An Unreported Asian Dust (Kosa) Event in Hokkaido, Japan: A Case Study of 7 March 2016

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Abstract

Monitoring particulate matter is essential to alert the public about health risks. The Terra/MODIS true color image clearly captured a yellow band over Hokkaido prefecture in Japan on 7 March 2016. We investigated whether this event was an Asian dust (Kosa) transport or not with the ground-based observations in Sapporo and Takikawa in Hokkaido and NASA's MERRA-2 re-analysis data. The timing of increased particle number concentrations (PNCs; greater than 0.5 μm) was clearly measured by a low-cost aerosol sensor at Sapporo and Takikawa in the early afternoon. For this particle size range, the PNC by this aerosol sensor had greater agreement with another commercial instrument for the 1-hourly mean data. The lidar data at Takikawa and NASA's AERONET at Sapporo also implied the increased dust particles (i.e., dominance of non-spherical and coarse particles, respectively), which supported that the PNC increase was due to the dust transport. The hourly $PM_{2.5}$ data in Sapporo significantly increased in the evening rather than around the noon to early afternoon. We concluded that this event was judged as an Asian dust (Kosa) event in Hokkaido starting from the early afternoon, which was, however, not reported by Japan Meteorological Agency (JMA) based on their visible observations.

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1. Introduction

Asian dust, or Kosa (in Japanese), has been well known as a spring phenomenon. The Kosa has been often transported to Japan (e.g., Iwasaka et al. 1983; Osada et al. 2011; Yasunari et al. 2016) and to remote regions such as the USA, Canada, Greenland, etc. (e.g., Rahn et al. 1977; Biscaye et al. 1997; McKendry et al. 2001; Yasunari et al. 2007; Yasunari and Yamazaki, 2009). Uno et al. (2009) also reported the case of global one-circuit transport of Kosa. Kosa has a typical particle size of around 4 μm when it is transported to Japan (Mori et al. 2003).

The Japan Meteorological Agency (JMA) has reported Kosa days since 1967 based on the visibility measurement (http://www.data.jma.go.jp/gmd/env/kosahp/kosa_data_index.html). However, this visibility method has not always been entirely accurate to judge Kosa days. For example, several studies reported their own "judged" Kosa days based on the methods different from that used by JMA (Matoba et al. 2005; Mizoguchi et al. 2009; Yasunari et al. 2016). These previous studies could imply that the number of Kosa days reported by JMA might be smaller than the actual number of Kosa days, that should have been reported.

In Hokkaido prefecture, a relatively small number of Kosa days has been reported by JMA since 1967 (Fig. 1). However, there were two Kosa-active time periods in Hokkaido during which Kosa days were observed more frequently than the other years (Fig. 1). During the late 1970s to early 1980s, and since 2000, Kosa transports to Hokkaido prefecture were more frequently observed by JMA, compared to the other time periods. It seems that the Kosa days in Hokkaido have become more active since 2000. However, as mentioned in the previous paragraph, it is possible that the reporting method by JMA sometimes could not judge Kosa days.

In a recent review paper by Hashizume et al. (2010), they summarized the effect of Kosa on human health based on the previous studies. Then, they pointed out that mass concentration of each Kosa event should be considered for the assessment of Kosa impact on human health rather than just using the number of Kosa

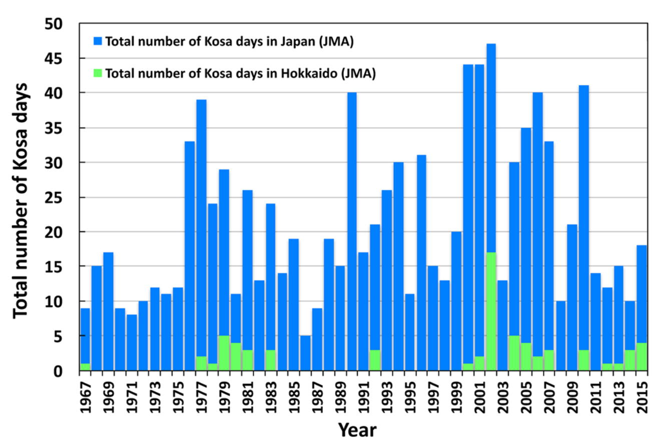

Fig. 1. Historically observed total number of Kosa days in Japan and Hokkaido prefecture since 1967 by JMA. The data are available at and were obtained from: http://www.data.jma.go.jp/gmd/env/kosahp/kosa_data_index.html. If any sites in Hokkaido observed Kosa on a certain day, we manually counted the number of cities for Kosa days in Hokkaido prefecture.

