Monitoring Long-range Transport of Asian Dust and Air Pollutants over China with Satellite Data

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Abstract – An intense dust storm event over Mongolia and northern China region on March 19-23, 2010 and its transport over the eastern and southern China are addressed using multi-satellite observations and ground-based measurements. A time series of FY-2D China geostationary satellite with temporal resolution of an hour and HYSPLIT model are used to analyze the temporal variation of the dust event. Terra/Aqua MODIS Aerosol Optical Depth (AOD) and aerosol fine-mode fraction (FM) index are also examined to provide the information of dust presence and plume location. Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) data and ground-based lidar data were used as an additional data source to monitor the dust vertical distribution. The results of satellite observations have good consistency with ground-based air quality measurements. This integrated satellite data with ground-based monitoring data and trajectory analysis is a promising technique for improving dust storm observation and forecasts.

Keywords: Asian Dust; FY-2; HYSPLIT model; CALIPSO; MODIS; FM index; AOD

1. INTRODUCTION

Massive dust storms were often occurred in North Western China and Mongolia deserts during spring time. Due to the high spatial variability of the dust plume characteristics along its transport, remote sensing is an established method for the detection and mapping of dust events (Pavese et al., 2009). However, the ability of the satellite data to detect dust plume is limited by several factors, such as the radiative properties of dust and the underlying land/ocean surface, the cloud presence, the density of dust plumes and the algorithms used in the aerosol retrievals (Badarinath et al., 2010). Therefore, dust monitoring is better achieved by the synergetic use of multi-sensor satellite data, lidar systems (Pérez et al., 2006), surface environmental monitoring and meteorological data (Lin et al., 2007), and with the support of HYSPLIT generated back trajectories (Pavese et al., 2009).

In the present study, data from China's first operational geostationary meteorological satellites FY-2D and FY-2E as well as HYSPLIT model are used to analyze the spread of mineral dust particles over China during the dust storm period between 19th and 23rd March 2008. CALIPSO observations as well as satellite data from MODIS are also analyzed in order to provide the vertical aerosol profile and the spatial distribution of aerosols during the dust event. Ground-based respirable particulate pollution (PM10) and Air Pollution Index (API) are used to trace the dust storm and to compare with the satellite result.

2. MATERIALS AND METHOD

In order to evaluate, compare and contrast the mineral aerosols for the dust event in China, several remote-sensing data are used in the present study.

FY-2D is China's operational geostationary meteorological satellite operated by National Satellite Meteorological Center (NSMC) of China Meteorological Administration (CMA). Dust Storm Monitoring (DST) products were provided in http://fy3.satellite.cma.gov.cn/arssen/, and the dust retrieval algorithm is based on the optical and radiative physical properties of dust storm in mid-infrared and thermal infrared spectral regions as well as the observation of all bands in the geostationary imager, which include the Brightness Temperature Difference (BTD) in split window channels, Infrared Difference Dust Index (IDDI) and the ratio of middle infrared reflectance to visible reflectance (Hu et al., 2008). To evaluate a complete picture of the dust events, all the dust detection results in every hour can be accumulated to form sand dust storm (SDS) distributions for a dust occurrence frequency analysis.

MODIS has been acquiring nearly daily or global coverage data in 36 spectral bands from visible to thermal infrared. The MODIS sensor is on board the polar-orbiting NASA-EOS Terra and Aqua spacecrafts with equator crossing times of 10:30 and 13:30 Local Solar Time, respectively. Daily AOD products have been retrieved operationally from the measured top-of-atmosphere (TOA) reflectances at 10 km × 10 km resolution since February 2000 (Terra) and June 2002 (Aqua) (Remer et al., 2005).

The Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) is the primary instrument on the CALIPSO satellite. CALIOP is designed to acquire vertical profiles of elastic backscatter at two wavelengths (532 nm and 1064 nm) from a near nadir-viewing geometry. In addition to total backscatter at the two wavelengths,

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CALIOP also provides profiles of linear depolarization at 532 nm (Winker, et al., 2009). The full sets of Lidar Level 2 products are available at the Atmospheric Science Data Center (http://www-calipso.larc.nasa.gov/search/).

The Hong Kong University of Science and Technology (HKUST) operates two lidar systems at Yuen Long and Sha Tau Kok, Hong Kong. The lidar system monitors the evolution of the atmospheric boundary layer using aerosols as the tracers of atmospheric motion. Hence, it can provide information on the boundary layer height. The real-time data of the lidar systems were downloaded from the HKUST website for the sampling period (http://envf.ust.hk/).

