Observations and transport modeling of dust storm event over Northeast Asia using HYSPLIT: case study

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Abstract. This study analyzes a regional dust storm event that occurred in spring 2016 using data from observation sites, Lidar measurements, and satellite imageries. PM_{10} concentrations at surface observation stations are considered as a primary indicator of the dust events. The dust events occurred on 3-12 March with PM_{10} reaching a maximum beyond 1682, 1498, 706, and 165 µg m^{-3} at observation sites in Mongolia, China, Korea and Japan, respectively. The dust event in Northeast Asia is captured by time series of PM_{10} concentrations at observation sites. On 3-4 March, the dust storm event originated from Mongolia move toward China, Korea and Japan. Vertical distributions of dust observed by Lidar measurements from stations in AD-Net capture a thick layer of nearly 2.2 km of high concentrations above surface in the area of origin. The maximum PM_{10} concentration drops with downwind transport. Dust source identification and dust-loaded air parcel trajectories are calculated using the HYSPLIT model. According to the HYSPLIT model, the dust storm started on 3-4 March from Mongolia and reached northern Japan in about 4 days passing over northern China and Korea.

1 Introduction

Dust storms in Northeast Asia from the Gobi deserts [1, 2] and northern China and western China. Frequent cyclonic activities over Mongolia result in frequent dust storms in Northeast Asia specifically during springtime [3]. Dust storms usually occur in high shear wind speed and low moisture in air and soil, and 70% of dust storms occur in dry soil conditions in Mongolia [3]. Statistical study on the dust storms observed in Mongolia showed that the number of dusty days varies with period of time.

Asian dust can spread out in wide areas and studies showed that the Gobi Desert is the origin of southwestward transport of Asian dust [4]. Statistical study has demonstrated that the dust-loaded air parcels are further transported eastward and southeastward forming regional dust storm events and the dust raised from the Gobi deserts is likely to be entrained to a height of <3 km [5]. It was shown that about 400 Tg of Asian dust are transported over long distances downwind of source regions by westerly winds [6]. A modeling approach demonstrates that the dust originated from the Mongolian Gobi has the potential to travel to the far Pacific, North America [7], and even to Arctic [8] under favorable weather conditions.

Different techniques (such as surface dust observations, remote sensing, satellite imagery, numerical modeling, trajectory analysis etc.) have been widely applied to investigate the dust storm events. To estimate the origins and trajectories of dust aerosols, the Lagrangian models are widely used. The HYSPLIT model has been applied in prior studies to examine the source of dust events [9, 10].

This study analyzes dust event in Northeast Asia region that occurred in 2016 using surface dust observations, satellite imageries and numerical modeling. Here, we report a case study of Northeastern Asian dust event on 3-12 March is reported here.

2 Data and methods

Several datasets are used in this study to assess the dust events in northeast Asia during spring 2016. Hourly PM_{10} concentrations measured at surface observation sites in Mongolia (4 sites operated by National Agency for Meteorology and Environmental Monitoring, NAMEM), China (10 sites operated by China National Environmental Monitoring Center), Korea (20 sites operated by Korea Meteorological Administration), and Japan (10 sites operated by the Ministry of the

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Environment, Japan) are used. Weather maps and records of meteorological stations obtained from the NAMEM are analyzed.

In addition to the ground measurements, lidar measurements from stations in AD-Net, the Asian dust and aerosol lidar observation network [11], are used to observe the vertical distribution of dust. The trajectory of an air parcel containing dust which arrives at the final destination is traced back for several days.

In order to analyze the origins and trajectories of horizontal and vertical pathways of dust aerosols, HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory) model has been utilized with $0.5° \times 0.5°$ resolution meteorological data. HYSPLIT model is capable in computing both simple air parcel trajectories and complex dispersion and deposition simulations. Three types (normal, matrix, and ensemble) of trajectories can be computed by HYSPLIT. The space and time calculations of path of individual air parcel can be done by the matrix trajectory calculation. More details can be found at http://www.ready.noaa.gov/HYSPLIT.php (NOAA Air Resources Laboratory).

