Validation of GOME with ground-based ozone measurements at Uccle (Belgium)

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Abstract

Total ozone measurements from a Dobson and a Brewer spectrophotometer at Uccle (5048'N, 421'E) are compared with the ozone data from GOME during the daily overpasses of the satellite. Electrochemical ozone soundings performed at our station give the opportunity for validation of the ozone vertical column density below the cloud cover.

The data obtained from July 96 to February 97 indicate that below about 250 Dobson Units (DU) the GOME data are in general higher than ground-based data. Above this value the mean differences between the GOME and the Dobson and Brewer ozone data show no statistically significant dependence on the total ozone amount and on the solar zenith angle (sza). For ozone amounts above 250 DU the mean differences standard deviations) amount to -1.4 2.7% and -2.2 2.5% for the Brewer and Dobson spectrophotometer respectively. On the other hand, for relatively small sza's (smaller than 45) the mean differences show a strong dependence on the cloud cover fraction (CCF) ranging from about -5% (for CCF=0) to 4% (for CCF=1). For larger sza's this dependence seems to disappear.

From Meteosat images and from temperature and humidity profiles of the correlative ozone soundings it appears that the mean cloud top pressure and the mean vertical column density of ozone below the cloud cover used in the GOME algorithm are correct. However, the day to day variations are not well described by the algorithm.

Introduction

The Global Ozone Monitoring Experiment (GOME) is a nadir viewing grating spectrometer aboard the ERS-2 satellite that was launched on 21 April 1995. The Meteorological Institute of Belgium participated in the GOME validation campaign, making use of measurements with a Brewer and a Dobson spectrophotometer as well as electrochemical ozone soundings performed at Uccle. The quality of the Dobson and Brewer data was ensured through recent comparisons with the respective world standard instruments and through regular calibration checks (see e.g. *De Backer and De Muer* [1991] and *De Muer and De Backer* [1992]). Quasi-simultaneous measurements with both instruments - of which the calibration is kept independent - offer the possibility of mutual quality control. Recently a new method was described to determine the air mass factor (amf) dependence of the instruments [*Schoubs et al.*, 1997]. The ozone soundings performed at Uccle were already used in the past for the validation of satellite data [*De Muer et al.*, 1990; *Schoubs and De Muer*, 1996] or Lidar ozone data [*De Backer et al.*, 1994]. A new pump efficiency profile was developed to improve the measurements at high altitudes [*De Backer et al.*, 1997].

In the present validation study GOME ozone data within a horizontal distance of 500 km from Uccle and in a time window of 3 hours, are compared with direct sun Dobson and Brewer data during the period from July 96 to February 97. In addition the GOME ozone vertical column density (VCD) under the cloud top is compared with corresponding ozone amounts from our soundings.

Data set Description

Every GOME total ozone data point from ground-pixels within 500 km horizontal distance from Uccle were compared with the closest in time (corrected) DS Dobson and Brewer ozone value. The time limit was set to 3 hours before or after the satellite overpass. Due to the fact that the Brewer instrument is completely automated and therefore frequent measurements are taken, more DS observations are available.

We have considered individual total ozone measurements obtained with the Brewer no.16 and Dobson no.40 spectrophotometers. Only direct sun (DS) ozone data with an amf smaller than 3.6 have been used because total ozone amounts from zenith sky observations are known to be less accurate and are calculated from empirical charts (see e.g. *De Backer and De Muer* [1991]). The data are corrected for the amf dependence of the instruments as follows:

$$O_3(\mathrm{corr}) = O_3(\mathrm{meas}) - \mathrm{dep} \times \frac{O_3(\mathrm{meas})}{100}(\mu - 1),$$

where O_3(meas) is the ozone measured with the instrument, O_3(corr) is the corrected ozone amount, is the amf and dep is the amf dependence of the instrument determined from the daily variation of individual Ds measurements (see *Schoubs et al.* [1997]). For the Dobson and Brewer spectrophotometer at Uccle dep is -0.592% and -0.882% per amf respectively.

At 9 days with correlative measurements (23/07, 27/07,,26/10, 7/11, 15/11, 16/11, 24/11, 22/12 and 23/12/96), the differences between the GOME total ozone and the ground-based data are real due to specific meteorological conditions. Therefore these days have not been considered in the following validation study.

