NICT Lidar Systems at Poker Flat Research Range

MIZUTANI Kohei, ITABE Toshikazu, YASUI Motoaki, AOKI Tetsuo, ISHII Shoken, MURAYAMA Yasuhiro, SASANO Masahiko, YOSHIOKA Kensuke, OHTANI Yoshiko, and Richard L. COLLINS

We have developed three lidar instruments for the observations of the Arctic troposphere, stratosphere and mesosphere at Poker Flat Research Range near Fairbanks, Alaska (65.1 N, 147.5 W). A multi-wavelength lidar to observe clouds, aerosols and water vapor distribution in the arctic troposphere and stratosphere is operated from March 2003. A Rayleigh lidar system for temperature observations of the stratosphere and mesosphere is working after November 1997. A Rayleigh Doppler lidar for wind measurements of the middle atmosphere was installed at Poker Flat in August 2005. Here, we give descriptions of the multi-wavelength lidar, the Rayleigh lidar, and the Rayleigh Doppler lidar for the observations of the Arctic atmosphere in Alaska.

Keywords
Mie lidar, Rayleigh lidar, Doppler lidar, Arctic atmosphere

1 Introduction

Foundation of lidar facilities in the Arctic region started after the recognition of ozone depletion in the Polar Regions as an important environmental problem. Several lidar instruments have been installed in Alaska in cooperation with Geophysical Institute of University of Alaska, Fairbanks (GI) and National Institute of Information and Communications Technology (NICT). Here, we will describe NICT lidar instruments deployed at Poker Flat Research Range (65.1 N, 147.5 W) in the international cooperation program between GI and NICT, so called, Alaska Project. Initially, one of instruments had been built up in the old lidar building. GI has built a new LIDAR Observatory (Fig. 1) and all the NICT lidar instruments have been installed in it. The LIDAR Observatory with NICT and GI lidar instruments is now one of synthetic lidar facilities established in the arctic region like ALOMAR observatory (69 N, 16 E)[1], ASTRO observatory (80 N, 86 W)[2], ARCLITE facility (67 N, 50 W)[3].

In the Alaska Project, various instruments for comprehensive observation of the arctic middle atmosphere were developed[4]. Lidar instruments developed by NICT are a multi-wavelength lidar, a Rayleigh lidar, and a

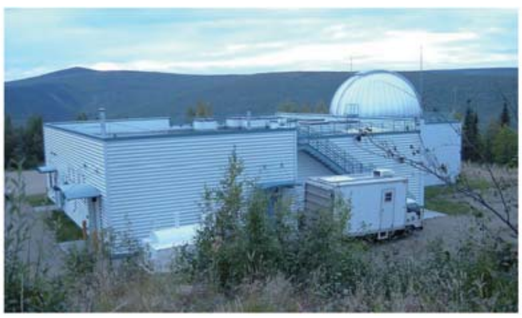

Fig. 1 LIDAR Observatory

Rayleigh Doppler lidar. The multi-wavelength lidar (Mie lidar) is one of complementary instruments, which covers the lower part of the arctic atmosphere in the comprehensive observation system. Objectives of It are clouds and aerosols in the troposphere and the stratoshpere which play important roles in the chemical process and radiation budget. We can observe temperature profiles in the stratosphere and mesosphere with the Rayleigh lidar and wind profiles in the middle atmosphere with Rayleigh Doppler lidar.

2 Multi-wavelength lidar

The multi-wavelength lidar was installed in March 2003 at Poker Flat to observe height profiles of atmospheric aerosols and clouds. It provides basic data on variations of aerosols and clouds distributions to study the effect of them to the radiation process. Water vapor distribution is also important to study the radiation process and condensation process of clouds. Then, we added Raman lidar function for water vapor observations to the multi-wavelength lidar. The characteristics of multi-wavelength lidar in Alaska are given in Table 1 and the block-diagram is shown in Fig. 2. Fundamental (1064 nm) and second harmonic (532 nm) laser light of a Nd:YAG laser (PL8020:Continuum) is transmitted in the multi-wavelength lidar (Fig. 3). Two telescopes of 35 cm aperture are used for the troposphere and stratosphere respectively, and a haze telescope with variable aperture is used for the altitude region lower than 2 km. The haze telescope consists of a 5 cmΦ lens, a variable aperture stop and a ND filter holder. Intense 532 nm scattered light from low altitude atmosphere is reduced by the aperture stop and ND filters and is detected by PMT to