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days. In addition, Kanatani et al. (2010) also reported significant increase in risk during the heavy Asian dust events, referring to hospitalizations of children due to asthma. Therefore, the monitoring of Asian dust is very important for assessing health risk in Japan. Furthermore, to continue the long-term Kosa-day measurement by JMA, other supportive measurements would be essential for more accurate Kosa judgements and to reduce the probability of unreported Kosa days.

On 7 March 2016, we could see a clear yellow band over Hokkaido prefecture by the Terra satellite image with the MODerate resolution Imaging Spectroradiometer (MODIS) (Fig. 2a). However, on this day, no Kosa events were reported by JMA not only in Hokkaido prefecture (see more information in the Supplemental Information, SI Text) but also in the other prefectures in Japan (http://www.data.jma.go.jp/gmd/env/kosahp/kosa_table_2016.html). Therefore, in this study, the purpose of this study is to investigate the aerosol characteristics for the yellow band event using ancillary ground-based observations with a re-analysis data, and to examine whether this event can be judged as Kosa or not.

2. Method: Observed data

To discuss the atmospheric pollution variability, we installed the so-called Sensor Stations (SS) at Sapporo (on the campus of Hokkaido University: 43.0857°N; 141.3367°E; 2.1 m a.g.l.) and Takikawa (Takikawa Skypark; 43.5473°N; 141.8966°E; 35 m a.g.l.) in Hokkaido, including ozone and aerosol sensors (Figs. S1a, S1b, and S1d), which have been discussed in the previous studies (e.g., Utiyama et al. 2014a, 2014b). The aerosol sensor was produced by Shinyei Technology Co. Ltd. and is a low-cost aerosol sensor (cheaper than 100,000 JPY) (Shinyei Technology Co. Ltd., 2016, personal communication). Although the type of aerosol sensor used in our study (AES1) uses the heater-generated updraft system and is different from that used in Utiyama et al. (2014a) in terms of air flow system, Utiyama et al. (2014a) confirmed that the aerosol sensor has sensitivities for the particles of 0.3−2.5 μm compared to the standard particles and they also found the sensor sensitivity during a Kosa event. The AES1 used in this study has two particle size ranges: particle number concentrations with 1) size range of ≥ 0.3 μm, and 2) size range of ≥ 0.5 μm. We use the data from these two particle size ranges and the difference between the two size ranges. Note that the current commercial aerosol sensor only provide the single particle size range of ≥ 0.5 μm (see at: http://www.shinyei.co.jp/stc/eng/optical/main_aes1.html), but the performance of the sensor is essentially the same as that of the two particle-size-range sensor (i.e., our sensor) (Shinyei Technology Co. Ltd., 2016, personal communication). Although Utiyama et al. (2014a) has already compared the aerosol sensor with a $PM_{2.5}$ instrument, here we also carry out another comparison with a well-established instrument for measuring particle number concentrations (PNCs). To see the interchangeability of the data (note that we do not intend to discuss which one is more correct or accurate in this study), the independent PNC data by KC-01D (RION Co., Ltd.; known as Optical Particle Counter, OPC; Fig. S1c) are also used to compare the data from the aerosol sensor. Hereafter, we call the aerosol sensor in Sensor Stations as SS and KC-01D as OPC for its simplicity. More information on the data treatments can be found in SI Text.

The NASA's AErosol RObotic NETwork (AERONET: http://aeronet.gsfc.nasa.gov/) is probably one of the widely-used ground-based aerosol measurements (e.g., Holben et al. 2001). An AERONET site was recently installed at the rooftop of the Faculty of Engineering in Hokkaido University in October 2015 in collaboration with NASA (see the website in Japanese: http://www.eng.hokudai.ac.jp/graduate/top/news/?topic=15102301) and its level 2.0 data are used for comparing size distributions during, before, and after the yellow band event.

