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Global Warming Increases the Incidence of Haze Days in China

Bing Xu[1,2,3], Zhaoyan Gu[1,2,3], Luo Wang[1], Qingzhen Hao[1], Haizhi Wang[4], Guoqiang Chu[1], Yanwu Lv[5], and Dabang Jiang[6]

[1]Key Laboratory of Cenozoic Geology and Environment, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China, [2]College of Earth and PlanetarySciences, University of Chinese Academy of Sciences, Beijing, China, [3]CAS Center for Excellence in Life and Paleoenvironment, Beijing, China, [4]Beijing Institute of Geology, Beijing, China, [5]Institute of Crustal Dynamics, China Earthquake Administration, Beijing, China, [6]Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

Abstract Both wind strength and anthropogenic emissions have been assumed to be the dominant factors in determining the occurrence of hazy weather in China. However, few records are available with sufficient temporal length and resolution, which enable the two signals to be separated, and hence address the dynamics of haze days and the global impact of the anthropogenic emissions in China, particularly in the context of global warming. Here we present the first long-term (last ~180 years) lake sediment records of changes in wind strength and atmospheric loading of anthropogenic emissions in China. Our results show that the atmospheric loading of anthropogenic emissions and haze formation are closely related to the changes in wind strength associated with temperature changes, which are likely forced by tropical sea surface temperature. Comparison of our results with Pb isotope records from Japan and with the record of Pb concentrations in Greenland ice core indicates that the anthropogenic pollutants emitted in China stagnate mainly over the source area and neighboring regions, which thus favors haze formation under a warming climate. However, they would be transported worldwide under conditions of strong winds and decreased temperature. Climatic warming, together with the periodic changes in temperature, has caused unprecedented heavy haze days in recent decades in China. The observed pattern of periodic temperature variations suggests that in the next ~30 years, wind strength will increase and thus reduce the incidence of haze days. However, this reduction may be attenuated by continued climatic warming as anthropogenic greenhouse gases emissions continue.

Key Points:
- Atmospheric pollutant concentrations decoupled from anthropogenic emissions in China
- Atmospheric loading of anthropogenic pollutants in China increased with temperature forced by tropical sea surface temperature
- Asian anthropogenic pollutants can be transported worldwide under the condition of cold temperature

Supporting Information:
- Supporting Information S1

Correspondence to:
B. Xu,
bingx@mail.iggcas.ac.cn

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Writing - original draft: Bing Xu
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1. Introduction

The increased occurrence of heavy haze in China during recent decades is of major concern due to its implications for human health, its effects on economic development and on the quality of daily life (Gao et al., 2017; Li & Zhang, 2014). Haze is an atmospheric phenomenon in which dust, smoke, and other dry particulates obscure the clarity of the sky. In China, haze includes gaseous pollutants and fine particles, of which PM2.5 is the dominant component (Gao et al., 2017). It is much debatable on the dominant forcing factor of haze days in China. Several studies have suggested that the increased anthropogenic emission of pollutants to the atmosphere, particularly from biomass burning, is the major forcing factor (Andreae et al., 1988; Cheng et al., 2014; Kang et al., 2013; Liu et al., 2013), whereas others have claimed that the incidence of haze days is closely related to the weakening of wind strength in China (H. Chen & Wang, 2015; Hui & Xiang, 2014; H. Wang et al., 2015; Xiao et al., 2014). However, all of these studies are based on the short-term observations (~50 years), and during this interval, the increased anthropogenic emissions have coincided with a trend of weakening wind strength across China. This co-occurrence makes it difficult to differentiate the effects of anthropogenic emissions from climatic forcing in the haze formation, because of the limited range of scenarios captured by short-term observations.

Here we present two high-resolution records of changes in both wind strength and atmospheric loading of anthropogenic pollutant emissions during the last 180 years, based on two lake sediment records from north China. We use the results to shed light on the dominant forcing factor of haze days in China, particularly its relationship with anthropogenic emissions and climate changes, and in addition, we try to assess possible future changes of the incidence of haze days in the context of ongoing global warming.

