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THE EFFECT OF ATMOSPHERIC SCATTERING AS INFERRED FROM THE ROCKET-BORNE UV RADIOMETER MEASUREMENTS

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ABSTRACT

Radiometers in UV and visible wavelengths were onboard the Korean Sounding Rocket(KSR)-1 and 2 which were launched on June 4th and September 1st, 1993. These radiometers were designed to capture the solar radiation during the ascending period of the rocket flight. The purpose of the instrument was to measure the vertical profiles of stratospheric ozone densities. Since the instrument measured the solar radiation from the ground to its apogee, it is possible to investigate the altitude variation of the measured intensity and to estimate the effect of atmospheric scattering by comparing the UV and visible intensity. The visible channel was a reference because the 450-nm wavelength is in the atmospheric window region, where the solar radiation is transmitted through the atmosphere without being absorbed by other atmospheric gases. The use of 450-nm channel intensity as a reference should be limited to the altitude ranges above the certain altitudes, say 20 to 25 km where the signals are not perturbed by atmospheric scattering effects.

1. INTRODUCTION

The Korean sounding rockets (KSR)-1 and KSR-2 have been launched on June 4th (09:58 a.m. local time) and September 1st (10:34 a.m. local time), 1993, respectively at An Heung, Korea (36° N, 126° E). Each KSR carried four radiometers in ultraviolet and visible wavelengths to measure ozone densities in the stratosphere over Korea (Kim *et al.* 1994). These radiometers measured the intensities of solar radiation at selected ultraviolet (UV) and visible wavelengths from the time when rocket lifted off the ground. The vertical profile of ozone densities retrieved by these rocket soundings was presented in Kim *et al.* (1997). In this paper, the effect of atmospheric scattering inferred from the rocket measurement of UV and visible radiation intensity is analyzed and discussed.

2. INSTRUMENTATION

The trajectories of KSR-1 and -2 tracked by radar are shown in Figure 1. The radiometers were fixed on the rocket skin looking at an angle of 55 degree from the rocket- body axis to capture the sun during the rocket flight within the FOV (field of view) of the detector considering the rocket trajectory, the predicted rocket attitude, and the position of the sun at the time and location of the launch. The radiometers measure the attenuation of sunlight in ultraviolet absorption bands of ozone as a function of height. Ozone absorbs primarily the radiation in the Hartley and Huggins bands:

$$\begin{aligned} O_3 + h\nu(170\text{nm} < \lambda < 310\text{nm}) &\rightarrow O_2(^1\Delta_g) + O(^1D) \\ O_3 + h\nu(310\text{nm} < \lambda < 360\text{nm}) &\rightarrow O_2(^1\textstyle\sum_g^+ \text{ or } {}^1\Delta g) + O(^3P). \end{aligned}$$

Figure 2 the ozone absorption and Rayleigh scattering cross sections together with the solar irradiance at these wavelengths. Note that the values of Rayleigh scattering cross sections are multiplied by 10^4 to show together in one figure. The absorption cross section is from Molina & Molina (1986), and the scattering cross section is from WMO (1986). The solar irradiance is from Mentall *et al.* (1981) and Thekaekara (1974).

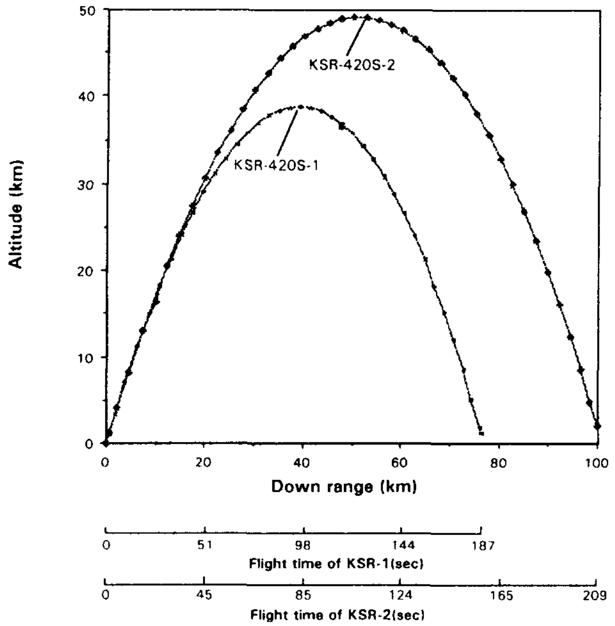

Figure 1. The trajectories of KSR-1 and KSR-2.