Table 1 *Characteristics of Multi-wavelength Lidar*

Transmitter		
Laser	Nd:YAG Laser with SHG (20Hz)	
Wavelength	1064nm	532nm
Energy	600mJ	550mJ
Receiver (Haze)	5cmΦ	
Wavelength	532nm(1ch, PMT)	
Receiver (Troposphere)	35cmΦ	
Wavelength	532nm(P 2ch, S 1ch, PMT)	
	607nm (N_2 Raman 1ch, PMT)	
	660nm (H_2O Raman 1ch, PMT)	
Receiver (Stratosphere)	35cmΦ	
Wavelength	532nm(P 2ch, S 1ch, PMT)	
	1064nm (1ch, APD)	
Photon Counter	SR430(10channel, 12m resolution)	

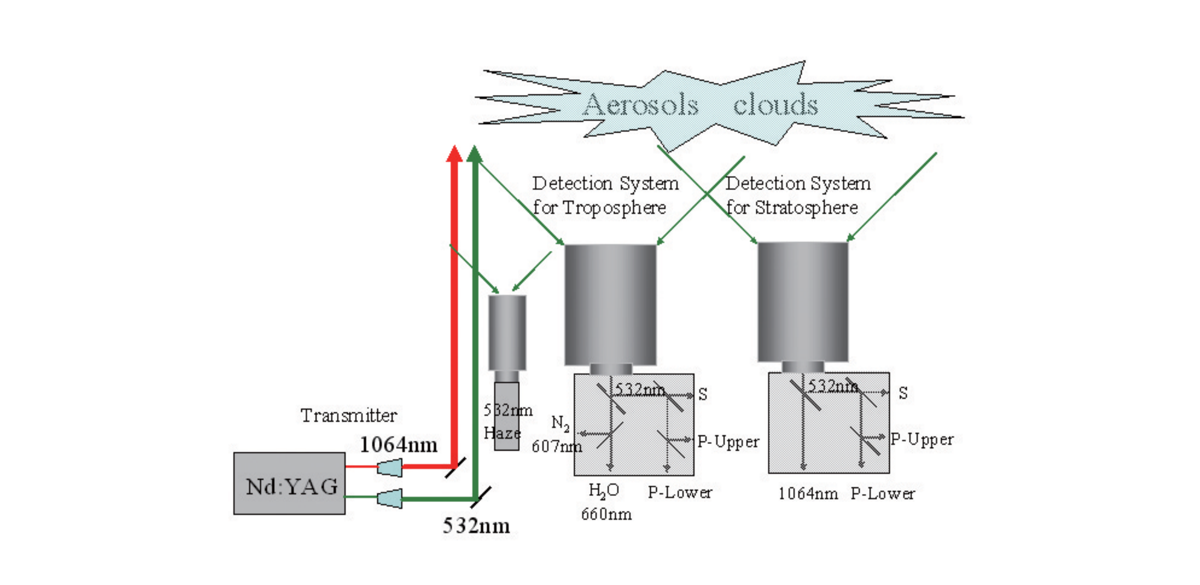

Fig.2 *Block-diagram of multi-wavelength lidar*

observe the Arctic haze[5] and aerosol distribution in the planetary boundary layer. In the troposphere system, N_2 Raman (607 nm) scattering and H_2O Raman (660 nm) scattering are observed to derive water vapor density and extinction[6] together with usual backscattering of 532 nm. Polarization observation at 532 nm, where polarized components parallel to and perpendicular to the laser light are measured, gives information about the non spherical degree of the backscattering particles. We can guess the classification of aerosols and clouds, and of solid and liquid from the data of polarization and water vapor. In the stratosphere system, we make the observations at two wavelengths of 1064 nm and 532 nm.

