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Comparative study on long-term visibility trend and its affecting factors on both sides of the Taiwan Strait

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ABSTRACT

The rapid industrial development and urbanization has lead to increasing particulate matter pollution in the Cross Taiwan Strait Region, which has significant impacts on atmospheric visibility degradation. Long-term visibility trends in five typical cities over the cross-strait region (i.e., Xiamen and Fuzhou in the Western Taiwan Strait (WTS) region and Taipei, Taichung and Tainan in Taiwan) and its correlation with air quality and meteorological conditions were investigated using visibility and meteorological data during 1973–2011 and air pollution data during 2009–2011. For the entire period, the overall average visibilities in the WTS region were better than those in Taiwan, with an average of 16.8, 16.6, 8.5, 10.3 and 9.0 km in Fuzhou, Xiamen, Taipei, Taichung and Tainan, respectively. Decline trends with decreasing rates of −0.5–0.1 km/yr existed in all cities except Taipei, which had an improvement in visibility after 1992. All seasons had decreasing trends during the 39-year period except in Taipei. The WTS region had the worse change trend compared with Taiwan. No statistically significant weekend effect in visibility is found over the region. Visibilities were better in summer and autumn, while worse in winter and spring. Correlation analysis revealed that significant negative correlations existed between visibility and NO_2 and airborne particles (i.e., PM_{10} and $PM_{2.5}$); $PM_{2.5}$ played an important role in visibility degradation. High temperature and low pressure is beneficial for better visibility. Principal component analysis further confirmed the impacts of high concentrations of air pollutants, stable synoptic systems and humid air with high relative humidity on visibility impairment. In addition, case studies highlighted characteristics and potential causes of typical regional low visibility episodes over the region.

1. Introduction

Atmospheric visibility degradation is an important indicator of deteriorating ambient air quality in urban area and has been reported to have adverse effects on human health, crop growth and traffic safety (Quinn and Bates, 2003; Bäumer et al., 2008; Hyslop, 2009). As the most direct way to visually determine the level of air pollution, visibility has attracted an increasing interest (Watson, 2002; Cao et al., 2012). However, atmospheric visibility is a complex issue: on the one hand, it is directly affected by air pollution caused by anthropogenic activities; on the other hand, it is also influenced by meteorological conditions.

Poor atmospheric visibility, if not caused by fog or rain, is always associated with poor air quality resulted from intensive emission of air pollutants or poor atmospheric conditions limiting the transport and dispersion of the emitted pollutants.

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Visibility impairment is mainly resulted from airborne particulate matter (PM), especially fine particles with aerodynamic diameter less than 2.5 μm ($PM_{2.5}$). In urban area, the major components of $PM_{2.5}$, including ammonium, sulfate, nitrate, organic matter and elemental carbon, contribute to most of light absorption and scattering and thus effectively reduce the visibility (Lee et al., 2005; Jung et al., 2009). In general, light extinctions by air pollutants and their effects on visibility have been shown to differ according to the level and mixing state of air pollutants (Watson, 2002). In addition to air pollutants, meteorological parameters including wind speed, wind direction, relative humidity (RH), air temperature, atmospheric pressure and precipitation can also directly or indirectly affect atmospheric visibility through influencing local and regional air quality in urban areas (Tsai, 2005; Wen and Yeh, 2010; Deng et al., 2011; Du et al., 2013). For example, the optical properties of aerosols are highly dependent on RH. The hygroscopic components of aerosols such as sulfate, nitrate and sea salt absorb moisture at high RH, which will increase the scattering cross sections of the aerosols (Jung et al., 2009). Malm and Day (2001) found that at 90% RH the scattering cross section of an ammonium sulfate particle would increase by a factor of five or more relative to that of a dry particle. Another example is that high air temperature usually enhances the dispersion capability of the atmosphere via thermal and mechanical turbulence, improving air quality and visibility.

