O3-SAF Report: Visiting Scientist Activities of INM at DLR

VALIDATION OF TOTAL OZONE GOME DATA WITH MEASUREMENTS OF SPANISH BREWER NETWORK

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INTRODUCTION

This report summarizes the Visiting Scientist Activity realized by Manuel Antón Martínez at DLR in April 2006. This activity is based on the collaboration between The Spanish National Meteorological Service (INM) and the German Aerospace Center (DLR) in the framework of O3M SAF project. The main objectives of the activity were to obtain detailed information on the scientific aspect of the new GOME-2 ozone product (method, limitation, etc), as well the technical aspects related to product format and dissemination. The second objective was to validate the GOME ozone product version 4.0 against data measured by Spanish Brewer Network and to investigate the possible causes in the differences between satellite data and ground-based measurements.

BACKGROUND

Satellite monitoring of the earth's atmosphere allows to record spatial and temporal information on different geophysical parameters. This information is required for its use in applications such as climate changes, numerical weather prediction and pollution monitoring (WMO, 1999).

One particular area where satellite monitoring has proven to be useful is in analysing global atmospheric ozone. Thus, accurate ozone observations from remote sensing instruments play an important role in ozone trend analysis in order to assess current and future changes of the atmosphere. To that effect**,** the ESA Global Ozone Monitoring Experiment (GOME) has been recording global measurements of total ozone since July 1995 (Burrows, 1999).

In order to guaranty the quality of satellite products a highly iterative process is absolutely necessary. This process involves several steps as calibration, radiative transfer modelling, validation, algorithm refinements and reprocessing. One the most important tasks of the O3M SAF programme is the product validation in order to improve the methods and algorithms used. Therefore, it is very interesting the validation of GOME total ozone values against ground-based observations **(**ESA, 1996; ESA, 2004).

TOTAL OZONE DATA

Satellite observations

GOME, the first European spaceborne UV-visible-near-infrared spectrometer, was launched onboard the Second European Sensing Satellite (ERS-2) in April 1995. A detailed instrument description can be found in the GOME User's Manual (ESA, 1995). To derive total ozone, GOME Data Processor (GDP) Version 4.0 was applied (Van Roozendael, 2006). This method is based on Differential Optical Absorption Spectroscopy (DOAS) technique which consists of the spectral fitting of the apparent slant column amount in the 325 to 335 nm, followed by its conversion into vertical column amount using a calculated Air Mass Factor (AMF). The exact determination of the AMF is a crucial point (and source of uncertainty) of the algorithm. Moreover, in the presence of clouds the total ozone has to be corrected for tropospheric ozone below the cloud top which is not seen by GOME. This latter determination is based in part on cloud information inferred from GOME measurements.

Figure 1: Locations of the Spanish Brewer spectrophotomer network

Ground-based measurements

Brewer spectrophotometer is a fully automated instrument which uses the principle of differential absorption. The total ozone amount is derived from measurements of the ratio of sunlight intensities at five wavelengths between 306 and 320 nm with a resolution of 0.6 nm, where the absorption by ozone presents large spectral structures. These wavelengths used in the Brewer ozone measurements are chosen to avoid interferences by SO_2. Moreover, interferences by NO_2 may be neglected for Brewer measurements, except during strong NO_2 tropospheric pollution events which can produce an erroneous increase of total ozone by 0.6% in extreme cases. Accurate Brewer total ozone amounts are obtained through direct sunlight (DS) measurements.

The Spanish National Institute of Meteorology (INM) operates a national Brewer spectrophotometer network. This network provides total ozone amount and spectral UV and it is monitored in real time through the intranet of INM. The ground-based stations used in this study are from north to south: A Coruña (43.33ºN, 8.42ºW), Zaragoza (41.01ºN, 1.01ºW), Madrid (40.45ºN, 3.72ºW), Murcia (38.03ºN, 1.17ºW), El Arenosillo (37.06ºN, 6.44ºW). The locations of Spanish Brewer spectrophotometer network are shown in figure 1.

VALIDATION PROCEDURE

The study presented in this work makes use of GOME data at distance from the Brewer station smaller than 150 km**.** GOME total ozone data for each location are provided by DLR.

Table 1: Pairs of Brewer-GOME data considered in the validation by year and location.

