Future Spaceborne Lidar Systems

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1. Introduction

Spaceborne lidars have unique features for global and long-term sensing of meteorological and environmental parameters which can not be obtained by passive sensors. The Mie-Ralyleigh scattering lidars have already been studied in many air-borne projects and in the spaceborne LITE project and satellite systems. For the next generation spaceborne lidar programs, several systems have been proposed and are in the research phase. Atmospheric temperature, winds, various constituents including water vapour are parameters with great obsevational needs.

In this paper, a study of the future spaceborne Metalic Atom Lidar (MAL) is introduced which was studied by the atmospheric lidar group of ISAS. A new Doppler spaceborne lidar technique is also introduced for measuring tropospheric and stratospheric wind based on the incoherent Doppler method, now under development.

2. Metalic Atom Lidar (MAL)

Groun-based resonant scattering lidars have been used to observe Na, K, Li, Ca, Ca^{+}, and Fe metalic atom layers at altitude of about 90 km with about 30 km width. These atomic layers correspond to the boundary layer between the neutral atmosphere and the ionosphere and the obsevation is important in twohold, 1) by measuring the gravity wave of the layer, dynamical structure can be analyzed in the neutral atmosphere where practical sensors are not existing, 2) the effect of the layer to the upper ionosphere can also be analyzed by comparing the electromagnetic phenomena.

The spaceborne resonant scattering lidar for detecting the metal atom layers was designed and proposed by the lidar research group of the earth atmosphere obsevation for the ISAS spaceborne ATOMS (atmospheric research satellite) project[1]. System design and simulation of the performance have already been reported.

In Table 1, observation parameters of the metal atom lidar are listed. The lidar system parameters are listed in Table 2. The platform height is 800km and the inclination angle is 70 deg.

Table 1 Observation parameters of the Metalic Atom Lidar

Density profile of Na, K, Fe Layers	
Polar stratospheric clouds (PSC)	Cloud height
Stratospheric and tropospheric aerosols	PBL height

Table 2 Specification of the Metalic Atom Lidar

Laser System		***Detection System***	
Laser wavelength	589.0 nm (Na)	Telescope diameter	1 m
	769.9 nm (K)	Filter spectral width	<1 nm
	372.0 nm (Fe)	Optical efficiency	>10 %
Spectrum width	< 5 pm	Field of view	< 1 mrad
Wavelength stability	±0.1 pm	Height resolution	1 km (atom)
Output energy	> 50 mJ		15 m (aerosol)
Pulse repetetion	> 10 Hz	Horizontal resolution	<1000 km (atom)
Beam divergence	< 1 mrad		< 10 km(aerosol)

In Fig.1, a system concept of the spaceborne metalic atom lidar is shown. The signal-to-noise ratio is plotted in Fig. 2 for altitudes in night-time observation of Na layer and air molecules using a photon counting detector. From this analysis, it is clear that the Na layer density can be detected well in night-time and sometimes in day-time observation.

As the transmitter, the diode-pumped solid-state, tunable light sourses are assumed including an optical parametric oscillator or a sum-frequency mixing of 1.33 μm and 1.06 μm Nd:YAG laser.

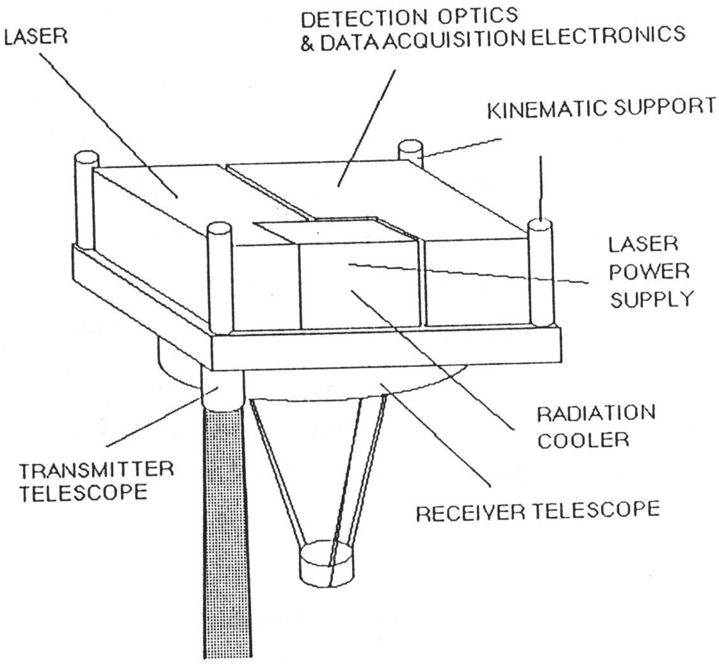

Fig. 1 The spaceborne metalic atom lidar

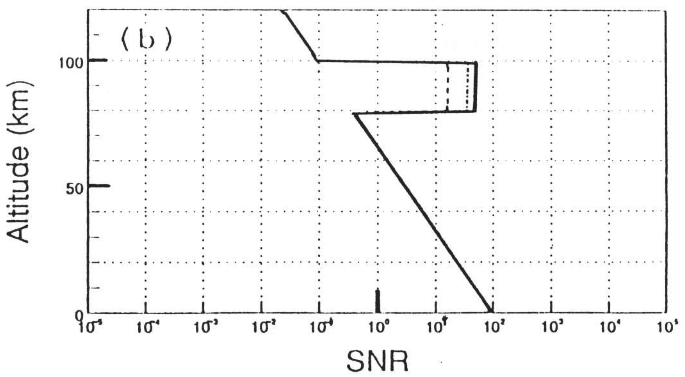

Fig. 2 Signal-to-noise ratio for Na layer and air molecules. (pulse averaging:1000 shots)

3. Doppler lidar for wind measurement

The coherent Doppler lidar technology is in progress for measuring wind speed and direction. The spaceborne coherent Doppler lidars are planned in the LAWS project of NASA, J-LAWS and other projects as future active sensors. In the coherent lidar system, the heterodyne detection is used and a high sensitive measurement can be achieved at nearly shot-noise limited level in 10 μm and 2 μm region. However, the heterodyne lidar requires high accuracy optics and the detection efficiency is reduced significantly by the atmospheric turbulence in the troposphere where wind measurement is primarily reqired. Complex spectral analysis also takes long computing time and requires large date memory for lidar signal processing.

The incoherent Doppler lidar using direct detection is simpler in system design and signal processing in comparison with the coherent lidars. Also, the direct detection is insensitive to the atmospheric turbulence and speckles. A new incoherent Doppler lidar technique, differential discrimination method, has been proposed for wind profiling[2] which will give higher sensitivity for the wind measurement than the previous incoherent edge technique[3] and can provide both aerosol and molecular intensities separately.

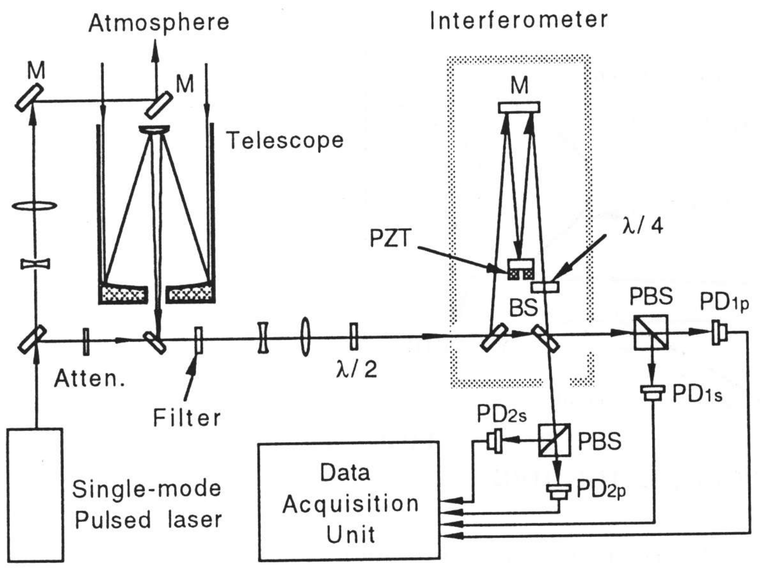

Fig. 3 Block diagram of the incoherent Doppler lidar

The basic system arrangement is shown in Fig. 3 A Mach-Zender interferometer is used as a frequency descriminator of the backscatter signal. The two polarization, differential discrimination method is used . With this interferometer, aerosol Mie scattering and molecular Rayleigh scattering are separately detected, which is not possible in the edge technique. The system parameters of the spaceborne incoherent Doppler lidar is shown in Table 3.

