Reply to T. McElroy's interactive comment

We would like to thank the reviewer, Tom McElroy, for his thorough review. The comments, recommendations, and corrections in this review have lead to a great improvement of the paper.

Referee comments and statements are in bold. Author replies are in italics. Referee line numbers correspond to the initial submitted paper. Author reply page and line numbers correspond to the published discussion paper. Figures are located at the end

General Comments

1. The authors state that only a single-scattering model will be used and acknowledge that shortcoming, but go on to show what they consider to be very good agreement with ozonesondes, etc. This is a little inconsistent, and could perhaps use a little more development.

We find it unsurprising that there is generally good agreement with ozonesondes using a single scattering model as multiple scattering has the largest influence on absolute intensities (i.e. the ratio largely removes tropospheric absorbers / cloudy situations). Also the influence of multiple scattering is most noticeable in measurements at SZAs higher than 86 degrees. We have clarified this by including the following text:

p. 8675, line 12: Added in sentence: "As the N value is a ratio of intensity values that are referenced to the lowest SZA, the offsets due to multiple scattering on the absolute intensities are mostly removed (Hendrick, 2006)"

We have also included appropriate reference in bibliography.

2. One great advantage of modelling every data point has not been included in the paper. It is the possibility of using the agreement between measurements and model observations to flag unreliable data and improve the final profile.

Using the residuals between the measured and modelled N-values to flag unreliable data is an enticing thought. However, we are concerned that if we alter the measurements based on the residuals, with no appropriate reason for doing so, we are no longer retrieving an optimal estimated profile. We wish to capture the full uncertainty of the retrieval, which is done by leaving all outliers in the measurement set.

3. Finally, the authors are making monthly averages of retrieved profiles. This will not remove the content of a priori in the final profile. It would be better to retrieve one profile that best fits all the data so that more observational information will be transferred to the mean profile.

While we agree that retrieving one monthly profile may contain slightly more observational information, both methods will retain a priori information, as is typical of all optimal estimation retrievals. We kept our processing as originally described as it is generally normal practice to retrieve profiles for individual days – then create monthly averages as a post-processing step. For future operational applications we will extend the code to allow both individual days and monthly retrievals.

4. The use of a column ozone constraint could, in some applications, improve the performance in the lower layers.

Adding a total column constraint to the measurement vector is a good idea. However, we don't have coincident total column ozone data for the Umkehr data, so it is not practical in our case.

Technical Comments

Abstract:

1. **Line 2 'coarse-resolution'**

   Done

2. **Line 36 'under represented'**

   Done

Main text:

1. **Line 41 …resolution retrievals… -**

   Done

2. **Line 55 …were done using Northern Hemisphere… -**

   Done

3. **Line 56 … about the Southern Hemisphere ozone … -**

   Done

4. **Line 58 … Delete 'The'**

   Done

5. **Line 65 … that measurements at Darwin …**

   Done

6. **Line 68 … Australian-run sites …**

   Done

7. **Line 76 The retrieved column is constrained by the a priori information, not the other way around**

   The Mateer and DeLuisi (1992) algorithm constrained the a priori by total column ozone that was derived from the Dobson direct sun observations. So we believe the statement in the text is correct. Removing the total column constraint from the a priori information removes the time dependence in the retrieval. This is described in detail in Petrapavlovskikh (2005).

8. **Line 78 … coinciding measurements of total column ozone …**

   Done

9. **Line 79 … time-dependent …**

   Done

10. **Line 80 … long-term trends …**

    Done

11. **Line 82 … variability introduced by the use of the a priori … -**

    Done

12. **Line 95 … Data are not used …**

    Done

13. **Line 96 … and information can be lost if the data are not well represented …**

    Done

14. **Line 108 Delete 'that' –**

    Done

15. **Line 112 Actually, the model can be run at a number of discrete SZAs and interpolated for use. Data cannot be reliably interpolated but model output can. This is also true for the Jacobian used in the**

retrieval. It is just necessary to ensure that the interpolation routine is operating on model points close enough together to be accurate.

We agree that the model can be run at a number of discrete SZAs and interpolated for use. However, as refraction can be solved for the radiative transfer as described in C.D. Rodgers' book (Rodgers, 2000) we do not need to make an approximation to include refraction in the light paths. We have updated the following text clarify this.

p. 8672, line 27. Changed "requires interactive refraction to be built into the forward model" to " allows the use of interactive refraction in the forward model"

16. **Line 116 … Due to this, important components …**

    Done

17. **Line 122 … and it is planned that they be implemented …**

    Done

18. **Line 127 … Instrumental stray light …**

    Done

19. **Lines 151-154 The meaning here is not clear.**

    Thank you, we agree that this statement is unclear. We have changed the following sentence:

    p. 8673, line 25. Changed "The vertically resolved ozone information contained in the measurements is dependent on the sum of the wavelength pair intensity ratio from downward scattered zenith sky radiation for a change in SZA." To "The Umkehr technique measures the ratio of downward scattered zenith sky radiation for each wavelength pair. This is performed over a range of SZA to allow retrieval of vertically resolved ozone profiles."

