Long-Range Transport of Saharan Dust to East Asia Observed with Lidars

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Abstract

Dust layers in the free troposphere were observed with the lidars in Suwon, Gosan, and Tsukuba in March 7 – 9, 2005. The observed dust distributions were compared with the results of the regional and global dust transport models (CFORS, NRL NAAPS, and SPRINTARS). The results with the global models reproduced the dust layer qualitatively, but the regional model did not. This suggests the source of the dust layers is located outside of the modeled region of the regional model that includes Taklimakan Desert and Gobi Desert. The global models showed the plumes were from the Sahara Desert, and the both models showed there was no major dust emission in Taklimakan and Gobi Desert during the observation period. The trajectory analysis using NOAA HYSPLIT showed that the dust originated in the Sahara Desert 5–10 days before.

1. Introduction

Mineral dust in the atmosphere generated by strong surface wind is considered to have significant effects on the radiation property of the atmosphere, atmospheric chemistry, and also on marine biology. In the North Asian region, a large amount of mineral dust, called yellow sand or Asian dust, is emitted every spring season. Various observations and modeling studies have been conducted for understanding Asian dust emission and transport mechanisms, and the effects on the climate and the environment. It is known that the major sources of Asian dust are the Gobi Desert in Mongolia and Inner Mongolia, the Taklimakan Desert, and the loess plateau. Asian dust is sometimes transported thousands of kilometers to Hawaii and North America (Gao et al., 1992; Iwasaka et al. 2003; Uno et al. 2004). The heavy dust phenomena in northeast China and Korea mostly originate in Gobi Desert in Mongolia and Inner Mongolia (Sugimoto et al. 2003). The dust from Taklimakan is generally transported in higher altitudes and often observed in the free troposphere over Japan. There are also cases of Middle Eastern and Saharan mineral dust observed in the East Asia (Tazaki et al. 2004; Tanaka et al. 2005).

To study the emission and transport of mineral dust and air pollution aerosols in East Asia, a network of continuously operated lidars was developed by the National Institute for Environmental Studies (NIES) (Sugimoto et al. 2005; Shimizu et al. 2004). With the network, dust plumes are occasionally observed in the free troposphere.

To identify the origin of the dust plumes, it is useful to compare the lidar data with the results of transport models. However, the origin is not necessarily clear because the contributions of various source regions overlap.

In early March 2005, we observed elevated dust layers in the free troposphere at several locations of the lidar network, yet there were no major dust emissions from the Taklimakan and Gobi Deserts in the period (See Comment 1). We deduced a Saharan origin of the dust plumes using the regional model, Chemical Forecast System (CFORS) (Uno et al. 2004) and the global model, Naval Research Laboratory (NRL) Aerosol Analysis and Prediction System (NAAPS) (http://www NRLmry.navy.mil/aerosol/), and the Spectral Radiation-Transport Model for Aerosol Species (SPRINTARS, Takemura et al. 2005). We also performed a backward trajectory analysis using NOAA HYSPLIT model (Draxler and Rolph 2003; Rolph 2003).

2. Lidar system and network observation

Lidar are useful tools for measuring the vertical profiles of aerosols with high spatial and temporal resolution. In the NIES lidar network, we use the lidars that measure the backscattering at 532 nm and 1064 nm, and the depolarization ratio at 532 nm. Currently the lidars are operated continuously at the following 13 locations in cooperation with various universities and research institutes: Tsukuba, Nagasaki, Amami, Miyakojima, Fukue, Sapporo, Toyama, Suwon, Beijing, Helei, Hohhot, Phimai (Thailand), and Gosan.

In this paper, we use the data from Suwon (37.14N, 127.04E), Gosan (33.60N, 126.50E), and Tsukuba (36.05N, 140.12E) to study the long-range transport of dust in the free troposphere.

The lidar in Suwon, Korea has been operated at Kyung Hee University since March 2002 (Lee et al. 2002). The lidar in Gosan, Korea was temporarily operated at the observatory for the Project ABC (Atmospheric Brown Cloud) of UNEP for the inter-comparison experiment (March-May 2005). The lidar in Tsukuba has been operated continuously since 1996 at NIES.

3. Lidar observations and comparisons with models

Figure 1 shows the time-height indications (THIs) of the range-corrected backscatter signal and the total depolarization ratio measured in Suwon, Gosan, and Tsukuba. A dust layer with a total depolarization ratio of 10–25 % was observed in Suwon in the period from 00:00 of March 8 to 08:00 of March 9, 2005 (UTC) at altitudes of 2–4 km. At the Gosan site, a thin layer of the dust was observed from 8:00 to 15:00 of March 7 at the altitude of 4–7 km with a total depolarization ratio higher than 12 %. After 18:00 of March 7 lower cloud interrupted the observation. In Tsukuba, a thin dust
layer was observed at altitudes of 3–4 km in the period from 00:00 of March 8 to 15:00 of March 9. The depolarization ratio at the layer was 15–20%. A similar thin dust layer in the free troposphere was also observed in Toyama (137.10E, 36.70N) in March 7–8 (not shown).

To study the origin of the dust layers, we compared the lidar data with the results of the chemical transport models. Figure 2 shows the THI plots of dust concentration calculated with CFORS for Suwon, Gosan, and Tsukuba, and with NAAPS for Gosan and SPRINTARS for Gosan. In the CFORS results, there are no high concentration dust plumes in March 7–8 where the dust layers were observed by the lidars, except for some low concentration dust in the lower part of the plume in Suwon. On the other hand, NAAPS and SPRINTARS results show a high concentration dust plume at altitudes of 3–8 km in March 7–9. The NAAPS and SPRINTARS results for Suwon and Tsukuba are similar to those for Gosan (See Comment 2). The observed dust layers in Gosan and Tsukuba in Fig. 1 show the laminar structure. The results with NAAPS and SPRINTARS, however, show the thicker structures.

