

## Comparison of OMI ozone and UV irradiance data with ground-based measurements at two French sites

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**Abstract.** Ozone Monitoring Instrument (OMI), launched in July 2004, is dedicated to the monitoring of the Earth's ozone, air quality and climate. OMI is the successor of the Total Ozone Mapping Spectrometer (TOMS) instruments and provides among other atmospheric and radiometric quantities the total column of ozone (TOC), the surface ultraviolet (UV) irradiance at several wavelengths, the erythemal dose rates and the erythemal daily doses. The main objective of this work is to compare OMI data with data from ground-based instruments in order to use OMI products (collection 2) for scientific studies. The Laboratoire d'Optique Atmosphérique (LOA) located in Villeneuve d'Ascq (VdA) in the north of France performs solar UV measurements using a spectroradiometer. The site of Briançon in the French Southern Alps is also equipped with a spectroradiometer operated by Interaction Rayonnement Solaire Atmosphère (IRSA). The OMI total ozone column data is obtained from the OMI-TOMS and OMI-DOAS algorithms. The comparison between the TOC retrieved with ground-based measurements and OMI-TOMS data shows good agreement at both sites for all sky conditions with a relative difference for most of points better than 5%. For OMI-DOAS data, the agreement is generally better than 7% and these data show a significant dependence on solar zenith angle. Comparisons of spectral UV on clear sky conditions are also satisfying with relative differences smaller than 10% except at solar zenith angles larger than 65°. On the contrary, results of compar-

isons of the erythemal dose rates and erythemal daily doses for clear sky show that OMI overestimates surface UV doses at VdA by about 15% and that on cloudy skies, the bias increases. At Briançon, such a bias is observed if data corresponding to snow-covered surface are excluded.

### 1 Introduction

The solar UV radiation has a large impact on human life, animals and plants, with both positive and negative effects. For example, exposure to solar UV enables the synthesis of vitamin D in skin whereas skin cancer or eye diseases can be caused by excessive doses of UV radiation (WMO, 2007). Atmospheric ozone is one of the main factors affecting the surface UV radiation, so its decline observed at middle and high latitudes since the 1980s has led to monitoring of atmospheric ozone content and UV radiation. Ground-based instruments devoted to this monitoring have been developed in many countries as well as satellite instruments which allow a global geographical coverage.

Satellite data are affected by instrumental errors, as data from ground-based instruments (Bernhard and Seckmeyer, 1999), but are also affected by modelling uncertainties in deriving surface UV irradiance from UV radiance measured at the top of atmosphere. Therefore, satellite derived products need to be validated with ground-based measurements. Previous comparisons between satellite surface UV data provided by TOMS and ground-based measurements have been extensively done (Kalliskota et al., 2000; McKenzie et al., 2001; Cede et al., 2004; Arola et al., 2005; Kazantzidis et al.,



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2006). They concern mainly snow-covered surface, clouds and aerosols effects on the UV irradiance derived from satellite. The TOC inferred from satellite measurements requests also validation. All these validations must be achieved with care because of a scale issue, indeed ground-based measurements are representative only of a small local area whereas satellite measurements are representative of a large region (OMI pixel at nadir  $\sim 13 \times 24 \text{ km}^2$ ) so that difficulties can arise from the cloud or aerosol variability.

The ground-based instruments used to perform spectral irradiance measurements and the OMI instrument are described in Sect. 2 along with the methodologies for inferring the TOC and surface UV from ground-based and from OMI measurements. Section 3 presents comparisons between the OMI products and the products retrieved at two French sites, Villeneuve d'Ascq ( $50.61^\circ \text{ N}$ ,  $3.14^\circ \text{ E}$ ,  $70 \text{ m a.s.l.}$ ) and Briançon ( $44.90^\circ \text{ N}$ ,  $6.65^\circ \text{ E}$ ,  $1330 \text{ m a.s.l.}$ ). Section 4 reports the conclusions.

## 2 Instruments and methodologies

### 2.1 Ground-based instruments

Measurements of the instruments located at Villeneuve d'Ascq and Briançon are used in this study. These sites are typical respectively of a flat region in the north of France and a high altitude valley of the French Southern Alps.

The spectroradiometers at VdA and Briançon are thermally regulated Jobin Yvon H10 double monochromators, and they scan the wavelength range from 280 to 450 nm with a sampling step of 0.5 nm. Their spectral resolution is about 0.7 nm (Full Width at Half Maximum, FWHM). Calibration is performed every 3 months with two standard lamps traceable to NIST (National Institute of Standards and Technology) and NPL (National Physical Laboratory), leading to an irradiance expanded uncertainty (coverage factor  $k=2$ ) of about 8% at 300 nm and about 5% at 400 nm for a high irradiance level and 10% and 7% respectively for a low irradiance level. The instrument has been checked within the QASUME (Quality Assurance of Spectral Ultraviolet Measurements in Europe) project in September 2004 (Gröbner et al., 2006). The spectroradiometers perform scans of the global irradiance from sunrise to sunset every 30 min. A single spectral scan takes about 6 min.

The broadband instrument in VdA is a UVB-1 type from Yankee Environmental System (YES), it delivers measurements of erythemal dose rate with a three minutes time frequency. It was calibrated in August 2006 during COST-726 campaign.

#### 2.1.1 Ozone retrieval

The total ozone column is routinely retrieved from the ground-based global irradiance spectrum using a differential absorption technique (Stamnes et al., 1991). This method is

based on the comparison between two ratios of irradiances at two selected wavelengths (one where the ozone absorption is strong and the other where it is weak). One ratio is simulated beforehand and is stored in a look up table (LUT) and the other is calculated from the UV measurements (Houët and Brogniez, 2004). The LUTs are built using a Radiative Transfer Code (DISORT, DIScret Ordinate Radiative Transfer, Stamnes et al., 1988) for various solar zenith angles and total ozone columns. The ozone absorption cross-sections used to calculate the LUT are taken from Paur and Bass at 221 K (1985). With this technique, it is possible to retrieve ozone under clear sky and cloudy conditions. A previous study (Brogniez et al., 2005) has shown that under cloudy conditions the daily ozone mean is a rather good estimation of the true value. The uncertainties on the ozone retrieval are about 3% on clear sky and on cloudy days, the performance depends on the cloudiness: for example for cloudiness lower than 4 octas, the averaged uncertainty is about 4%, when cloudiness is larger than 4 octas, the averaged uncertainty is about 7%. So, in this study daily averages of the ground-based data obtained for all sky conditions and for zenith angles smaller than  $75^\circ$  are compared with OMI values obtained during overpass. Other comparisons with averaged ground-based values close to the satellite overpass time are also conducted.

