Lidar Network System for Monitoring the Atmospheric Environment in Jakarta City

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A lidar network system consisting of two Mie scattering lidars and one differential absorption lidar was developed to measure the atmospheric environment in Jakarta. The three lidars were installed at three locations in Jakarta to study atmospheric boundary layer structure and transportation of atmospheric pollutants. The Mie scattering lidars employ compact flashlamp pumped Nd:YAG lasers operated at 1064 nm fundamental. They are installed in shelters and directed vertically. One of the Mie lidar has a rotating wedged window for scanning conically to measure wind velocity using a correlation method. The DIAL system employs two Nd:YAG laser-pumped optical parametric oscillators. The DIAL is designed to measure distribution of ozone and SO_2 in the near UV region, and NO_2 in the 450-nm region. The system is installed in a shelter and has a full scanning capability.

Key words: lidar, Mie scattering lidar, differential absorption lidar (DIAL), air pollution monitoring, atmospheric boundary layer, aerosol, NO_2, SO_2, O_3.

1. Introduction

Air pollution in Jakarta is getting worse due to growth of the urban population, the increasing number of cars and traffic congestion, and industrial expansion. Jakarta city faces the Sea of Java to the north, and a typical air pollution phenomenon which is generated by photochemical reactions of pollutants and transportation by a sea/land breeze is believed to be occurring in Jakarta. In fact, a high concentration of ozone is often recorded in an inland part of the Jakarta area. The wind system in Jakarta is a combination of seasonal wind and sea/land breeze. The seasonal wind is westerly in the wet season and easterly in the dry season. During the transition period, this seasonal wind is weak and there is heavy air pollution.

Lidar is known to be an effective tool for measuring the vertical profiles of aerosols and pollutants such as ozone, SO_2 and NO_2.[1,2] A lidar network system consisting of two Mie scattering lidars and one differential absorption lidar was constructed to study the air pollution phenomenon in Jakarta. Mie scattering lidars are for measuring vertical profile of aerosols. One of the Mie scattering lidars has a wedge window conical scanner for measuring wind profile using the time correlation method.[3] The differential absorption lidar (DIAL) system measures ozone, SO_2, NO_2, and aerosols, and has full scanning capability. The two Mie scattering lidars and the DIAL system are controlled from a central data processing system by telephone lines and a local network. Three lidars are installed at three locations along a line perpendicular to the coast to mea-

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sure atmospheric boundary layer structure and transportation of air pollutants by the sea/land breeze.

2. Mie Scattering Lidar System

The two Mie scattering lidars in the network system are for continuous measurement of the aerosol profile in the atmospheric boundary layer. The two lidars have the same design except that one, called Mie-1 has a conical scanner for wind profile measurement. Figure 1 shows a block diagram of the Mie lidar, and their specifications are listed in Table 1. The lidar system is installed in an air-conditioned container as illustrated in Fig. 2.

These lidars employ a compact flashlamp pumped Nd:YAG laser. Fundamental at 1064 nm is used instead of the second harmonics, simply because it is invisible and suitable for operating continuously in an urban area without drawing unnecessary attention. The lidar signal is received with a 25 cm diameter telescope and detected with Si avalanche photodiodes (APD). The receiver has two receiving channels with different sensitivities to cover the wide dynamic range of the lidar signal. The low gain channel is intended to avoid saturation in the cloud measurement. The signals from the APDs are recorded with a two channel 12 bit accuracy analog-to-digital converter (ADC) and transferred to a personal computer (PC). The lidar data is processed on the PC and stored on a hard disk. The PC is linked with a telephone line to the central data processing system described in Sect. 4. In a continuous observation, lidar signals are accumulated typically for 100 seconds (1000 shots) on the PC and stored on the hard disk. The measurement is continued intermittently typically every 10 min.

One of the two Mie lidars in the network has a conical scanner using a wedge prism window for wind measurement by means of the time correlation method.[3] In the wind measurement mode, the scanner is rotated at 2 cycles per second and lidar signals are recorded in 5 slant directions with 10 Hz repetition. The temporal change of the

