Ground-based validation of GOME total ozone measurements by means of Dobson, Brewer and GUV instruments


Abstract. Within the scope of its validation programme, GOME total ozone measurements carried out between July 1995 and January 1996 were compared with ground-based data originating from different instrumental techniques. This paper reports on validation results obtained by means of the European part of the Dobson and Brewer networks including nine stations located between the Alps and Spitzbergen. At several Nordic stations, these data are complemented by O₃ measurements with multichannel UV filter instruments (GUV). Differences between GOME and ground-based measurements and their dependence on measurement conditions and parameters are studied based, for the latest GOME version, on a limited set of data covering only two months (July and August 1996). Compared to validation results obtained in January 1996 at the commissioning phase, the current version of the GOME total ozone retrieval algorithm shows significant progress. At small SZA (<50°), the average deviation between GOME and ground-based measurements is virtually zero. At larger SZA, it increases progressively to reach about -10% at 90°. Except for the low SZA (<35°), no significant dependence on the cloud fraction is observed.

Introduction

The GOME (Global Ozone Monitoring Experiment) instrument was launched aboard the ERS-2 platform on the 21st of April 1995. It is a nadir viewing UV-visible grating spectrometer aiming to provide measurements of O₃ total columns and vertical distributions as well as total columns of several additional constituents like NO₂, ClO, BrO, SO₂, etc. GOME is the first space-borne instrument using the differential absorption method for the retrieval of vertical column abundances. Organised and coordinated by ESA, the GOME geophysical validation campaign started in July 1995 for a scheduled duration of 6 months (the commissioning phase). In January 1996, a workshop meeting was held in Frascati (Italy) and a first statement of the GOME performance was then established showing the existence of several problems in the then operational GOME data processor (GDP v. 1.21). This led to the conclusion that a reprocessing was needed and, consequently, the release of the GOME ozone data was postponed. Between February and July 1996, various changes were introduced into the GDP and a 'tiger team' was formed in order to validate small sets of reprocessed data. Finally the first GOME total ozone values produced by the operational version of the GDP (version 2.0) were released on July 26, 1996.

This paper presents an overview of the main findings obtained by means of Dobson, Brewer and GUV instruments during the GOME validation campaign and reports on the first results of the validation (by the same ground-based instruments) of the operational GOME total ozone data recently released to the public domain.

Ground-based measurements

The stations involved in the validation, their coordinates and the instruments available there are listed in Table 1.

Dobson and Brewer instruments

The Dobson and Brewer spectrophotometers are the standard instruments to measure total ozone from the ground and have been described before. In principle, measurements can be obtained using the light from the direct-sun or the zenith sky. In this work however, only direct-sun data were used as it has been established that their precision is better (2-3% for well calibrated instruments, see e.g. De Bakker and De Muer, 1991).

GUV instrument

The Ground-based UV radiometer is a multi-channel moderate bandwidth UV filter instrument. Absolute irradiances are measured in 4 UV channels (305, 320, 340, 380 nm) of which the two first are used to derive total ozone based on transfer tables established with a radiative transfer model. Details on the instrument and data analysis are given in Dahlback (1996). Comparisons with standard techniques indicate that the precision of this method for total ozone measurements is comparable to the Dobson or Brewer one (Dahlback, unpublished results).
Selection of the data

Correlative data are obtained when GOME obtained at ground stations first implied the development of Table 1. List of the stations involved in the validation of GOME total ozone measurements.

<table>
<thead>
<tr>
<th>Station</th>
<th>Instruments</th>
<th>Lat.</th>
<th>Long.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haute Provence</td>
<td>D</td>
<td>44°N</td>
<td>6°E</td>
</tr>
<tr>
<td>Bordeaux</td>
<td>D</td>
<td>46°N</td>
<td>1°E</td>
</tr>
<tr>
<td>Arosa</td>
<td>D + B</td>
<td>47°N</td>
<td>10°E</td>
</tr>
<tr>
<td>Hohenpeissenberg</td>
<td>D + B</td>
<td>48°N</td>
<td>11°E</td>
</tr>
<tr>
<td>Uccle</td>
<td>D + B</td>
<td>51°N</td>
<td>4°E</td>
</tr>
<tr>
<td>De Bilt</td>
<td>B</td>
<td>52°N</td>
<td>5°E</td>
</tr>
<tr>
<td>Oslo</td>
<td>D + B + GUV</td>
<td>60°N</td>
<td>11°E</td>
</tr>
<tr>
<td>Tromso</td>
<td>D + B + GUV</td>
<td>70°N</td>
<td>19°E</td>
</tr>
<tr>
<td>Ny-Alesund</td>
<td>D + GUV</td>
<td>79°N</td>
<td>12°E</td>
</tr>
</tbody>
</table>