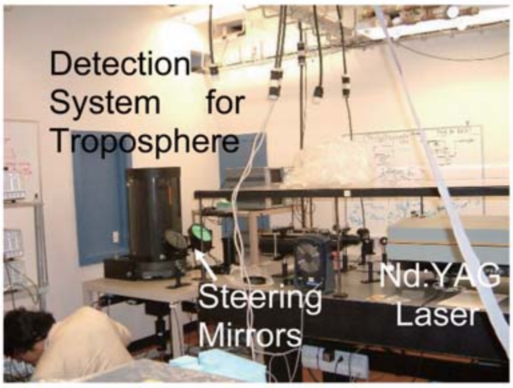

Fig.3 *Laser transmitter and detection system for troposphere*

Data on wavelength dependence of backscattering light is used to derive particle size distribution. Both in the troposphere and the stratosphere, we use two PMTs for observations of parallel component at 532 nm to extend the dynamic range. Adding another haze channel to measure the lowest part, five channels cover the distribution observation of clouds and aerosols in the troposphere and stratosphere. Perpendicular component is measured by one channel in the troposphere and stratosphere systems respectively. We use PMT (R3234-01) made by Hamamatsu Photonics for the seven channels at 532 nm (Haze 1, Parallel 4, Perpendicular 2), PMT (R3237-01) which is sensitive in the longer wavelength for the N_2 Raman (607 nm) and H_2O Raman (660 nm) channels, and Si-APD module made by Licel for the 1064 nm channel. Photon counting by Stanford SR430 is applied for the data acquisition of each channel. Raw data of all the ten channels from the ground to height of 40 km is shown in Fig. 4. Cloud at about 11 km is prominent in this figure. In the short-range region, incomplete beam overlap and/or saturation of signal hinder taking correct data, and in the long-range region, low S/N is problem. Then, each channel has effective range and we designed all the system so as to observe the atmosphere between about 300 m and 40 km by

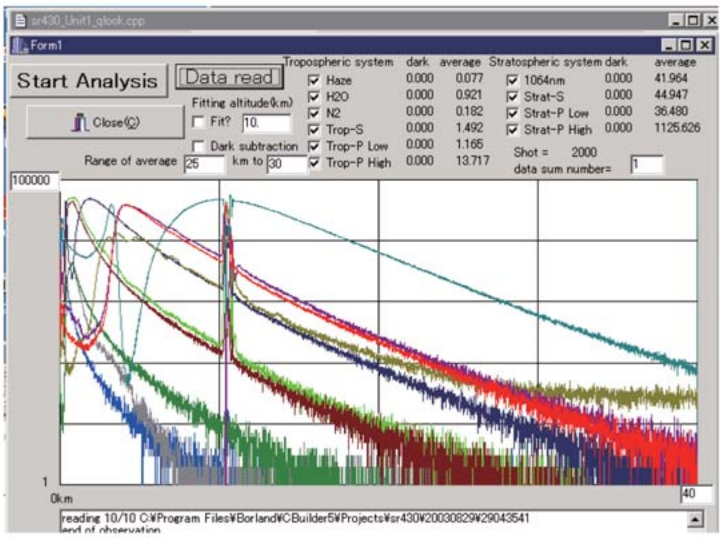

Fig.4 *Raw data taken by multi-wavelength lidar*

connecting data of each channel.

The distributions of the stratospheric aerosols observed by the multi-wavelength lidar are shown in Fig. 5. Tropopause height (dash line) is about 10 km in both days. Scattering ratio (total backscattering / molecular backscattering: = 1 if there is no cloud and aerosol) is enhanced up to about 1.07 between 10 km and 30 km, and indicates the distribution of the stratospheric aerosols. Depolarization ratio is small around the peak of the stratospheric aerosol distribution near 20 km, suggesting existence of liquid aerosols. Scattering ratio on 2003 10/16 shows a peak of cirrus cloud between 8 km and 10 km, where depolarization ratio is abruptly enhanced by ice particles. These data shows that the distributions and characteristics of the stratospheric aerosols and cirrus clouds can be observed with fine height resolution by the multi-wavelength lidar.

Water vapor mixing ratios deduced from N_2 Raman and H_2O Raman channels of the multi-wavelength lidar are compared with