Table 3 Specification of the spaceborne Doppler lidar

Laser wavelngth	1064 nm	532 nm
Pulse energy	1 J	0.2 J
Laser linewidth	60 MHz	120 MHz
Photodetector	Si-APD	PMT
Quantum efficiency	0.05	0.15
Optics efficiency : 0.3 , Receiver area : 1 m^2, Virtical resolution : 100 m		

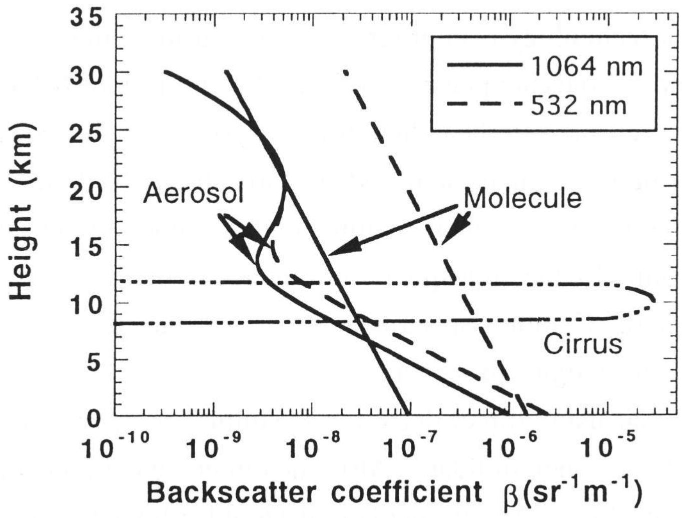

Fig. 4 Backscatter coefficient model.

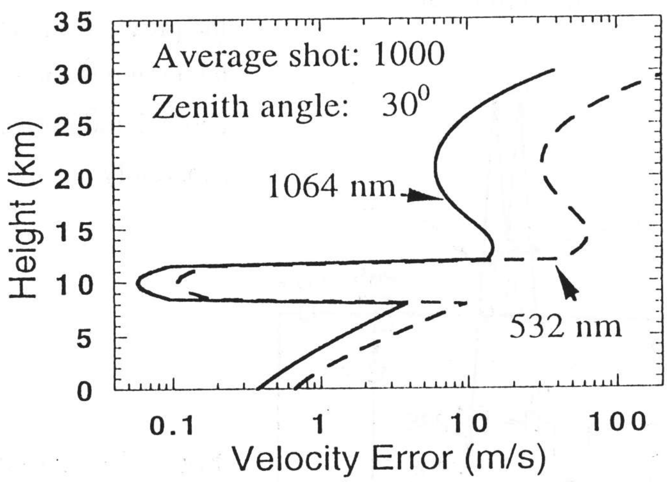

Fig. 5 Estimation of velocity error vs height relation.

The model of volume-backscattering coefficient profile is shown in Fig. 4 and the velocity error vs height relation is calculated and shown in Fig. 5 for the two laser wavelengths of the spaceborne lidar at altitude of 500 km and zenith angle of 30 degree. From these results, higher accuracy can be expected with 1,064 μm laser system. Experimental test of the ground based lidar is in progress.

References

1) "Earth atmosphere observation project", ISAS Earth Atmospheric Observation working group report (Jan.1991)
2) Zhaoyan Liu and Takao Kobayashi: Optical Review, in printing (Nov. 1995)
3) C. L. Korb, B.M. Gentry and V.Y. Weng: Appl. Optics, 31,4203 (1992)

International Workshop on Spaceborne Lidar 1995
- Technology and Applications -
Oct. 24-26, 1995, Nara, Japan

Future Spaceborne Lidar System

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1. Introduction

Observational Needs

2. Metallic Atom Lidar in ATMOS

3. Doppler Lidar for Wind Measurements

ATMOS (Atmospheric Research Satellite Project)

Organization : **ISAS**

Group : **Earth Atmosphere Observation WG**

Scientific Object : ① **Atmospheric chemistry and physics of stratosphere and troposphere**

② **Structure and transition process of mesosphere**

③ **Dynamics of thermosphere and ionosphere**

Satellite : **Total weight : 1370 kg, sensor : 440kg**

: **Altitude : 500km, inclination angle : 98deg**

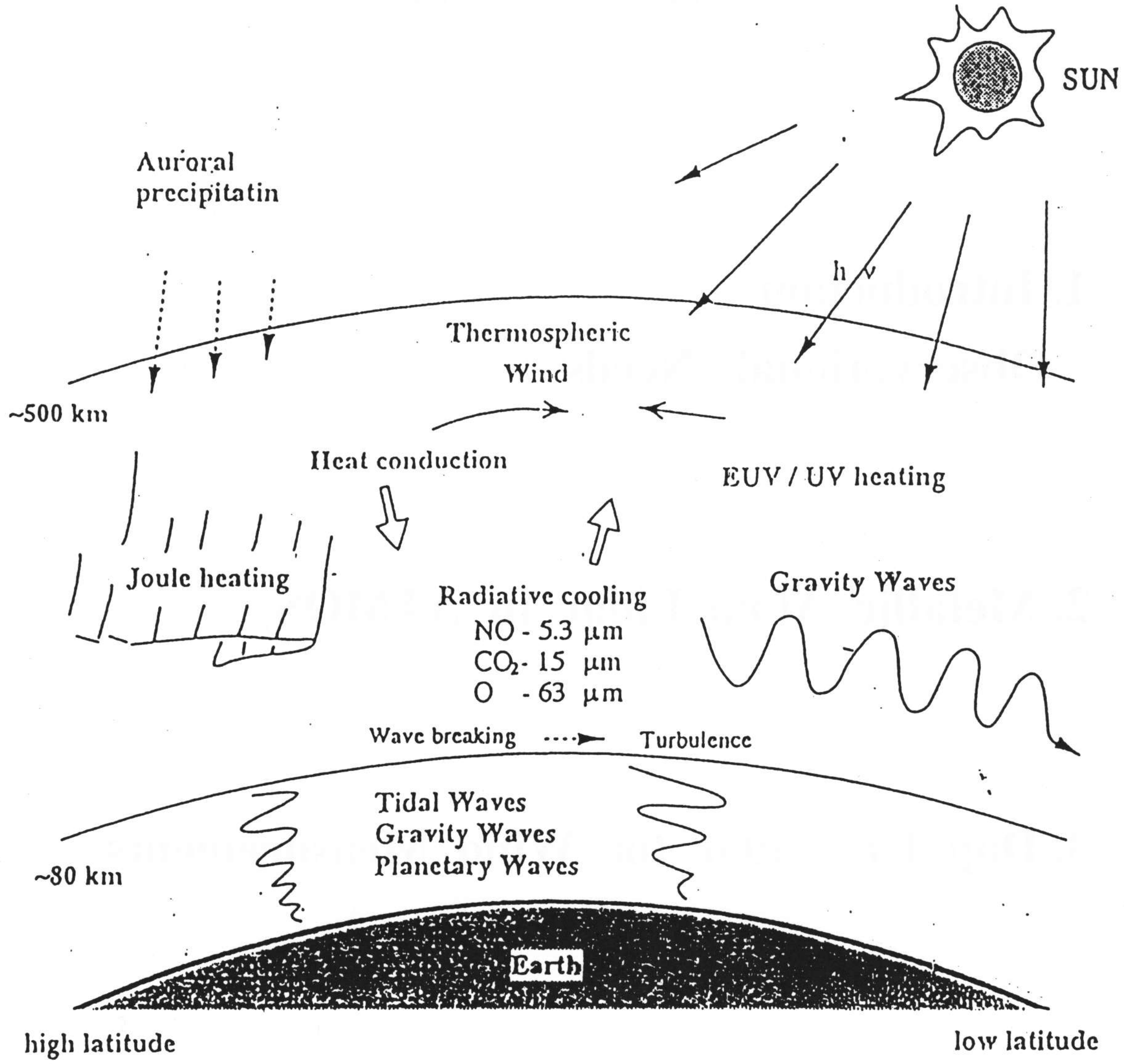


Fig. 1 Energy budget and dynamics of mesosphere and thermosphere (50-500km)

Table 2 ATMOS (Atomspheric Research Satellite Project)

Instrument	Sensing Parameters	Weight (Kg)	Power (W)	Trans-mission (kpbs)
Metallic Atom Lidar (MAL)	Na, K, Fe layers (80-100km) Nocturnal cloud, Pol. Str. Cloud Str. & Tropo. aerosol, Cloud height	145	110	12
Triple Etalon FP-Interferometer (TRP)	Wind & temp. (Strato, meso., Thermophere) O_2 abs. line (<45km), O_2 emission (<60km), OI (100~250km)	20	50	4
OH Airglow Rot. Temp. Radiometer (OHT)	OH airglow, O_2 airglow (1.48~1.54μm Rot. temp.)	8	21	4
Stratosphere Minor Mol. Visible Spect. (SVS)	Stratospheric minor molecule (O_3, H_2O, NO_2)	15	25	8
Semiconductor Laser Heterodyne Spect. (LHS)	Strato. & Mesosph. atm. (O_3, H_2O, NO, NO_2, CH_4, HNO_3, ClO, CFC) Profile	24	60	20
Submillimeter Radiometer (SMS)	Str. middle atm. (O_3, ClO, HOCl, HCl, HO_2, BrO) Profile	63	90	80
Ozone Layer UV Image Spectr. (UVO)	3D-Profile, Str. ozone (250~350nm Scatt. spectr.)	10	10	8
Troposphere Green House Eff. Mol. Sensor (TGS)	Stratosphere (CO_2, CH_4, H_2O, HDO, N_2O)	20	45	36
Solar UV Ep. Intens. Monitor (UVM)	Solar UV (110~400nm) EUV (10Å`110nm) Spect. irrad.	15	15	32
Neutral Atm. Mass Spectr. (NMS)	Thermosphere Particle, Elect. field, Mag. field, Ion, Plasma wave, Electron density	4	12	4
Plasma Environ. Monitor (PEM)	Chirged particle, Elect. field, Mag. field, Ion, Plasma wave, Electron density	50	120	65
Total		374	558	273

