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# A ROCKET MEASUREMENT OF OZONE CONCENTRATION PROFILE OVER THE KOREAN PENINSULA USING THE KOREAN SOUNDING ROCKET KSR-420S : OZONE DETECTOR, ITS CALIBRATION AND DATA REDUCTION

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## ABSTRACT

The first sounding rocket in Korea, KSR-420S has been under the development at Korea Aerospace Research Institute (KARI), and is expected to be launched in 1993 to measure the vertical ozone profile over the Korean Peninsula. The KSR-420S is expected to provide the first *in situ* measurement of ozone concentrations over the Korean Peninsula. An optical ozone detector has been developed at Korea Research Institute of Standards and Science (KRISS), and its calibration has been completed recently. In this paper, measurement principles of the ozone detector in KSR-420S, its calibration data, ozone measurement procedure and data reduction algorithm are presented with sample calculations.

## 1. INTRODUCTION

Ozone depletion in the stratosphere has been a serious global concern, especially since the discovery of ozone hole in Antarctica in 1985 (Farman, J. C. *et al.* 1985). KARI (Korea Aerospace Research Institute) has been concentrating its efforts in developing the first Korean sounding rocket since 1988 to carry out scientific experiments (Ryoo *et al.* 1991). It is expected to be launched in 1993 at the west side of the Korean Peninsula to measure the ozone concentration profile over the Korean Peninsula. Ground-based measurements of total ozone amounts have been carried out by Dobson spectrometer at Yonsei University since 1984 (Cho *et al.* 1988). From these total ozone amounts, Cho and Lee (1990) obtained the altitude profile by an indirect procedure called Umkehr technique. The altitude profiles of the ozone over the Korean Peninsula have been indirect ones mainly because there have been no *in situ* measurements of the vertical ozone profiles so far. The KSR-420S is expected to provide the first *in situ* measurement of ozone concentrations over the Korean Peninsula in the stratospheric and lower mesospheric altitude range, by measuring the solar radiation intensities at selected UV wavelengths (Moon *et al.* 1991). In this paper, the ozone detector in KSR-420S, and ozone measurement procedure will be presented. Calibration data for the detector and data reduction algorithm with sample calculations starting from Japanese S-310 raw data will also be presented in detail.

## 2. OZONE DETECTOR OF THE KOREAN SOUNDING ROCKET, KSR-420S

The KSR-420S rocket is a unguided, fin stabilized and solid propellant vehicle. The initial phase of design was finished in 1989, and the wind-tunnel and structural tests have been carried out. The name of the rocket, KSR-420S stands for the single-stage Korean Sounding Rocket with its body diameter of 420 mm. The KSR-420S can deliver any scientific instruments less than 50 kg such as ionospheric instrument and microgravity measuring device, as well as ozone detecting device. The payload will be housed in the section between the nose cone and the motor. Figure 1 shows the trajectory of KSR-420S and its main events during the flight. The maximum altitude for KSR-420S is approximately 80 km. Its total lift off weight is 1.3 ton, diameter is 420 mm, and total length is 6.7 m. It takes about 130 sec for KSR-420S to reach the apogee with its total flight time of 258 sec. KSR-420S can also be used for many other scientific purposes such as ionospheric and x-ray measurements, and microgravity experiments.