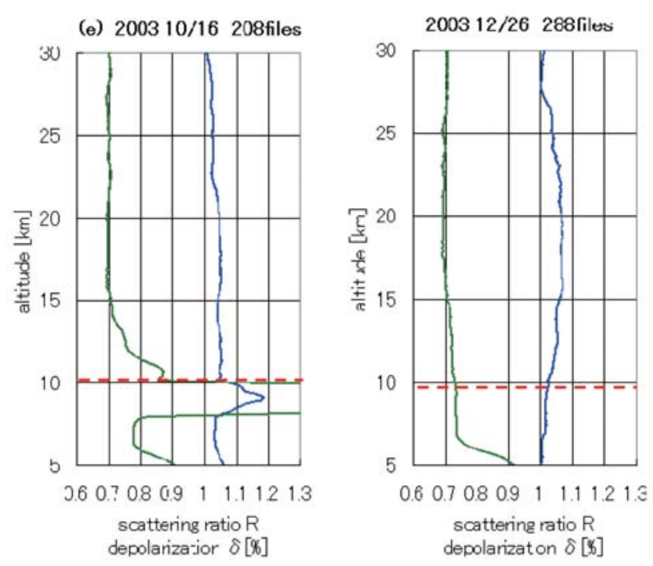

Fig.5 *Stratospheric aerosols by multi-wavelength lidar*

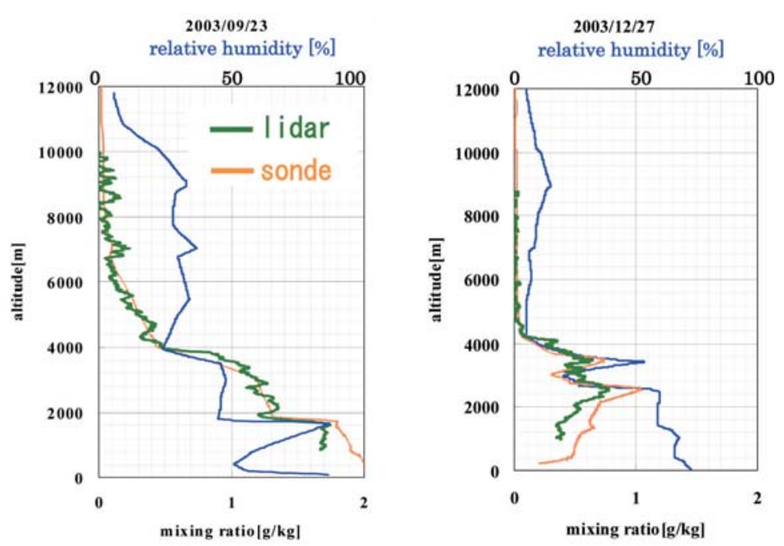

Fig.6 *Water vapor mixing ratios by multi-wavelength lidar and sonde*

those from balloon sonde observations at Fairbanks in Fig. 6. Two kinds of water vapor profiles shows good correlation each others except for the altitude range lower than 2 km. One of causes for these differences in the lower altitude might be the position difference of about 50 km in two kinds of observations. Time variation of water vapor mixing ratio profiles an hour is shown in Fig. 7, where variation in lower troposphere is remarkable. Difference of water vapor distribution from place to place is also expected to be larger in the lower troposphere. Continuous measurements of water vapor profile are possible by lidar observations as shown here. We can measure the water vapor profiles up to altitude of about 10 km in the summer when it distributes more and up to about 8 km in the winter with the multi-wavelength lidar.

3 Rayleigh lidar

The Rayleigh lidar system was installed at the old lidar bulding of Poker Flat in November 1997, and now moved to new LIDAR Observatory[7]. The system specifications are given in Table 2. The transmitter is common with the multi-wavelength lidar and the Nd:YAG second harmonic (532 nm) laser light is used. The backscattered light from the atmospheric molecules is collected by a Newtonian telescope of the diameter of 61cm, detected with a PMT (R3234-01) and photon-counted with Turbo-MCS (SEIKO EG&G). In Rayleigh lidar, backscattered light intensity by air molecules is observed and temperature profiles are deduced from it under the assumption of hydrostatic equilibrium[8]. Then, the observed light in the range of the analysis must be backscattered only by the air molecules. It means that the lower limit for the temperature measurement is an altitude of about 30 km that is determined by the upper bound of the stratospheric aerosols. Moreover, there is another lower limit in operation of the Rayleigh lidar at the maximum ability, because the counting is saturated in the range lower than 40 km. The temperature profiles on 2003 8/29 derived from the sonde data, the Rayleigh lidar data and the multi-wavelength lidar data are shown in Fig. 8. The temperature derived from the Rayleigh lidar shows a tendency to increase in the altitude lower than 40 km because of the counting saturation. While uncertainty in the

Table 2 Rayleigh lidar system at Poker Flat

Transmitter		Receiver	
Laser	Nd:YAG laser with SHG	Telescope	61cmΦ F/3.1 Newtonian
wavelength	532 nm	Detector	PMT(R3234-01)
Output energy	550 mJ at 20 Hz	Photon counter	Turbo-MCS(75m resolution)

