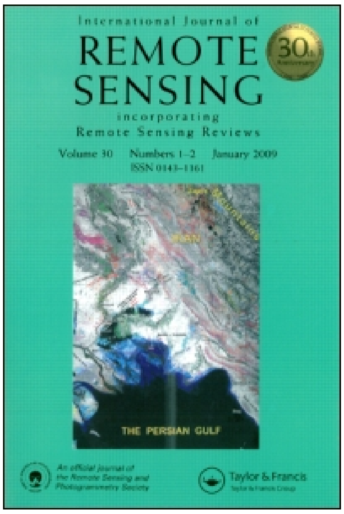

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Desert dust aerosols observed in a tropical humid city: a case study over Hong Kong

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Observations from the AErosol RObotic NETwork (AERONET) sunphotometers, MODerate resolution Imaging Spectroradiometer (MODIS) satellite images, back-trajectory modelling and 'in-situ' PM10 measurements in Hong Kong confirmed that two dust storms on 16–17 April 2006 and 27–30 April 2009, with source areas in northwest China, affected the city. The impacts of the dust on the air quality of Hong Kong were quantified using aerosol optical properties from AERONET data and local PM10 (particle size less than 10 μm) concentrations. Combined analysis of back trajectories and the microphysical properties of the dust aerosols from AERONET inversion data suggest that the dust particulates are sometimes associated with industrial chemicals on arrival in Hong Kong. This is the first remote-sensing study to observe the presence and characteristics of Asian dust carried into the humid tropical region of south China.

1. Introduction

The deserts of northwest China release *ca*. 800 Tg dust each year (Zhang *et al.* 1997), and dust storms are natural phenomena in cities downwind, such as Beijing. Aerosols from dust storms in north China cover wide areas, with urban populations in South Korea (Chung and Yoon 1996), Japan (Var *et al.* 2000) and Taiwan (Lin 2001) being increasingly affected. Indeed, Chinese dust has been traced to north America, where it is capable of reducing solar radiation by 30–40% (Husar *et al.* 2001) and producing intense haze (McKendry *et al.* 2001). In addition to the known impacts of dust aerosols on local and global climate (Huang *et al.* 2006), serious impacts on human health have recently been demonstrated (Chan *et al.* 2007). This may arise from the mineral components contained in the dust, or synthetic organic chemicals, such as dioxins, anthropogenic inorganic pollutants and trace metals, picked up by the dust. The association of pathogenic fungi and bacteria with dust particles has been shown by Garrison *et al.* (2003). Chan *et al.* (2007) reported up to 67% increase in hospital emergency visits for cardiopulmonary diseases during dust storm days in Taipei. All dust storms in China result from cold-air outbreaks over the Gobi deserts in Mongolia and north China. Sun *et al.* (2001) established that long-distance transport of dust to North America is entrained at higher levels in the troposphere than that which is deposited locally. Local dust (within China) is carried east- and south-eastwards

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along three main trajectories, within 3000 m of the surface. The most southerly trajectory passes over the Yangtze estuary at 38° N, significantly north of Hong Kong, which is at 21° N latitude. Observations of dust pollution in humid tropical south China, including Hong Kong, are rare, and dust events are often unrecognized by environmental authorities and the media, due to high industrial pollution from the nearby Pearl River Delta in recent years. To date, there have been no remote-sensing studies of dust events in south China and Hong Kong.

This paper demonstrates the use of MODerate resolution Imaging Spectroradiometer (MODIS) images and AErosol RObotic NETwork (AERONET) sunphotometer data for the observation of two dust storms, on 16–17 April 2006 and 27–30 April 2009, which were reported extensively in Beijing. These dust storms were recorded by the Hong Kong Polytechnic University (PolyU) AERONET stations, although the dust trajectory between Hong Kong and source areas in north China approaches 4000 km. After the establishment of the second AERONET station at a remote rural site in Hong Kong, long-distance aerosols can be more confidently identified as distinct from local urban types. Between January 2006 and May 2009, 20 dust events have been observed by the AERONET stations, mainly in spring, but occasionally in winter and autumn, and rarely in summer due to heavy rainfall during the Asian monsoon.