#### 2.1.2 UV irradiance

Erythemal dose rates are computed from ground-based spectra using CIE action spectrum (Diffey and McKinlay, 1987) and erythemal daily doses are computed integrating the erythemal dose rates over the day.

To carry out comparison of two spectra measured by two instruments with slit functions of different FWHM one has to process the spectra to set them at a common FWHM (Slaper et al., 1995; Bais et al., 2001). Therefore, the ground-based spectra were first deconvolved using their own FWHM and then reconvolved with a triangular slit function with FWHM of 0.55 nm in order to make the spectroradiometer irradiance comparable to the spectral irradiances produced by the OMI surface UV algorithm. The processing was carried out using the SHICrvm tool (Slaper et al., 1995).

### 2.2 Ozone monitoring instrument

OMI is a Dutch/Finnish instrument onboard the NASA Earth Observing System (EOS) Aura spacecraft (Levelt et al., 2006a). OMI is a nadir-viewing UV/Visible spectrometer with a spectral resolution about 0.63 nm for the visible channel (349–504 nm) and about 0.42 nm for the UV channel (307–383 nm). It measures the solar light scattered by the atmosphere in the 270–500 nm wavelength range with a spatial resolution at nadir of  $13 \text{ km} \times 24 \text{ km}$ . The sun-synchronous orbit of Aura and the wide viewing angle of OMI enable daily global coverage of the sunlit portion of the Earth. OMI is

the successor of TOMS instruments and contributes to monitoring of the atmospheric ozone, trace gases, aerosols and surface UV radiation (Levelt et al., 2006b).

### 2.2.1 OMI total column ozone data

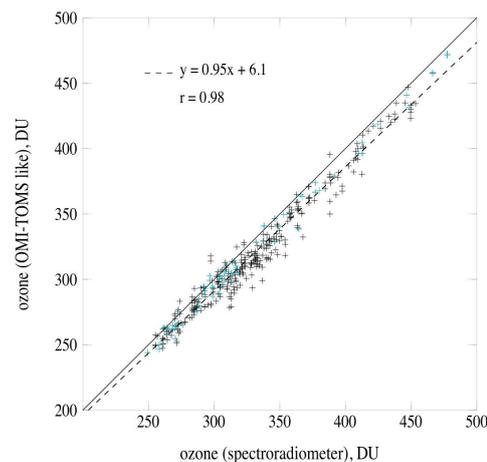
Two algorithms are used to derive the total column of ozone from OMI measurements. One of the two algorithms is the TOMS Version 8 algorithm (Bhartia et al., 2002). The same algorithm was used to reprocess all the TOMS data since 1978. It uses two wavelengths to derive total ozone, 317.5 and 331.2 nm under most conditions, 331.2 and 360 nm for high ozone and high solar zenith angle and also other wavelengths for quality control.

The relative uncertainty on this OMI-TOMS-like product is around 2% for solar zenith angle lower than 70° and increasing to 5% at 85° according to Bhartia et al. (2002).

The other algorithm developed by KNMI (Koninkrijk Nederlands Meteorologisch Instituut in the Netherlands) is based on the Differential Optical Absorption Spectroscopy (DOAS) technique. In the DOAS algorithm, the TOC is determined in three steps. In the first step, to obtain the so-called slant column density (the amount of ozone along an average photon path from the Sun to the satellite), the actual DOAS fitting is performed. In the second step, the air mass factor is determined, which is needed to convert the slant column density into a vertical column. The third step consists of a correction for cloud effects. According to Veeffkind et al. (2006), the relative uncertainty on this OMI-DOAS-like product is about 3% for cloudy days and 2% for clear days.

### 2.2.2 OMI surface UV data

The algorithm used to estimate the UV radiation reaching the Earth's surface is similar to the algorithm used to retrieve UV from the TOMS data (Herman et al., 1999; Krotkov et al., 2002). This OMI surface UV algorithm is based on the use of a radiative transfer model using the OMI-derived total ozone and cloud information as input parameters for modelling. The surface albedo data are obtained from a climatology based on the Nimbus-7/TOMS measurements (Tanskanen, 2004). First of all, the clear-sky surface irradiance is calculated and then a correction is made taking into account the attenuation of the UV radiation by clouds and scattering aerosols (Tanskanen et al., 2006). The speed of the algorithm is optimized using precalculated lookup tables. The OMI surface UV algorithm produces estimates of erythemal daily dose as well as local solar noon erythemal irradiance and spectral irradiances at 305.1, 310.1, 324.1 and 380.1 nm which are calculated using a triangular slit function whose FWHM is 0.55 nm. For validation purposes a modified version of the OMI surface UV algorithm was used to produce for VdA a time series of OMI-derived erythemal dose rates and spectral irradiances corresponding to the OMI overpass



**Fig. 1a.** Comparison between TOC from the ground-based instrument in Briançon and from OMI-TOMS-like method for all sky conditions (blue cross represents snowy surface days). The equation of the regression line (dash line) and the correlation coefficient are indicated, the solid line is the first bisector.

time. In the future these additional products will be added to the standard OMUVB product.

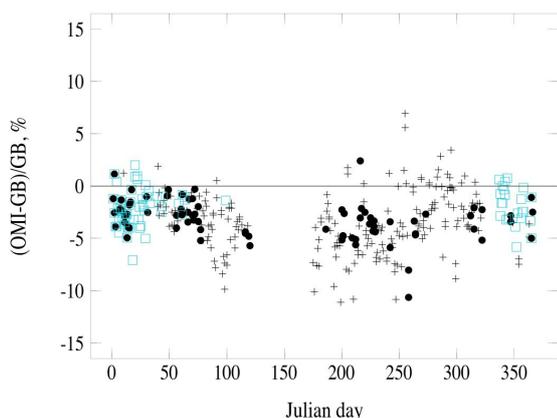
The accuracy of the OMI-derived daily doses was assessed in a recent validation study (Tanskanen et al., 2007). According to the validation results the OMI-derived daily erythemal doses have a median overestimation of 0–10% for flat, snow-free regions with modest loadings of absorbing aerosols or trace gases, and some 60 to 80% of the doses are within  $\pm 20\%$  from the ground reference. For sites significantly affected by absorbing aerosols or trace gases the positive bias can be up to 50%. Because the aerosol absorption cross sections tend to increase as the wavelength decreases, even bigger biases are expected for the low wavelength spectral irradiances derived from the OMI measurements. Thus, comparison of the OMI-derived spectral irradiances with the ground-based measurements will contribute to understanding of the effect of aerosols on surface UV as well as further development of the OMI surface UV algorithm.

