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Atmospheric Measurement Techniques Discussions

Ozone Comparison between Pandora #34, Dobson #061, OMI, and OMPS at Boulder Colorado for the period December 2013 – December 2016.

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Abstract

A co-located Pandora Spectrometer Instrument (Pan #034) has been compared to a well calibrated Dobson spectroradiometer (Dobson #061) in Boulder, Colorado and with two satellite instruments over a 3-year period. The results show good agreement between Pan#034 and Dobson #061 within their statistical uncertainties after both records are corrected for ozone retrieval sensitivity to stratospheric temperature variability obtained from the Global Modeling Initiative (GMI) and Modern-Era Retrospective analysis for Research and Applications (MERRA2) model calculations. Pandora#034 and Dobson#061 differ by an average of 2.2 % when both instruments use their standard ozone absorption cross sections in the retrievals algorithms. The results demonstrate the stability of Pandora observations against NOAA Dobson in Boulder, CO over a three year period of continuous operation. The relative drift between two systems is 0.6% per year.

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Introduction

A Pandora Spectrometer Instrument located on top of the NOAA building in Boulder, Colorado has been operating since December 2013 with little maintenance and using the original calibration. The purpose of this paper is to give a comparison between two co-located ozone measuring instruments, Pandora #034 and Dobson #061 for the period December 2013 to December 2016. Additional comparisons are made with satellite overpass data from OMI (Ozone Measuring Instrument on board the AURA spacecraft) and OMPS (Ozone Mapping Profiler on board the Suomi NPOESS satellite). This paper is an extension of a previously published paper (Herman et al., 2015) presenting just 1 year of data.

The characteristics of both the Pandora Spectrometer instrument and the Dobson Spectroradiometer are described in Herman et al. (2015). Briefly, the Pandora consists of a small Avantes low stray light spectrometer (280 – 525 nm with 0.6 nm spectral resolution with 4 times oversampling) connected to an optical head by a 400 micron core diameter single strand fiber optic cable. The spectrometer is temperature stabilized at 20^{O}C inside of a weather resistant container. The optical head consists of a collimator and lens giving rise to a 2.5^{O} FOV (field of view) FWHM (Full Width Half Maximum) with light passing through two filter wheels containing diffusers, a UV340 filter (blocks visible light), and an opaque position (dark current measurement). The optical head is connected to a small suntracker capable of accurately following the sun's center using a small computer-data logger contained in a weatherproof box along with the spectrometer. Pandora#034 is capable of obtaining NO_2 and Total Column Ozone TCO amounts sequentially over a period of 80 seconds. The integration time in bright sun is about 4 milli-seconds that is repeated and averaged for 30 seconds to obtain very high signal to noise and a precision of less than 1 DU or 0.2% (1 DU = 2.69×10^{16} molecules/cm^2).

The Dobson record in Boulder started in 1978 based on an improved design from the instrument first deployed in the 1920's (Dobson, 1931). Dobson instrument is using differential absorption method to derive total column ozone from direct–sun measurements at two pairs of spectral regions in UV and Visible Solar spectrum (see Herman et al., 2015). The extensive Dobson network uses the Bass-Paur ozone absorption cross sections (Bass and Paur, 1985) for operational data processing (Komhyr et al., 1993).

All NOAA Dobson instruments are calibrated against WMO standard Dobson #083, which is in turn uses Langley method calibrations at the Mauna Loa Observatory station (Komhyr et al., 1989). Standard lamps are used to check Dobson spectral registration stability.

The main sources of noise in the Pandora measurement comes from the presence of clouds or haze in the FOV, which increases the exposure time needed to fill the CCD wells to 80% and reduces the number of measurements in 30 seconds. For this comparison study, data were selected for scenes that are clear-sky conditions as determined from the Dobson A-D pair direct-

Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-157, 2017
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Atmospheric Measurement Techniques Discussions
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sun data record.

Accuracy in the Pandora spectral fitting retrieval is obtained using careful measurements of the spectrometer's slit function, wavelength calibration and knowledge of the solar spectrum at the top of the atmosphere. The Pandora ozone retrieval algorithm uses an extraterrestrial solar flux from a combination of the Kurucz spectrum (wavelength resolution λ/1λ = 500 000) radiometrically normalized to the lower-resolution shuttle Atlas-3 SUSIM spectrum (Van Hoosier, 1996; Bernhard et al., 2004, 2005), BDM ozone cross sections (Brion et al. (1993, 1998) and Malicet et al. (1995)), corrections for stray light, and an effective ozone weighted temperature.