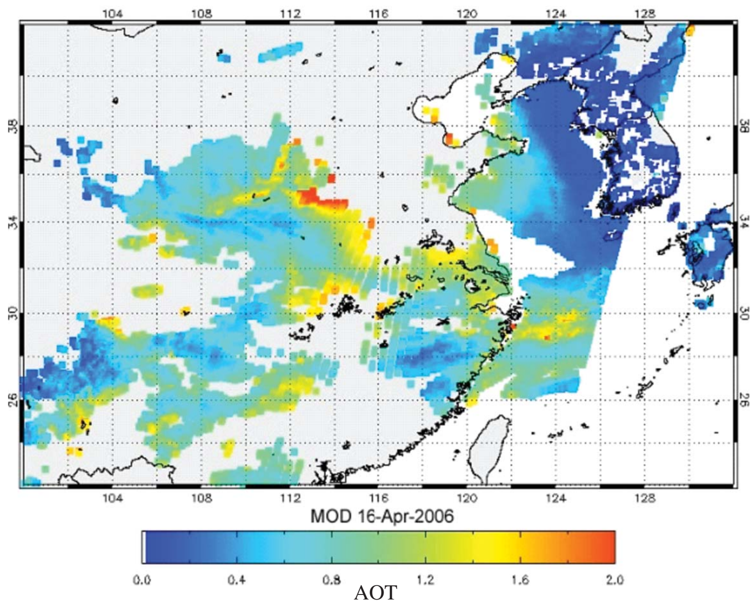
2. Data used

This study makes use of MODIS images and two AERONET stations in Hong Kong. The AERONET (Holben *et al.* 1998) is a federated network of ground sunphotometers, of which there are over 400 sites around the world. An AERONET station consists of a Cimel sunphotometer that measures the aerosol extinction every 15 minutes using eight wavelengths (340, 380, 440, 500, 675, 870, 1020 and 1640 nm). The AERONET data provide aerosol optical thickness (AOT), precipitable water and inversion products, including size distribution, single scattering albedo (SSA) and refractive index, based on the solutions of radiative-transfer equations. There are three levels of data: 1, 1.5 and 2, which present the raw data, cloud-screened data and cloud-screened and quality-assured data, respectively. AERONET stations have been deployed since 2005 at an urban site (roof of the Hong Kong PolyU library) and 2007 at a rural site (Hok Tsui, a remote peninsula in the southeast of Hong Kong Island). The level 1.5 cloud-screened AOT and inversion data were used in this study.

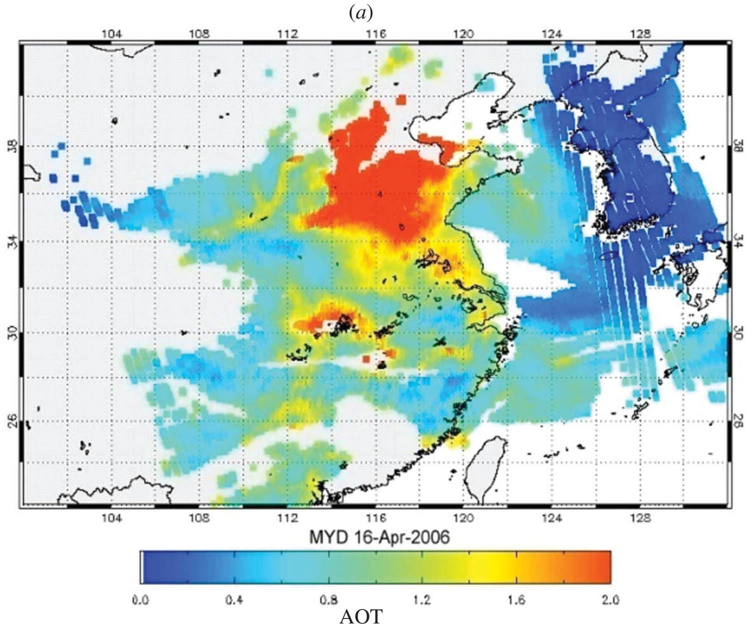
In addition, Terra/MODIS and Aqua/MODIS level 2 aerosol products (MOD04) were analysed for the two dust-storm events. With 36 wavebands and twice-daily coverage, the MODIS is currently the most suitable sensor for atmospheric monitoring at both local and global scales. Back trajectories for the two dates were also obtained from the National Oceanic Atmospheric Administration (NOAA) Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Draxler and Hess 1998) to indicate the likely source and pathway of the dust.