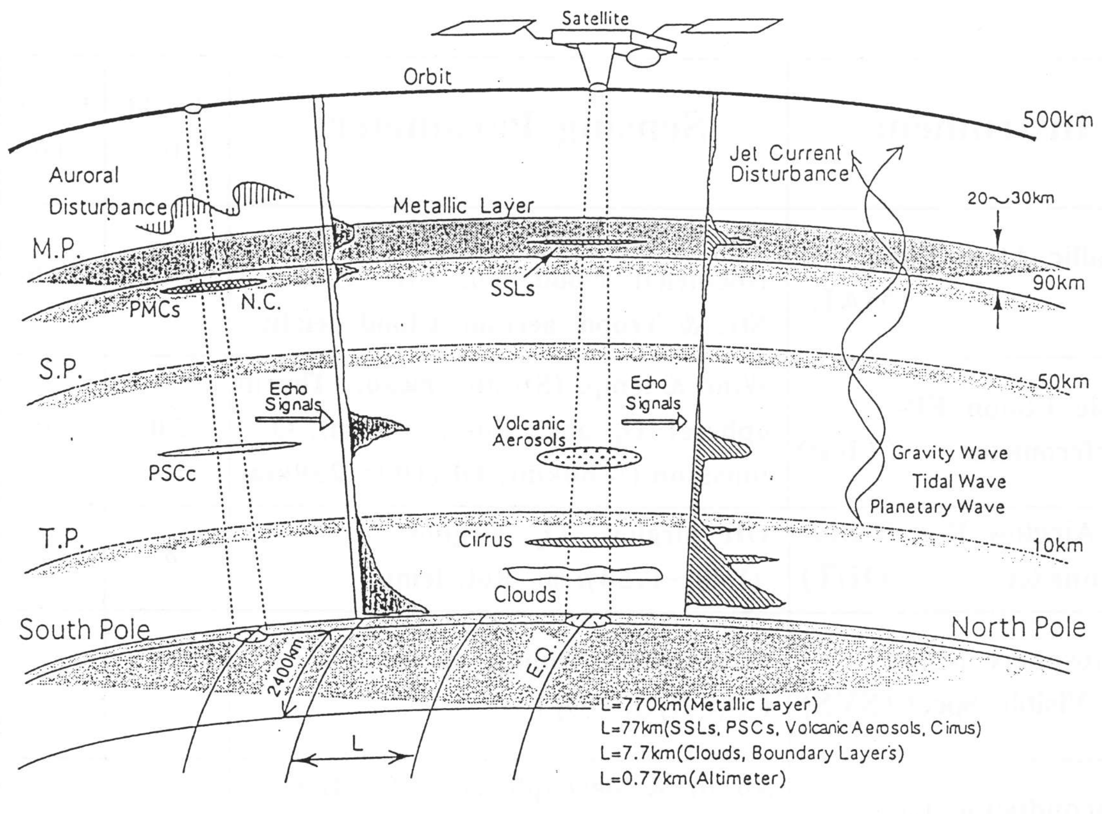
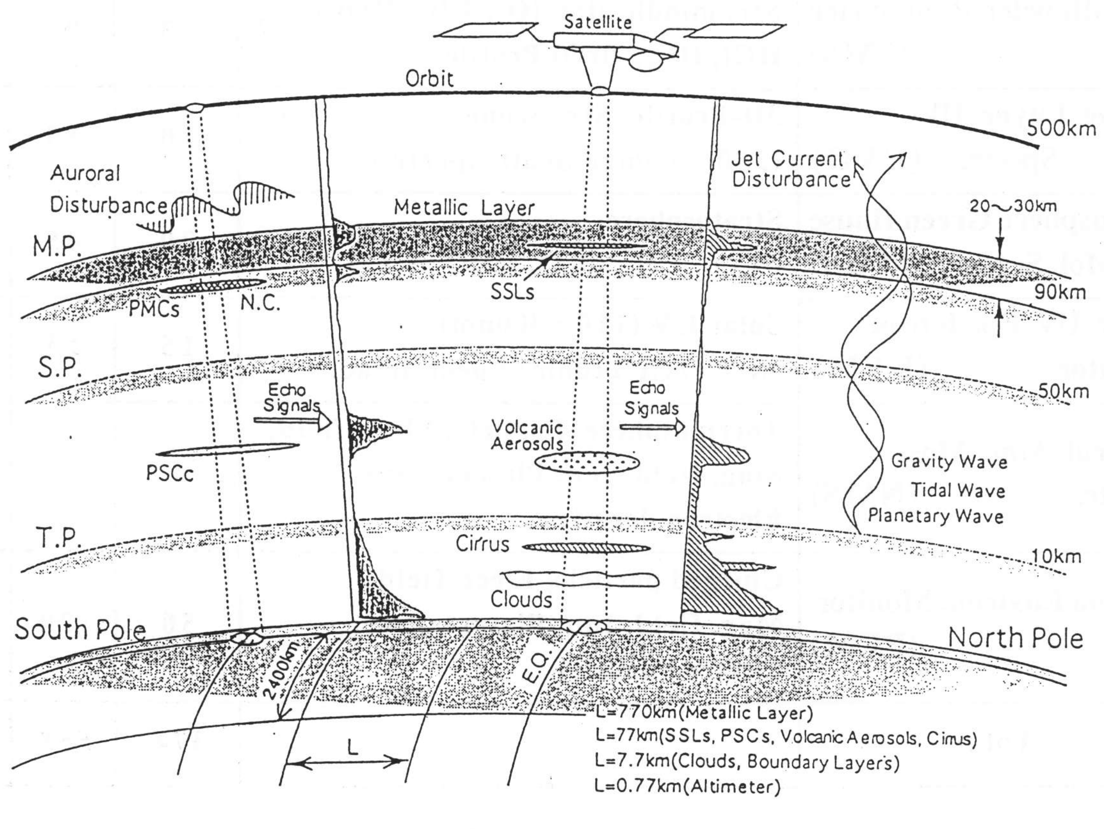


Fig. 2 Observation geometry and targets of the MAL (Metallic atom lidar).



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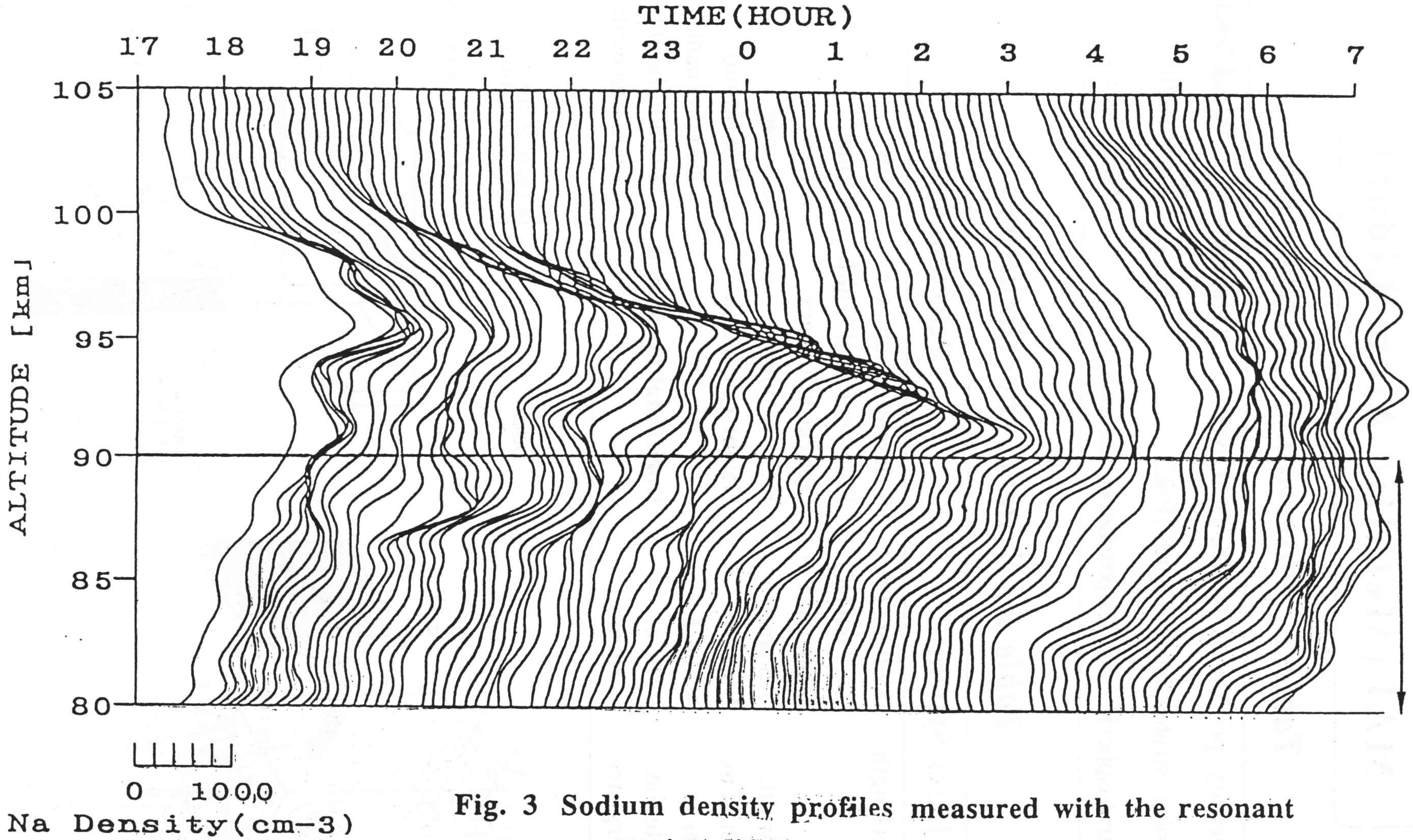