All of the three models showed no major dust emission in Taklimakan and Gobi Deserts during the period. The non-Asian origin of the dust is investigated with retrospective NAAPS simulations separately masking Sahara and Taklimakan dust sources beginning on February 24, 2005. A comparison of this simulation with the operational run shows that the dust above 3 km shown in Fig. 2(d) is of Saharan origin. NAAPS simulated dust events on Feb 25–27, Feb 28–Mar 2, and Mar 3–6 in the Sahara Desert. The dust from the first event takes 10 days to reach East Asia and the second is quicker, about 6 days. The third one is not transported to East Asia. (See Comment 3). The SPRINTARS dust column loading map also shows the source of the dust was the Sahara Desert (See Comment 4).

The SYNOP data reported large dust events in the Sahara Desert in Feb 26–Mar 2. In contrast, only few events were reported in Taklimakan and Gobi (See Comment 1). One event we must take into account is the “slight or moderate duststorm or sandstorm” observed in Mongolia on Mar 6. This event probably contributed to the lower part of the dust observed in Suwon. However, it seems impossible to form the plume above 3 km that lasted long time. The observed dust plume lasted 40 hours over Tsukuba.

Figure 3 shows vertical profiles of the lidar extinction coefficient and the total depolarization ratio in Suwon, Gosan, and Tsukuba. The extinction coefficient obtained with the Fernald’s method (Fernald 1984) is approximately 0.05 km$^{-1}$ at the laminar plumes in Gosan and Tsukuba with an assumption of the lidar ratio of 50 sr. The profile in Suwon is different from those in Gosan and Tsukuba. The lower part of the plume was probably not from Sahara as seen in the CFORS THI in Fig. 2. We will discuss the origin of the dust further in the trajectory analysis section.

We may estimate the mass concentration of dust if we apply the mass/extinction conversion factor. The conversion factor for typical dust case in Beijing was 1.78 g m$^{-2}$ (Sugimoto et al. 2003). However, the conversion factor is dependent on particle size and is probably much smaller for the transported dust with smaller
Fig. 3. Vertical profiles of extinction coefficient (black) and particle depolarization ratio (red) derived from the lidar observations in (a) Suwon (18:00 March 8), (b) Gosan (15:00 March 7), and (c) Tsukuba (00:00 March 9). The arrows indicate the height of the dust layer.

Fig. 4. HYSPLIT backward trajectories from (a) Suwon (March 8, 15:00), (b) Gosan (March 7, 15:00), and (c) Tsukuba (March 9, 00:00). The circles on the paths indicate the period of one day.
sized. If we assume that the conversion factor is 0.5–1.5 g m$^{-2}$, the concentration at the laminar plume in Gosan is 25–75 µg m$^{-2}$.

The dust concentration obtained by NAAPS for the plume at Gosan is 50–400 µg m$^{-2}$ and may be overestimated. The concentration calculated with SPRINTARS is 20–40 µg m$^{-2}$ and is close to the lidar estimation. The depth of the modeled layer is large compared with the lidar observation, though the plume above the optically thick low cloud after 18:00 March 7 was not clearly observed. The high extinction coefficients observed below 0.7 km in Gosan and below 2.5 km in Tsukuba are mostly air pollution aerosols with low depolarization ratios.

4. Backward trajectory analysis

In order to confirm the transport paths of the dust observed in Suwon, Gosan, and Tsukuba, the backward trajectories are calculated with the NOAA HYSPLIT model. Figure 4 shows the results.

The result for Suwon at 18:00 of March 8 shows that the dust observed above 2.5 km originated in the Sahara Desert region about 10 days before. However, the trajectory for 1.5 and 2 km was trapped once at the western part of China.

The backward trajectory for the laminar plume observed in Gosan at 15:00 of March 7 clearly shows the origin is Sahara, and the dust was transported in 5–6 days. The backward trajectory for Tsukuba at 00:00 March 9 also shows the laminar plume was from Sahara, and the transport time was 8–9 days.

The results of the trajectory analysis are consistent with the NAAPS simulation described above. The transport path was similar to that in the Middle East dust case in 2003 (Tazaki et al. 2004; Tanaka et al. 2005).

5. Conclusion

We have observed a case of long-range transport of Saharan dust to East Asia in March 2005 using a network of lidars. The transport models and the backward trajectory analysis have shown the origin to be the Sahara Desert.

The global aerosol transport models NAAPS and SPRINTARS reproduced the transport of the dust plume from Sahara. However, differences from the observations were seen in vertical profiles of the dust distribution. Also, difference between models was seen in the dust concentration. Validating the models in the case studies like that described in this paper will be essential for understanding the effects of long-range transported dust on climate.

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Comments and supplements

1. Number of observed dust events in Sahara and Taklimakan regions is shown in the Supplement 1.

2. Time-height indications of dust concentration at Suwon, Gosan, and Tsukuba calculated with NAAPS and SPRINTARS are shown in Supplement 2.

3. An animation of dust optical depth calculated with NAAPS is given in Supplement 3.

4. An animation of dust column loading calculated with SPRINTARS is given in Supplement 4.

References


