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Validation of the MetOp-A total ozone data from GOME-2 and IASI using reference ground-based measurements at the Iberian Peninsula

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A B S T R A C T

One of the most important atmospheric composition products derived from the first EUMETSAT Meteorological Operational satellite (MetOp-A) is the total ozone column (TOC). For this purpose, MetOp-A has two instruments on board: the Global Ozone Monitoring Experiment 2 (GOME-2) that retrieves the TOC data from the backscattered solar ultraviolet–visible (UV–Vis) radiance, and the Infrared Atmospheric Sounding Interferometer (IASI) that uses the thermal infrared radiance to derive TOC data. This paper focuses on the simultaneous validation of the TOC data provided by these two MetOp-A instruments using the measurements recorded by five well-calibrated Brewer UV spectrophotometers located at the Iberian Peninsula during the complete 2009. The results show an excellent correlation between the ground-based data and the GOME-2 and IASI satellite observations (R^2 higher than 0.91). Differences between the ground-based and satellite TOC data show that the IASI instrument significantly overestimates the Brewer measurements (about 4.4% when all five ground-based stations are jointly used). In contrast, the GOME-2 instrument shows a slight underestimation (~1.6%). In addition, the absolute relative differences between the Brewer and GOME-2 data are quite smaller (about a factor higher than 2) than the Brewer–IASI absolute differences. The satellite viewing geometry (solar zenith angle and the view zenith angle) has no significant influence on the Brewer–satellite relative differences. Moreover, the analysis of these relative differences with respect to the ground-based TOC data indicates that GOME-2 instrument presents a slight underestimation for high TOC values. Finally, the IASI–GOME-2 correlation is high (R^2~0.92), but with a mean relative difference of about ±6% which could be associated with the bias between UV–Vis and infrared spectroscopy used in the retrieval processes.

1. Introduction

Monitoring the evolution of the ozone layer has become a subject of major concern both by the scientific community and the general public from a wider perspective, including the close relationship between the ozone layer changes and the global climate change (World Meteorological Organization, WMO, 2006). With the most advanced atmospheric models predicting global ozone recovery only on the next decades, it is of great scientific and societal importance to maintain a global long-term record of accurate ozone measurements (Loyola et al., 2009).

There are several instruments on board satellites which have been designed for retrieving ozone and other trace gases in the atmosphere, providing daily images of the global total ozone column (TOC) with uniform spatial coverage. These satellite instruments are a very useful tool for understanding the geographical and temporal distribution and variability of the ozone on a global scale. In this context, the Meteorological Operational satellite program (MetOp) from the European organization for the exploitation of METeorological SATellites (EUMETSAT) foresees a series of three polar-orbit platforms which will be launched sequentially every 5 years in order to provide continuous meteorological observations for at least 15 years (2006–2020). The first of these satellites (MetOp-A) was launched in October 2006 and the MetOp-B and MetOp-C are expected to be flying in 2012 and 2016, respectively. The main objective of the MetOp mission is to deliver continuous and long-term datasets supporting operational meteorology, global weather forecasting and climate monitoring (Edwards et al., 2006).

Two of the instruments on board MetOp-A are the Global Ozone Monitoring Experiment 2 (GOME-2) (Munro et al., 2006) and the

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Infrared Atmospheric Sounding Interferometer (IASI) (Clerbaux et al., 2009, 2007). Both sensors retrieve total ozone column and ozone profile information with a high spatial and temporal resolution, but while the GOME-2 instrument obtains the total ozone from the backscattered solar ultraviolet–visible (UV–Vis) radiance emerging at the top of the atmosphere, the IASI instrument retrieves it from the thermal infrared radiance (TIR) resulting from the interaction between the Earth's thermal emission and the atmosphere.

To ensure the quality of the satellite TOC observations, the comparison of these satellite data with reliable ground-based ozone measurements has proven to be a crucial activity (WMO, 1999). In this context, the Spanish Agency of Meteorology (AEMet) has accumulated nearly twenty years of experience in measuring TOC with Brewer spectrophotometers. All instruments from the Spanish Brewer network follow the same protocol of calibration and are biannually calibrated by comparison with the traveling references Brewer #017 from the International Ozone Services (IOS) and Brewer #185 from the Regional Brewer Calibration Centre — Europe (RBCC-E). Comparisons with these traveling reference instruments confirm the reliability of the Spanish Brewer calibration (Redondas et al., 2002, 2008). When Brewer spectrophotometers are properly calibrated and regularly maintained, as is the case of the entire Spanish Brewer Network, the TOC records obtained through direct sunlight (DS) measurements can potentially maintain an estimated accuracy of 1% over long time intervals (WMO, 1996). Thus, the instruments of this network have been successfully used to perform exhaustive validation exercises of diverse satellite total ozone datasets (Antón et al., 2010a, 2009a,b, 2008, 2010).