## 3 Results

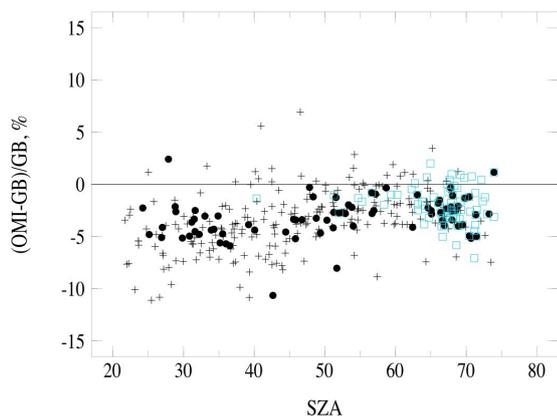
### 3.1 Ozone comparisons

We present scatter plots of the TOC derived from the ground-based instrument at both sites and from OMI derived with the two techniques and also time series of the relative differences (OMI-GB)/GB in percent, where GB represents the TOC from the ground-based instrument. As stated in Sect. 2.1.1, the ground-based data are daily averages.

Figure 1a shows the comparison between the TOC retrieved in Briançon and the TOC OMI-TOMS-like, for the period October 2004–September 2005 considering all sky



**Fig. 1b.** Time series of the relative differences between ground-based and OMI-TOMS-like TOC in Briançon (cross represent cloudy day data, black dots represent clear days and blue squares represent snowy surface days, black dots inside blue squares are for clear snowy days).

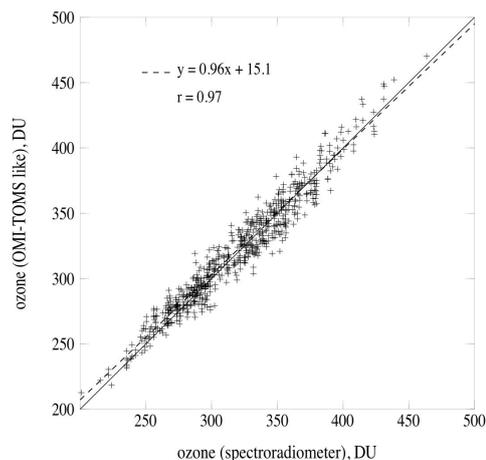


**Fig. 1c.** Relative differences between ground-based and OMI-TOMS-like TOC in Briançon versus SZA (cross represent cloudy day data, black dots represent clear sky days and blue squares represent snowy surface days, black dots inside a blue squares for clear snowy days).

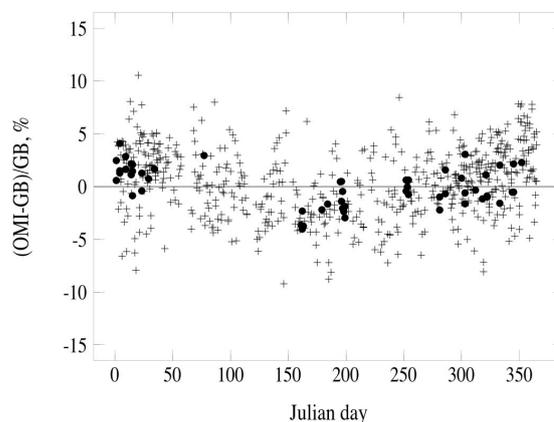
conditions. (The comparison with the TOC OMI-DOAS-like is not presented for Briançon since the data are not available for the previous period).

Figure 1b presents the time series of the relative differences, with cloudy sky data plotted as cross, clear sky data as black points and with the snow-covered surface data as blue squares.

Accounting for the uncertainties on both products, the comparison is rather satisfying but we note a negative bias (TOC spectroradiometer > TOC OMI) about  $-3.1\%$ , with discrepancies more important in summer. This seasonal effect can be explained by a cloud effect since clear sky data (black dots) show no seasonal variation. In this study, the days with snow-covered ground (blue squares) show no par-



**Fig. 2a.** Same as Fig. 1a for OMI-TOMS-like method but in VdA.



**Fig. 2b.** Same as Fig. 1b for OMI-TOMS-like method but in VdA.

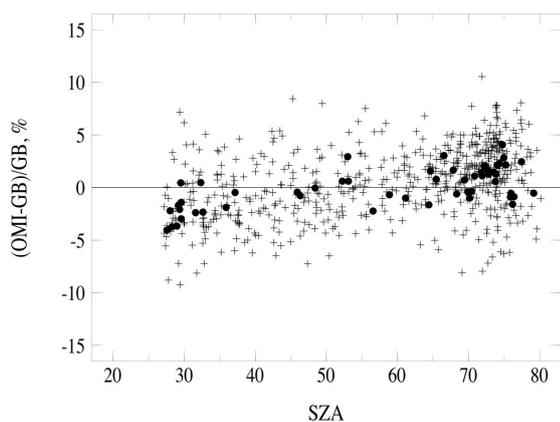
ticular effect. If we consider only the clear days, the comparison is slightly better, the equation of the regression line is  $y=0.99x-7.1$  with a correlation coefficient equal to 0.99.

When looking at relative differences versus the solar zenith angle (SZA) corresponding to OMI data (Fig. 1c), the largest discrepancies observed in summer (smallest SZA) are confirmed for cloudy sky condition data. For clear sky the dependency is small.

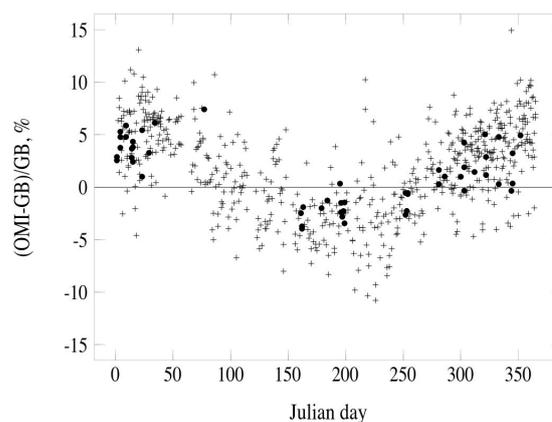
Figure 2a–c present the results for the site of VdA for OMI-TOMS-like method for the period October 2005–February 2007.

