Atmospheric turbidity estimated from visual range with microphysics and active remote sensing data at SKYNET sites

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Abstract

Aerosol has a crucial role in earth radiation budget on a global scale as well as in a source of air pollution on a regional scale. We investigated atmospheric visual range with aerosol particle size and extinction coefficient using in-situ observation and ground-based remote sensing data to estimate the atmospheric turbidity. In this study, we analyzed the data observed at two SKYNET sites, Fukue-jima (32.6°N, 128.8°E) and Amami-oshima (28.2°N, 129.2°E) islands from 2003 to 2004. Both islands are considered as the best sites to observe the aerosol all through the year because they are located at downwind region where we can observe the Asian aerosol with little influence of local pollution. We have several kinds of in-situ observations and remote sensors at both islands, such as Optical Particle Counter (OPC), LIDAR, skyradiometer, and so on. We estimated the extinction coefficient from OPC and LIDAR measurement data to compare it with atmospheric visual range data obtained by eye observation. We made detailed match-up data analyses based on the report of the atmospheric visual range by Japan Meteorological Agency. We obtained the following results: 1) there is a consistent relationship between OPC and LIDAR measurements, related to the atmospheric visual range; 2) a coefficient in the theoretical relationship between extinction coefficient and atmospheric visual range are consistent to the previous studies; 3) the coefficient is more than double when the atmospheric visual range is less than 10 km. These results suggest that aerosol ground-based measurements with atmospheric visual range observation could provide an index of atmospheric turbidity statistically.

Keywords **:** Atmospheric turbidity, Visual range, OPC, LIDAR, SKYNET

1. Introduction

Aerosol has a crucial role in earth radiation budget on a global scale as well as in a source of air pollution on a regional scale. We investigated atmospheric visual range with aerosol particle size and extinction coefficient using in-situ observation and ground-based remote sensing data to estimate the atmospheric turbidity.

2. Observation data

In this study, meteorological observation data, LIDAR and Optical Particle Counter (OPC) data were used to evaluate the atmospheric turbidity at two SKYNET sites, Fukue-jima (32.4°N, 128.4°E) and Amami-oshima (28.2°N, 129.2°E) islands from 2003 to 2004. Both islands are considered as the best sites to observe the aerosol all through the year because they are located at downwind region where we can observe the Asian aerosol with little influence of local pollution.

Weather conditions and visual range (km) data are provided by Japan Meteorological Agency (JMA) for public use. These meteorological observation data are available from Jan. 2003 to Dec. 2004. In this study, non rainy day and daytime observation (6:00, 9:00, 12:00, 15:00, and 18:00 JST) were used to a make match-up dataset.

LIDAR aerosol extinction coefficient profiles are kindly provided by National Institute of Environmental Studies (NIES)[1)]. These profiles are available from surface to 5970m altitude every 30m from Jan. 2003 to Nov. 2004. We estimated average aerosol extinction coefficients for the lower atmosphere.

OPC data were kindly provided by Chiba University. Particle number per Litter was observed every ten minutes with particle diameter (d in μm) bins: $d \geq 0.3$, $d \geq 0.5$, $d \geq 1$, $d \geq 2$, and $d \geq 5$. These archived data is available from Feb. 2003 to Dec. 2004.

3. Methodology

Generally, meteorological visual range V in km is inversely proportional to atmospheric extinction coefficient σ in km^{-1} as

$$V = \frac{1}{\sigma} \ln \frac{1}{\varepsilon}, \quad (1)$$

where ε is a is threshold of human eye sensitivity for black object[2]. World Meteorological Organization (WMO) recommends 0.05 as ε, for example[3]. In this case, the recommend relationship by WMO is expressed as

$$V = \frac{3.00}{\sigma},$$

which is equivalently expressed as

$$\sigma_{inv} = 0.333V, \quad (2)$$

where σ_{inv} is an inverse of atmospheric extinction coefficient σ. There is other relationship based on the observation[4]

$$\sigma_{inv} = 0.526V. \quad (3)$$

It seems that different proportional coefficients in Eqs. (2) and (3) are relevant to atmospheric condition as well as human eye sensitivity.

In this study, we investigated the relationship between the inverse of the extinction coefficients σ_{inv} derived from LIDAR or OPC measurements and visual range V:

$$\sigma_{inv} = S \cdot V. \quad (4)$$

That is, linear regression curve with zero intercept is estimated with a least square analysis. We discuss the slope S of the regression line in terms of the data with visual range V less than 10 km as well as all match-up data.

Spectral atmospheric extinction coefficients σ_λ are estimated with following relationship

$$\sigma_\lambda = \sigma_{a,\lambda} + \sigma_{m,\lambda} + \sigma_{w,\lambda} + \sigma_{O_3,\lambda} + \sigma_{x,\lambda}, \quad (5)$$

where $\sigma_{a,\lambda}$, $\sigma_{m,\lambda}$, $\sigma_{w,\lambda}$, $\sigma_{O_3,\lambda}$ and $\sigma_{x,\lambda}$ are the spectral extinction coefficients of aerosol, molecular scattering, water vapor, ozone, and other gases, respectively.

The aerosol extinction coefficient $\sigma_{a,\lambda}$ is estimated from LIDAR or OPC observation assuming Mie particles as a constant value over the human eye sensitive spectral range, while other gaseous extinction coefficients are estimated with LOWTRAN 7 assuming US standard atmosphere 1976. We further take the human eye sensitivity every 10 nm into consideration to estimate extinction coefficient σ which is comparable to visual range observation..

4. Results and discussion

We estimated the extinction coefficient from OPC and LIDAR measurement data to compare it with atmospheric visual range data obtained by eye observation. We made detailed match-up data analyses based on the report of the atmospheric visual range by Japan Meteorological Agency.