Several validation exercises on the GOME-2 total ozone data have been performed using ground-based spectrophotometers (e.g., Antón et al., 2009a; Balis et al., 2007, 2008). Loyola et al. (in press) showed that the GOME-2/MetOp-A total ozone data (GDP 4.4 version) slightly underestimates ground-based TOC data by about 0.5% to 1.0% over the middle latitudes of the Northern Hemisphere. In addition, some studies have focused on the comparison of the IASI TOC data with ground-based measurements recorded by spectrophotometers, e.g. Boynard et al. (2009), who showed that IASI ozone retrievals present a positive bias of about 3% compared to both GOME-2 and ground-based measurements. These works confirm the need of a continuous validation effort of the GOME-2 and IASI total ozone data using reliable ground-based measurements is required in order to assess its quality and accuracy.

The main objective of this paper is to report on a detailed validation of the MetOp-A TOC data derived from the GOME-2 and IASI instruments, using as reference spatially and temporally co-located ground-based measurements from the well established Spanish network of Brewer spectrophotometers. The period of study covers the period January–December 2009. The observed discrepancies are quantified and their likely origins examined in detail. Although this work is focused on a regional scale (Iberian Peninsula), it provides new insights into the accuracy of the satellite retrievals since to the best of our knowledge, no simultaneous comparisons between these two instruments flying aboard the MetOp-A satellite and ground-based data have been published to date. In addition, this paper presents the first validation of the IASI total ozone data derived from the new operational retrieval software called FORLI (Fast Optimal Retrievals on Layers for IASI).

The paper is organized as follows. The satellite and ground-based measurements are described in Section 2. Section 3 introduces the validation methodology. The results and discussion are presented in Section 4. Finally, Section 5 summarizes the main conclusions.

2. Data

2.1. Satellite observations

GOME-2 is a nadir-viewing scanning spectrometer that covers the UV–Vis spectral range from about 240 to 790 nm, with a resolution varying from 0.26 to 0.51 nm. GOME-2 instrument has a swath-width of 1920 km with a constant ground pixel size of 80×40 km^2, resulting in a daily near global coverage at the equator. The current operational algorithm for the retrieval of total ozone column from the GOME-2 instrument is the GOME-2 Data Processor Version 4.4 (GDP 4.4). The GDP algorithm has undergone several years of progressive improvements since its first release in 1995 (Loyola et al., 1997, in press; Spurr et al., 2005; Van Roozendael et al., 2006). This retrieval algorithm uses two main steps to derive the total ozone column: the Differential Optical Absorption Spectroscopy (DOAS) least-squares fitting over the 325–335 nm fitting window for the retrieval of the slant ozone column, followed by the computation of a suitable Air Mass Factor (AMF) from the multiple-scattering radiative transfer code LIDORT (Spurr, 2008) to perform the conversion to the vertical column density. In addition, the GDP 4.4 includes two algorithms (OCRA and ROCCIN) for the treatment of clouds from GOME-2 measurements (Loyola et al., 2007).