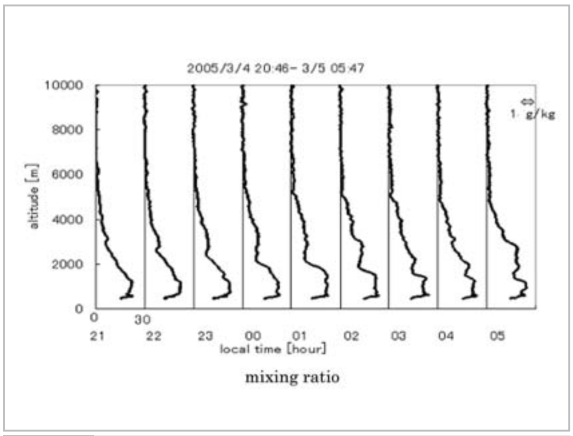

Fig.7 Time variation of water vapor mixing ratio profiles

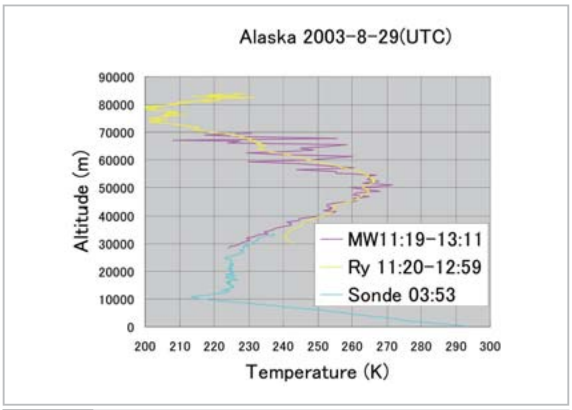

Fig.8 Temperature profiles by sonde, Rayleigh lidar and multi-wavelength lidar

data of the multi-wavelength lidar is large in the altitude higher than 50 km, the temperature profile between 40 km and 50 km agrees well to that from the Rayleigh lidar. A balloon sonde was launched 8 hours before lidar observations at GI in Fairbanks that is about 50 km apart from Poker Flat. The temperature profile from the balloon sonde is similar to that from the lidar data with temperature difference of 3 K higher in the sonde data. We think that the profiles derived from the Rayleigh lidar and Multi-wavelength lidar data are good measurements of the real temperature of the middle atmosphere. Several structures appear in the temperature profile derived from the Rayleigh lidar data. We can study activities of gravity waves and tides from these data[9][10]. This system fills the big blank area in Rayleigh lidar sites surrounding the arctic region. It is also a complementary instrument for the comprehensive observations of the arctic middle atmosphere at Poker Flat, and also working for validation experiments of satellite instruments[11].

4 Rayleigh Doppler lidar

The Rayleigh Doppler lidar was installed at the LIDAR Observatory on August 2005. It is an instrument to observe the wind profiles by measuring spectroscopically the Doppler shift of the Rayleigh scattering from the atmospheric molecules. The system design and parameters are shown in Fig. 9 and Table 3. The transmitting light is the second harmonic (532 nm) laser pulse of a Nd:YAG laser (PL9030:Continuum). The laser pulse energy is about 600 mJ in the repetition of 30 Hz. A CW laser frequency-stabilized by referring absorption line in an iodine molecular cell is