Figure 1a shows the relationship between atmospheric extinction coefficients using LIDAR aerosol extinction coefficients and visual range at Fukue-jima and Amami-oshima islands from 2003 to 2004. The slope of the regression line is 0.381 for all data (1246 samples), which is consistent to the previous studies within 0.333 to 0.526 in Eqs. (2) and (3). The slope of the regression line is, on the other hand, 0.811 for the data with visual range less than 10 km (79 samples), which is by more than twice all the data.

We could estimate aerosol extinction coefficients using OPC volume spectrum to make Mie simulations assuming bi-modal volume log-normal size distribution:

$$\frac{dV}{d\ln r} = C_1 \exp\left[-\frac{1}{2}\left(\frac{\ln r - \ln r_{m1}}{\ln s_1}\right)^2\right] + C_2 \exp\left[-\frac{1}{2}\left(\frac{\ln r - \ln r_{m2}}{\ln s_2}\right)^2\right], \quad (6)$$

where r is aerosol particle size, C_1 and C_2 are the constants relevant to total volume. The parameters r_{m1} and r_{m2} are the mode radii, while the parameters s_1 and s_2 define size distribution width. The subscripts 1 and 2 for each parameter are for the accumulation and coarse mode, respectively. Using the OPC volume spectrum, we could determine the two parameters C_1 and C_2 out of six parameters in Eq. (6), since it seems that OPC data are most sensitive to the aerosol volume. For the other four parameters r_{m1}, r_{m2}, s_1 and s_2, we assigned the values 0.13μm, 2.00μm, 1.7 and 2.0, respectively, based on the previous study with skyradiometer data analyses. We further assume the accumulation and coarse modes are sea salt and dust, respectively, to provide the refractive index for the Mie calculations. The simulations are carried out at

10nm interval over the visible spectrum range and weighted with the human eye response.

As a result, we obtained the same relationship in Fig. 1b as in Fig. 1a. The slopes of the regression line are 0.342 and 0.807 for all data (626 samples) and the data with visual range less than 10 km (87 samples), respectively.

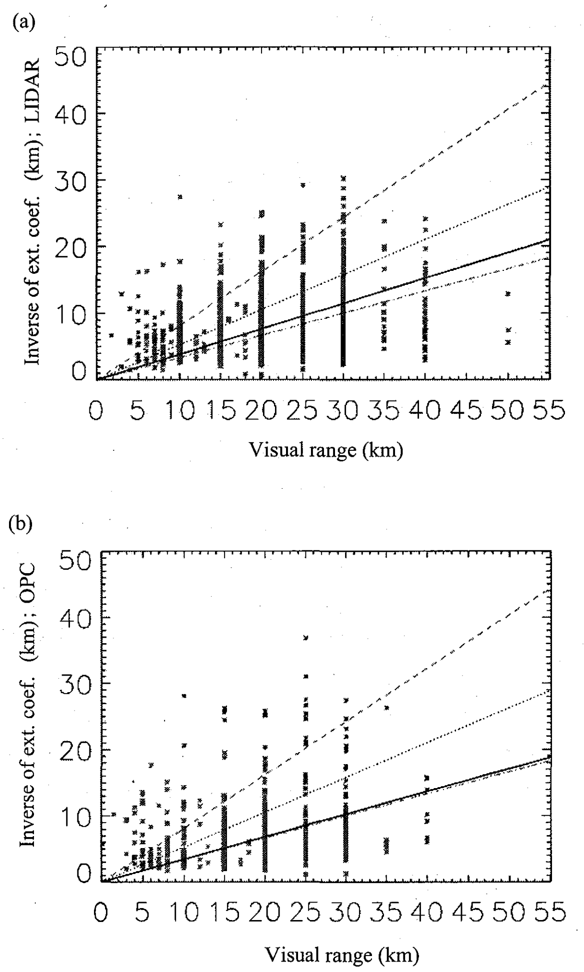

Fig. 1. (a) Relationship between the inverse of atmospheric extinction coefficients estimated with LIDAR observation and visual range at Fukue-jima and Amami-oshima islands in 2003 and 2004. Black and red lines show regression lines for all data and for the data with visual range less than 10 km, respectively. The orange and green lines correspond to Eqs. (2) and (3), respectively as references. (b) Same as Fig. 1a, but for the extinction coefficients estimated with OPC observation.

Table 1 summarizes the above results on the relationships LIDAR and OPC respect to Visual range, respectively (Fig. 1).

Table 1. Statistics of the Slope in Eq. (4).

	All data		Low Visibility*	
	Slope	Number	Slope	Number
LIDAR	0.38	1246	0.81	79
OPC	0.34	626	0.81	87

* Visual range is less than 10 km.

As a consequence, we obtained following points: 1) LIDAR and OPC measurements are consistent in terms of extinction coefficients compared to the visual range. 2) Fukue-jima and Amami-oshima islands are best sites for monitoring atmospheric environment since the slope of the regression lines are consistent to the WMO's. But 3) some deviation from the WMO line suggests the influence of cloud and surface reflection, for example, other than atmospheric attenuation, which encourages that aerosol ground-based measurements with atmospheric visual range observation could provide more detailed atmospheric turbidity statistically.

5. Concluding remarks

We investigated the relationship between the atmospheric extinction coefficient and visual range at Fukue-jima and Amami-oshima islands from 2003 to 2004. As a result, the relationship is consistent to the previous studies, while there exists some deviation in case of lower visibility in particular, which suggests that aerosol ground-based measurements with atmospheric visual range observation could provide more detailed atmospheric turbidity statistically on a basis of monitoring of the atmospheric environment.

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