Pergamon
www.elsevier.nl/locate/asr

Adv. Space Res. Vol. 23, No. 8, pp. 1393–1396, 1999

0273-1177/99 $20.00 + 0.00

PII: S0273-1177(99)00289-6

PERFORMANCE DEGRADATION OF GOME POLARIZATION MONITORING

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ABSTRACT

The Global Ozone Monitoring Experiment (GOME) is a nadir-viewing double spectrometer which measures solar radiation backscattered from the Earth's atmosphere over a broad wavelength range, from the ultraviolet (UV) to the near infrared (Burrows, 1998). It has been operating since 1995 on board the ESA ERS-2 satellite, monitoring a large range of atmospheric trace constituents, with particular emphasis on ozone. The performance of the instrument is monitored in-flight by means of routine on-board calibration measurements, observing the sun and, occasionally, the moon. In this way, degradation of optical components in space can be monitored. The performance of the broad-band detectors which monitor the polarization state of the incoming light is analyzed by means of solar measurements. The measurements of the polarization detector which samples UV light show a degradation of 6% per year. The optical components affected can be (partially) identified by monitoring the fractional polarization, which is a characteristic of the light back-scattered by the Earth's atmosphere. The influence of the observed degradation on Earth radiation measurements is estimated to be in the order of 1.5% per year in the UV wavelength range.

INTRODUCTION

The large wavelength dispersion of GOME (240 to 790 nm) at moderate resolution (0.2 to 0.4 nm) is achieved by means of a quartz prism. The light is then split into four continuous wavelength ranges, where high spectral dispersion is obtained by means of diffraction gratings. Light is sensed by four Silicon diode linear arrays, with 1024 elements each. Optical components such as diffraction gratings and the pre-disperser quartz prism are known to be polarization sensitive. Three broad-band detectors, the Polarization Monitoring Devices (PMDs), are used to determine the polarization fraction of the incoming light. A scan mirror is used to sweep the instantaneous field of view of GOME over a maximum angle of ±30° in the across-track direction, covering a maximum footprint on the Earth surface of 960 Km. The along-track footprint for each acquired spectrum is 40 km (80 km in the UV due to longer integration time). The scan mirror is oriented each day to view a calibration unit. This is equipped with a mirror that points directly at the sun, which together with a sun diffuser and a protective mesh enable the use of the sun as a reference source.

Degradation of optical elements which are adversely affected by exposure to UV radiation has been observed. The degradation of the response of the detectors which monitor polarization is addressed in the present study. The fraction of polarization is a key parameter for the performance of the entire GOME instrument, as it also affects the radiometric calibration.

RADIOMETRIC CALIBRATION OF GOME

The radiometric calibration of GOME transforms the readouts of the pixels of each detector into absolutely calibrated radiances. Several corrections, such as dark current, pixel-to-pixel gain and straylight, are applied. Solar and Earth (ir)radiance are determined from the measured intensity knowing, from the on-ground calibration, the (spectrally resolved) radiance sensitivity function. For solar irradiance, the bi-directional scattering distribution function (BSDF) of the solar calibration unit must also be known. This is because the response of the sun diffuser is function of the elevation and azimuth angle of the incident sun light. Solar light scattered by the Earth's atmosphere by air molecules and aerosols is polarized. Because of the polarization-sensitive optics of GOME, a correction must account for the sensitivity to the polarization of the incoming light.

POLARIZATION CORRECTION

For Earth radiance measurements, the measured (polarized) intensity has to be related to the intensity of the unpolarized light that would enter the instrument, by means of a correction factor. In general, the Earth radiance S is linearly polarized (Coulson, 1988). In the GOME spectrometer, the possible contribution of circular polarization is *a priori* neglected (GOME Users Manual, 1995). Therefore the light entering GOME can be described as the sum of two perpendicularly polarized components, $I_\parallel$ and $I_\perp$, with respect to the GOME slit direction. The response of the instrument to the two polarization directions is not equal, *i.e.* the polarization sensitivity $a_\parallel \neq a_\perp$. The radiance S_{pol} detected by GOME can be expressed as $S_{pol} = a_\parallel I_\parallel + a_\perp I_\perp$. The relative polarization sensitivity as function of wavelength, $a_\perp / a_\parallel = \eta$, is known from the pre-flight calibration. The correction for the polarization of the incoming light can be derived by estimating the fraction of incoming parallel polarized light, the fractional polarization $p = I_\parallel / I_{unpol}$. This correction relates the measured intensity S_{pol} to the incoming radiance, as if the latter were unpolarized:

$$C = S_{unpol}/S_{pol} = \frac{1}{2}\frac{1+\eta}{p\,(1-\eta)+\eta}\,. \tag{1}$$

The fractional polarization p is derived from three broad-band measurements by the PMDs. An additional value for the lower UV-range – not covered by the PMDs – is calculated analytically (Stammes, 1997). An interpolation between these four values of p yields a continuous function across the entire wavelength range of GOME.