Results

Mean Dependence and Dependence on the Total Amount of Ozone

As an example we show in Figure 1 the percentage differences of VCD's of ozone calculated from GOME and DS Dobson measurements as a function of the ground-based total ozone amount. The asterisks represent the whole data set (as described earlier) while the circles represent the differences derived from the daily closest (in distance) GOME pixels. We see that for small ozone amounts (below about 250 DU) GOME data are in general higher than ground-based Dobson data. The same effect was observed in the comparison with the Brewer instrument.

For ozone values above 250 DU the mean difference between GOME and DS Brewer and Dobson ozone values amounts to -1.4 2.7% and -2.2 2.5% respectively.

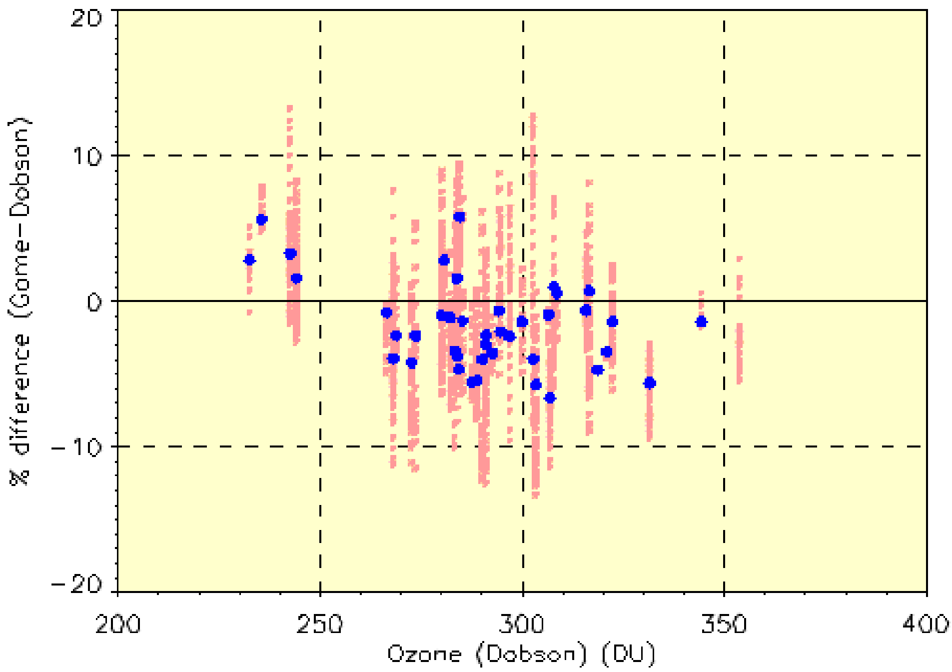


Figure 1: Percentage differences between GOME and DS Dobson VCD's of ozone as a function of the ground-based ozone amount. The circles represent the closest pixels

We found (for ozone values above 250 DU) no statistically significant dependence of these mean differences on the total ozone amounts. The slopes (standard deviation) of the least squares linear regression curves through the closest pixels are the comparison with the Dobson and Brewer data are -0.010% (0.024%) and 0.025% (0.013%) respectively. In the following discussion we always have rejected the observations at low total ozone values (below 250 DU).

Dependence on the Solar Zenith Angle

Figure 2 shows the differences between GOME and Brewer VCD's of ozone as a function of the sza of GOME. Although the slope of the linear regression line is not statistically significant (see Table 1) it seems that the GOME ozone values are somewhat smaller than the Brewer values around sza's of 60. The results we found for the comparison with the Dobson spectrophotometer are somewhat less representative because they are based on correlative measurements from only 37 days. Especially in winter (at high sza's) there are only few DS observations taken around real noon. For the automated Brewer useful measurements were available on 77 days.

Figure 3 shows the results from the comparison of TOMS (version 7) ozone data and our DS Brewer measurements [*Schoubs et al.*, 1997]. Here we see a clear (but small) sza dependence of the TOMS instrument of about -0.0757 0.0034% per degree sza. For 12 European stations in a latitude band between 32N and 68N the TOMS instrument shows a mean dependence on the sza, giving too low ozone values of about 0.04% (0.001%) per degree of sza.