signals reflects the movement of aerosol distribution pattern across the laser beam. The wind velocity is thus obtained from the temporal correlations between the signals measured in multiple directions.OP
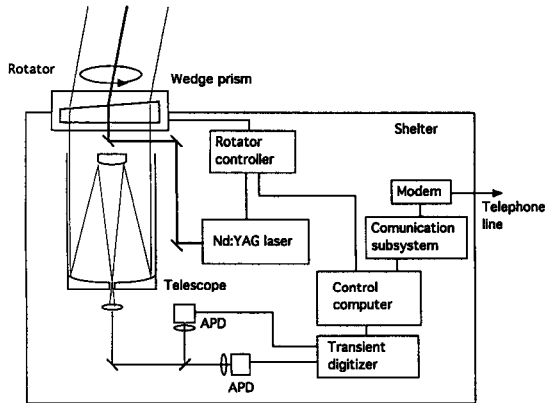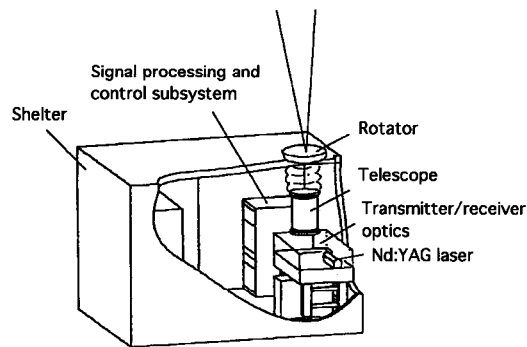

Fig. 1.   Block diagram of the Mie scattering lidar.

Fig. 2.   Structure of the Mie scattering lidar system.

Table 1.   Specifications of the Mie scattering lidars.

Laser	Compact flash lamp pumped Nd:YAG laser
Wavelength (nm)	1064
Output energy (mJ)	300
Pulse repetition (Hz)	10
Receiver telescope diameter (cm)	25
Receiver field of view (mrad)	0.5-2
Filter bandwidth (nm)	10
Detector	Si Avalanche photodiode (APD)
Analog to digital converter (ADC) sampling rate (Msamples/s)	20
ADC accuracy (bits)	12
Conical scanner (Mie-1)	Rotating wedge window with a 5 deg tilt angle
Measurement mode	vertical/conical scan (Mie-1)

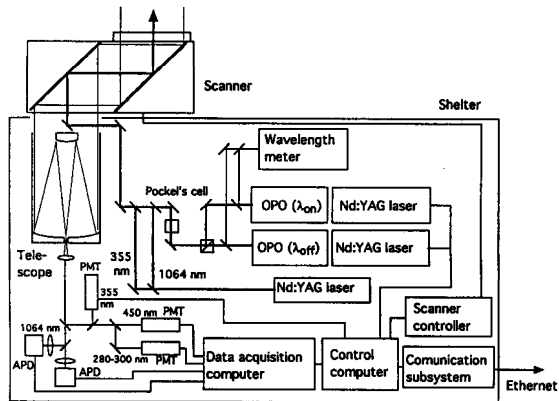

Fig. 3.   Block diagram of the DIAL.

Table 2.   Specifications of the DIAL.

Laser	Nd:YAG laser pumped OPO (Spectra Physics MOPO 730, 2 sets) Compact Nd:YAG (Mie scattering lidar mode)			
Target	O_3	SO_2	NO_2	Aerosol
Wavelength (nm) (on)	280.0	300.05	448.1	1064
(off)	285.0	299.50	446.6	
Differential absorption cross section (m^2)	2.0×10^{-22}	9.8×10^{-22}	2.2×10^{-23}	
Output energy (mJ)	10	10	50	100
Pulse repetition (Hz)	20	20	20	10
Receiver telescope diameter (cm)	25			
Receiver field of view (mrad)	0.5-2			
Filter bandwidth (nm)	10 (or 35)	4 (or 35)	4	9
	Detector Photomultiplier (DIAL) APD (Mie at 1064 nm)			
Analog to digital converter (ADC) sampling rate (Msamples/s)	20			
ADC accuracy (bits)	12			
Scanner	two mirror two axes scanner			
Measurement mode	scan/slant/vertical			

3. Differential Absorption Lidar System

The DIAL system employs two commercial Nd:YAG laser-pumped optical parametric oscillators (OPO; Spectra Physics MOPO 730). The OPOs using β-BaB$_2$O$_4$ (BBO) crystals are pumped by the third harmonics of the Nd:YAG lasers. The DIAL is designed for measuring distribution of ozone and SO$_2$ in the 300 nm region, and NO$_2$ in the 450 nm region. Figure 3 shows a block diagram of the DIAL system, and its specifications are summarized in Table 2. The output wavelength of the OPOs is switched depending on the target molecules. In the NO$_2$ measurement, the two OPOs are operated in the 450 nm region; in the measurement of ozone and SO$_2$, the OPOs are operated in the 600 nm region, and the outputs in the 300 nm region are generated by the second harmonics. The beams from the two lasers are combined with a polarization coupler. Pockel's cell is used after the beam combiner for rotating the polarization of one of the laser beams by 90 deg to obtain the same polarization for both wavelengths. This feature is necessary for the future incorporation of an electrooptical shutter in the receiver optics. The combined beam is collimated by a beam expander and transmitted coaxially to a 25-cm receiver telescope.