D= Dobson, B= Brewer

Validation of GOME total ozone

Selection of the data

The comparison of GOME data with total ozone data obtained at ground stations first implied the development of tools for identification, extraction and gathering of both GOME and ground-based measurements. Such a tool ‘DOBSGOME’ was jointly developed by G. Hansen from NILU and R. Koopman from RIVM as a general service to all members of the GOME geophysical validation campaign. In addition to this, several other extraction programs were locally developed for specific applications not included in the general DOBSGOME facilities.

The selection of GOME and ground-based coincident measurements is meant to minimize the impact of differences in space and time between GOME and ground-based data that will naturally introduce a noise in the comparisons because of the natural inhomogeneities of the O₃ field. Of course the best correlative data are obtained when GOME and ground-based measurements are exactly coincident. However, given the limited amount of data available, it is clear that the choice of very strict constraints on the coincidences reduces drastically the number of comparison points and that a compromise has to be found between low noise and good statistics. Preliminary investigations performed by several groups revealed that, with the current level of precision of both GOME and ground-based measurements, no strong dependence of the deviation between GOME and ground data was found up to 150-200 km for data selected within a time window of ±3 hours.

Validation of initial versions of data products

The first results of the GOME total ozone validation were presented at Frascati (Italy) at the end of the commissioning phase in January 1996 (Hansen and Dahlback, 1996, Koopman and van der Woerd, 1996, Lambert et al., 1996, Piers et al., 1996, Schoubs and De Muer, 1996, Staehelin and Renaud, 1996). This work was based on the old version 1.20/1.21 of the GOME data processor (GDP). As a general statement, a satisfactory agreement between GOME and ground-based O₃ data was found for small and moderate solar zenith angle (SZA), GOME yielding slightly smaller values (by about 3-5%) than ground-based instruments. A dependence of the differences on the SZA was also reported, with increasing deviations at large SZA reaching about -10% at 74.6°. At SZA larger than 74.6°, GOME started to deviate dramatically from ground-based instruments due to the non-inclusion of the multiple scattering in the GOME airmass factors (AMFs) used in the old GDP version. In addition to this, a dependence on the cloud fraction was identified, GOME underestimating total O₃ for large cloud fractions.

Validation of GOME version 2.0

Following the Frascati meeting, it was established that the determination of O₃ slant columns from GOME spectra was reliable but that significant problems remained in the conversion from slant to vertical columns due to a lack of properly calculated AMFs. Hence new tables were produced and implemented into the GDP. These new AMF tables include multiple scattering corrections up to 92° SZA, better climatologies of ozone, pressure and temperature profiles and are calculated at the wavelength of largest weight in the DOAS fitting window (325 nm). Among other changes, an improved algorithm to derive cloud cover from GOME data was also implemented.

The operational version of the GDP (v. 2.0), accessible to the scientific community since August 1996, is the most advanced to date and reflects the progress accomplished since January 1996. At the time of writing, only 2 months of data are available: July and August 96. Due to the lack of time the validation results presented below are based on a limited set of data from 6 ground stations operating either Brewer or GUV instruments:

- Arosa, Hohenpeissenberg, Uccle (Brewer) 46-48-51° N
- Oslo (GUV) 60° N
- Tromso (Brewer) 70° N
- Ny Alesund (GUV) 79° N

Note that these stations are well distributed from the mid-to the very high latitudes so that, even over the limited period of time covered, ozone measurements are available over a large range of SZA. Figure 1 shows the dependence of the total ozone deviation (percentage difference) on the SZA of the GOME measurements between 25 and 90° SZA. According to above considerations, GOME pixels were selected within 200 km of the ground stations (GS) and compared to ground-based data averaged within a time window of ±3 hours relative to the GOME overpass. It is clear from Figure 1 that the SZA dependence of the total ozone deviations has not been fully eliminated. However, relative to previous comparisons, a significant improvement is obtained at small SZA (below 50°) where the mean difference is virtually zero, as well as at large SZA (above 75°) where the deviation can now be kept reasonably small (around -10%) up to 90° SZA.

