AEROSOL OPTICAL PROPERTIES RETRIEVED FROM DUAL-WAVELENGTH POLARIZED LIDAR MEASUREMENTS DURING MIRAI MR01K02 CRUISE

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ABSTRACT

We analyzed the data measured with a dual-wavelength polarized Mie-scattering lidar over the western Pacific Ocean near the Japan island during two weeks in May 2001. We developed two types of algorithm, i.e., forward and backward. The algorithms retrieve the extinction coefficients of two types of aerosol component, i.e., water-soluble and sea-salt or water-soluble and dust, at each layer from the lidar data. Distinct from the algorithms developed to date, our algorithms can distinguish types of aerosol, estimate the vertical profiles of concentration for each aerosol component, and further retrieve lidar-ratio of aerosols. The results show that most of water-soluble and sea-salt aerosols were concentrated below the altitude of 1 km. Some plumes dominated by water-soluble and dust particles were found above the altitude of 1 km. The values of extinction coefficient at λ = 532 nm of total aerosols averaged over the whole observation period ranged from 0.02 to 0.12 km^{-1} in all the layers. The distributions of each aerosol type simulate by the aerosol transport model SPRINTARS were roughly consistent with those retrieved in this study. Validation of these algorithms were also conducted and showed good agreement within 10% for aerosol optical thickness between the lidar and skyradiometer measurements.

1. INTRODUCTION

It is inevitable to grasp temporal and spatial variation of aerosol microphysics in order to study the earth's climate. The ship-borne measurement with the research vessel MIRAI of JAMSTEC (Japanese Maritime Science and Technology Center) was conducted in the western Pacific Ocean near the Japan island from May 14 to May 27, 2001. This ship-borne program was a component of Japanese participation in the Asian Pacific Regional Aerosol Characterization Experiment (ACE-Asia). A dual wavelength polarized Mie-scattering lidar of NIES (National Institute for Environmental Studies) and a 95-GHz cloud profiling radar of NICT (National Institute of Information and Communications Technology) were installed on the vessel in the cruise. It is the first time that the ship-borne measurement with both lidar and cloud profiling radar was conducted. The analysis of the lidar and radar data will provide information about the temporal and spatial distribution of aerosols and clouds over the sea, and further will be helpful for the validation with products from such numerical models as aerosol transport models and cloud-resolving models.

We have developed two types of algorithm, i.e., forward and backward. Those classify aerosol components and retrieve the extinction coefficients at the wavelength (λ) of 532 nm of two types of aerosol component, i.e., water-soluble (σ_{WS}) and sea-salt (σ_{SS}) or water-soluble and dust (σ_{DS}), at given layer. We use the dual-wavelength polarized lidar data which has three channels that are receiving signal strength (P_{obs}) at λ = 532 nm and 1064 nm and total depolarization ratio (δ_{obs}) at λ = 532 nm. Using both the algorithms, we analyzed the lidar data measured in the MIRAI cruise.

2. ALGORITHM

The backward-type algorithm can estimate the calibration constant of the lidar as well as the vertical profiles of aerosol properties, however, its application has to be limited to the data under clear-sky condition since the data over clouds are contaminated with their strong attenuation. The forward-type algoritm can retrieve the aerosol properties under a layer of clouds as well as clear-sky condition, however, it needs the calibrated lidar signals. Distinct from the widely used Fernald's method [3], our algorithms can retrieve the vertical profiles of each aerosol component, and also the lidar ratio (i.e., extinction-to-backscattering ratio). It is also an advantage that the forward-type algorithm can estimate the aerosol optical properties under a layer of cloud; it is expected that this algorithm can provide knowledge related to aerosol-cloud interaction around cloud bottom layers.

