

# Pole-to-pole validation of GOME level-2 products with ground-based networks

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The Global Ozone Monitoring Experiment (GOME) flown onboard ERS-2 satellite has been providing vertical columns of ozone and NO<sub>2</sub> routinely since July 1996. Those level 2 products, as well as total ozone measured from space by two NASA's Total Ozone Mapping Spectrometers (TOMS), have been compared to ground-based colocated observations of the Network for the Detection of Stratospheric Change (NDSC) and of the SAOZ/UV-visible network. Comparisons with each space-borne sensor have been combined altogether for investigating the solar zenith angle (SZA) dependence, the dispersion and the difference of sensitivity of the space instruments. The present paper summarises the current conclusions on the quality of GOME level-2 products. The GOME and ground-based total ozone agree within a few percent on average. However the analysis demonstrates a clear dependence on the SZA and the ozone column. The preliminary validation of the GOME total NO<sub>2</sub> and 'near-real-time' ozone profiles is also reported.

## Introduction

A better knowledge of the global composition of the atmosphere as well as its long-term evolution are urgently required to assess its current and future changes. Space-borne atmospheric sensors only can provide the needed continuous monitoring of relevant atmospheric trace species at the global scale. GOME yields vertical columns of ozone and NO<sub>2</sub> routinely since July 1996. In addition, information on other trace species such as BrO, OCIO, CH<sub>2</sub>O, SO<sub>2</sub> and aerosols, can also be derived from GOME spectra. However, since the measurements and the retrieval algorithms are sensitive to a variety of instrumental as well as atmos-

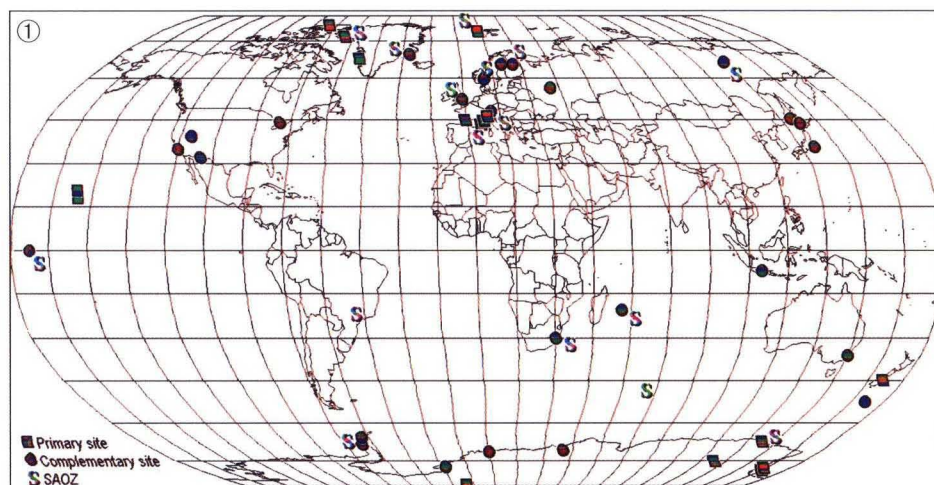
pheric sources of errors, they need to be validated carefully and independently by means of correlative measurements at the global scale and on the long term. This is a main goal of the Network for the Detection of Stratospheric Change (NDSC) and the SAOZ/UV-visible network. Those sets of high-quality atmospheric remote-sounding stations have demonstrated at many occasions their efficiency and complementarity in satellite validation research (Lambert *et al.* 1997a, and references). They have played a major role during the maturation of the ERS-2 GOME Data Processor's developmental version GDP 1.x (ESA WPP-108, 1996), of its first publicly available operational

version GDP 2.0 (e.g. Lambert *et al.* 1996, 1997a-c), and of its newly improved operational version GDP 2.3. They will also be valuable in the validation and interpretation of data from future missions such as Envisat-1. The present paper summarises the current conclusions on the quality of GOME ozone and nitrogen dioxide data, derived from investigations carried out in the frame of the satellite validation activities of the NDSC and the SAOZ/UV-visible network.

