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Atmospheric Measurement Techniques
Discussions

Interactive comment on "A new Dobson Umkehr ozone profile retrieval method optimising information content and resolution" *by* K. Stone et al.

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The paper by Stone at al. "A new Dobson Umkehr ozone profile retrieval method optimizing information content and resolution" describes the development of the new algorithm to process data from Dobson Umkehr measurements. In-depth analyses of measurements are presented with the aim to further improve the information content of the retrieval and to reduce noise in the conventional Umkehr ozone profiles. Authors exploit the measurements at three wavelength pairs vs. single standard C-pair approach, make use of all available measurements taken during the Umkehr observation in place of traditional interpolation to the nominal SZAs, extension of measurements

beyond 90-degrees SZA (before the sunrise and after the sunset), and make adjustments to the a priori information. The method involves change to the forward model and development of the refraction correction code to accommodate the use of measurements at the variable SZAs. Among main limitations of the code is a lack of multiple scattering contributions in the zenith sky intensities simulated in the forward model and absence of the stray light corrections. The work is done on the Umkehr method that has been in use since 1930s. There are about 80 reporting Dobson instruments that monitor ozone around the world. Among these there are only about 19 stations that currently report Umkehr ozone profiles. Umkehr ozone profile data had been successfully used for long-term trend analysis and in validation of other ozone datasets. Special attention is paid to the data available prior to the onset of the ozone depletion and before the global satellite ozone profile retrievals became available (before 1978). In this case Australian Dobson data represent very important piece of puzzle that can be provided to the studies of the ozone in the Southern Hemisphere where the early period data are fairly scarce. The approach described in the paper shows potential improvements to the retrieved information, which can help to reduce retrieval noise in the profile (currently up to 25 % in the troposphere), separate ozone information into the vertical columns with less interference from adjacent layers and to extend retrieval sensitivity to 50 km (currently sensitivity to ozone changes above 42 km (2 hPa) is very limited in C-pair Umkehr retrievals). However, several concerns exist about the proposed approach. A demonstration of the stability of the retrieval is needed, as well as implementation of the multiple-scattering and stray-light corrections in the forward model is of the importance for the high quality profile retrievals. This paper presents novel concepts and improvements to the existing Umkehr ozone profile retrieval algorithm, and thus is within the scope of AMT. The manuscript needs several clarifications and adjustments as indicated below before the paper can be published.

Comments: p. 8670, line 13, also on p.8672, line 11 and line 26, 27 (and more in the text) – I would not call these "raw" measurement since N-values are derived from R-values (which are raw measurements) by applying lamp and R-N table corrections.

You can probably call it operational? p. 8675 line 15. Please be aware that the errors were derived for C-pair only from the co-incident measurements between two co-located Dobsons. I expect that the noise in the A-pair might be higher and in the D-pair might be lower, but it needs to be cofirmed. p. 8677, line 16 The lack of the stray light impact on the time series was shown for only C-pair retrieval, it has not been tested for the three pair retrievals or the use of variable number of observations per Umkehr curve ("raw measurements" in your case). The stray light is expected to have the largest effect on the A-pair at large SZAs. Thus, please change "the Umkehr" to "the traditional Umkehr" or (C-pair Umkehr) in the text. One point is worth to make about the stray light effect in time series. It will likely remain the same if the same instrument is in operations for the entire record. However, if the instrument is replaced (see Miyagawa et al, JGR, 2009, DOI: 10.1029/2008JD010658) then the step change can occur in the measurements and in the ozone record. It will be nice to mention in this section if there are any records of the instrument replacements for Australia stations. It could also be helpful to indicate these periods in Figure 4. P. 8677 Equations 6 and 7 Not sure if they are needed here – I did not find a reference to these equations further in the text. If you want to keep it – please include Figure with schematics of the light propagation to the surface with single scattering event and define apparent and local SZA. p.8678, line 18 add reference to Petropavlovskikh et al (2005) and to clarify that in the Umkehr algorithm ca. 2005 the a priori was modified from the algorithm ca. 1992 to remove constrain to the total ozone column. p.8679, lines 4-7, Please clarify how the Sa is constructed. The way I read it now tells me that new Sa is constructed for each profile with the adjustment (scaling) to the diagonal elements based on the L-curve analysis. It might create a better profile, while the time series might have an effect from the variability in the Sa matrix, which can impact the trend analysis. If this is the case, it needs to be mentioned in the text. It is also mentioned on the page 8683, line21 " Sa changes slightly with the season" – may be changes with total ozone as well? This can be checked by using trends analysis on Sa. By changing Sa you are changing the smoothing of ozone profile and the AKs. How much does it impact