	Madrid	**Murcia**	**A Coruña**	**Zaragoza**	**Arenosillo**	***Iberian Peninsula***
1995	43	49	------	------	------	***92***
1996	78	84	------	------	------	***162***
1997	67	87	------	------	------	***154***
1998	81	79	------	------	60	***160***
1999	76	82	71	------	67	***296***
2000	85	73	66	17	61	***302***
2001	69	66	63	55	60	***313***
2002	80	80	64	73	69	***366***
2003	44	56	43	54	51	***248***
2004	------	72	65	69	69	***275***
TOTAL	**608**	**637**	**370**	**268**	**437**	***2320***

On the other hand, the ground-based data selected for the comparisons are based on records of DS measurements. Moreover, the Brewer measurement nearest to GOME overpass time (between 10.83 y 11.54 UTC hours) is selected everyday in order to gain the best time coincidence possible. The time delay between the satellite observation and ground-based measurements ranges between 16 minutes at Arenosillo (minimum) and 44 minutes at A Coruña (maximum).

Time series of both satellite and ground based total ozone data extend from July 1995 to December 2004. In the table 1, we show the number of quasi-simultaneous values pairs of Brewer-GOME data considered in this work by year and location.

A whole regression analysis is performed for each location. Thus, regression coefficients, coefficients of determination (R^2) and the root mean square errors (RMSE) were evaluated for each of them. Moreover, the mean absolute bias error (MABE) and the mean bias error (MBE) parameters were calculated for each station. These parameters are obtained by the following expressions:

$$MABE = \frac{100}{N}\sum_{i=1}^{N}\frac{\left|GOME_i - Brewer_i\right|}{Brewer_i},$$

$$MBE = \frac{100}{N}\sum_{i=1}^{N}\frac{GOME_i - Brewer_i}{Brewer_i}$$

The uncertainly of two parameters is characterized by the standard error:

$$SE = \frac{SD}{\sqrt{N}},$$

where N is the number of data and SD is the standard deviation.

Table 2: Parameters obtained in the correlation between satellite and ground-based measurements

	Slope	**R^2**	**RMSE (%)**	**MBE (%)**	**MABE (%)**
Madrid	1.01±0.01	0.92	2.88	-0.93	2.28
Murcia	0.96±0.01	0.93	2.65	-0.67	2.14
Coruña	0.98±0.01	0.92	3.29	-1.16	2.54
Zaragoza	1.02±0.02	0.92	2.36	-2.11	3.29
Arenosillo	1.01±0.01	0.93	2.72	0.18	2.09
Iberian Peninsula	***1.00±0.01***	***0.92***	***3.04***	***-0.92***	***2.28***

RESULTS AND DISCUSSION

Figure 2 shows the comparison between GOME versus Brewer ozone data for each station. The solid line is the regression line showing negative GOME bias and the red dashed line is zero bias line (unit slope). The slopes and statistical parameters obtained in these correlations are showed in table 2. The correlation between GOME and Brewer data is high for all stations (R^2~0.92). Moreover, the noise is significant low in all cases: RMSE=3.29% for Coruña (maximum) and RMSE=2.36% for Zaragoza (minimum). In addition, the MABE parameter is lower than 4% in all locations. The analysis of all data together confirms these excellent results. Therefore, the mean differences between satellite and ground based data are similar to systematic errors introduce by the both total ozone retrieval methods. This fact indicates the excellent agreement between the two series analyzed. Finally, the negative sign of MBE parameters indicates that GOME underestimates the Brewer measurements in all locations except Arenosillo station where MBE shows a slight overestimation.

The validations have been focused on the identification of disagreement between satellite and surface observations. Thus, we firstly examined the temporal evolution of the differences and afterwards we analyzed the dependence of these differences on cloudiness, solar zenith angle (sza) and total ozone amount.

Temporal evolution of the differences for each station is presented in figure 3. We can see that the differences are included in all cases in ±10%. In this figure, we can find some plots with gaps due to lack of reliable Brewer spectrophotometer data during those periods. When we study the mean monthly courses of the differences, we find out that differences GOME-Brewer are closer to zero during winter-spring period. In contrast, during summer-autumn GOME underestimates ground-based ozone values by 2-4%. Therefore, the amplitude of this seasonality is always lower than 4% in all stations. Furthermore, the temporal evolution of the differences does not show any clear trend.