IASI is a nadir-viewing Fourier Transform Spectrometer (FTS) designed to measure the spectrum emitted by the Earth-atmosphere system in the TIR spectral range from 3.62 to 15.5 μm with a resolution varying between 0.002 and 0.003 μm. This spectral range includes the strong absorption features from the ozone absorption band around 9.6 μm. Regarding the horizontal coverage, the IASI instrument has a swath-width of about 2200 km achieving global coverage. Each instantaneous field-of view (50 km $\times$ 50 km at nadir) is composed of a matrix of 2×2 circular pixels, with 12 km diameter footprint on the ground at nadir. TOC values are retrieved from the IASI spectra using the FORLI retrieval software which is based on the optimal estimation method described by Rodgers (2000). The FORLI software was initially developed to retrieve carbon monoxide (George et al., 2009; Turquety et al., 2009) and nitric acid (Wespes et al., 2009) concentrations, and was recently adapted to ozone. The FORLI code minimizes the difference between the observation and simulation by iteratively updating the state vector (set of unknown parameters) under constraints. For each observation the inputs are the corresponding IASI level 1C spectra and the IASI level 2 temperature and humidity profiles, as well as the IASI level 2 cloud cover. The direct computation of each spectrum is based on appropriate radiative transfer with speed-up approximations, and line-by-line computations saved in look-up tables which have a spectral oversampling of 100 (e.g. sampling of 2.5×10^{-4} cm^{-1}). These tables are pre-computed on a logarithmic grid in pressure (4.5×10^{-5} to 1.22 atm), a linear grid in temperature (162.8 to 322.64 K) and eventually a linear grid in humidity (for water vapor lines), and interpolated accordingly. The spectrum is processed when the cloud contamination of the pixel is lower than 13%. This threshold was empirically set up by looking to nearby pixel data that are not contaminated by clouds. The outputs are the ozone profile, the total ozone column, as well as the error covariance and averaging kernel matrices describing the vertical sensitivity.

Fig. 1 shows the averaging kernel (AK) profiles of both IASI and GOME-2 algorithms over Madrid for a specific date (10-June-2009). In addition, the experimental ozone profile recorded in this location for the same date has been added to the plot. This ozone profile was recorded using a balloon-borne ozonesonde which employs Electrochemical Concentration Cell (ECC) sensor and it is interfaced to Vaisala RS80-15G radiosonde. The figure shows that ozonesonde reached an altitude of 32 km. Moreover, the different vertical sensitivities of two satellite instruments can be clearly seen. On the one hand, the IASI instrument has a maximum sensitivity in the free troposphere between 5 and 10 km approximately. The vertical resolution of this instrument depends on the emissivity and thermal contrast at the location of the observation. The retrieved profiles are vertically correlated and the number of independent information ranges between 3 and 5. On the other hand, the sensitivity of GOME-2 instrument to the ozone density is strongly height dependent in the troposphere, presenting a maximum sensitivity in the stratosphere where the larger amount of ozone is located. Furthermore, the GOME-2 AK profile in the troposphere depends

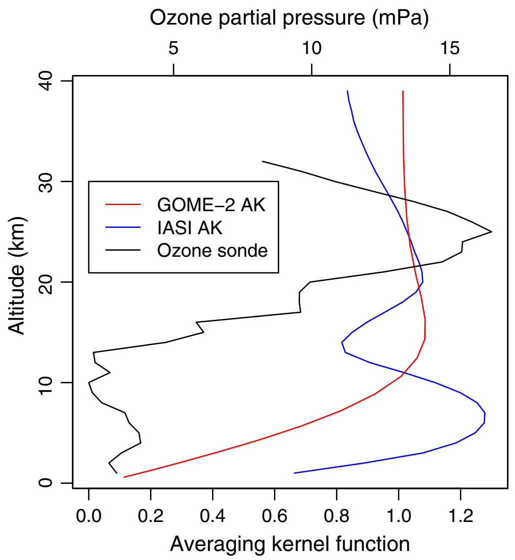

Fig. 1. The averaging of kernel (AK) profiles of both IASI and GOME-2 algorithms over Madrid for a specific date (10-June-2009). The experimental ozone profile recorded in this location for the same date has been also added to this plot (black curve).

strongly on the albedo. The surface albedo for the selected (cloud-free) measurement over Madrid is ~4% in the UV region.

2.2. Ground-based measurements

In the satellite remote sensing community, the worldwide network of Brewer spectrophotometers is considered as the "ground-truth" standard for observations of total ozone column. The fully automated ozone measurement of the Brewer instruments relies on the method of differential absorption in the Huggins band where ozone exhibits strong absorption features in the ultraviolet part of the solar spectrum. The Brewer spectrophotometer takes the ratio of sunlight intensities at four wavelengths between 306 and 320 nm with a resolution of 0.6 nm overcoming the spectral interference of sulphur dioxide with ozone (Kerr, 2002; Kerr et al., 1984). This technique has been described in detail by several reference papers, e.g., Dobson (1957), Komhyr (1980), Basher (1982).

