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Intensity Measurement of the (1,0) γ-Band of NO at 2150 Å with a Polarizing Nitric Oxide Photometer

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Abstract. As a possible reason of the winter anomaly an enhancement of nitric oxide can be considered. Therefore, a polarizing nitric oxide photometer was inserted into the Western Europe Winter Anomaly Campaign 1975/76. The experiment was a filter photometer with a sapphire plate at Brewster's angle as a polarizer. This polarizer was necessary because of the Rayleigh scattering background. The calibration procedure and the data evaluation is described shortly. Finally, the hight profiles of the (1,0) γ-band intensity of NO is given for two winter anomalous days.

Key words: D-region – Winteranomaly – Nitric oxid – Polarizing photometer.

1. Introduction

Several processes are discussed as possible reasons for the winter anomaly. These processes must essentially either increase the electron production rate or decrease the electron loss rate. One of these possible processes may be a downward transport of NO from higher atmospheric layers by, for instance, eddy diffusion due to a local increase of temperature. This warming also effects the NO chemistry to increase the concentration of nitric oxide. Therefore, besides recording winds, temperature and ions, the accurate measurement of the minor neutral constituents like NO is of major importance.

Nitric oxide has been a subject of aeronomy since Nicolet 1955 proposed, that the D-region of the ionosphere is the result of photoionization of NO by solar Lyman-α radiation. However, the distriburion of the neutral nitric oxide, as a function of height, is not well-known and up to date it has not been possible to establish a general model for the electron production in the D-region of the ionosphere.

Up to now information on the distribution of nitric oxide in the mesosphere and lower thermosphere has been obtained in three different ways: from photochemical considerations, from changes in the D-region electron density profiles with variation of solar radiation, and from rocket measurements of the NO dayglow in the ultraviolet γ-bands. The nitric oxide γ-bands are electron transitions between the level $A^2\Sigma^+$ excited by sunlight and the ground level $X^2\Pi$. The strongest band of these γ-transitions is the (1,0)-band at 2150 Å.

The polarizing nitric oxide photometer, to be described here, is one of a group of rocket borne experiments, developed for the Western Europe Winter Anomaly Campaign 1975/76. This experiment has strong interrelation to other experiments like the cryogenic mass spectrometer, the $O_2(^1\Delta)$ photometer, and the solar Lyman-α photometer.

2. Instrumentation

The NO-photometer is a classical filter photometer which records the resonance re-emission of the ultraviolett (1,0) γ-band of NO around 2150 Å (Beran, 1974a). Especially at lower heights a high quanty of atmospheric Rayleigh background reaches the photometer. Because of the linear polarization of this Rayleigh radiation it is possible to eliminate it by computation. The degree of polarization of the Rayleigh radiation is a function of the angle between the direction of incoming solar radiation and the direction of observation and is a maximum of about 93% at an angle of 90°.

Figure 1 shows a schematic drawing of the nitric oxide photometer. The optical part of the experiment consists of a stray light baffle, a polarizer, an interference filter and imaging optics. The stray light baffle protects the detector from direct solar light. The polarizer is a sapphire plate used in reflection at Brewster's angle where the degree of polarization is theoretically 99.2% if the angle of view is $\pm 4°$. Since the refractive index of sapphire at a wavelength of 2150 Å is 1.88 the Brewster angle becomes 62°. The reflection is about 16% at the front plane and 7% at the back surface of the sapphire plate. The interference filter has a half bandwidth of approx. 90 Å.

A second source of background in the measurement of NO γ-bands may be a radiation scattered at possible aerosol layers in the upper atmosphere. Like the resonance or fluorescence emission of the nitric oxide γ-bands this radiation is not polarized. To record this background the intensity, passing through the sapphire plate, was measured in a wavelength region around 2860 Å which is free of airglow emissions. With the additional polarizing filter it is possible to differentiate between Rayleigh scattering and aerosol scattering.

The detectors are two 18-stage EMR side window photomultipliers with a solar-blind photocathode. To get a good dynamic resolution at low intensities pulse counting technique is used. Figure 2 shows the block diagram of the experiment. Each pulse from the photomultiplier output is amplified by a fast low sensitive pulse amplifier. The gain as well as the discriminator threshold of this pulse amplifier are adjustable. A monostable multivibrator gives a constant width of 40 ns for the outcoming pulses.