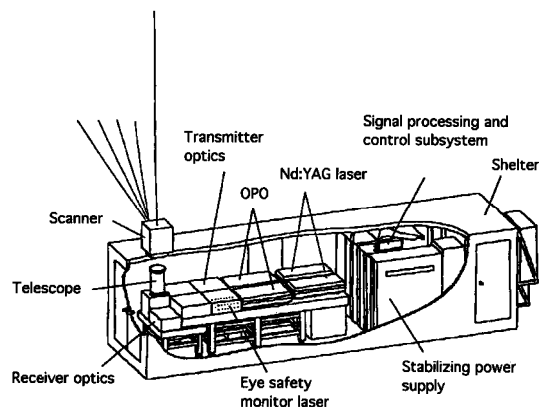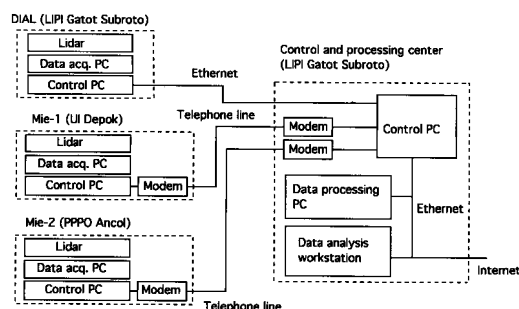The receiver system has two photomultipliers for the 300 nm and 450 nm regions. Inteference filters which cover on and off wavelengths are used for the DIAL measurements. The bandwidth is 4 nm for SO$_2$ and NO$_2$. The filter for ozone has a wider bandwidth of 10 nm because the difference of on and off wavelengths is larger. A broadband filter with a wide bandwidth of 35 nm is used for the nighttime measurement of ozone and SO$_2$. Electrical gating of the photomultipliers is employed to reduce their signal induced noise. The received lidar signals are recorded with a 12 bit accuracy ADC, transferred to a PC and stored on a hard disk. The DIAL system is linked to the central data processing system by a local network. The system is installed in a container as illustrated in Fig. 4, and has full scanning capability.

Another feature of the DIAL is the use of a low power laser at 355 nm for detecting obstacles to ensure eye safety during scanning measurements. The 355 nm beam is transmitted with a wider divergence of 2 mrad before transmitting beams from the OPOs. When an obstacle is detected at 355 nm, the OPO outputs are automatically shut off. The Nd:YAG laser is also used in the Mie scattering lidar mode to observe the vertical profile of aerosols at a wavelength of 1064 nm; two APDs are used in this Mie lidar mode operation.

4. Central Data Processing System

The three lidar systems are controlled from a central data processing system. The measured data are also transferred to this system and analyzed. Figure 5 shows a block diagram of the system which consists of an engineering work station and a PC. The workstation has a 10 Gbytes hard disk. The DIAL system is linked to the ethernet, and the two Mie scattering lidars are linked by telephone lines. In remote operation mode, the measured data are automatically transferred to the hard disk of the central workstation. The data stored on the hard disk is then processed and analyzed by the work station and the PC.

Fig. 4. Structure of the DIAL system.

Fig. 5. Block diagram of the central data processing system.
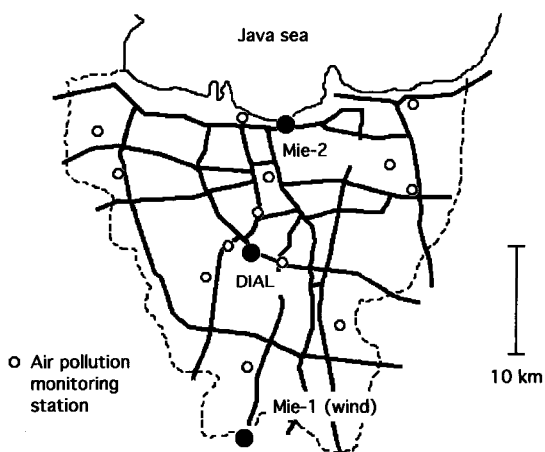

