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# Aircraft measurements of $SO_2$ and aerosols over northeastern China: Vertical profiles and the influence of weather on air quality

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## HIGHLIGHTS

- Dramatic change in air quality caused by shift in weather pattern.
- Significant difference in aerosol properties between N China and E U.S.
- Prevalent dust layers in the free troposphere over N China.

## ARTICLE INFO

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## ABSTRACT

Aircraft measurements of $SO_2$ and aerosol scattering coefficients ($b_{sp}$) were made over Shenyang, an industrialized city in northeastern China in April 2005. Weather conditions were found to have strong impact on the area's air quality. Between two flights on April 10 and 11, the $SO_2$ loading increased by an order of magnitude within 24 h, from ~0.1 DU (Dobson Unit) to ~1 DU. Meteorological observations and back trajectory analyses suggest that anthropogenic pollutants emitted from the area accumulated under stagnant conditions induced by a mid-latitude cyclone approaching from the west. The observed rapid buildup demonstrates that strong local emissions can expose the populace to high pollutant levels under unfavorable weather conditions. Ångström exponents determined from the aircraft and ground-based sun photometers are significantly smaller over China than over the U.S., suggesting the prevalence of dust particles in northern China, particularly in spring. The coarse mode became more pronounced with altitude, indicating dust-dominant aerosol layers in the lower free troposphere, which should be accounted for in the satellite remote sensing of surface pollution over the region. Information on the vertical distribution of aerosols and precursor gases over China will also help better understand their transport as well as effects on weather and climate.



## 1. Introduction

Shenyang, the capital of Liaoning Province in northeastern China, is a heavily industrialized city located about 600 km northeast of Beijing. Consuming more than ten million tons of coal every year (Hao et al., 2006), this city of over seven million residents was once among the most polluted cities in the world (He et al., 2002). Hence, drastic environmental measures were implemented in recent years to reduce emissions from major industrial sources. Locally, $SO_2$ and particulate matter (PM) have adverse effects on human health, as suggested by the positive association between daily mortality and pollutant levels in Shenyang (Xu et al., 2000). Regionally, pollutants emitted from the area can travel long distances under certain weather conditions, influencing regions thousands of kilometers downwind (e.g., Bey et al., 2001). Aerosols over Shenyang absorb solar radiation (e.g., Xia et al., 2007), and may exert impacts on weather and regional climate.

The vertical distribution of atmospheric pollutants is a critical factor determining their long-range transport (e.g., Li et al., 2010a), and should be accounted for in remote sensing of air pollution from space (e.g., Krotkov et al., 2008). Several aircraft campaigns (e.g., Jacob et al., 2003; Huebert et al., 2003; Parrish et al., 2004) have been carried out over the Western Pacific to characterize outflow from East Asia. Airborne measurements over mainland China are

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relatively scarce and reports on them have only recently become available (e.g., Hatakeyama et al., 2005; Ma et al., 2010; Wang et al., 2006, 2007; Zhang et al., 2006). Despite their limited spatial and temporal coverage, these flights were able to provide insight into the meteorological mechanisms for long-range transport of Asian pollution and dust. For example, Ding et al. (2009) observed the long-range transport of pollutants within the warm conveyer belt associated with a mid-latitude wave cyclone over northern China. Chen et al. (2009) described the ventilation of pollutants from the Beijing area through the mountain chimney effect. Airborne observations over China have also proved useful for evaluating and improving satellite retrievals (He et al., 2012; Krotkov et al., 2008; Xue et al., 2010).

In April 2005, an air campaign was carried out around Shenyang, under the auspices of EAST-AIRE, East Asian Study of Tropospheric Aerosols: an International Regional Experiment (Li et al., 2007a). Eight research flights were made under various synoptic conditions. In our previous study (Dickerson et al., 2007), two flights (April 5 and 7, 2005) were analyzed to reveal the role of dry (non-precipitating) convection in lifting pollutants out of the boundary layer over China. In this paper, we focus on the remaining six flights to shed more light on the vertical distribution of pollutants under diverse weather conditions, as well as on aerosol properties and their dependence on altitude.

