Science of the Total Environment 478 (2014) 163–174

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Case study of the Asian dust and pollutant event in spring 2006: Source, transport, and contribution to Taiwan

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HIGHLIGHTS

• We analyzed an Asian dust and pollutant event over Taiwan in spring 2006.
• We found the different sources and transport routes for dust and pollutant.
• We found the different arrival time of the two types of aerosol over Taiwan.
• We found the mixing processes of the two types of aerosol over Taiwan.
• We quantify the contribution of the two types of aerosol on Taiwan.

ARTICLE INFO

Article history:
Received 2 December 2013
Received in revised form 19 January 2014
Accepted 20 January 2014
Available online 12 February 2014

Keywords:
Asian dust
Aerosol pollutant
Transport
Taiwan
Model

ABSTRACT

Surface measurements and a regional dust model were used to analyze the source, transport, and contribution of a dust event transporting with aerosol pollutant over Taiwan from 16 to19 March, 2006. During the event, the hourly aerosol concentrations reached close to 400 μg m^{-3} in northern Taiwan, and approximately 300 μg m^{-3} in other areas of the island. Trajectory and regional dust models show that the dust event originated in eastern Mongolia and northern China, and the dust layer can descend from 2 to 3 km in the source area to below 1.5 km over Taiwan. On the other hand, model results show that pollution was transported near the surface from coastal China to Taiwan. During this dust event, polluted aerosol was first observed over northern Taiwan right after a frontal passage, and the concentration was strongly enhanced following the passage of the light rainfall 12 h later. The descent of dusty air from the free troposphere lagged the arrival of polluted air by 7 h, and was partially mixed with polluted aerosol when the transport decelerated over Taiwan.

During the event, dust particles accounted for up to 60% of observed particulate matter less than 10 μm (PM_{10}) over Taiwan, but decreased to less than 35% for particulate matter less than 2.5 μm ($PM_{2.5}$) over most areas of the island. On the other hand, the long-range transport of non-dust aerosols, mainly anthropogenic pollutants, accounted for close to 30% of observed PM_{10} concentration in northern and western Taiwan prior to dust arrival, and the contribution of $PM_{2.5}$ increased to close to 40% over the same areas. Local emission of aerosols accounted for less than 25% of PM_{10} concentrations in northern Taiwan, but was about 60% for $PM_{2.5}$ in central and southern Taiwan because these areas are less influenced by long-range transport.

1. Introduction

Asian dust is mainly generated from three sources: the Taklamakan and Gobi Deserts as well as Loess Plateau (Fig. 1). During springtime, when frontal and cyclonic activities favor the generation of Asian dust from the dry surfaces of these sources, dust can travel long distances (McKendry et al., 2001; Prospero et al., 2003). The long-range transport of dust has been observed to affect aerosol concentrations over downwind areas, including Korea, Japan, Taiwan, and the North Pacific (Iwasaka et al., 1983; Chung, 1992; Chun et al., 2001; Ma et al., 2001; Kwon et al., 2002; Liu et al., 2009). In addition, dust deposition affects marine biogeochemistry by providing crustal nutrients to ocean biology (Lin et al., 2007b; Hsu et al., 2009), and affecting the climate due to the dusts direct effect on scattering and absorption of solar radiation. Indirectly, it acts as ice nuclei in the atmosphere for the formation of ice crystals (Levi and Rosenfeld, 1996; Sassen, 2002).

During dust events, air pollutants are sometimes transported downwind with dust particles. Since China's rapid economic development in the recent decades, mixing of anthropogenic pollution and dusty air parcels over downwind cities has been observed over Beijing

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0048-9697/$ – see front matter
http://dx.doi.org/10.1016/j.scitotenv.2014.01.072

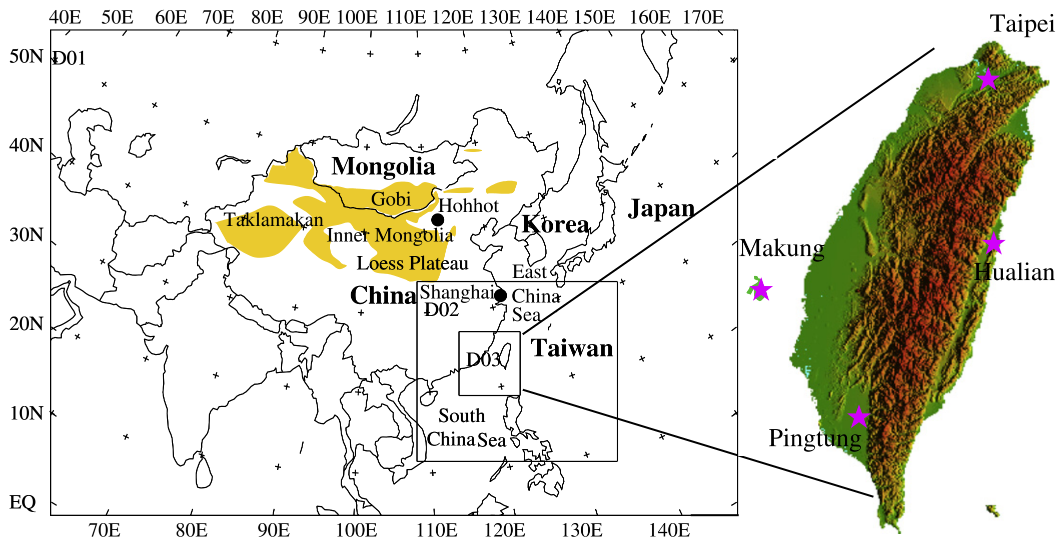

Fig. 1. TAQM model domain and aerosol observation sites (★) at Taipei, Makung, Hualian and Pingtung in Taiwan. Deserts in China are indicated by shaded areas.