The ground-based lidar measurements have been carried out by the National Institute for Environmental Studies (NIES) in Japan so far (see at: http://www-lidar.nies.go.jp/). The one of the lidars was installed at Takikawa (43.55°N; 141.90°E; 30 m a.s.l.; based on Google Earth), which is located at the same place where the SS at Takikawa was installed, using the lasers with the wavelength of 532 nm and 1064 nm for attenuated backscatter coefficient and depolarization ratio (see at: http://www-lidar.nies.go.jp/Takikawa/). Because the depolarization ratio is available, the lidar data can provide us the information on non-spherical particles such as dust particles (e.g., Shimizu et al. 2004; Osada et al. 2011; Yasunari et al. 2016). We use the calculated dust and spherical extinction coefficients of the lidar data (Sugimoto et al. 2003; Shimizu et al. 2004) at Takikawa to confirm Kosa (dust) transports there (also see SI Text).

We also use "provisional" $PM_{2.5}$ data, which were obtained from the Atmospheric Environmental Regional Observation

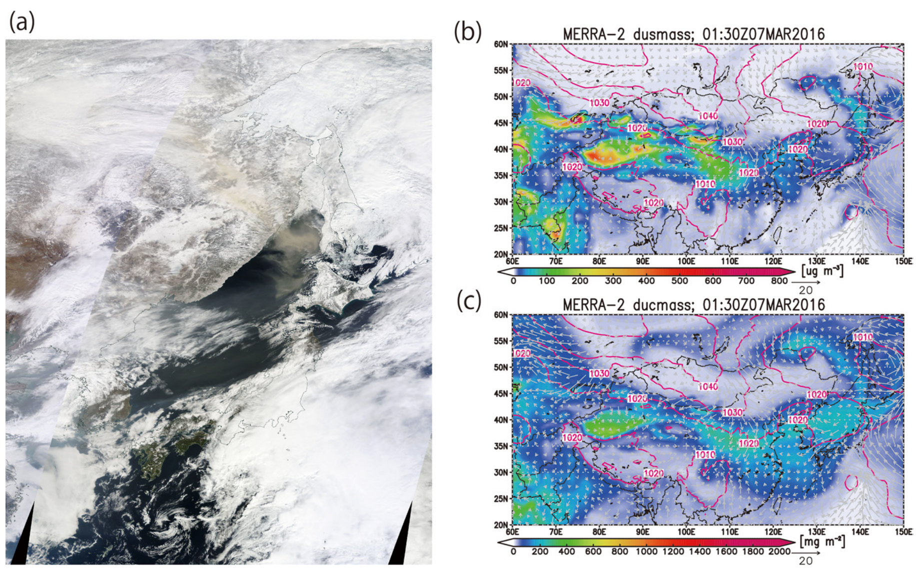

Fig. 2. Satellite image and MERRA-2 data on 7 March 2016. (a) Terra MODIS True Color image obtained from the NASA's Worldview website (https://worldview.earthdata.nasa.gov/); (b) Hourly mean surface dust mass concentration in the surface layer (i.e., in the pressure thickness of the surface layer) of the MERRA-2 reanalysis data (shaded contour) with 10-m wind vectors (in gray; plotted every three gridded data in latitude and longitude; unit of m s^{-1}) and sea level pressure (pink contour; unit of hPa); (c) Dust column mass density with the same wind vectors and sea level pressures as in Panel (b). The time for Panels (b) and (c) is shown in UTC.

System (AEROS) managed by the Ministry of Environment, Japan (http://soramame.taiki.go.jp). Because of the provisional values, we manually removed unrealistic $PM_{2.5}$ values in Sapporo (i.e., too large and/or negative values). To discuss the Kosa transport on the satellite view, we use a satellite image obtained from NASA's Worldview website (see at: https://worldview.earthdata.nasa.gov/).

Other necessary information on the methods and data were summarized in SI Text.

3. Method: MERRA-2 reanalysis data

NASA has a history of producing gridded re-analysis data, the Modern-Era Retrospective Analysis for Research and Applications (MERRA) reanalysis data (Rienecker et al. 2011). Recently, the next version of re-analysis data, called MERRA-2, was released (Bosilovich et al. 2015), in which aerosol components were produced using the GOCART module (e.g., Chin et al. 2000, 2002; Ginoux et al. 2001; Colarco et al. 2010) in the Goddard Earth Observing System, version 5 (GEOS-5) (Rienecker et al. 2008). The aerosol data assimilation method uses MODIS, and other stellated-derived and ground-based Aerosol Optical Depth (AOD) data (e.g., Buchard et al. 2016b; Randles et al. 2016, 2017). The aerosol data assimilation method in MERRA-2 (Bosilovich et al. 2015, Buchard et al. 2016b; Randles et al. 2016, 2017) was advanced from the product of MERRAero (e.g., Provencal et al. 2014; Buchard et al. 2015, 2016a). We use the hourly mean MERRA-2 outputs (0.5° × 0.625° in latitude and longitude) and calculated $PM_{2.5}$ data with the method proposed by Buchard et al. (2016a).

