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Quiescence of Asian dust events in South Korea and Japan during 2012 spring: Dust outbreaks and transports

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HIGHLIGHTS

- Quiescence of Asian dust in South Korea and Japan for spring 2012 was confirmed.
- In March and May 2012, decreased dust outbreaks over source regions were observed.
- We confirmed that dust outbreaks for April 2012 were similar to previous years.
- In April 2012, southeastward pathway of dust was blocked by anomalous anticyclone.

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ABSTRACT

This study examined the quiescence of Asian dust events in South Korea and Japan during the spring of 2012, presenting a synoptic characterization and suggesting possible causes. Synoptic observation reports from the two countries confirmed that spring 2012 had the lowest number of dust events in 2000–2012. The monthly dust frequency (DF) in March 2012 over the dust source regions, i.e., deserts in northern China and Mongolia, indicated a significant decrease compared to the 12 year (2000–2011) March climatology. The DF in April 2012 was comparable to the 12 year climatology values, but in May 2012 it was slightly lower. The daily Ozone Monitoring Instrument Aerosol Index and the Navy Aerosol Analysis and Prediction System simulations revealed stagnant dust movement in March and May 2012. Anomalous anticyclones north of the source regions decreased the dust outbreaks and enhanced the southeasterly winds, resulting in few dust events over the downwind countries (i.e., South Korea and Japan). By contrast, in April 2012, a strong anomalous cyclone east of Lake Baikal slightly increased the dust outbreaks over northeastern China. However, the major dust outbreaks were not transported downwind because of exceptional dust pathways, i.e., the southeastward pathway of dust transport was unusually blocked by the expansion of an anomalous anticyclonic circulation over the Sea of Okhotsk, with dust being transported northeast.

1. Introduction

The extensive arid or semiarid highlands of northern China and Mongolia (i.e., Taklimakan desert, Gobi desert, Loess Plateau, and Hunshdak Sandy Lands) represent major sources of dust in Asia (Prospero et al., 2002; Washington et al., 2003; Zhang et al., 2008; Gao et al., 2012). Compared to the Chinese anthropogenic emissions of about 280 Tg (Zhang et al., 2009), the annual emissions from these regions are much larger (460–800 Tg), with half of the dust being transported over long-ranges to Korea, Japan, the North Pacific, and beyond (Zhang et al., 1997; Husar et al., 2001; Sun et al., 2001; Liu et al., 2004; Laurent et al., 2006; Uno et al., 2009), and potentially affecting a wide range of climatic and environmental phenomena downwind.

Every spring, a strong cold wave from Siberia and Mongolia, and cyclone activity around the dust source regions generate strong air motion, providing the dynamic conditions for the development of dust storms (McKendry et al., 2001; Sun et al., 2001; Qian et al., 2002, 2004). The originating dust is normally transported east or

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southeastward within 2–3 days of formation by strong northwesterlies accompanied by low pressure systems (Wang et al., 2000; Chun et al., 2001a, 2001b; Kwon et al., 2002; Tian et al., 2007; Kim, 2008). Asian dust events occurring downwind (e.g., eastern China, Korea, and Japan) are directly related with the variation in dust outbreaks in the source regions and dust transport pathways to the surrounding areas. The outbreak and transport of Asian dust have been often observed from ground-based stations, aircraft, and satellites, with many studies focusing on severe events which occurred in the past decade (e.g., springs of 2001, 2002, 2006, and 2010) (Sakai et al., 2002; Park and In, 2003; Sugimoto et al., 2003; Darmenova et al., 2005; Sugimoto et al., 2005; Lim and Chun, 2006; Zhang et al., 2008; Tsai et al., 2014). Sugimoto et al. (2003) analyzed the heavy Asian dust event in Beijing in 2002 using observations and model simulations and suggested that a change in the transport pattern due to a slight variation in the regional climate features could cause large differences in the dust events in Korea and Japan. Furthermore, considering the geographical location of the downwind areas, the air quality over eastern China is more affected by Asian dust than Japan. However, dust events in Korea strongly varied, with dust outbreaks and transport patterns affected by the simultaneous synoptic conditions, which are relevant for the study of the annual variability of spring dust events.

In the springs (March–May) of 2000–2011, dust events in South Korea lasted on average 6.6 days in duration (http://www.kma.go.kr/weather/asiandust/observday.jsp). The annual dust events showed large inter-decadal variations, with an increase in dust days in the recent decade of about 37% compared to the previous two decades (7 days in 2000–2010 versus 5 days in 1981–1999). Additionally, the maximum recorded frequency (27 days) occurred in 2001, while the most severe events were observed in March and April 2002 (Sugimoto et al., 2003; Darmenova et al., 2005; Lim and Chun, 2006). However, in 2012, no dust events occurred in South Korea. This highly unusual lack of dust events may be due to the decrease in dust outbreaks in the source regions and/or different dust transport pathways. This study examined the various dust-related processes in Korea, to identify the possible causes behind these variations and potentially improve long-term dust event forecasting in Korea.