FRACTIONAL POLARIZATION

In order to monitor the polarization state of the incoming light, light with polarization parallel to the entrance slit of GOME is directed towards three hybrid broad-band detectors, the PMDs, which cover a broad wavelength range each: 300 - 400 nm (PMD 1), 400 - 600 nm (PMD 2) and 600 - 800 nm (PMD 3). These wavelength ranges correspond to the spectrometer arrays 2 to 4 (channel 1 measures in the 240 - 315 nm range). The intensity measured by the PMDs allows the determination of the fractional polarization p, by accepting the approximation that the latter is constant over the relevant wavelength range (DLR, 1996):

$$S_{\mathrm{PMD}} = \sum_i p\,\xi_i \frac{S_i}{p(1-\eta_i)+\eta_i}\,, \tag{2}$$

where S_i is the intensity measured by each diode i and ξ_i is the ratio of the sensitivity to parallel polarized light of the PMD with respect to each corresponding diode i (by design no perpendicular polarized light reaches the PMD). The value of p is determined by numerically solving Eq. (1).

DEGRADATION OF POLARIZATION MEASUREMENTS

The sun is a source of constant irradiance for the operational period of GOME. The calibrated intensity measured by the PMDs during solar measurements is shown in Fig. 1, relative to one of the first days of scientific operation of GOME, normalized to 1 AU. Deviations of the measured intensities from constant values are an indication of either calibration artefacts or degradation of the instrument performance. Most striking in Fig. 1 is a degradation in time, which is largest for PMD1 (300-400 nm), in the order of 6% per year. We show below how the degradation does not exclusively affect the solar calibration unit, but is present in the optical path followed by Earth radiance as well.

The seasonal oscillation seen in Fig. 1 is an artefact of the instrument calibration. It is associated with the solar azimuth angle, and is interpreted as an overcorrection of the azimuth angle dependence of the BSDF of the sun diffuser, which has been determined during the pre-flight calibration. Steps to improve the calibration *a posteriori* – by minimizing this spurious effect – are presently undertaken.

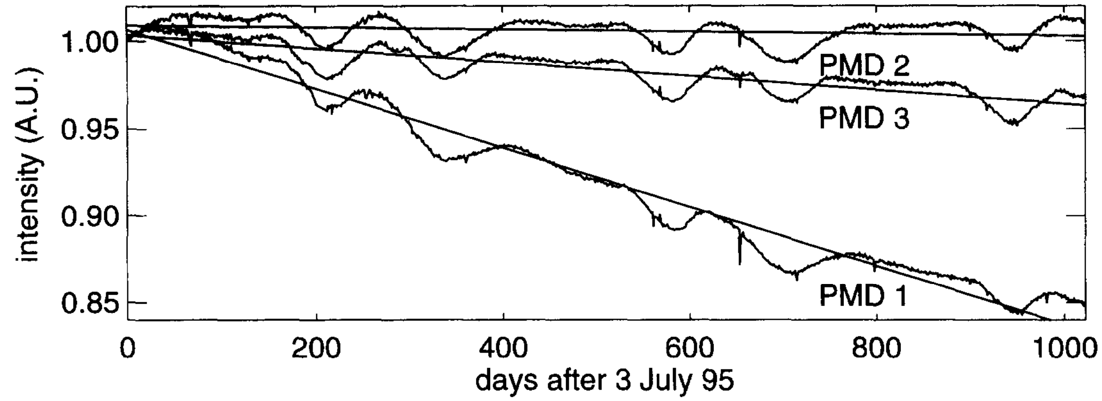

Fig. 1. Intensity measured by the PMDs of GOME during solar measurements, relative to July 3, 1995, one of the first days of scientific operation of GOME. The intensities are normalized to 1 AU.

FRACTIONAL POLARIZATION ALONG A GOME ORBIT

In order to examine the effect of the PMD degradation on radiance measurements, we follow the values of fractional polarization for an entire orbit extending form the Northern to the Southern Hemisphere over the Atlantic Ocean. The general behaviour of the fractional polarization p along the orbit is mainly determined by single scattering by molecules (Rayleigh), in particular over ocean dark surfaces (Stammes, 1997). The variability of p is caused by the presence of clouds and aerosols (Stammes, 1997). It has been shown that specific geolocations can be found where the fractional polarization p of the light reflected by the Earth's atmosphere is exactly 0.5. This is a result of the specific illumination geometry, regardless of the actual atmospheric scene observed (Aben, 1996). This situation is verified twice along each orbit, and the value of p exceeds 0.5 between these two points (Aben, 1996).