The scatter plot in Fig. 2a shows similar results as in Fig. 1a.

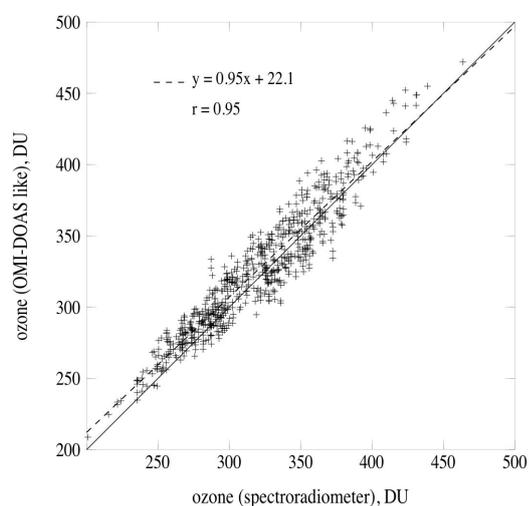
In Fig. 2b no obvious seasonal effect appears for cloudy days (cross) but in case of clear sky (black dots), the seasonal effect appears unambiguously, OMI TOC is smaller than GB TOC in summer while it is generally the reverse (or no difference) during the rest of the year. If we look at Fig. 2c, we notice that, for the majority of points with large SZA for all sky conditions, OMI TOC is greater than GB TOC.



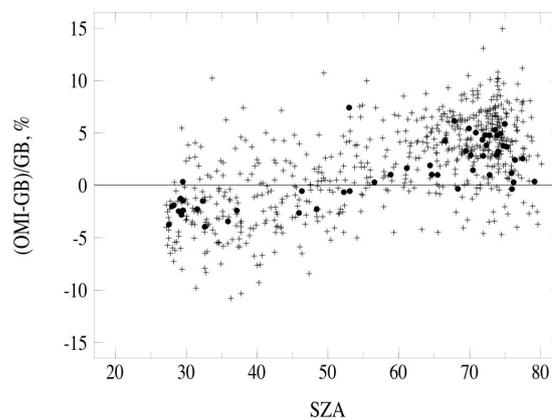
**Fig. 2c.** Same as Fig. 1c for OMI-TOMS-like method but in VdA.



**Fig. 2e.** Same as Fig. 2b but for TOC from OMI-DOAS-like method.



**Fig. 2d.** Same as Fig. 2a but for TOC from OMI-DOAS-like method.



**Fig. 2f.** Same as Fig. 2c but for TOC from OMI-DOAS-like method.

For the comparison on clear sky days, the relative differences do not exceed 5%, the correlation coefficient is 0.98 and the equation of the regression line is  $y=0.98x+7.6$  much satisfying that for all sky conditions.

Figure 2d–f present the results for the site of VdA for OMI-DOAS-like method for the same period as previously.

Considering the Fig. 2e and f, obviously there is a seasonal effect for both clear and cloudy sky condition data. Dependence with SZA is very important even by clear sky. Balis et al. (2007) found also a significant dependence on SZA between OMI-DOAS and ground-based data at several sites.

The regression line for only clear sky data is  $y=0.99x+6.3$  much better than for all sky conditions with a correlation coefficient equal to 0.96. The agreement is better particularly in summer, with relative differences lower than 5%.

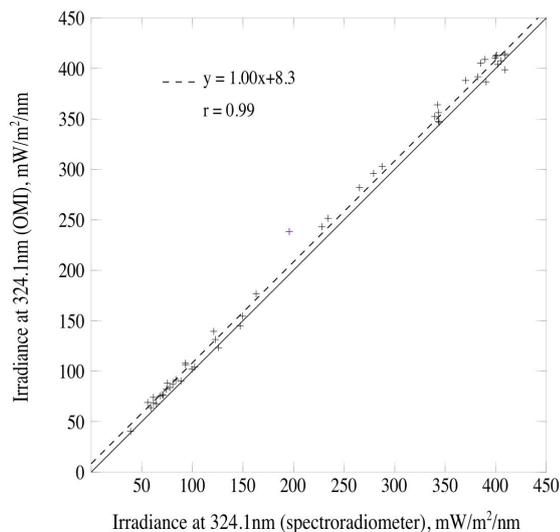
Other comparisons with averages of ground-based values close to the satellite overpass time show similar results (not shown).

To summarize, in VdA we have a better agreement between the ground-based TOC and OMI-TOMS-like TOC (the RMS (root mean square of the relative differences) is equal to 3.2% and the average of the relative differences is equal to 0.5%) than with the DOAS method (RMS=4.7%, average of the relative differences=1.9%) and there is a strong SZA effect.

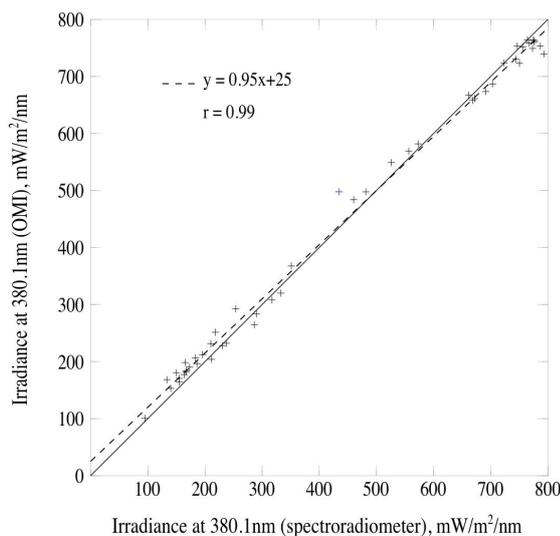
## 3.2 Surface UV comparisons

### 3.2.1 Spectral UV

OMI spectral irradiances are available in VdA at the time of overpass. Figure 3a shows the comparison with the spectroradiometer at wavelength 324.1 nm and Fig. 3b shows the comparison at wavelength 380.1 nm for the period October 2005–February 2007 only for clear sky conditions. The correlations are excellent at both wavelengths but we observe that there is a bias at 324.1 nm and that the regression line is worse at 380.1 nm.