In GDP total ozone retrieval, cloudiness plays explicitly a role in the calculation of the AMF and in the estimation of the so-called ghost column hidden by the cloud cover and added to the actually measured vertical column. We use GOME Cloud Factor (CF) in order to investigate the clouds influence in the differences between satellite and ground-based data. Figure 4 shows the relative difference between GOME and Brewer total ozone as a function of the GOME CF. The scatter of the comparison is larger with increasing cloud fraction. In cases of cloud-free conditions, (CF<10%), the differences are close to zero. When satellite detects some cloudiness, (10%<CF<20%), the difference decrease strongly (~ -2%). Then, the differences present a smooth positive dependence with the CF values. Thus, for the CF values higher the differences are close to zero. This fact could be related to the GDP estimation of tropospheric ozone ('ghost' ozone column) which is located below clouds and to the estimation of AMFs for cloudy conditions.

Analysis of relative differences for all cloudiness conditions between GOME and ground-based total ozone as a function of the GOME sza shows no significant dependence. We study this relation for cloud-free conditions. The percentage of clear cases selected is about 40% of the total. Figure 5 shows the relative differences between GOME and Brewer data as a function of the sza considering only the cloud-free cases. A sza dependence is shown. GOME observations overestimate ground-based Brewer data for low sza by 1-2% while for high sza values satellite underestimates ground-based ozone values by down to 1% resulting to an amplitude of about 3%. This is in agreement with other studies of GOME total ozone product (**ESA, 2004**).

Finally, we study the influence of total ozone amount in differences GOME/Brewer. Figure 6 shows the relative differences as a function of the Brewer ozone data. All plots show that low ozone amounts (240-250 DU) are overestimated by GOME satellite (1-4%). In contrast, high ozone values (380-420 DU) are underestimated (2-4%). Therefore, GOME satellite observations do not completely cover the ozone variability recorded by the Brewer spectrophotometers.

CONCLUSIONS

Some important conclusions may be drown from the GOME-Brewer comparison over five locations in the Iberian Peninsula. In general, the average agreement of GDP 4.0 with Brewer ozone measurements falls within the precision level of ground-based sensors and the correlation between two instruments is excellent. We have checked the influence of several factors (clouds, sza and ozone amount) in the differences GOME-Brewer. The best agreement between satellite observations and ground-based measurements is obtained for low sza values and cloud-free cases.

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FIGURES

Figure 2: Ozone amount measurements of Brewer spectrophotometer versus GOME satellite observations. Regression line (solid line) and unit slope (dashed line)