The Dobson data used in this study contain the individual measurements (more than 1 per day between 09:00 and 15:00 local time with almost all of the data between 10:00 and 14:00) for clear-sky direct-sun observations using the quartz plate and A-D wavelength pairs for ozone retrieval. These were made available by one of the co-authors (I. Petropavlovskikh, private communication, Table 1). The NOAA Dobson total ozone data are typically archived WOUDC (World Ozone and Ultraviolet Radiation Data Centre) or NDACC (Network for the Detection of Atmospheric Composition Change) with one representative ozone value per day.

1. Temperature Sensitivity

The Pandora ozone retrieval algorithm is more sensitive to the effective ozone weighted average temperature than is the 4 wavelength Dobson retrieval (Redondas et al., 2014). Neglecting the temperature sensitivity creates a seasonal difference between the two instruments. To correct for this, we use an effective ozone temperature T_E based on daily ozone weighted altitude temperature averages. The temperature and ozone profile data were obtained from the GMI (Global Modeling Initiative) model calculation for 2013 to 2016 (https://gmi.gsfc.nasa.gov/merra2hindcast/). The GMI model provides atmospheric composition hindcasts using MERRA2 (Modern-Era Retrospective analysis for Research and Applications, Version 2, meteorology (Strahan et al., 2013Wargan and Coy, 2012) https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/). The simulation with 2x2.5 resolution uses the CCMI emissions and boundary conditions. MERRA2 uses assimilation schemes based on hyperspectral radiation, microwave observations and ozone satellite measurements. The resulting seasonal cycle for T_E shows variations over the three year period, while day-to-day variability is enhanced during winter and spring season (Figure 1).

Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-157, 2017
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Discussion started: 23 May 2017

Atmospheric Measurement Techniques Discussions

The T_E time series data are used for an ozone retrieval temperature correction TCO_{cor} coefficient per ^{O}K given in the form TCO_{corr} = TCO (1 + C(T)) and O_3(corr) = O_3 TCO_{corr} (Herman et al., 2015), where C(T_E) is given by equations 1 and 2.

$$C_{Pandora}(T_E) = 0.00333(T_E - 225) \quad (1)$$

$$C_{Dobson}(T_E) = -0.0013(T_E - 226.7) \quad (2)$$

As mentioned earlier, the Dobson TCO retrieval normally uses the Bass and Paur (BP) ozone absorption coefficients, while Pandora uses the BDM coefficients. A change in T_E of $+1^{O}$ change leads to TCO changes for the Pandora(BDM) and Dobson(BP) instruments of +0.33% and -0.13%, respectively. For a nominal TCO value of 325 DU, the change would be +1.1 and -0.4 DU, a net relative change of 1.5 DU.

While BDM cross sections are not currently recommended for use in standard Dobson processing, their use yields slightly different values of TCO and a smaller sensitivity to temperature −0.042% per ^{O}K (Redondas et al., 2014). The basic Dobson algorithm based on pairs of wavelengths is intrinsically less sensitive to T_E than Pandora's spectral fitting retrieval.

2. TCO Comparisons between Pandora, Dobson, OMI and OMPS

Comparing retrieved TCO from the Pandora, Dobson, OMI and OMPS instruments show that there are small, but significant differences between the Pandora and Dobson instruments and between the ground-based instruments and satellite derived values of TCO. The difference is noticed especially in the three-year estimates of secular change based on a linear least squares fit to the differences between the instruments. The cloud-free direct-sun A-D pair Dobson ozone data are selected for comparison with time-matched Pandora retrieved ozone data (Herman et al., 2015). The Pandora retrieved ozone (every 80 seconds) are matched to the less frequent Dobson retrieval times and averaged over ±8 minutes (Figure 2).

Before the middle of 2014 the bias between Pandora and Dobson was small, but gradually increased and remained approximately constant for the rest of the 3-year comparison period. The difference between the Dobson and Pandora retrieved ozone values as shown in the Figure 2B reach about 3±0.1% in 2016 (average value of 296±33 DU).