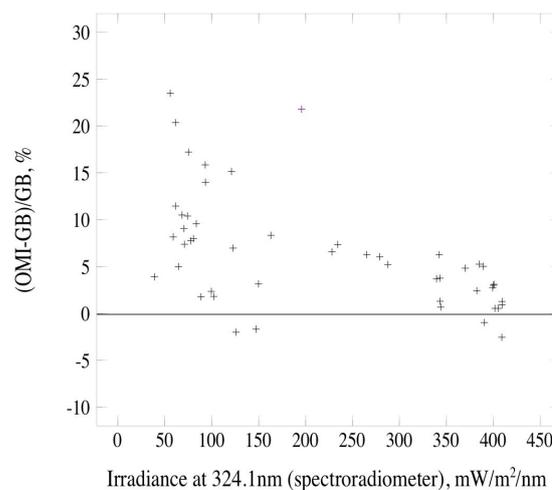
**Fig. 3a.** Comparison between spectral irradiance at 324.1 nm from the spectroradiometer in VdA and from OMI at the time of overpass for clear skies (the violet cross is studied later).



**Fig. 3b.** Same as Fig. 3a but at 380.1 nm.

The relative difference is plotted versus the spectral irradiance measured by the spectroradiometer in Fig. 3c (324.1 nm) and in Fig. 3d (380.1 nm). The bias observed in Fig. 3a for 324.1 nm appears clearly, it is about 6.5%; moreover we can note at both wavelengths larger differences up to 25% for low irradiances.

If we look at the plot of the relative differences versus SZA (Fig. 3e), we see larger discrepancies for  $SZA > 65^\circ$  at both wavelengths with  $OMI > GB$  in most cases. For these SZA, the irradiance is low and the uncertainty on the measurements with the ground-based spectroradiometer is larger than at smaller SZA. Only one measurement obtained for  $SZA=53^\circ$  gives differences larger than the average values at both wavelengths (violet cross and circle).

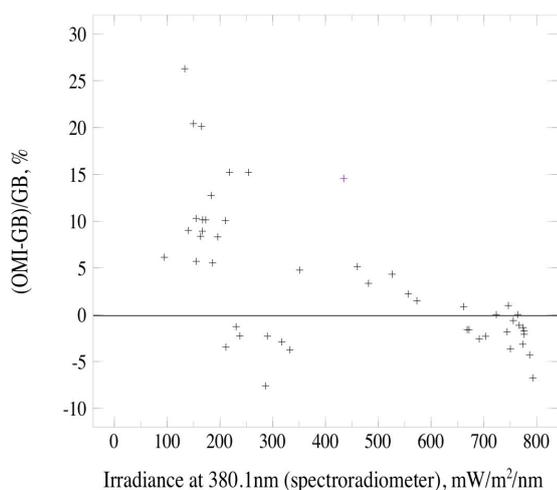


**Fig. 3c.** Relative differences between ground-based and OMI spectral irradiances at 324.1 nm as a function of the spectroradiometer irradiance in VdA for clear skies.

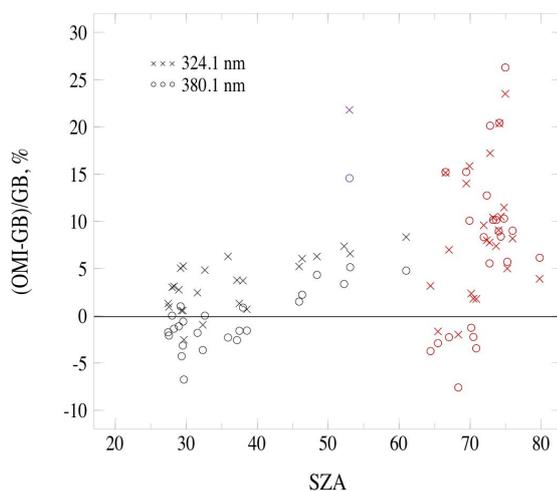
Under clear sky conditions, the aerosol optical thickness (AOT) is routinely retrieved from the spectroradiometer measurements (Brogniez et al., submitted, same issue), the lower wavelength at which AOT is retrieved with confidence is 330 nm. Figure 3f and g shows that there exists a weak correlation between the differences and the AOT for most days (the correlation coefficient is about 0.6), larger relative differences correspond to larger AOT. Arola et al. (2005) have also studied for TOMS the correlation between UV irradiance differences at 324 nm and absorption AOT, they found a better correlation (about 0.8). Kazantzidis et al. (2006) made the same studies but with AOT and found a correlation greater than 0.65. But larger differences at larger SZA seen on Fig. 3e are not systematically explained by large aerosol contents (the AOT for these days are small). Concerning the violet cross for 324.1 nm in Fig. 3e ( $SZA=53^\circ$ ), the large relative difference (23%) can be explained by the large AOT (0.47, violet plus in Fig. 3f). Similarly for 380.1 nm, the large relative difference (15%) (violet circle in Fig. 3e) is explained by the large AOT (0.47, violet plus in Fig. 3g).

### 3.2.2 Erythral dose rate

OMI-derived erythral dose rates (EDR) are also available for VdA at the time of overpass. Figure 4a and b shows the comparison with the spectroradiometer and the radiometer for the period October 2005–February 2007 for all sky conditions. OMI surface UV algorithm overestimates the dose rate by about 33% on average for the spectroradiometer and about 69% on average for the radiometer. These values can be explained by the large relative differences at low levels. If we remove the low EDR values, for example lower than  $20 \text{ mW/m}^2$ , we get 22% and 34% (with about half of the points) respectively.



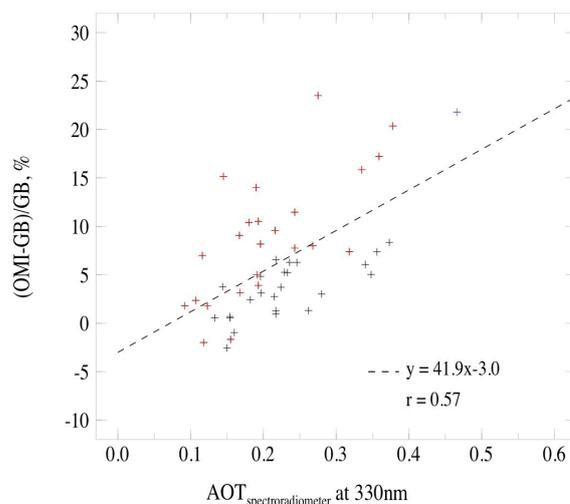
**Fig. 3d.** Same as Fig. 3c for 380.1 nm.