For optimum performance much care is taken with the grounding concept of the experiment. The output signal and its ground from the pulse amplifier are

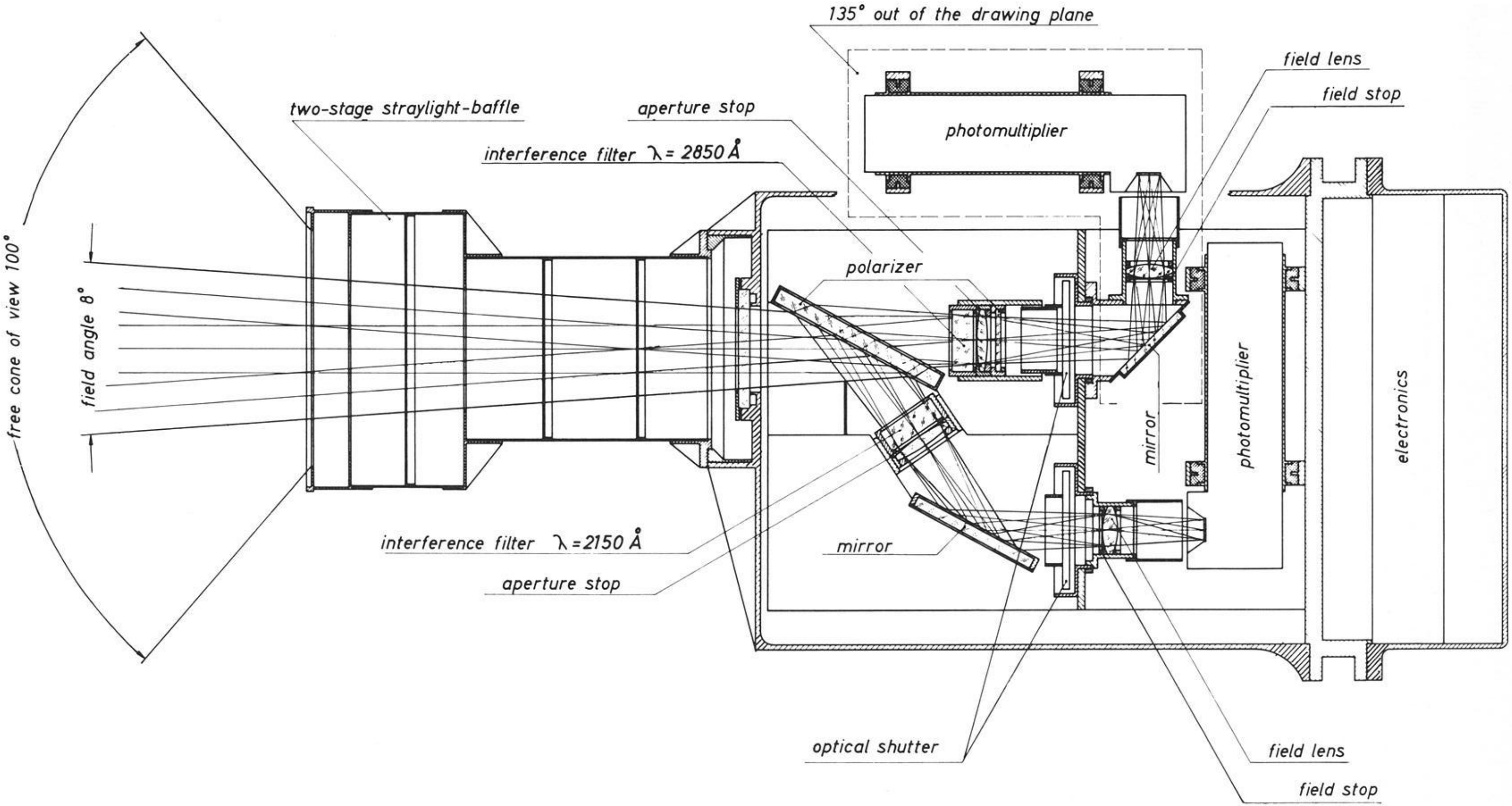

Fig. 1. Schematic drawing of the nitric oxide photometer

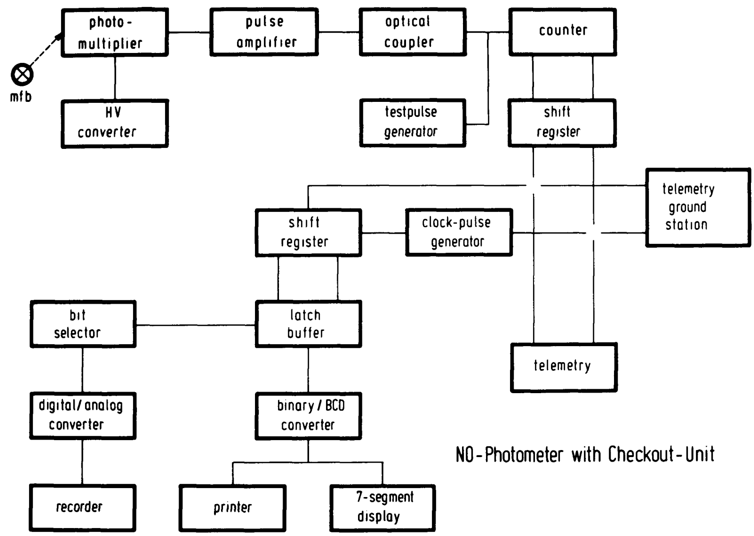

Fig. 2. Block diagram of the nitric oxide photometer

isolated from the following logic circuit by a high speed 20 M bit optical coupler; the high voltage common and the photomultiplier shield are connected to the amplifier ground case. The outcoming pulse from the optical coupler is fed to a 16 bit binary counter. A shift register takes over this 16 bit parallel information and the telemetry interrogates these data serially from the shift register 100 times per second.

The photomultiplier high voltage supply is a self-oscillating dc-dc converter with an adjustable output between 1500 to 3200 Volts depending on the desired amplification of the photomultiplier. A small test lamp can be switched on to illuminate the photomultiplier cathode to give a certain signal at the data output. Alternatively a testpulse generator can be switched on which gives a constant pulse rate to the data unit.

