Interactive comment on “Comparison of ozone retrievals from the Pandora spectrometer system and Dobson spectrophotometer in Boulder, Colorado” by J. Herman et al.

Anonymous Referee #1

Received and published: 13 April 2015

The manuscript describes a comparison of total ozone column (TOC) measurements obtained from the World reference Dobson and a Pandora diode array spectroradiometer system. The procedure to retrieve the ozone from solar irradiance measurements is described and analysed with respect to the sensitivity to ozone temperature. A further comparison to satellite products from AURA/OMI and NPP/OMPS is provided.

The manuscript is well written and structured. The figures are helpful and illustrative. In general I think that this manuscript provides a good status of the TOC retrievals that are possible with a system such as Pandora, which comprises a small commercial array spectroradiometer to measure solar UV spectra. While the results look promising, a thorough discussion of the possible parameters affecting the TOC retrieval are missing (only ozone temperature is discussed), as well as an uncertainty estimate for the TOC retrieval, which therefore stops short from being the expected reference paper which it could have become.

Specifically, I would have liked to see a more detailed metrological approach to the direct irradiance measurements, which can be expected from such a study:

1) Effect of applying (or not) a stray-light correction using for example a straylight matrix as from Zong et al, 2006, Y. Zong, S. W. Brown, B. C. Johnson, K. R. Lykke, and Y. Ohno,“Simple spectral stray light correction method for array spectroradiometers,” Appl. Opt. 45, 1111–1119 (2006).

We have applied both a matrix stray light correction and a simpler correction based on “dark” pixels at the short wavelength limit of the spectrometer. We found that the subtraction of the straylight measured in the “dark” pixel region was as good as the matrix method. The stray light was determined in the laboratory using lasers at several wavelengths. The comparison of stray light methods is a useful study for specific Avantes spectrometers used by Pandora, it would not affect the stray light corrected retrieval of ozone by spectral fitting used in this paper.

I have now added comments about the stray light correction. Also, note that ozone is retrieved using a UV340 filter that blocks light longer than 380 nm, and, therefore, most of the stray light that would be present at 310-330 nm.

2) Nonlinearity, which is a significant factor for the Avantes array spectrometers used in the pandora systems,

I am not sure which non-linearity you mean. There are two possibilities. 1) Wavelength and 2) Radiometric response. Both of these were carefully measured in the laboratory. The wavelength response was determined using a series of line emitting lamps (e.g., sodium, cadmium, etc.). From the

data, a correction polynomial was derived that gives the wavelength vs pixel number to within 0.13 nm over the entire spectrometer range 280 – 525 nm. A wavelength response correction was also determined at several spectrometer operating temperatures. The high resolution extraterrestrial solar flux was not used for wavelength calibration, but the position of the Fraunhofer lines was used as validation.

Since we have measured the radiometric response in the laboratory, we always operate in the linear range of the linear range of the instrument. The measurement method always adjusts the exposure time to fill the readout wells to 80% of full well capacity at the most intense wavelength. For ozone measurements, this is usually at about 340 nm. This is accomplished by making a test exposure before each set of direct-sun measurements lasting 20 seconds, and then determining an appropriate individual measurement exposure time for the specific conditions (clear to cloudy and SZA).

Regarding the ozone retrieval, the use of different ozone cross section datasets for the Dobson and Pandora is inconsistent, and adds an unknown uncertainty to this comparison. As shown by Redondas et al., 2014, the dataset from Serdyuchenko et al., 2014 (Serdyuchenko, A., Gorshelev, V., Weber, M., Chehade, W., and Burrows, J. P.: High spectral resolution ozone absorption crosssections – Part 2: Temperature dependence, Atmos. Meas. Tech.Discuss., 6, 6613–6643, doi:10.5194/amtd-6-6613-2013, 2013.) gives the most consistent results between Dobson and brewers and has been recommended for use in the Ground-based Dobson and Brewer networks. I would have preferred therefore that Dobson and Pandora would use the same ozone-xsection, and preferably the recommended one.

Our goal was not to compare cross sections, but rather to compare the Pandora standard retrievals using BDM (Malicet et al., 1995 and Brion et al. 1993, 1998) cross sections, which appear to be in agreement with the Serdyuchenko et al., 2014 referenced above, and the standard Dobson retrieval cross sections from Bass an Paur (1985). The question being answered in this paper was, could the Pandora retrievals provide continuity for historical Dobson records. Using BDM for Pandora should be acceptable, since to quote from Serdyuchenko et al., 2014, "The new data agree within experimental uncertainty with the BDM dataset at all temperatures, excluding the region near 380 nm at low temperatures (below 1 % in the Hartley band, 1–2 % in the Huggins band and about 2–3 % in the Chappuis band)."