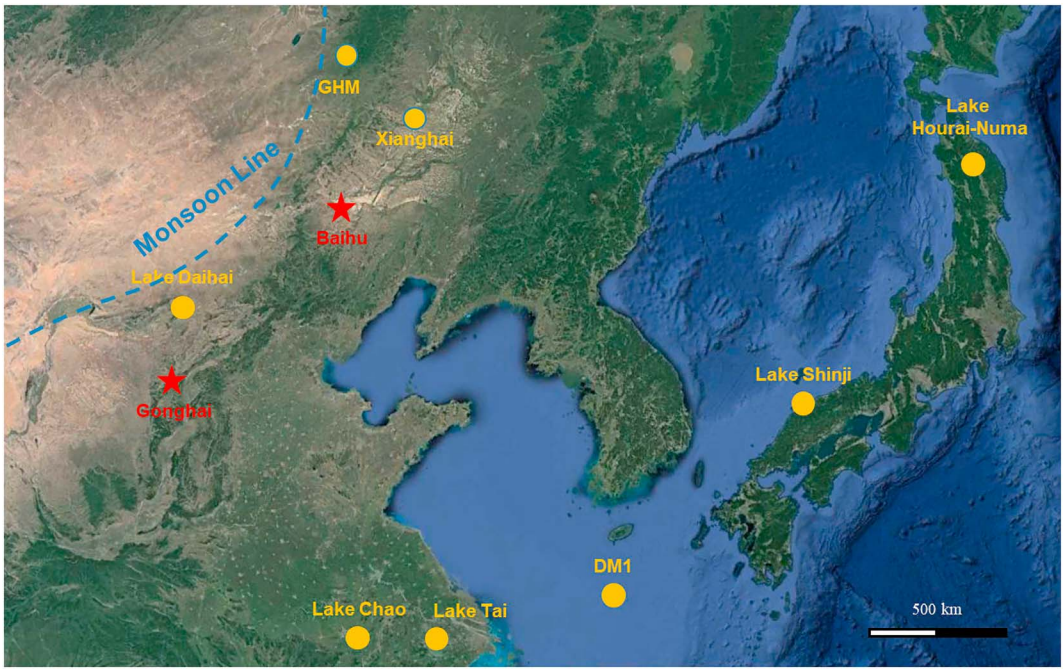

Figure 1. Locations of Lake Gonghai and Baihu (red stars) and the major records of atmospheric pollutants in the eastern Asia (orange cycles)

2. Materials and Methods

2.1. Samples and Analysis

Two closed lakes (Gonghai and Baihu) were selected for reconstructing past changes in both wind activity and atmospheric loading of anthropogenic emissions (Figure 1). Lake Gonghai (112.23 °E, 38.91 °N) is an alpine lake in the eastern margin of the Chinese Loess Plateau. The lake lies at the top of a hill, 1,860-m above sea level and has an extremely small catchment area (0.21 km^2; Figure 1). The lake receives a minimal quantity of clastic materials via runoff due to its small catchment areas and good vegetation coverage. Most importantly, the lake is little affected by human impacts and its sedimentary record has successfully been used for paleoclimatic studies in the past [*F* Chen et al., 2015; Rao et al., 2016]. The lake basin acts as a natural sediment traps for materials delivered to the site by atmospheric transport and provides a potential record of past variations in atmospheric anthropogenic pollutant emissions and aeolian activity. Lake Baihu (119.06 °E, 43.05 °N) is located in the marginal area of the Horqin Sandy Land (Figure 1). The lake is sensitive to the changes in both aeolian activity and climate due to its location on the southeastern margin of present eastern Asian dust sources and at the northern limit of the East Asian summer monsoon. As is the case for Lake Gonghai, the lake is relatively undisturbed by human activity and there is minimal industrial activity in the catchment and the surrounding areas, which suggests that the sedimentary record of anthropogenic emissions should be derived from long-distant transport by winds.

Sediment cores were obtained from Lake Gonghai (length 45.5 cm) in 2007 and from Baihu (112.0 cm) in 2011 using a gravity corer. After the cores were retrieved, the water at the top of the core tube was removed using a syringe. The cores were then sealed and transported vertically to the laboratory. The cores from Lake Gonghai and Baihu were sampled continuously at a 0.5- and 1.0-cm interval, respectively, and then lyophilized.

The grain size distributions of the sediments were measured using a Malvern Mastersizer analyzer, with a measurement range of 0–2,000 μm, after the following pretreatment: 30 ml of 30% H_2O_2 for 12 hr to remove organic matter, 10 ml of 1.0 M HCl to remove carbonates, and 10 ml of 0.05 M $(NaPO_3)_6$, followed by ultrasonic vibration to facilitate dispersion. Lead (Pb) and Antimony (Sb) concentrations were determined using 50 mg of freeze-dried sediment and total digestion with Aqua Regia, HF, $HClO_4$. The concentrations of Pb, Sb, and Al were measured using a Perkin-Elmer Sciex Elan 6000 inductively coupled plasma-mass

spectrometer and inductively coupled plasma-Atomic Emission Spectroscopy at the Beijing Research Institute of Uranium Geology. The detection limits for Pb and Sb are better than 0.0001 μg/ml. The accuracy was checked by analysis of blank reagents, standard reference materials (GBW07314), and replicate samples. The analytical uncertainties are better than 3.0% for Pb and Sb and 5.0% for Al.

2.2. Chronology

The cores were dated using stratigraphic profiles of ^{210}Pb and ^{137}Cs. The activities of ^{137}Cs, ^{210}Pb, and ^{226}Ra were measured using a low-background well-type germanium detector (EGPC 100P-15R) with counting errors less than 3%. Each sample was packed and stored in a sealed 5-cm high polyethylene tube for 3 weeks to allow radioactive equilibration (Appleby et al., 1986; Hamilton et al., 1994). Each sample was counted for 24 hr. The total activity of ^{210}Pb was determined by gamma spectrometry via its energy at 46.5 keV. To calculate excess ^{210}Pb ($^{210}Pb_{ex}$), the activities of the short-lived daughter nuclides of ^{226}Ra (^{214}Pb and ^{214}Bi) were measured to determine the supported ^{210}Pb concentration. ^{137}Cs was measured by its emissions at 662 keV. An activity standard (GB08304) with essentially the same geometry and density was used. The energy and efficiency calibration methods and quality control follow the method of Foster *et al.* (Foster et al., 2005). The radiometric ages of the cores were calculated using the constant rate of supply model (Appleby, 2002; Appleby et al., 1986; Goldberg, 1963). For ^{137}Cs activity, the uncertainty of the peak in activity (1963) and initial occurrence (1952) is less than 3 years. The age ranges of the cores from Lake Gonghai and Lake Baihu are from 1854 to 2007 AD and from 1854 to 2011 AD, respectively (Figure S1 in the supporting information).