Air Pollution Index (API) is computed as a piecewise-linear function of the daily average of the principal pollutant in the ambient air, which is defined as the one most exceeding its standard. In most of the cities in China, 85% ~ 90% of the major pollutants is PM10. Daily API reports for 86 major cities in China are released to the public every day (http://datacenter.mep.gov.cn/). Measurements of hourly PM10 and API were also taken from the Hong Kong Environmental Protection Department (HKEPD) (http://www.epd-asg.gov.hk/english/24pollu/24pc.html).

The Air Resources Laboratory's HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Draxler and Hess, 1998) is a complete system for computing both simple air parcel trajectories and complex dispersion and deposition simulations (http://ready.arl.noaa.gov/HYSPLIT.php). The model calculation method is a hybrid between the Lagrangian approach, which uses a moving frame of reference as the air parcels move from their initial location, and the Eulerian approach, which uses a fixed three-dimensional grid as a frame of reference.

3. RESULTS AND ANALYSIS

Northeast Asia, including China, Mongolia, Korea and Japan, covering 10°N–60°N and 30°E–140°E, is chosen as the domain for the operational dust product of FY-2D. A SDS distribution is generated from all results at one hour interval every day.

Figure 1 shows the dust identification IDDI images on 19 March in 2010, at 01:30, 02:30, 03:30, 04:30, 05:30, 06:30, 07:30, 08:30 and 09:30 UTC. At the beginning phases, the dust outbreak formed at the border area between Mongolia and China at 01:30 UTC, and then it strengthened quickly in two hours and extended to the middle-east region. At the same time there was another relatively weak dust event came into being in the Taklamakan desert in Xinjiang province. The dust storm process had already attached into Neimenggu, Ningxia and Gansu provinces at 07:30 UTC. This dust layer was continuously increasing in thickness and moving southeast, affecting Shangdong, Anhui and Jiangsu provinces and the Huanghai Sea of China at 08:30 UTC.

Except for the dust storms, anthropogenic emissions over East Asia also received much attention recently. Takemura et al. (2002) pointed out that 50% of the total optical thickness around Japan is due to anthropogenic aerosols during the strong Asian dust events. The method proposed by Barnaba and Gobbi (2004) is implemented here to distinguish the desert dust aerosols from others. Terra/Aqua MODIS AOD values at 550 nm as well as aerosol fine-mode fraction (FM) index are extracted from MOD04/MYD04 products. The threshold values for the desert dust aerosols were selected to be $AOD_{550} > 0.3$ and $FM < 0.5$. Figure 2 shows dust aerosols obtained from Aqua-MODIS as well as API values from 86 major cities in China on 21 and 22 March 2010. API due to anthropogenic aerosols generally less than 300, but API can reach to 500 during very short time when dust storm occurs. Figure 2(a) shows that the thick dust plume on 21 March 2010 moved to Anhui, Jiangsu, Shangdong, Fujian provinces, and then mostly eastward toward Donghai Sea and Japan. The daily API in Jiangsu, Anhui and Fujian provinces were more than 300, which also confirmed the transport paths of dust aerosols. From Figure 2(b), we can see that the transport pathways of the dust plumes turned to southeast coast of China on 22 March 2010. Dust plumes transported along the Chinese coast from Shanghai across the Taiwan Strait and finally reached Hong Kong, also confirmed by the high API along the coastal cities. Figure 3 shows 24 hours PM10 ($\mu g/m^3$) concentration of Tai Po station in Hong Kong from 21 March 2010 to 24 March 2010. PM10 of Tai Po experienced an unusually increase from 98 to 683 $\mu g/m^3$ during 4 hours (from 17:00 to 21:00 LST) on 21 March 2010.

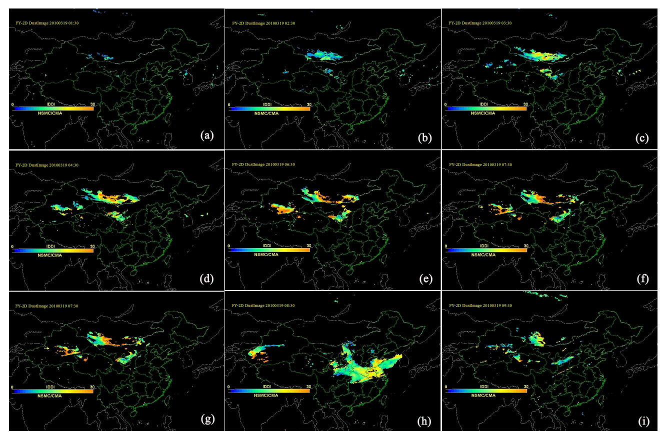

Figure 1. Dust event motion animation detected by FY-2D on 19 March 2010, (a)-(i) 01:30 ~ 09:30 UTC.