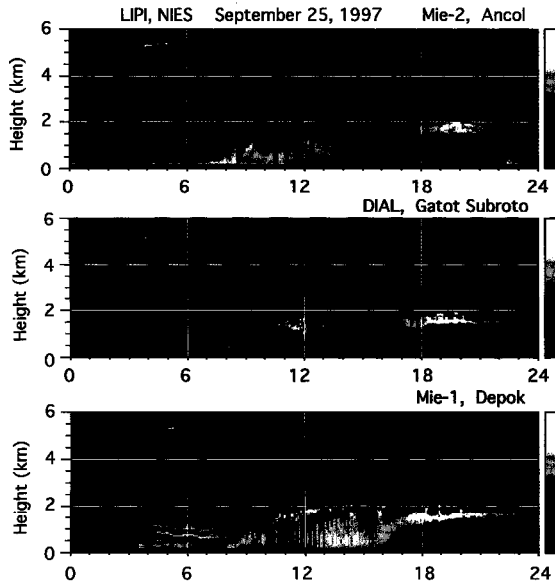Fig. 6. Map showing the three lidar locations in the city of Jakarta.

Fig. 7.   Diurnal variation of boundary layer structure measured with the lidar network system. Range-corrected lidar signal is indicated with a color scale.

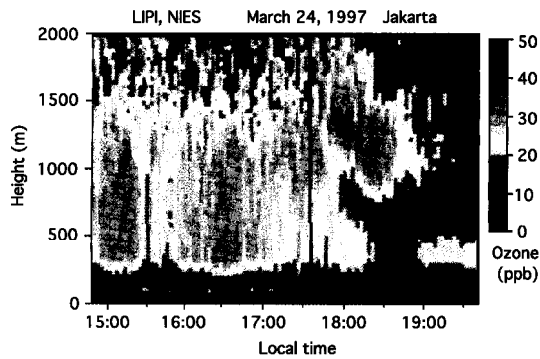Fig. 9.   Distribution of NO_2 measured with an azimuth scan with the DIAL.

Fig. 8.   Temporal variation of vertical profile of ozone measured with the DIAL. Concentration derived with the DIAL equation is indicated with a color scale.

5.   Results of Initial Experiment Using the Lidar Network System

The lidar network system was completed in Jakarta in March 1997, and observations were begun. Figure 6 shows a map with the locations of the three lidars, and an example of the network observation of aerosol vertical profiles at the three locations is shown in Fig. 7. The DIAL was operated in the Mie lidar mode in this observation. Range-corrected lidar signal which is approximately proportional to aerosol concentration is indicated with a color scale. Brighter color indicates higher aerosol concentration. Aerosol concentration is usually high in the atmospheric boundary layer which is the layer up to approxi-

mately 2 km above the ground, and the aerosol distribution reflects the structure of this layer. A typical diurnal variation of the boundary layer is observed in this example in Fig. 7. It was a fine calm day in the dry season, and it can be seen that the maximum mixed layer height at around noon is higher at the Mie-1 site which is located inland. Difference in the variation of aerosol profiles at the three locations infers that the sea/land breeze also affects the transportation of pollutants. The structure with a lower aerosol concentration seen at around 17:00 is a sea breeze front which moved inland. The result demonstrates the usefulness of the network observation to analyze the spatial structure and the movement of the atmosphere which is closely related to the air pollution phenomenon.

Figure 8 shows an example of DIAL measurement of ozone. Temporal variation of the ozone profile is indicated with a color scale. The weather was fine and calm. A relatively high concentration of ozone probably formed by photochemical reaction was observed in the atmospheric boundary layer. Clean air came in probably with a sea breeze at about 18:00.

The measurement errors of the DIAL were experimentally evaluated by tuning both lasers to the same wavelength. The error was estimated from the derived concentrations as the deviation from zero. The estimated sensitivity was approximately 10 ppb both for ozone and NO_2 at a distance of 2 km when the number of the signal average was 1000. This was close to the result of the computer simulation carried out in the design stage.

An example of the scan measurements of NO_2 is shown

in Fig. 9. The direction angle of the scanner was from 270 to 360 deg with an elevation angle of 20 deg. Lidar signals were averaged 1000 times for each direction. It was a fine day, and the wind speed was low. A high concentration of NO_2 is observed above the road.

6. Conclusions

The performance of a lidar network system constructed to measure air pollution in Jakarta was demonstrated. The observations of the distribution of aerosols and the pollutants have been started to study the air pollution phenomenon over the city, with one purpose being to determine the structure of the atmospheric boundary layer over a city in a tropical area. Diurnal variation of this structure with a strong convection and its movement with the sea/land breeze is a target of the study. It will also be interesting to observe the difference of the boundary layer structure in the wet and dry seasons. Study of the movement of air pollutants by comparing the boundary layer structure with the data from conventional ground-based air pollution monitoring equipment in Jakarta city is also valuable.

