4-5 Lidar instruments for the observations of the arctic atmosphere in Alaska-project

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We developed a Rayleigh lidar system and it is now working well for temperature observations of the Arctic middle atmosphere at Poker Flat Research Range near Fairbanks, Alaska (65.1 N, 147.5 W). A Rayleigh Doppler lidar for wind measurements of the middle atmosphere is in the development phase. The combination of these lidars and radars installed at Poker Flat gives us an opportunity of simultaneous observations of the structure and dynamics of the atmosphere in broad range of altitudes. We also developed Multi-wavelength lidar to observe clouds and aerosol distribution in the arctic tropospher and stratosphere. It will be installed at Poker Flat in this year. Here, we give descriptions of the Rayleigh lidar, the Rayleigh Doppler lidar and multi-wavelength lidar for the observations of the Arctic middle atmosphere at Poker Flat.

Keywords
Rayleigh lidar, Doppler lidar, Aerosol, Arctic middle atmosphere

1 Introduction

Height profiles of temperatures and winds of the middle atmosphere between 30 km to 60 km are observable continuously only by Rayleigh lidar and Rayleigh Doppler lidar except for rocket sounding. Though Rayleigh lidar have been used to measure temperature profiles of the middle atmosphere in middle latitude, deployment to the arctic region were done in recent years; ALOMAR observatory (69N, 16E) in 1994[1], ASTRO observatory (80N, 86W) in 1993[2], ARCLITE facility (67N, 50W) in 1993[3]. We installed a Rayleigh lidar at Poker Flat Research Range (65.1N, 147.5W) in 1997 as one of instruments for the comprehensive observations of the Arctic atmospheric in, so called, Alaska project. This Rayleigh lidar is expected to be a complementary instrument in Alaska project and also in Rayleigh lidar observation network around the Arctic. Rayleigh Doppler lidar is a possible instrument to observe continuously the wind profiles in the middle atmosphere and is under the developing phase as a complementary instrument in Alaska project. It is an incoherent Doppler lidar system with a frequency stabilized high power laser, a telescope, a Fabry-Perot interferometer and a multi-ring detector system. We have also developed a multi-wavelength lidar to observe clouds and aerosols in the troposphere and the stratoshpere which play important roles in the chemical process and radiation budget. It is a complementary instrument, which covers the lower part of the arctic atmosphere and will be installed in this year.

2 Rayleigh Lidar

The Rayleigh lidar system was installed at Poker Flat in November 1997. The system configuration is shown in Fig.1 and the system specifications are given in table 1. The transmitter is a Nd:YAG pulse laser with a second harmonic generator. The laser pulses of the wavelength of 532 nm are transmitted to the zenith by a steering dielectric mirror after passing a beam expander (×10). The backscattered light is collected by a Newtonian telescope (61 cmΦ, F/3.1). The field of view is limited to 1.6mrad by an aperture put on the focus point of the telescope. Though this large field of view permits much background sky noise, it brings large tolerance to axis adjustment. The light through the aperture is collimated and passes a narrow band filter. A filter wheel with ND filters, which are used for alignment and calibration, is put in front of the focusing lens. We employ a low noise PMT and the electric gating up to the altitude of 25 km to protect it against intense light signal. In Rayleigh lidar, light backscattered by air molecules is observed and temperature profiles in the middle atmosphere are derived. The lower height of temperature measurements is limited by the stratospheric aerosols, which extends up to the altitude of about 35 km.