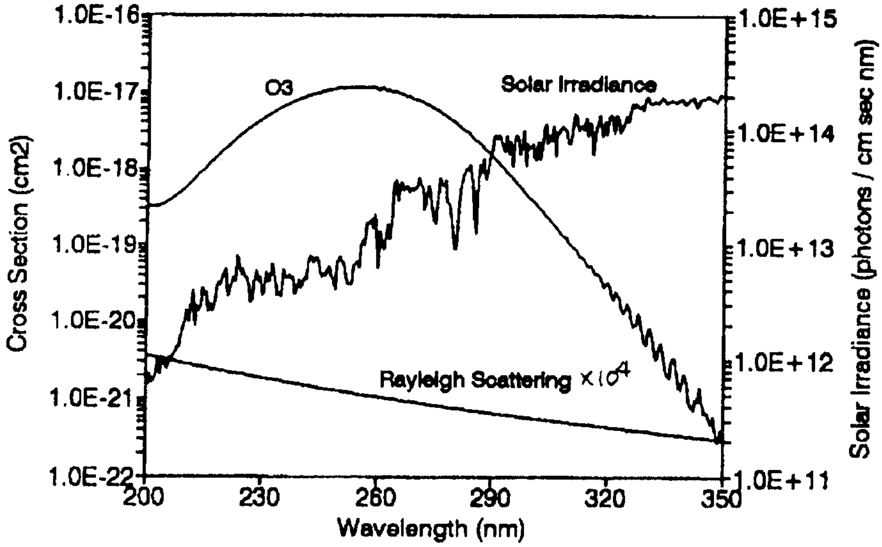

Figure 2. The absorption and Rayleigh scattering cross section of ozone. The solar irradiance at these wavelengths are shown together with the scale on right-side (Lee 1994).

The radiometer consists of phototubes and interference filters to detect direct solar radiation at three UV and one visible wavelengths (255 ± 20, 290 ± 20, 310 ± 20, and 450 ± 20 nm) during the ascending period of the rocket. This simple design provides FOV about 50 degree. Figure 3a shows the calculated intensity at the above three UV wavelengths as a function of ozone column density. Figure 3b and 3c shows the vertical profiles of measured UV intensities by KSR-1 and KSR-2. The measured output of the 310-nm channel in KSR-2 is fluctuating because of the shadow effect of the telemetry antenna. The outer envelope which represent maximum values should be the correct values.

These radiometers use spin of the rocket to sweep the field-of-view past the solar disc. This captured solar radiation induces current from the phototube, which is then converted to analog voltage (0 - 5 V) in the circuit box. In order to have larger S/N ratio, signals were preamplified and sent to the circuit part where signals were conditioned and processed. The electronics has an autoranging capability to give higher data resolution. Analog output voltages and six step gain levels for each radiometer channel were sampled at every 4 msec and telemetered in S-band to the KARI's ground station.

3. RESULTS AND DISCUSSION

As mentioned above, Figure 3b and 3c show the vertical profile of measured intensities, that is,

$$I(z) = \int_{\lambda_1}^{\lambda_2} F(\lambda)S(\lambda,\theta)\ \exp[-\sigma_a(\lambda,T^*(z))N(z) - \sigma_R(\lambda)M(z)]d\lambda \qquad (1)$$

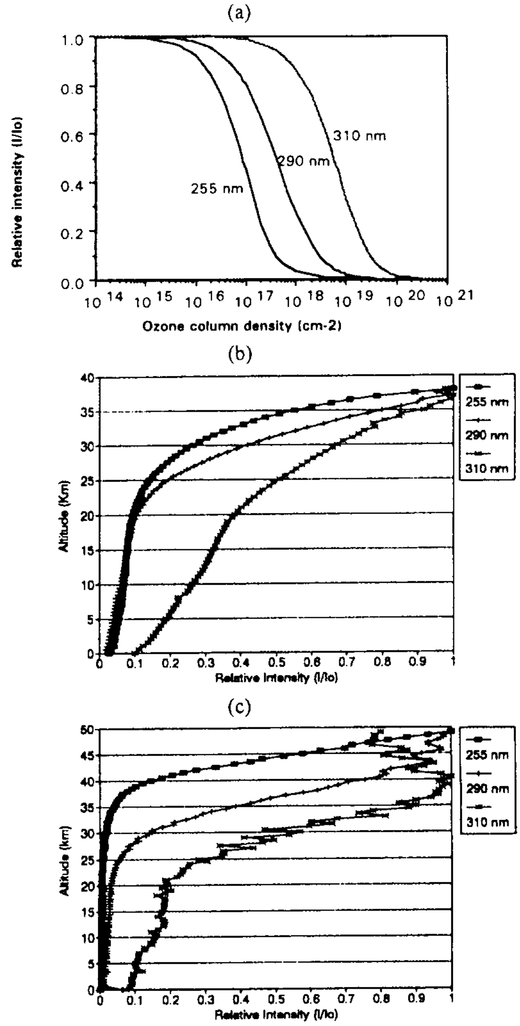

Figure 3. (a) The calculated UV intensities as a function of ozone column densities, (b) The measured UV intensities by KSR-1, (c) KSR-2(b and c from Lee (1994)).