References

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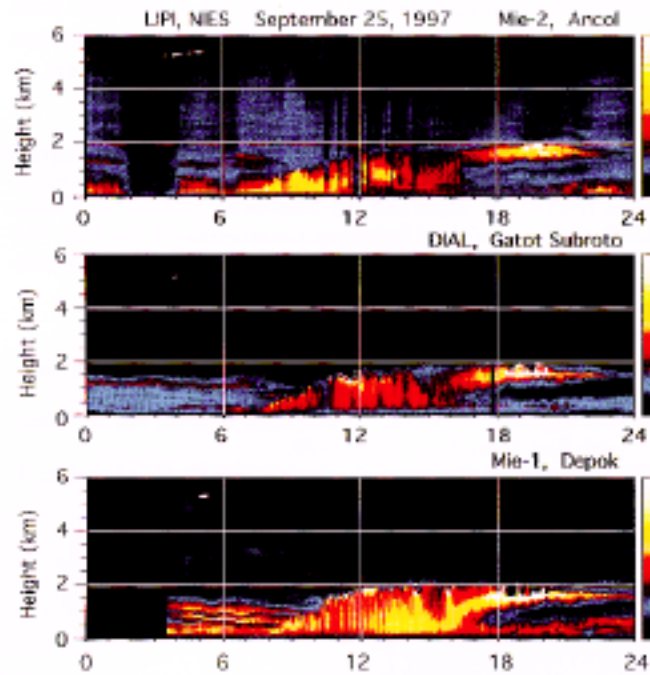
Fig. 7.   Diurnal variation of boundary layer structure measured with the lidar network system. Range-corrected lidar signal is indicated with a color scale.

Fig. 9.   Distribution of NO_2 measured with an azimuth scan with the DIAL.
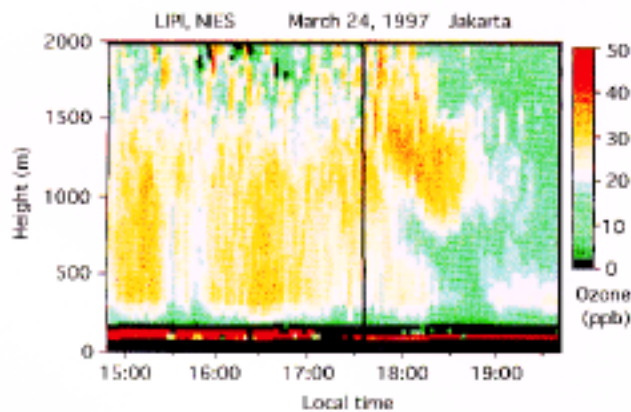

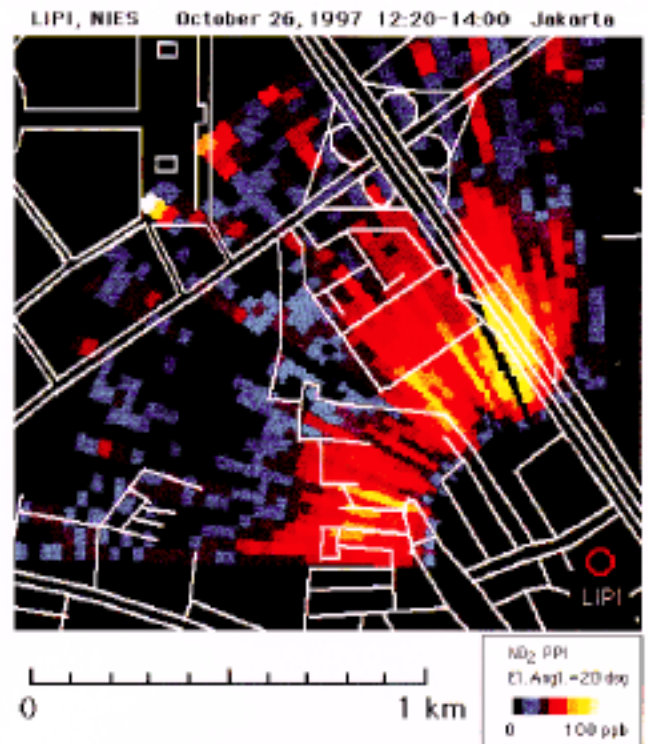Fig. 8.   Temporal variation of vertical profile of ozone measured with the DIAL. Concentration derived with the DIAL equation is indicated with a color scale.