

Interactive comment on “Odin/OSIRIS observations of stratospheric NO₃ through sunrise and sunset” by C. A. McLinden and C. S. Haley

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Received and published: 2 July 2008

Author responses begin with "AU:".

It's a pity because the first one is rather a technical issue which could be much better demonstrated validating the ozone profiles retrieved at large solar zenith angles. The latter has much larger scientific importance and would conform much better with the title of the paper. So, I think, besides technical details described in my specific comments below, authors need to reconsider the weighting of the paper goals in the abstract and the conclusions focusing more on the scientific importance of NO₃ observations.

AU: Fair enough. This has been done, although I would argue that the "discovery" of valuable information at these large SZAs is somewhat of an unexpected surprise

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and simply this realization is very valuable in its own right. Furthermore, it should be noted that the fitting of the slant columns is just an intermediate step to the retrieval of NO₃ vertical distributions. Thus, taking into account that the vertical profile retrieval for photochemically active species is not quite straightforward, possible ways how to do the next step, i.e., the profile retrieval, need to be discussed at least schematically.

AU: A brief sketch of how this might proceed has been added at the end of the conclusions.

Specific comments: 1. Page 5903, Fig 1: It would be useful to show the nighttime profile and the shadow height at each solar zenith angle.

AU: This has been done, as suggested.

2. Page 5903, Fig 1: "At SZA of 95.5_ altitudes above _25 km are directly illuminated (neglecting refraction)" - an estimation of the illuminated altitude without refraction is not meaningful.

AU: This statement has been removed.

3. Page 5903, line 6: "At the onset of sunrise (SZA=97.8_)" - how the "onset"; of the sunrise is defined? Which altitude is illuminated at specified SZA?

AU: This has been altered slightly and clarified to SZA of 97 and an altitude of 50 km.

4. Page 5903, line 11: ".. due to the time constant of Reaction (R1)" - please provide an estimation for the time constant.

AU: About five minutes at 40 km; now included.

5. Page 5903, lines 14 -16: "Stellar and lunar occultation ... most recently with GO-MOS"; - this is correct for the stellar occultation but not for lunar, where SCIAMACHY and SAGE III retrievals should be cited as "most recent".

AU: Changed.

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6. Page 5903, line 22: "off-axis zenith technique" - conflicting attributes. "zenith"; - means that the instrument looks vertically upwards (elevation angle 90°) and everything which is not "zenith" is commonly referenced as "off-axis";.

AU: Corrected.

7. Page 5903, lines 25 - 27: "The fitting window 590-680 nm was selected over the more common 640-680 nm window as the additional pixels increased signal-to-noise and reduced correlations with other absorbers, particularly ozone." - the spectral points below 610 nm are quite noisy and contain no additional NO₃ information, so it is not obvious that adding pixels between 590 and 610 nm one really increases the signal to noise ratio. This statement has to be justified in any way. Moreover, looking in page 5906 one sees that this additional spectral range seems to be responsible for the negative bias in the fitted slant columns: "This was determined to be an effect of using the wider fitting window that includes the peak in the ozone absorption at 603 nm. That is, increasing the short wavelength end of the fitting window to, e.g., 610 nm, eliminates this feature". So, please, give the reasons why you do not want to get rid of the bias skipping "unnecessary"; spectral points. The statement about "reduced correlations with other absorbers" would be more convincing when supported by the plots (all other absorbers and pseudo-absorbers).

AU: See the discussion for point 8, below.

8. Page 5904, line 27: "The two spectral windows give very similar SCDs" - which two windows? 590 - 680 nm and 640 - 680? If yes, that means that the "correlations with other absorbers" mentioned above do not play any role, right? Furthermore, if the SCDs from these two regions (i.e., including and excluding the ozone peak at 603 nm) are similar, the explanation of the negative bias given at page 5906 (as mentioned above) is wrong.

AU: Based on these comments and those of the other reviewer, we decided to re-examine the issue of the spectral fitting window. It was determined that the negative

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bias could be removed using the 610-680 nm fitting window, which avoids the ozone absorption maximum at 603 nm. This compromise still contains the two large NO₃ absorption features, and leads to only a small increase in fitting residuals. The SCDs derived in this way appear to be very similar to those using the 590-680 nm window but slightly larger where the negative biases used to occur.