The five Brewer instruments used in this work belong to the Spanish Brewer spectrophotometer network which is operated by the Spanish Agency of Meteorology (AEMet). The ground-based stations are from north to south: Coruña (43.3° N, 8.42° W), Zaragoza (41.01° N, 1.01° W), Madrid (40.45° N, 3.72° W), Murcia (38.03° N, 1.17° W) and El Arenosillo (37.06° N, 6.44° W). Thanks to the traveling reference Brewer instruments, the absolute ozone calibration of all Spanish Brewer spectrophotometers is traceable to the triad of international reference Brewer instruments maintained by Meteorological Service of Canada at Toronto (Fioletov et al., 2005). In addition, periodic checks and tests (daily, weekly, and monthly) are performed to guarantee the accuracy in the spectral measurements and consequently the quality in TOC retrieval.

3. Validation methodology

We work with the GOME-2 total ozone data within 100 km of the ground-based stations. The Brewer measurement nearest to GOME-2 overpass time (between 9:15 and 11:30 local time) is selected everyday in order to gain the best time coincidence. The average delay between the GOME-2 observations and the Brewer measurements ranges between 24 min at Murcia (minimum) and 40 min at Coruña (maximum).

IASI observations within 0.5° of each Brewer station are selected, resulting in a maximum distance of 50 km between the center of the satellite pixel and the ground-based station. In addition, IASI measures on average twice a day each location on the Earth's surface about at 09:30 and 21:30 local time. In this work, the daytime satellite TOC observations, collocated to the ground-based stations, are averaged every day. Finally, we select the Brewer measurements closest to these daily IASI overpasses for the morning overpass. The average differences in time between the IASI and the Brewer measurements are of about 20 min. Since the Brewer instrument only measures during daytime, only morning IASI observations are considered.

Table 1 shows the number of pairs of ground-based-satellite data used in this work. It can be seen that the number of cases corresponding to GOME-2 instrument is significantly higher than the number of cases for IASI instrument. This fact is due to the IASI instrument only records TOC data under cloud-free conditions, while the GOME-2 instrument derives TOC data for all sky conditions.

The relative differences (RD) between the satellite (SAT) TOC observations and the ground-based (GB) TOC measurements are calculated for spatial-temporal collocation of each station with the following. expression:

$$RD_i = 100 \times \frac{(SAT_i - GB_i)}{GB_i} \quad (1)$$

Comparisons between satellite and ground-based TOC data are obtained separately using the GOME-2 and IASI datasets. Thus, the dependence of these relative differences as a function of the solar zenith angle (SZA), satellite view zenith angle (VZA), and Brewer TOC measurements are analyzed for each** dataset.

From the relative differences derived from expression 1, the mean bias error (MBE) and the mean absolute bias error (MABE) parameter were also calculated for each dataset as:

$$MBE = \frac{1}{N}\sum_{i=1}^{N} RD_i \quad (2)$$

$$MABE = \frac{1}{N}\sum_{i=1}^{N} |RD_i| \quad (3)$$

where N is the number of data pairs GOME-2–Brewer (or IASI–Brewer).

In addition, a linear regression analysis is performed between the TOC values recorded by ground-based spectrophotometers and the satellite instruments. Regression coefficients, coefficients of correlation

Table 1
Parameters obtained in the correlation analysis between GOME-2 data (upper rows) and Brewer measurements as gathered over the Iberian Peninsula during 2009. Results for the IASI correlation are shown in the lower rows. The parameters are the following: the number of data (N), the slope of the regression, the correlation coefficients (R^2), the root mean square errors (RMSE), the mean bias error (MBE) and the mean absolute bias error (MABE).

	N	Slope	R^2	RMSE (%)	MBE (%)	MABE (%)
Madrid	320	0.99 ± 0.01	0.98	1.58	−1.15 ± 1.58	1.58 ± 1.15
	226	0.93 ± 0.01	0.94	2.44	+4.59 ± 2.58	4.70 ± 2.37
Murcia	318	0.99 ± 0.01	0.97	1.81	−2.20 ± 1.77	2.43 ± 1.43
	224	0.93 ± 0.01	0.94	2.65	+5.21 ± 2.80	5.25 ± 2.72
Coruña	249	1.00 ± 0.01	0.94	2.70	−2.71 ± 2.63	3.04 ± 2.25
	173	0.91 ± 0.02)	0.94	3.01	+4.06 ± 3.26	4.35 ± 2.84
Zaragoza	292	0.96 ± 0.01	0.98	1.70	−1.24 ± 1.79	1.78 ± 1.25
	189	0.91 ± 0.01	0.94	2.42	+4.34 ± 2.61	4.44 ± 2.43
Arenosillo	319	0.98 ± 0.01	0.97	1.82	−1.28 ± 1.92	1.56 ± 1.33
	236	0.91 ± 0.02	0.91	2.65	+3.68 ± 3.40	3.96 ± 3.07
Iberian	1498	0.98 ± 0.01	0.96	1.90	−1.59 ± 2.04	2.04 ± 1.59
Peninsula	1048	0.91 ± 0.02	0.93	2.81	+4.38 ± 2.99	4.55 ± 2.74