3. Result and Discussion

3.1. Median Grain Size as Proxy of Wind Activity

A paleowind activity time series was obtained based on grain size distributions of the lake sediments. The hydrologically closed nature of the lakes indicates that clastic materials should be transported to lake basins mainly by wind. To confirm that wind is the major transport agent of clastic materials at the two sites, we compared the median grain sizes of the lake sediments with the past 60-year meteorological registers of the annual mean gale days and windless days in north China (Shaowu et al., 2004; Su et al., 2014). The median grain (MD) size of the two sites has a strong inverse correlation with the number of windless days ($r = -0.73/-0.85$) and a positive correlation with the annual mean gale days ($r = 0.60/0.76$; Figure 2). In contrast, the MD shows little correlation with the meteorological registers of precipitation (Figure S2), indicating little impact from runoff and its associated lake level on the deposition of clastic materials in the studied lakes. This characteristic is consistent with the small catchment areas of Lake Gonghai and Baihu, which limit the development of strong surface runoff. All these evidences consistently indicate that our MD record is a reliable indicator of wind strength and reflects the variations of wind strength in north China. This conclusion gets further test by the similarity of the grain size distribution of the sediments in Lake Gonghai and aeolian dusts collected from around the lake basin (Figure S3).

3.2. Heavy Metals as an Indicator of Atmospheric Pollutant Aerosol Loading

It is well known that haze is characterized by a specific particle concentration, which is closely associated with high atmospheric loadings of anthropogenic emissions (Andreae et al., 1988; *S* Guo et al., 2014; G Wang et al., 2016). Several heavy metal elements are important components of anthropogenic emissions, because of their volatility during high-temperature biofuel combustion, metal extractions, and industrial and technological processing. In this study, we use Pb and Sb as the indicators of anthropogenic emissions for the following reasons: (1) Anthropogenic production of Pb and Sb is closely associated with biomass burning (Candelone et al., 1995; Grigholm et al., 2016; Hezhong Tian et al., 2012; HZ Tian et al., 2011), which is the major source of anthropogenic emissions (Thomson, 2003); (2) they are enriched in anthropogenic aerosols relative to the Earth's crust and can be transported for long distances (Martin, 2012; Shotyk et al., 1996; Hezhong Tian et al., 2012; Hezhong Tian et al., 2014; Zhang et al., 2012); 3) antinomy oxides are usually unaffected by post depositional redox conditions (Fawcett et al., 2015; Filella et al., 2002), and their long emission history exceeds 3,000 years in China (Dodson et al., 2014); and (4) the presence of these elements in aerosols and the use of their records in ice deposits, lake, and peat sediments as tracers of air pollutants is extensively documented (Hansson et al., 2015; McConnell & Edwards, 2008; Shotyk et al., 1996).

