A-3.1 Data retrieval methods for minor constituents in the atmosphere related with green-house gases from solar occultation satellite sensors

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Abstract

In order to retrieve profiles of greenhouse gases and minor constituents in the lower stratosphere and upper troposphere from solar occultation satellite sensors, sensitivity and error analyses were done by numerical simulation for Improved Limb Atmospheric Spectrometer-II (ILAS-II) and Solar Occultation FTS for Inclined-orbit Satellite (SOFIS). The following results were revealed. The retrieval precision on ILAS-II data around the altitude of 20 km will be improved five times for ozone and eight times for methane from that on ILAS data, because of the additional spectral information of shorter wavelengths in ILAS-II measurement. One of the major error sources for gas retrieval is temperature estimation. ILAS-II and SOFIS could provide mixing ratios of carbon dioxide and other gases in the upper troposphere with reasonable precisions and with no bias as long as pressure and temperature data are correctly introduced into the retrieval procedure. SOFIS would also detect CH_4, N_2O, PFC-14, and SF_6 with reasonable precision. A new method of a micro-window selection for sensors with high spectral resolution has been developed with consideration of aerosol effects. A fast and simplified method of global inversion, which uses a multiple regression model and a principal component expansion has been developed for gas profile estimation directly from ILAS-II transmittance data and pressure & temperature profiles. Effectiveness of this method was confirmed by applying to the ILAS measurement data.

Key Words Stratosphere, Troposphere, Greenhouse gases, Data processing algorithm, Satellite data

1. Introduction

Atmospheric remote sensing from space is an effective method to monitor global environment like ozone depletion and global warming status. Ministry of the Environment (MOE) have promoted projects with National Institute for Environmental Studies (NIES) to monitor high latitudinal ozone depletion by using satellite sensors, ILAS and ILAS-II. MOE has also had another project for SOFIS to monitor global warming gases as well as species related to ozone layer depletion. In order to obtain useful information from these satellite sensors, reliable data retrieval methods for these sensors, especially for green-hose gas retrieval, are strongly desired to be developed.

2. Research Objective

About five years ago, ILAS had measured polar ozone layers for about eight months and provided good quality data to the researchers. The ILAS successor, ILAS-II instrument has been developed and it will measure polar ozone layers soon. Some researchers have pointed out that ILAS-II could also detect concentrations of greenhouse gases (GHGs) in lower stratosphere and upper troposphere[1]. Therefore the study of GHGs detectability by ILAS-II is important. The next sensor SOFIS has measurement targets of GHGs for global mapping of the data. From these circumstances, this research aims to develop practical methods to retrieve GHGs and other minor constituents from measurement data by solar occultation sensors such as ILAS, ILAS-II, and SOFIS. The research tools are numerical simulation and statistical examinations.

3. Research Method

The sensitivity tests for GHGs detection were done by computer simulation, where aerosol effects and strong refraction of ray paths in upper troposphere are taken into consideration. The retrieval precision of ILAS-II was compared with that of ILAS, when a precise non-linear least square method is used as a retrieval algorithm. Similar tests have been done for SOFIS with additional measurement spectral band of shorter wavelength region. A new selection method of micro-windows for FTIR sensors, which is robust to aerosol effects in upper troposphere, is proposed by modifying Rodgers's method. A fast and simplified method, where the multiple gas profiles are estimated simultaneously and directly from measured limb transmittance spectra and given pressure and temperature profiles is also developed. The usefulness of this method is confirmed by applying it to the past ILAS measurement data.

4. Results and discussion

(1) Sensitivity tests for ILAS-II and modified SOFIS

In the data retrieval simulation results, measurements using the 3 - 5.7 μm band and the 6 - 11.8 μm band with 12-bit data (i.e. for ILAS-II) caused five times better precision for O_3, and eight times better precision for CH_4 around the altitude of 20 km than those using only the 6 - 11.8 μm band with 10-bit data (i.e. ILAS). By the retrieval simulation tests for CO_2 according to the instrument specification of ILAS-II, CO_2 could be retrieved in 1 - 3% total error around the altitude of 20 km, if there is no error in temperature data, pressure data, and the altitude determination. It was found that one of the major error sources is an atmospheric temperature profile, which is used in the data retrieval procedure. Temperature information is essential for the CO_2 retrieval. By a numerical simulation for ILAS-II, if there is 3 K random error in temperature data, the total retrieval error in the upper troposphere at the altitudes of 7 - 9 km is up to about 8%.