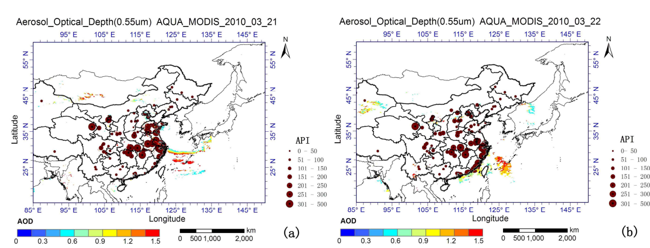

Figure 2. Dust aerosols ($AOD_{550} > 0.3$ and $FM < 0.5$) obtained from MODIS plus API values from 86 major cities in China on (a) 21 March 2010 and (b) 22 March 2010.

Both FY-2D and MODIS AOD measure the columnar aerosol properties without providing any information about the vertical structure of the aerosols. However, in many cases the surface aerosol properties may be different from columnar ones because of the presence of distinct aerosol layers above (Satheesh et al., 2006). Therefore, knowledge of the vertical distribution of the aerosols in the atmosphere is important. Figure 4 shows the overpass trajectory, the vertical profile of the total attenuated backscatter at 532 nm and the aerosol subtype image for daytime (05:09~05:23 UTC) over China obtained from CALIPSO observations on 21 March 2010. The aerosol subtype image highlights the signals into 7 categories. The category 2 (in yellow) has a greater importance as well as the presence of dust. In the lower part of the figures, the coordinates of the overpass (latitude above and longitude below) are also given. The daytime pass of CALIPSO at 05:09~05:23 UTC (13:09~13:23 LST) mainly covers a part of northeast China and southeast coast of China, where the dust storm occurred. Figure 5 shows lidar-normalized relative backscattering signal monitored in Sha Tau Kok of Hong Kong on 21 and 22 March 2010. Vertical distribution of dust aerosols was mainly below 500 m, corresponding to the high backscattering signal. It is important to note that mineral dust presumably reached Hong Kong after 16:00 LST, which was earlier than deduced from routine environment monitoring data that the first peak of hourly PM10 concentration at 18:00 LST at Tai Po station.

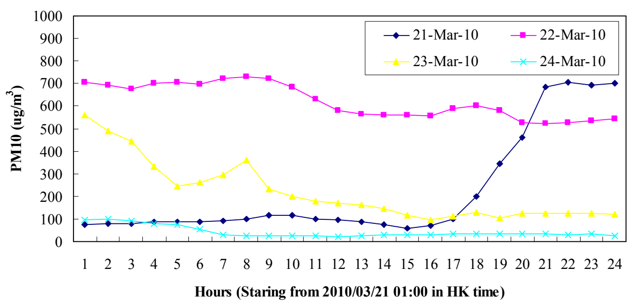

Figure 3. 24 hours PM10 ($\mu g/m^3$) concentration of Tai Po station in Hong Kong from 21 March 2010 to 24 March 2010.

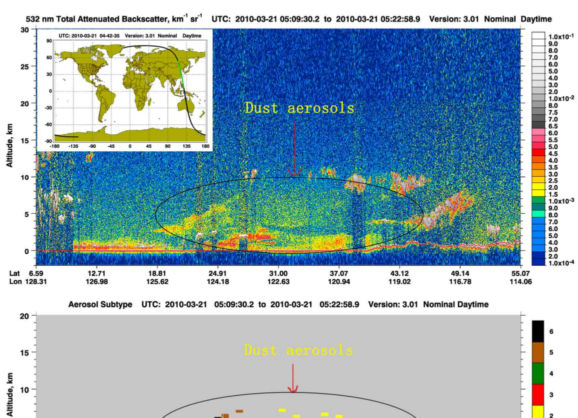

Figure 4. Total attenuated backscatter profiles at 532 nm and the aerosol subtype image for daytime (05:09~05:23 UTC) over China obtained from CALIPSO observations on 21 March 2010.