3. Dust storm on 16–17 April 2006

The movement of the April 2006 dust storm can be observed on MODIS true colour images as a grey-brown haze across the images, as well as on MODIS, Total Ozone Mapping Spectrometer (TOMS) and Multiangle Imaging SpectroRadiometer (MISR) AOT products. Since the MODIS AOT product has a higher resolution (10 km compared with 1 x 1° and 17.6 x 17.6 km for TOMS and MISR respectively), only the MODIS AOT product is shown here. Figure 1 provides a sequence of AOT image



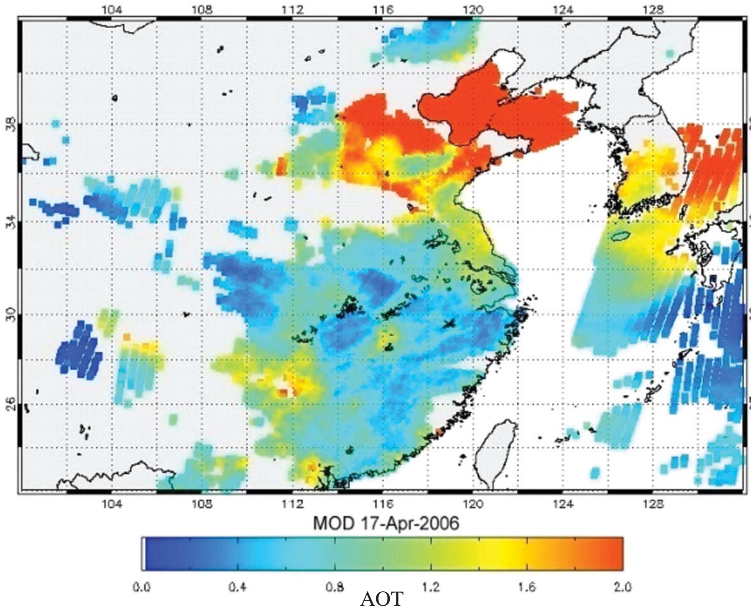
(*a*)



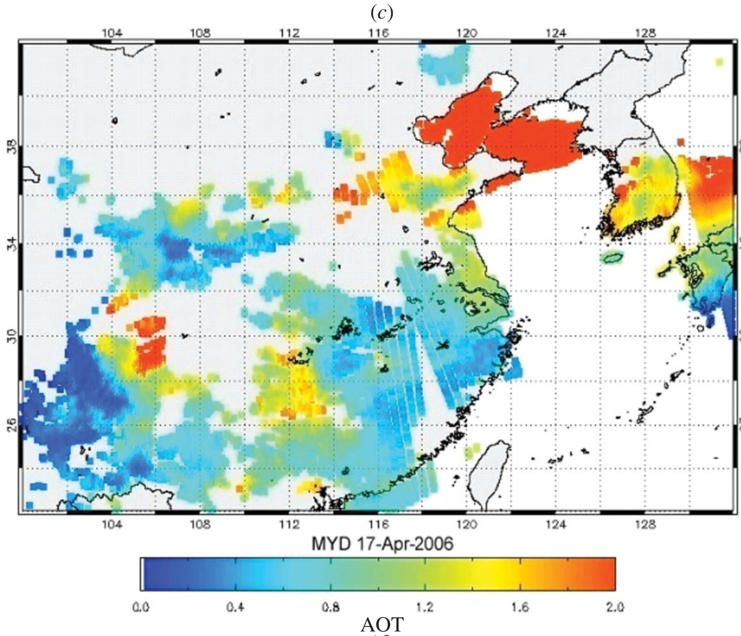
(*b*)

