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THE RETROREFLECTOR IN SPACE(RIS) EXPERIMENT

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INTRODUCTION

Experiments on the earth-satellite-earth laser long-path absorption measurements of atmospheric trace species will be performed with the Retroreflector In Space(RIS) for the Advanced Earth Observing Satellite(ADEOS). The ADEOS is a Japanese sunsynchronous polar-orbit satellite (Table 1) which carries eight earth-observing sensors including the RIS.[1] The RIS is a single-element hollow cube-corner retroreflector with an effective diameter of 0.5 m.

In the RIS experiments, a laser beam is transmitted from a ground station, reflected by RIS, and received at the ground station. The absorption spectrum of the atmosphere is measured in the round-trip optical path. The column contents and the vertical profiles of atmopspheric trace species are derived from the measured spectra.[2]

Table I Characteristics of the ADEOS orbit.

Category	Sunsynchronous sub-recurrent
Local Sun Time	10:30+/-15
Recurrent Period	41 days
Altitude	Approx. 797 km
Inclination	Approx. 98.6 deg
Period	Approx. 101 minutes

THE RETROREFLECTOR IN SPACE (RIS)

The structure of the RIS is shown in Fig.1. We use a spherical mirror with a very small curvature for one of the three mirrors forming the corner cube[3] to optimized the ground pattern of the beam reflected by the RIS on ADEOS which moves with a velocity of approximately 7 km/s. The direction cosine of the optical axis of the RIS is (0.508, - 0.279, 0.815).

Figure 2 shows the ground tracks of the ADEOS over Japan. The RIS experiment is performed when the ADEOS passes over the areas indicated in Fig.2. The frequency is approximately once a day including both descending (daytime) and ascending (nighttime) paths.

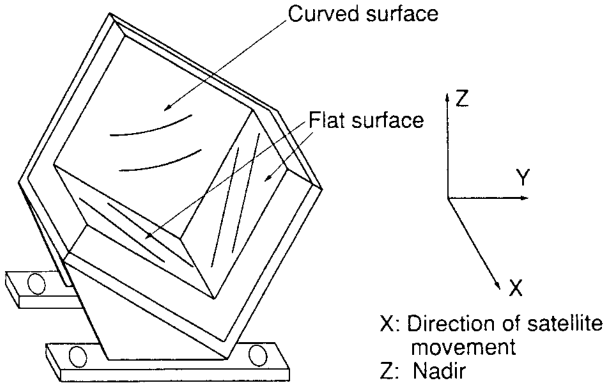


Fig. 1 Structure of the RIS.

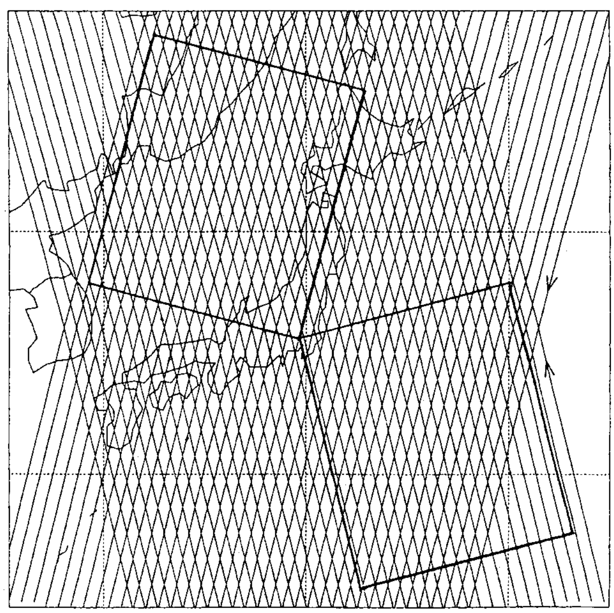
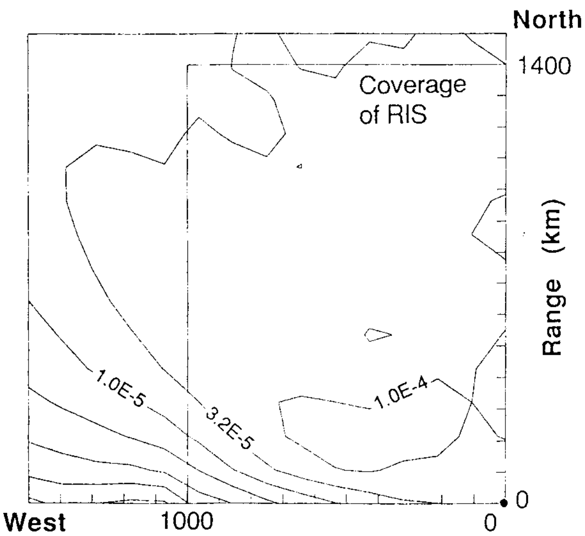
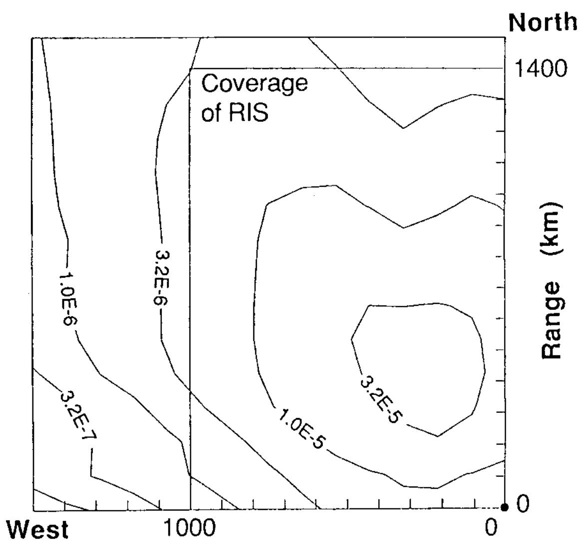


