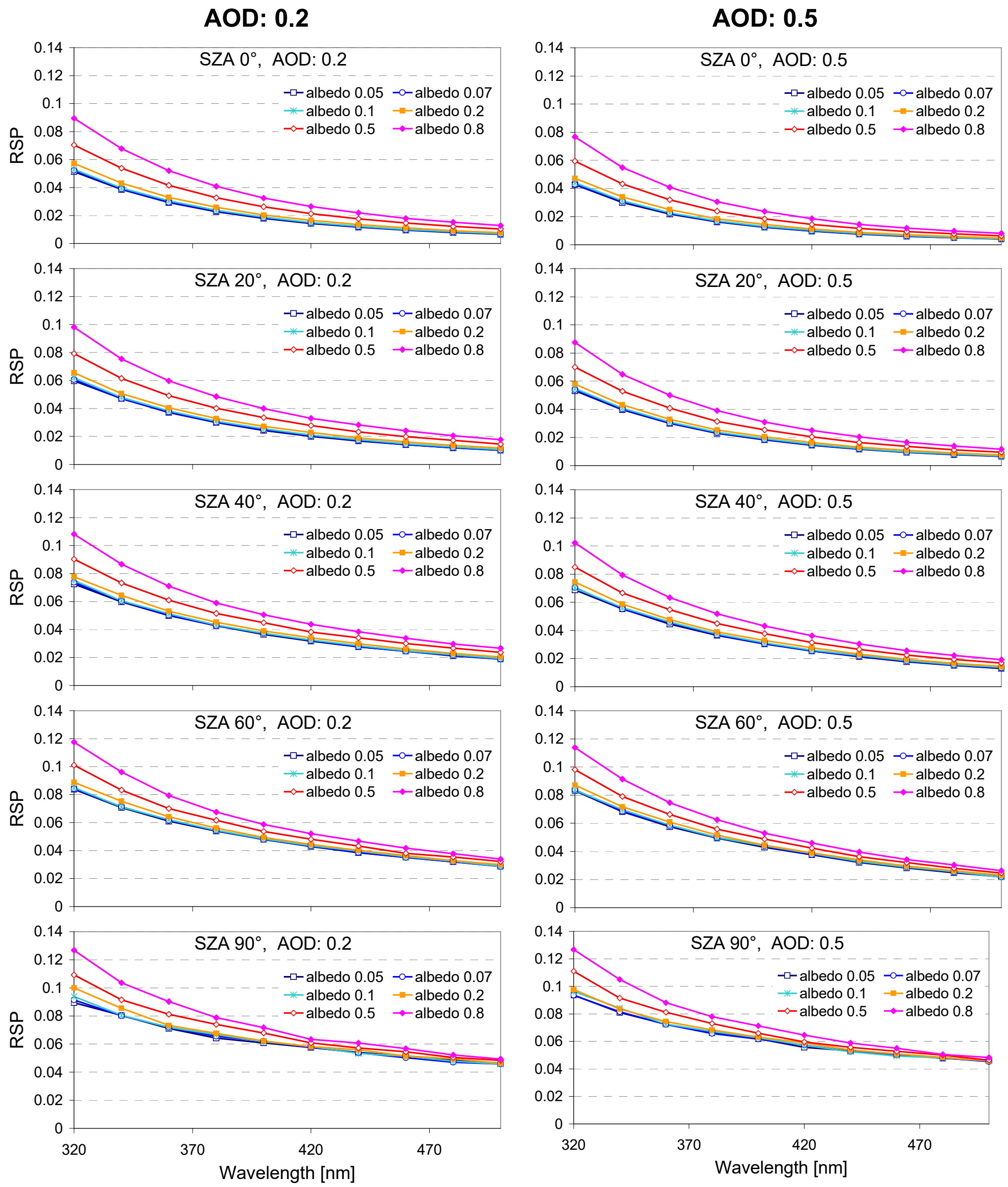


Fig. A7 RSP as function of wavelength for different surface albedos SZA and AOD derived from radiative transfer simulations with the radiative transfer model MCARTIM (Deutschmann et al., 2011). The aerosol profile is assumed as box-profile from the surface to 1 km. Single scattering albedo and asymmetry parameter are set to 0.95 and 0.68, respectively.

Table 2 should mention the unit (nm).
the unit was added

Figure A6 says "with Raman" and "without Raman", but I think "without" is Raman removed, which is a bit different because the Raman was calculated and removal might not be perfectly correct. The x axis should also probably be "date" rather than "time", possibly specifying dd.mm.yy
corrected

Line 399. The word "might" has a missing "t".

corrected

Line 519. Should say "which is monotonic with wavelength..."
corrected