Fig.2 shows a photon count profile obtained in the night of March 17, 1999. Though the electric gating reduces the signal up to 25 km, some signal in the region of intense backscattered light appears against the gate voltage. Detector sensitivity recovers at the altitude of 25 km from the gating. However, counting is saturated up to about 38 km. The signal above 120 km is only background. After subtracting the background, the signal is corrected for the atmospheric extinction. The derived profiles are proportional to the atmospheric molecular density /range-square. Temperature profiles is deduced from it under the assumption of hydrostatic equilibrium[4]. In the evening of March 17, 1999, we launched an ozone sonde in Fairbanks about 50 km southwest of Poker Flat. In the time of the sonde observation, a ND filter of 20 % was used to avoid saturation of the counting. The temperature profiles derived from the sonde data and the lidar data are shown in Fig.3. The difference of two profiles in the overlapped altitudes around 35 km is about 2 K. Considering the possible difference of observed position of a few hundred km in sonde from the lidar site and short time variation of the temperature profile, the agreement is good. Fig.4 shows successive temperature profiles in the night of January 21, 1999. Many wavelike structures appear in the profiles. Some of these structures seem to propagate downward, indicating the existence of upward gravity waves. These data show that the instrument has enough ability to study the atmospheric fluctuations like gravity waves and tides. 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, where

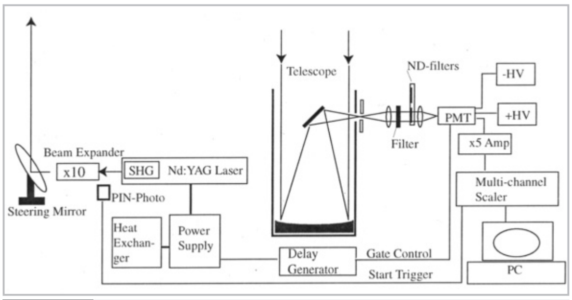

Fig.1 Block-diagram of Rayleigh lidar

Table 1 Rayleigh Lidar system at Poker Flat (65.1N,147.5W)

Transmitter		Receiver	
Laser	Nd:YAG laser with SHG	Telescope	61 cmϕ F/3.1
wavelength	532 nm		Newtonian
Output energy	550 mJ	Field of view	1.6 mrad
Repetition Rate	20 Hz	Height resolution	75 m
Pulse width	<7 nsec	Detector	PMT(R3234-01)
Beam divergence	<0.1 mrad		

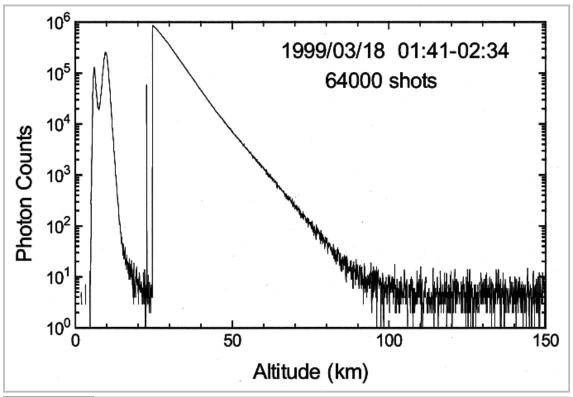

Fig.2 A 53 minutes integrated photon count profile. Each time bin of 500 nsec corresponds to 75 m range bin

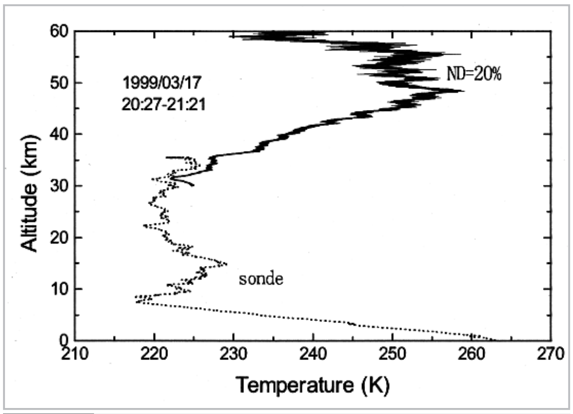

Fig.3 Temperature profiles derived from the Rayleigh lidar and balloon sonde (dashed line) in the night of March 17, 1999