The percent difference comparisons in Figure 3 show that the Pandora agreement with satellite data (OMI and OMPS) is within statistical error, and is typically 1.2±2.5 %, which is not significantly different from zero. However, the secular trends are small, but significant, since they exceed the estimated linear slope uncertainty by 2 to 3 standard deviations. The Dobson appears to have a negative long-term linear change (-0.6 ± 0.09%/Year) compared to OMI and

Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-157, 2017
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Discussion started: 23 May 2017

Atmospheric Measurement Techniques Discussions

OMPS (0.4 ± 0.09%/Year), while Pandora has a smaller positive change (0.3 ± 0.1%/Year) compared to OMI and a small positive (0.2 ± 0.1%/Year) change compared to OMPS. The Pandora, OMI, and OMPS data used in this study are from the overpass files located on the public websites (Table 1).

Table 1 Data Availability

OMI:
https://avdc.gsfc.nasa.gov/index.php?site=1593048672&id=28/aura_omi_l2ovp_omto3_v8.5_boulder.co_067.txt
OMPS:
ftp://toms.gsfc.nasa.gov/pub/omps_tc/overpass/suomi_npp_omps_l2ovp_nmto3_v02_boulder.co_067.txt
Pandora34:
https://avdc.gsfc.nasa.gov/pub/DSCOVR/Pandora/DATA/Boulder/Pandora34/L3c/
Dobson061:
ftp://aftp.cmdl.noaa.gov/data/ozwv/Dobson/WinDobson/Pandora%20comparisons/Dobson61%20Boulder%20Ad-dsgqp%20120213-032717_w_Header.txt

Figure 4 shows a comparison between Pandora #034 and the Dobson #061 for both the Dobson retrievals using BP and BDM ozone absorption coefficients. The standard Dobson retrieval uses BP absorption coefficients, while Pandora uses the BDM absorption coefficients. There is a difference of 0.5 % in the mean value from the use of different O_3 absorption coefficients and have the same secular trend consistent with the small secular change in T_E.

Figure 5 shows that the TCO between Pandora and Dobson are highly correlated with 1:1 slope and the correlation coefficient $r^2 = 0.97$. Similar correlation plots (Figure 6) for Pandora and Dobson with OMI and OMPS also show very high correlation.

Summary

Temperature corrected Pandora#034 and Dobson#061 differ by an average of 2.1% with Pandora using its standard retrieval BDM ozone absorption cross sections and Dobson using the recommended BP ozone absorption cross sections. Comparisons with OMI and OMPS are statistically equivalent within their respective error estimates. Both Pandora#034 and Dobson#061 have small different secular trends with respect to OMI and OMPS satellite measurements suggesting that there is long-term stability in all four instruments..

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Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-157, 2017
Manuscript under review for journal Atmos. Meas. Tech.
Discussion started: 23 May 2017