(R^2) and the root mean square errors (RMSE) are evaluated in this analysis.

4. Results and discussion

A linear regression analysis on the total ozone column data measured from the satellite-based and ground-based instruments is performed in order to investigate their consistency. Statistical parameters obtained from the fitting between the Brewer and the GOME-2 and IASI total ozone data are shown in Table 1 for the five ground-based stations and for the "Iberian Peninsula" dataset (all data). When comparing the MBE values of each ground-based station, it is noted that for the GOME-2–Brewer analysis, the difference between the maximum (−1.15% at Madrid) and minimum (−2.71% at Coruña) MBE value is 1.56%. In addition, for the IASI–Brewer analysis, the difference between the maximum (+5.21% at Murcia) and minimum (+3.68% at El Arenosillo) MBE values is 1.53%. Therefore, the station-to-station biases are lower than 1.6% for the two satellite instruments, indicating the consistency and low variability of the Spanish Brewer Network. The correlation between the satellite total ozone observations and the Brewer measurements is significantly high for the two satellite instruments onboard MetOP-A, with correlation coefficients higher than 0.91 for all cases. The two scatter plots shown in Fig. 2 between satellite and ground-based data for the "Iberian Peninsula" dataset reveal this high degree of agreement. The solid line is the zero bias line (unit slope). The plots indicate that while GOME-2 TOC observations slightly underestimate the ground-based TOC data, the IASI instrument tends to overestimate the measurements recorded by the Brewer spectrophotometers. This behavior is corroborated by the opposite sign of the MBE parameters for both correlations. On average for the "Iberian Peninsula" dataset, the underestimation is 1.59% with ±2.04% one standard deviation for GOME-2 instrument and the overestimation is (4.38±2.99)% for the IASI instrument. In addition, it can be seen that the RMSE values and uncertainty of MBE and MABE parameters are significantly lower for GOME-2 data than the IASI data. These results indicate that the Brewer–GOME-2 correlation presents a smaller statistical spread that the Brewer–IASI correlation which could be probably due to the higher signal to noise response of the GOME-2 instrument. On the other hand, the MABE parameter presents a value for the "Iberian Peninsula" dataset of (4.55±2.74)% for the IASI instrument. It can be seen that the MBE and MABE values present very similar values for this satellite instrument, revealing the presence of a significant bias. The MABE parameter is reduced to a more reliable value of (2.04±1.59)% when GOME-2 data are used in the comparison with the Brewer measurements. Therefore, the GOME-2 instrument shows a clear better agreement with respect to the Brewer spectrophotometer than the IASI instrument. This result can be related to the fact that while IASI instruments measures in the infrared spectral range, both GOME-2 and Brewer instruments derive TOC from measurements in the UV–Vis spectral range. It is well known that a discrepancy in spectroscopic data exists when comparing UV–Vis and infrared instruments. In this direction, Schneider et al. (2008) reported a bias of 4.5% for simultaneous ground based observations recorded by UV–Vis and infrared instruments. In addition, it should also be pointed out that IASI and GOME-2 instruments have different vertical sensitivities (see Fig. 1).

In order to quantify the influence of the different vertical sensitivities on satellite ozone columns, we have analyzed a study case. The experimental ozone profile measured in Madrid in 10 June 2009 is convolved with both the GOME-2 and IASI averaging kernel profiles shown in Fig. 1. After the convolution, the ozone column for each satellite instruments is obtained by integration. The values of these estimated ozone columns (of altitude 32 km) are 228.1 DU and 232.1 DU for GOME-2 and IASI instruments, respectively. The experimental ozone column derived from the direct integration of the ozonesonde presents a value of 229.8 DU. It can be seen that while IASI instrument slightly overestimates the experimental data, the GOME-2 instrument slightly underestimates it. This result could partially explain that GOME-2 TOC data are on average smaller (1.59%) than Brewer measurements. However, the result shown for IASI instrument does not justify the notable overestimation of Brewer data (4.38%) obtained with this satellite instrument. For instance the Brewer TOC data measured in Madrid in 10 June 2009 was 324 DU. For this selected day, the satellite observations were 318 DU (GOME-2) and 342 DU (IASI). Therefore, this high total ozone value derived from IASI instrument is not related to its vertical sensitivity.