Figure 1. AOT images of East Asia from: (*a*) Terra MODIS on 16 April 2006, (*b*) Aqua MODIS on 16 April 2006, (*c*) Terra MODIS on 17 April 2006 and (*d*) Aqua MODIS on 17 April 2006.

products from MODIS Terra and Aqua satellites. On 16 April 2006, the dust storm was passing over Beijing and Tianjin (the dust is red coloured in figure 1(*b*)). On 17 April 2006, the dust was crossing the Yellow Sea and reaching South Korea. Very high AOT values (> 1.5) were observed from MODIS AOT images and AERONET stations in Beijing and Anmyon (figures 1(*c*), 1(*d*) and table 1).



(*c*)



(*d*)

Figure 1. (*Continued.*)

The back trajectories (figure 2(*a*)) indicate low-altitude (500 m) airflow along the coast, from northeast China. The AERONET level 2 inversion data permit the characterization of dust aerosols reaching Hong Kong, including the size distribution (figure 3), as well as the SSA. Hong Kong's AERONET site recorded high AOT values ($\tau_{500\ \mathrm{nm}} \sim 1.0$, with τ representing AOT) dominated by coarse particles on 16 April (represented by the abnormally large second peak on the graph), but the size

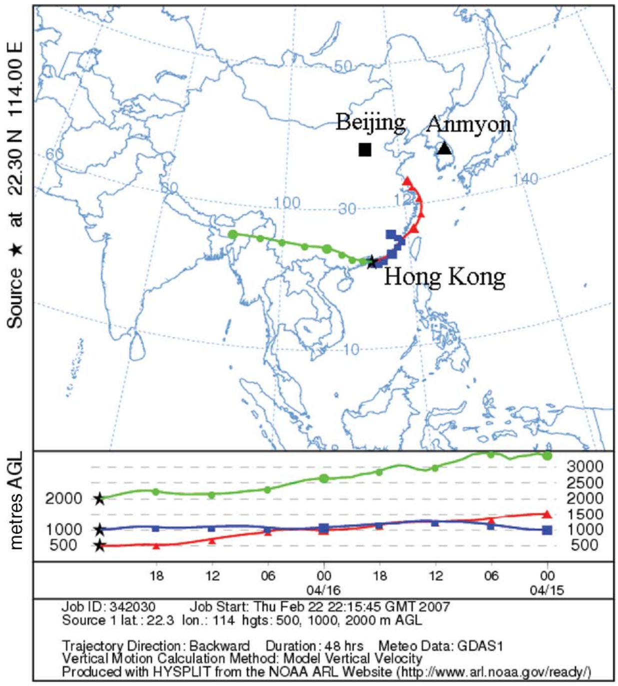
Table 1. AOT at 500 nm from 16 to 18 April 2006 recorded from Beijing, Anmyon and Hong Kong AERONET stations.

	AOT (500 nm)					
	16 April 2006 (am)	16 April 2006 (pm)	17 April 2006 (am)	17 April 2006 (pm)	18 April 2006 (am)	18 April 2006 (pm)
Beijing	1.84	1.71	3.68	3.48	–	–
Anmyon	0.10	0.17	1.55	–	–	–
Hong Kong	1.00	–	1.02	–	0.89	0.73