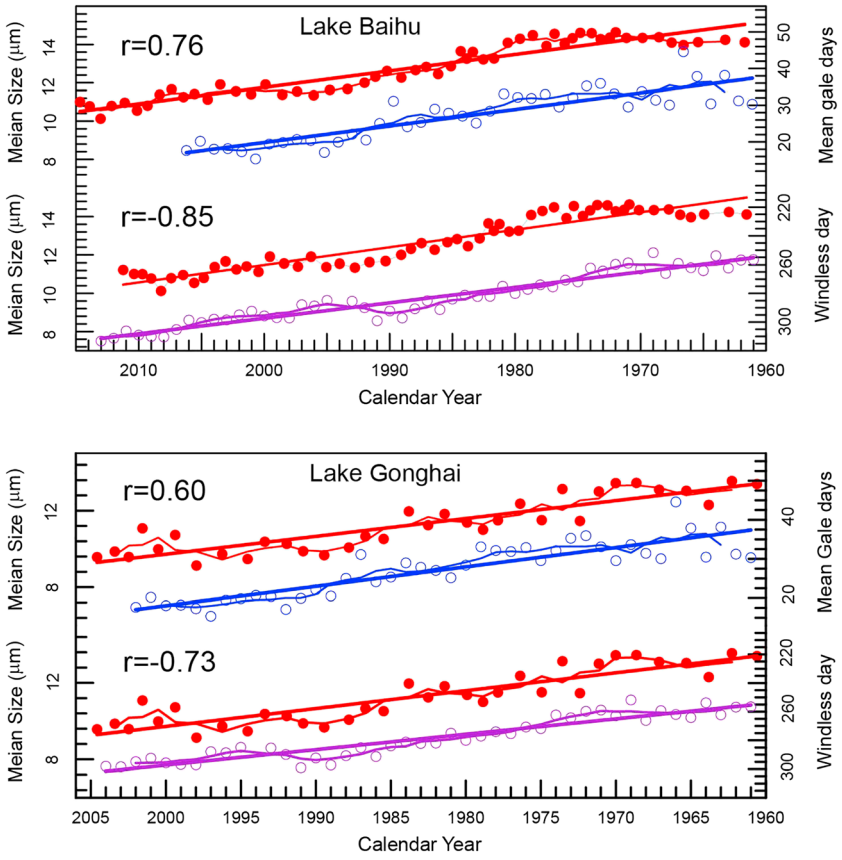

Figure 2. Correlation of the median grain size of Lake Gonghai and Baihu (red) with the incidences of windless (purple; Su et al., 2014), and mean gale days (blue) in north China (Wang et al., 2004). The bold lines are the linear trends.

Two factors can influence the anthropogenic signals in lake sediments: dilutions by natural lithogenic components and mobility during diagenesis. To eliminate the influence of the dilution by lithogenic components, heavy metal concentrations are often normalized by the contents of conservative elements in rocks, such as Al or Sc (Tam & Yao, 1998; Aloupi & Angelidis, 2001; Liu et al., 2003; Ip et al., 2004). In this study, we used Al rather than Sc as the conservative lithogenic element because Sc is enriched in the emissions of biofuel burning (Senior et al., 2000; Taggart et al., 2016). Aluminum usually originates from the natural lithogenic components of lake sediments, which dominate the grain size distributions. In contrast, Pb and Sb have two potential sources: lithogenic and anthropogenic origins. The lithogenic components of Pb and Sb have same origin of Al in lake sediments. Furthermore, the lithogenic Pb and Sb, like Al, are usually concentrated in the fine components of sediments (Taylor & McLennan, 1985). Therefore, the Al-normalized Pb and Sb eliminate the influence of granulometric and/or mineralogical variations of sediments and mainly reflect the changes of anthropogenic Pb and Sb transported into lakes (Tam & Yao, 1998; Aloupi & Angelidis, 2001; Liu et al., 2003; Ip et al., 2004).

Diagenetic impacts are limited in the case of the Pb and Sb contents of the studied lakes because of the following reasons. First, the mobility of anthropogenic heavy metals with redox conditions is the major post depositional diagenetic process. As discussed above, anthropogenic antimony is insensitive to changes in post depositional redox conditions, and thus, the covariation of Sb and Pb in the records indicates that there were limited changes in redox conditions during the studied interval (Figure 3), with no obvious impact on Pb concentrations. Second, the exponential decrease of excess ^{210}Pb with depth also suggests minimal changes in redox conditions during the studied interval (Figure S1), despite the fact that Pb is sensitive to redox conditions (Kuwae et al., 2013). Therefore, the Al-normalized Pb and Sb records from Lake Gonghai and Baihu can confidently be interpreted as reflecting changes in the atmospheric loading of anthropogenic emissions.