the retrieval? p.8680, section 5.1. Figure 1 shows Umkehr data for the clear sky day (very smooth curves). Can you show an example of the day with partial cloudiness and the model fit? One of the reasons for using nominal SZAs (or designated) in the traditional Umkehr retrieval is to be able to preserve some Umkehr measurement while removing cloud-affected points from the fit. Is it something that you are applying as well in the retrieval? It may not be a problem for the fit if outliers are dispersed throughout the entire range of data, but it would certainly be a concern if these points are located at either end of the SZA range (near 60 or near 90 degrees). The effect of the cloud on N-value often results in a constant offset of the Umkehr measurement. If you are using relatively displaced N-value at 60-degrees SZA to normalize the entire curve you may introduce the offset in the retrieved profile. Have you looked into these cases? p.8681 line 2. It would be better to provide numbers to explain term "larger". line 4-5. When matching measurements at SZA larger than 90 degrees, how do you deal with the diurnal changes in ozone in the upper and even middle stratosphere. It takes between 90 to 180 minutes to perform full range of SZAs (depends on the station and season). By extending measurements over 90 degrees the profile retrieval has to account for a strong diurnal effect in order to derive a single ozone profile. Diurnal effect exists in the C-pair measurements, but it is likely more significant in the A-pair as it samples ozone at higher altitudes and thus encounters stronger photochemically driven changes in ozone. Lines 14-16. Can you please clarify what you mean by the statement - "the least smoothing occurs in layer 4" If you calculate the smoothing errors for all layers (Rodgers, 2000, eq. 3.29, or Bhartia et al., 2013, equation 9) – does it show the larges errors in layer 4? (WâĂŤI)*Sx*(W-I)ˆt, were Sx is the natural variability covariance matrix, it is different from Sa matrix that I sused in the retrieval, W is the smoothing matrix W =ãĂŰSKãĂŮ_nˆT ãĂŰ(K_n SK_nˆT+S_e)ãĂŮˆ(-1) K_n (Bhartia et al, 2013, equation 6) Discussion of Figure 3. The vertical distribution of the AKs seems to be unequally weighted – layers 5, 6, 7 and 8 have lower maximum while layers 2+3 and 4 show larger sensitivity in the profile retrieval. This may be caused by applying the "climatological" Sa which is constructed using time series of profiles from