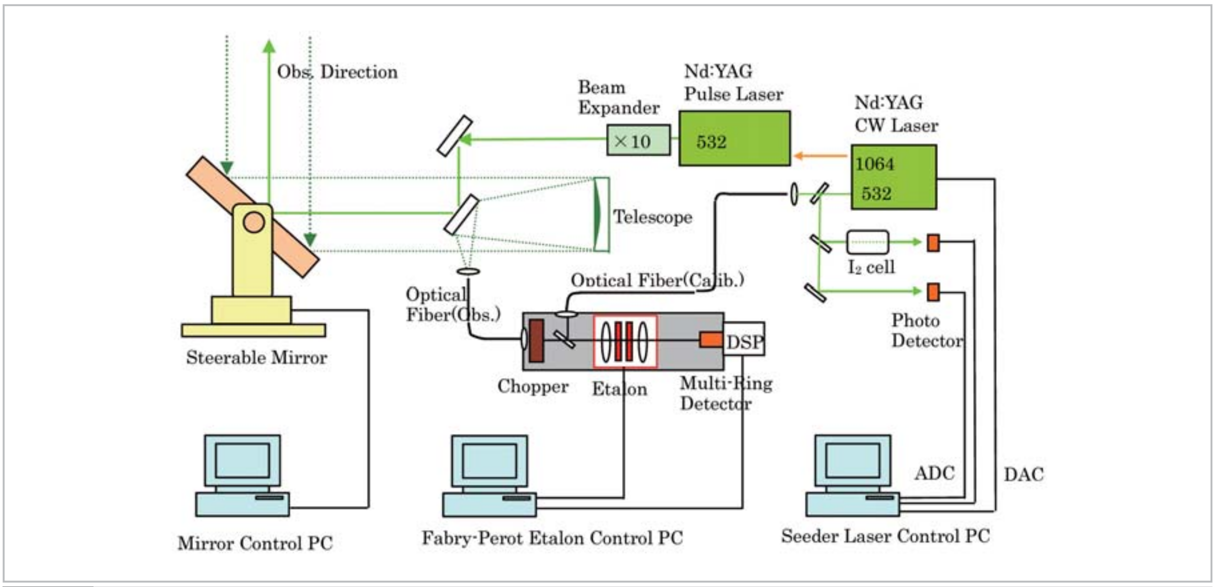

Fig.9 Block-diagram of Rayleigh Doppler lidar

Table 3 Characteristics of Rayleigh Doppler Lidar

Transmitter		Fabry-Perot Spectrometer	
Laser	stabilized Nd:YAG with SHG	Type	Capacitance-stabilized Etalon
Wavelength	532 nm	Working aperture	15 cm
Pulse energy	600 mJ	Etalon gap	25 mm (6 GHz FSR)
Repetition	30 Hz	Reflectivity	90%
Beam div.	<0.1 mrad	Detector	
Receiver Telescope		type	24 equal area ring detectors (1channel≒300MHz)
Diameter	80 cm		
Field of view	0.4 mrad	Height resolution	196m

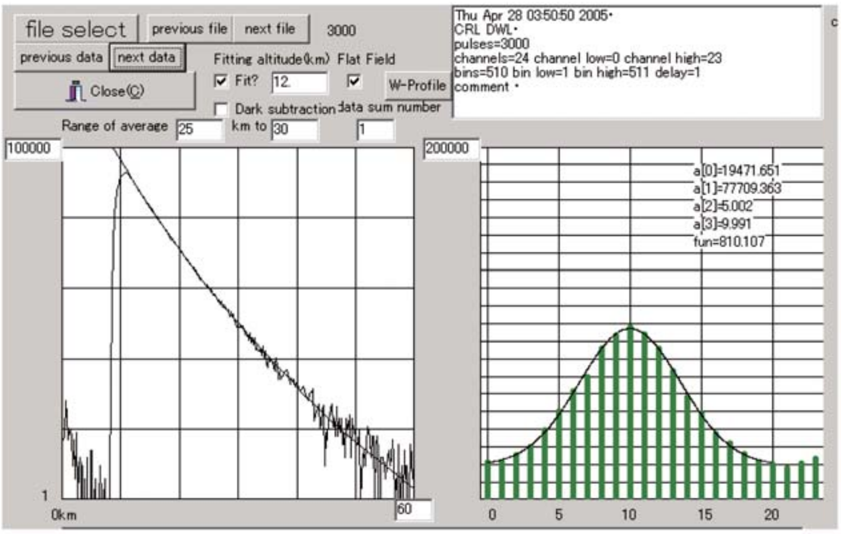

Fig. 10 Rayleigh Doppler lidar data to the Zenith direction at Koganei

used to seed the pulse laser for wavelength stable single mode operation. The laser pulses are transmitted to the sky by a large scanning mirror. The backscattered light is directed to a 80 cm Newtonian telescope by the same scanning mirror and collected in a multimode optical fiber. The fiber guides the light to the spectrometer in another room and scrambles spatially the light homogeneously. The out coming light from the optical fiber is once focused at a chopper position, then collimated and passes through a Fabry-Perot etalon (made by Havemere Ltd) of working aperture of 15 cm and spacing of 2.5 cm. The etalon is thermally controlled in a container and capacitance-stabilized. The fringe image of the surface of the optical fiber is focused on a 24-channel equal area ring detector (made by Havemere Ltd). Each channel of the 24-channel photon detector is set to the spectral resolution of about 300 MHz and one free spectral range (FSR) of 6 GHz is covered by these detectors.

The frequency Doppler shift of the backscattered light is expressed as $\Delta\nu = 2\nu\,(v/c)$, where ν is the frequency of the laser light, c is the light speed and v is the line of sight (LOS) velocity of winds. As vertical velocity is usually small, the LOS component of the horizontal wind is measured. When we set the beam to a zenith angle of 30° by the scanning mirror, LOS component is half of the horizontal wind velocity. A horizontal velocity of 5 m/s (=2.5 m/s LOS wind) corresponds to 9.3 MHz Doppler shift.

