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DATA REDUCTION ALGORITHM FOR EARTH-SATELLITE LASER LONG-PATH ABSORPTION MEASUREMENT USING RIS

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INTRODUCTION

We plan to carry out earth-satellite-earth laser long-path absorption measurement of atmospheric trace species by using the Retroreflector In Space (RIS). By utilizing Doppler effect caused by the satellite movement, we can measure absorption spectrum of target molecules, such as ozone, methane, and CFC12 with TEA-CO_2 lasers and their second and third harmonics.

In this paper, we present the algorithm for data reduction and the evaluation of the measurement by a computer simulation.

ALGORITHM FOR DATA REDUCTION

Two TEA-CO_2 lasers are used for the RIS experiment. By firing two lasers within a short period of time, we can cancel the effect of atmospheric turbulence and the change in the reflectivity of the RIS. One laser is tuned to laser lines near to absorption lines of a target molecule. The other is tuned to laser lines where the absorption of the molecule is small.

We measure laser powers received at a ground station for the two lasers. Received laser powers are not proportional to the atmospheric transmittance, because the wavelength of the laser beam reflected by the RIS is shifted by Doppler effect. The path length also changes during one measurement. However, we found the density of target molecule can be derived from the logarithm of received powers for two lasers. The logarithm of the received signals, Y_i, is written as

$$Y_i=\ln\{(P_{ai}P_{ri0})/(P_{ri}P_{ai0}\} \quad (1)$$
$$=\ln(C_a/C_r)+\int\{q(z)\,(-\sigma(\lambda_a,z) - \sigma(\lambda_{ai},z) + \sigma(\lambda_r,z) + \sigma(\lambda_{ri},z))/\sin\theta_i\}dz+\tau/\sin\theta_i.$$

We assumed that the atmosphere is horizontally uniform. Subscripts, a and r, indicate the laser for measuring absorption and the laser for reference, respectively. Subscript, i, indicates the sequence of laser pulses. P_{ai0} and P_{ri0} are powers of transmitted pulses from two lasers. P_{ai} and P_{ri}, are laser powers received at ground station. C_a and C_r are system constants for two lasers. $q(z)$ represents the density of target molecule at an altitude of z. $\sigma(\lambda,z)$ represents the absorption cross section of target molecule at a wavelength of λ and at an altitude of z. θ_i is the elevation angle of the satellite looked from the ground station. τ is the differential optical thickness of the continuous absorption due to water vapor and aerosol.

Equation (1) can be written in a matrix form as

$$\mathbf{Y=AX}. \quad (2)$$

Where

$$\mathbf{Y} = \begin{vmatrix} y_1 \\ y_2 \\ \cdot \\ y_m \end{vmatrix},$$

$$\mathbf{A} = \begin{vmatrix} w_{11} & w_{12} & \cdots & w_{1n} & k_1 & 1 \\ w_{21} & w_{22} & \cdots & w_{2n} & k_2 & 1 \\ \cdot & & & \cdot & \cdot & \cdot \\ w_{m1} & w_{m2} & \cdots & w_{mn} & k_n & 1 \end{vmatrix},$$

$$w_{ij}=\{-\sigma(\lambda_a,z_j)-\sigma(\lambda_{ai},z_j) +\sigma(\lambda_r,z_j)+\sigma(\lambda_{ri},z_j)\}\Delta z_j k_i,$$

$$k_i=1/\sin\theta_i,$$

$$\mathbf{X} = \begin{vmatrix} q_1 \\ \bullet \\ q_n \\ \tau \\ \ln[C_a/C_r] \end{vmatrix}.$$

Vector **Y** consists of Y_i's. **A** is a matrix calculated from absorption cross section and the elevation angle. Vector **X** consists of unknown parameters, q(z), $\ln(C_a/C_r)$, and τ. Now that the measured data, **Y**, is expressed as a product of the matrix, **A**, and the vector, **X**, we can derive **X** by means of inversion methods.

In order to measure absorption spectrum in wider wavelength region, we may switch laser wavelength in a few lines in one measurement. In this case, the matrix is written as

$$\mathbf{A}' = \begin{vmatrix} \mathbf{A}_1 \\ \mathbf{A}_2 \\ \bullet \\ \mathbf{A}_k \end{vmatrix}, \qquad (3)$$

where $\mathbf{A}_1$, $\mathbf{A}_2$ ... can be calculated in the same manner as **A** in Eq.(2).

We used the singular value decomposition to retrieve density profiles, q(z). In the case that measured data are not sufficient to retrieve density profiles, column contents are derived by means of least squares method. In derivation of the column contents, we assumed the relative profile.

COMPUTER SIMULATION OF THE MEASUREMENT

We have evaluated the accuracy of the RIS measurement by means of computer simulation. First, we generated the simulation signals. In the simulation, we considered actual parameters, such as reflectivity of the RIS, characteristics of the detectors, and parameters of the ground system. Two types of noise are added to the simulated signals. (A)Noise which is proportional to the signal. The noise of this type is caused by atmospheric turbulence, fluctuation of the laser, and digitization error of the transient digitizer. (B)Noise which does not depend on signal. This type includes the detector noise and the amplifier noise. In the simulation, we assumed that the magnitude of type (A) noise is 0.01 of the signal. Type (B) noise was estimated from the specification of the detectors. Multiple data sets including the noises were generated by using different random numbers.

We applied data reduction algorithm to the simulated data and derived density of target species. Random errors and systematic errors were estimated in the derived density. The random error was estimated form the standard deviations of derived densities. The systematic error was estimated form the difference between the average of the derived densities and true densities which are given in the simulation. Preliminary results of the simulation are summarized in Table I to III. The results show that the vertical profiles of ozone and methane and the column contents of CFC12 and other species can be derived from measured data by means of inversion methods.

Table I Error in the retrieved ozone profile

Altitude (km)	Random error(%)	Systematic error(%)
0	0.92	67.27
10	1.01	3.61
20	0.57	0.14
30	0.40	3.70
40	0.56	0.73
50	2.97	5.74

Table II Error in the retrieved methane profile

Altitude (km)	Random error(%)	Systematic error(%)
0	0.42	13.00
10	0.60	3.12
20	0.77	5.05
30	1.62	1.78
40	2.45	1.77
50	2.91	0.04

Table III Errors in the measured column contents

Molecule	Random error(%)	Systematic error(%)
CO_2	0.61	1.36
N_2O	1.58	12.36
HNO_3	10.99	3.06
CO	2.21	47.20
CFC12	0.59	0.27