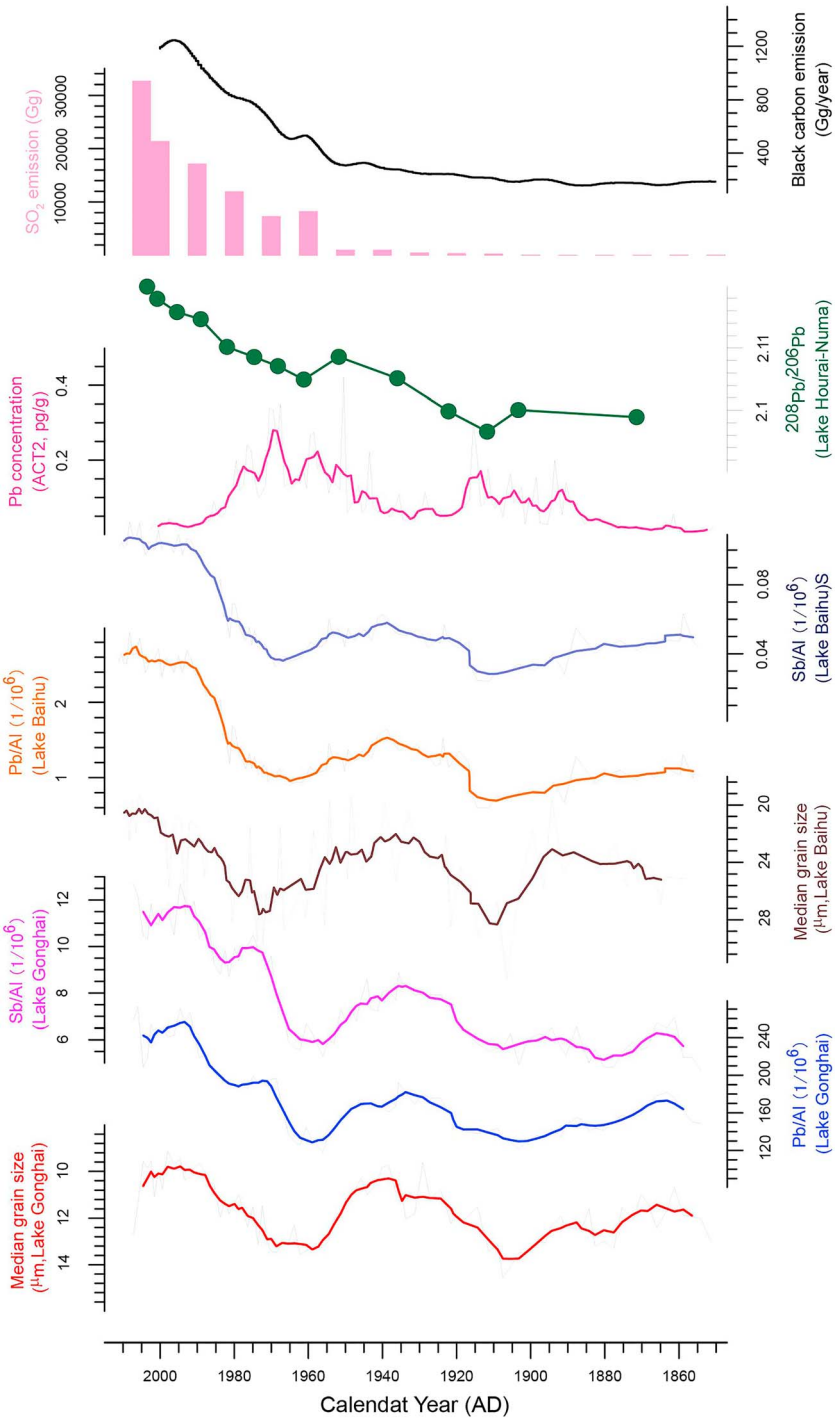

Figure 3. Comparison of MD, Pb/Al, and Sb/Al records from Lake Gonghai and Baihu with Pb concentrations in Greenland ice core (McConnell & Edwards, 2008), Pb isotope record of Lake Hourai-Numa in Japan (Kuwae et al., 2013), and anthropogenic emissions of SO_2 (Smith et al., 2011) and black carbon (Bond et al., 2007) in China.

3.3. Changes of Wind Strength and Atmospheric Loading of Anthropogenic Emissions During the Past 180 Years

The concentrations of Pb and Sb are higher in the sediments of Lake Gonghai than Baihu. The respective concentrations of Pb and Sb at Lake Gonghai range from 82.99 to 110.79 (average of 97.46 ± 6.65 mg/kg) and from 3.0 to 5.26 mg/kg (average of 4.04 ± 0.46 mg/kg). At Lake Baihu, the respective concentrations

of Pb and Sb are from 17.42 to 27.8 mg/kg (average of 22.74 ± 2.92 mg/kg) and from 0.68 to 1.15 mg/kg (average of 0.93 ± 0.13 3.0). By contrast, the grain size of the sediments from Lake Baihu (MD = 23.96 ± 2.66 μm) is much coarser than that of Lake Gonghai (MD = 11.69 ± 1.26 μm). These characteristics are consistent with the respective limnological settings of the studied lakes. Lake Baihu is located in the margin of Korqin Sandy Land, and the human activity in the windward areas is low. By contrast, Lake Gonghai is located at the top of a mountain and the downwind areas of the regions with a high industrial activity in northern China. Therefore, the atmospheric dust transported into Lake Gonghai would be expected to be relatively enriched in heavy metals. In addition, the high sediment rate might also contribute to the low heavy metal concentrations in the sediments of Lake Baihu. In Baihu, the location in the margin of the sandy land results in a higher sedimentary rate of clastic materials, which dilute the heavy metal concentrations of the sediments.

The Al-normalized heavy metals display a consistent change for the two lakes during the past 180 years, though the absolute values are smaller in Lake Baihu than Lake Gonghai. The low values of Pb/Al and Sb/Al ratios in Lake Baihu is consistent with the fact that the anthropogenic emissions around the lake and its windward areas are low. The values of Pb/Al and Sb/Al show a periodical vibration superimposed on a linear increasing trend during the past 180 years. The atmospheric loading of anthropogenic emissions was low around 1910 and 1970 and reached the maximum during recent decade (Figure 3). Two peaks of high atmospheric loading occurred during the intervals from 1920 to 1950 and after 1980, respectively (Figure 3). This consistent change indicates that the atmospheric loading of anthropogenic emissions over the studied lakes should be dominated by the same dynamics.

During the past 180 years, the atmospheric loading of anthropogenic emissions is inversely related to the wind strength on both decadal and centennial time scales (Figure 3). On the centennial time scale, the atmospheric loading exhibits a linear increasing trend with the weakening wind strength. Superimposed on this linear trend is a pattern of quasi periodic multidecadal fluctuations of atmospheric pollutant concentrations and wind strength. The results of spectral analysis indicate that the fluctuations are dominated by a ~60-year periodicity (Figure S4). During the intervals of strong wind strength, in around 1900 and 1970, the atmospheric loadings of anthropogenic emissions were low, and the peaks of anthropogenic Pb and Sb concentrations corresponded to the intervals of the weakest wind strength from 1920 to 1950 and after 1980 (Figure 3).