	Brewer	Dobson
26<sza<=75	-0.022 0.023%	-0.062 0.030%
26<sza<=45	0.111 0.111%	-0.150 0.145%
45<sza<=75	0.049 0.044%	0.030 0.056%

Table 1: Slope ± standard deviation (in %) of the least squares linear regression line fitted to the differences between GOME and spectrophotometer data as a function of the sza, for different ranges of sza.

Dependence on the Cloud Cover Fraction

In Figure 4 the percentage differences between GOME and DS Brewer data are plotted as a function of the cloud cover fraction (CCF) for different ranges of sza's. No statistically significant dependence on the CCF was found, for observations in the whole sza range (from about 26 to 75). As distinct from this, a highly significant dependence of the mean difference on the CCF was found for ozone measurements at relatively small sza's (up to 45), ranging from about -5% (for CCF=0) to 4% (for CCF=1). This dependence seems to vanish for observations at sza's between 45 and 75 (see Table 2 and Figure 4). The same results were found in the comparison of GOME data with our Dobson ozone values. It seems that the ICFA algorithm works quite well at high sza's (above 45), but needs some corrections at relatively small sza's (below 45).

26<sza<=75	2.342 1.486%
26<sza<=45	8.971 2.624%
45<sza<=75	0.899 1.673%

Table 2: Slope ± standard deviation (in %) of the least squares linear regression line fitted to the differences between GOME and Brewer data as a function of CCF, for different ranges of sza.

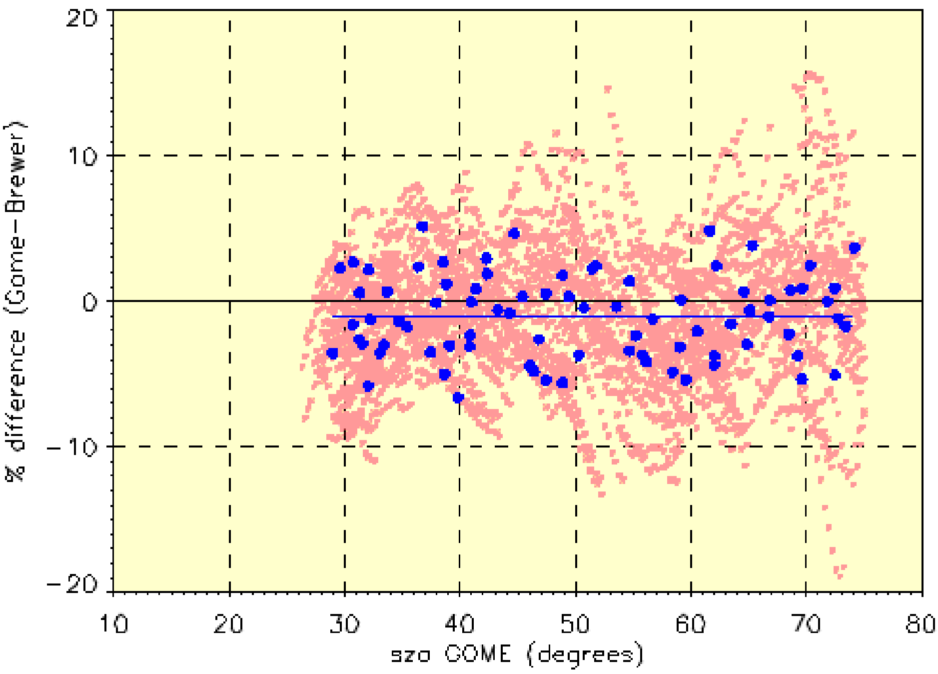


Figure 2: Percentage differences between GOME and Ds Brewer VCD's of ozone as a function of the sza of GOME. The least squares linear regression curve is fitted through the data of the closest pixels.

