Feasibility study for atmospheric water vapor measurements from spaceborne DIAL

Chikao Nagasawa[1], Makoto Abo[1], Tetsuri Sugisaki[1] and Osamu Uchino[2]

[1] Department of Electronics and Information Engineering, Tokyo Metropolitan University, 1-1 Minami-Ohsawa, Hachioji, Tokyo 192-03, Japan
[2] Japan Meteorological Agency, 1-3-4 Ohtemachi, Chiyoda-ku, Tokyo 100, Japan

ABSTRACT This paper presents the results of error estimation associated with differential absorption lidar (DIAL) measurements of water vapor profiles in the atmosphere from spaceborne for the low-latitude(15N), and for summer and winter in the mid-latitude(45N) and for summer and winter in the high-latitude(60N), respectively. We think that a Nd:YAG laser pumped Ti: sapphire laser is available to use with the spaceborne water vapor lidar at present. Then the water vapor absorption lines used in these calculations are in 820nm spectral region. The analysis suggests that the spaceborne DIAL system can perform at least two pairs of the on (strong absorption) - off (weak absorption) laser lines for the better than 10% profile measurement accuracy with the 1km altitude resolution from ground to upper troposphere.

1. INTRODUCTION

Measurements of water vapor profiles are probably very important in studies of the atmospheric dynamics, aerosol growth effect and the earth's radiation effects. Passive remote sensing techniques from space provide global coverage of water vapor distribution but do not provide good vertical resolution, while lidar remote sensing techniques can provide high resolution measurements of water vapor distributions. Several researchers have developed the water vapor DIAL systems or laser systems for airborne or spaceborne lidars using tunable solid state lasers such as an alexandrite laser [1-4]. Ismail and Browell[5] reported a comprehensive sensitivity analysis for a DIAL system for range-resolved measurements of water vapor profiles from the Lidar Atmospheric Sensing Experiment (LASE) developed at NASA. By using their method, we performed feasibility study for the spaceborne water vapor DIAL planned in Japan. The diode laser pumped Ti:sapphire laser is chosen for the transmitter in the Japanese spaceborne water vapor DIAL plan so that the water vapor absorption lines in 820nm band are used in all calculations. The diode laser pumped Ti:sapphire laser system is presented in the Ref.6 in detail. For this feasibility study, the parameters of this laser system and the HITRAN models[7] for water vapor distributions are used.

2. SIMULATION PARAMETER

The DIAL parameters used in this feasibility study are shown in Table 1. All calculations are performed for a nadir-viewing system. The detectors are silicon avalanche photodiodes (Si:APD). Its quantum efficiency is about 50% at 820nm. They are operated with photon counting mode. In the DIAL method, the spectral purity of the laser is very important and this value is 0.999. Assuming a nominal spacecraft altitude of 460km, a receiver diameter of 1m, a laser energy of 100mJ, the repetition rate of the laser shot pair (on-off) of 50Hz, and horizontal resolution of 100km, the simulations are performed. Because of small influence of the aerosol and molecule profiles to the calculation, their aerosol and molecule profiles are assumed like Fig.1 in all calculations. The water vapor concentration profile in the troposphere depends strongly on seasons and local regions. Generally, water vapor concentration in summer is one order more than that in winter, and water vapor in the ocean area and low-latitude has more concentration than that of in the continental area and high-latitude area.

Table 1 Parameters of a Spaceborne Water vapor DIAL System.

Transmitter		Receiver	
Pulse energy	100mJ (ON&OFF)	Aperture	1m
Rep. rate	50Hz	Field of view	0.1mrad (day) 1mrad (night)
Wavelength	810~820nm	Filter bandwidth (FWHM)	0.05nm (day) 1.0nm (night)
Spectral width	<0.5pm	Optical transmittance	30%(day) 50%(night)
Wavelength stability	<±0.05pm	Detector quantum efficiency	50% (APD)
Spectral purity	0.999	Dark count	50 count/s
Altitude	460km	Δz	1000m
Ground velocity	7km/s	Δx	100km

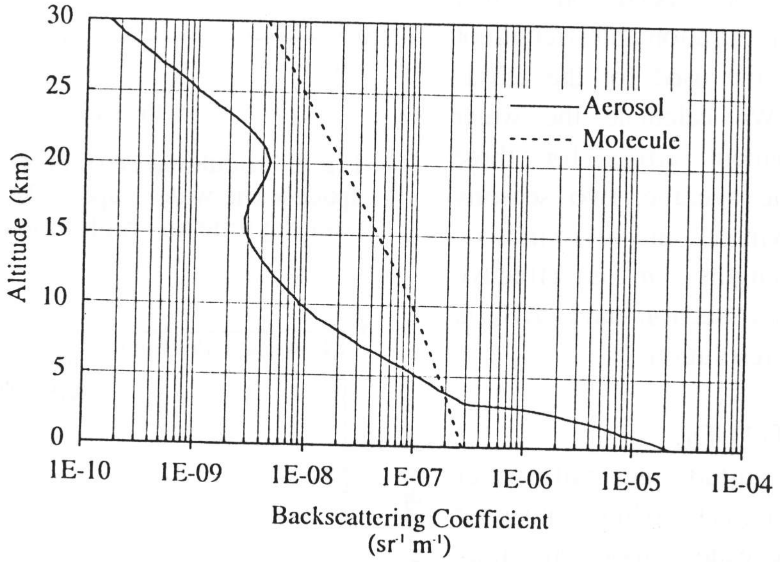

Fig.1 Assumed aerosol and molecule backscattering coefficient profiles.