20. **Line 154 It is the log intensity ratio if it is an N-value**

    Done

21. **Line 155 Suggest ' … due to changes in the mean scattering height…'**

    Done

22. **Line 175 'consitutes'?? Suggest "… this leads to …**

Done

23. **Line 177 and 181 ‘turnaround’**

    Done

24. **Line 191 It doesn’t matter which SZA is used for normalization as long as the model is normalized at the same angle. Using the lowest angle makes all subsequent values have the same sign, however.**

    Thank you for picking this up. We have removed the following incorrect statements.

    p. 8675, line 1. Removed: “The lowest SZA is used to ensure minimum information loss within the retrieval. However, this value can vary with different measurements, resulting in a different degree of information loss per measurement.”

25. **Line 195 The amount of information depends on the range of zenith angles and the largest zenith angle included.**

    Please see previous comment

26. **Line 206 Stray light effects increase with the increasing ratio of long-wavelength intensity to short-wave intensity. So as the curve reaches the first Umkehr, the stray-light induced error will be at a maximum. The error will decrease again after that. It will then increase again after the second Umkehr…**

    Thank you, we have amended the following sentence.

    p. 8675, line 9: “Due to the low intensity received at the detector for high SZAs, errors can be introduced due to stray light effects…” to “Due to the combination of low intensities and large intensity ratios received at the detector for high SZAs near the turn around point, errors can be introduced due to stray light effects,…”

27. **Line 209 ‘… Umkehr-derived, long-term…’**

    Done

28. **Line 211, 212 Suggest ‘measurement uncertainties’**

    Done

29. **Line 227 ‘Suggest ‘measurement uncertainties’**

Done

30. **Line 230 ‘Delete ‘database’ at the end of the line.**

    This was a little confusing. We have attempted to clarify it in the text. The binary database of profiles and the vertically resolved ozone database are separate datasets. We have added in “the” to distinguish between the two.

31. **Line 232 ‘…based on that…’**

    Done

32. **Line 268 Perhaps: ’…refracted light paths…’**

    Done

33. **Line 277 ‘…set up…’**

    Done

34. **Line 287 ‘suggest either exp[-t(z)] or e-t(z)’**

    Thank you for picking this up, changed to exp[-t(z)]

35. **Line 434 Suggest ‘turnaround’.**

    Done

36. **Line 538 Umkehr retrievals, the ozonesonde data is convolved by the averaged retrieved C-pair AKs.’ This is not exactly correct. Perhaps the description is not complete. The AK should be used to smooth the difference between the ozonesonde and the a priori profile. Then the smoothed difference would be added to the a priori. This mirrors the way the retrieval works. There is a typo as well.**

    Thank you, we have fixed the typo. The referee is correct, we had incorrectly used the AKs to compare the two datasets as shown in Rodgers (2003). The updated figure included in the paper with the corrections is shown in figure 1, this figure also excludes interpolation of individual missing months and a reduced time series from 1970-1975. We have also amended the following text.

    p. 8684, lines 24-24. Changed: “the ozonesonde data is convolved by the averaged retrieved C-pair averaging kernels” to “the difference between the ozonesonde data and the a priori is convolved with the C-pair averaging kernels, which is then added to the a priori (Rodgers, 2003).”

Included Rodgers reference in bibliography.

p. 8685, line 7. Changed: "and convolving the ozonesondes with the C-pair averaging kernels reduces the variability…" to "Convolving the ozonesondes with the C-pair averaging kernels slightly reduces the variability"

p. 8685, lines 12-14. Changed: "The agreement is best in the un-convolved ozonesonde case, with the convolved ozonesonde case decreasing the layer amount and variability slightly." To "Both the convolved and un-convolved ozonesonde cases are very similar in this layer"

37. **Line 544 '…ozonesonde data are also…'**

    Done

38. **Line 550 '…ozonesonde data were not…'**

    Done

39. **Line 569 Typo in Umkehr –**

    Done

40. **Line 573 highlights**

    Done

41. **Line 577 (supposed to be 677?) 'Div.' (Add period)**

    Done

42. **Line 579 slightly lower ozone**

    Done

43. **Line 580 '…unaccounted-for…'**

    Done

44. **Line 582 'It isn't clear how good ozonesondes are above the maximum if time lags are not corrected for.**

    We do not exactly understand the comment. If the referee is concerned about the time to take ozonesondes measurements, we believe that monthly averaging will remove this.