A similar pattern of changes in atmospheric anthropogenic emission loadings has been detected in the records from eastern Asia (Figure 4). These records include the atmospheric soot concentrations in PM2.5 recorded in Lake Daihai and Lake Taihu (Han et al., 2010), Pb concentrations at Erbaifangzi in Xianghai Peatland (Wang et al., 2004), atmospheric Pb and Sb enrichments (Bao et al., 2015), Hg Flux (Bao et al., 2016) in the peatlands of the Hinggan Mountains, and the flux of airborne polycyclic aromatic hydrocarbons in the East China Sea (*Z* Guo et al., 2006). These records consistently show that the atmospheric loadings of anthropogenic emissions were low during the intervals of strong winds. In addition, the soot concentrations in the sediments of Lake Chaohu was low at around 1970 and increased significantly with weakening wind strength, rather than with anthropogenic emissions (Han et al., 2011). This provides further confirmation of the consistency of the variations in atmospheric pollutant loading in eastern China during the past 180 years. The increased anthropogenic flux after 1980 detected in a previous study of Lake Gonghai is also consistent with our results, although the minor changes in $^{210}Pb_{ex}$ above 20 cm and in the ^{137}Cs profile of the uppermost part of the core indicate a possible disturbance of the sediments (Wan et al., 2016).

3.4. Forcing of Wind Strength and Haze Days in China

There is no obvious correlation between the atmospheric heavy metal loading recorded at the studied sites and the anthropogenic emissions in China during the past 180 years (Figure 3). Anthropogenic emissions were low and barely changed from 1930 to 1950, but the concentrations of anthropogenic Pb and Sb at studied sites increased by about 40%. Anthropogenic emissions increased significantly around 1960s, but the atmospheric loading reached its lowest values (Figure 3). After 1980, although the increase in anthropogenic emissions (SO_2 and black carbon) seemingly coincided to the high atmospheric pollutant loading, detailed observation finds that the atmospheric loading changed little after 1995, whereas the SO_2 and black carbon emissions continued to increase and reached a maximum in around 2005 (Bond et al., 2007; Smith et al., 2011). Therefore, we conclude that the major forcing factor of atmospheric loading of pollutants and the resulting haze days in China was wind strength rather than anthropogenic emissions. This conclusion is consistent with the coincidence of the haze days with weak wind strength observed in the meteorological

registers of the past several decades (H Chen & Wang, 2015; Hui & Xiang, 2014; H Wang et al., 2015; Xiao et al., 2014). Nevertheless, the dominant role of wind strength cannot exclude the contribution of anthropogenic emissions to high exposure to aerosol pollutions in China. Under weak wind condition, the threshold for haze days is more frequently attained with high anthropogenic emissions. As a result, a high frequent and severe haze days would occur, causing a high risk of exposure to aerosol pollution.

To discriminate the major forcing factors of wind strength over the past 180 years, we compared our records with the observed temperature changes in China (Shaowu et al., 2004), the annual average tropical ocean surface temperature (TSST; Huang et al., 2015), the Atlantic Multidecadal Oscillation (AMO; Trenberth & Shea, 2006), and the Arctic sea ice extent (ICE; H Wang et al., 2015; Figure 5). All these factors have been suggested as the major forcing factors of heavy haze days in China (Hui & Xiang, 2014; H Wang et al., 2015; Xiao et al., 2014). Notably, the wind strength is inversely related to the meteorological registers of temperature changes in China, suggesting a close association between them (Figure 5). This postulation has been tested by climate modeling studies. The results of the coupled GCM and the coupled atmosphere-ocean GCMs consistently indicate that global warming would weaken the Asian winter monsoon (the dominant atmospheric circulations during the seasons of haze formation in China) through the weakening the Aleutian Low, the Siberian High, and the contrast in sea level pressure and near-surface temperature between the Asian continent and the Pacific Ocean (Hori & Ueda, 2006; Hu et al., 1999).

During the past 40 years, the TSST, AMO, and ICE exhibited a coherent pattern of changes characterized by an increase in the TSST, a positive anomaly of the AMO, and a decrease in the ICE (Figure 4). All of these changes have been suggested as the cause of the weak wind strength favoring haze formation in China (Hui & Xiang, 2014; H Wang et al., 2015; Xiao et al., 2014). The consistent variations of these factors clearly demonstrate that the short-term observations are insufficient to capture all change scenarios to identify the major forcing factor of haze formation in China. Our long-term records provide the first opportunity to make deep insights into the dynamics of haze formation.

The TSST, AMO, and ICE exhibit different patterns of variation during the past 180 years. The TSST and AMO varied with a pattern of high-amplitude periodic fluctuations, whereas there is no obvious periodicity in the variations of the ICE, which excludes the ICE as the major forcing factor of the haze days in China. In addition, the changes in the AMO evidently lag those of both the wind strength and observed temperature in China, although they are dominated by a similar periodicity (Figure 5). Wind strength/temperature began to decrease/increase in around 1907, while the positive shift of the AMO occurred around 1925 (Figure 4). Similarly, temperature started to decrease in around 1945, but the onset of the corresponding negative shift of the AMO occurred in around 1960. To further constrain their phase difference, we conducted a cross-correlation analysis of the AMO and the observed temperature in China. The results reveal that the temperature changes in China lead the AMO by about 10 years ($p << 0.001$; Figure S5), which is consistent with the observed out-of-phase relationship between the East Asian winter monsoon and the Arctic and North Atlantic Oscillations (*D Y* Gong et al., 2001).