A part of test data at NICT (Koganei, Tokyo) is shown in Fig. 10. The data was taken in 3000 laser shots (100 s) to the zenith direction. Height profile of signal summed for all the channels is displayed in the left side of the figure. It agrees well to the fitting curve calculated from molecular density profile of a model atmosphere. Spectrum of signal summed for all range bins is displayed in the right side of the figure. The line width of backscattered light became broad due to the thermal motion of the atmospheric molecules. We compared the wind profile obtained by the Rayleigh Doppler lidar with the sonde data at Tateno about 70 km apart from NICT in Fig. 11. Wind observations by the lidar seem to measure the wind profiles up to altitude of about 30 km. Observation time was about 20 minutes for East-West and North-South winds, respectively. We expected that observable altitude would be higher than 30 km[7]. The reason of low S/N ratios in the higher altitude is that the efficiency of the receiver system is lower than the planned one. We are investigating the cause of the low efficiency.

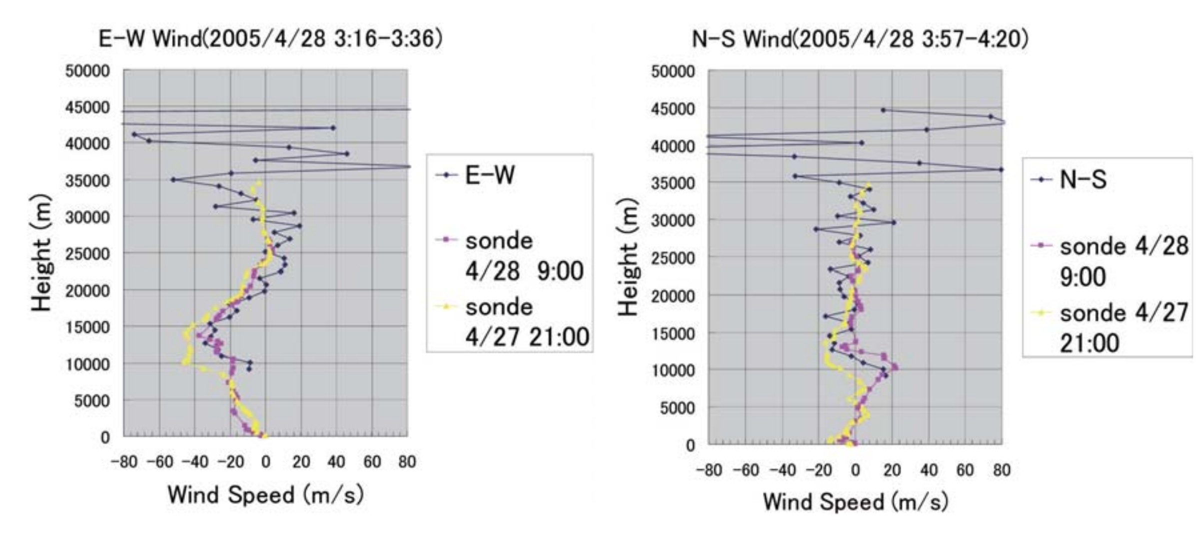

Fig. 11 *Wind profiles by Rayleigh Doppler lidar (Koganei) and sonde (Tateno)*

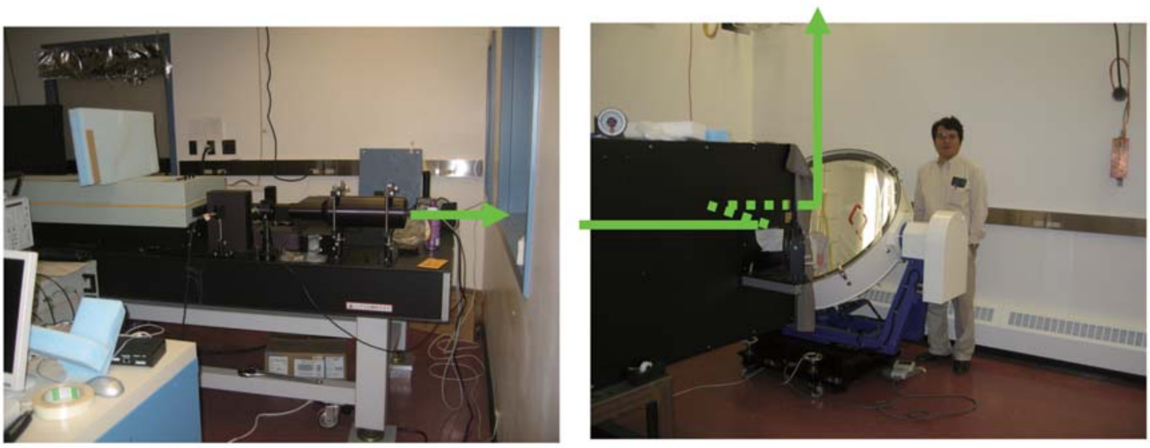

Fig. 12 *Rayleigh Doppler lidar at Poker Flat*

The Rayleigh Doppler lidar installed at Poker Flat is shown in Fig. 12. The test data taken just after the installation is also given in Fig. 13. Though smoke covering the sky affected the spectrum with some bias, the spectrum of the backscattered light was measured and the instrument fulfilled its function. After the installation, the Rayleigh Doppler lidar didn't work well because of the trouble of the laser. However, the instrument is now ready for observations, fixing problems of the laser. Continuous observations of wind profiles of the arctic atmosphere are now possible, though the range is limited up to about 30 km.

5 Conclusions