## 2. Methodology

A modified Chinese Y-12 twin engine turboprop aircraft was used in this experiment. The Y-12 has a cruise speed of ~200 km $h^{-1}$ and a ceiling of ~7000 m. A forward-facing isokinetic inlet mounted

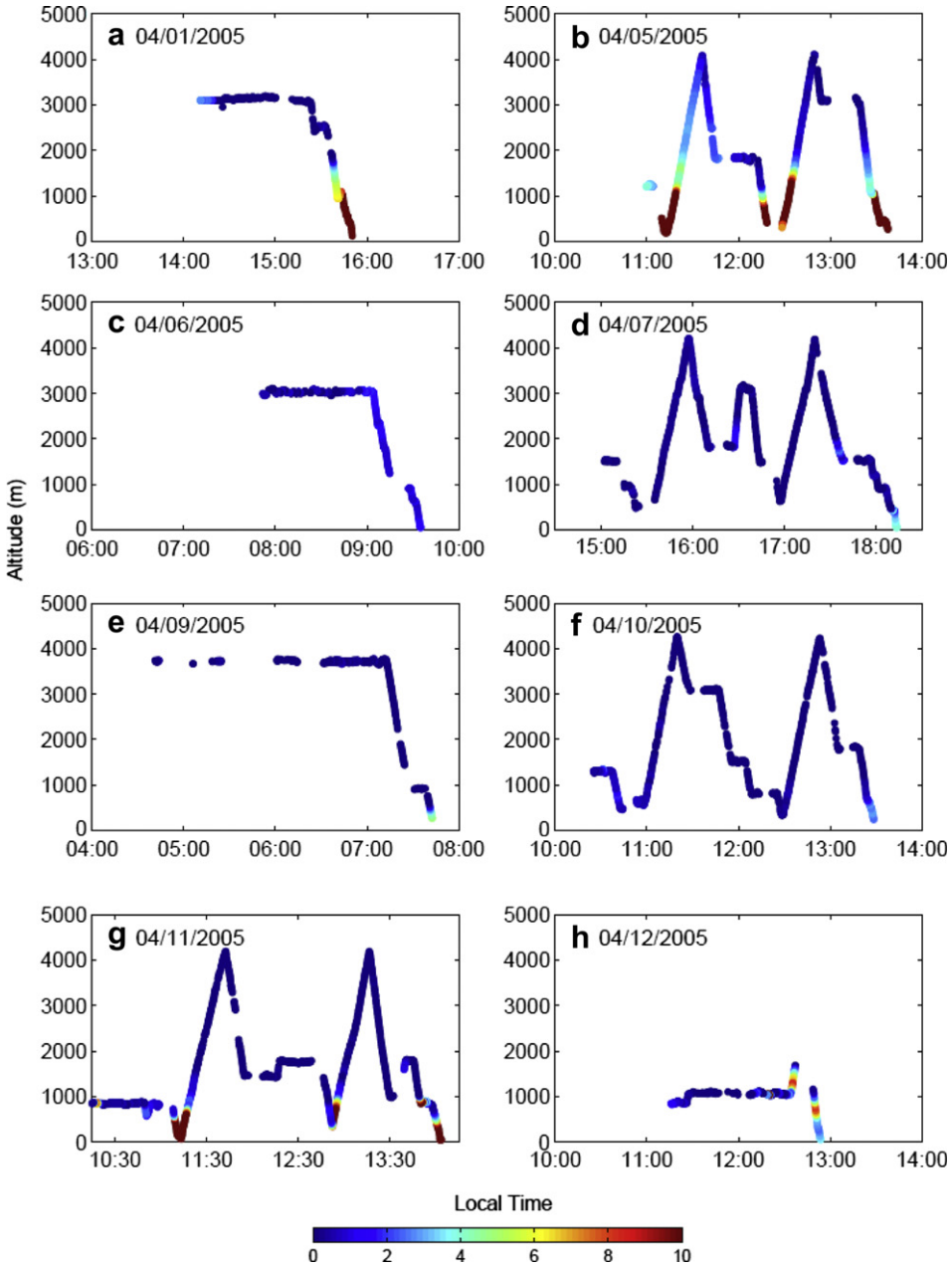


**Fig. 1.** $SO_2$ concentration (color, unit: ppbv) and flight altitude along the flight routes on April 1, 5, 6, 7, 9, 10, 11, and 12, 2005 over the Shenyang area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)