4. Inter-comparisons of PNC between SS and OPC

Before starting the main discussion on the air pollution characteristics on 7 March we carried out inter-comparisons of PNC data measured by SS and OPC to check the PNC interchangeability. The hourly mean data at Sapporo on PNC data for SS and OPC in three different particle size ranges were used for this purpose. All three size ranges showed high correlations between SS and OPC (Fig. 3). The highest R^2 was seen for the particle size range (PSR) of ≥ 0.5 μm (Fig. 3b). In addition, the lowest R^2 were seen for 0.3−0.5 μm in the three ranges (Fig. 3c). This indicates that the detectability of the finer aerosol particles by SS was still high but lower than that of PSR of ≥ 0.5 μm. This characteristic was also seen in the similar aerosol sensor but with the different air flow system (Utiyama et al. 2014a). Utiyama et al. (2014a) discussed that this sensitivity was due to smaller scattering intensity of finer aerosol particles. Higher PNC cases detected by OPC were not well reproduced in the SS data (Fig. 3). This is another current issue of the aerosol sensor probably due to its upper limits (see SI Text), which should be improved in the future. In any case, the current commercial product has the only one PSR (i.e., ≥ 0.5 μm: http://www.shinyei.co.jp/stc/eng/optical/main_aes1.html), our result confirmed that the PNC data by SS have the great interchangeability to those by OPC. Based on above, discussions with the PSR of ≥ 0.5 μm would be more useful for future usages and sensor applications, and we use the PNC data in this coarser size range in the following section.

5. Characteristics of the yellow band event

On 7 March 2016, the yellow band reached Hokkaido prefecture (Fig. 2a). Surface dust mass concentration (Fig. 2b) and column mass density of dust (Fig. 2c) from the MERRA-2 data increased, suggesting that the yellow band was likely associated with the dust transport. If we look at the MERRA-2 dust movie (Mov. S1), the dust plume was kicked off from the Gobi Desert region on 3−4 March concurrent with the dust outbreaks over the Taklamakan desert region. A branch of the dust plume was transported to the Hokkaido area along the developed low pressure