We have developed a multi-wavelength lidar for observations of aerosols and clouds in the troposphere and stratosphere and are making observations at Poker Flat from March 2003. A Rayleigh lidar system is operated to observe temperature profiles of the Arctic middle atmosphere since 1997. It has already revealed the characteristics of the structure of mesospheric inversion layer and noctilucent clouds. The Rayleigh Doppler lidar system was installed on 2005 and now ready for making observations, though its optical efficiency is rather low. These instruments will be used

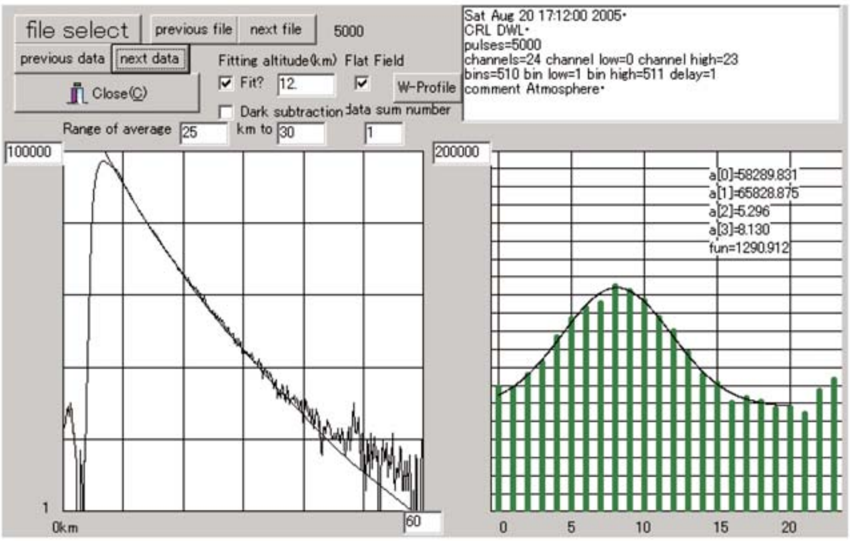

Fig. 13 Rayleigh Doppler lidar data to the Zenith direction at Poker Flat

for the studies of wave activities such as gravity waves, radiation budget and atmospheric chemistry. In the long term, change of the structure of the polar atmosphere sensitive to the global warming will be investigated using these instruments.

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***MIZUTANI Kohei**, Ph.D.*

Research Manager, Environment Sensing and Network Group, Applied Electromagnetic Research Center

Laser Remote Sensing

***ITABE Toshikazu**, Ph.D.*

Executive Researcher

Laser Remote Sensing

***YASUI Motoaki**, Ph.D.*

Senior Researcher, Environment Sensing and Network Group, Applied Electromagnetic Research Center

Atmospheric Science

***AOKI Tetsuo**, Ph.D.*

Director, Project Promotion Office, Applied Electromagnetic Research Center

Laser Remote Sensing

***ISHII Shoken**, Ph.D.*

Senior Researcher, Environment Sensing and Network Group, Applied Electromagnetic Research Center

Laser Remote Sensing

***MURAYAMA Yasuhiro**, Dr. Eng.*

Planning Manager, Strategic Planning Office, Strategic Planning Department

Dynamics in the Thermosphere and Mesosphere

***SASANO Masahiko**, Ph.D.*

Researcher, Sensing Technology Group, Navigation and System Engineering Department, National Maritime Research Institute

Laser Remote Sensing

YOSHIOKA Kensuke

JGC Corporation, (former:Tokyo Metropolitan Institute of Technology)

Laser Remote Sensing

OHTANI Yoshiko

Audio-Technica Corporation, (former:Tokyo Metropolitan University)

Laser Remote Sensing

***Richard L. COLLINS**, Ph.D.*

Associate Professor, University of Alaska Fairbanks

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