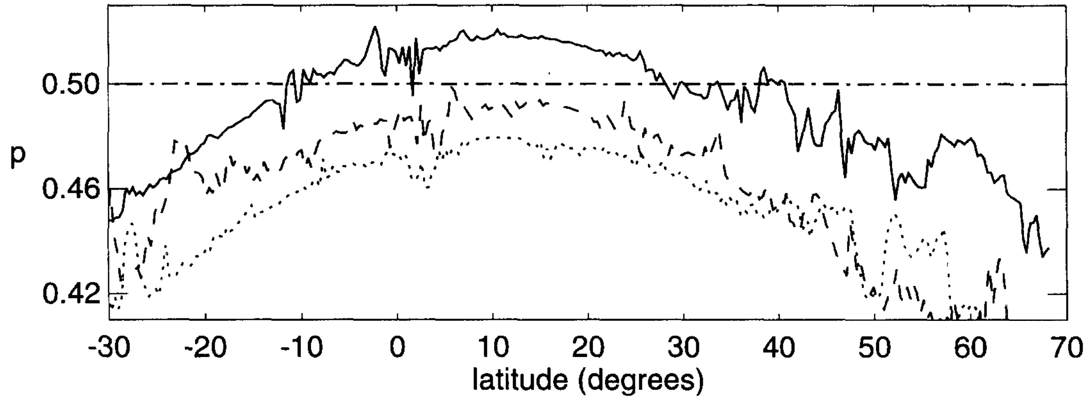

Fig. 2. Fractional polarization p calculated from PMD 1 (300-400 nm) for the same orbit over the Atlantic Ocean at end March/begin April in 1996 (solid line), 1997 (dashed line) and 1998 (dotted line). The decrease of p with time (each orbit should cross the reference dash-dotted line at p=0.5) is caused solely by degradation of GOME.

Values of the fractional polarization p along identical orbits – acquired at the interval of one and two years – can be compared in Fig. 2. Figure 2 shows that p calculated from PMD1 in 1997 and 1998 is consistently smaller than $p = 0.5$. In order to quantify the degradation, ratios of p at the same latitudes are calculated. The mean of the ratio can then be compared to the calculation of the decrease of p following Eq. (2), assuming the degradation given by Fig. 1: the solution of Eq. (2) with a reduced intensity S_{PMD} is a lower value of p. This is shown in Fig. 3, where the standard deviation gives an indication of the effect of varying atmospheric conditions on the values of p from year to year. The calculations are in agreement with the measurements. This is consistent with the hypothesis that the light path common to Earth and solar observations is affected by the same degradation of Fig. 1. This affects the radiometric calibration and results in an underestimation of $\approx$ 3% of Earth radiances over two years of operation of GOME (Tanzi, 1998).

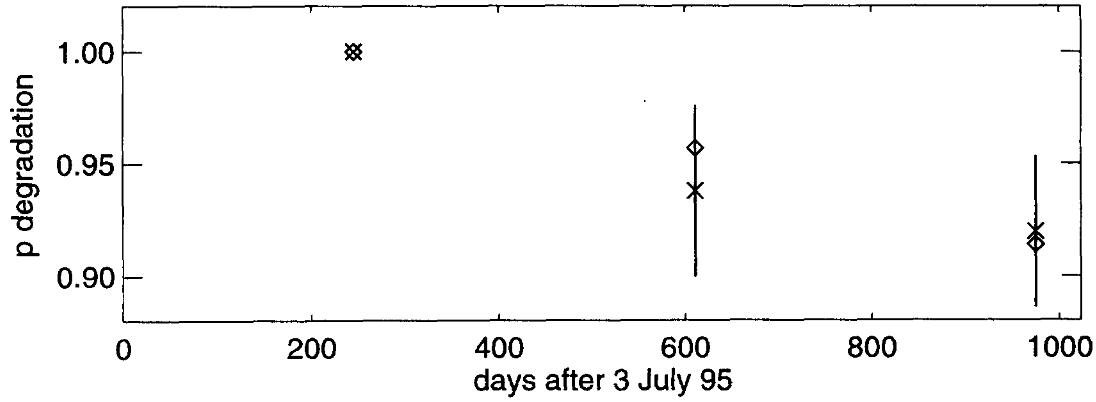

Fig. 3. Mean values (crosses) of ratios of p of the orbits of Fig. 2 (1997/1996 and 1998/1996 respectively), with their standard deviations (1 σ) given as error bars. For comparison, calculations of degradation of an Earthshine scene with p=0.5, following Fig. 1, are added (diamonds).

CONCLUSIONS

The solar intensity measured by the Polarization Measuring Device operating in the UV range (300-400 nm) degrades at a rate of $\approx$ 6% per year. Degradation of the two other PMD channels, which cover the visible and near infrared wavelength ranges, is also present, but is nearly an order of magnitude smaller than that observed for the UV. A similar degradation of the fractional polarization of the Earth radiance of comparable GOME orbits – measured at an interval of years – is observed. Because the light path for solar irradiances and Earth radiance differ, we conclude that the observed degradation is for the large part present in optical elements which are common to both light paths.

ACKNOWLEDGMENTS

The authors are grateful to S. Slijkhuis, D. Loyola and B. Aberle (DLR). ESA is acknowledged for providing the GOME data through DLR Oberpfaffenhofen. This work has partly been funded by SRON (GO-2) and ESA/ESRIN.

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