45. **Line 592 Introducing a column constraint could possibly improve the lower layer performance.**

    Please see specific comment 4.

46. **Line 633 'show poorer agreement'**

    Done

47. **Line 670 'Applied Optics'**

    AMTD editors changed to 'Appl. Optics' during typesetting

48. **Line 685 '…Journel of Terrstrial Physics…'**

    AMTD editors changed to 'J. Atmos. Terr. Phys.' during typesetting

49. **Line 693 Space before comma 'Ozone in the Atmosphere , Proceedings of the Royal'**

    Fixed during typesetting phase.

50. **Line 707 And extra initial 'C' or misplaced comma. 'De Mazierem…**

    Fixed during typesetting phase

51. **Line 715 'Journal of Atmospheric and Terrestrial Physics'**

    AMTD editors changed to 'J. Atmos. Terr. Phys.' during typesetting

52. **Line 718 'Tech. Rep.'**

    Done

53. **Line 761 '2nd edn.'**

    Done

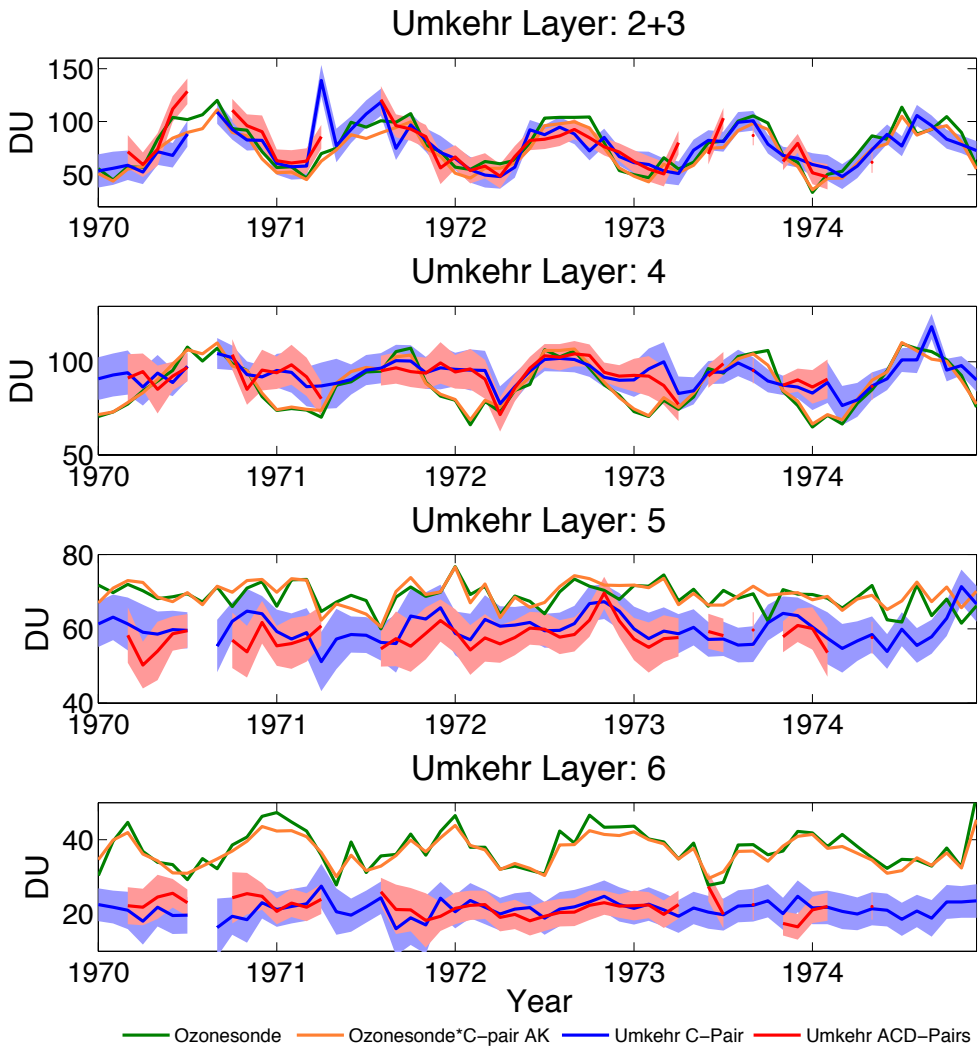

*Figure 1. Updated figure 4 with correct Ozonesonde*c-pair AK.*