For check-out and data quick-look a test unit was constructed which clocks out the data from the telemetry ground station into a storage register. A binary to BCD converter yields a decimal information to a printer and an optical 7-segment LED display. In addition a digital to analog converter gives the signal to a recorder.

3. Calibration

Within the calibration procedure for the experiment (Beran, 1974b) at first the dependence of sensitivity from the angle of incidence was measured. The half width of this sensitivity curve is defined as the angle of view.

As a next step the dependence of the pulse rate from the number of incident photons was determined. At high photon intensities the number of the regis-

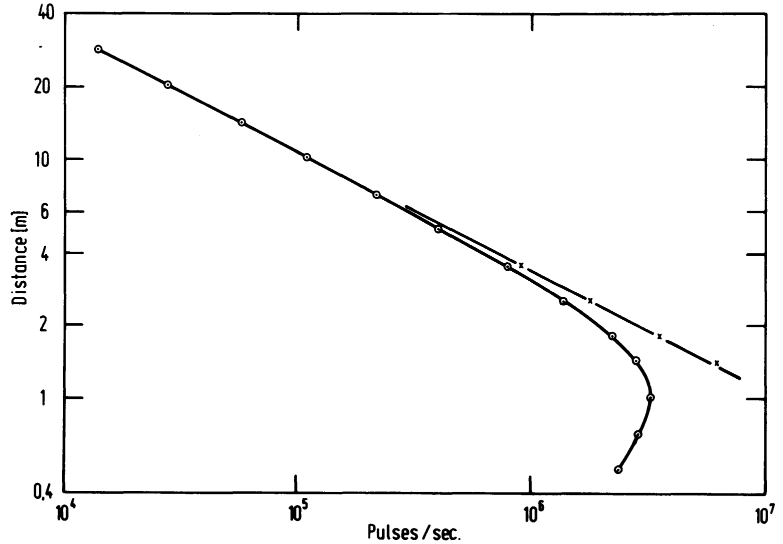

Fig. 3. Dependence of pulses per second from the illumination intensity given by the distance of the light source. ⊙ = registrated number of pulses P_g; × = computed number of primary pulses P_0