Ozone absorbs UV radiation at Hartley band (200 - 320 nm) and Huggins band (320 - 360 nm), contributing to the heating of the stratosphere (e.g. Lee and Kim 1991). Using the physical properties of ozone, vertical profiles of ozone can be measured. Ozone concentrations are obtained by measuring the absorbed solar radiation and using the Beer's law, which states that the absorbed UV solar radiation is proportional to the concentrations of absorbing gas, ozone in this case. The ozone detector is an optical one with optical interference filter. Compared to expensive monochromator, filter photometer is a convenient rocket-borne optical sensor because of its size and cost performance. The detector measures the attenuation of the solar UV radiation as a function of altitude. Prior to the launch of the rocket, the angle between the line of sight of the detector and rocket spin axis is preset at a calculated value for the exact position of the sun, and the expected launch time and position because it is important for this optical system to point the sun during the flight. Due to the spinning motion of the rocket with a frequency of 3-4 Hz, the measured output will be sine-type curves. From these data points, the maximum points are selected which correspond to the data when the detectors point the sun. That leads to one data per spin. Prototype of the instrument has been manufactured and calibrated with mercury, standard tungsten and deuterium lamps. At present, the instrument is going through the environmental tests-vibration, shock and temperature tests. Autoranging is done by six steps (×1, ×4, ×16, ×64, ×256, ×1024) with the comparator in order to keep the output from the instrument within the voltage range of 300 mV - 4.9 V. In other words, when the voltage is less than 300 mV, gain is increased, and when the voltage is greater than 4.9 V, gain is decreased.

As the solar radiation comes into the detector, certain wavelength bands are allowed to pass through the interference filters, and produces current in the phototubes. The current at each phototube is amplified by the respective amplification factor so that the voltage output corresponding to the maximum current is less than 5V, which then is connected to the onboard telemetry part. Onboard telemetry transmits the measured voltage output to the ground at a rate of 160 Kbit/sec.

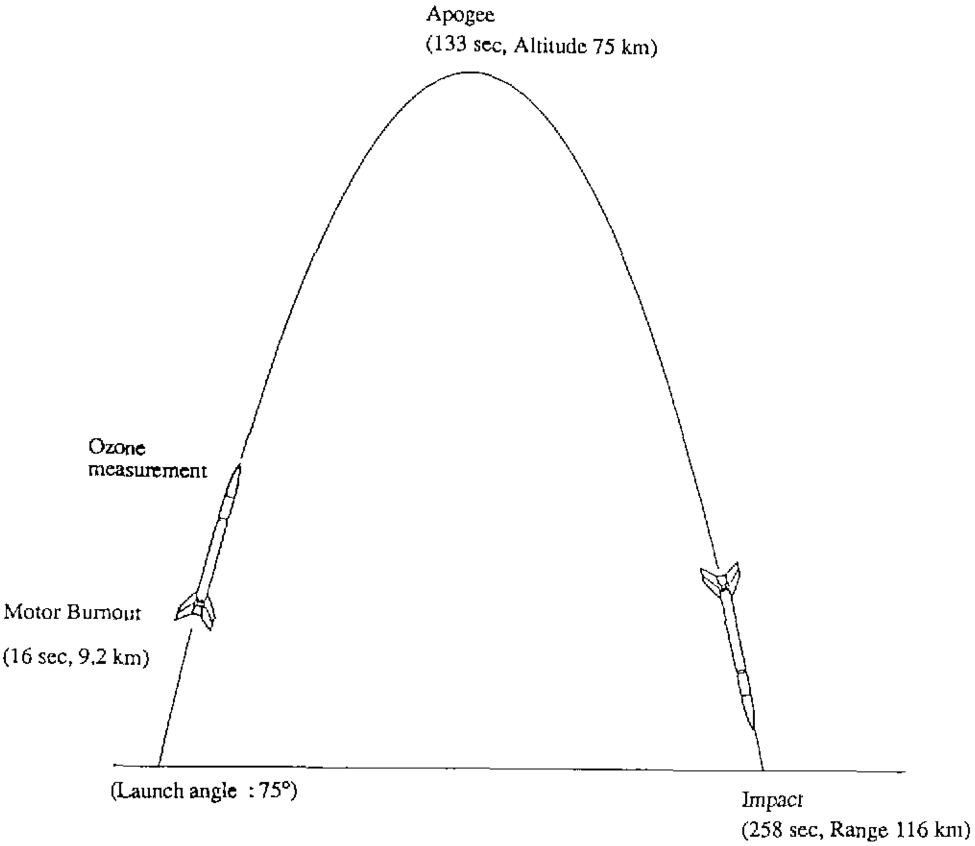

Figure 1. The trajectory of KSR-420S with its main events during the flight.