Atmospheric Measurement Techniques
Discussions

229 **Figures**

230

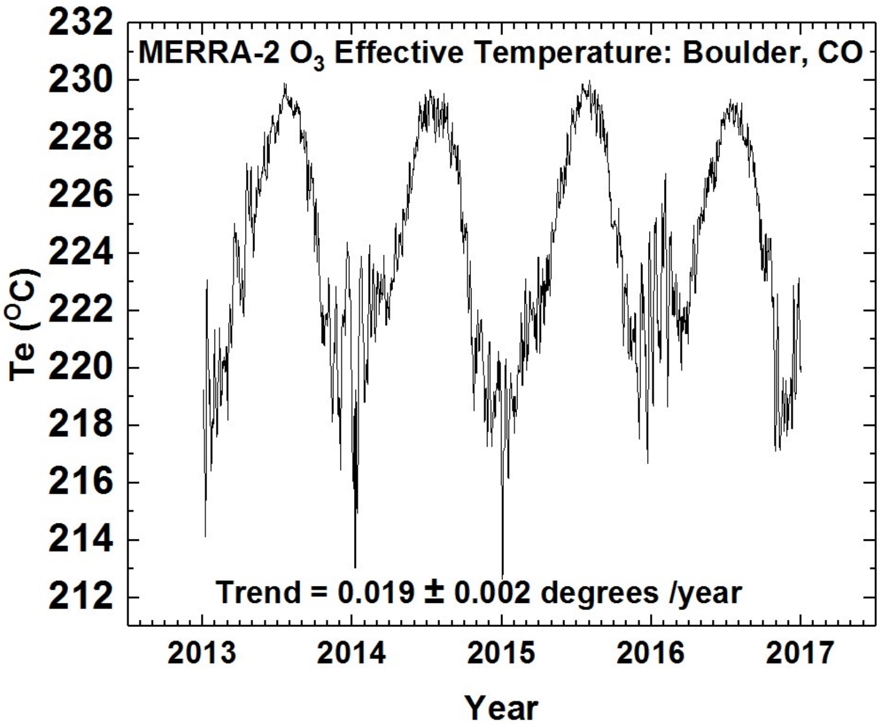

Figure 1 Calculated T_E using model estimates of O_3 and temperature profiles. The Trend is calculated from the difference of T_E from its 4-year daily mean.

231

232

Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-157, 2017
Manuscript under review for journal Atmos. Meas. Tech.
Discussion started: 23 May 2017

Atmospheric Measurement Techniques
Open Access
Discussions

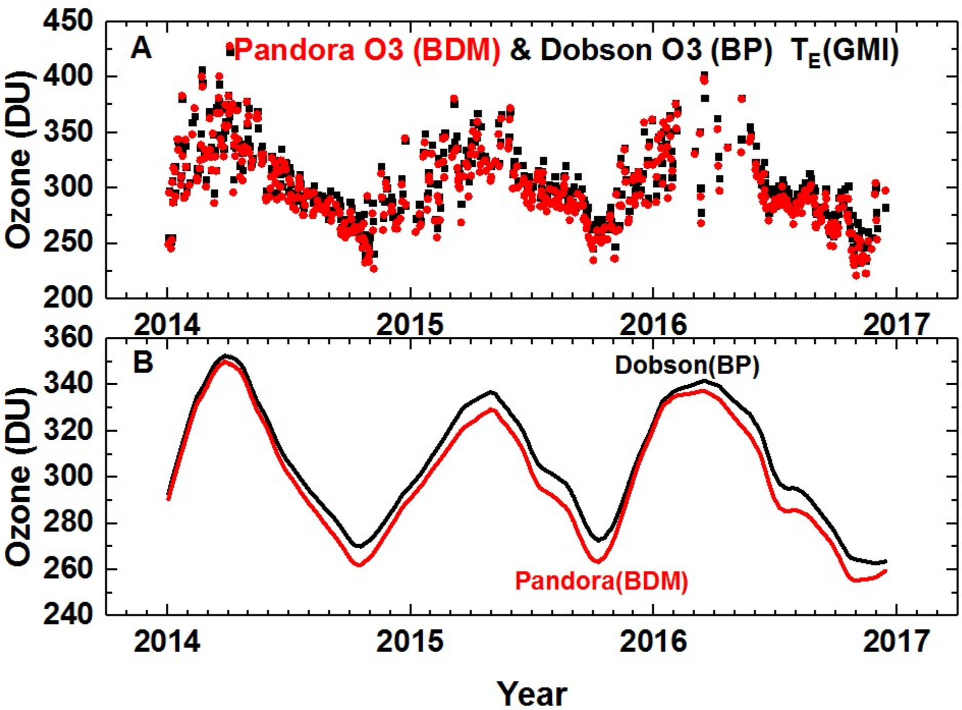

Figure 2 Panel A shows the retrieved ozone time series for Pandora (red) and Dobson (Black). Panel B shows Lowess(0.1) fit to the time series.

Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-157, 2017
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Discussion started: 23 May 2017