By contrast, the changes of temperature in China are in-phase with the tropical ocean surface temperature (Figure 3), and no phase difference was detected by cross-correlation analysis between them (Figure S5). The dominant role of the TSST in climate changes in China was tested by the close correlation between the TSST (e.g., in tropical Pacific) and warming in the Arctic region (Ding et al., 2014), a weak Siberian High, and a weak Aleutian Low (D-Y Gong & Ho, 2002; Hasanean et al., 2013), all of which would weaken wind strength and thus promote the occurrence of haze days in China.

Our results also have some implications for the impact of anthropogenic emissions in China on the global environments. Based on the previous studies, mineral dust and pollutants from China can be transported across the entire globe (Jaffe et al., 1999; Uno et al., 2009). Radiogenic isotope and mineralogical compositions of modern dust and the dust in Greenland ice cores indicate that from the last glacial maximum to the present, the dust primarily, if not exclusively, originated in Asia (Biscaye et al., 1997; Bory et al., 2002; Bory et al., 2003). The evidence of heavy metals in a Greenland ice core (ACT2) suggests that coal burning in middle latitudes may be a major source of the Pb deposited in the Arctic (McConnell & Edwards, 2008). The Pb concentrations in ice core ACT2 (McConnell & Edwards, 2008) are well correlated with wind strength in China but are decoupled from the atmospheric loading of anthropogenic emissions. The two peaks of Pb concentrations from 1895 to 1915 and from 1955 to 1975 in core