The dependence of the ozone deviation on the cloud fraction (that is determined from GOME data using the so-called ICFA algorithm, K. Chance, 1996) has been investigated. In order to minimise the impact of the SZA dependence, results shown in Figure 2 were grouped in four different SZA regimes. For SZA>35°, no significant dependence on GOME cloud fraction (CF) can be detected which confirms the progress made since January 1996 in the GOME cloud fitting algorithm. For SZA<35°, the data indicate a small overestimation of GOME measurements (by about 5%) for large cloud fractions. However this behaviour has to
Figure 1. Percentage difference in total ozone between GOME and ground-based (GS) data as a function of the SZA of GOME measurements. Triangles denote mid-latitude data (Arosa, Hohenpeissenberg and Uccle), circles Oslo data, squares Tromso data, and diamonds Ny-Alesund data. Only pixels closer than 200 km to ground stations were considered.

be confirmed by further comparisons based on a larger set of relevant data points. Note that, if confirmed, this CF dependence would be opposite to the one reported in previous GOP versions (i.e. an underestimation of GOME total ozone for large CF).

Together with the release of the version 2.0, ESA produced a statement of the confidence level for GOME total ozone data which is reproduced in Table 2. This table was established from results obtained by the Tiger Team of validation based on limited series of data processed with intermediate versions of the GDP. For comparison purpose, the percent differences shown in Figure 1 were averaged per bin of 10° in SZA and the standard deviation (2σ) were calculated within each bin. Represented in Figure 3, the calculated mean differences confirm the values given in Table 2, column 2, i.e. an agreement between GOME and ground-based measurements better than 5% for SZA<60° and better than 10% for SZA<90°. As regards the dispersion, determined here by 2σ standard deviations, the values obtained from the present comparisons (error bars in Figure 3) appear significantly smaller than the value stated in Table 2, column 3. They indicate that the intrinsic noise of GOME data could be of the order or even smaller than 5% at 2σ.

Table 2. Confidence level of GOME total ozone values as derived from the GDP comparison with ground-based measurements (table extracted from the GOME data disclaimer released by ESA on 26 July 1996)

<table>
<thead>
<tr>
<th>SZA range</th>
<th>Mean difference (abs. value)</th>
<th>Standard deviation (2σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 60°</td>
<td>&lt; 5%</td>
<td>10%</td>
</tr>
<tr>
<td>&lt; 90°</td>
<td>&lt; 10%</td>
<td>20%</td>
</tr>
</tbody>
</table>

Conclusion

GOME total ozone data have been compared to ground-based measurements performed by means of Brewer, Dobson

Figure 2. Total ozone deviation (in percent) between GOME and ground-based data as a function of cloud fraction for SZA<35° (upper left panel), 35°<SZA<50° (upper right panel), 50°<SZA<65° (lower left panel), and 65°<SZA<90° (lower right panel). Data from mid-latitude stations are marked with triangles, data from Oslo with circles, data from Tromso with squares, and data from Ny-Alesund with dots.
and GUV instruments at nine stations in the northern hemisphere. The results of the validation of the latest (operational) version of the GOME total ozone data processor (v. 2.0) show significant progress as compared to results obtained at the end of the commissioning phase in January 1996. In summary, the GOME total ozone values turn out to be in excellent agreement with ground-based measurements for SZA<50°. At larger SZA, GOME shows a tendency to underestimate ozone values, the deviations reaching -10% at 90° SZA. The dependence of the deviations on the cloud fraction (reported with previous version of the GOME algorithm) has been largely eliminated, although a small effect might still remain at low SZA (<35°). The dispersion of the comparison plots, of the order of 5% at 2σ whatever the SZA, is smaller than reported in the GOME data disclaimer and probably reflects better the intrinsic noise of GOME data.

These findings are roughly consistent with validation results obtained with the SAOZ network (Lambert et al., this issue) as well as with the TOMS instrument (Burrows et al., this issue). Of course they have to be confirmed by further comparisons including longer time-series of GOME measurements and possibly an extended set of ground-based stations.

Acknowledgements.

This work has been supported by the PRODEX-GOME A.O. ERS-2 Project I and by the Belgian State-Prime Minister's Service - Science Policy Office (contract GC/35/002). We gratefully acknowledge José Granville and Pierre Gérard for the support provided in developing the essential evaluation softwares.

References


Dahlieback, A., Measurements of biological effective UV-doses, total ozone abundance and cloud effects with multi-channel moderate bandwidth filter instruments, Appl. Optics, in press, 1996.