where I is the measured intensity, λ is wavelengths, F is solar irradiance, S is the response function of the detector, σ_a is the absorption cross section, σ_R is the Rayleigh scattering cross section, T^* is the ozone-density-weighted atmospheric temperature to account for the absorption above altitude z, N is the column density of ozone and the M is the total air number density.

From the absorption property of the atmosphere, one can expect that the intensities in UV wavelengths should increase as altitude increase and converge to constant value. In these measurements, however, the 255- and 290-nm channel output did not reach to the converged value since the solar radiation at these two wavelengths are absorbed at higher altitudes in the middle atmosphere. In these results, one has to note that the effect of rocket attitude change on UV measurements were corrected using the 450 nm channel which is a reference channel because the wavelength is in the atmospheric window region and thus is free from the absorption by the atmosphere. Figure 4a compares the output from the 450 nm radiometer with the incident angle measurement by the sun sensor. This figure shows the highly-correlated behavior of these two curves, which confirms that the radiation at 450-nm channel is free from absorption and mainly depends on the incidence angle of the sunlight on radiometer. Figure 4b clearly shows the cosine behavior of 450-nm channel output with respect to the incidence angle of sunlight on radiometer. Note that the normal vector of the radiometer has an angle of 55° from its body axis, thus the output of 450 nm channel has a maximum value at this angle when it views the sun at 0° incidence angle.

It is worthwhile to investigate the effect of sunlight incidence angle, θ variations on the measurements. When θ values become large, for example, 450-nm signals become very weak and insensitive to the attitude variations, and therefore, rocket attitude corrections introduce large errors. Note that the 450-nm signals is used for other UV absorption signals to account for the variation of θ. Figure 5 shows the 290-nm channel signals versus the 450-nm channel for KSR-2 or the variation of 290-nm intensity as a function of sunlight incidence angle as altitude changes. The data points are grouped together for five altitude ranges: 0-10 km, 20-30 km, 30- 40 km, and 40-50 km. Note that the slope 'a'of the regression lines increases as altitude increases except for the 10-20 km range. In the 10-20 km group, there are limited number of data points because of the fast rocket acceleration in this region, and thus the regression line may not be a meaningful one. The data in the top altitude range, 40-45 km for KSR-2 and 30-34 km for KSR-1, are not reliable because the sunlight incidence angle, θ were too large near apogee where the 450-nm channel signals were very weak and thus unable to distinguish the incoming radiation at different θ values. In other words, the slope 'a'of each regres-

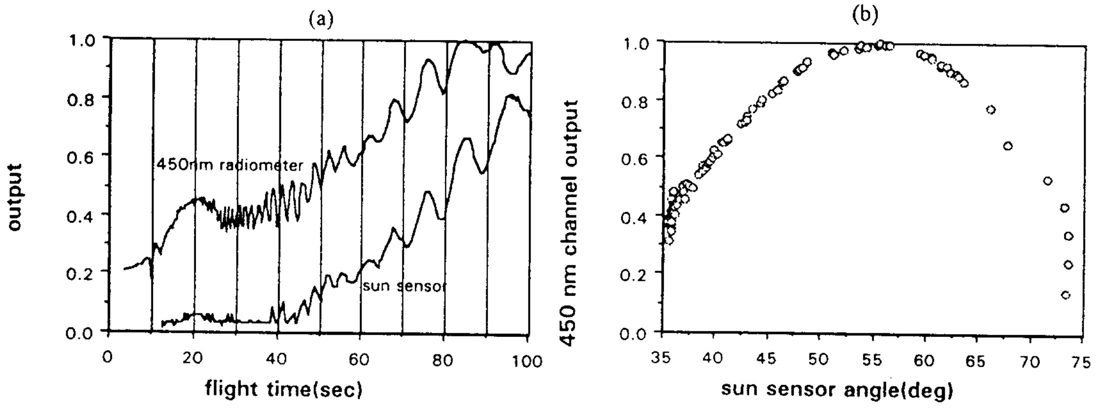

Figure 4. (a) The comaprison of 450 nm channel and sun sensor output. (b) The cosine relation of 450 nm channel vs. incidence angle of sunlight on radiometer.