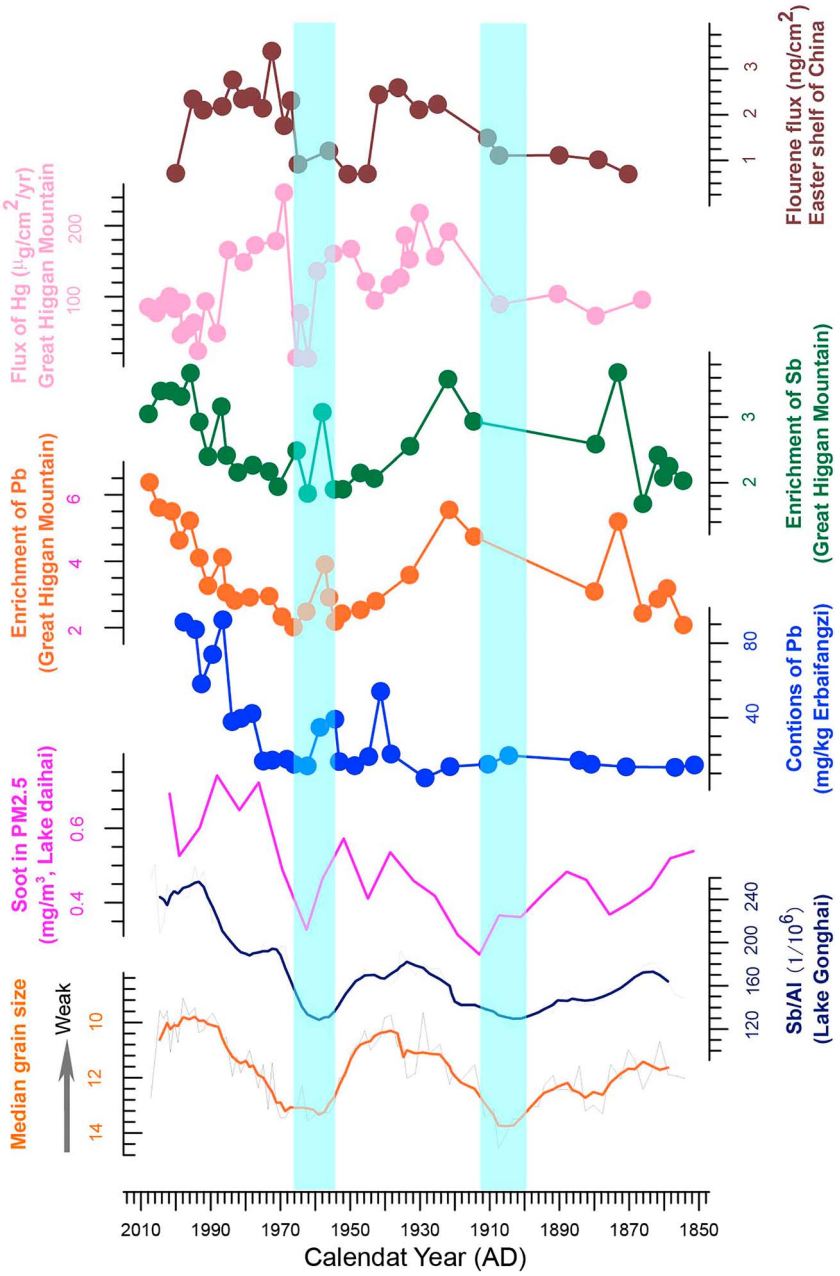

Figure 4. Comparison of MD and Pb/Al of Lake Gonghai and Baihu with atmospheric soot concentrations in PM2.5 of Lake Daihai (Han et al., 2010), Pb concentrations (normalized to aluminum) of Erbaifangzi in Xianghai Peatland (Wang et al., 2004), atmospheric Pb and Sb enrichment (Bao et al., 2015), Hg Flux (Bao et al., 2016) in the peatlands of Hinggan Mountain, and flourence flux in the eastern shelf of the East China Sea (Guo et al., 2006)

ACT2 correspond to intervals of strong winds in China (Figure 3). By contrast, Pb isotope records from Japan suggest that the anthropogenic Pb transported from China and Russia increased with the atmospheric loadings of anthropogenic emissions in China (Kuwae et al., 2013; Figure 3).This evidence shows that the anthropogenic pollutants emitted from the eastern Asia can potentially stagnate over the source areas and neighboring regions under the conditions of low wind strength but be transported worldwide by strong winds and thus have a global impact. This postulation is consistent with the dominant role of atmospheric circulation in the long-distant transport of Asian mineral dust during the Holocene (Xu et al., 2018).

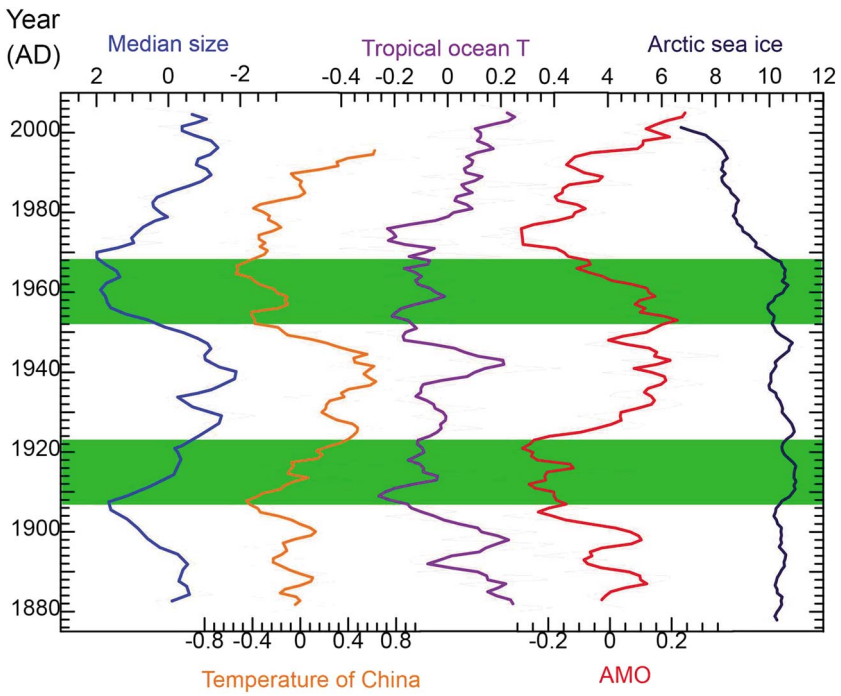

Figure 5. Comparison of median grain size of the Lake Gonghai sediments (detrended) with temperature in China, average annual sea surface temperature of 20 °N–20 °S (with linear trend removed; Huang et al., 2015), AMO (Trenberth & Shea, 2006), and Arctic sea ice extent (Wang et al. 2014).

4. Conclusion

Our results provide the first major long-term insight into the dynamics and possible future changes in the incidence of haze days in China, in the context of ongoing global warming. The weak wind strength associated with global warming plays a major role in the formation of haze days. The observed good correlation between temperature and the atmospheric loading of anthropogenic emissions suggests that continued global warming will increase the incidence of haze days in China by further weakening the wind strength. Under the conditions of high temperature, the anthropogenic pollutants will stagnate mainly within the atmosphere over the source areas and the neighboring regions and thus favor haze formations. However, they would be transported to long distance areas by strong winds associated with decreasing temperature. Temperature changes in China are more closely associated with tropical sea surface temperature rather than with the AMO and Arctic ice. The observed pattern of periodic temperature changes indicates that wind strength will increase and thus the incidence of haze days will be reduced over the next 30 years, but this alleviation may be undermined by continued rising temperature as anthropogenic greenhouse gas emissions continue to increase. The dominant role of wind strength in haze day formation cannot exclude the contribution of anthropogenic emissions to high exposure to aerosol pollutions in China. Weak wind strength, together with high anthropogenic emissions, would cause a high frequent and severe haze days and thus high risk of exposure to aerosol pollution. Therefore, reducing anthropogenic greenhouse gases emissions, which is often accompanied by emissions of the anthropogenic pollutants, should be the principal strategy for reducing the haze days and risk of exposure to aerosol pollution in China.

Acknowledgments
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