Fig. 2 Ground tracks of the ADEOS over Japan.

Figure 3 shows the intensity of the reflected beam as a function of the satellite position for the descending paths at (a) 532 nm and (b) 10 μm. The quantity indicated in Fig.5 is the ratio of the power of the reflected beam per unit area at the ground station to the power of the incident beam per unit area at RIS. RIS has an effective area of 0.2 m^2 when looked from the direction of the optical axis, and the effective divergence of the reflected beam is approximately 40 μr in half angle.



(a)



(b)

Fig. 3 Intensity of the reflected beam as a function of the satellite position at (a) 532 mn, (b) 10 μm.

GROUND SYSTEM AND THE MEASUREMENTS OF ATMOSPHERIC TRACE SPECIES

Schematic diagram of the ground system for the RIS experiment is shown in Fig.4. The ground system consists of an optical satellite tracking system and a laser transmitter/receiver system for spectroscopic measurements. The satellite tracking system with a 1.5-m diameter telescope at the Communications Research Laboratory (CRL) will be used in the experiment. We have developed an active satellite tracking method which utilizes the image of RIS lit by a second-harmonics Nd:YAG laser in collaboration with CRL. The active method will be used at the same time with the programmed tracking to achieve the accuracy required by the RIS experiments.

For the spectroscopic measurements, we have developed a method which utilize the Doppler shift of the reflected beam resulting from the satellite movement. Two single-longitudinal-mode TEA-CO_2 lasers are used. One of the lasers is tuned to the laser lines close to the absorption lines of the target molecule. The other is used for measuring the reference signals to correct atmospheric effects. The magnitude of the Doppler shift of the reflected light is 0 - 0.04 cm^{-1} at 10 μm, which depends on the satellite position relative to the ground station. High-resolution

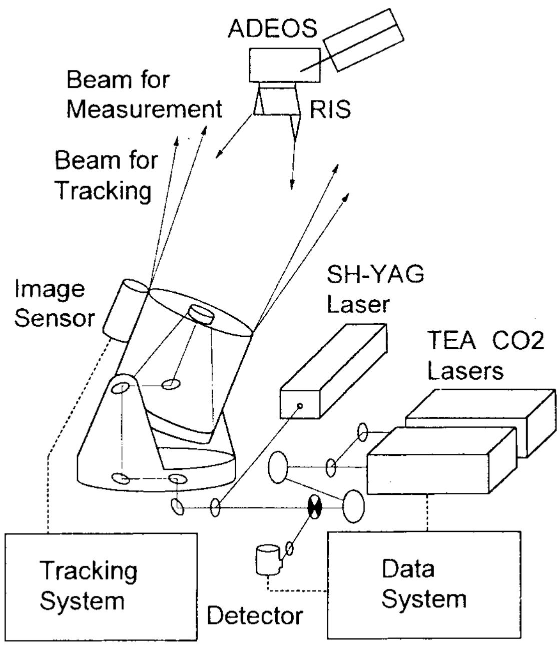


Fig. 4 Ground system for the RIS experiment.

transmission spectra of the atmosphere is measured by using the change in the wavelength of the Doppler-shifted return beam.