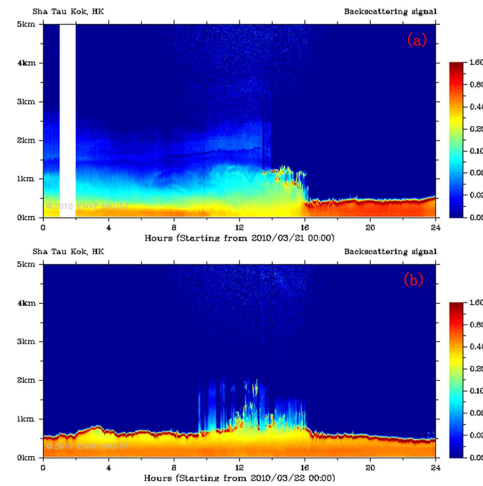

Figure 5. Time series of lidar-normalized relative backscattering signal observed in Sha Tau Kok of Hong Kong on (a) 21 March 2010 and (b) 22 March 2010.

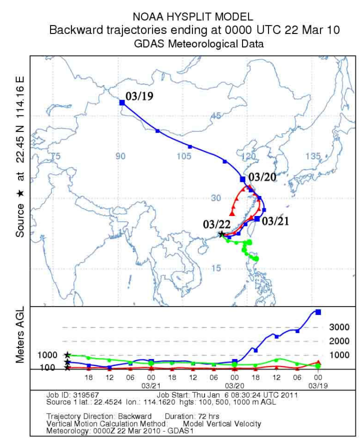

Figure 6. Result of the HYSPLIT model 3-day backward trajectory analysis started at altitudes of 100, 500 and 1000m at 00:00 UTC (08:00 LST) at Tai Po station in northern Hong Kong on 22 March 2010. The top and bottom panels display horizontal and vertical motion. Symbols denote the location of the air parcel every 6 hours.

In order to identify the sources and to examine how transport paths affect the concentrations of air pollutants, a three-day backward trajectory analysis was preformed for this case. The analysis was computed using the HYSPLIT model. The 72-h backward trajectory analysis was performed for altitudes of 100, 500, and 1000 m at Tai Po station in northern Hong Kong starting from 00:00 UTC (08:00 LST) on 22 March 2010, as shown in Figure 6. The backward trajectory analysis in Hong Kong showed that the air parcels at 500 m with the source of air masses originated from desert areas at the border area between Mongolia and China. During three days of transport, the air parcels of 100 m and 500 m are mostly at relatively low altitude (below 1000 m). In other words, air masses are mostly transported in the low boundary during the transport periods. The air parcels of 500 m broadly reflect one of the transmission paths of this dust storm event.

The integration usage of satellite data from multiple satellite sensors, in situ measurements and the HYSPLIT model shows the promising results on the dust storm monitoring. The results showed that the dust outbreak formed at the border area between Mongolia and China at 01:30 UTC on 19 March 2010, and then it strengthened quickly in two hours and extended to the middle-east region. At the same time there was another relatively weak dust event came into being in the Taklamakan desert in Xinjiang province. The dust storm process had already attached into Neimenggu, Ningxia and Gansu provinces at 07:30 UTC on 19 March 2010. This dust layer was continuously increasing in thickness and moving southeast, affecting Shangdong, Anhui and Jiangsu provinces and the Huanghai Sea of China on 19 and 20 March 2010. The thick dust plume on 21 March 2010 moved to Anhui, Jiangsu, Shangdong, Fujian provinces, and then mostly eastward toward Donghai Sea and Japan. Dust plumes transported along the Chinese coast from Shanghai across the Taiwan Strait and finally reached Hong Kong on 22 March 2010.

4. CONCLUSIONS AND FUTURE WORK

In the present study, a springtime intense dust storm occurred in China was investigated via remote-sensing observations and ground-based measurements. It is reasonable to conclude that recent progress in satellite remote sensing technology and data analysis has enabled the successful identification of dust storms from satellite imagery. The combined use of satellite sensors with ground-based measurements and trajectory analysis provide an adequate dust monitoring system, as multi-sensor satellite data could provide a tridimensional space information and intensity information of dust storms and with the help of trajectory analysis could reappearance the transport path of the dust storm. Since the contribution of dust to the total atmospheric aerosol load is significant, future efforts in examining the global climate could focus their main efforts on understanding the role of dust in the climate system.

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