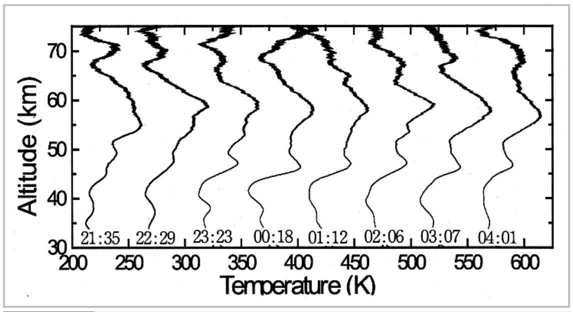

Fig.4 Sequence of temperature profiles in the night of January 21, 1999. Profiles excepted for the first profile are shifted by 50K each on the temperature scale

several instruments have been already working for measurements of many parameters of the middle atmosphere.

3 Rayleigh Doppler Lidar

The Rayleigh Doppler lidar is an instrument to measure the winds and temperatures from the Doppler shift and the broadening of the Rayleigh scattering by the atmospheric molecules. As temperature profiles are also obtained from the Rayleigh lidar, main objective of the Rayleigh Doppler lidar is wind measurements. The system design and parameters are shown in Fig.5 and Table 2. A Nd:YAG laser with a second harmonic generator emits 800 mJ laser pulses at 532 nm in the repetition of 30 Hz. A CW seeder laser frequency stabilized against an Iodine molecular line is used to seed the pulse laser for stable single mode operation. The laser pulses are transmitted to the sky by a large scanning mirror. The backscattered light is directed to a 75 cm Newtonian telescope by the same scanning mirror and collected in an 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 capacitance-stabilized Fabry-Perot etalon[5] of working aperture of 15 cm and spacing of 2.5 cm. The fringe image of the surface of the optical fiber is focused on a 24-channel equal area ring detector. Each channel of the 24-channel photon detector is actually set to the spectral resolution of 300 MHz and one free spectral range (FSR) of 6 GHz is included in the detector coverage.

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

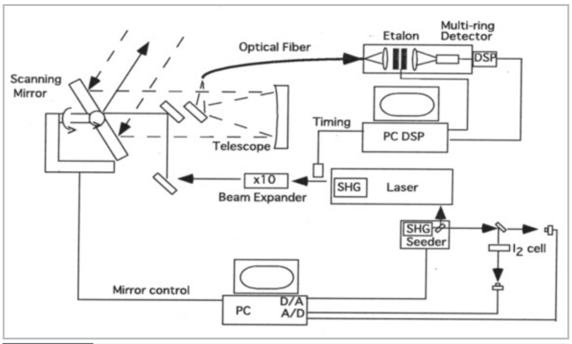

Fig.5 Block-diagram of Rayleigh Doppler Lidar

Table 2 *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	800 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= 300 MHz)
Diameter	75 cm		
F-ratio	3.7	Height resolution	200 m
Field of view	0.4 mrad		

sight (LOS) velocity of winds. As the vertical velocity is usually very small, the LOS component of the horizontal wind is measured. When we use 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. We have to measure one thirtieth of one channel in the 24 channel detector to realize a wind determination of 5m/s in the zenith angle of 30˚. The line width of the laser is about 100 MHz and the frequency stabilization of 2 MHz is thought to be possible[5]. The Doppler broadening of the Rayleigh backscattered light by the random motion of the air molecules is about 2.5 GHz (FWHM) and is the main cause of the line broadening. In these conditions, horizontal wind measurement with accuracy better than 5 m/s up to an altitude of 43 km is possible in 10 minutes and accuracy of 6m/s at 60 km is obtained in 2 hours[6]. On the other hand, the data coverage by MF radar at Poker Flat is >68 km at night[7]. The combination of MF radar and Rayleigh Doppler lidar will enable us to make wind measurements from about 10 km to 100 km.