Figure 5 shows an example of the atmospheric transmission spectrum and the laser lines for measurement of ozone. The wavelength of the laser will be switched alternately between P(18) and P(20) during the measurement, and the spectra in the three wavelength regions indicated in Fig.5 will be measured. The single-longitudinal-mode TEA-CO_2 laser with the wavelength agility has been developed for the RIS experiment.[4)]

Target molecules with the isotope TEA-CO_2 lasers ($^{12}C^{16}O_2$, $^{13}C^{16}O_2$) and their second and third harmonics are listed in Table II. The vertical profiles will be obtained by inversion method using absorption line shape for the molecules with large absorption such as ozone and methane. The column contents will be obtained for other molecules by means of the least squares method with the assumption on the vertical distribution. Measurement method and data reduction method for CFC12 are different because absorption spectrum of CFC12 is almost continuum. In this case, the absorption at the multiple laser lines will be measured by switching laser lines, and the column content will be derived by the multiple wavelength differential absorption method.

Figure 6 shows an example of the simulated return signals calculated by a simulator program which includes the actual system parameters and the simulation results for thereflection characteristics of the RIS. In this example, the line of one of the CO_2 lasers is switched every one second. The system parameters used in the simulation is listed in Table III.

Figure 7 shows the ozone profile retrieved from the simulated signals shown in Fig.6. The retrieved ozone profile agreed well with the profile given in the simulation.

We have obtained a good result also for the measurement of methane. Fig.8 shows the profile of methane retrieved from the simulated return signals.

Table II Target molecules and CO_2 laser lines

Molecule	Laser line	CO_2 isotope	Wavenumber (cm^{-1})
O_3	P(18)	636	1002.4778
	P(20)	636	1000.6473
CO_2	P(26)	626	938.6883
	R(36)	636	938.7776
HNO_3	P(8)	636	907.0528
CFC12	R(6) - R(14)	636	918.74 - 924.53
CO	R(30)	626*	2169.27
N_2O	R(38)	626*	2178.002
CH_4	R(14)	626**	2915.79
	R(16)	626**	2919.89
Reference			
	R(34)	636	937.5844
	R(8)	626*	2140.925
	R(26)	626**	2939.12

*Second harmonics; **Third harmonics.

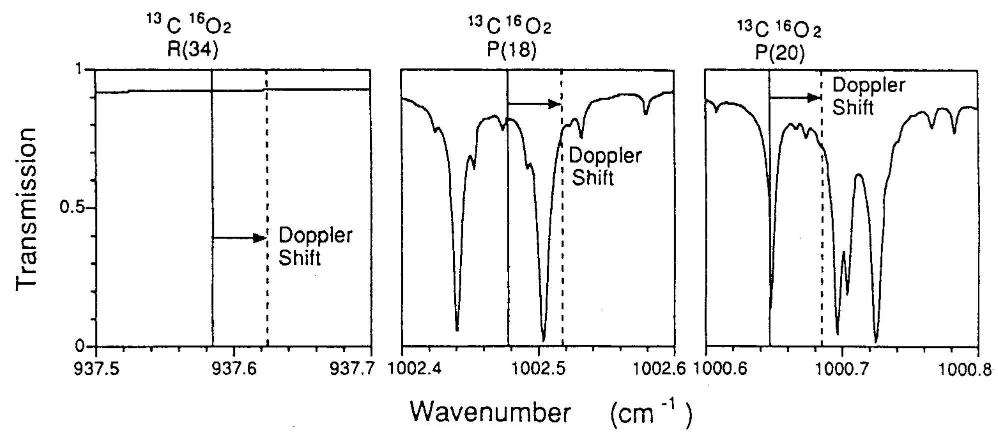


Fig. 5 Synthesized atmospheric transmission spectrum (ground-satellite one-way path; elevation angle, 60 deg.) and the laser lines for measurement of ozone.