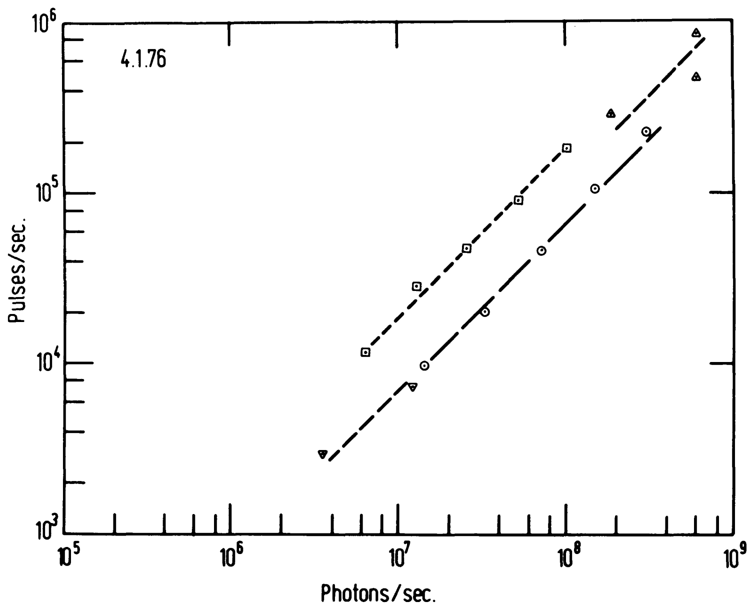

Fig. 4. Absolute calibration factor for the NO photometer of the first flight on January 4; the calibration is performed by: ⊡ = tungsten ribbon lamp; △ = vacuum diode; ▽ = vacuum diode and $BaSO_4$-screen; ⊙ = Rayleigh scattering background

trated pulses P_g is not proportional to the number of incident photons, but is given by the following equation:

$$P_g = \frac{P_O}{(1 + P_O\, t_O)(1 + P_O/P_V)} \tag{1}$$

whereas P_O is the number of primary pulses from the photomultiplier, t_O is the width of these pulses, and P_V is the limiting frequency of the pulse amplifier. Figure 3 shows an example for this dependence from the incident intensity given by the varying distance between the light source and the experiment.

For data evaluation the kowledge of the instrumental degree of polarization q is very important. The calibration of this was performed with a quartz plate at Brewster's angle as a polarizer in front of the experiment. Then the photometer was revolved. For the experiment we launched in the first flight the degree of polarization was 98.3% and for the photometer of the second flight 99.3%.

At last the absolute calibration factor was measured with a calibrated tungsten ribbon lamp and independently with a calibrated vacuum diode. Figure 4 shows the results for the photometer launched in the first flight. In this figure we also inserted results given by the Rayleigh scattering during the flight.

4. Rayleigh Scattering Background

Because of the small scattering optical depth of the mesosphere in this wavelength region, only single scattering of direct sunlight needs to be considered. On the assumption of an ideal molecular atmosphere the amount of Rayleigh scattered light at a certain altitude can be predicted theoretically. The cross-section for Rayleigh scattering per molecule is a function of the wavelength λ.

$$\sigma(\lambda) = \frac{32\pi^3}{\lambda^4} \frac{(n-1)^2}{\rho^2} \frac{2+\Delta}{6-7\Delta} \tag{2}$$

where n represents the refractive index and ρ the number density of the gas, whereas Δ is a depolarizing factor. This factor is a consequence of the asymmetry of the air molecules and has an average of 0.0303 for the earth's atmosphere (Gucker et al., 1969).

The degree of polarization for the plane-polarized Rayleigh scattered light is given by:

$$p(\theta) = \frac{(1-\Delta)\sin^2\theta}{1+\Delta+(1-\Delta)\cos^2\theta}. \tag{3}$$

The degree of polarization is only a function of the scattering angle θ and remains constant with altitude.

5. Results

Two nitric oxide photometers were launched with Skylark rockets on the winter anomalous days of January 4 and 21. Since the cryogenic mass spectrometer