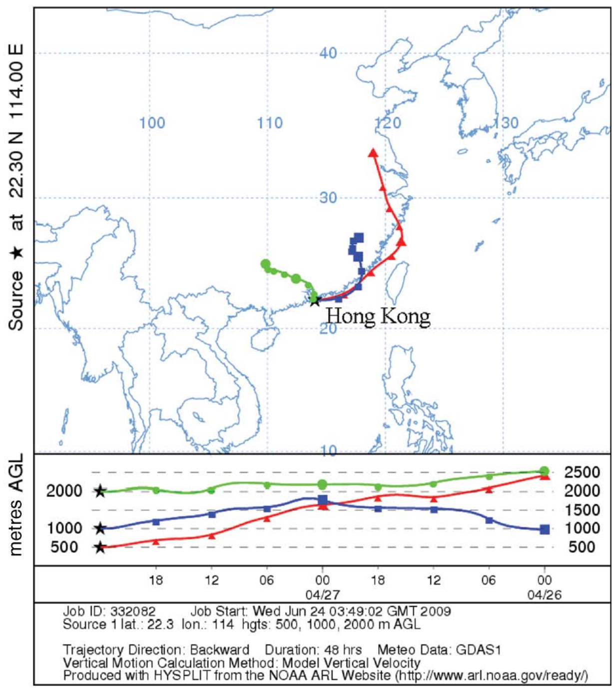
distribution gradually changed to mixed mode (two equal-sized peaks representing fine and coarse particles, respectively) on 17 April, which represents a mixture of dust and local urban pollutants. On 18 April, Hong Kong's typical urban aerosol mode dominated by fine particles was re-established. On the two dust days, the Tap Mun air-quality station deployed by Hong Kong's Environmental Protection Department, in a remote coastal site free from local pollution sources, recorded a high loading of Respiratory Suspended Particulates (RSP) ($\sim$75 μg m^{-3}), which was between 2 and 5 times higher than on non-dust days. The back trajectories (figure 2(*a*)) indicate that the air mass was transported in a south-southeast direction over coastal cities, including industrial areas in Guangdong Province; thus, the dust particulates may be associated with certain amounts of industrial chemicals on arrival in Hong Kong. Such a situation was reported by Chan *et al.* (2007) between 1995 and 2002 in Taipei and was accompanied by a very high number of hospital visits. The SSA from the AERONET inversion data on the two dust days was around 0.8 or lower, suggesting spectral absorption by darker particles, such as black carbon attached to the dust, since dust alone cannot be so absorptive (Dey *et al.* 2004).

4. Dust storm on 27–30 April 2009

Another large dust storm was reported in Beijing on 27–30 April 2009 and high AOT levels can be observed on the MODIS AOT images. The dust storm crossed the Yellow Sea and spread toward South Korea and Taiwan on 28 April 2009. On that day, the AERONET station in Taipei (Taipei_CWB) and both AERONET stations in Hong Kong recorded a high volume of coarse particles (>1 μm) (figure 4). The AOT ($\tau_{500\ \mathrm{nm}}$) level of 0.494 observed in Taipei was lower than in Hong Kong (0.703 and 0.687 at Hong Kong PolyU and Hok Tsui, respectively). These two observations on dust days are much higher than Hong Kong's yearly average AOT of 0.492 for 2008. The very small difference in AOT levels between Hong Kong's urban and rural AERONET sites suggests that local anthropogenic pollutants only contributed 0.016 on the dust days. The back trajectories (figure 2(*b*)) suggest that the major aerosol source may be long-distance dust from the Chinese mainland. As with the 2006 dust event, high loading of RSP ($\sim$93 μg m^{-3}) was recorded at the Tap Mun rural air-quality station, which was 2.5 to 6.2 times higher than on non-dust days. However, unlike the 2006 dust event, a high SSA of approximately 0.9 indicated low absorptive properties of the aerosols, contra-indicating dirty industrial pollutants, such as black carbon, associated with the dust. The back trajectories (figure 2(*b*)) indicate an offshore transport path for the lower level winds below 1000 m, which would normally give fresh air for Hong Kong.



