# Validation of the ERS-2 GOME ozone total columns with the SAOZ ground-based network during the period: 28 June-17 August 1996

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**Abstract.** The first GOME version 2.0 total ozone measurements obtained in July and August 1996 have been compared to those provided by the SAOZ ground-based network over a wide range of latitude from the Arctic to the Antarctic. The comparison demonstrates a solar zenith angle (SZA) dependence of the GOME measurements. At the S.H. tropics and mid-latitudes in winter as well as at the N.H. mid-latitude and in the Arctic in summer, the agreement between the GOME v.2 total ozone and the SAOZ is on average better than 4% at SZA <65° and 10% beyond 65° up to 92° SZA. The scatter of less than 10% ($2\sigma$) of the relative difference between the two measurements is mainly the result of the temporal and spatial variability of the ozone field. The comparison also demonstrates a difference of sensitivity, the GOME underestimating high total ozone columns. The SZA dependence and the reduced sensitivity combine to give a high ozone column underestimation increasing with the SZA. In the winter Antarctic vortex, the low ozone columns are systematically overestimated by 10-20% by the GOME with an average 25% scatter at $2\sigma$ level.

## Introduction

The Global Ozone Monitoring Experiment (GOME) on board the Earth Remote Sensing (ERS-2) satellite was launched by ESA on 21 April 1995 onto a heliosynchronous polar orbit. GOME is a nadir viewing UV-visible grating spectrometer. It aims at the measurement of total ozone in the ultraviolet Huggins bands as well as nitrogen dioxide, OClO and BrO, by differential absorption (DOAS). This retrieval technique consists in studying the narrow features generated in the atmospheric absorption spectra by atmospheric constituents, after removal of the broad band signal due to Mie and Rayleigh scattering processes. Column densities along the line of sight, or slant columns, are retrieved by least squares iterative fitting with high resolution absorption cross-sections measured in the laboratory and convolved with the instrument slit function. Slant columns are converted into vertical columns by using an air mass factor (AMF), calculated with a radiative transfer model, taking into account the vertical distribution of the constituent.

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Since the late 1980s, ozone and nitrogen dioxide are monitored permanently at a number of stations by means of SAOZ instruments, using a similar analysis technique, but by looking from the ground at the sunlight scattered by the atmosphere at zenith (Pommereau and Goutail, 1988). The SAOZ UV-visible DOAS spectrometer measures total ozone in the 450-580 nm spectral region and nitrogen dioxide in the 400-500nm range, twice daily during twilight periods for SZA ranging from 86° up to 91°. Preliminary total columns retrieved from a real time spectral analysis at the station and a standard AMF calculated for 60°N, are transmitted by satellite data collection at the laboratory. Seventeen SAOZ and SAOZ-like UV-visible spectrometers are currently operated at a variety of sites in the world, over an extended latitude range. The data of the network have been collected by the Belgian Institute for Space Aeronomy and the Service d'Aéronomie du CNRS for investigating the performances of the GOME from the Arctic to Antarctica.

The GOME Geophysical Validation Campaign started on 20 July 1995. A first comparison with the GOME v1.20 and v1.21 ozone measurements in the ultraviolet Huggins bands at northern mid-latitude was conducted using a variety of instruments including a SAOZ spectrometer, part of the NDSC/Alpine station (Lambert et al., 1996[a]). The comparison was extended to all latitudes using the SAOZ network (Lambert et al., 1996[b]). Based on 45 days of data from July to December 1995, both exercises concluded to a total ozone underestimation by the GOME and to a significant SZA dependence at all latitude when compared to SAOZ: 5% underestimation on average at 45° SZA, 10% at 60° SZA and even much more beyond where multiple scattering was not considered in the first version of the algorithm. The comparison also showed i) a dependence of the relative difference between the GOME v1.20 - v1.21 and the SAOZ total ozone, on the amplitude of total ozone amount, that is a difference in sensitivity, and ii) an overestimation of the ozone column by 10-20% at high latitude in summer, as well as in ozone hole conditions in Antarctica at spring.

Since this first validation exercise, the GOME retrieval of ozone in the Huggins bands has been revisited and improvements have led to the current version 2.0, including among other things the calculation of the AMF at the lowest weight wavelength (325 nm), the correction for multiple scattering up to 92° SZA, and a better treatment of the cloud cover. A comparison at NH mid-latitude with Dobson, Brewer and GUV instruments has been conducted by Van Roozendael et al. (this issue) demonstrating an excellent agreement between the two measurements at this latitude. Here we report on an extension of the validation of the GOME V2.0 total ozone measurements using eleven stations of the SAOZ network combined together, except those deployed in Antarctica which will be presented separately. The validation methodology which takes into account the uncertainty of the SAOZ measurement and the time difference between the total ozone measurements of both instruments, is already described by Lambert et al. (this issue). The GOME pixels are selected such as the line of sight of the satellite observations matches at best the location of the correlative SAOZ measurement. The only difference is the use of preliminary SAOZ results transmitted in real time from the remote stations. However, changes between preliminary and final ozone SAOZ data are generally small and therefore are not expected to modify significantly the conclusions. Since the GOME V2.0 data were available from 28 June to 17 August 1996 only, the largest limitation at present time is the limited period of validation and hence the range for parameters such as the SZA or the AMF. More precision will be gained in the future when longer time series will be made available.

