GOME and TOMS Total Ozone in Northern Winter 1996/1997: Comparison with SAOZ/UV-visible Ground-based Measurements in the Arctic and at Middle Latitude

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INTRODUCTION

The geophysical exploitation of satellite data requires a high level of accuracy to be maintained over the lifetime of the experiment. It is therefore of prime importance to investigate, by means of intensive validation programmes relying on well controlled correlative measurements, the sensitivity of both the measurement and the retrieval algorithms to a variety of instrumental as well as atmospheric parameters. Here, total ozone measured from December 1996 through April 1997 by three space-borne sensors, the ERS-2 GOME and the two TOMS on-board the Earth Probe (EP) and the ADEOS (AD) platforms, is compared with ground-based observations in Europe, Greenland and Siberia, over an extended latitude range. The agreement between satellite and ground-based data is investigated and possible sources of discrepancies are highlighted.

ANALYSIS AND DISCUSSION

The present study is based on ground-based total ozone measured by eight SAOZ [1] or SAOZ-like UV-visible zenith-sky spectrometers [2] at eight northern stations of the SAOZ/UV-visible network : O.H.P. (44°N, France), Jungfraujoch (47°N, Switzerland), Harestua (60°N, Norway), Zhigansk (67°N, Eastern Siberia), Sodankylä (67°N, Finland), Scoresbysund (70°N, Eastern Greenland), Thule (77°N, Western Greenland) and Ny-Ålesund (79°N, Spitsbergen). The comparison methodology [3] takes into account the differences between the nadir and zenith viewing and optimises the coincidence between the air masses probed by the satellite and the ground-based instruments. Meteorological analyses of potential vorticity and temperature are used to identify polar vortex overpasses and the possible occurrence of PSC formation. The vortex boundary is defined by PV of 40±8 PVU (10^{-6} $K.m^2.kg^{-1}.s^{-1}$) at the 475 K isentropic level and 90±12 PVU at 550 K.

Figure 1 shows the relative difference between the satellite and ground-based total ozone at seven stations. The comparison is illustrated in more details at Sodankylä in figure 2. At middle latitude, the average agreement between the GOME and SAOZ total ozone is better than ±3%, that is within the uncertainty of the SAOZ measurement. The negative differences of 4-5% observed in December at the O.H.P. originate mainly in the seasonal variation of the SAOZ air mass factor, due to the seasonal change in the shape of the ozone profile and scattering geometry [4-6], and not taken into account in the real-time SAOZ data used here. At the Jungfraujoch, where SAOZ data are corrected for this effect, negative differences in December are significantly reduced. The scatter is about 4-7%, increasing during fast total ozone changes. At 60°N, the comparison yields similar results to that obtained at lower latitude. At the Arctic circle, GOME overestimates in January the SAOZ total ozone by 10% on average, due to a solar zenith angle (SZA) dependence