Fig. 3 Sodium density profiles measured with the resonant scattering lidar.
(Dec. 15-16, 1993 by C. Nagasawa and M. Abo)

MAL(Metallic Atom Lidar)

Table 1 Observation Parameters

Density profile of Na, K, Fe Layers	Temperature, Wind Velocity
Polar stratospheric clouds (PSC)	Cloud height
Stratospheric and tropospheric aerosols	PBL height

Table 2 System specifications

Laser System		Detection System	
Laser wavelength	589.0 nm (Na)	Telescope diameter	1m
	769.9 nm (K)	Filter spectral width	< 1nm
	372.0 nm (Fe)	Optical efficiency	> 10%
Spectrum width	< 5 pm	Field of view	< 1mrad
Wavelength stab.	± 0.1 pm	Height resolution	1km (atom)
Output energy	> 50mJ		15m (aerosol)
Pulse repetetion	> 10Hz	Horizontal resolution	< 1000km (atom)
Beam divergence	< 1mrad		< 10km (aerosol)

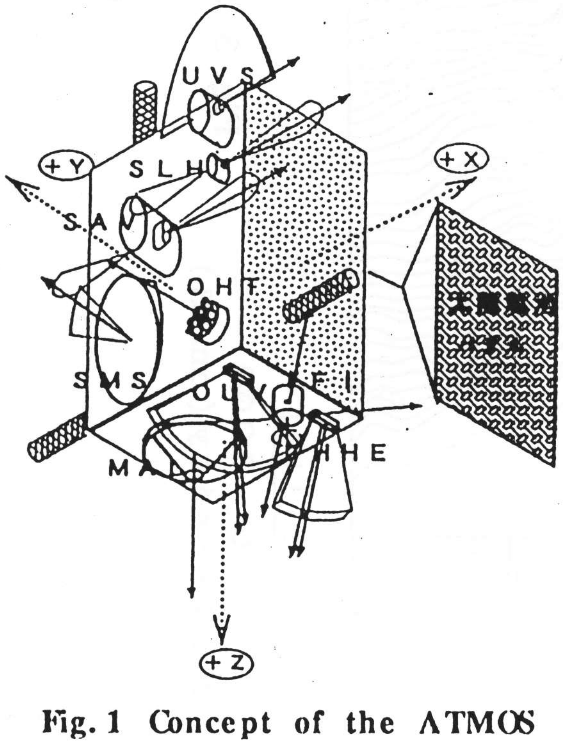


Fig. 1 Concept of the ATMOS

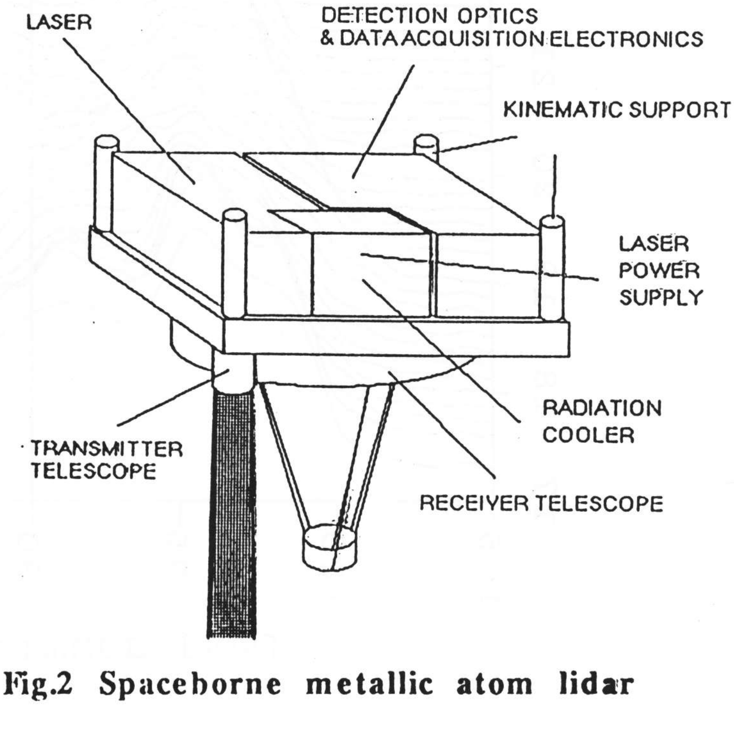


Fig.2 Spaceborne metallic atom lidar

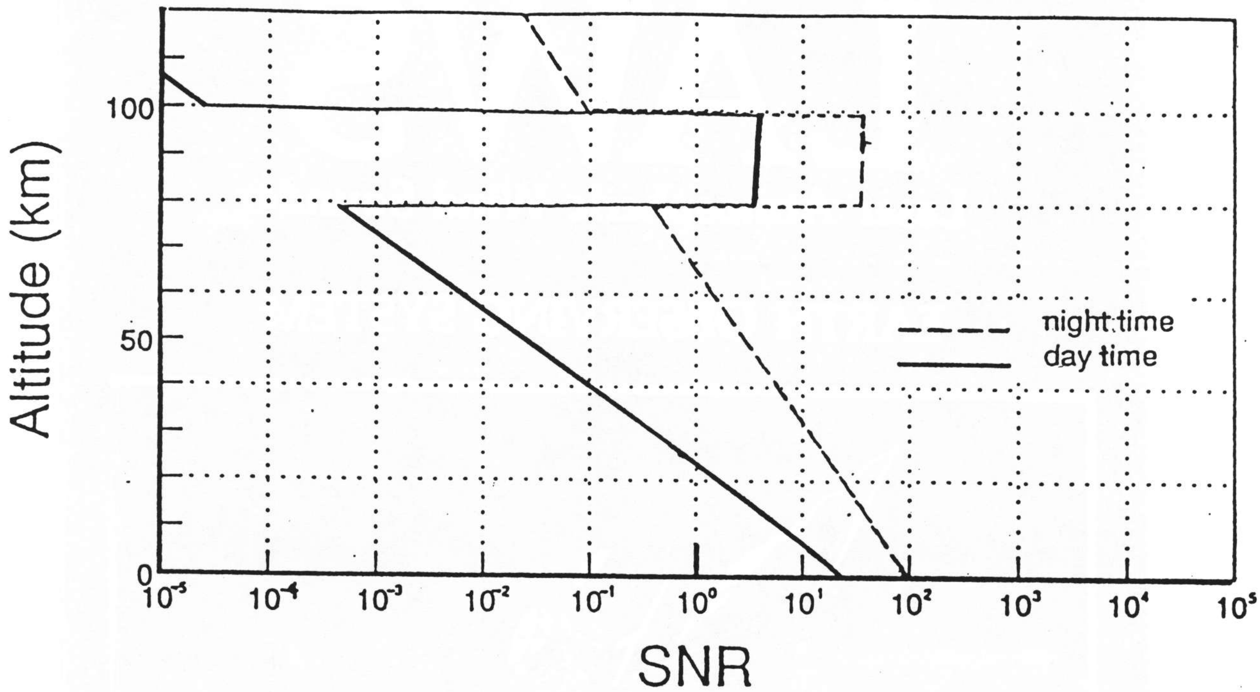


Fig. 3 Na layer observation (single shot)