3. ANALYSIS AND RESULT

Errors in the DIAL measurement consist of the random errors and the systematic errors. The systematic errors are caused by the following systematic effects presented in Ref. 5.

(1) Doppler broadening of the elastically backscattered signal and other atmospheric spectral broadening effects,

(2) Modification of the laser spectral profile by molecular absorption,
(3) Pressure shifts of absorption lines,
(4) Temperature sensitivity of absorption lines,
(5) Laser spectral purity,
(6) Laser wavelength uncertainty, and
(7) Knowledge of laser spectral output.

Influences (1) and (5) are contained in this simulation. Influences (2), (6) and (7) are negligible under consideration of the lidar specifications in Table 1. Influence (3) can be reduced by using the low-pressure photoacoustic cell for tuning to the absorption line of the water vapor[8-9]. Influence (4) is negligible by selecting the temperature insensitive absorption line in 820nm band. The random errors are caused from uncertainties in the detected signals, background signal noise from optical background noise (ex. solar radiation, moonlight and urban light), detector dark current and amplifier noise. In this simulation, their all random errors are contained. However, uncertainties in the detected signals and optical background noise influence to the random error, because other noises are negligible in operating with photon counting mode.

Fig. 2 shows the error lines of the daytime (albedo:0.8) measurement and the nighttime measurement in the summer water vapor of mid-latitude. This figure shows that the measurement is possible even under the high background conditions as well as nighttime conditions. Measurement error depends on mainly water vapor concentration and strength of the absorption line used for the DIAL measurement. We calculate the water vapor measurement errors for three latitudes on the average, two seasons (summer and winter), and two kinds of absorption strengths. σ is effective absorption cross section and ΔR is vertical altitude resolution.

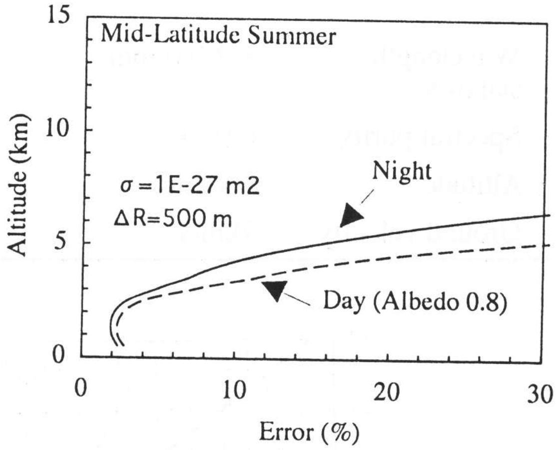

Fig. 2 Calculated error profiles for the spaceborne water vapor DIAL system over daytime and nighttime conditions.

3.1. LOW-LATITUDE

In the low-latitude, generally water vapor concentrations keep high values for all seasons. The water vapor concentration in the U.S. tropical model (15N) of the HITRAN database is used in our simulation as typical water vapor example in the low latitude. The calculated error lines for two kinds of absorption strengths are described in Fig. 3.

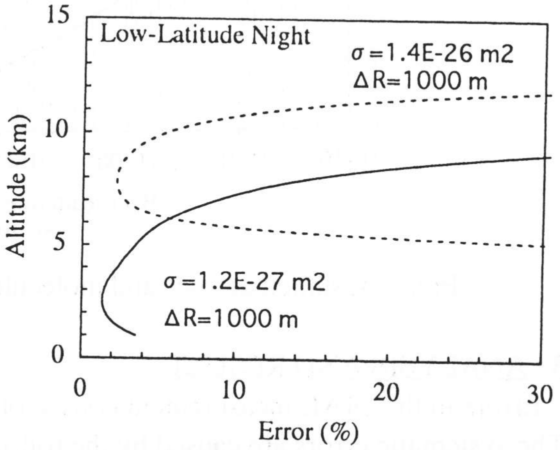

Fig. 3 Calculated error profiles for the spaceborne water vapor DIAL in the low-latitude at night background conditions.

3.2. MID-LATITUDE

Generally, the seasonal variation of the water vapor concentration is very large in the mid-latitude. The water vapor concentrations in the summer are one order larger than those in the winter. The summer and winter water vapor concentrations in the U.S. mid-latitude model (45N) of the HITRAN database are used in our simulation as each typical water vapor example in the mid-latitude. The calculated error lines for two kinds of absorption strengths are shown for summer in the mid-latitude in Fig.4, and for winter in Fig.5.