Recently, the calibration of the detector has been finished with the facilities at KRISS. The main parts of the calibration system are a monochromator with its focal length of 0.32m, and a photomultiplier tube which can cover UV and visible range, with mercury, standard tungsten, and deuterium lamps. The wavelength of the monochromator and the photomultiplier tube were calibrated first by measuring the wavelengths and intensity of the above mentioned lamps. The filters of the radiometers were fixed with the Goniometer, whose angle was changed from 0° to 15° to measure the angle dependency of the filter transmittance at each wavelength. The results from these measurements at 255, 290 and 310 nm are shown in Figure 2. As expected, one can note the tendency that the wavelength of the peak intensity tend to move to shorter wavelength as the angles of the filter are changed from 0° to 15°. The amplitudes of the curves are decreased as angle changes from 0° to 15°. The interference filters used in this calibration are purchased from Japan Vacumm Optics Corp. Figure 3 shows the response function of the phototube (Hamamatsu R765). The overall response function of the detector is obtained by multiplying the filter function by that of the phototube at each wavelength band. The response functions as a function of wavelength, S($\lambda$) obtained above, will be used in the data reduction algorithm to be presented in next section.

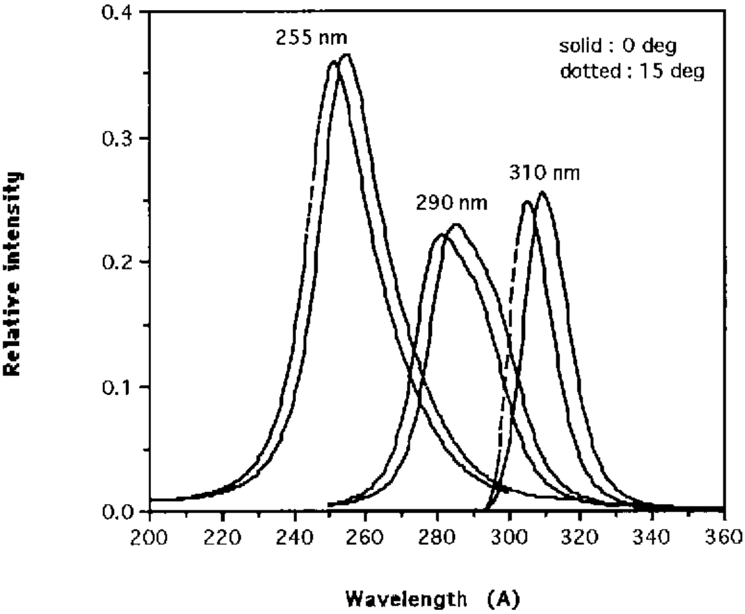

Figure 2. Measured filter transmittance for 255 nm, 290 nm, and 310 nm interference filters.

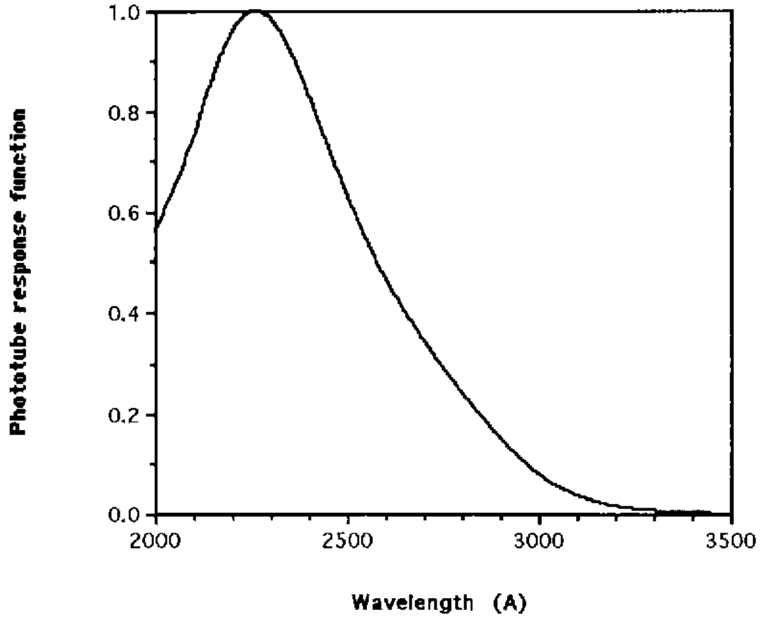

Figure 3. Measured response function of the phototube, Hamamatsu R765.