In this paper, Section 2 gives a brief description of the data used, while in Section 3, the synoptic characteristics causing severe dust events in South Korea and Japan are described. Section 4 presents an overview of the Asian dust activity in 2012 spring, with the dust frequency in the source and downwind regions analyzed in Section 4.1, the dust transport patterns and associated daily synoptic conditions described in Section 4.2, and the monthly synoptic conditions and possible causes for the lack of dust events in 2012 spring, and especially in April, analyzed in Section 4.3. Finally, the results are summarized and the implications discussed in Section 5.

2. Methodology

The dust frequency (DF) over the source region (northern China and Mongolia) and downwind (South Korea and Japan) regions for 2000–2012 were examined using 3 h synoptic observation (SYNOP) reports, which are meteorological reports sent worldwide by the World Meteorological Organization (WMO) through the global telecommunication system (GTS). These reports, including weather codes and meteorological variables, were obtained from the Korean Meteorological Administration (http://www.kma.go.kr/index.jsp). As noted by Kurosaki and Mikami (2003) and Park and In (2003), dust storms (codes #9, 30–35, and 98) and blowing sand (codes #6–8) should be included when considering the DF in both source and downwind regions. For quality control, the SYNOP reports were only selected when they included at least 330 daily reports per year or when at least four daily 3 h reports were submitted for the analysis period.

Fig. 1 depicts the selected 97 SYNOP stations and three regions, including the major dust sources in northern China and Mongolia. In addition, 109 SYNOP stations from South Korea and Japan are shown. Region R1 (35°–45°N, 75°–95°E) covers the Xinjiang Uygur region, including the Taklimakan, Gurbantonggut, and Kumtag deserts. Region R2 (35°–50°N, 95°–110°E) covers the arid regions of northern China and Mongolia, including the Gobi, Badain Jaran, Tenger, and Ulan Buh deserts. Region R3 (40°–50°N, 110°–125°E) includes the Otindag and Hunshdak sandy lands in the middle of Inner Mongolia and northeastern China. The division of these three regions was empirically based on the divergent characteristics (i.e., generating mechanisms and long-term trends) of dust outbreaks depending on the source regions (Xuan et al., 2004; Zhu et al., 2008; Lee and Sohn, 2011; Gao et al., 2012; Lee et al., 2013).

To investigate the details of the 2012 spring dust events in the source regions and the related transport pathways downwind, the daily Ozone Monitoring Instrument Aerosol Index (OMI AI) with a resolution of $1^\circ \times 1^\circ$ in latitude and longitude was analyzed (http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/omto3d_v003.html). The AI concept based on Total Ozone Mapping Spectrometer (TOMS) observations in the near ultraviolet (UV) region was applied to the OMI measurements (Veihelmann et al., 2007). Because the OMI AI detects UV-absorbing aerosol particles such as mineral dust and smoke through the spectral difference between the 340 and 380 nm, the AI provides information about the horizontal distribution of dust over the land and ocean surface (Husar et al., 2001; Prospero et al., 2002; Engelstaedter and Washington, 2007; Gao and Washington, 2010). However, the OMI AI may also include other UV-absorbing aerosols and missing data can result from cloud contamination (i.e., limited retrieval algorithm for clouds with high reflectivity), and the satellite orbit (i.e., restricted temporal resolution for the sun-synchronous orbit). To compensate for these limitations, we also used the Navy Aerosol Analysis and Prediction System (NAAPS) from the Naval Research Laboratory (NRL) to simulate the surface dust concentration (http://www.nrlmry.navy.mil/aerosol/). The model, with a spatial resolution of $1^\circ \times 1^\circ$, is driven by global meteorological analyses and forecasts from the Navy Operational Global Atmospheric Prediction System (NOGAPS) and provides simulations for 6 h intervals and 18 vertical levels reaching 10 km (Tratt et al., 2001). These worldwide global simulations of dust, sulfate, and smoke were compared to the satellite aerosol analyses and provided accurate information to detect outbreaks and transport of Asian dust (Thulasiraman et al., 2002; Kim et al., 2010).

The atmospheric conditions and circulation patterns associated with the dust outbreaks and their subsequent transport pathways were examined using the daily and monthly values from the $2.5^\circ \times 2.5^\circ$ resolution reanalysis 2 dataset from the National Center for Environmental Prediction-Department of Energy (NCEP-DOE) (Kanamitsu et al., 2002).

3. Synoptic characterization for the severe dust events in the downwind regions

Before showing the Asian dust activity for 2012 spring, we investigated the synoptic characteristics of severe dust events that significantly affected South Korea and Japan in 2000–2012. As previously mentioned, many studies analyzed heavy dust events from the past decade using various measurements and modeling studies, and identified the synoptic conditions for those periods (Sakai et al., 2002; Park and In, 2003; Sugimoto et al., 2003; Lim and Chun, 2006; Zhang et al., 2008). Generally, an enhanced meridional