9. Page 5905, cross sections: why did you select 230 K to scale the NO₃ cross sections to? As follows from Fig. 5 the temperature variation of 20 K is not unusual in the stratosphere. So, why should it be scaled at all and why not to, for example, 220 K (as ozone), 202 K (as NO₂) or 243 K as H₂O? How strong is the dependence of NO₃ cross section on the temperature?

AU: The cross-sections were scaled from the temperature at which they were measured; 293 K, to a generic temperature more appropriate to middle stratosphere - 230 K. This scaling is a ~10% effect. The different temperatures for the different cross-sections are based on the temperatures they were measured. In each case the temperature that is most representative of "stratospheric"; temperatures was selected, although in cases such as ozone this is a little arbitrary (240 and 220 K are available) but others such as NO₂ (202 and 293 K) it is clearer. True there is temperature variation but there is no straightforward way to account for this in cross-sections used in the spectral fitting so it is common to use a single, "generic" value.

10. Page 5905, line 29: "...SZA bins between 91_ and 97_"; - are these SZAs at the tangent point?

AU: Yes, this was clarified.

11. Page 5906, line 1: "...SZA changes by 0.5_ to 0.8_ over the course of a scan..." - is this a variation of SZA at tangent point? What is the variation of SZA along the line of sight?

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AU: No, this is due to the motion of the spacecraft and the finite integration time. In other words, it is a result of latitudinal smearing. The variation along the line-of-sight is highly dependent on geometry - the observations shown in this work were in fact selected so that SZA variation along the line of sight was a maximum. The variation is 2-3 degrees over a change in altitude of 8 km (along the LOS). This is now discussed in the first paragraph of section 2.

12. Page 5906, Fig 3: error bars need to be shown

AU: Agreed. However, adding them to this figure proved too confusing so they have been plotted separately in a new figure (Figure 4 in the revised manuscript).

13. Page 5906, line 8: "...SZA of 96_ during sunrise abundances are near their nighttime levels..." - neither from Fig 3 nor from Fig 4 is clear what the nighttime level of NO₃ SCDs is. I understand that it is impossible to show the retrieved nighttime SCDs but may be you can plot simulated values in Fig 4.

AU: This is not really feasible since the SZA would be too large.

14. Page 5906, lines 10 - 12: "At a SZA of 93_ there is only a small amount remaining near 12 km and at a SZA of 92_ the SCDs do not differ significantly from zero." - Unfortunately, this is not so nice as described, namely, the SCDs are negative almost in the entire altitude range at 92_ and above 20 km at 93_. So, I think it would be much more fair to say that the retrieval results are not meaningful for solar zenith angles lower than 94_.

AU: With the new fitting window, the original statement makes more sense.

15. Page 5906, lines 12 - 13: "At sunrise there is insufficient signal to obtain SCDs at a SZA of 97_" - please explain why the signal at the sunrise is weaker than at the sunset. According to Fig 1 there should be a lot of NO₃ seen. Does OSIRIS get less light during the sunrise than during the sunset? Why so?

AU: While the SZA at the tangent point may be the same, the overall geometry differs

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due to the orbit and time of year. Specifically, how the SZA varies along the viewing line of sight is different due to the different scattering angle. So the amount of light does differ between sunrise and sunset. Both model and measurements show that the amount of light measured is 3-5 times less at sunrise than at sunset. A line has been added to this effect.

16. Page 5907, lines 17 - 19: "Note that neither VECTOR nor the photochemical model account for refraction. For a geometric tangent height of 30 km and SZA of 94_, refraction reduces the tangent height by about 2 km (e.g., Uhl and Reddmann, 2004)" - So what? You are talking about the tangent height of the direct solar beam which has absolutely no relation to the discussion in the manuscript. What you really need to know is how the illumination of the atmosphere is changes due to the refraction. Namely, the shadow height is lower than the refraction is accounted for, however, the entire illumination is a little bit weaker due to the longer light path. The first effect which, I guess, is more important for your study can be approximated by an effective solar zenith angle at which then all the model simulation have to be done (instead of the geometrical solar zenith angle).