## 3. OZONE MEASUREMENTS AND ITS DATA REDUCTION

The motor of KSR-420S burns out its solid fuel about 16 seconds after its launch, when the rocket is at the altitude of about 9.2 km (see Fig. 1). After the burnout, the rocket separates the access doors which were kept over the ozone detector windows to protect those from the smoke and ablation, then starts to measure the ozone densities during its ascending period. The detector measures the solar radiation intensities at the UV wavelengths of 255, 290, 310 nm for ozone concentrations, and at 450 nm for reference. The radiometer at 450 nm is to obtain the information on the attitude of the rocket because the solar radiation at 450 nm is free from any atmospheric absorption except small amount of Rayleigh scattering. Thus, any signal changes at 450 nm indicate the attitude history of the rocket. Solar aspect sensor measures the angle between the sun and rocket spin axis, and also provides the attitude information. With the solar radiation intensities as a function of wavelength reaching the top of the atmosphere, the absorbed amount of solar radiation by the ozone can be determined because ozone is the dominant absorbing gas in the UV wavelengths selected. One main assumption in this data reduction algorithm is that the atmosphere is plane parallel, and horizontally uniform in its composition, which is a reasonable assumption when SZA is small.

Furthermore, assuming that the attenuation of solar radiation at the wavelength considered was solely due to the absorption by ozone in the atmosphere, the absorbed amount of solar radiation at certain wavelength can lead to ozone densities by using the Beer's law. In order to demonstrate how ozone density profile is obtained, a sample raw data of S-310, Japanese rocket flight to measure ozone densities were taken from Watanabe (1986) [see Figure 4]. Given the wavelength response function, S(l) at a wavelength band between $\lambda_1$ and $\lambda_2$, I(z), the intensity observed by the rocket at an altitude z can be expressed as:

$$\frac{I(z)}{I_o(z=\infty)} = \frac{\int_{\lambda_1}^{\lambda_2} F(\lambda)S(\lambda)exp[-\sigma_{03}(\lambda)N(z)]d\lambda}{\int_{\lambda_1}^{\lambda_2} F(\lambda)S(\lambda)d\lambda}$$

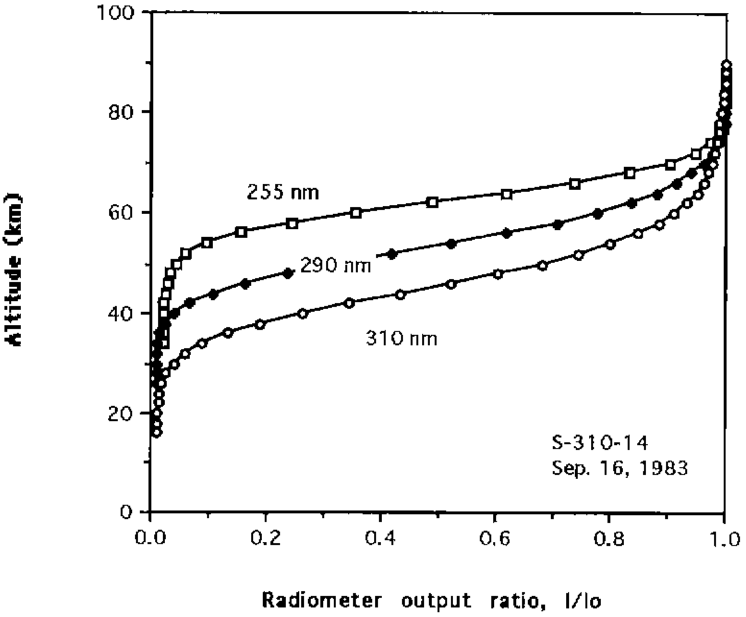

Figure 4. A sample I/Io ratio of 255 nm, 290 nm and 310 nm measured from Japanese sounding rocket, S-310 [from Watanabe(1986)].