We have tested gas retrieval sensitivities for FTIR sensors with a resolution of 0.2 cm^{-1}, by considering instrumental S/N, digitizing error, and IFOV movement in the atmosphere during data scanning (i.e. interferogram smearing). The used spectral bands are Band #1 of SOFIS [780 – 1723 cm^{-1}, with $\Delta\nu$=0.001 cm^{-1} for simulation] and an additional band in shorter wavelength [3500 – 4904 cm^{-1}, with $\Delta\nu$=0.002 cm^{-1} for simulation]. The simulation results[2,3] of retrieval error are shown in Table 1. From Table 1, it was found that trace gases (CO_2, O_3, N_2O, H_2O, and HNO_3) and PFC-14, SF6, could be detected reasonably from these spectral band data. It was also found that bias error is dominant in lower atmosphere. The reason should be aerosol effects on measured spectra and its estimation error in data retrieval.

(2) A robust micro-window selection to aerosol effects

One of the useful micro-window selection methods for FTIR sensors is Rodgers's method[4,5], which utilize "information content" as an efficiency index of the selected data set. We developed a new method with similar criteria as "information content" by modifying the

Rodgers's method. Our proposed method is robust to aerosol effects in the lower atmosphere.

Table 1. Retrieval error for SOFIS with an additional spectral band data [%]

	H_2O	CO_2	O_3	N_2O	CO	CH_4	NO_2	HNO_3	SF_6	$ClONO_2$	N_2O_5	CFC11	CFC12	PFC14
7 km	1.85	0.14	0.68	0.32	1.05	0.40	–	0.77	1.41	18.6		0.30	0.31	16.6
	-0.27	0.33	4.41	0.73	0.16	0.03		5.48	-4.66	33.5		-1.08	1.73	-26.6
10 km	0.10	0.15	1.12	0.30	1.16	0.15	15.9	0.89	2.45	38.4	42.4	0.41	0.47	3.11
	-0.04	0.14	3.01	0.47	-0.40	-0.04	3.51	4.07	-5.30	36.9	15.3	-0.86	1.03	0.34
20 km	0.18	0.44	0.43	0.48	26.3	0.29	3.32	0.29	26.4	5.75	8.89	9.82	3.63	3.37
	-0.07	-0.03	0.18	0.16	-3.08	-0.01	0.35	0.15	-6.0	3.05	-3.53	-0.51	0.19	-0.76
30 km	0.35	0.46	0.49	2.41	62.0	0.88	4.09	0.94		12.0	2.43			5.81
	-0.07	-0.07	0.17	0.99	-24.8	0.42	-0.85	0.37		2.0	-0.43			0.18
40 km	1.83	0.94	1.09	28.8		4.69	7.04	90.8			15.3			41.0
	-0.07	-0.06	-0.05	5.2		1.29	-0.82	-14.3			-1.7			9.2
50 km	4.5	3.5	4.5			9	20							
	$\lvert\epsilon\rvert < 2$	$\lvert\epsilon\rvert < 2$	$\lvert\epsilon\rvert < 3$			$\lvert\epsilon\rvert < 3$	$\lvert\epsilon\rvert < 3$							
60 km	4.5	5	13			20								
	$\lvert\epsilon\rvert < 2$	$\lvert\epsilon\rvert < 2$	$\lvert\epsilon\rvert < 3$			$\lvert\epsilon\rvert < 3$								

(Upper column: random noise, Lower column: bias noise)
(Used spectral bands: [780 – 1723 cm^{-1} (SOFIS Band #1)] and [3500 – 4904 cm^{-1}])

As an example of comparison between our method and Rodgers's one, the selected micro-windows are presented in Figure 1 (Rodgers) and Figure 2 (our method) with transmittance variation spectra of CO_2 at the altitude of 10 km.

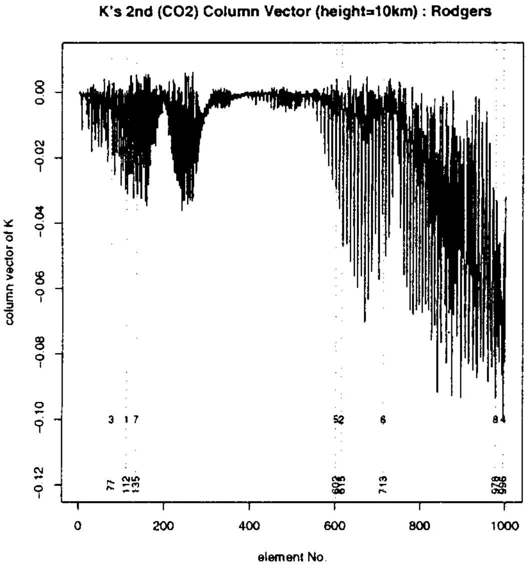

Fig.1 Selected micro-windows by Rodgers's method (CO_2, at 10 km altitude)