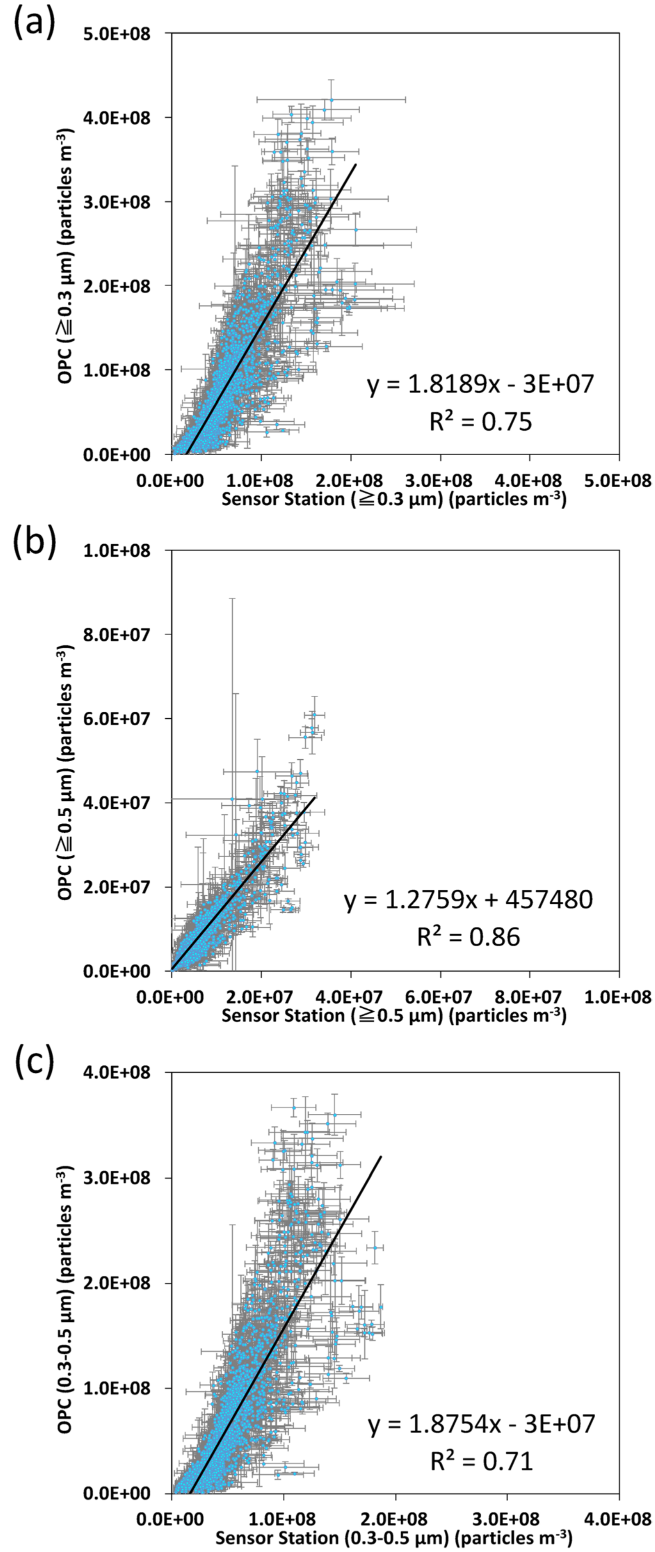

Fig. 3. Comparisons of the calculated hourly mean PNCs between SS and OPC measurements for the particle size rages of (a) ≥ 0.3 μm, (b) ≥ 0.5 μm, and (c) 0.3−0.5 μm based on the available data during 12:00 JST, 25 November 2015, and 10:00 JST, 30 March 2016 (see more detailed information in SI Text). The error bars denote the standard deviations from the mean data. The R^2 values were rounded to two decimal places.

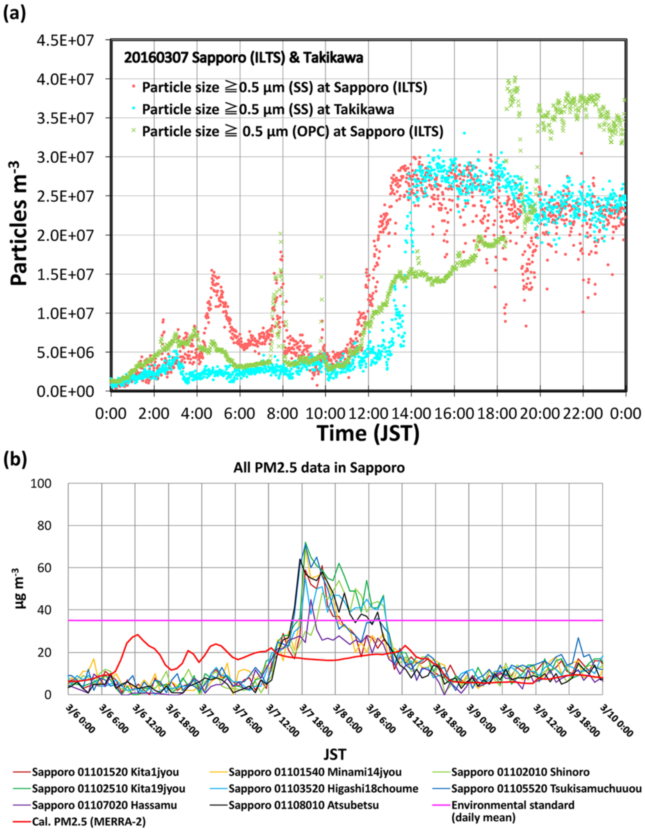

Fig. 4. Characteristics of (a) PNC data at Sapporo (measured by SS in red and OPC in light green and cross) and Takikawa (measured by SS in light blue) on 7 March 2016, and (b) $PM_{2.5}$ data at the eight stations in Sapporo during 6 and 10 March 2016. The calculated $PM_{2.5}$ from the MERRA-2 data with the method of Buchard et al. (2016a) is shown in red. The pink line in Panel (b) is the environmental standard for the daily mean $PM_{2.5}$ in Japan of 35 µg m^{-3} (defined by the Ministry of Environment, available in Japanese at: http://www.env.go.jp/air/osen/pm/info.html#STANDARD; shown for reference).