The following assumptions have been made in both the algorithms: (1) the volume size distribution of aerosols is assumed to be bimodal, with peaks of lognormal shape. (2) Two types of aerosol model are assumed: the sea-salt and dust models. The sea-salt model has two aerosol components: water-soluble aerosols with modal radius in the fine-mode region and sea-salt aerosols with modal radius in the coarse-mode region. The dust model also consists of two aerosol components: water-soluble aerosols and dust aerosols with modal radius in the coarse-mode region. (3) The microphysical and optical properties assumed for water-soluble, sea-salt and dust particles are based on results from other studies [1][2]. (4) We assume a scale height value of 1.3 km for the vertical profile of the aerosol extinction coefficient under the lowest layer to correct the attenuation of lidar signals.

The forward-type algorithm uses the three channels of the lidar, however, the P_{obs} has to be calibrated in advance. We define the calibrated signals, i.e., attenuated backscattering coefficient β_{obs}, as $\beta_{obs} = CP_{obs}$, where C is calibration constant. We retrieve the vertical profiles of aerosols sequentially from the lowest layer to the highest layer, repeating the following steps at each layer: (1) retrieving the extinction coefficients of the two aerosol components for each model, i.e., the sea-salt and dust models, that can simulate the β_{obs} at the two wavelengths, (2) determining the model by using the δ_{obs}, and (3) estimating the aerosol optical thickness from the retrieved σ_{WS} and σ_{SS} or σ_{WS} and σ_{DS} in order to correct the attenuation of the β_{obs}. In step 2, we first compute the depolarization ratio of aerosols themselves (δ_a) for each model from the δ_{obs} and the backscattering coefficient of aerosols retrieved for each model. We adopt the sea-salt model / dust model when both the δ_a-values computed for the sea-salt and dust models are smaller / larger than 0.1. There might be cases that the δ_a-values do not match the conditions, for example, δ_a-values for sea-salt and dust models are larger and smaller than 0.1, respectively. Then, it is indicated by labeling the layer 'Unknown model', and the aerosol optical thickness is estimated from the σ_{WS} and σ_{DS} obtained using the dust model.

The backward-type algorithm uses the three channels of the lidar, however, the spectral ratio of P_{obs} (i.e., $P_{obs,532}$ / $P_{obs,1064}$) has to be calibrated in advance. It retrieves the calibration constant of the lidar as well as the vertical profiles of aerosols, involving the following steps: (1) setting an appropriate value for extinction coefficient at λ = 532 nm of total aerosols at the highest layer ($\sigma_{a,h}$), (2) retrieving the vertical profiles of aerosols sequentially from the highest layer to the lowest layer, repeating the similar steps as the forward one takes, and (3) computing the C at the two wavelengths. In step 2, in order to simulate P_{obs} at each layer, we use the P_{obs} and extinction and backscattering coefficient of aerosols at the highest layer; $\sigma_{a,h}$ and the optical properties of dust particles assumed in the algorithm are used in order to compute the extinction and backscattering coefficient of aerosols at the highest layer. We repeat the above steps changing the value of $\sigma_{a,h}$ and find solution to match the measured C_{532} / C_{1064}.

3. OBSERVED DATA

The lidar data were recorded up to 12 km with 6 m resolution. The signals were averaged every 10 s. The spectral ratio of calibration constant of the lidar data (i.e., C_{532} / C_{1064}) was obtained by using the signals returned from water clouds [4]. We use the radar data in order to remove the data contaminated by clouds and drizzle. The radar data were recorded up to 12 km with 82.5 m resolution. The return-signals were averaged every 10 s. The noise signals were also measured for each record.

We averaged the lidar data every 82.5m in vertical direction in order to match the resolution of radar data. Further we averaged the lidar and radar data every minute. Consequently, we used the lidar and radar data with the vertical and temporal resolution of 82.5m and 1 min, respectively. The application of the algorithms to the data was limited to layers from 0.2 km to 6 km, since the signal to noise ratio is worse as the altitude increases and also the lidar has a blind region under 0.2 km due to the insufficient overlapping of the laser beam and the field of view of the receiving telescope.