Table III The ground system parameters

Laser Pulse Energy	100 mJ (10 μm) 10 mJ (5 μm) 5 mJ (3 μm)
Laser Beam Divergence	0.1 mr 3 mr (Active Tracking)
Receiver Tel. Diam.	1.5 m
Overall Optical Effi.	0.005
Detectivity of Detector	7×10^{10} cmHz$^{1/2}$/W(10 μm) 1×10^{11} cmHz$^{1/2}$/W(5 μm) 6×10^{10} cmHz$^{1/2}$/W(3 μm)
Area of Detector	0.001 cm^2
Quantum Efficiency	0.6
Time Constant	1 μs

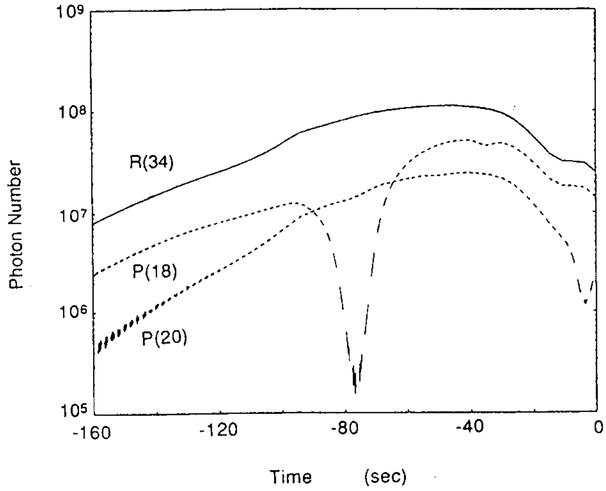


Fig.6 Simulated return signal (photonnumber per shot) in the ozone measurement.

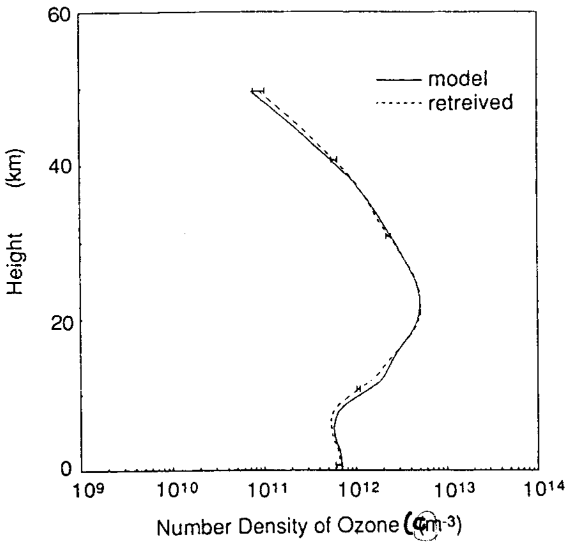


Fig. 7 Ozone profile retrieved from the simulated signal.

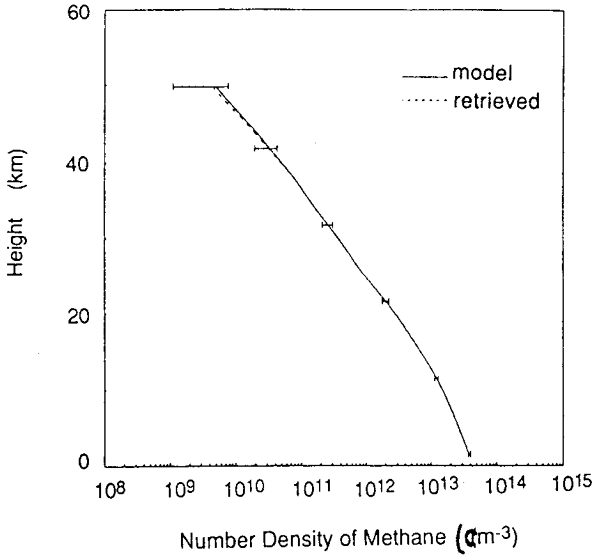


Fig. 8 Methane profile retrieved from the simulated signal.

The RIS Science Team has been formed for the experiments at the ground station in Japan. Also, experiments using RIS from other stations will be organized based on the proposals to the Joint Research Announcement by NASDA and Japan Environment Agency. These experiments will include atmospheric measurements using a tunable laser and experiments on laser ranging.

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