The TOC comparison between Pandora and Dobson discussed on pages 6-10 and summarised in Figure 3 show nearly simultaneous values versus time. An interesting figure would have been to show the differences in TOC between the instruments against ozone airmass (airmass times ozone amount). Deviations at high ozone airmasses would be expected due to the internal light scattering of the Pandora monochromator and could show to which level reliable TOC can be determined with this system. This is crucial at high latitudes, where large airmasses and high ozone amounts are typical for most of the year.

The Pandora O3 retrieval study already did this comparison with a Brewer double monochromator (Tzortziou, M., J. R. Herman, A. Cede, and N. Abuhassan (2012), High precision, absolute total column ozone measurements from the Pandora spectrometer system: Comparisons with data from a Brewer double monochromator and Aura OMI, J. Geophys. Res., 117, D16303,

doi:10.1029/2012JD017814, 2012). The results show agreement out to slant column ozone of 1400 in comparisons conducted in Fairbanks Alaska with O3 varying between 387 and 460 DU. This translates to good ozone retrievals up to 70 and 80 degrees SZA depending on the value of O3.

Some minor comments: Page 1: The affiliation of Cede (4) is missing.

Affiliation was provided.

Page 3, line 54: Parentheses are missing in Equation 2

N = Log[IETC(S2)/IETC(S3)] – Log[Imeas(S2)/Imeas(S3)]

There are no missing parentheses 2 sets of [] and 4 sets of ()

Page 4, line 83: Can the statement "~0.5% " be made more specific?

Should have been: **0.5% ±1% lower than Dobson #083 results**

Page 4, line 104: Convolved, instead of convoluted. **Done.**

I miss a discussion of the wavelength to pixel relationship, and the methodology by which it is determined. I presume that the high resolution solar spectrum is used for that, and I would suggest adding a sentence to that effect.

I have added:

Wavelength calibration is performed at several spectrometer temperatures using a variety of narrow line emission lamps that cover most of the spectral range 280 - 525 nm. From the laboratory data, a polynomial is fitted to the results as a function of pixel column number 1 – 2048. Wavelength calibration was validated using comparisons with the slit function convolved high resolution Kurucz spectrum's solar Fraunhofer lines. Based on laboratory measurements, the Avantes spectrometers are corrected for response nonlinearity to the incoming signal, which can amount to 3% at high counts and is negligible at low counts. The exposure times to sun or sky photons are adjusted so that the readout pixel with the highest intensity is never in excess of 80% of the CCD readout well depth of 200,000 electrons. This means that each pixel in the 64 rows for each wavelength is limited to less than 2500 electrons.

Page 7, 8, Tables 1, 2,3: I was confused by the discussion on the ozone temperature climatology: Why should it depend on the total amount of ozone in the atmosphere?

The following sentences have been added

A compiled climatology of ozone and temperature (Table 1) was used to generate the ozone weighted effective temperature T_E for the location of Boulder, Colorado at 40^ON latitude. The tables are given as a function of latitude and ozone amount for each month (see ftp://toms.gsfc.nasa.gov/pub/ML_climatology for climatology data files, and discussions by Wellemeyer et al., 1997; McPeters et al., 2007; McPeters and Labow (2011)). For this study, only the monthly data for latitudes of 30^O-40^ON and 40^O-50^ON are used to form an average suitable for 40^ON. T_E is not an intrinsic function of TCO. However, for a given latitude and month, the ozone profile shape climatology was systematically organized by total column amount, so that the T_E tables can be parameterized by TCO.

Shouldn't there be a better proxy for that? A better approach would have been to use measured ozone and temperature profiles instead of climatological values for the comparison of this specific measurement period in order to determine the effective ozone temperature or even better the effective ozone cross section based on the profile information.

There is a better proxy. We could use measured temperatures from balloon sondes, which happen to be available from the NOAA Boulder site. We could also derive effective O3 temperatures as part of the ozone retrievals and compare with measured temperatures. This is the subject of another paper. However, the overall results are not statistically significantly better than using the climatology. Since not all sites have balloon sonde measurements, the comparison was done without using the extra information. The goal of this paper was to show that Pandora produces equivalent O3 retrievals to a well-calibrated Dobson instrument that could be located almost anywhere without requiring coincident temperature measurements.

Interactive comment on Atmos. Meas. Tech. Discuss., 8, 3049, 2015.

Replies added to the paper in response to reviewer #1 are in yellow, and those for reviewer #2 are in green.