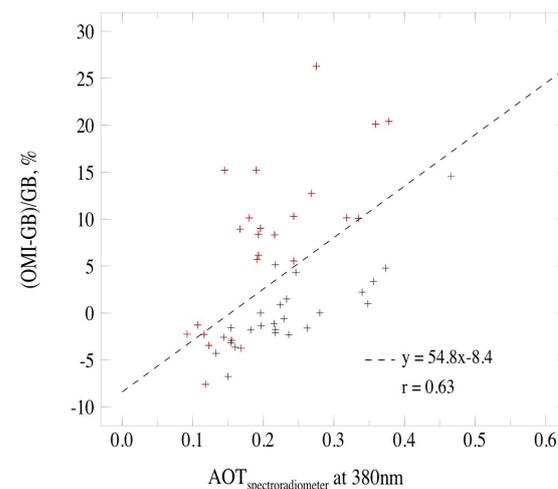
**Fig. 3e.** Relative differences between ground-based and OMI spectral irradiances for both wavelengths as a function of SZA in VdA for clear skies (red cross and circle for  $\text{SZA} > 65^\circ$ ).

The relative differences  $(\text{OMI-GB})/\text{GB}$  studied versus the cloud optical depth at 360 nm (COD) that is derived by the OMI surface UV algorithm, show a dependence (Fig. 4c). The difference between OMI and GB is more important for large COD. A similar study of the relative difference versus the distance between the OMI pixel and the VdA site shows no correlation (not shown).

The same comparison conducted on spectroradiometer data for clear skies only (Fig. 4d) exhibits the same behaviour, however the number of pairs is small (54 points). The points are less scattered than for all sky conditions, (the correlation coefficient is equal to 0.99 and the RMS is about 20%).



**Fig. 3f.** Relative differences between ground-based and OMI spectral irradiance at 324.1 nm as a function of AOT at 330 nm in VdA for clear skies (red cross for  $\text{SZA} > 65^\circ$ ).



**Fig. 3g.** Relative differences between ground-based and OMI spectral irradiances at 380.1 nm as a function of AOT at 380 nm in VdA for clear skies (red cross for  $\text{SZA} > 65^\circ$ ).

As can be seen in Fig. 4e, a weak correlation ( $r=0.60$ ) exists between the relative difference and the aerosol content. The bias appears larger at bigger values of AOT. Correlation with the presence of absorbing aerosols is not yet studied since the SSA is not available in the UV range in VdA.

### 3.2.3 Erythemal daily dose

Figure 5a shows the scatter plot of the erythemal daily doses (EDD) derived from OMI and from the spectroradiometer in Briançon for the period October 2004–September 2005 for all sky conditions.

Time series of the relative differences are shown in Fig. 5b. The data pairs are grouped in three classes: clear-sky, cloudy sky, and snow-covered surface (cloudy or not).

**Table 1.** Summary of TOC OMI validation results ( $r$  is the correlation coefficient;  $n$  is the number of days included in the comparison; the Root Mean Square:

$$\text{RMS} \left( \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - x_i)^2} \right), \text{ the \% RMS} \left( \sqrt{\frac{1}{n} \sum_{i=1}^n \left( \frac{y_i - x_i}{x_i} \right)^2} \times 100 \right) \text{ and the mean relative difference in \%} \left( \frac{1}{n} \sum_{i=1}^n \left( \frac{y_i - x_i}{x_i} \right) \times 100 \right).$$

	$n$	$r$	slope	intercept	RMS	Mean relative differences
Briançon TOC (OMI TOMS-like)	348	0.98	0.95	6.1	13.8 DU (4.1%)	−3.1%
clear sky Briançon TOC (OMI TOMS-like)	78	0.99	0.99	−7.1	11.9 DU (3.7%)	−3.2%
VdA TOC (OMI TOMS-like)	662	0.97	0.96	15.1	10.4 DU (3.2%)	0.5%
clear sky VdA TOC (OMI TOMS-like)	56	0.98	0.98	7.6	6.2 DU (1.9%)	0.1%
VdA TOC (OMI DOAS-like)	684	0.95	0.95	22.1	15 DU (4.7%)	1.9%
clear sky VdA TOC (OMI DOAS-like)	56	0.96	0.99	6.3	10.6 DU (3.3%)	1.4%

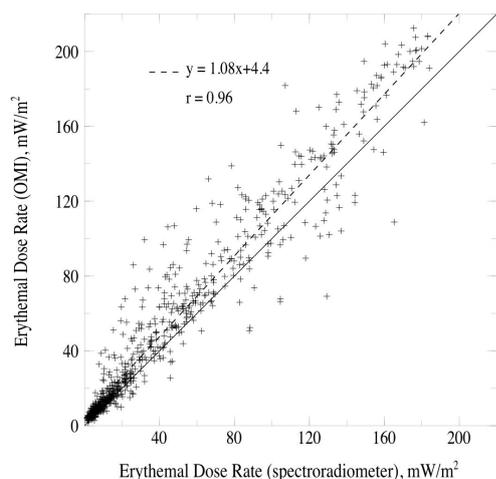
**Table 2.** Summary of UV OMI validation results.

	$n$	$r$	slope	intercept	RMS	Mean relative differences
VdA EDR OMI= $f$ (spectroradiometer)	723	0.96	1.08	4.4	16.5 mW/m <sup>2</sup> (58%)	32.5%
clear sky VdA EDR OMI= $f$ (spectroradiometer)	54	0.99	1.14	0.5	14.7 mW/m <sup>2</sup> (20%)	16.8%
VdA EDR OMI= $f$ (radiometer)	627	0.96	1.13	6.2	17.1 mW/m <sup>2</sup> (110%)	69.3%
clear sky VdA EDR OMI= $f$ (radiometer)	45	0.99	1.14	4.2	15.1 mW/m <sup>2</sup> (45%)	38.9%
Briançon EDD OMI= $f$ (spectroradiometer)	293	0.97	1.22	−154	514 J/m <sup>2</sup> (24%)	7.9%
VdA EDD OMI= $f$ (spectroradiometer)	349	0.99	1.14	16.6	340 J/m <sup>2</sup> (27.5%)	17.1%
clear sky VdA EDD OMI= $f$ (spectroradiometer)	33	0.99	1.13	2.3	340 J/m <sup>2</sup> (13.5%)	13%
clear sky VdA Spectral UV 324.1 nm	49	0.99	1.0	8.3	12.5 mW/m <sup>2</sup> /nm (8.8%)	6.4%
clear sky VdA Spectral UV 380.1 nm	49	0.99	0.95	25	21.5 mW/m <sup>2</sup> /nm (8.4%)	3.7%