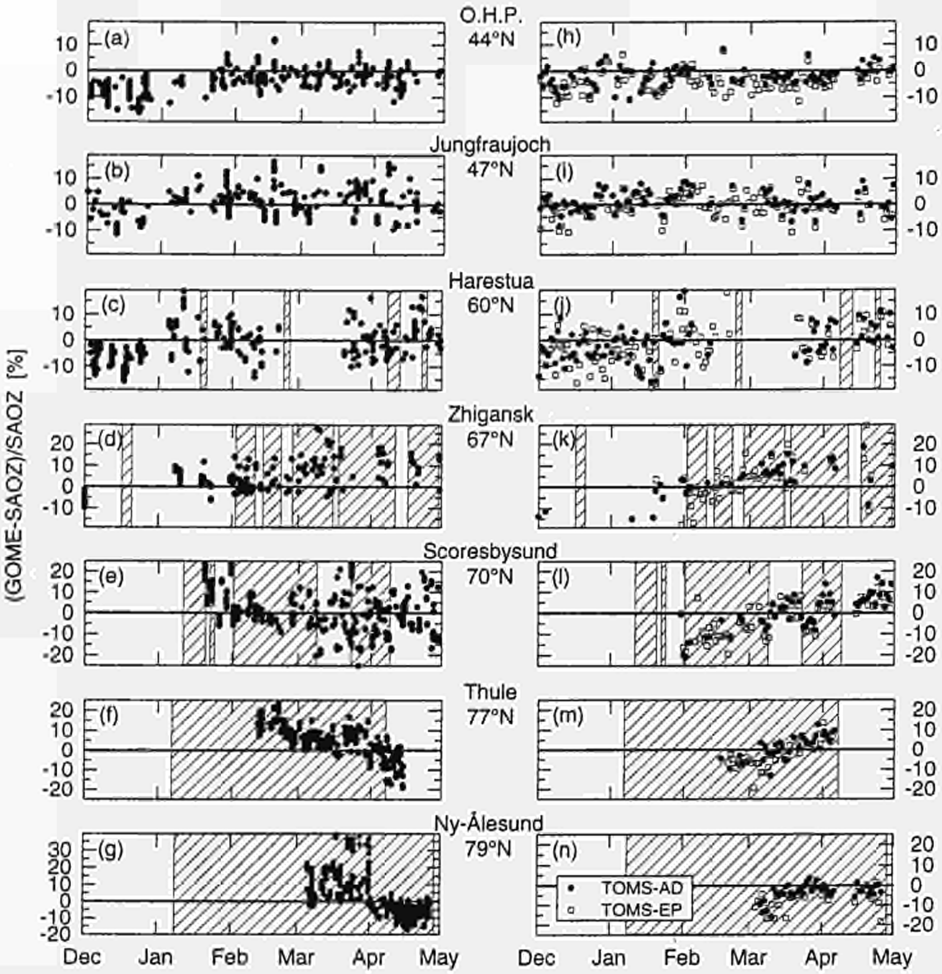

Figure 1 - Winter-spring 1997 time series of the relative difference between the ground-based total ozone at 7 stations (from top to bottom) and that measured by the GOME (a-g) and both TOMS-AD and TOMS-EP (h-n).

of the GOME measurement (see below). The difference in sensitivity which combines with this SZA dependence (see below) may result in larger deviations up to 25% and more for low ozone columns, e.g. like at Sodankylä in early December (see figure 2). The average agreement after January is within ±5%, and the scatter is about 5-10%. The comparison in Scoresbysund becomes much more scattered after the stratospheric warming in March. Beyond the polar circle, results are qualitatively similar. The 10% overestimation noticed at the polar circle extends through March in Thule and even April in Ny-Ålesund, and turns into a few percent underestimation in April.

Comparison results with TOMS-EP and with TOMS-AD are consistent together, and consistent with GOME up to 60°N. Around the Arctic circle, the mean agreement is within ±5%. The SZA dependence of TOMS (see below) generates systematic negative deviations at Sodankylä and Scoresbysund in February. In late March, positive deviations of 5-8% occur around the polar circle and persist through April. Beyond the Arctic circle, TOMS underestimates SAOZ total ozone by 5-10% in winter, due to a TOMS SZA dependence. Positive mean deviations in springtime occur earlier than at 67°N, except at Ny-Ålesund where a 3% underestimation remains.

For both GOME and TOMS, the agreement with ground-based observations at high latitude and low Sun elevation clearly depends on the SZA (figure 3). Ground-based total ozone beyond 80°

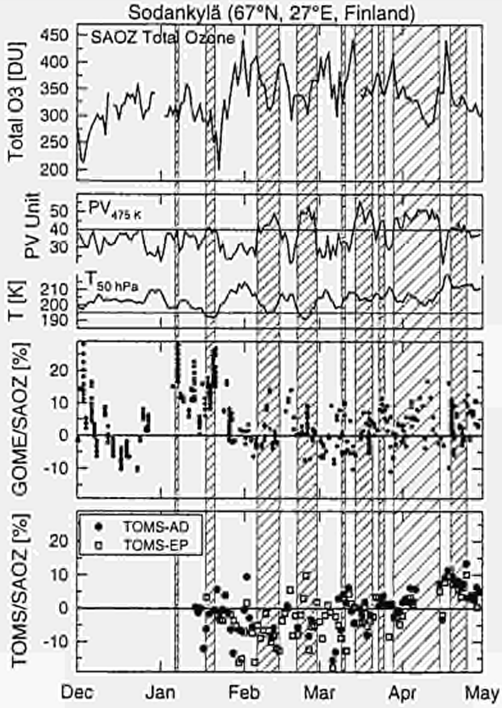

Figure 2 - Winter-spring 1997 time series at Sodankylä Vortex overpass episodes are highlighted by dashed boxes.