## Ground-based networks

The NDSC (Fig. 1) consists in five primary stations (Arctic, Alpine, Hawaii, New Zealand and Antarctic) including a dozen of sites fully equipped with a variety of instruments such as lidars, UV-visible spectrometers, Fourier transform infrared spectrometers (FTIR) and millimetre-wave radiometers. Primary stations are completed by two dozens of complementary sites equipped with a limited number of instruments but always validated as those of the primary stations. Each NDSC primary station monitors total columns of ozone, NO<sub>2</sub> and other key constituents

*Current configuration of the NDSC and the SAOZ/UV-visible network.*

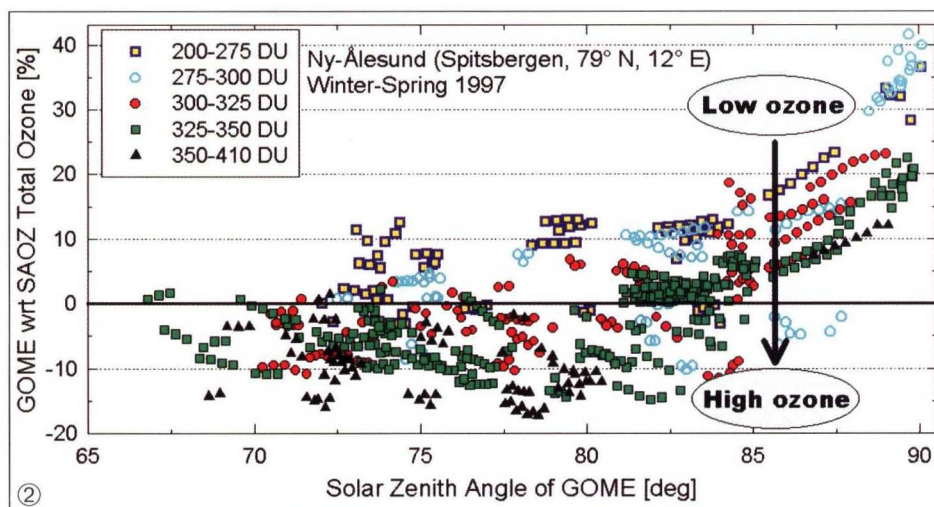




such as  $\text{NO}_y$ ,  $\text{ClO}_y$  or  $\text{CH}_4$ , and vertical profiles of ozone, temperature, water vapour,  $\text{ClO}$  and aerosols. In particular, total ozone is measured with UV-visible spectrometers, Dobson and Brewer spectrophotometers, and FTIR spectrometers. Ozone vertical distribution is measured from the ground up to burst point (typically 30 km) by ozonesondes, from 20 to 45 km by stratospheric lidars, for altitude below 15 km by tropospheric lidars, and from 25–30 to 70 km by mm-wave radiometers, allowing investigations over the complete vertical range from the ground up to 70 km. In the frame of the NDSC, 17 SAOZ (Système d'analyse par observations zénithales, Pommereau & Goutail, 1988) and other NDSC-qualified UV-visible zenith-sky spectrometers have been deployed from the Arctic to the Antarctic, constituting the so-called SAOZ/UV-visible network. These instruments monitor the ozone and  $\text{NO}_2$  column amounts at dawn and at dusk, within a constant narrow range of solar zenith angle ( $86^\circ$ – $91^\circ$  SZA).