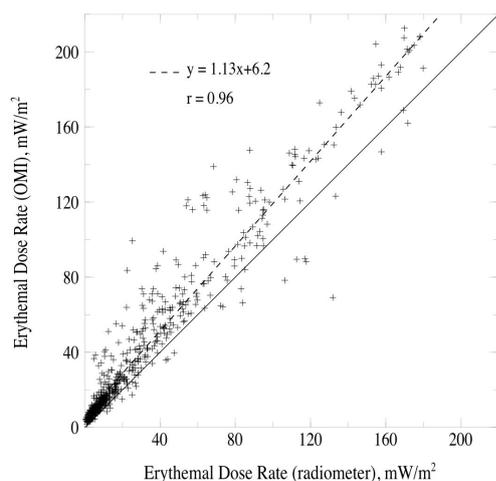
It appears that when the ground is covered with snow, the OMI-derived daily dose is generally lower than the ground-based measurement, with large relative difference. The surface albedo used by the OMI surface UV algorithm is a climatological one, and likely it was lower than the actual effective surface albedo at least during the validation campaign. Past studies have also revealed this underestimation

of the surface UV provided by TOMS data (Kalliskota et al., 2000; Krotkov et al., 2001, 2002).

If we consider all the data, the average of the relative differences is 8%, but when excluding snowy days, there is a positive difference for the majority of points (generally in summer) and the average of the relative differences is about 14%.



**Fig. 4a.** Comparison between erythemal dose rate from the spectroradiometer in VdA and erythemal dose rate from OMI at the time of overpass. The equation of the regression line (dash line) and the correlation coefficient are indicated, the solid line is the first bisector.

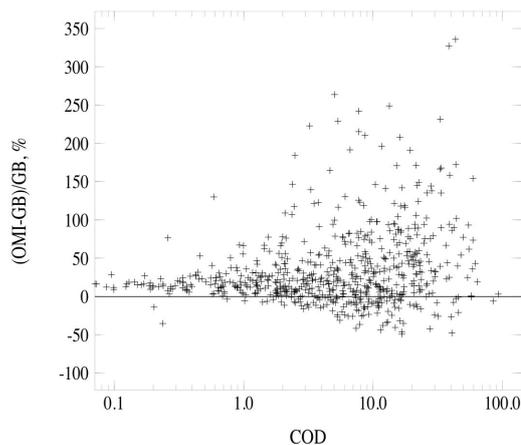


**Fig. 4b.** Same as Fig. 4a but for the broadband radiometer.

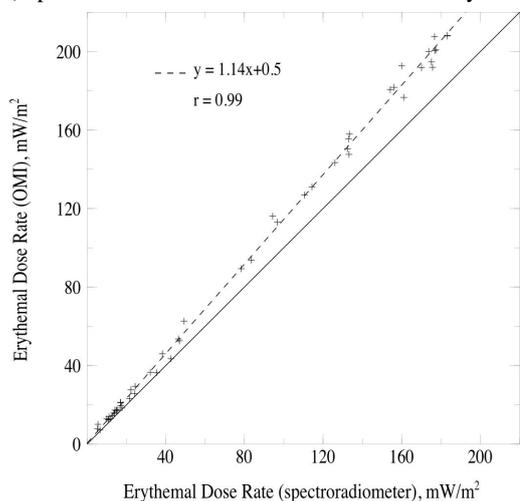
Finally, Fig. 5c compares the erythemal daily doses in VdA for the period October 2005–July 2006 for all sky conditions.

In VdA, a positive bias appears ( $OMI > GB$ ) as well as in Briançon when excluding snowy days, the average of relative differences is about 17% for all sky conditions (Fig. 5d). For clear sky days (black dots), the relative differences are smaller, they do not exceed 22%, but the bias remains (Fig. 5d), the average of relative differences is about 13%.

As mentioned in Sect. 2.2.2, a bias is also observed in a previous validation work conducted with measurements at several sites (Tanskanen et al., 2007).



**Fig. 4c.** Relative differences of erythemal dose rates (OMI-spectro)/spectro as a function of COD in VdA for all sky conditions.



**Fig. 4d.** Same as Fig. 4a but for clear skies only.

## 4 Summary

The previous results from the scatter plots are summarized in Table 1 for ozone, in Table 2 for UV. For each comparison, we report the number of data pairs and in parentheses the number of points ( $n$ ), the correlation coefficient ( $r$ ), the slope and the intercept of the regression line, the RMS

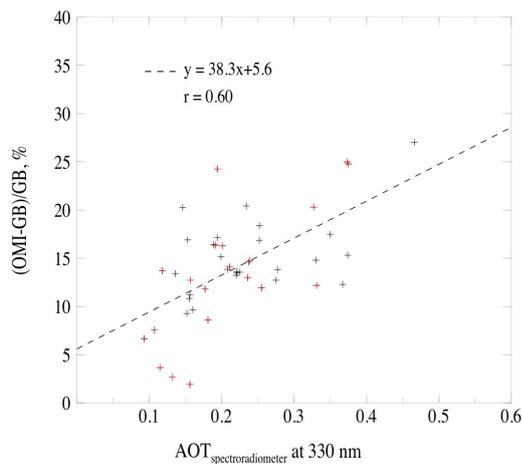
$$\left( \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - x_i)^2} \right),$$

the % RMS

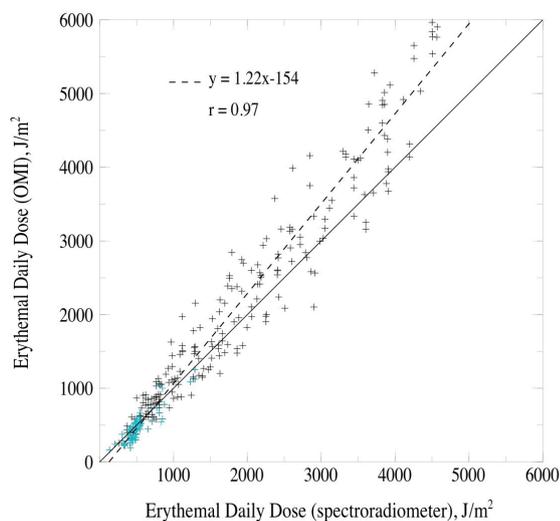
$$\left( \sqrt{\frac{1}{n} \sum_{i=1}^n \left( \frac{y_i - x_i}{x_i} \right)^2} \times 100 \right)$$

and the mean relative difference in %

$$\left( \frac{1}{n} \sum_{i=1}^n \left( \frac{y_i - x_i}{x_i} \right) \times 100 \right).$$