Atmospheric Measurement Techniques Discussions

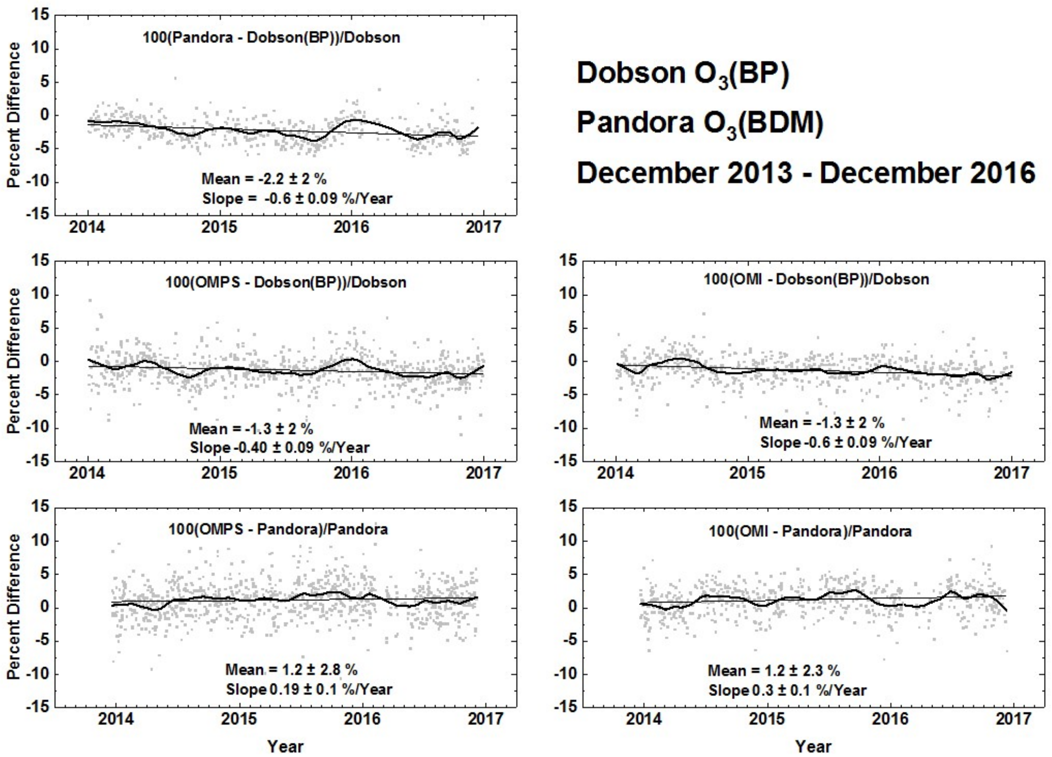

Figure 3 Comparisons of Pandora(BDM) with Dobson(BP) retrieved ozone in percent differences of retrieved ozone and comparisons with OMI and OMPS

Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-157, 2017
Manuscript under review for journal Atmos. Meas. Tech.
Discussion started: 23 May 2017

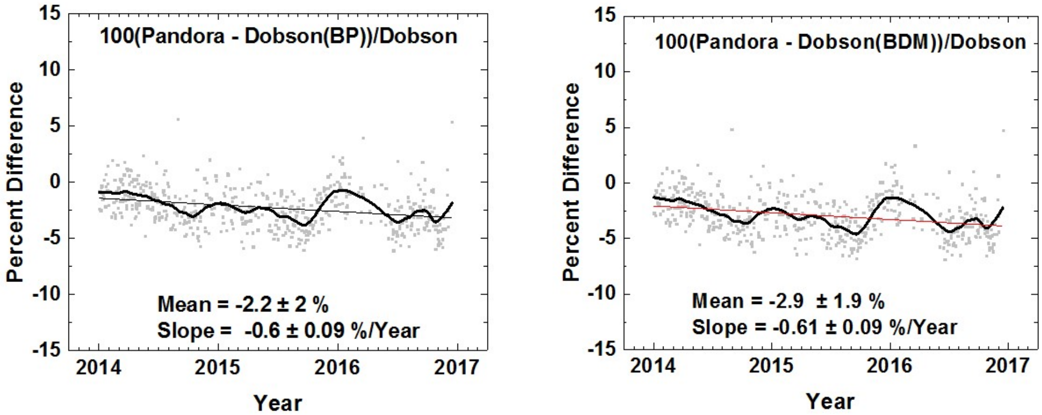

Figure 4 The percent difference between Pandora 034 and Dobson 061 retrievals of TCO after temperature T_E corrections for Dobson retrievals using BP (left) and BDM (right) absorption coefficients.