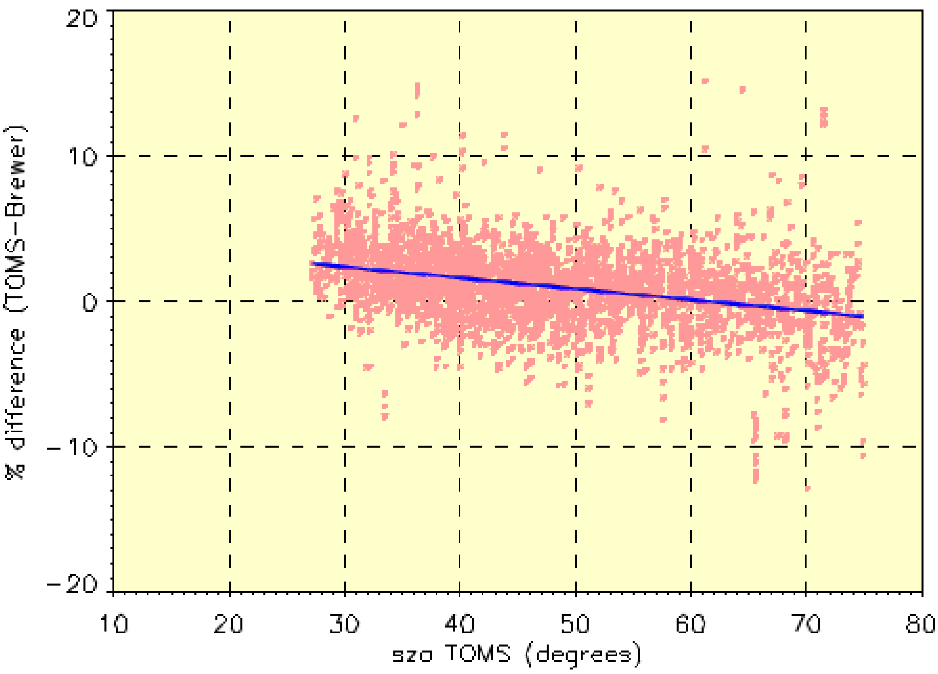
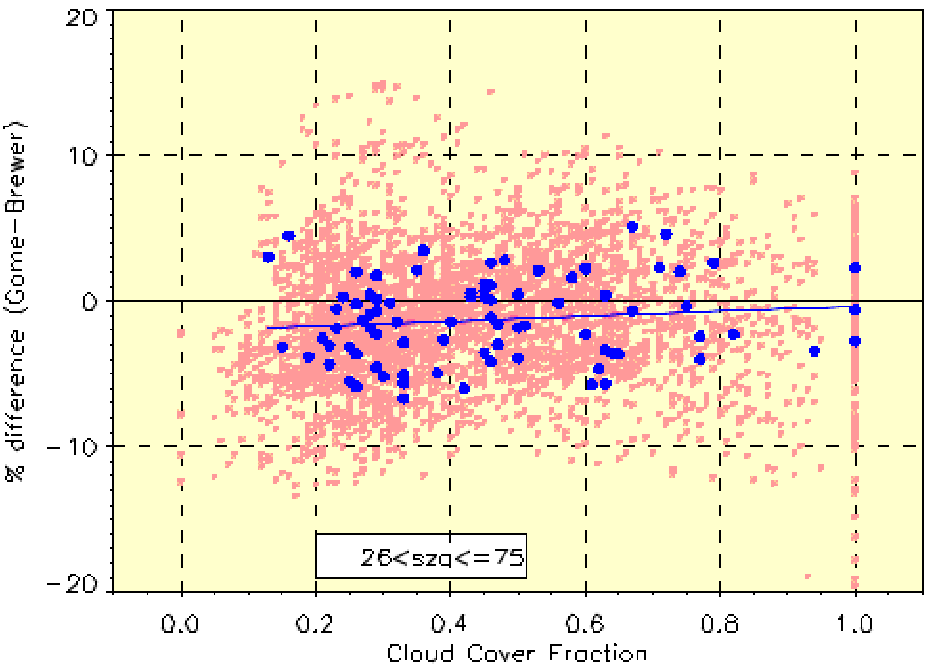
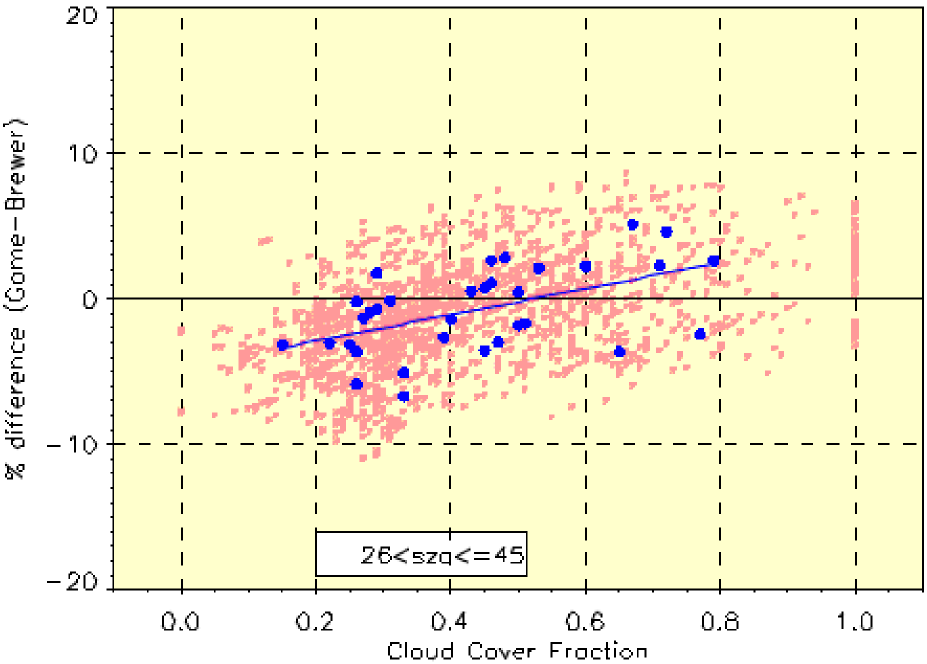