and other parts of northern China (Wang et al., 2005; Zhang et al., 2010). Similar mixing of air parcels has also been measured by aircraft off the coast of China, Japan, and Korea (Takemural et al., 2002; Maxwell-Meier et al., 2004; Tsai et al., 2004). Dust and pollution particles have likewise been observed as concurrently increasing over the northwestern Pacific during long-range transport events (Prospero et al., 2003). Although mixing occurs in many areas, Zhang et al. (2005) found that polluted air parcels were being carried in prefrontal air while dusty air was in postfrontal air at Qingdao, a coastal city of China. Additionally, Guo et al. (2004) studied air masses over Beijing and pointed out that polluted air precede dusty air during dust episodes, although mixing between the two types of air does occur. Similarly, Uematsu et al. (2002) studied a dust event in Japan and found that fine aerosol particles appeared first, followed by an air plume of dust particles 12 h later.

Taiwan is located offshore of continental East Asia, and downwind of China's east coast (Fig. 1). From mid-October to mid-May, when the northeasterly monsoon prevails, air pollutants and dust particles are transported to the island from China (Chiang et al., 2009; Liu et al., 2009). Besides pollution arriving on long-range transport, Taiwan also suffers from local pollution (Cheng, 2001; Lin et al., 2004; Tsai et al., 2013). Liu et al. (2009) analyzed aerosol concentrations in Taiwan from 2002 to 2006 and found that Asian dust particles contribute approximately 30% of aerosol concentrations over Taiwan during northeasterly wind conditions. Lin et al. (2007a) and Chang et al. (2010) found that, during dust events, some anthropogenic chemicals, such as CO and SO_2, precede dust particles over northern Taiwan after frontal passage. Although chemical pollution accompanying dust has been observed over northern Taiwan, the evolution of dust and long-range transport of aerosol particles over the island and the contributions of two types of aerosols from continental East Asia in concert with local aerosol emissions were not discussed and quantified in previous research.

Several severe Asian dust events have occurred in the past decade, including the events of spring 2001, 2002, 2006, and 2010. Among these severe events, the dust event that occurred in spring 2006 affected the whole of Taiwan and resulted in poor air quality, because of elevated dust and pollution concentrations. During the two peak days of the dust event, 73 out of 75 local air quality stations reported a daily average PM_{10} concentration exceeding the air quality standard of 125 μg m^{-3}. During this extreme event, aerosol samples were collected, and dust-related composition in the samples was analyzed over different areas of the island. Through the measurements of aerosol samples, Asian dust, long-range transport of other aerosol, and local aerosols can be quantified. The observed aerosol parcels are traced back to their source locations, and regional model simulations are applied to analyze the transport of aerosol parcels from source to downwind areas and their evolution over Taiwan. In addition, the contributions of long-range transported dust and aerosol pollutants to Taiwan can be quantified.

2. Data

2.1. Particulate matter and SO_2

Hourly PM_{10}, $PM_{2.5}$, and SO_2 concentrations are obtained from four Taiwan EPA stations, including Taipei-Guting (121.52°E, 25.02°N), Makung (119.57°E, 23.57°N), Hualian (121.59°E, 23.97°N), and Pingtung (120.49°E, 22.67°N) stations. These four stations are located in northern, western, eastern, and southern Taiwan, respectively (Fig. 1). At Taipei and Pingtung stations, the PM_{10} and $PM_{2.5}$ concentrations are continuously measured using the Verewa F710 monitors. At Hualian and Makung, the concentrations are measured using the Met One Bam1020 monitors. Both monitors are operated at a total flow rate of 16.7 L min^{-1} and a detection limit of 2 μg m^{-3}. At all stations, the SO_2 concentrations are continuously measured using the Ecotech 9850 monitors with a detection limit of 0.5 ppb.

2.2. Dust concentrations

The observed dust concentrations are derived from aluminum (Al) mass analyzed from PM_{10} and $PM_{2.5}$ samples. The aerosol samples are collected at the Central Weather Bureau (CWB) (121.54°E, 25.04°N) in Taipei, National Penghu University of Science and Technology in Makung (119.58°E, 23.57°N), Dahan Institute of Technology in Hualian (121.61°E, 24.04°N), and National Pingtung University of Science and Technology in Pingtung (120.60°E, 22.65°N), respectively (Fig. 1). These sampling sites are within 13 km of the four EPA stations previously mentioned, and so the obtained data on PM_{10} and $PM_{2.5}$ can be used for comparisons. The Partisol-Model 2000-FRM air sampler is used to collect ambient PM_{10} and $PM_{2.5}$ aerosol particles. Flow rate is maintained at 16.7 L min^{-1}, and PTFE membrane filters are used as the substrate. The collection interval is 12 h, i.e., from 0800 local standard time (0800 LST or 0000 UTC) to 2000 LST (1200 UTC) and from 2000 LST (1200 UTC) to the next day 0800 LST (0000 UTC).

Aerosol samples include both anthropogenic and natural sources of particles, such as dust. To identify dust's contribution to the samples, chemical analysis of aerosol samples is performed. Among the upper crustal elements that contribute to aerosol particles, Al is an ideal tracer