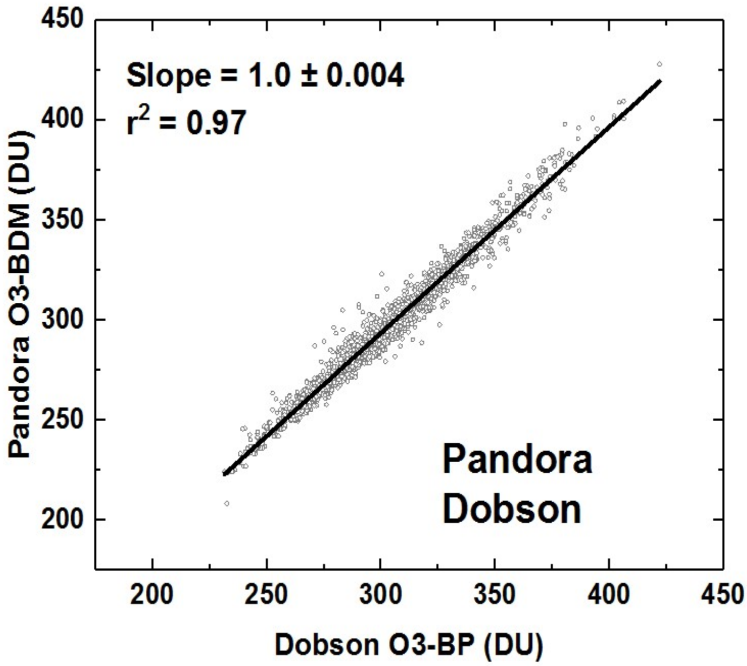

Figure 5 Correlation between Pandora #034 and Dobson #061

Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-157, 2017
Manuscript under review for journal Atmos. Meas. Tech.
Discussion started: 23 May 2017

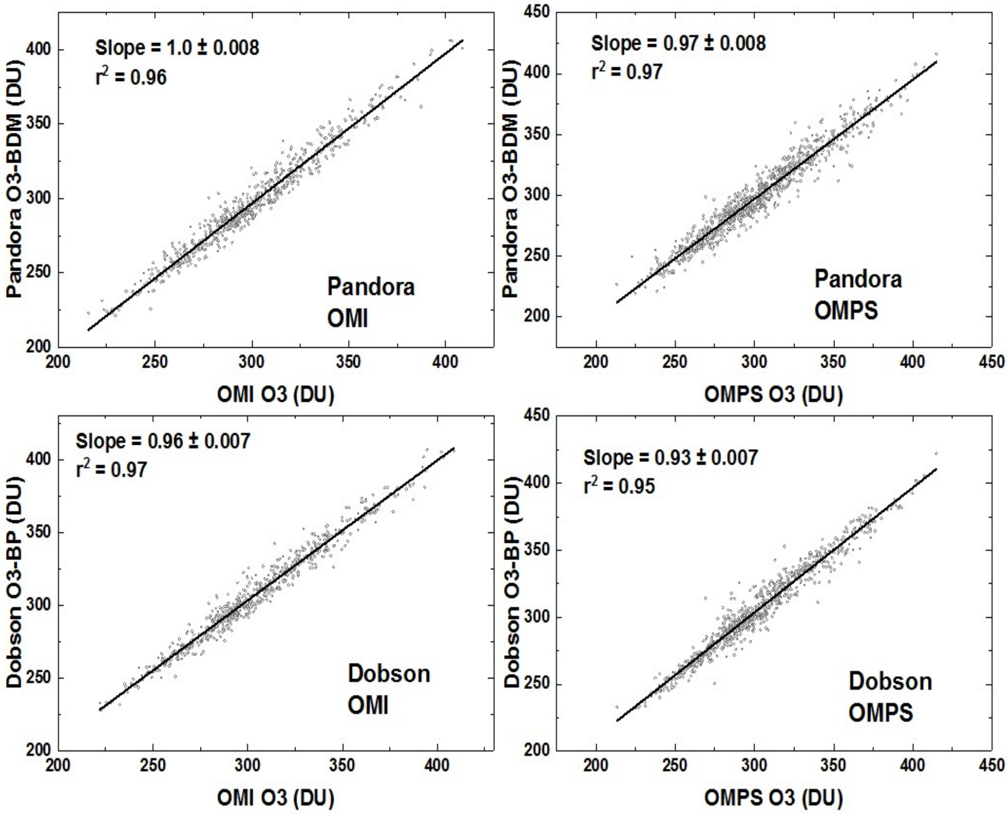

Figure 6 Correlation of Pandora and Dobson with OMI and OMPS

241