4. RESULTS

First of all, we applied the backward-type algorithm to the lidar data in order to calibrate them. We then extracted data under clear-sky condition, applying the following criterion: radar return-signal is smaller than noise level plus 0.5 dB and the retrieved value of backscattering coefficient of total aerosols at λ = 532 nm is smaller than 0.01 km^{-1} in all the layer. After that, the value of C at each time during the observation period was linearly interpolated from the retrieved C-values, and thus the β_{obs} were computed (Fig. 1).

Next, we removed the data contaminated by clouds and drizzle using the calibrated lidar-signal at λ = 1064 nm ($\beta_{obs,1064}$) and radar data. When the lidar or radar data at a given layer satisfy one condition among the followings, we consider that the data at the layer is fulfilled with clouds or drizzle: (1) the radar signal is larger than noise plus 0.5 dB, (2) the $\beta_{obs,1064}$ is larger than 0.01 $km^{-1}sr^{-1}$, and (3) the $\beta_{obs,1064}$ is larger than 0.003 $km^{-1}sr^{-1}$ and the slope of $\beta_{obs,1064}$ against altitude is larger than 0.025 $km^{-2}sr^{-1}$, where the threshold values are empirically determined. The data for the upper layer than clouds or drizzle are removed.

Finally, after the calibration constant was determined by the backward-type algorithm, we applied the forward one to the lidar data to retrieve aerosol properties after clouds and drizzle were removed. In the following, we show the results for the forward-type algorithm since the occurrence of clouds and drizzle in the whole observation period reached to 70%, the value evaluated from the above cloud mask scheme. Fig. 2 shows the distribution of σ_{WS}, σ_{SS} and σ_{DS}. Most of water-soluble and sea-salt aerosols were concentrated in the planetary boundary layer, which is below 1 km. Plumes of water-soluble and dust particles were found around 2.5 km on 20th, 21st and 26th, where the δ_{obs} is about 0.2, the value larger than that at the other area ($\delta_{obs} < 0.1$).

The aerosol distribution over the whole observation period was simulated by aerosol transport model, SPRINTARS (Spectral Radiation Transport Model for Aerosols Species) [5]. The model can treat transport of sulfate, carbonaceous, dust and sea-salt particles using a framework of an atmospheric general circulation model of NIES-CCSR-FRCGC. The temporal and spatial distribution of sulfate, sea-salt and dust simulated by the

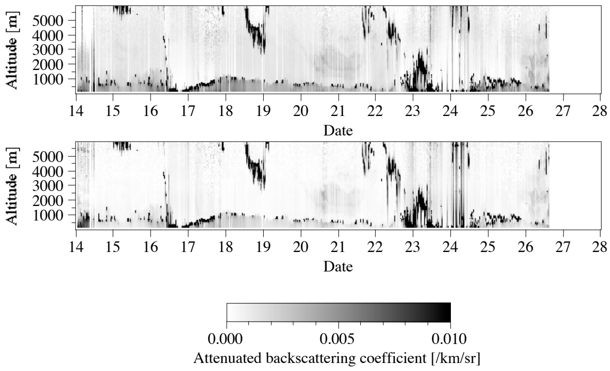

Fig. 1 Time-height cross-section of β_{obs} at λ = 532 nm (Upper) and 1064 nm (Lower).