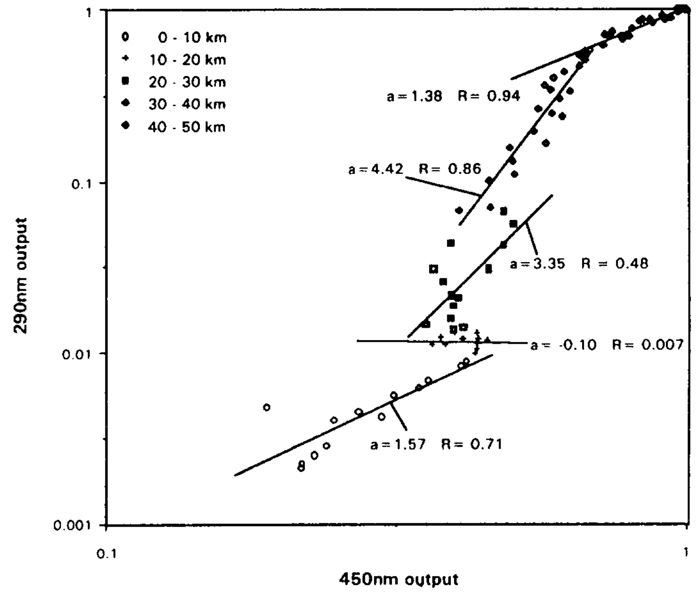

Figure 5. The 290-nm vs. 450-nm signals in different altitude groups.

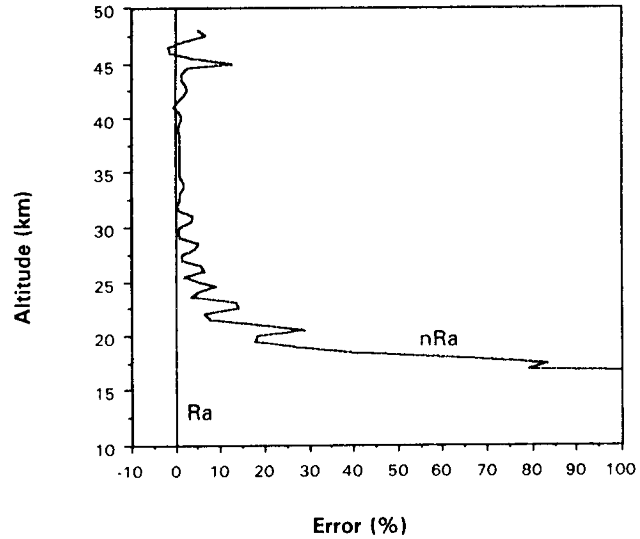

Figure 6. The retrieval error in ozone densities caused by neglecting the Rayleigh scattering effect. The 'Ra'curve represents the reference case when the Rayleigh scattering effect is included in the data retrieval, while the 'nRa'curve represents the case when the effect is neglected.

sion line represent the magnitude of scattering effect in the atmosphere. As the value of 'a'becomes small, the scattering effect becomes significant. For the lowest two altitude ranges, 0-10 and 10-20 km, the 450-nm channel signals were perturbed by a large scattering effect at lower altitudes and do not represent the attitude change properly. For the middle range (20-40 km for KSR-2 and 20-30 km for KSR-1), however, the 450-nm output represents attitude change very well. Similar conclusions were made for other UV channel data at 255 and 310 nm.

Uncertainties in atmospheric pressure affect absorption cross sections and Rayleigh scattering in the data retrieval. In order to see the effect of Rayleigh scattering effect on the radiometer measurement, the percentage errors of retrieved ozone densities for the case with and without the Rayleigh scattering effect are shown in Figure 6. The reference case is when the Rayleigh scattering effect is considered in the retrieval (straight line denoted as 'Ra'). The other curve (denoted as 'nRa') is when Rayleigh scattering effect is neglected in the data retrieval. One can note that the scattering effect is large at lower altitudes because of the large densities of the atmosphere, but is negligible above about 25 km. As a matter of fact, the Rayleigh scattering effect and the effect of using T^* instead of normal T have compensating error magnitudes so that the combined effect becomes small above 25 km. The detail description of the data retrieval algorithm were described in Kim *et al.* (1993, 1997).

In summary, the vertical profiles of UV intensities with the 450-nm intensity as a reference were investigated carefully to see the effect of Rayleigh scattering on the radiometer measurement. The effect was significant below about 25 km and negligible above. The use of 450-nm channel intensity as a reference should be limited to the altitude ranges above the certain altitudes, say 20 to 25 km where the signals are not perturbed by atmospheric scattering effects.

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