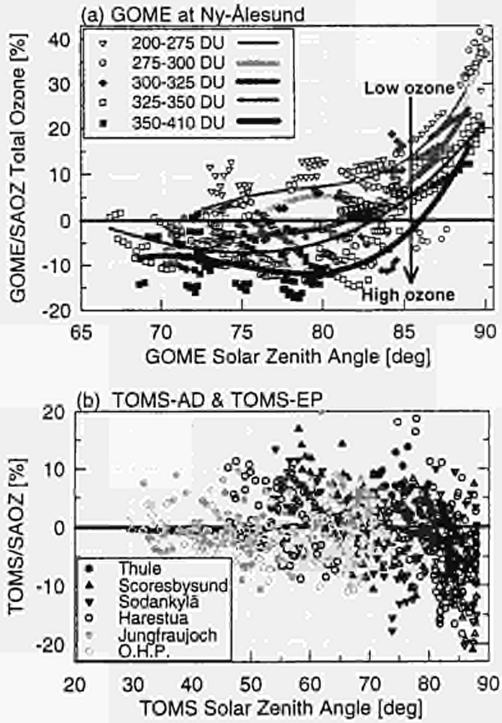

Figure 3 - Solar zenith angle dependence of the percentage relative difference in total ozone during winter-spring 1997 at six stations from 77°N down to 44°N.

SZA is systematically overestimated by the GOME and underestimated by the TOMS. Except at the Jungfraujoch and at Harestua, the ground-based data sets used here are not corrected for the seasonal variation of the SAOZ AMF [4-6], which could contribute partly to the SZA dependence. However, this can certainly not account for the full systematic bias observed at high SZA, nor for the shape of the SZA dependence which in addition is different for GOME and for TOMS. Moreover, the GOME SZA dependence in winter-spring differs from that in summer-fall [7], while the TOMS SZA dependence remains the same year-round. The GOME SZA dependence at large SZA also combines with a difference in sensitivity (see figure 3-a). Comparison with both TOMS-AD and TOMS-EP is still too scarce to detect this feature. The difference between the GOME and the TOMS behaviours at large SZA might arise from basic algorithm differences in the treatment of their sensitivity to the ozone density and temperature profile shapes. In particular, the seasonal variation of the GOME SZA dependence is most likely to originate in the profiles used in the current version of the algorithms. Its column dependence might be associated with the use of seasonal profiles. This effect could be significantly reduced by using a column-resolved climatology of profiles, like in TOMS V7. The column-resolved SZA dependence of GOME data might also be related to a difference of sensitivity resulting from the wavelength dependence of the GOME AMF or from a small wavelength calibration shift between the GOME spectra and the laboratory cross-sections. For both GOME and TOMS, an overcorrection for multiple scattering arising from uncertainties on the ozone profile and radiative parameters cannot be ruled out.

The average scatter between the satellite and ground-based total ozone increases from ±4-7% at mid-latitude, up to ±10% and more at high latitude and also at high SZA. Results are similar with GOME and both TOMS. The dispersion is partly related to the spatial and temporal difference in air masses probed by the different instruments, combined with the presence of horizontal gradients and of variability. It might partly explain the larger scatter near the edge of the polar vortex, where total ozone can change rapidly, than inside the vortex. A lower scatter might be expected at large SZA since the air masses probed by nadir-viewing space-borne and zenith-sky ground-based instruments are much more coincident. However, the opposite is observed, partly due to the poor sensitivity of UV nadir measurements at high SZA to the low troposphere, and partly due to the uncertainty on radiative transfer modelling and parameters in the UV when the SZA increases. The scatter also originates in deviations of the actual ozone, pressure and temperature profiles from those in use in the retrievals. Other possible contributions are related to the cloud cover: (a) perturbations generated in the ground-based measurements by tropospheric multiple scattering in presence of dense clouds or haze, combined with local ozone changes; (b) uncertainties in the cloud treatment in the satellite retrieval; (c) perturbations due to dense polar stratospheric clouds (type II); (d) reduction of the tropospheric contribution to the satellite measurement, masked by clouds.

CONCLUSIONS - IMPACT ON STUDIES USING SATELLITE DATA

During the northern winter 1996/1997, the ERS-2 GOME, TOMS-AD and TOMS-EP total ozone at northern mid-latitude are in good general agreement with correlative ground-based observations, within ±3-4% with a scatter of 4-7%. Around the Arctic circle and beyond, the mean agreement is about ±5% and the scatter increases. However, the relative difference depends on the SZA of the satellite measurement, GOME overestimating by about 10-15% and TOMS underestimating by 5-10% ground-based total ozone at SZA larger than 80°. The scatter becomes significant beyond 85° SZA. In addition, the GOME SZA dependence combines with a difference of sensitivity at high total ozone. At first glance, the impact of the polar vortex is mainly an increase of the scatter during fast total ozone changes between the satellite and ground-based measurements.

The SZA dependence and the difference in sensitivity must be kept in mind in studies based on satellite data recorded in polar areas during winter and spring. As an example, for an ozone loss assessment combining satellite total ozone measurements and trajectories modelling, the SZA dependence or the difference of sensitivity, if not taken properly into account, might both introduce large uncertainties in the ozone loss calculation since the studied air parcels travel through polar areas and hence can experience a wide range of SZA and total ozone.

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