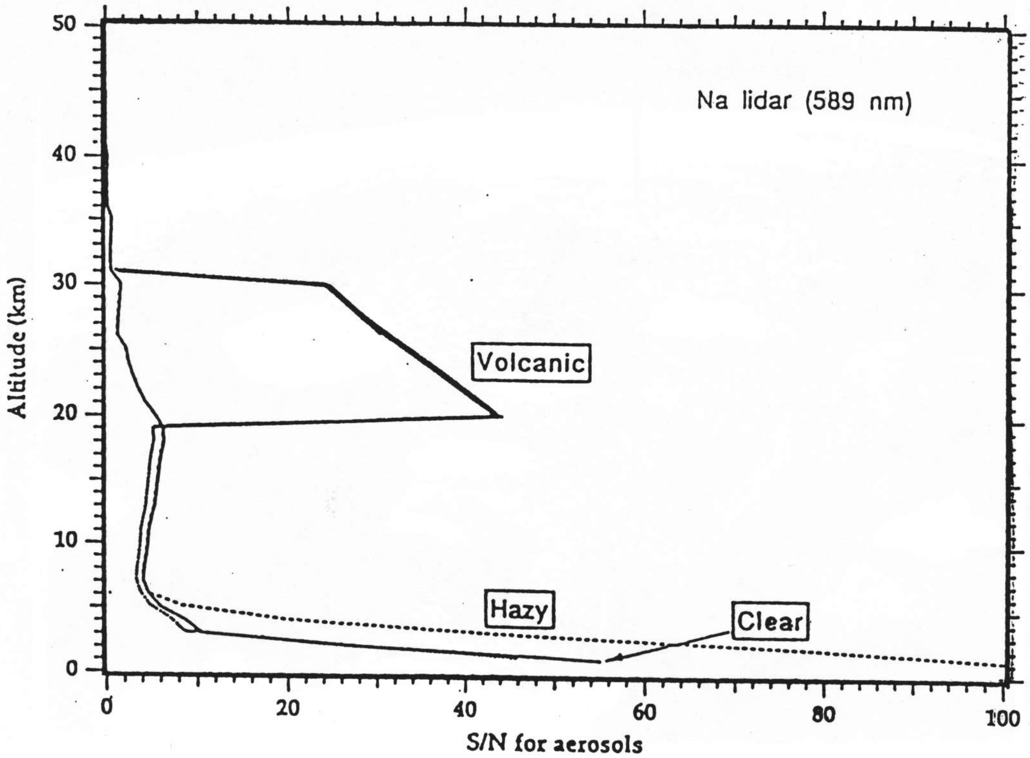
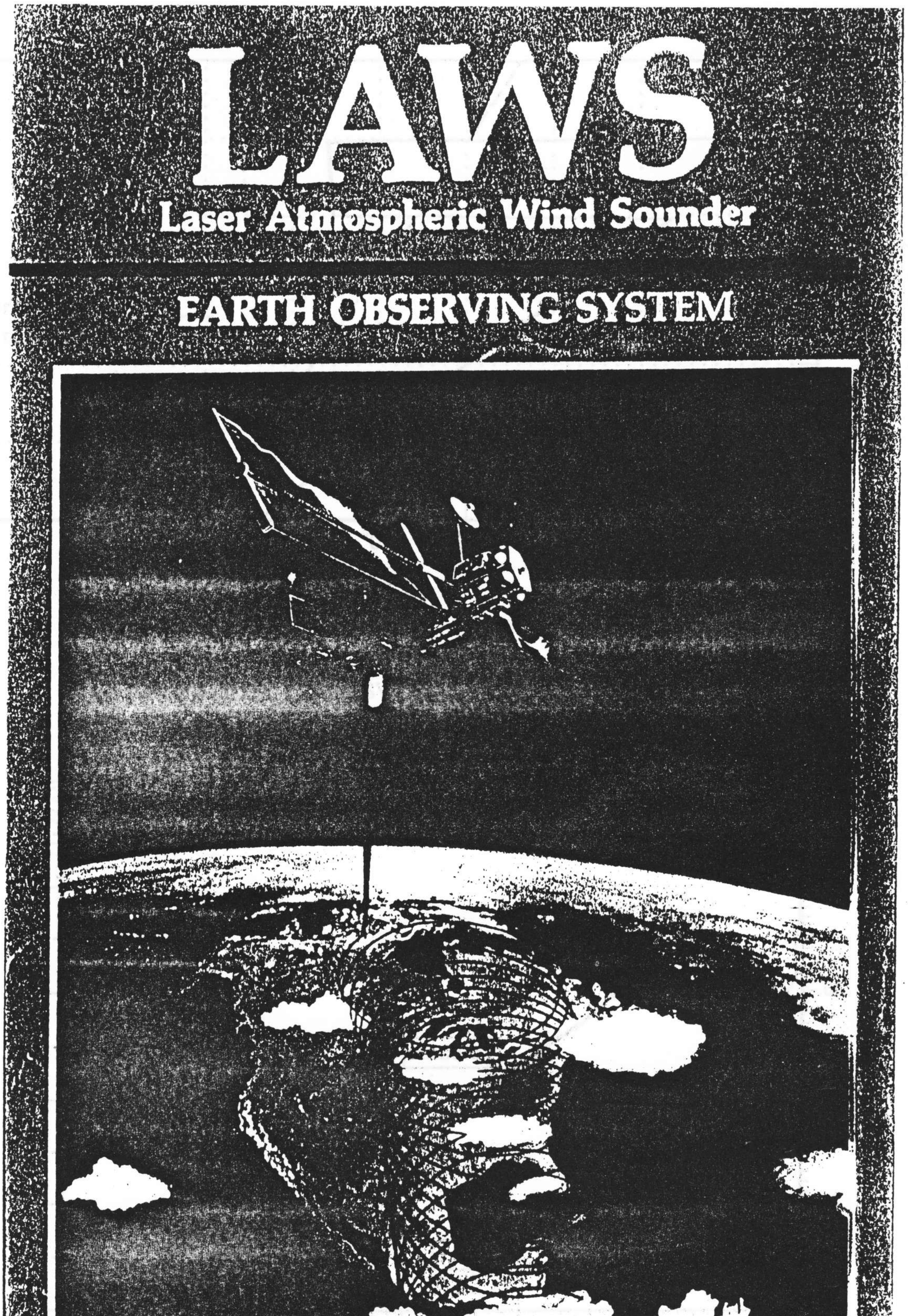
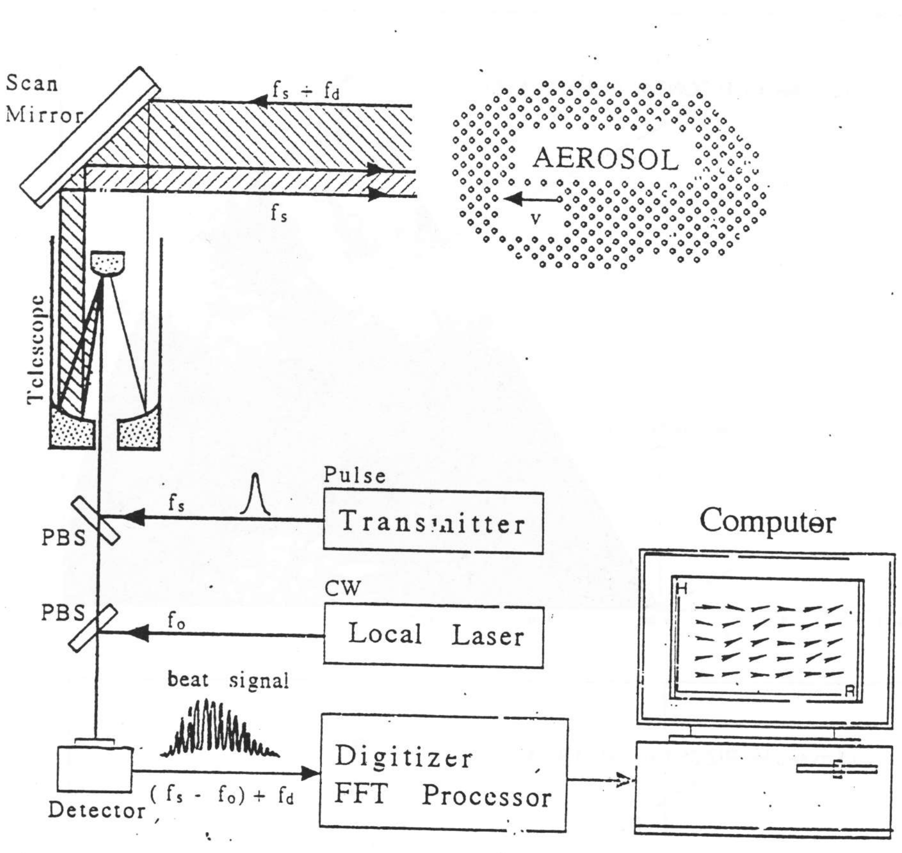


Fig . 4 Cloud, aerosols and molecules observation (single shot)