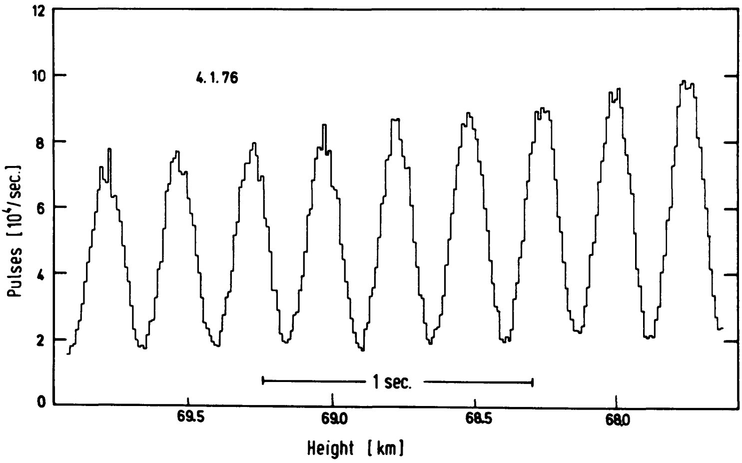

Fig. 5. Analogue data registration from the first flight

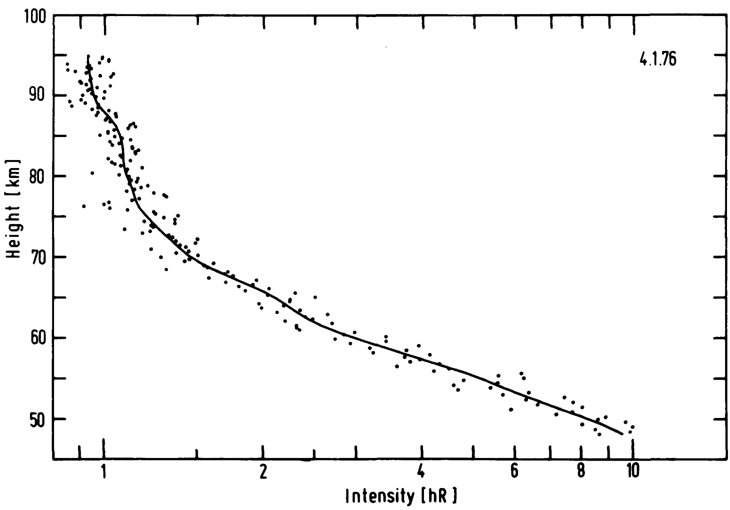

Fig. 6. Intensity of the (1,0) γ-band of nitric oxide from the first flight

which was on the same rocket occupied almost the whole space at the top of the payload and also required that the spin axis followed the tangent of trajectory, the NO photometer viewed rearward and measured only during the descent. In addition the scattering angle θ between the direction of solar incidence and the direction of observation was measured by a solar sensor integrated into the payload.

Good data were received for both flights. From the first flight on January 4 a short recorder registration of the sinusoidally varying data is shown in Figure 5.

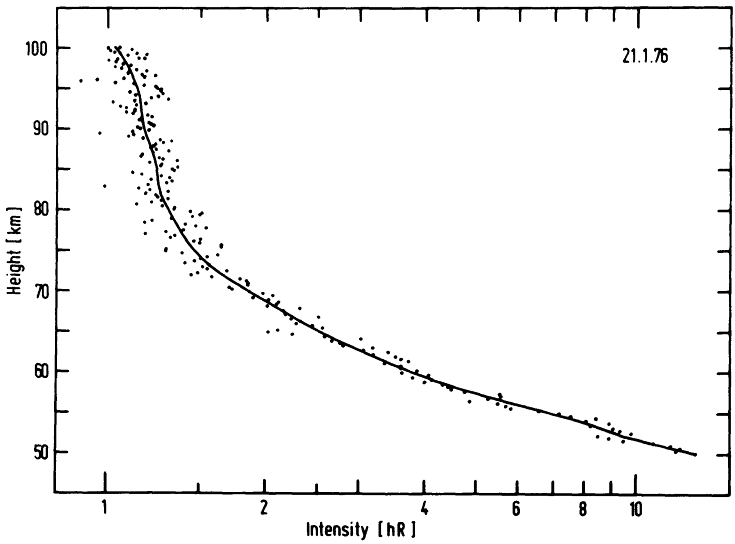

Fig. 7. Intensity of the (1,0) γ-band of nitric oxide from the second flight

With a smoothing sinus

$$y=(a+b\cos\omega\tau+c\sin\omega t)\,e^{dt} \qquad (4)$$

drawn trough 70 data points, the minimum I_i and the maximum I_a in the middle of each intervall was determined at the "Rechenzentrum Graz" (Torkar and Friedrich, 1976). From these extrema the nitric oxide intensity I_{NO} was computed by the following equation (Beran, 1974a):

$$I_{NO}=\frac{(1+pq)\,I_i-(1-pq)\,I_a}{2\,\mathrm{pq}}\cos\phi \qquad (5)$$

whereas ϕ is the zenith angle of the direction of observation. Figure 6 shows the nitric oxide intensity I_{NO} as a function of height. The smoothing curve trough the intensity values is computed by spline functions. The same diagram for the second flight on January 21 is shown in Figure 7.

6. Conclusions

The polarizing nitric oxide photometer, developed novelly, is a reliable instrument for measuring the ultraviolet γ-bands of NO. The results between 50 and 95 km are reasonable, whereas the result above 95 km need some further correction due to the big zenith angle of the direction of observation. With a rocket only spin-stabilized and with the optical axis perpendicular to the direction of the sun the results would be much more reliable.

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