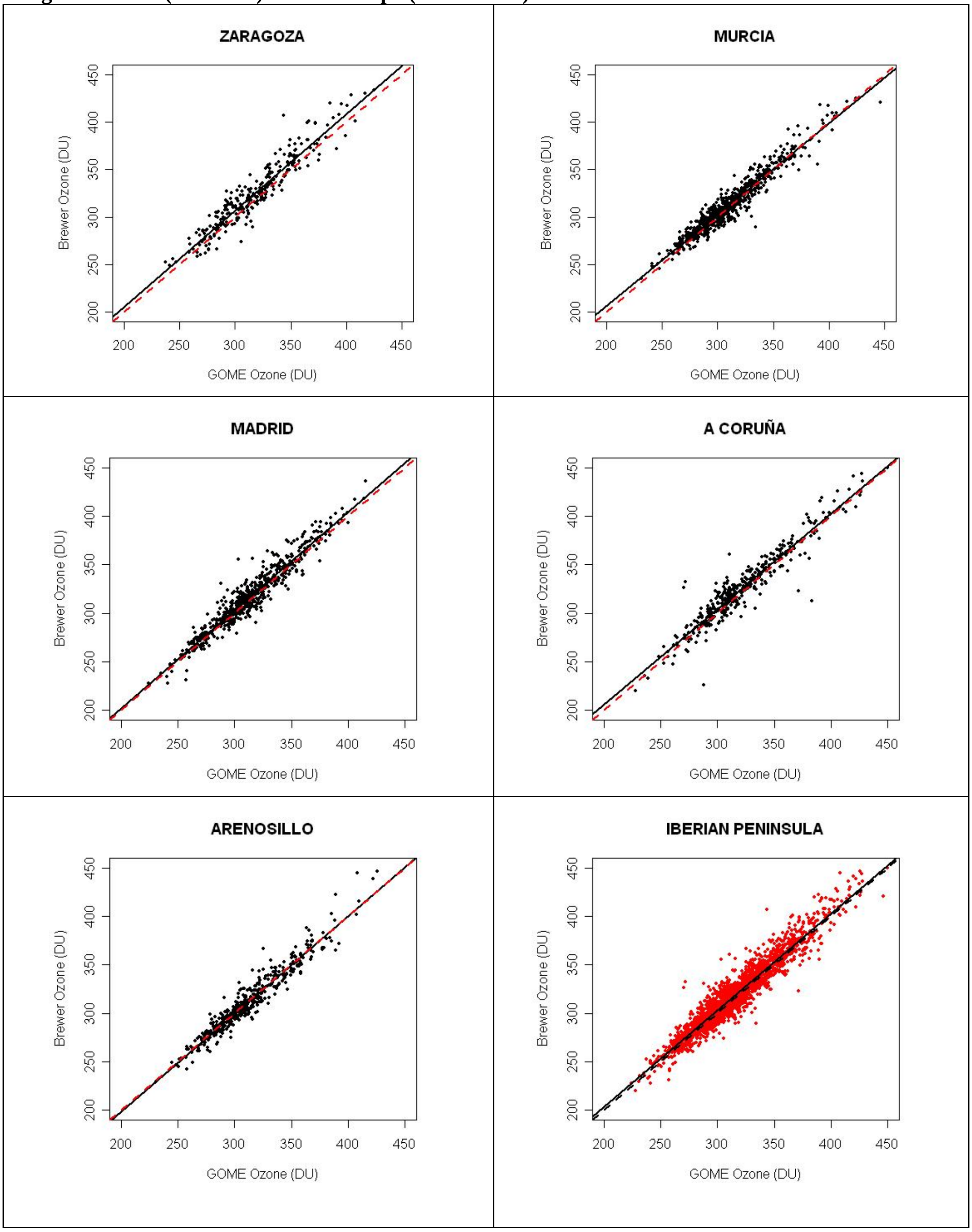

Figure 3: Temporal evolution of GOME/ground relative differences

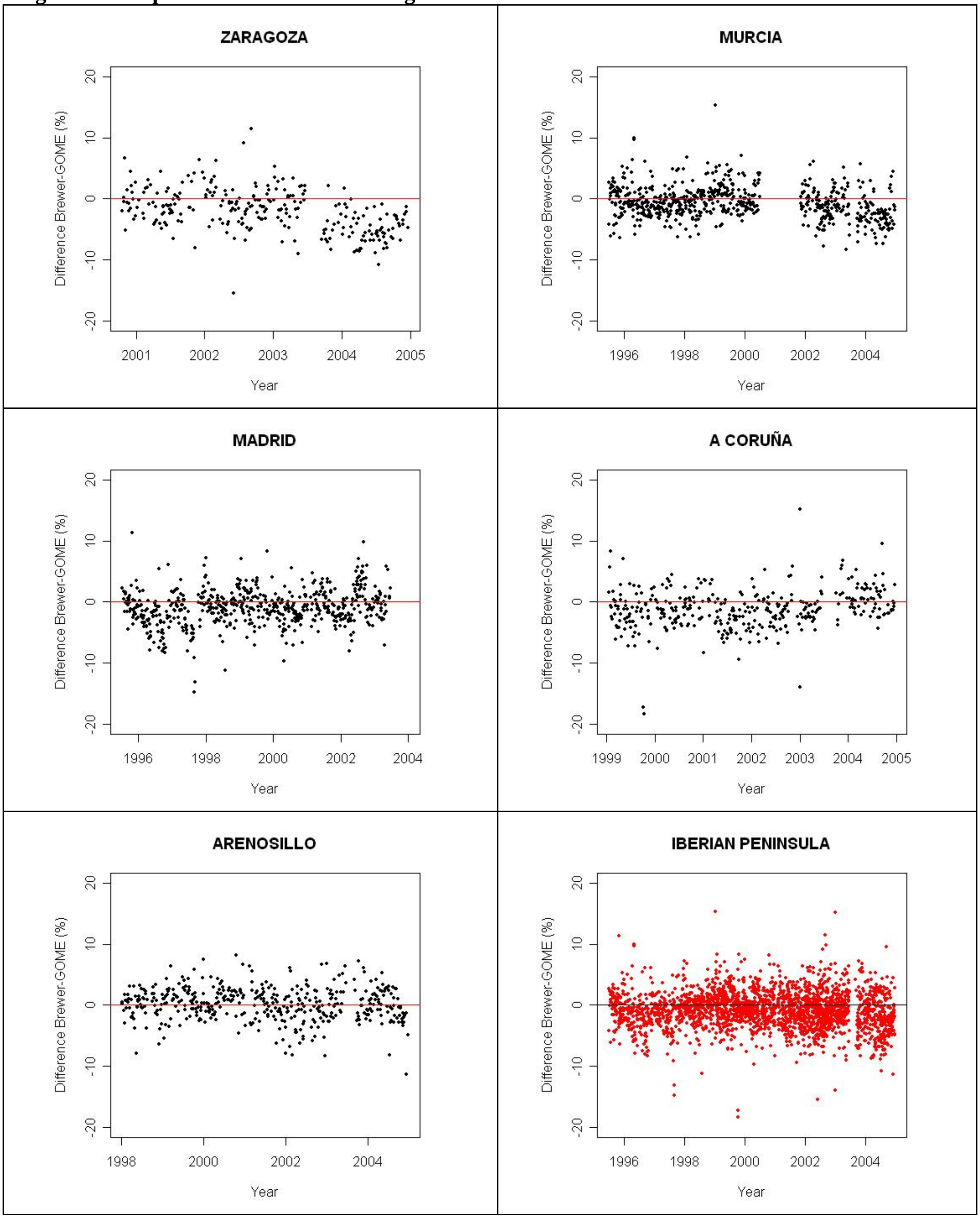

Figure 4: Variation of relative