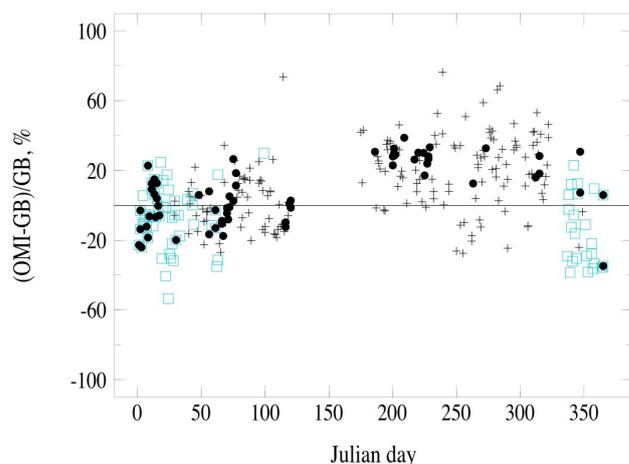
**Fig. 4e.** Relative differences of erythemal dose rates (OMI-spectro)/spectro as a function of AOT at 330 nm in VdA for clear skies (red cross for SZA >65°).



**Fig. 5a.** Comparison between erythemal daily doses from the spectroradiometer in Briançon and from OMI. The blue cross indicate snowy surface. The equation of the regression line (dash line) and the correlation coefficient are indicated, the solid line is the first bisector.

## 5 Conclusions

The aim of this study was to compare OMI products with measurements performed by ground-based UV instruments located at two French sites. Two spectroradiometers were used, one operating at VdA and the other at Briançon. The comparison of the total column of ozone shows a satisfying agreement at both sites for the OMI-TOMS-like product (the RMS are 4.1% for Briançon and 3.2% for VdA). For the OMI-DOAS-like product, the comparison conducted at VdA is less satisfying (RMS=4.7%) and a seasonal variation of the agreement appears. This phenomenon is related to a SZA effect and has been reduced in the new version of the



**Fig. 5b.** Time series of the relative differences between ground-based and OMI erythemal daily doses in Briançon (cross for cloudy day, blue squares are for snowy surface and black dots are for clear days, black dots inside blue squares are for clear snowy days).

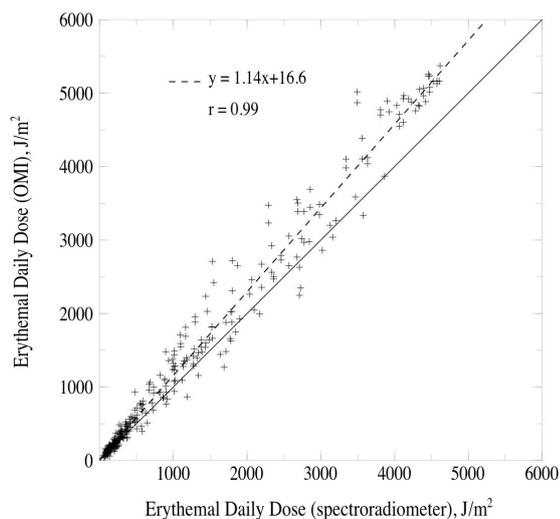
data according to (Kroon et al., 2008) (collection 3, overpass files not yet available).

For this validation campaign a modified version of the OMI surface UV algorithm was used to provide irradiances at 324.1 and 380.1 nm and OMI erythemal dose rates at the time of overpass at VdA.

Spectral UV comparisons are satisfying for VdA (the mean relative differences are 6.5% and 3.7% for 324.1 and 380.1 nm respectively). For both wavelengths, the largest differences are observed at low irradiance level (large SZA). If we neglect the low EDR values, the comparisons of OMI erythemal dose rates for VdA show an overestimation of the ground-based dose rates of about 22% on average for the spectroradiometer and 34% on average for the radiometer. The same effect appears for the erythemal daily doses with an overestimation of about 17%. For the site of Briançon, for most days OMI overestimates also ground-based erythemal daily doses (14% for all sky days without snow-covered surface). If we take into account the days with snow-covered surface, the mean difference is reduced (about 8%). These observed biases between OMI erythemal dose rates, OMI erythemal daily doses and ground-based data are in agreement with previous results obtained at other sites, including snow-covered surface cases (Tanskanen et al., 2007).

The study of the impact of the AOT on the quality of the agreement show that large AOT values can explain sometimes, large discrepancies between ground-based and satellite UV products.

The better agreement observed for spectral UV compared to the erythemal daily dose and dose rate can be explained considering that the erythemal doses concern a shorter wavelength range and that the validation of spectral irradiance at 305 and 310 nm is not included in the current validation work.



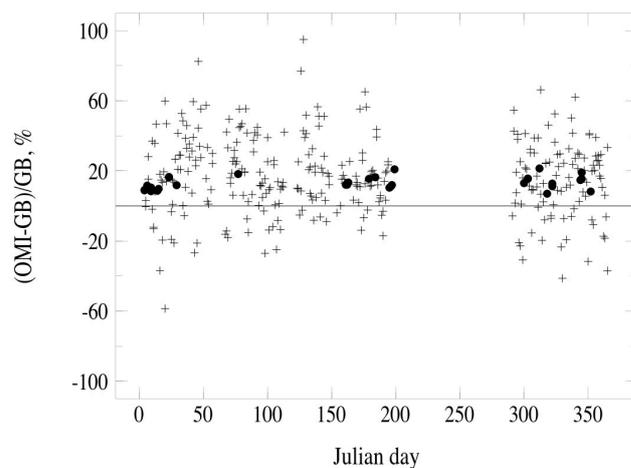
**Fig. 5c.** Same as Fig. 5a but in VdA.

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**Fig. 5d.** Same as Fig. 5b but in VdA.

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