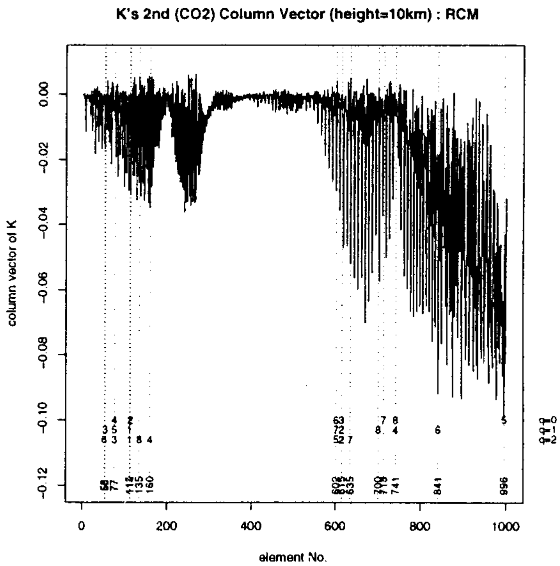

Fig.2 Selected micro-windows by our new method (CO_2, at 10 km altitude)

(3) A fast and simplified estimation method for gas profile retrieval

We propose a simplified method, where a set of the gas profiles is estimated directly from a set of the measured limb transmittance spectra and given pressure and temperature profiles by using a multiple regression model. The principal component expansion (PCE) is used for reducing the scale of the model. In the training process, coefficients of the estimation model are adjusted from the data sets including measured limb transmittance spectra, pressure and temperature profiles, and their retrieved gas profiles. Then, the model is applied to other new data sets, which are the newly measured data or are not used in the model training process.

The validity of the method was confirmed by numerical simulation using the MODTRAN v3.5, which is a radiative transfer code. The method was also applied to the actual 3474 ILAS observation data. The multiple regression model trained by 3372 data sets well described the gas profiles for another 100 of independent measurement data sets. This method will be used for a quick look of gas profiles, and for generating the initial values and climatological values in the operational precise spectral fitting procedure.

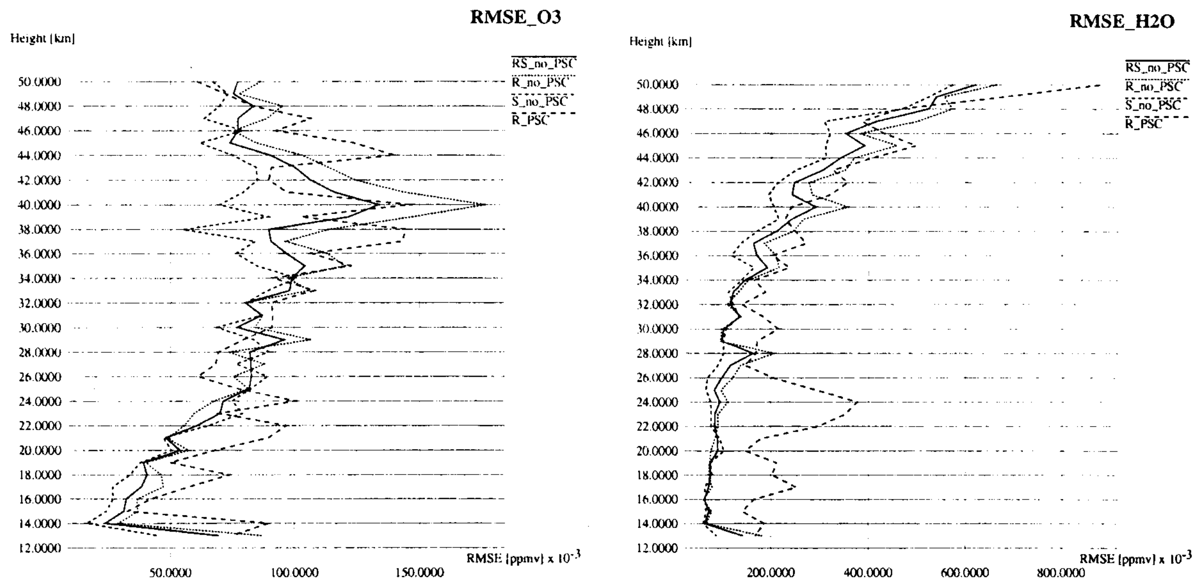

Fig.3 Root mean square error (RMSE) of profile estimation ((Left): O_3 and (Right): H_2O) by the proposed method applied to ILAS measurement data. ('RS_no_PSC': for training data, 'R_no_PSC': Non-PSC events for sunrise mode, 'S_no_PSC': Non-PSC events for sunset mode, 'R_PSC': PSC observation events for sunrise mode).

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