differences with the GOME Cloud Fraction

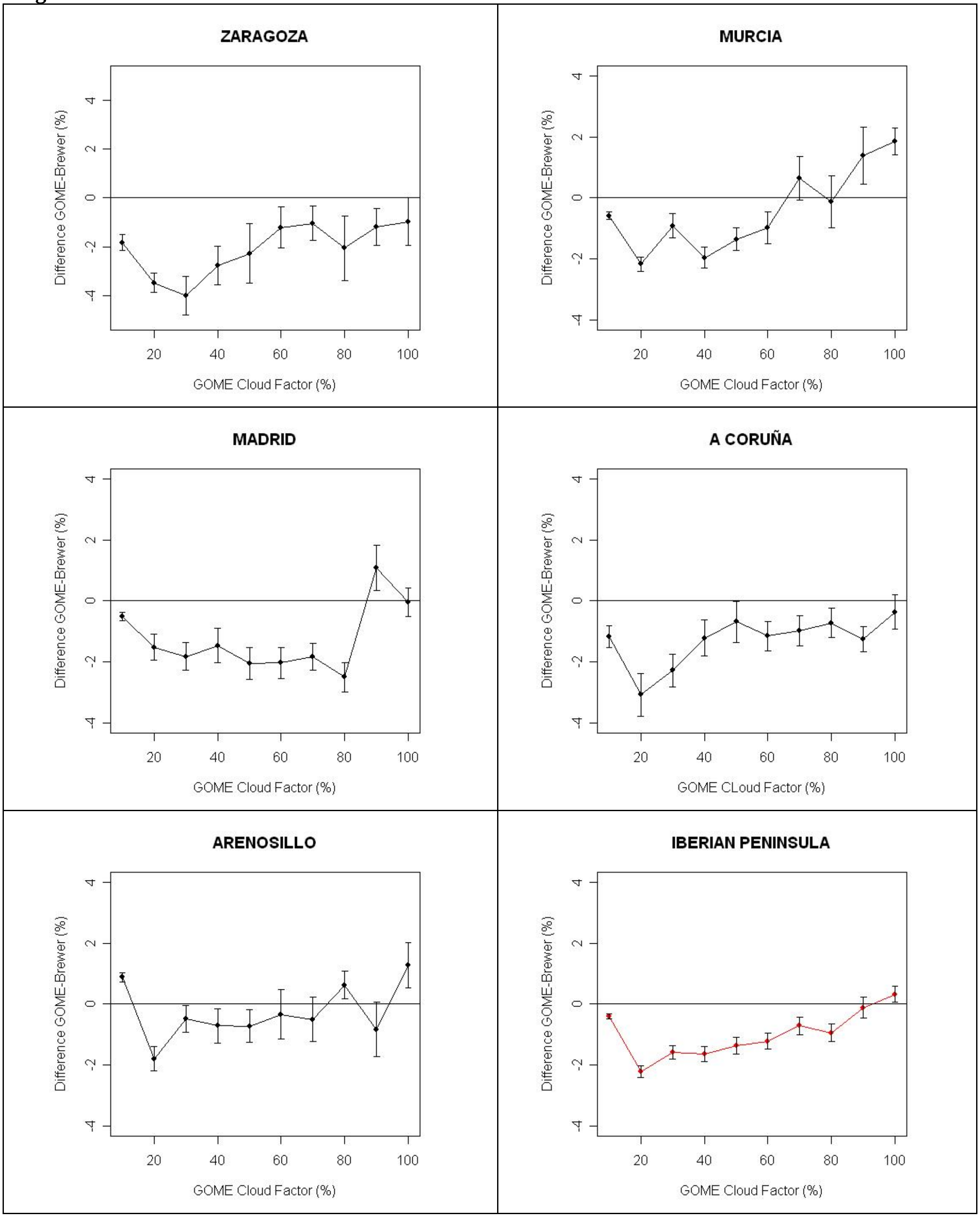

Figure 5: Variation of relative differences with the GOME solar zenith angle for cloud-free cases