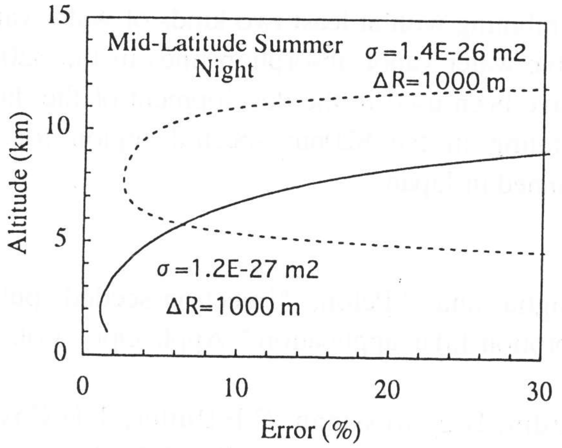

Fig. 4 Calculated error profiles for the spaceborne water vapor DIAL in the mid-latitude summer at night background conditions.

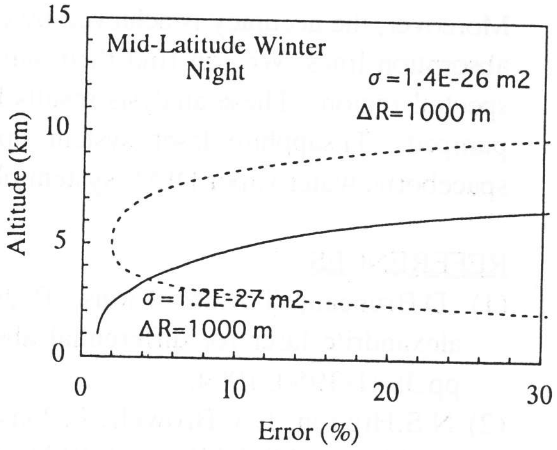

Fig. 5 Calculated error profiles for the spaceborne water vapor DIAL in the mid-latitude winter at night background conditions.

3.3. HIGH-LATITUDE

The seasonal variation of the water vapor concentration in the high latitude is not so large as that of mid-latitude. The water vapor concentrations in the U.S. sub arctic model (60N) of the HITRAN database are used in our simulation as typical water vapor example in the high-latitude. The calculated error lines for two kinds of absorption strengths are shown for summer in the high-latitude in Fig.6, and for winter in Fig.7.

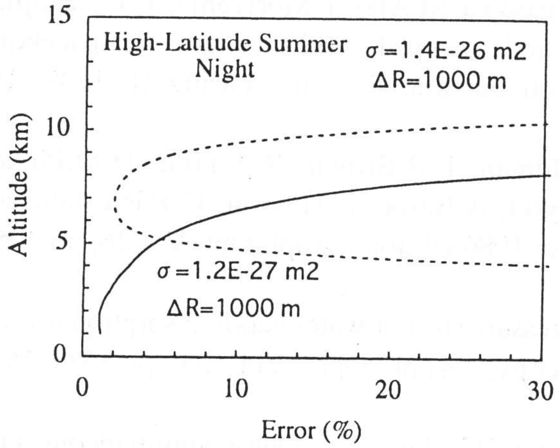

Fig. 6 Calculated error profiles for the spaceborne water vapor DIAL in the high-latitude summer at night background conditions.

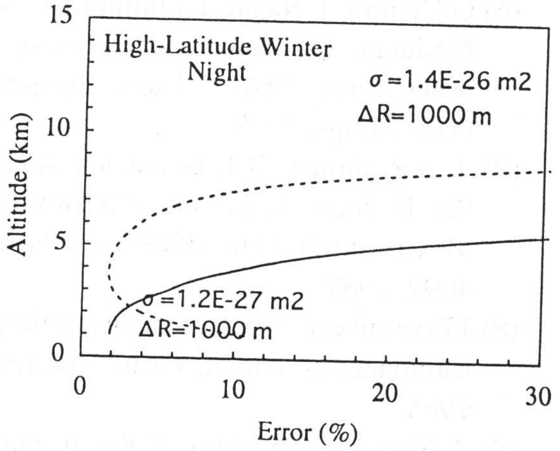

Fig. 7 Calculated error profiles for the spaceborne water vapor DIAL in the high-latitude winter at night background conditions.

4. CONCLUSION

Global measurements of water vapor profiles from the spaceborne Ti:sapphire laser DIAL system with the 820nm band planned in Japan are simulated with spatial resolutions of 1000m in the vertical and 100km in the horizontal. The most suitable pair of the on-off laser lines depends on the altitude range, the season, the global area and so on. The measurement accuracy strongly depends on the distribution of water vapor in the region of measurement. It is shown that the better than 10% water vapor profile measurement accuracy is possible globally from 0km altitude until 10km altitude during summer. However, this accuracy is degenerated from 0km altitude until about 7km during winter. Moreover, the accuracy is achieved by combining with at least two kinds of water vapor absorption lines. We can find their suitable water vapor absorption lines in the 820nm spectral region. These analysis results have been used in the development of the diode pumped Ti:sapphire laser system operating in the 820nm spectral region for the spaceborne water vapor DIAL system planned in Japan.

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