Figure 3: Percentage differences between TOMS (version 7) and DS Brewer VCD's of ozone (with amf <= 3.6) as a function of the sza of TOMS from July 83 to December 94. TOMS measurements with the total ozone >= 250 DU and sza <= 75° have been considered.


20
10
0
-10
-20
% difference (Gome-Brewer)
26<sza<=75
0.0
0.2
0.4
0.6
0.8
1.0
Cloud Cover Fraction


20
10
0
-10
-20
% difference (Gome-Brewer)
26<sza<=45
0.0
0.2
0.4
0.6
0.8
1.0
Cloud Cover Fraction

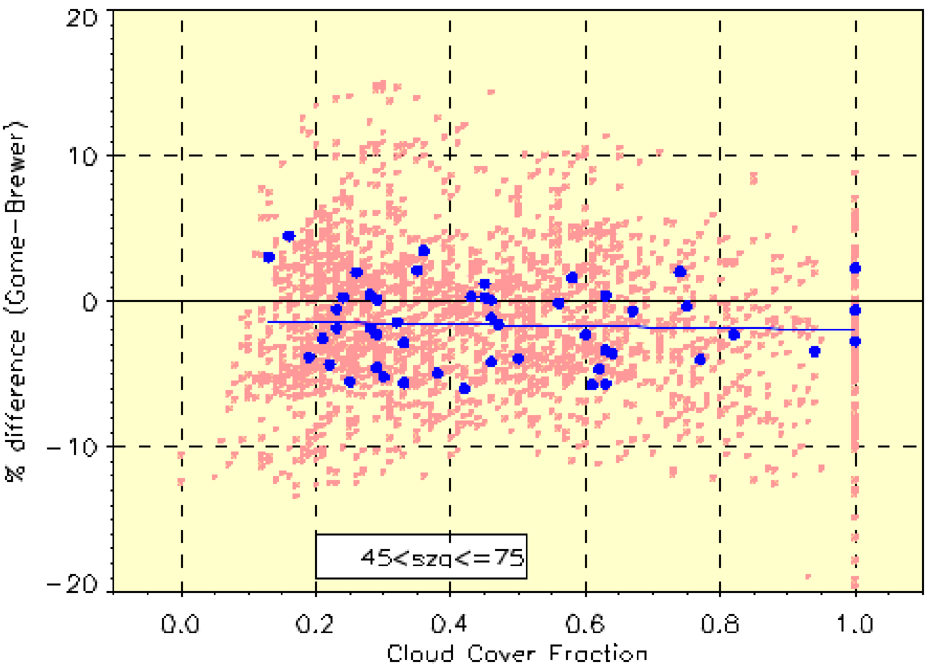


Figure 4: Plot of the percentage differences between GOME and DS Brewer VCD's of ozone as a function of the cloud cover fraction of the GOME pixels, for the whole sza range and in 2 subranges.