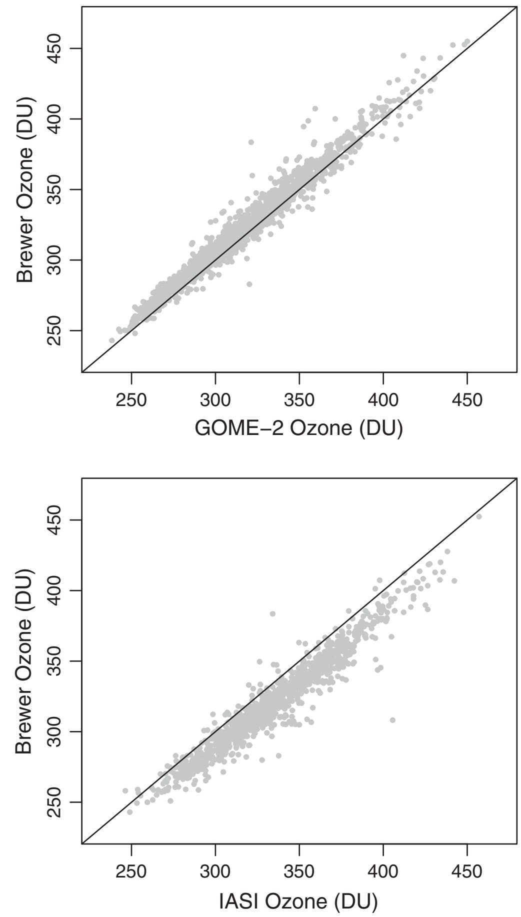

Fig. 2. Scatter plot between satellite and ground-based total ozone observations for the year 2009, plotted separately for GOME-2 (top) and IASI (bottom) instruments.

The time series of the ten-day running average of the daily mean relative differences between the satellite and the ground-based TOC measurements for the "Iberian Peninsula" dataset are shown in Fig. 3. This plot reveals the absence of systematic seasonal dependencies on the relative differences between the ground-based measurements and the satellite observations. Therefore, there is no evidence for significant change in the satellite TOC data over the period of comparison. This fact suggests that the relative differences between ground-based and satellite data present no significant dependence on the satellite ground pixel SZA. In this sense, using 5° bins of SZA, Fig. 4 shows the mean relative differences between ground-based measurements and satellite observations as a function of satellite ground pixel SZA for GOME-2 and IASI instruments. The error bars represent ±one standard deviation. This plot shows a remarkable constant behavior of these differences with respect to the satellite ground pixel SZA in the Iberian Peninsula, confirming the null seasonal dependence observed in Fig. 3.

It is known that the viewing geometry of the satellite observations notably varies over the covered ground swath, which is characterized

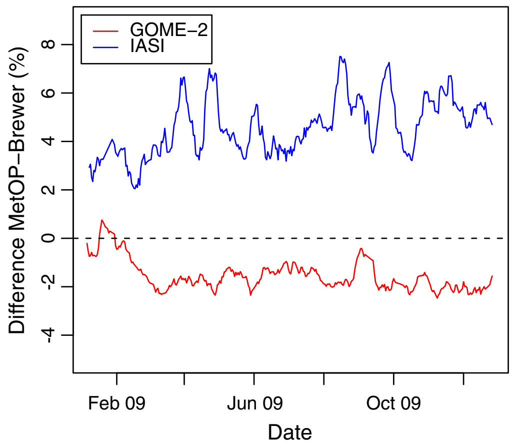

Fig. 3. Time series of the daily relative difference between satellite and ground-based total ozone data (running mean over ten days).