LAWS
Laser Atmospheric Wind Sounder
EARTH OBSERVING SYSTEM



<u>Range Measurement</u>

$$t = \frac{2R}{c} \cdots\cdots (1)$$

R : distance

t : time

c : optical velocity

$$R = \frac{c}{2} t \cdots\cdots (2)$$

<u>Velocity Measurement</u>

Doppler effect

$$f_d = \frac{2v}{\lambda} \cdots\cdots (3)$$

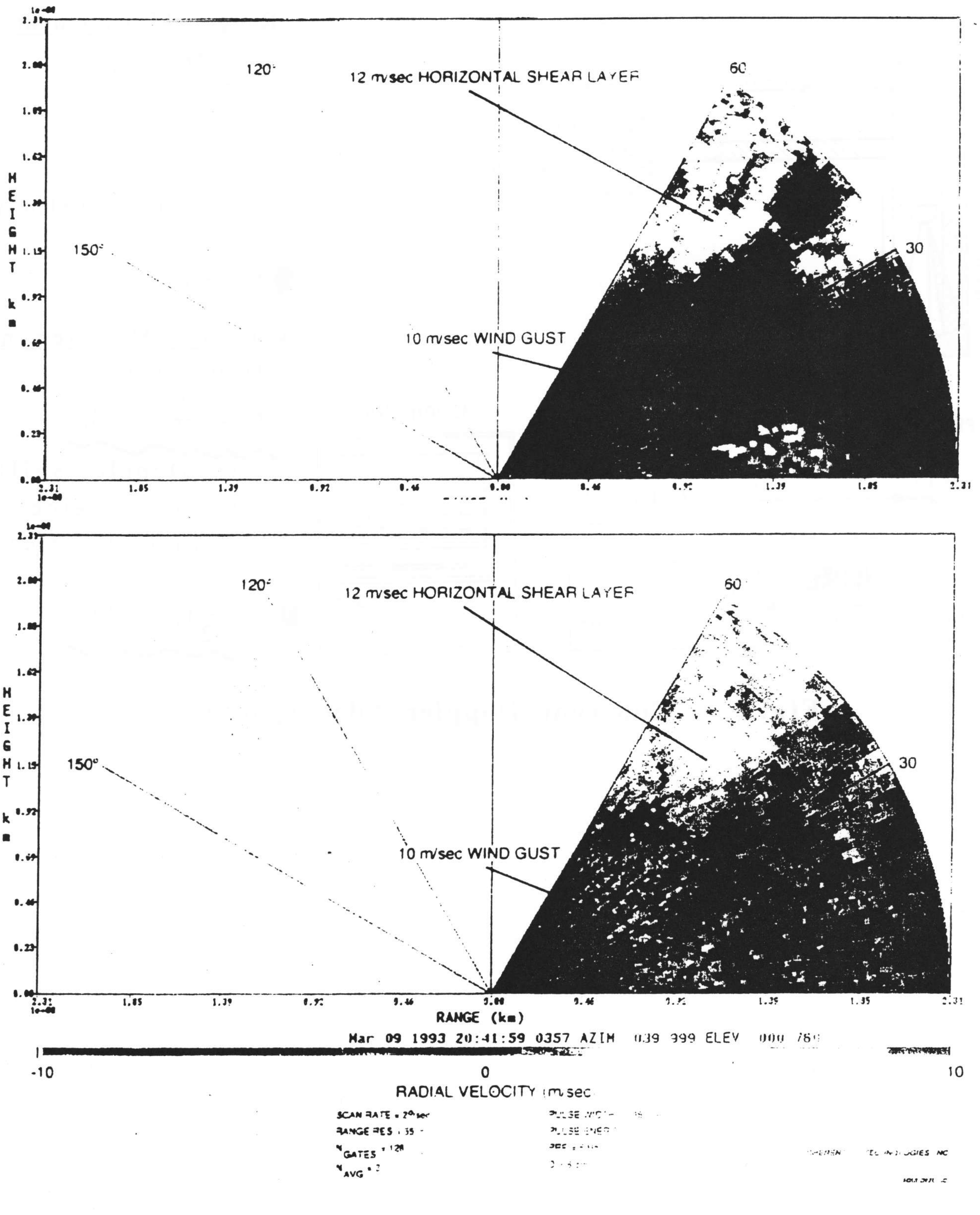
f_d : Doppler shift

v : target velocity

λ : laser wavelength

$$v = \frac{\lambda}{2} f_d \cdots\cdots (4)$$

Fig.1 Coherent Doppler lidar system



RHI @ 40° NEAR COLORADO FRONT RANGE

MEASURED RADIAL VELOCITY - 2 Time Slices Separated By 36 secs.

(POSITIVE AWAY FROM LIDAR)

(**S. M. Hannon and S. W. Henderson.** Coherent Tech. Inc.)

LAWS Parameters

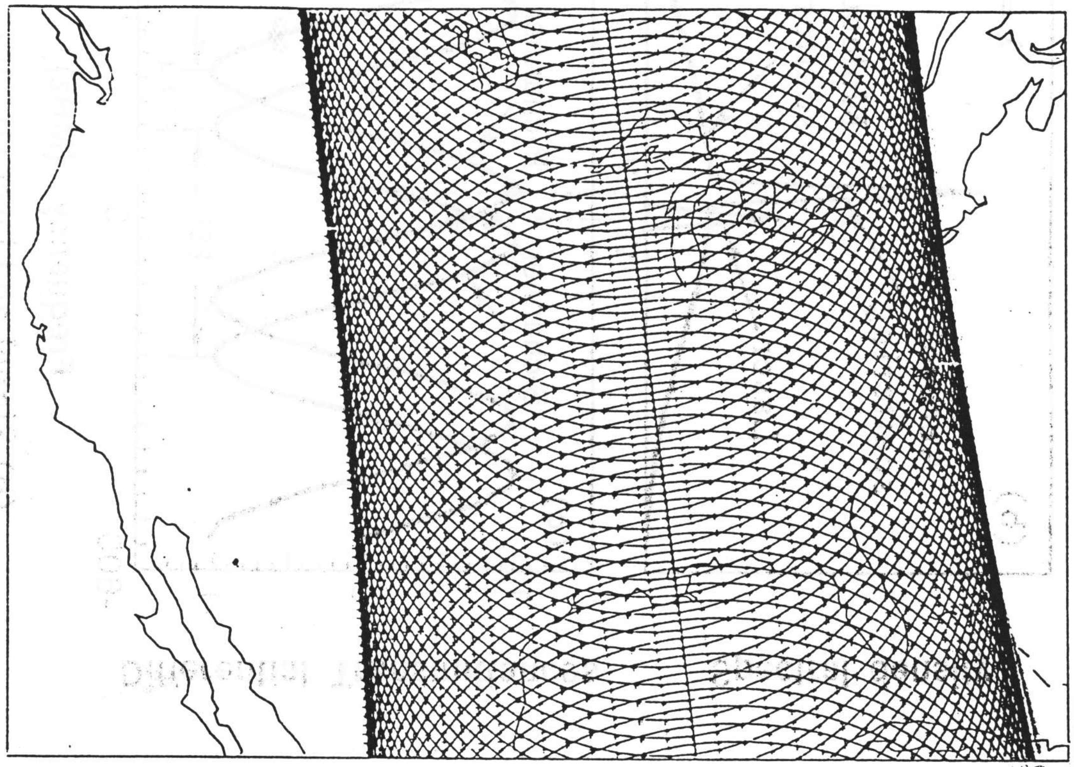


Figure 19. Example of conical scan pattern for a polar-orbiting, space-based Doppler lidar wind profiler as it passes over the Eastern U.S. The satellite height is 800 km, velocity is 7.5 km s⁻¹, scan angle = 56°, PRF = 8 s⁻¹, scan period = 10 s, and modulation amplitude = 0.33 (modulation amplitude is a function which controls the rate of rotation so that shot-pair separation is optimized).

Table 6. Base Parameters

	Space Shuttle Orbit	Near-Polar Orbit
Altitude	300 km	830 km
Target volume (patch)	300 × 300 × 20 km	300 × 300 × 20 km
Nadir angle	62° (600 km reach)	52° (1,200 km reach)
Conical scan period	7 s	19 s
Pulse repetition frequency	8 Hz average	2 Hz average
Wavelength	9.11 μm ($^{12}C^{18}O_2$)	
Telescope diameter	1.25 m	
Pulse duration	6.7 μs	
Optical-detector efficiency	10%	
rms Long-term pointing error	50 μrad	
rms Short-term pointing error	2 μrad	
Local oscillator	50 kHz	