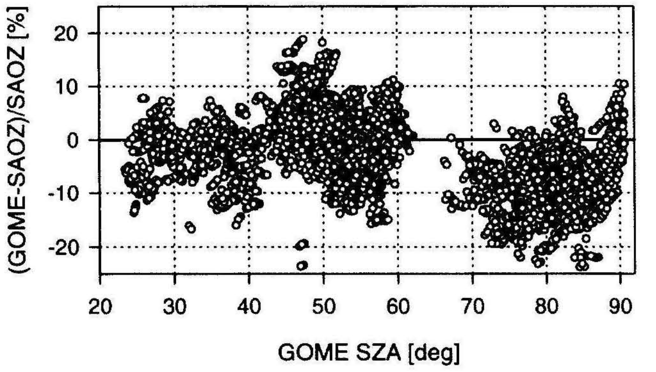


**Fig. 1.** Percentage relative difference between GOME v2.0 and SAOZ total ozone as a function of the SZA at the location of the GOME measurement at all latitude but in Antarctica.

## Solar zenith angle dependence

The comparison between the GOME v2.0 ozone and that of the eleven SAOZ stations in July-August 1996 is displayed in Table 1. Their relative difference combining all latitudes, but Antarctica, is shown in Figure 1 as a function of the GOME SZA.

At SZA < 65°, the mean difference between the two data sets does not exceed ± 4%. This is within the known uncertainty of the SAOZ real time ozone measurements using the standard winter 60°N AMF (e.g. overestimation by 2.8% at the tropics (Denis et al., 1996) and - 2% at 67°N in the summer (Hoiskar et al., 1996)). Intercomparison between co-located ground-based instruments themselves yields similar results (see e.g. Vaughan et al., 1997). Data from both GOME and SAOZ instruments are therefore in excellent agreement.

At SZA > 65°, the GOME underestimates ozone by 7-10% compared to SAOZ at SH mid-latitude in the winter (Kerguelen) as well as in the Arctic summer, except at Zhigansk in Siberia where the mean underestimation is only 3.9%. Most of the difference at Zhigansk compared to the western stations comes from a known systematic error in the residual ozone amount in the reference spectrum used in the real time analysis at Zhigansk since the installation of the instrument in 1992.

Although a systematic seasonal cycle exists in the SAOZ AMF of 5-6% amplitude at 67°N and 3-4% at 44°N because of the change in the shape of the ozone profile (Hoiskar et al., 1996; Sarkissian et al., 1996; Van Roozendael et al., 1996), not included in the real time analysis, its impact on early summer data is small. Moreover, it cannot explain the -9.5% difference between the GOME and the SAOZ at Kerguelen in the SH mid-latitude winter, singularity which does not exist when comparing SAOZ and TOMS. In addition, a 5-10% bias is observed in the Arctic between GOME data obtained in the descending and ascending parts of the orbit, that is at SZA below 65° (at noon) and beyond (midnight Sun). When plotted altogether as a function of the GOME AMF (Figure 2), the variation of relative difference between the two instruments still suggests an AMF dependence of the GOME data.

## Dispersion

The two standard deviation of the relative difference between GOME and SAOZ is of about 8-10% or smaller for

**Table 1.** Pole-to-pole comparison between the GOME v2.0 total ozone and that of the SAOZ network, from 28 June to 17 August 1996. The mean percentage difference ([GOME-SAOZ]/SAOZ), the 2σ standard deviation and the number of data points available are displayed for eleven SAOZ arranged by latitude belt and identified by their respective location, latitude, longitude and institution. The results are sorted into two SZA classes: GOME SZA lower and higher than 65°.