(*a*)



(*b*)

Figure 2. Maps of back trajectories for Hong Kong created from HYSPLIT model on: (*a*) 17 April 2006 and (*b*) 28 April 2009. AGL: Above Ground Level.

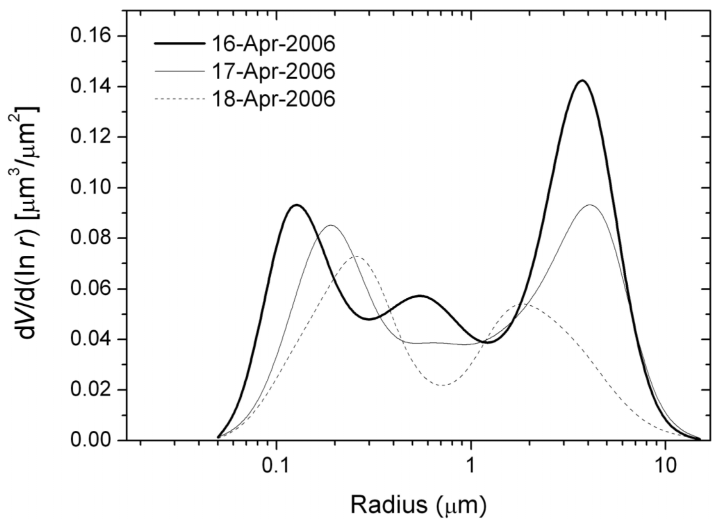


Figure 3. Size distribution plot of 16 to 18 April 2006 for Hong Kong PolyU AERONET data. *V* represents volume and *r* represents radius.

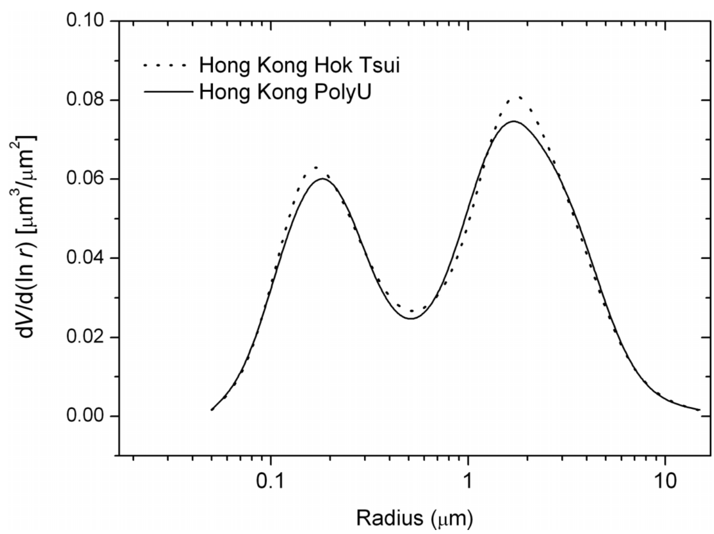


Figure 4. Size distribution plot of 28 April 2009 for Hong Kong PolyU and Hok Tsui AERONET data. *V* represents volume and *r* represents radius.

5. Conclusion

This is the first remote-sensing study to observe the presence and characteristics of Asian dust carried into humid tropical south China. With only 14 air-quality stations in Hong Kong, the occurrence and intensity of trans-boundary air pollution, which has long been a controversial issue, is difficult to establish. Although a rural air-quality station indicated that RSP levels were 2 to 6 times higher than normal on dust days, ground stations cannot provide predictive capability of the dust event, source areas or characteristics of the dust. In view of recent research in South Korea and Taipei, which establishes increased cardio-vascular and respiratory complaints and mortality following dust events, it is important to predict their occurrence downwind of industrial regions where toxins can be adsorbed onto the dust particles. The combined use of the MODIS, NOAA HYSPLIT and AERONET can help to resolve this long-standing issue about source regions and characteristics of pollutants carried to Hong Kong.