Validation of the GOME Ghost Vertical Column Density

The Ghost Vertical Column (GVC) of ozone is the amount of ozone under the cloud top. Because the GOME instrument can not look down through the clouds, the effective slant column (ESC) from the DOAS algorithm should be corrected for this amount. We deduced the GOME GVC as follows:

$$GVC = VCD + \frac{(1 - CCF) \times VCD \times AMF_g - ESC}{CCF \times AMF_c},$$

with AMF_g and AMF_c the amf to the ground and the cloud top. On 60 days this GVC was compared with the amounts of ozone below the cloud top deduced from our ozone soundings. Making use of infrared Meteosat images around the ERS-2 overpass time, the temperature range of the cloud top within the GOME pixel was determined. The corresponding range of cloud top pressures (CTP) was deduced from the ozone soundings performed at our station. Therefore we made the assumption that the measured temperature profile and the temperature profile at the closest GOME pixel did not differ significantly. In table 3 the CCF, CTP and GVC used in the GOME algorithm and the CTP and GVC deduced from Meteosat images and our soundings are given for July and August. The mean values and their standard deviations (sd) are calculated for all the 60 days. We see that the mean CTP and GVC from GOME and from our calculation differ not significantly. However the day to day variations are not well described by the GOME algorithm.

Conclusions

For the period July 96 to February 97, the mean differences between GOME and direct sun Brewer and Dobson ozone values above 250 DU amount to -1.4 2.7% and -2.2 2.5% respectively. For ozone values below about 250 DU the GOME data are in general larger than ground-based data.
For ozone values above 250 DU, we found no statistically significant dependence of the mean difference on the total amount of ozone and the sza. It seems however that around sza's of 60 the GOME data are somewhat lower than the ground-based observations. As distinct from this, TOMS (version 7) shows a small but statistically significant dependence on the sza.
For relatively small sza (below 45) the mean difference shows a strong dependence on the CCF ranging from about -5% (for CCF=0) to 4% (for CCF=1). For larger sza's this dependence vanishes.
From Meteosat images and from temperature and humidity profiles from correlative ozone soundings it was found that the mean CTP and GVC used in the GOME algorithm are correct, but the day to day variations are not well described.

Acknowledgments

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	GOME			Meteosat and sounding	
date	CCF	CTP (hPa)	GVC (DU)	CTP (hPa)	GVC (DU)
7/03	.87	637.2	10.86	504.7 - 880.4	3.29 - 17.58
7/05	1.00	650.7	10.80	277.4 - 446.3	17.57 - 24.08
7/08	.43	651.3	10.81	679.2 - 937.3	1.13 - 9.92
7/12	.51	639.8	10.77	478.9 - 968.3	0.66 - 24.91
7/15	.47	650.6	10.83	666.7 - 986.0	0.30 - 12.50
7/17	.39	621.1	11.20	490.7 - 1016.9	0 - 20.49

7/26	.53	573.4	12.82	749.5 - 1013.6	0 - 10.23
7/29	.57	575.3	13.06	315.4 - 555.0	12.94 - 27.50
7/31	.79	634.2	11.25	466.3 - 635.3	8.92 - 17.34
8/02	.67	608.0	12.49	663.6	10.95
8/07	.83	628.6	11.25	462.9 - 1005.6	0 - 21.85
8/09	.45	637.4	11.14	369.8 - 957.3	1.96 - 31.40
8/12	.79	640.0	11.26	370.8 - 815.6	4.77 - 23.60
8/14	.92	574.3	12.84	552.2 - 818.1	7.77 - 21.80
8/21	.29	585.9	13.37	361.8 - 1000.9	0 - 36.77
8/26	.45	614.6	12.07	621.5 - 962.1	0.82 - 13.82
8/28	1.00	625.1	11.87	320.1 - 636.8	9.02 - 24.67
8/30	.82	546.4	14.03	408.1 - 787.3	5.31 - 23.46
...	...	...	...	...	...
mean	**0.58**	**590.0**	**14.32**	**688.3**	**10.29**
sd	**0.24**	**39.4**	**3.08**	**223.8**	**8.77**

Table 3: The CCF, CTP and GVC used in the GOME algorithm and the CTP and GVC deduced from Meteosat images and our soundings for July and August 96. The mean values and their standard deviations (sd) calculated for 60 days of correlative ozone soundings and ERS-2 overpasses are given

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