Hassler et al (2009) time series (representative of natural variability in the zonal mean approach). In Petropavlovskikh et al (2005) Figure 1 demonstrates the effect of using uniform vs. climatological Sa. May be this can be mentioned in the paper? Typically, one would prefer to have equally weighted AKs to get vertical information from profile, unless it is preferred to have enhanced sensitivity to the certain part of atmosphere. It is important to make sure that the results presented in this paper as "C-pair retrieval: registered SZA" are not mistaken with the retrievals from Petropavlovskikh et al (2005). It would worth to add a sentence to clarify this point. lines 21-22 – In comparisons between AKs for "raw" and "designated" measurements, and A+C+D vs. C -pairs do you use the same Sa in all retrievals? p. 8684, lines 17-19. I would not recommend adding the interpolated points to Figure 4 since it is misleading for the reader, even for the illustration purposes. Since, interpolation might create large differences between the two compared datasets, it is better to avoid it all together. The acknowledgement of the difference in sampling rates for the Umkehr and sounding records would point to the limitation of comparisons and would be appropriate in the discussion of results. I also find Figure 4 to be too busy to clearly see the points you are trying to demonstrate. I wonder if it is better to have an additional plot for the shorter time period when the 3-wavelength pair algorithm is applicable. Or replacing the entire time series with the shorter period when both types of algorithms are applicable (1970-1975) is another way to make comparisons more clear. Yet another approach is to replace a time series with a scatter plot. It would allow you to demonstrate the offset and correlation between several pairs of data in one plot. These results can also be captured in the table. p. 8685 lines 2-4. Following up on the discussion of Figure 4. It would be nice to demonstrate the result of application of the A+C+D pair AK smoothing on ozone-sonde data vs. C-pair. It can be done on the data with even a shorter time scale (1970-1975 should have sufficient number of profiles for comparisons). This should be possible because when the A+C+D pair measurements are taken there is always the C-pair. The scatter plot of these results would be a nice demonstration of the advantage of the three pair retrieval… Otherwise it is hard to discern the difference in the Figure 4 format. One

way to show the differences is to subtract the a priori profiles from the retrieved data (or to plot data as referenced to a priori, in percent). It will reduce seasonal cycle and allow for less noise in the results and thus would create cleaner comparisons…. line 9-10. Are you showing C-pair retrieval with all measured points in Figure 4? The AKs for layer 2+3 are more close between "C-pair: measured SZA" and A+C+D pair (0.7 vs. 0.8 at the maximum), as compared to "C-pair :designated SZA" (∼0.55 vs 0.8) as shown in Figure 3. It should be clarified in the text by replacing "C-Pair" with "C-pair with measured SZA (CMS)" or "C-pair with designated SZAs (CDS)" line 11, correct mistake in spelling Umkehr lines 17-21. Please provide quantitative numbers of differences between two algorithms and in regards to the ozone-sonde data. It is impossible to deduce results from the Figure 4. lines 26-27. Add another reason to the list: "omission of the multiple scattering from the forward model". p. 8686 lines 1-3. I would rephrase it as "The algorithm presented here illustrates potential improvements to the ozone retrieval from the Umkehr technique. Results clearly demonstrate an increase in the informational content of the retrieved ozone profile when using measurements at three Umkehr wavelength pairs." line 5. Please remove "accurately", replace "slight discrepancies" with numbers (residuals should be available from the retrieval of the data). Even if you can fit the profile to the observed Umkehr measurements by using only single scattering in the forward model, it may be for the wrong reason. For example, stray light effect could be interfering with the Umkehr measurement fit that causes the offset in the retrieved profile. Lines 5-8. If you are outlining improvements in regards to the Umkehr retrieval ca 2005 algorithm (Petropavlovskikh et al., 2005), the removal of total ozone dependent a priori has been already applied (but not in algorithm ca 1992, Mateer and DeLuisi , 1992). It is better to state that "The presented algorithm uses a priori profiles and covariance matrix derived from the zonally and monthly averaged climatological dataset (Hassler et al., 2009). " Lines 16-18. This is the first time that the spline extrapolation is discussed in the text. This should be moved into section 2.1. The estimates of errors for using spline extrapolation should be provided. It can be estimated from data that have data beyond 90-degrees SZA: applying extrapolation to the data with limit at 90-degrees SZA and comparing to the measurements between 90 and 94 degrees. In my experience the extrapolation at these SZAs does not work very well and should be avoided. p. 8687 Lines 8-7. Please provide the number to quantify “large”. The number should be in %, which would allow for comparisons with the stray light effect (5-10 % in layers 7 and 8). (see above comments to p. 8685, lines 15-21). Lines 26-28. You might add the following to the future work “ assessment of the errors in the fitting of Umkehr curves in partial cloud conditions, assessment of errors in measurements at three wavelengths, assessment of the changes in a priori covariance on the ozone profile retrieval. “ And further validation work is needed to assess the improvement in operational ACD retrievals.

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