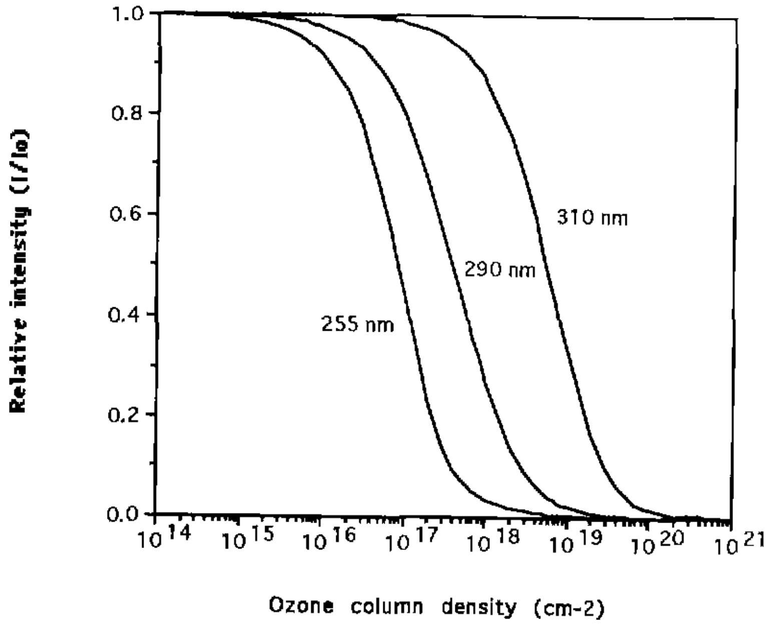

Figure 5. Calculated values of I/Io ratio for 255 nm, 290 nm and 310 nm are shown for the possible range of ozone column densities, $1x10^{14}$ to $1x10^{20}$ $cm^{-2}$.

where $I(z=\infty)$ is the intensity outside the ozone layer, $F(\lambda)$ the extraterrestrial solar irradiance, $\sigma$ $(\lambda,T)$ the absorption cross section for ozone at wavelength $\lambda$ and temperature T, and N(z) the slant column density of ozone between the rocket at an altitude z and the sun. From this expression, the $I(z)/I(z=\infty)$ ratio on the left-hand-side can be calculated for the possible values of N(z), for example in this case, from $1x10^{14}$ to $1x10^{20}cm^{-2}$ since all other quantities are known [see Figure 5]. $F(\lambda)$ are taken from Mentall *et al.* (1981), and $\sigma(\lambda)$ are from Molina and Molina (1986). When the rocket measurements of $I(z)/I(z=\infty)$ become available as a function of altitude, the column density N(z) can be determined from the curve in Figure 5. With a sample $I(z)/I(z=\infty)$ vs. altitude as shown in Figure 4, the slant column density at each altitude grid is calculated following the above procedure as shown in Figure 6. For solar zenith angle less than 60° number densities can be obtained by differentiating the column densities with respect to z,