3 Results

Both surface and satellite observations/retrievals are used to identify dust events. As indicator of dust, PM_{10} concentrations are considered. Table 1 shows the maximum of hourly PM_{10} concentrations at observation sites in Mongolia, China, Korea and Japan for the period 3-8 March. Time series of PM_{10} concentrations at observation sites capture the dust event in northeast Asia. Enhanced PM_{10} concentration of 1682 μg m^{-3} is observed at the Dalanzadgad station, Mongolia, on 4 March when the dust event is originated over the Mongolian Gobi. On the same day, the maximum hourly PM_{10} concentration reaches 1498 μg m^{-3} at Hohhot station, China, confirming the arrival of the dust event. Further, two days later, the PM_{10} concentrations decrease rapidly to about 700 μg m^{-3} in western Korea. Later, the maximum PM_{10} concentration reaches 165 μg m^{-3} in northeastern Japan. The dust has accounted for approximately 90, 47, and 23% of observed PM_{10} concentrations at stations in China, Korea, and Japan, respectively, during southeastward transport of dust event on 3-12 March.

Table 1. Maximum PM_{10} concentration at observation sites in Mongolia, China, Korea, and Japan.

Country	Site	Max. PM_{10}, μg m^{-3}	Max.Period
Mongolia	Dalanzadgad	1682	4 Mar
	Sainshand	350	4 Mar
	Zamiin-Uud	472	4 Mar
	Ulaanbaatar	135	5 Mar
China	Baotou	1335	4 Mar
	Chifeng	718	5 Mar
	Hohhot	1498	4 Mar
	Yan'an	1308	4 Mar
	Datong	680	4 Mar
	Dalian	287	6 Mar
	Ji'nan	491	5 Mar
	Jinzhou	341	4 Mar
	Shenyang	798	5 Mar
	Qingdao	324	6 Mar
Korea	Sokcho	114	8 Mar
	Gwangde	166	6 Mar
	Deagwallyeong	86	8 Mar
	Baengnyeongdo	706	6 Mar
	Ulleungdong	78	8 Mar
	Kwanaksa	160	6 Mar
	Yeongwol	82	8 Mar
	Kwago	238	6 Mar
	Andong	114	8 Mar
	Gunsan	166	6 Mar
	Daegu	109	8 Mar
	Gwangju	117	8 Mar
	Gudeoksan	104	8 Mar
	Heuksando	305	6 Mar
	Gosan	94	8 Mar
	Jinju	96	6 Mar
	Ganghwa	190	6 Mar
	Cheonan	156	6 Mar
	Uljun	92	8 Mar
Japan	Rishiri	160	7 Mar
	Ochiishi	165	8 Mar
	Tappi	58	8 Mar
	Sado-seki	71	3 Mar
	Ijira	72	8 Mar
	Oki	79	8 Mar
	Banryu	100	8 Mar
	Yusuhara	88	8 Mar
	Ogasawara	53	6 Mar

As one of the indicators of a dust event, the extinction coefficients by lidar measurement for March 2016 at several stations in Mongolia, Korea, and Japan, are shown in Figure 1. The stations belong to the AD-Net [11]. According to the vertical distribution of dust, the measurement of extinction coefficient demonstrates that, on 3-4 March, the dusts are observed in a thick layer up to 2.2 km near the area of origin (Sainshand site, Mongolia), and further the dust travels to Japan passing by the north of Korean Peninsula as compared to the area of its origin. An elevated dust layer is observed at around 0.7-3.0 km at the Takikawa site in the early hours on 8 March. Further, at the later hours, the dust layer is observed from near the ground up to <1 km. Thus these trajectory pathways are responsible for relatively lower PM_{10} concentrations at some sites which are located in southern part of Korea (Table 1). The high concentrations at southern site of Korea (Jeju) are not obvious.
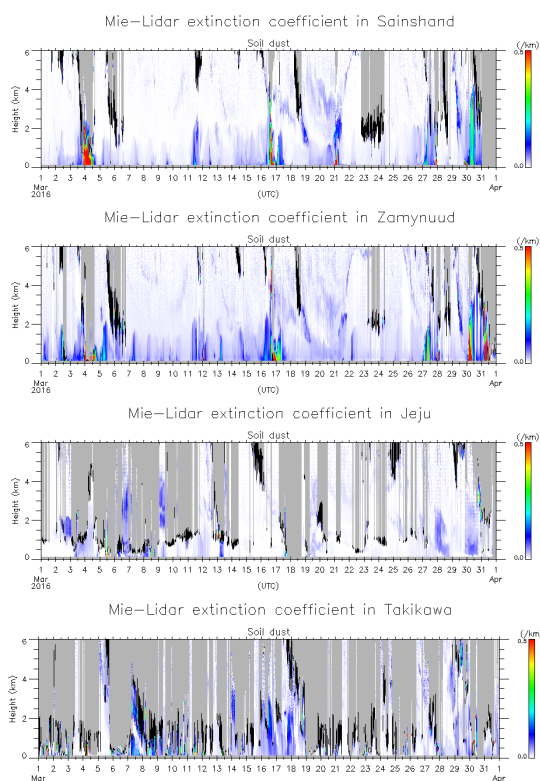
Fig. 1. Mie-Lidar dust extinction coefficient showing vertical distribution of soil dust 2-12 March 2016 at Sainshand, Zamynuud, Jeju and Takikawa.