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References

CHAN, C.C., CHUANG, K.J., CHEN, W.J., LEE, C.T. and PENG, C.M., 2007, Increasing cardio-pulmonary emergency visits by long range transported Asian dust storms in Taiwan. *Environmental Research*, **106**, pp. 393–400.

CHUNG, Y.S. and YOON, M.B., 1996, On the occurrence of yellow sand and atmospheric loadings. *Atmospheric Environment*, **30**, pp. 2387–2397.

DEY, S., TRIPATHI, S.N., SINGH, R.P. and HOLBEN, B.N., 2004, Influence of dust storms on aerosol optical properties over the Indo-Gangetic basin. *Journal of Geophysical Research*, **109**, D20 211.

DRAXLER, R.R. and HESS, G.D., 1998, An overview of the HYSPLIT-4 modeling system for trajectories, dispersion, and deposition. *Australian Meteorological Magazine*, **47**, pp. 295–308.

GARRISON, V.H., SHINN, E.A., FOREMAN, W.T., GRIFFIN, D.W., HOLMES, C.W., KELLOG, C.A., MAJEWSKI, M.S., RICHARDSON, L.L., RITCHIE, K.B. and SMITH, G.W., 2003, African and Asian dust: from desert soil to coral reefs. *BioScience*, **53**, pp. 469–480.

HOLBEN, B.N., ECK, T.F., SLUTSKER, I., TANRÉ, D., BUIS, J.P., SETZER, A., VERMOTE, E.F., REAGAN, J.A., KAUFMAN, Y.J., NAKAJIMA, T., LAVENU, F., JANKOWIAK, I. and SMIRNOV, A., 1998, AERONET – a federated instrument network and data archive for aerosol characterization. *Remote Sensing of Environment*, **66**, pp. 1–16.

HUANG, Y., DICKINSON, R.E. and CHAMEIDES, W.L., 2006, Impact of aerosol indirect effect on surface temperature over East Asia. *Proceedings of the National Academy of Sciences of the United States of America*, **103**, pp. 4371–4376

HUSAR, R.B., TRATT, D.M., SCHICHTEL, B.A., FALKE, S.R., LI, F., JAFFE, D., GASSÓ, S., GILL, T., LAULAINEN, N.S., LU, F., REHEIS, M.C., CHUN, Y., WESTPHAL, D., HOLBEN, B.N., GUEYMARD, C., MCKENDRY, I., KURING, N., FELDMAN, G.C., MCCLAIN, C., FROUIN, R.J., MERRILL, J., DUBOIS, D., VIGNOLA, F., MURAYAMA, T., NICKOVIC, S.,WILSON, W.E., SASSEN, K. and SUGIMOTO, N., 2001, Asian dust events of April 1998. *Journal of Geophysical Research*, **106**, pp. 18 317–18 330.

LIN, T.H., 2001, Long range transport of yellow sand to Taiwan in spring 2000: observed evidence and simulation. *Atmospheric Environment*, **35**, pp. 5873–5882.

MCKENDRY, I.G., HACKER, J.P. and STULL, R., 2001, Long-range transport of Asian dust to the Lower Fraser Valley, British Columbia, Canada. *Journal of Geophysical Research*, **106**, pp. 18 361–18 370.

SUN, J., ZHANG, M. and LIU, T., 2001, Spatial and temporal characteristics of dust storms in China and its surrounding regions, 1960–1999: relations to source area and climate. *Journal of Geophysical Research*, **106**, pp. 10 325–10 334.

VAR, Y., NARITA, Y. and TANAKA, S., 2000, The concentration, trend and seasonal variation of metals in the atmosphere in 16 Japanese cities shown by the results of National Air Surveillance Network (NASN) from 1974 to 1996. *Atmospheric Environment*, **34**, pp. 2755–2770.

ZHANG, X.Y., ARIMOTO, R. and AN, Z.S., 1997, Dust emission from Chinese desert sources linked to variations in atmospheric circulation. *Journal of Geophysical Research*, **102**, pp. 28 041–28 047.