AU: The statement quoted by the referee has been removed. As to the rest of this comment, I believe the reviewer is correct but as this study is only semi-quantitative we feel the geometric SZAs suffice for now.

17. Page 5907, lines 21 - 22: "Overall, the magnitude and behavior with SZA is very consistent between the modeled and observed SCDs." - comparing Fig 3 and Fig. 4 I can not agree that the magnitude and behavior with SZA is very consistent. Yes they are similar but not more.

AU: This was changed to "similar within the caveats discussed", namely the possible reasons for differences" temperature, refraction, etc"

18. Page 5907, lines 22 - 26: "However, there appear to be some differences in the growth of NO₃ after sunset (panel b), with modeled SCDs lagging the observations by

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about 0-0.5_. Likewise, the model calculations seem to be systematically smaller during sunrise (panel a), and lead the observations by 0.5-1" - I think the refraction is the main reason for that because the real illumination of the atmosphere does not match the assumed one. I think the results would look much more similar if the simulations were done for the effective solar zenith angles rather than for geometrical ones. A little bit more mysterious is a quite different behavior of the measured and simulated SCDs at sunset below the maximum. Namely, the measured values are significantly larger. Perhaps authors should think a bit more about how to explain this disagreement.

AU: I am not ready to say that the lack of refraction as the primary error source, especially given the important of temperature as shown in Figure 5 (now Figure 6). Using the effective SZAs may improve the sunrises but may decrease the level of agreement for the sunsets. The addition of refraction to the model is not underway and we feel that use of geometric SZAs suffices for this work. As to the issue of sunset SCDs. I assume that the reviewer is referring to the fact that the modeled values are larger than the observations. With the new fitting window the only SZA at which occurs is 93 and only between 10 and 14 km. Delving into this detail considering some of the potential error sources does not seem worthwhile.

19. Page 5907, Fig 4: I'm a little bit confused by the negative values in simulated SCDs. In absence of errors (either systematic or stochastic) the negative values can only be caused either by a correlation of some fit parameters or by a bug in the fit software. So I would suggest authors to check their retrieval software and reconsider the fitting spectral range to eliminate negative bias at least in the model simulations.

AU: It is believed to be due to a correlation of the fit parameters. In the new fitting window this feature is absent. That is, all model SCDs are >0 .

20. Page 5908, line 15: "the temperature profile is consistent with the SCDs." - This is not completely true. Between 38 and 43 km the temperature in scan 1 is higher whereas the SCDs are smaller. Please explain this.

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AU: This is likely due to the integrated nature of the SCDs. That is, the SCDs represent the NO₃ at the tangent altitude and altitudes above. Thus, one would expect that the cross-over altitude in SCD would be below the cross-over altitude in temperature. This has been incorporated into the text.

21. Page 5908, lines 26 - 27: "Furthermore, the strong temperature dependence suggests the potential to derive atmospheric temperature information as has been successfully carried out using GOMOS data (Marchand et al., 2007)" - this is only true if NO₃ concentration is known or can be easily modeled like nighttime NO₃ in the steady state assumption in the cited paper. This is, however, not the case for a very complex dynamical system during sunrise and sunset. I suggest to remove this sentence from the manuscript.

AU: Agreed. It has been removed.

22. Page 5909, lines 17 - 18: "A logical next step is to test the consistency of OSIRIS NO₃ by finding coincidences with SCIAMACHY, GOMOS, and/or SAGE III occultation measurements." - I do not think that such comparison is possible in terms of SCDs, so the next step should be the retrieval of vertical profiles from SCDs and then the comparison.

AU: It would be difficult and would require modeling to "fill in" missing information. Specifically, if an NO₃ profiles was known at one particular SZA (or local time) then modeling would be needed to map that to other local times. However, the same is true for retrievals. Only a single profile can be retrieved from OSIRIS, but the NO₃ over all range of local times is also required.

Technical corrections: Page 5903, line 13: "Noxen et al." - should be "Noxon et al."

AU: Corrected.

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 5901, 2008.