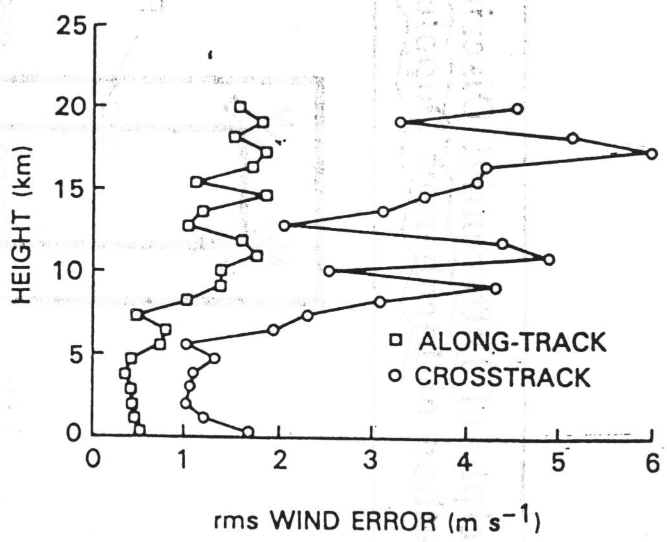
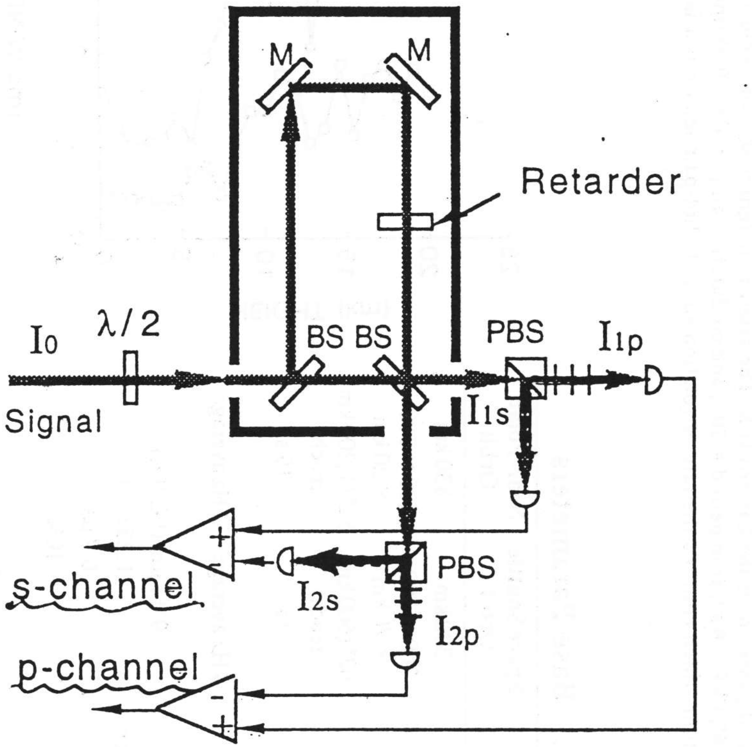
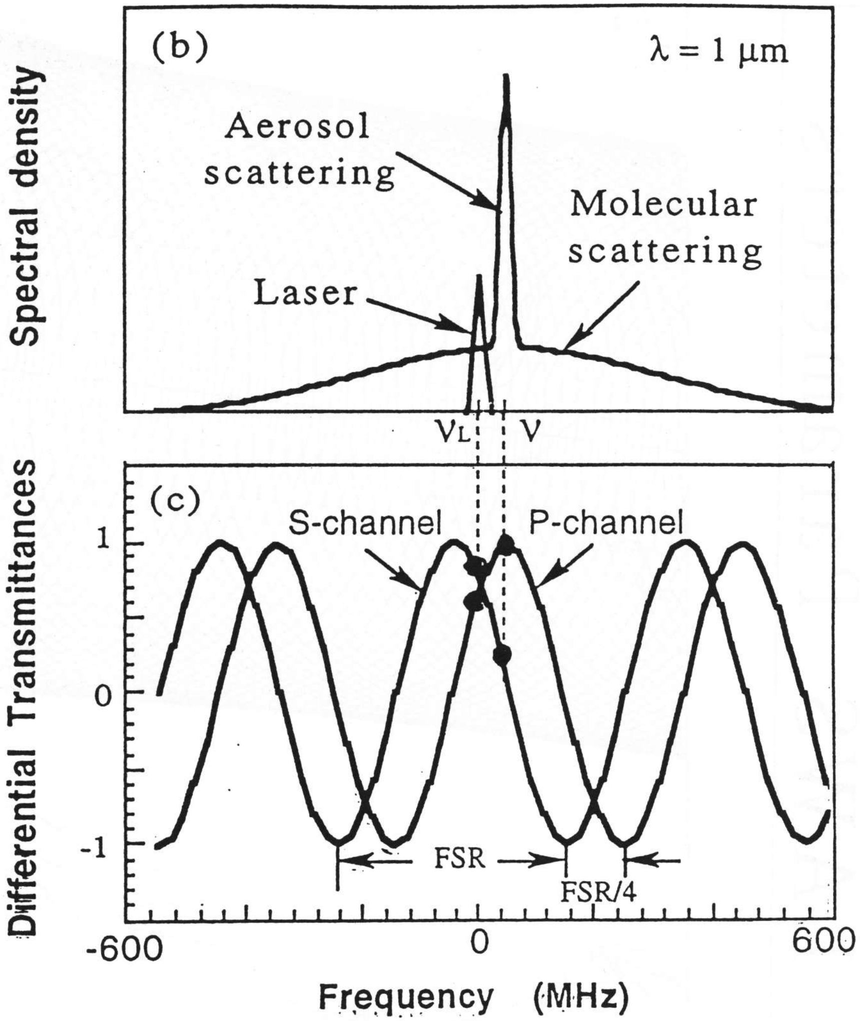


Figure 18. Along-track (a) and crosstrack (b) wind errors determined from advanced TIROS-N performance simulations (1.25 m optics, 10 J laser, 2 pps, 800 km orbit, $\beta = 3 \times 10^{-11} m^{-1} sr^{-1}$ at 10 km altitude).

Principle of Differential Discrimination Method of Incoherent Doppler Lidar



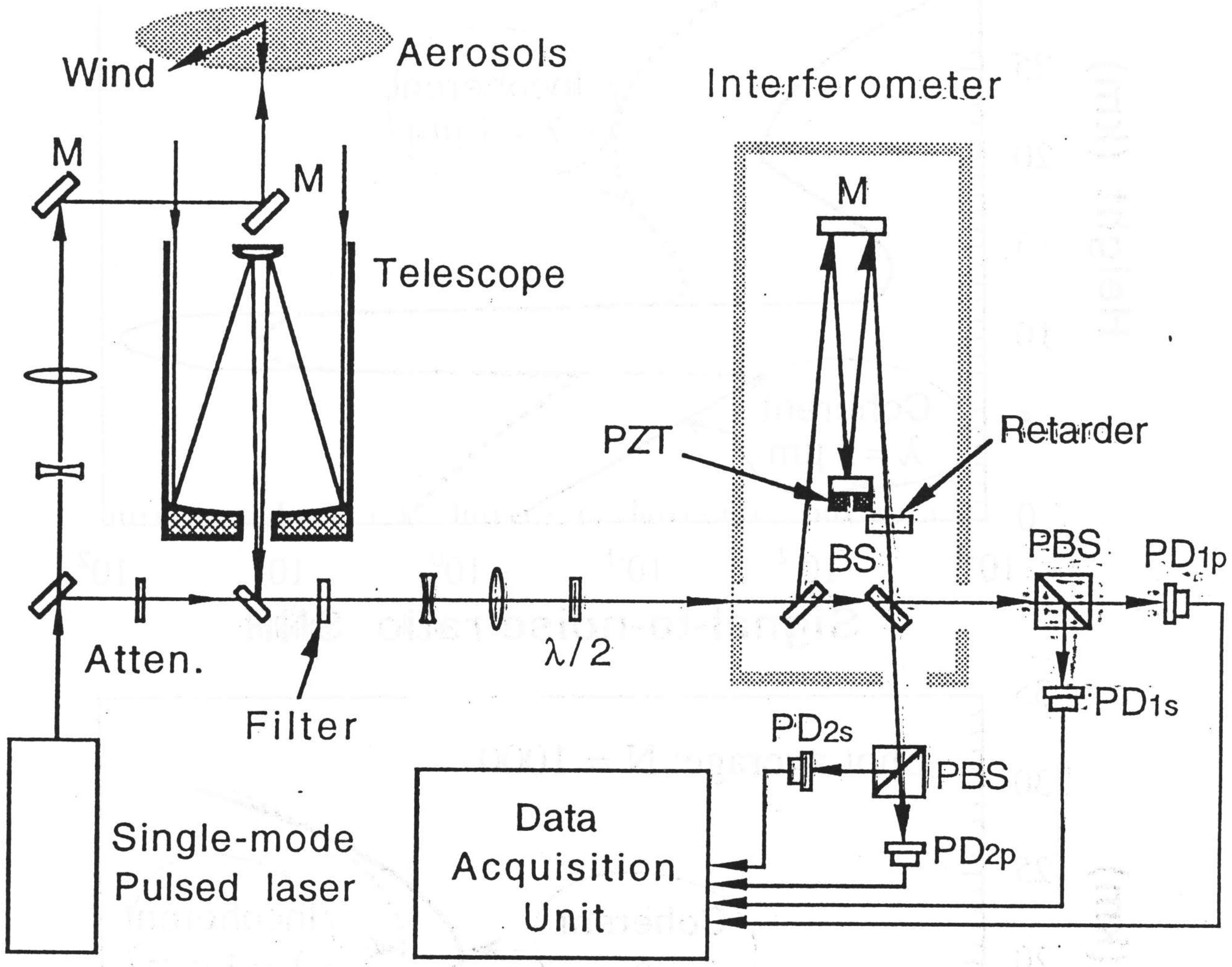
(a) Two-channel Mach-Zehnder Interferometer