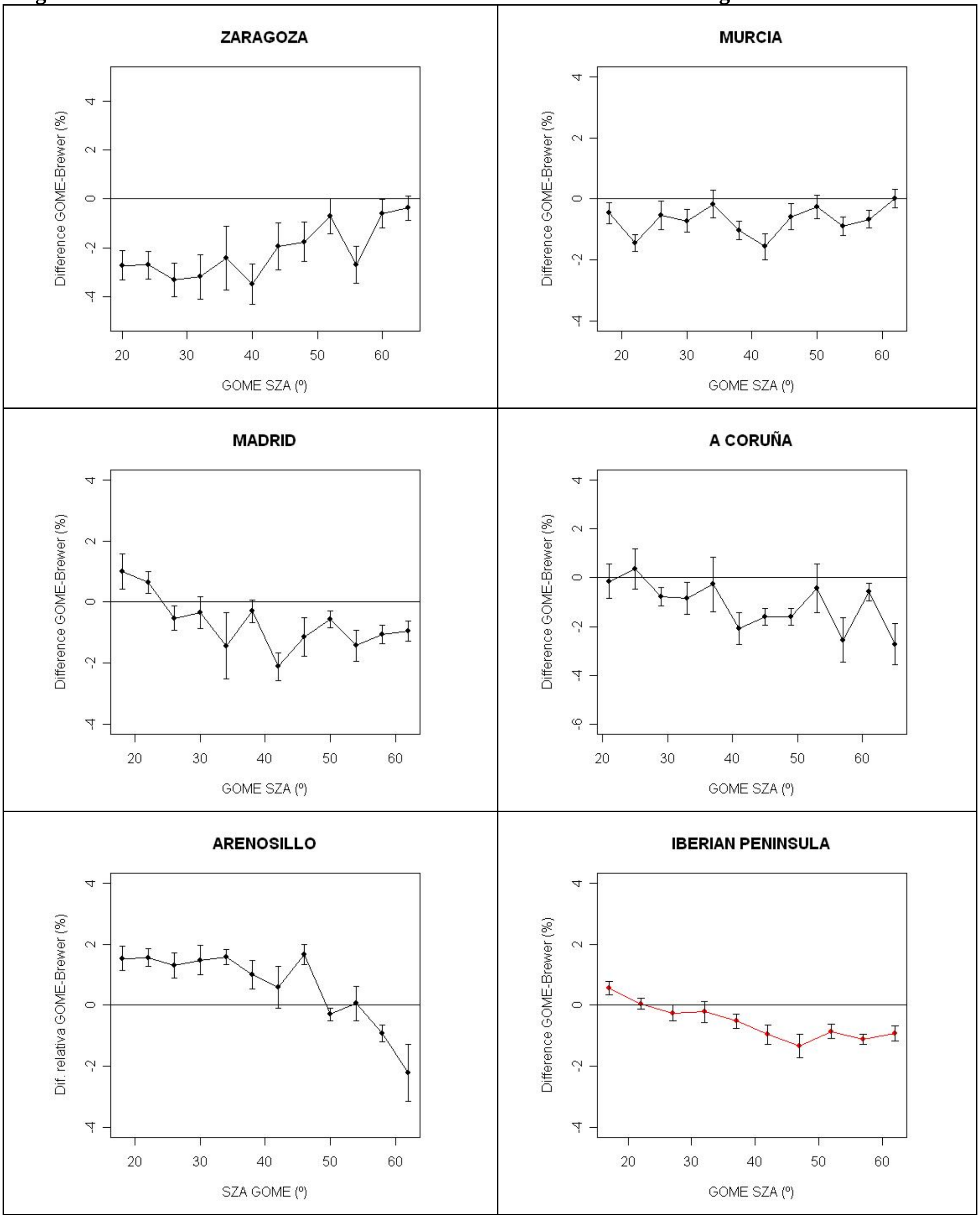

Figure 6: Variation of relative differences with the Brewer ozone measurements