### Total ozone vertical column

Total ozone measured from space by ERS-2 GOME (since June 1996) as well as by two NASA's Total Ozone Mapping Spectrometers (TOMS) onboard the Earth Probe (since July 1996) and ADEOS platforms (Sept. 1996 - June 1997) has been compared to ground-based observations from the whole SAOZ/UV-visible network and from Dobson and Brewer spectrophotometers operating at selected sites of the NDSC Alpine and Antarctic stations. The comparisons with each space-borne sensor have been combined altogether for investigating their respective performances. The study demonstrates a good average agreement to within  $\pm 2$ – $4\%$  between all space-borne and ground-based instruments at northern middle latitude. At high latitude, in both hemispheres, the mean agreement and the scatter vary with the SZA of the space observation, largely due to the retrieval method and its sensitivity to errors in the ozone profile shape derived from a seasonal climatology. The dispersion of satellite data increases significantly beyond  $85^\circ$  SZA. The GOME total ozone increases



Percentage relative difference between the GOME and SAOZ total ozone at the Arctic station of Ny-Ålesund, as a function of the solar zenith angle and the ozone vertical column (SAOZ data: NILU).

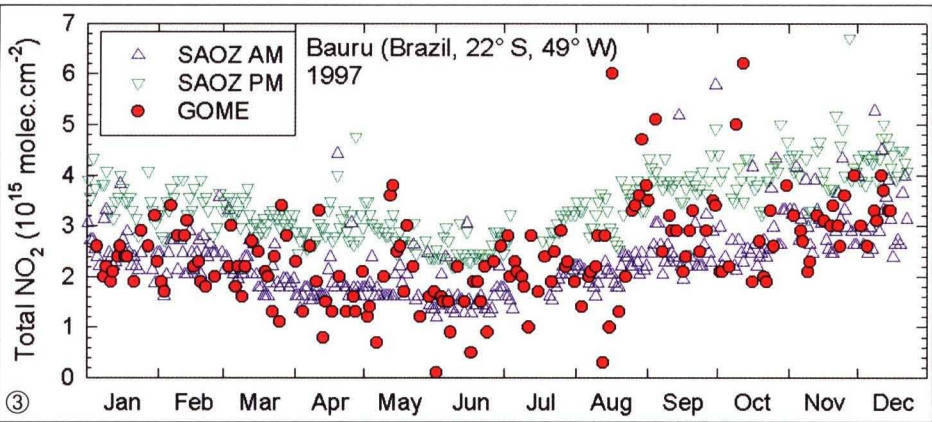
systematically beyond  $80^\circ$  SZA, however its average SZA dependence is dominated by a seasonal variation resulting in positive mean deviations beyond  $80^\circ$  SZA in winter-spring (Fig. 2) and in negative mean deviations beyond  $65$ – $70^\circ$  SZA in summer-fall. Although a SZA dependence is also present in the TOMS data, its amplitude is smaller than that of the GOME, does not vary with the season, and is not significant below  $80^\circ$ . The agreement between the GOME and the ground-based total ozone also depends on the ozone column, indicative of a difference of sensitivity. In particular, low ozone columns are overestimated by the GOME by a few percent at the tropics and more under ozone hole conditions. Such a feature is not observed with the TOMS, except at the southern tropic. However, TOMS data are found to overestimate ground-based data in the Southern Hemisphere. The use in the GOME total ozone retrieval of the so-called 'modified DOAS' approach, as well as a column-resolved climatology based on real ozone profile measurements like that used in the TOMS algorithm, could reduce both the seasonal SZA dependence of the GOME and its difference of sensitivity. But before using a column-resolved climatology similar to that used by the TOMS, it is recommended to investigate more deeply the sensitivity of the GOME retrieval to the

ozone profile shape errors as well as the inter-hemispheric shift in TOMS data.

### Nitrogen dioxide vertical column

GOME total  $\text{NO}_2$ , retrieved routinely with GDP 2.0 since 28 June 1996, has been compared to observations from the SAOZ network (Lambert *et al.* 1997c), following a methodology taking into account the error budget of the SAOZ measurement and the diurnal variation of total  $\text{NO}_2$  (Lambert *et al.* 1996). GOME  $\text{NO}_2$  measured in 1996 between 29 July and 15 October is irrelevant, due to a strong wavelength registration shift in the GOME spectral channel 3 (where  $\text{NO}_2$  is retrieved). Outside this period,  $\text{NO}_2$  data are consistent, although scattered, especially in polluted areas. This scatter originates partly in the high sensitivity of the GOME observation (nadir geometry) to the tropospheric  $\text{NO}_2$  content - which can exhibit sharp gradients - compared to the ground-based zenith-sky observations at twilight. Day-to-day fluctuations of GOME total  $\text{NO}_2$  generally are reasonable, but the pole-to-pole comparison with SAOZ data shows that the mean agreement depends clearly on the latitude, the season and the SZA. The southern tropic is the sole region where GOME and SAOZ are in good agreement (10–15%) all through the year (Fig. 3). This seasonal and latitudinal dependence arises