(b) Signal and laser spectra

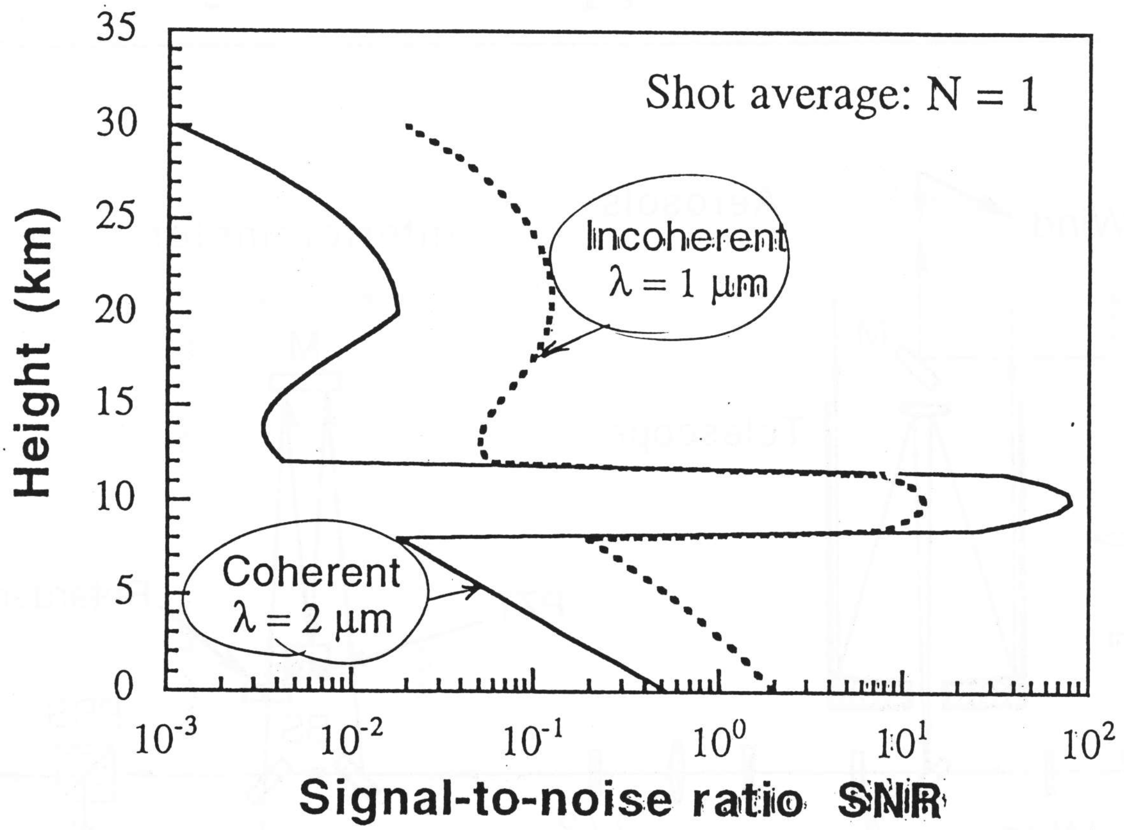
(c) Differential transmittances of the interferometer

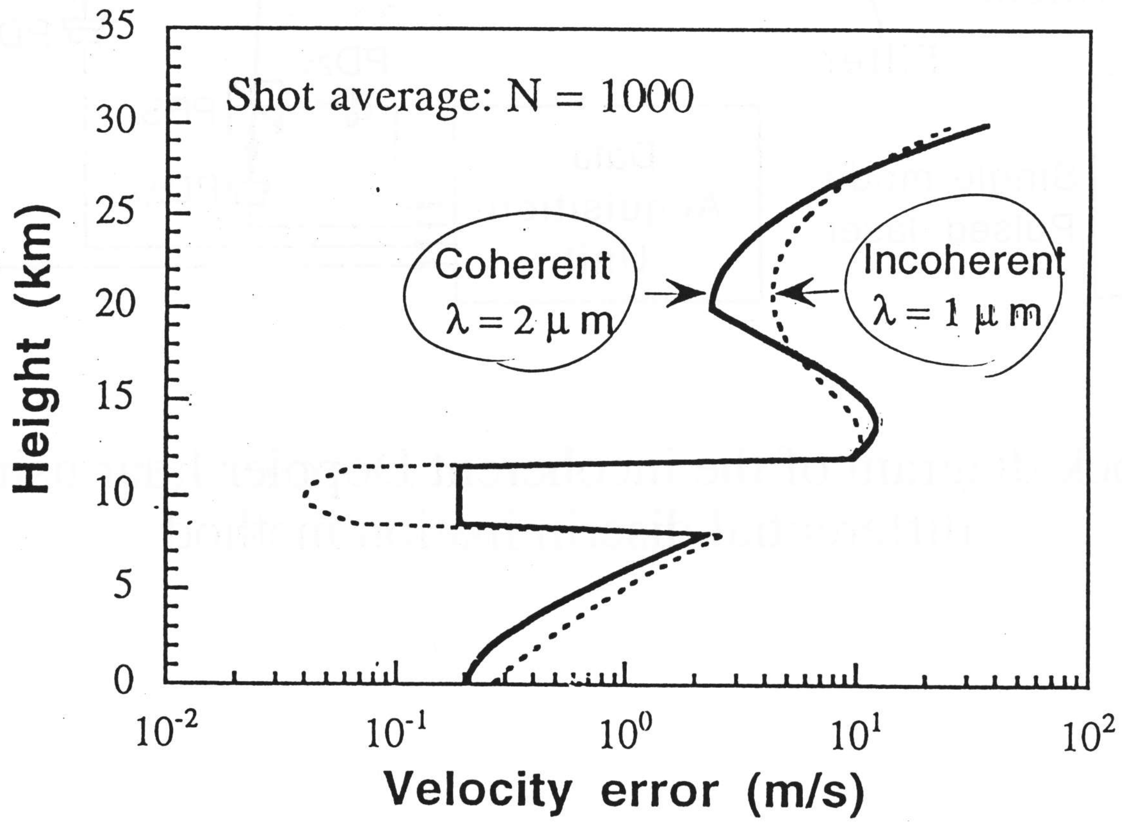
Incoherent Doppler Lidar System



Block diagram of the incoherent Doppler lidar using differential discrimination method

Comparision of SNR and Velocity Error





Atmospheric model

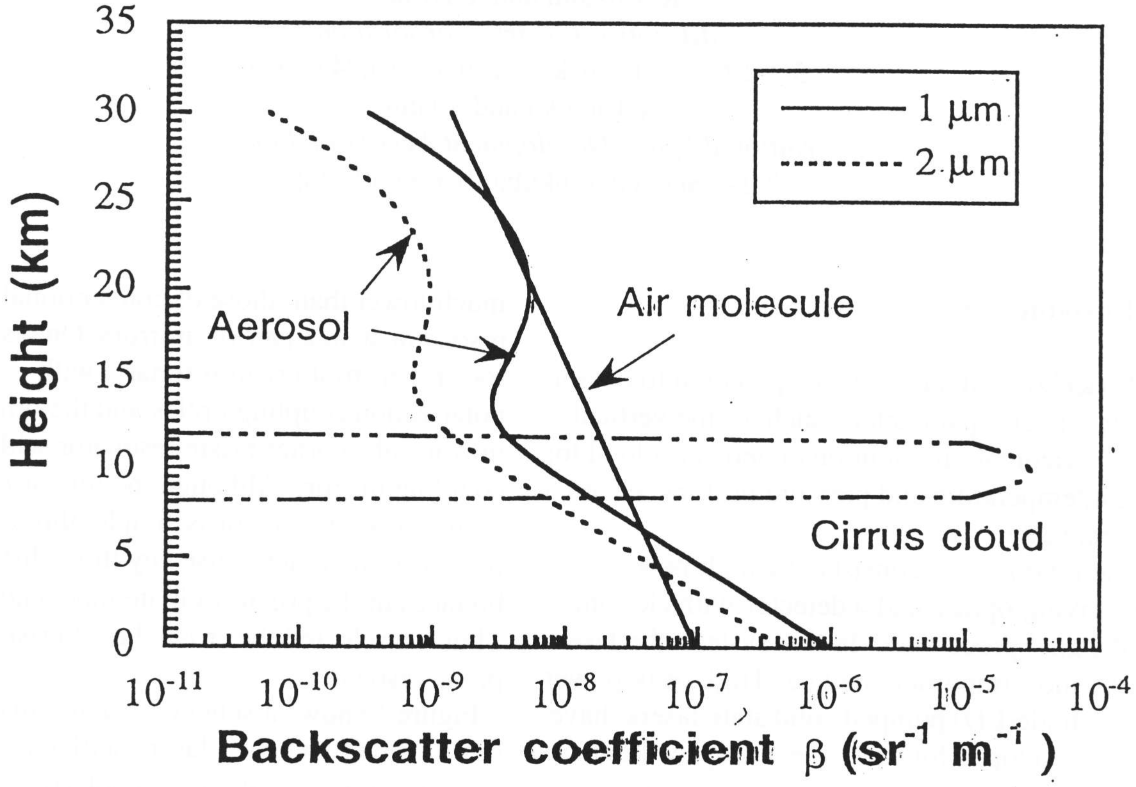


Table System parameters for coherent and incoherent Doppler lidars

Lidar	Coherent	Incoherent
<u>Laser:</u>	2 μm	1 μm
Energy	1 J	1 J
Pulse width	500 ns	10 ns
Spectral width	0.88 MHz	44 MHz
<u>Detection System:</u>		
Telescope diameter	1 m ←	1 m
Optical efficiency	0.3 ←	0.3
Quantun efficiency	0.7	0.15
Range resolution	100 m	100 m
Bandwidth	50 MHz	0.24 MHz