To further examine the transport of Asian dust, the ensemble HYSPLIT backward trajectory model is applied to identify the source area of the dust event. The back-trajectories of the dust event are shown in Figure 2. Figure 2 indicates that the dust-loaded air parcels are transported from Mongolia to the northeastern Japan. The particle backward trajectories are calculated for 96 h periods starting from 10 m above the receptor sites. The dust-loaded air parcels arriving in northeastern Japan at 23 UTC on 7 March are originated from Mongolia and pass over north China and Korea. The passage duration from Mongolia to Japan is nearly 4-5 days which is in agreement with measurements of surface PM_{10} concentrations. Height of dust transport passages varies with time.

4 Summary

In the present study, the dust event that occurred over Northeast Asia on 3-12 March 2016 is analyzed using surface observation data, satellite imageries, and numerical modeling. As the nature of dust events may not be exactly the same for each event, the dust storm event on 3-12 March is documented in this short paper and the analysis of the other events will be given on the conference talk. As a primary indicator of the dust events, PM_{10} concentrations monitored at surface stations are analyzed. The dust events are captured by the time series of PM_{10} concentrations at observation sites, vertical measurements at Lidar network stations. Surface dust observations show that the maximum
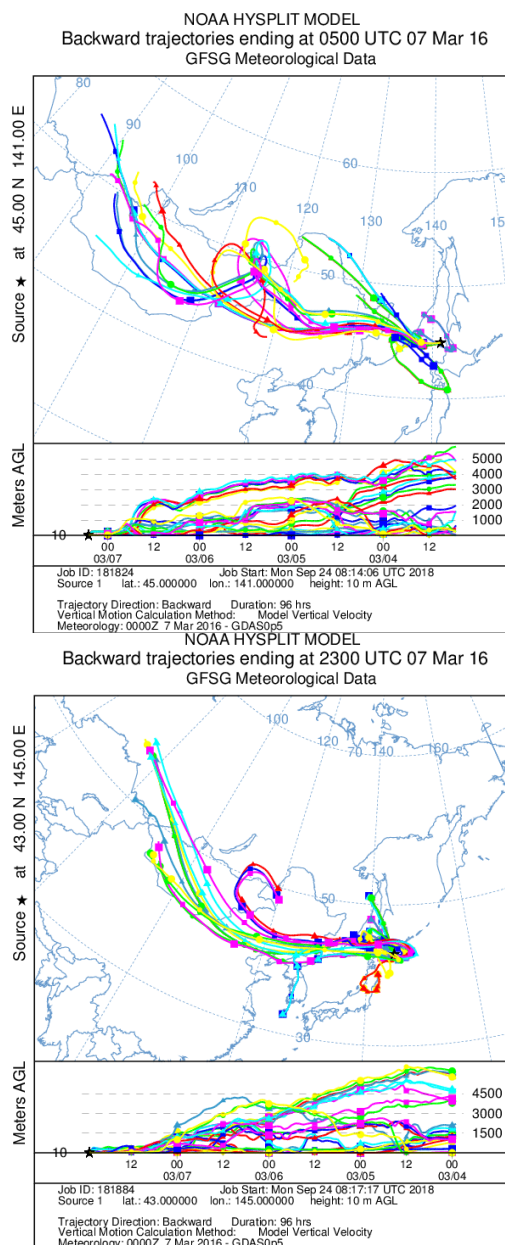

Fig. 2. HYSPLIT trajectories showing the path and height of the dust-loaded air parcel arriving Rishiri and Ochiisi, Japan, originate from Mongolia. Colors indicate the individual air parcels arriving from different source areas.

PM_{10} concentration varies from 1682 to 165 $\mu g \, m^{-3}$ during 3-12 March with a time lag from Mongolia to Japan. Measurements at Lidar stations showed thick layer of dust in the Mongolian Gobi, which is an origin area of dust, and further the layer descends at distant sites. Trajectory calculations by HYSPLIT verify the origin of dust-loaded air parcel and its transport pathway. Analysis shows that the Asian dust over Northeastern Asia can last for several days and the dust concentrations drop and the layer with dust-loaded air parcel descends with dust travels downwind.

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