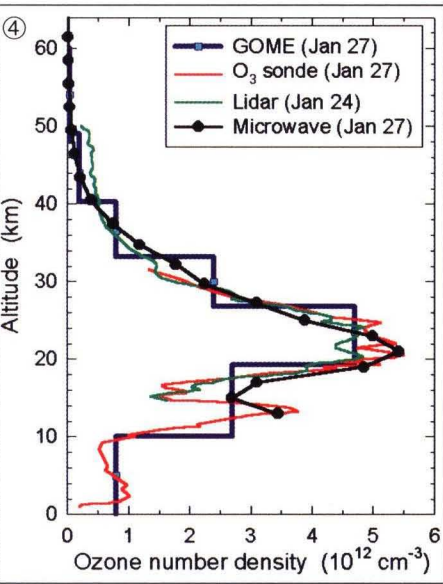
③ Time series of the nitrogen dioxide total column measured in 1997 at the tropical station of Bauru by the ERS-2 GOME before local noon and by the SAOZ at dawn and at dusk (SAOZ data: CNRS/UNESP).

mainly from the NO<sub>2</sub> vertical distributions used in the NO<sub>2</sub> retrieval of GDP 2.0, derived from a two-dimensional atmospheric chemical transport model. In some cases, those profiles are found inconsistent with real NO<sub>2</sub> density profiles measured with SAOZ-balloon sondes. Investigations based on GOME data retrieved with other NO<sub>2</sub> profiles – more consistent with SAOZ-balloon data, and implemented in the newly operational GDP 2.3 – show a better

general agreement between GOME and SAOZ total NO<sub>2</sub> (Lambert *et al.* 1997c). Despite this recent improvement with GDP 2.3, it is still recommended to revisit the NO<sub>2</sub> profile database used in the GOME retrieval. Test case studies with a 3D model suggest that a 2D climatology might be inadequate for nadir observations, partly due to the sharp gradients of the tropospheric NO<sub>2</sub> field.

Ozone vertical distribution

From a joint effort of IUP/IFE Bremen, DFD/DLR and ESA, preliminary GOME ozone profiles were provided in ‘near-real time’ (NRT) during the 1997 Arctic winter campaigns. To evaluate the relevance of these NRT profiles, a quick comparison was carried out with correlative ozone profiles measured from a variety of primary and complementary NDSC stations in the northern hemisphere (Fig. 4). Limited to a sparse dataset of clear-sky GOME pixels recorded between 24 January and 31 March, a preliminary study concluded to a reasonable 10-15% agreement in the stratospheric layer from 20 to 27 km (Lambert *et al.* 1997b). Larger deviations up to 30-40 % and more were observed in the tropospheric and lowest stratospheric layers, partly due to the natural variability and gradients of the ozone field. The influence of the tropopause altitude and of sharp ozone laminae suggests that the use of pre-defined atmospheric layers fitted to the vertical resolution of the profile retrieval (7 layers from ground to 60 km) lacks accuracy. The study also revealed that the retrieved tropospheric content is



④ Height-resolved ozone derived from GOME spectra above Austria on 27 January 1997, compared to ozone profiles measured in southern Germany (Hohenpeißenberg) by ozonesonde and lidar (Deutsche Wetterdienst) and in Switzerland by microwave radiometry (University of Bern).

highly constrained by the tropospheric content of the climatological profile used as a priori in the NRT algorithm. Recent improvements in the profile retrieval algorithms at IUP/IFE, not available at the time of this study, could modify the conclusion.

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