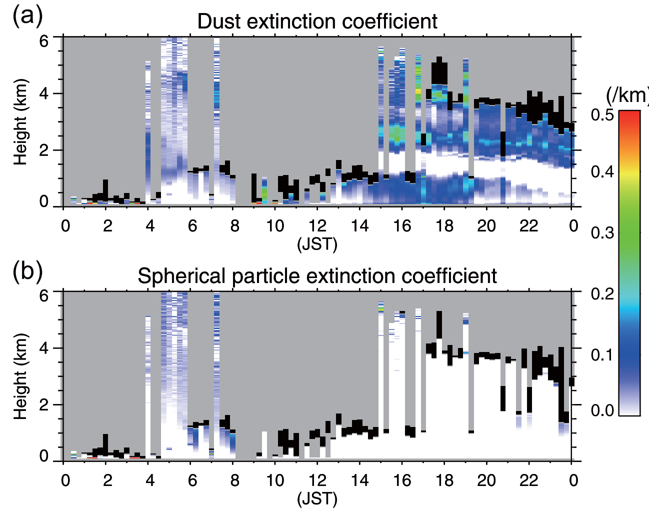

Fig. 5. Calculated (a) dust and (b) spherical particle extinction coefficients at 532 nm from the ground-based lidar data at Takikawa on 7 March 2016. Note that the data in black and gray denote clouds and unobservable areas because of the heights above clouds, precipitation, etc., respectively.

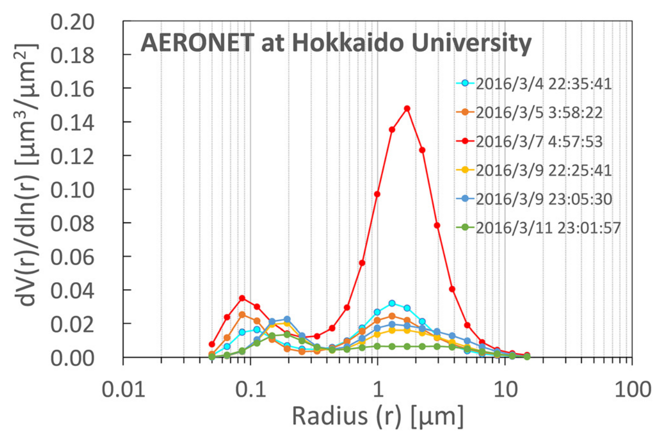

Fig. 6. Aerosol particle size distributions from the AERONET Level 2.0 data at Hokkaido University in Sapporo on 7 March 2016, and before and after that day. The time shown here is in UTC.

system in East Asia (Mov. S1 and Figs. 2b and 2c). Based on the hourly horizontal $PM_{2.5}$ map over Japan (Mov. S2), we found that this Kosa plume only impacted on the increase of $PM_{2.5}$ in Hokkaido prefecture. Other areas in the northern part of Japan did not show such increases of $PM_{2.5}$ during this period (Mov. S2).