4 Multi-Wavelenth Lidar

Multi-wavelength lidar will be used to observe height profiles of atmospheric aerosols and clouds, and provide basic data on variations of aerosols and clouds distribution to study the effect of them to the radiation and chemical processes. The block-diagram of multi-wavelength lidar is shown in Fig.6 and the characteristics are given in Table 3. Fundamental (1064 nm) and second harmonic (532 nm) laser light of Nd:YAG laser is transmitted. Two telescopes are used for the troposphere and stratosphere. N_2 raman (607 nm) and H_2O (660 nm) raman scattering are observed in troposphere with usual backscattering of 532 nm. The data of these lines are used to derive correction factor of extinction by clouds and aerosols, and relative density of water vapor. Polarization observation in 532 nm measures the non-sphericity 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, we make the observations at two wavelengths of 1064 nm and 532 nm. Data on wavelength dependence of backscattering will be used to derive particle size distribution. Both in the troposphere and the stratosphere, we use two PMTs to extend the dynamic range of observations at 532 nm. Adding another Haze channel to measure the lowest part, five channels cover the observations of clouds and aerosols in the troposphere and stratosphere. Multi-wavelength lidar will be installed at Poker Flat in this year. It is used to study the movement of the stratospheric aerosols which play important roles in the chemical processes and the effect of cloud and aerosol distribution to radiation budget. It will be more effective to make simultaneous observations of the multi-wavelength lidar, FIIR in emission measurement mode and Infrared Camera measuring 10 μm emission of the atmosphere.

5 Conclusions

Table 3 *Characteristics of Multi-wavelength Lidar*

Transmitter	
Laser	Nd:YAG Laser with SHG
Wavelength 1064 nm	532 nm
Receiver (Troposphere)	
Telescope	35 cmϕ
Wavelength	532 nm (P 2 ch, S 1 ch)
	607 nm (N_2 Raman 1 ch)
	660 nm (H_2O Raman 1 ch)
Receiver (Stratosphere)	
Telescope	35 cmϕ
Wavelength	532 nm (P 2 ch, S 1 ch), 1064 nm (1 ch)

*Haze channel (532 nm) 5 cmϕ Telescope

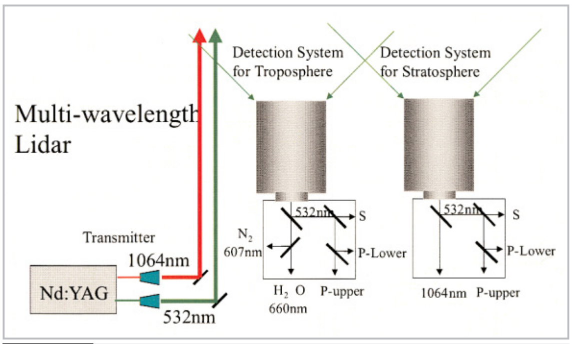

Fig.6 *Block-diagram of Multi-wavelength Lidar*

A Rayleigh lidar system is installed at Poker Flat and works well to observe temperature profiles of the Arctic middle atmosphere. It has already revealed the characteristics of the structure of mesospheric inversion layer. The Rayleigh Doppler lidar system is in the developing phase. Multi-wavelength lidar to observe aerosols and clouds in the troposphere and stratosphere will be installed at Poker Flat in this year. These instruments will be used for the comprehensive observations of the Arctic middle atmosphere with other instruments deployed for the Alaska project. In the short term, studies of wave activities are strengthened because gravity waves have significant effects on the structure and the dynamics of the middle atmosphere. In the long term, change of the structure of the middle atmosphere and radiation budget is interested. The effect of the global change like global warming is said to be manifested in the Polar region.

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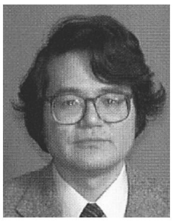

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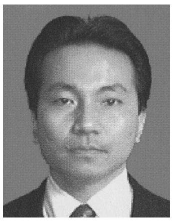

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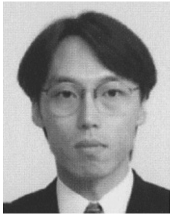

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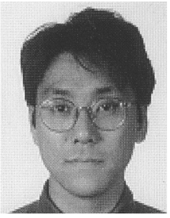

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