| Location | Lat. | Long. | Institution | SZA < 65° | | | SZA > 65° | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean | Scatter | Points | Mean | Scatter | Points |
| Scoresbysund | 70°N | 22°W | CNRS/DMI | -1.7 | 10.7 | 1339 | -9.2 | 10.8 | 1034 |
| Zhigansk | 67°N | 123°E | CNRS/CAO | 2.4 | 11.6 | 1084 | -3.9 | 8.2 | 790 |
| Sodankylä | 67°N | 27°E | CNRS/FMI | -0.6 | 8.8 | 1186 | -7.2 | 8.6 | 384 |
| Aberystwyth | 52°N | 4°W | U. of Wales | -3.9 | 10 | 541 | - | - | - |
| Jungfraujoch | 47°N | 8°E | IASB | -0.2 | 7.5 | 421 | - | - | - |
| Obs. Haute Provence | 44°N | 6°E | CNRS | -2.4 | 8.2 | 419 | - | - | - |
| Reunion Islands | 21°S | 55°E | U. Reunion | 4.0 | 4.6 | 215 | - | - | - |
| Bauru | 22°S | 48°W | CNRS/UNESP | 1.6 | 7.4 | 274 | - | - | - |
| Kerguelen Islands | 49°S | 70°W | CNRS | - | - | - | -9.5 | 8.9 | 353 |
| Dumont d'Urville | 67°S | 142°E | CNRS | - | - | - | 7.1 | 21.3 | 187 |
| Rothera | 68°S | 68°W | BAS | - | - | - | 6.8 | 29.0 | 68 |

the height stations outside Antarctica. There are several explanations for this: i) the total ozone variation between the SAOZ measurements at twilight and that of the GOME around local noon; ii) the difference in location between the noon nadir and twilight zenith viewings in presence of horizontal gradients (Lambert et al., this issue); iii) the use of a constant AMF in the SAOZ retrieval instead of the real AMF corresponding to the actual ozone profile, which can account for 1% scatter; iv) a similar contribution from the constant climatic GOME AMFs; v) the dispersion generated in the SAOZ measurements by tropospheric multiple scattering in presence of dense clouds or haze, combined with local ozone changes (Van Roozendael et al., 1994); and vi) finally, the contribution of clouds to the GOME measurements which mask the tropospheric contribution. As a result, the dispersion varies from one station to another depending on its location with respect to sources of tropospheric ozone and cloudiness. The smallest dispersion is observed at the tropics where total stratospheric ozone is the most stable and in absence of clouds during the dry season at Reunion Island. It is already significantly larger at Bauru in Brazil during the season of biomass burning where scattered high altitude clouds are also frequent. Note that clouds may also contribute to significant systematic deviations. The worst situation among the stations is certainly Kerguelen, almost permanently overcast in the winter season.

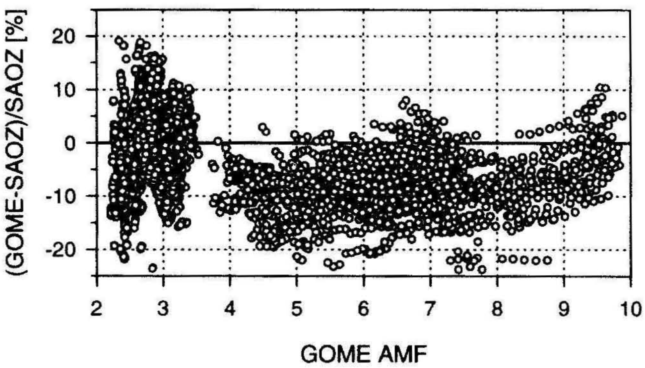


**Fig. 2.** Percent difference between the GOME and SAOZ total ozone as a function of the GOME AMF, for all latitudes except Antarctica.

## Ozone hole conditions in Antarctica

Two SAOZ are currently operating at Antarctic stations: at Dumont d'Urville (66°S) and Rothera (67.6°S). In July and August 1996, both stations are located alternately inside and outside the polar vortex. In August, after the start of ozone depletion, columns as low as 125 DU are observed at Rothera when located in the ozone hole as illustrated in Figure 3.

Table 1 and Figure 3 show that, when compared to SAOZ in Antarctica, GOME overestimates total ozone by 7 % on average, for SZA ranging from 80° to 92°. At Dumont d'Urville, the agreement between the satellite and the ground-based measurements improves rapidly after 28 July (day 210). After this date, the GOME and SAOZ data at both SAOZ sites are in reasonable agreement, except in the ozone hole where the GOME overestimates SAOZ total ozone by up to 20%. There may be two explanations for this which need to be explored: the use of a climatic profile in the GOME retrieval which cannot match the fast changes at the vicinity of the ozone hole and also a possible artefact in the GOME as well as the SAOZ data, due to dense (type II) PSCs which form at extremely low temperature in the polar vortex and hence more frequently above Rothera.

When including all the data up to 92° GOME SZA, the $2\sigma$ standard deviation of the order of 21% at Dumont d'Urville, increases to 29% at Rothera. Although total ozone may vary rapidly at the edge of the polar vortex, a 29% scatter exceeds that observed by comparison with TOMS in the same conditions (Pommereau et al., 1996). This suggests that a problem still exists in the GOME retrieval at very large SZA that is at latitude poleward of the polar circle before the end of July.