$$n(z) = \cos\chi \cdot \frac{dN(z)}{dz}$$

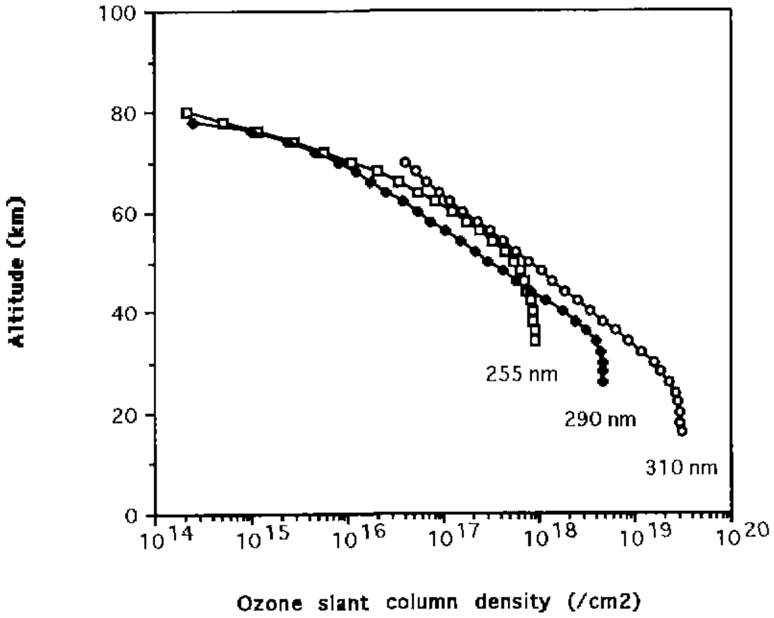

Figure 6. Calculated slant column densities are obtained and shown as a function of altitude from the sample 255 nm, 290 nm and 310 nm I/Io data.

For larger solar zenith angles, optical path length become a complicated function of solar zenith angle because the curvature of the Earth has to be considered. The calculated results of ozone number density profile from the $I(z)/I(z=\infty)$ is shown in Figure 7. Different wavelength bands are used to obtain ozone densities at appropriate altitude ranges. The measured data from 255 nm provide the ozone number density at higher altitudes than the data from other channels, because of the absorption characteristics of the ozone. Data from 290 nm provide the ozone concentration at about 40 - 60 km range, and data from 310 nm provide the results at lower altitudes. The final vertical profiles of ozone density is obtained by taking a weighted average of ozone densities from the measurements for each wavelength bands.

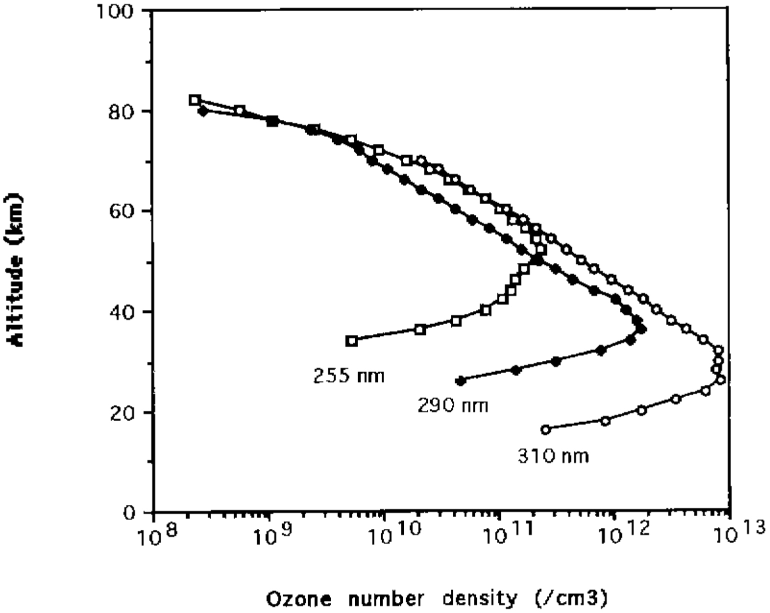

Figure 7. Calculated number densities of ozone as a function of altitude are shown for the sample 255 nm, 290 nm and 310 nm I/Io data.

## 4. SUMMARY

Brief description of the KSR-420S and its ozone detector have been presented. The results from the recent calibration of ozone detector were also shown, and were used in the data reduction algorithm for KSR-420. A sample calculation starting from the S-310 rocket measurement was carried out for 255 nm, 290 nm, and 310 nm in order to demonstrate the data reduction procedure. A reasonable ozone number density profile was obtained. This algorithm will be used when KSR-420S measures I/Io ratio in 1993.

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