In mainland China, dramatic urbanization was driven by unprecedented economic growth and industrial development since the economic reforms began in 1978, which led to sharp increases in energy consumption and anthropogenic emission (e.g., the combustion of fossil fuel and vehicle emissions). The increasing emissions naturally resulted in deterioration of air quality in urban areas and city clusters, which has been a primary environmental challenge the government was confronted with (Chan and Yao, 2008; Tie and Cao, 2009). As a consequence, visibility degradation occurred in urban (Deng et al., 2008; Chang et al., 2009; Chen and Xie, 2013), regional (Gao et al., 2011; Deng et al., 2012), and nationwide (Che et al., 2007) scales. In the Western Taiwan Strait (WTS) region in Southeast China (Fig. 1), the air quality has also deteriorated due to increased emission of air pollutants as well as air pollutants transported from the emission hotspots in urbanized areas in East China (Chen et al., 2012). Deng et al. (2012) revealed an obvious degradation in atmospheric visibility in the WTS region with a decreasing rate of −0.2 km/yr over the past four decades. However, further research focusing on the potential impacts of air quality and meteorological condition on atmospheric visibility in the WTS region is required because air pollution and visibility over this region actually show distinctive regional characteristics due to the special geographical (e.g., coastal and mountainous) and climatic (e.g., subtropical oceanic monsoon, sea-land breeze and high RH) conditions in this area.

Taiwan is located to the east of the Taiwan Strait (Fig. 1). Several cities in Taiwan are also experiencing air quality degradation due to limited land, high population density and pronounced economic growth (Chang and Lee, 2008). Long-term trends in visibility and the relationship of visibility with its causal factors including air quality and meteorological conditions in some areas over Taiwan have been investigated (Cheng and Tsai, 2000; Yuan et al., 2002; Tsai et al., 2003, 2007; Lee et al., 2005; Tsai, 2005; Wen and Yeh, 2010; Wen et al., 2012).

Although the WTS region and Taiwan are geographically close and have similar meteorological conditions, characteristics of air pollution and atmospheric visibility over the two regions may differ due to the different diffusion capability and emission characteristics resulting from the varying economic development, urbanization level and industrial distribution. In order to better protect the air quality, there are increasing calls for joint efforts on both sides of the Taiwan Strait, which

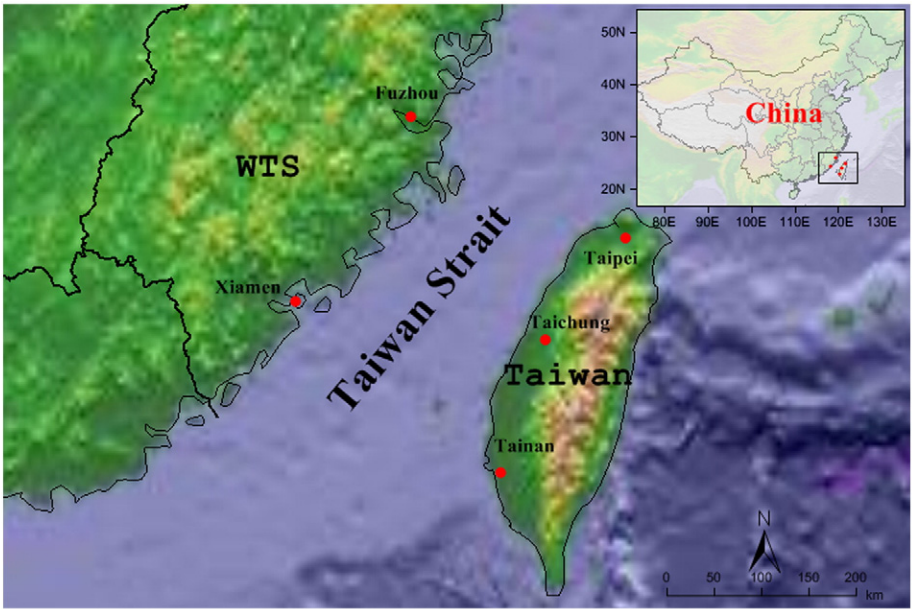

Fig. 1. Locations of the five large cities (FZ, XM, TP, TC and TN) in the Cross Taiwan Strait Region.