## Sensitivity

The correlation between the GOME and SAOZ total ozone for nine stations distributed between SH mid-latitude and the Arctic polar circle is displayed in Figure 4 (left-hand panel for SZA<65°, centre for SZA>65°). These two graphs show that: (i) compared to SAOZ, GOME underestimates the largest vertical columns of ozone; (ii) this difference in sensitivity increases at increasing GOME SZA, which is geophysically linked to the GOME AMF. It would suggest a systematic error in the GOME AMF dependent on the total ozone amount as well as on the SZA. The right-hand panel of Figure 4 shows that GOME overestimates the lowest vertical columns of ozone observed in ozone hole conditions in Antarctica.

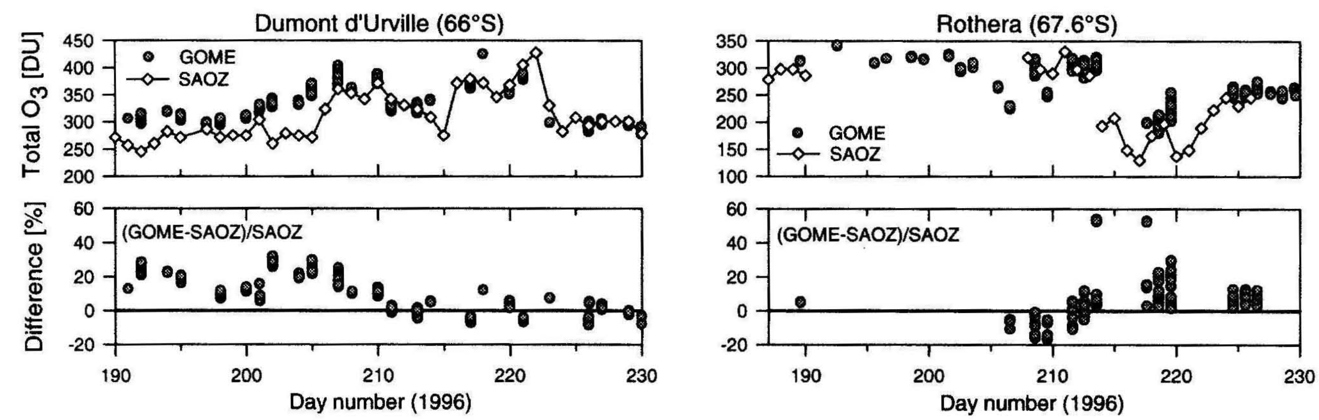


**Fig. 3.** GOME v2.0 and SAOZ ozone vertical columns at Dumont d'Urville and Rothera and percentage relative differences.

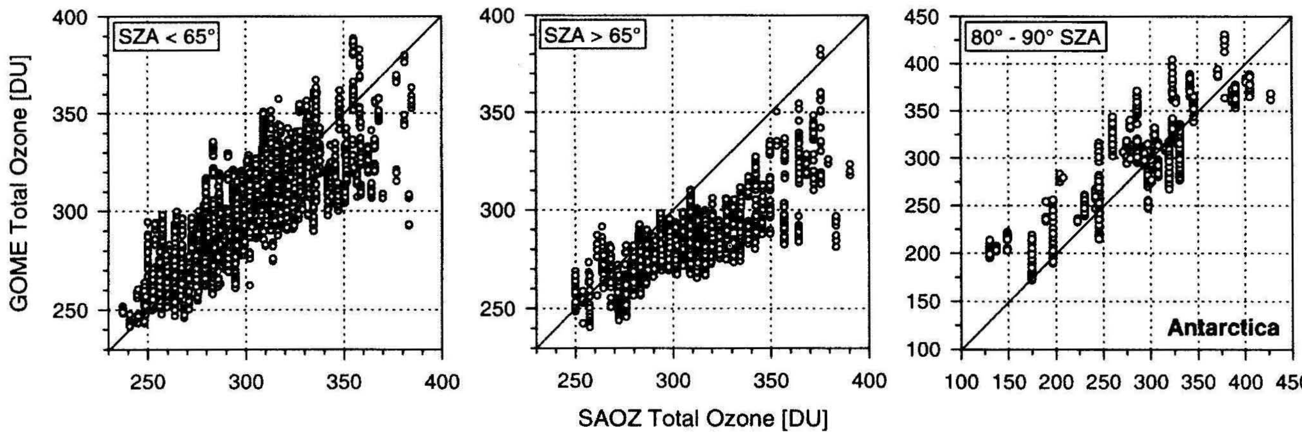


**Fig. 4.** Correlation between GOME v2.0 and SAOZ total ozone for the whole SAOZ network except Antarctica (left and centre panels) and for Antarctica only (right panel). GOME underestimates high ozone, the divergence increasing at large SZA. In Antarctica, GOME overestimates low ozone in the winter polar vortex.

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