On the same day, the PNCs by SS at Sapporo and Takikawa started greatly increasing in the early afternoon by 14:00 JST (Fig. 4a). The spike-like peak by SS at around 8:00 JST, which coincided with that of OPC, which could be judged as a local aerosol event because of the very short time period. Although the PNC by OPC at Sapporo also started increasing from around noon, its degree of increase was much smaller than that of SS (Fig. 4a). Moreover, we found that the peaks of PNC measured by OPC and the observed $PM_{2.5}$ data in Sapporo were both after around 18:00 JST (Figs. 4a and 4b). The calculated MERRA-2 $PM_{2.5}$ showed some increase but its peak was not clear (Fig. 4b). Therefore, if there were no observations by SS in Sapporo, we could not know the correct start timing of the dust event and misunderstood that it mainly started from the evening. The mismatch of the data between SS and OPC can be explained by several reasons and/or their combinations such as the differences of particle size sensitivities and linearity of each sensor on the data, the SS limitations (see Section 4 and SI Text), etc. In any case, the SS had higher sensitivity for the polluted air mass in the early afternoon. Then, if we looked at the lidar data at Takikawa on dust extinction coefficient (Fig. 5a), we could confirm that the amount of dust (i.e., non-spherical particles) in the lower troposphere (lower than 500 m) clearly increased after 14:00 JST (getting blue color darker after this time), which is consistent with the increased PNC by SS shown at Takikawa. Furthermore, at Sapporo (Hokkaido University), the AERONET data at 4:57 UTC (i.e., 13:57 JST) also did show the dominance of coarser particles of greater than 1.0 µm in radius in the particle size distribution (Fig. 6). If we compare the size distribution to those before and after 7 March, it is obvious that the magnitude of the distribution on 7 March was much larger than those before and after the event. In addition, the peak radius size of the coarse mode on 7 March was larger than those before and after 7 March. These indicate the dominance of non-spherical and coarser size aerosol particle (i.e., dust particles) at the beginning of the event as an unusual case (Figs. 5 and 6). This also supports the start timing of the Asian dust transport to Sapporo was in the early afternoon. Therefore, these results indicate that the Asian dust plume started reaching Sapporo and Takikawa (i.e., western parts of Hokkaido) during 12:00–14:00 JST, and the main dust air mass was passing after 14:00 JST there. Another feature of this dust event is that dust particles in the $PM_{2.5}$ size were dominant after the evening at around 18:00 JST (Fig. 4b). We can suggest that if we only rely on, for example, the observed $PM_{2.5}$ data in Sapporo from the AEROS network, we would probably miss the right timing of Asian dust arrival there because of the weaker signals of $PM_{2.5}$ in the early afternoon. In addition, JMA could not report any Kosa events in Hokkaido (even in Japan) based on their visibility measurements on and around 7 March (http://www.data.jma.go.jp/gmd/env/kosahp/kosa_table_2016.html). In conclusion, we are convinced that the low-cost aerosol sensor, AES1, was very useful for judging this Kosa event in terms of clearly detecting the start timing of the Asian dust transport because of its high sensitivity for the PNC data at the beginning of the dust transport as shown in Fig. 4a though it still has some issues to capture whole the characteristics of the dust event as discussed above.

6. Conclusions and summary

We identified that the satellite-detected yellow band heading to Hokkaido on 7 March 2016 (Fig. 2a) was due to an Asian dust (Kosa) transport event based on the available ground-based observations together with the MERRA-2 data. The timing of the dust increases at the surface level was clearly captured by the low-cost aerosol sensor (AES1; Shinyei Technology Co., Ltd.) at Sapporo and Takikawa in Hokkaido prefecture. At Takikawa, the timing of the PNC increase was consistent with the increase of dust extinction coefficient measured by the ground-based lidar there. However, in Sapporo, the OPC and $PM_{2.5}$ data showed the time-lagged peaks from the evening after the actual dust arrivals in Sapporo in the early afternoon, which may sometimes let people misunderstand the start timing of the dust event. Combination of the different observations like in this study would reduce the probability of such misleading. Although we should appreciate the long history of JMA's visibility measurements for detecting Kosa since 1967 (see at: http://www.data.jma.go.jp/gmd/env/kosahp/kosa_data_index.html), we suggest and/or encourage the additional operation of a hybrid Kosa measurement by JMA in the near future, including the low-cost sensor together with the ongoing visibility measurement. Then, this kind of aerosol events can be judged as Asian dust events by JMA in the future. This would help to reduce the probability of unreported Kosa events in Japan. Furthermore, because of its low cost, the usage of the aerosol sensor would also be very cost-efficient for future measurements of dust and/or $PM_{2.5}$ related aerosol events. However, still a lot of works are needed for future development of the low-cost sensor. For example, the lidar data at Takikawa detected the dual-layer structures of Asian dust (Fig. 5a), but single sensor at the near surface level is not capable for depicting such vertical structures. In addition, the weaker or lacking detectability of the sensor to higher aerosol concentrations would also be an issue and its improvement will be necessary. More developments and its validations on this kind of low-cost aerosol sensor with other aerosol data would be essential for these purposes.

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Supplement

Supplemental Information (SI) includes SI Text, Fig. S1, and movies, Mov. S1 and S2.

Captions for SI Movies:

Mov. S1. Movie on dust transport based on the hourly mean surface dust mass concentration (top) and dust column mass density (bottom) from the MERRA-2 re-analysis data. See the figure caption on Fig. 2b and 2c for the data and unit information, but the sea level pressure is shown in black contour here. The time period is during 00:30 UTC on 2 March and 23:30 UTC on 9 March in 2016.

Mov. S2. Movie on hourly $PM_{2.5}$ distributions over Japan based on the AEROS data (filled circle in color) with wind fields (vector). More information on the data are available in SI Text. The time period is during 01:00 JST on 7 March and 00:00 JST on 9 March in 2016.

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