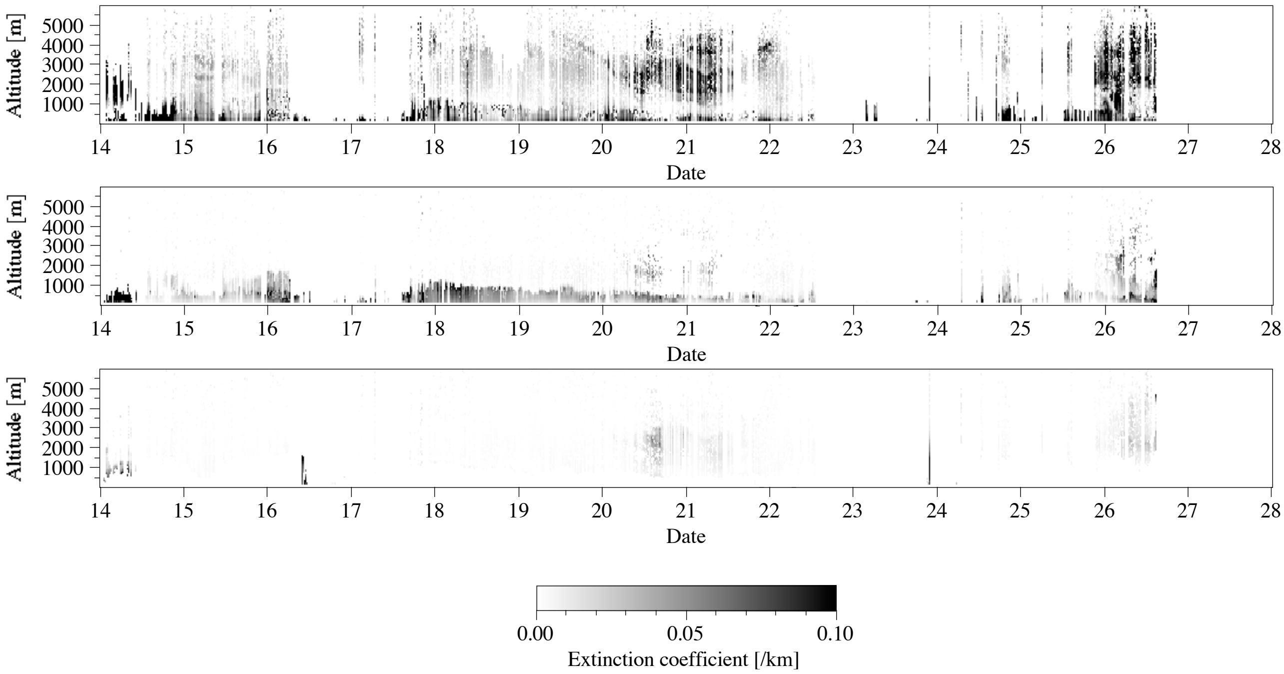

Fig. 2 Time-height cross-section of σ_{WS} (Upper), σ_{SS} (Middle) and σ_{DS} (Lower) retrieved by the forward-type algorithm over the whole observation period.

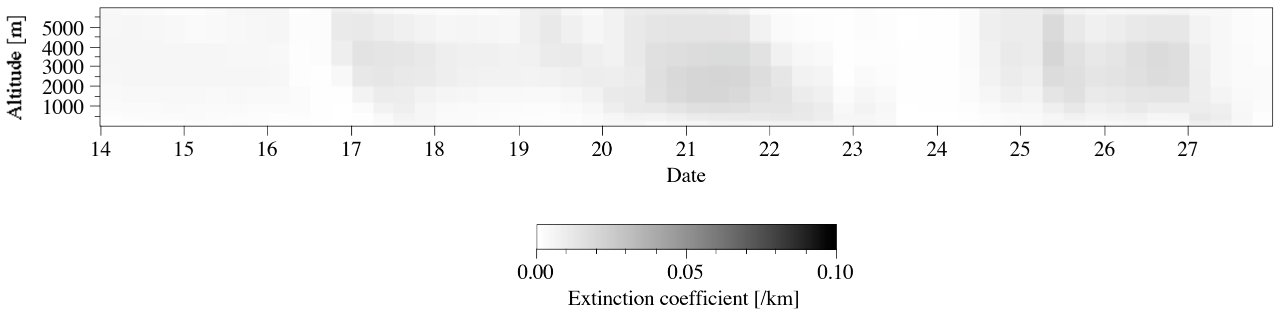

Fig. 3 Time-height cross-section of extinction coefficient at λ = 532 nm of dust particles simulated by the SPRINTARS over the whole observation period.

SPRINTARS over the whole observation period roughly matched those of water-soluble, sea-salt and dust retrieved from the lidar measurements, respectively (Fig. 3). The simulation by the SPRINTARS implied that the plumes of water-soluble and dust found on 20th, 21st and 26th were transported from Gobi desert in Mongolia and the seaboard of China, respectively.