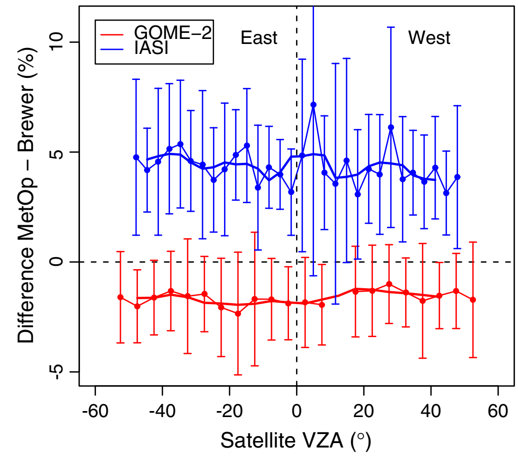

Fig. 5. Mean relative differences between satellite and ground-based total ozone data as a function of the satellite view zenith angle. The error bars correspond to ±one standard deviation.

by the view zenith angle (also called satellite scan angle), the solar zenith angle, and the relative azimuth angle as seen from the ground pixel. The GOME-2 instrument measured 24 scenes along the ground swath, one for each satellite view zenith angle stepping at 5° intervals between −60° and +60°. In a similar way, the IASI instrument presents 30 views spaced by 3.2° between −48° and +48°. Thus, it is very interesting to analyze whether the variation of the satellite scan angle affects the differences between satellite and ground-based TOC data. Fig. 5 shows the variation of the satellite–Brewer differences as a function of the satellite zenith view angle. Each point on the plot (in red and blue colours for GOME-2 and IASI instruments, respectively) represents the mean value of all relative differences for each satellite view. The error bars correspond to ±one standard deviation. The running average over four satellite views is superimposed on the plot for both instruments. Although the curve for the IASI instrument shows a slight negative slope East/West, this scan angle dependency is no significant (smaller than 1% between extreme views). The curve for the GOME-2 instrument shows a remarkable stability for the full range of view zenith angles. Therefore, the satellite TOC data retrieved from the GOME-2 and IASI instruments are independent of their satellite view zenith angle. Antón et al. (2009a) found a significant bias (about +1.5%) for the Brewer–GOME-2 differences between the West and East pixels (West higher than East). These authors worked with the GDP 4.2. Thus, this scan angle dependency has been already corrected in the more recent version 4.4 of the GOME-2 retrieval algorithm thanks to empirical corrections (Loyola et al., in press).

Fig. 6 shows the relative differences between ground-based and satellite TOC data as a function of the Brewer measurements for GOME-2 and IASI instruments. It can be seen that the IASI–Brewer relative differences present no significant ground-based total ozone dependence. In contrast, GOME-2 instrument shows slight total ozone dependence, with the relative differences about −2% except at the highest total ozone values where the deviation increases to −4%. This result could be associated with the differences between the true and the a priori climatological ozone profiles used in GDP (Antón et al., 2009a). Nevertheless, the satellite observations derived from the two satellite instruments practically cover the total ozone variability recorded by the Brewer spectrophotometer in the Iberian Peninsula.

Finally, the direct intercomparison between the GOME-2 and IASI instruments is analyzed for the period of study and for the "Iberian Peninsula" dataset. The number of simultaneous cases is 1141. Fig. 7 shows the scatter plot between the TOC data measured from the two satellite instruments. The solid line is the zero bias line (unit slope). The agreement is high with an excellent coefficient of correlation of 0.92. In addition, the noise is moderate (RMSE~3.0%). For most cases, IASI total ozone data overestimates the GOME-2 observations, with an average relative difference (IASI minus GOME-2 divided by GOME-2) of (+6.1±3.2)%. These results agree with Massart et al. (2009) which

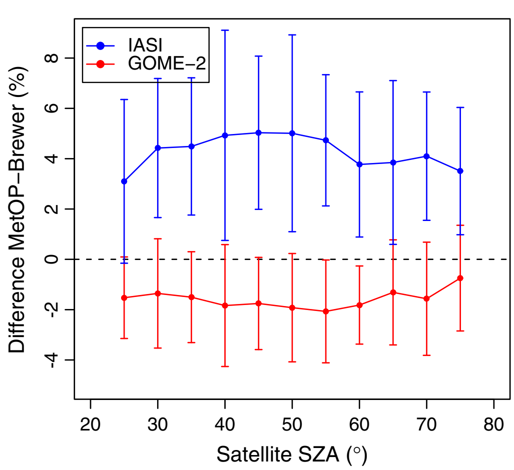

Fig. 4. Mean relative differences between satellite and ground-based total ozone data as a function of the ground pixel SZA grouped in 5° bins. The error bars correspond to ±one standard deviation.