We averaged the data of σ_{WS}, σ_{SS} and σ_{DS} at each layer over the whole observation period (Fig. 4). The results showed that the σ_{WS} and σ_{SS} in the planetary boundary layer ranged from 0.02 to 0.08 km^{-1} and from 0.01 to 0.04 km^{-1}, respectively, larger than those over 1.0 km (σ_{WS} < 0.04 km^{-1} and σ_{SS} < 0.01 km^{-1}). This result matches the results of the past observational studies that the aerosols in the planetary boundary layer are generally more abundant than those in the free troposphere. Over 1 km, the σ_{WS} had two peaks around 2.5 and 4 km where the values were about 0.04 km^{-1}. The σ_{DS} showed its peak at the altitude of around 2.0 km, however, the value itself was extremely small, 0.004 km^{-1}. The values of extinction coefficient for total aerosols ranged from 0.03 to 0.12 km^{-1} below 1.0 km and from 0.02 to 0.04 km^{-1} above 1 km. This result is almost similar to the result of the other study, where vertical profiles of aerosols were deduced from the lidar measurements carried out over the western Pacific Ocean in summer of 1999 [1].

We retrieved the aerosol optical thickness at λ = 532 nm (τ). The value averaged over all the observation period was 0.27, the value larger than that reported from skyradiometer measurements over the open sea in the Pacific region (generally τ < 0.1). The validation of algorithm was carried out, where the τ retrieved by both the algorithms from the lidar data were compared with that estimated from data measured with a skyradiometer installed on the MIRAI. It turned out to be good agreement within 10% between the lidar and skyradiometer measurements.

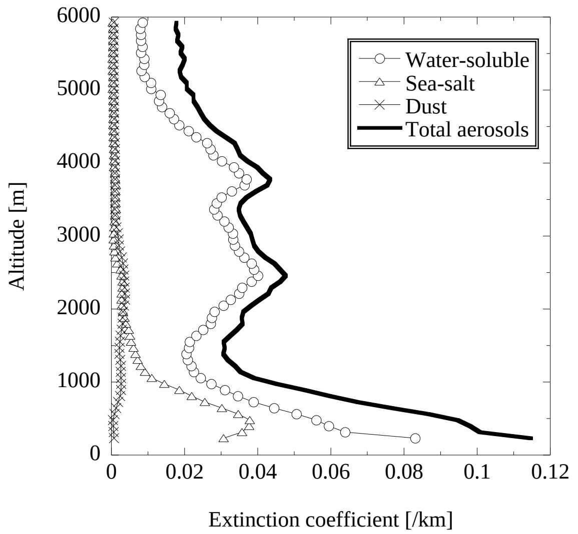

Fig. 4 Vertical profiles of extinction coefficient at λ = 532 nm of water-soluble, sea-salt, dust and total aerosols, the values averaged over the whole observation period.

5. SUMMARY

We retrieved the vertical profiles of aerosols over the western Pacific Ocean from the dual-wavelength polarized lidar data measured in May 2001, using our developed algorithms that can retrieve the extinction coefficient of two types of aerosol component, i.e., water-soluble and sea-salt or water-soluble and dust, at each layer. The major findings are as follows: (1) most of water-soluble and sea-salt aerosols were concentrated below the altitude of 1 km, (2) some plumes dominated by water-soluble and dust particles appeared above the altitude of 1 km, (3) the extinction coefficient at λ = 532 nm of total aerosols averaged over the whole observation period was in range from 0.02 to 0.12 km^{-1} in all the layers; this result is similar to the other observational study, and (4) the distribution pattern of each aerosol component was in rough agreement between the simulation by the SPRINTARS and retrieval from the lidar measurements. (5) The aerosol optical thickness averaged at λ = 532 nm over all the observation period was 0.27, the value larger than that over the open sea in the Pacific region (generally τ < 0.1). (6) The validation of the algorithms was conducted and showed the good agreement within 10% between the lidar and skyradiometer measurements.

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