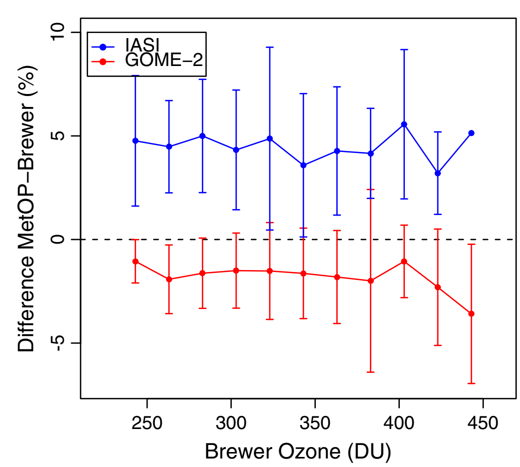

Fig. 6. The relative difference of satellite and ground-based data as a function of the total ozone column for the "Iberian Peninsula" dataset. The error bars correspond to ±one standard deviation.

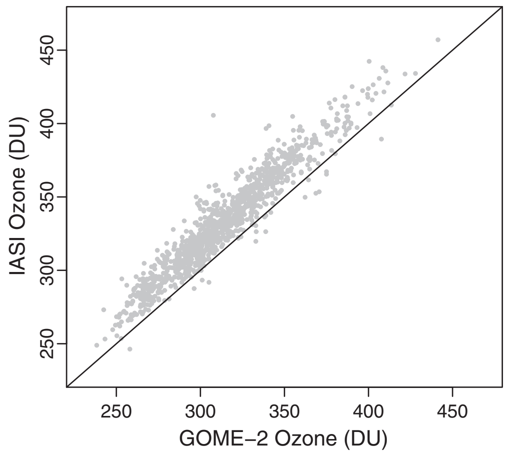

Fig. 7. Correlation between IASI and GOME-2 total ozone data for the "Iberian Peninsula" dataset.

indicated that the IASI TOC data are overestimated compared to the GOME-2 data by about 6% at midlatitudes with a coefficient of correlation of about 0.92. Boynard et al. (2009) showed that the overestimation of the IASI TOC data with respect to GOME-2 observations ranged from 2.9% to 4.4% (3.0% on average) for global comparison. A value of the standard deviation around 3% suggests that random errors of satellite instruments and the total ozone variability due to a difference in observation time between both satellites are relatively small. The discrepancies between the IASI and GOME-2 instruments are mainly related to the bias between UV–Vis and infrared spectroscopy which are use in the retrieval processes, as well as to the different vertical sensitivities as was previously discussed. In addition, both satellite instruments present different viewing geometry of the observation, and the cross-section as well as the a priori information used in both retrieval algorithms also differs.

5. Conclusions

The objective of this work was to validate simultaneously the TOC data from two satellite instruments (GOME-2 and IASI) by comparison with TOC measurements from five reference Brewer UV spectrophotometers located at the Iberian Peninsula. The agreement with respect to these ground-based TOC data is excellent for both satellite instruments. In addition, the study indicates that GOME-2 TOC data underestimates Brewer measurements by 1.6% on average for the Iberian Peninsula dataset which could be due to the vertical sensitivity of GOME-2 instrument to the ozone density is strongly height dependent in the troposphere. In contrast, the IASI instrument clearly overestimates the ground-based data (~4.4%) but this behavior is not related to its vertical sensitivity. The uncertainties of the relative differences between satellite and ground-based measurements are significantly higher for IASI instrument than for GOME-2 instrument, revealing more variability in the IASI data. The relative differences present no significant dependence on the satellite geometry factors (SZA and VZA) for the two satellite instruments. Moreover, GOME-2 instrument presents a slight underestimation for high ground-based TOC values. Finally, the correlation between the IASI and GOME-2 instruments show a good agreement (R^2~0.92), but the IASI data overestimate the observations given by GOME-2 by 6%.

All these results evidence the excellent performance of the GOME-2 instrument for obtaining TOC data for all sky conditions. In addition, the IASI total ozone retrieval (only available for cloud-free cases) is very promising. The identified bias is consistent with the findings of previous studies, and could be related to discrepancies in the associated spectroscopic data, which should trigger further laboratory studies that couple UV–Vis and infrared measurements of spectroscopic parameters at the same time.

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