Sunshine dimming and brightening in Chinese cities (1955–2011) was driven by air pollution rather than clouds

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ABSTRACT: Sunshine hours in 42 big cities across China declined at a rate of 0.26 h d^{-1} decade^{-1} from 1955 to 1989. The decreasing trend in sunshine hours levels off from 1990 to 2011, with a marginal decline of 0.02 h d^{-1} decade^{-1}. Since 1990, there has been a recovery of sunshine hours on average by 0.19 h d^{-1} decade^{-1} in a third of the country, especially South China. In the other two-thirds of the country, sunshine hours have continued to decrease by 0.13 h d^{-1} decade^{-1} on average. For spring and winter seasons, sunshine hours rebounded in 1990 to 2011 across the country by 0.27 and 0.08 h d^{-1} decade^{-1}, respectively. Total cloud cover (TCC) and air pollution index (API)—2 potential driving factors—were selected as likely candidates for explaining the change in the sunshine trend. Based on Grey Relational Analysis (GRA), for cities and seasons with increasing sunshine hours, the prime driver of recent sunshine hour recovery is API rather than TCC. Annual trends in sunshine hours and TCC of the 42 cities and 42 nearby counties were compared for 1955 to 2011. There is a growing gap in sunshine trends between cities and counties from ~1978 onwards. By contrast, TCC trends remained very similar. It is therefore most likely that the best explanation for recent stabilization of sunshine hours in the 42 big cities across China is the decline in API. In general, cities with increasing sunshine hours have good air quality and frequent cloud events.

KEY WORDS: Sunshine hours · Air pollution index · Total cloud cover · Grey relational analysis

1. INTRODUCTION

A steady reduction in surface solar radiation occurred worldwide from the 1950s to late 1980s (popularly known as global dimming); since, however, a reversal in the form of global brightening has been observed in most of the world, especially the heavy industrialized regions (Wild et al. 2005, Wild 2012). In China, following a dimming phase since the 1960s, solar radiation reached a stable level after 1990 (Tang et al. 2011). Broadly used as a surrogate for solar radiation, sunshine hours have also been noted to be recovering in the developed world since the 1980s or earlier. Angell & Korshover (1978) pointed out an abrupt reversal in annual sunshine hours within the contiguous USA in 1972. Sanchez-Lorenzo et al. (2008) verified an increasing trend in annual mean sunshine hours over Western Europe from 1980 to 2000 following a decreasing trend from 1950 to 1980. Stanhill & Cohen (2008) confirmed an accelerated increase in annual sunshine duration in Japan since the mid-1980s following a small and irregular decline from the 1950s. In China, recent studies have revealed strong declines in sunshine hours during the latter half of the 20th century (Kaiser & Qian 2002, Che et al. 2005, Xia 2010b, Wang et al. 2012b).

This is especially the case for South China (Li et al. 2011), the Yangtze River Delta (Chen et al. 2006) and North China (Yang et al. 2009a,b).

Clouds and aerosols are the most likely candidates to explain global dimming and brightening (Wild 2009). By reflecting solar radiation, clouds negatively affect sunshine hours. The critical role of clouds in regulating sunshine hours has been observed in the Tibetan Plateau (You et al. 2010), South China (Li et al. 2011) and Southwestern China (Li et al. 2012). Xia (2010b) noted that cloudiness predominantly determines the short-term variability of sunshine hours in China. On the other hand, there is abundant evidence that air pollution negatively affects solar radiation and sunshine hours in China (Kaiser & Qian 2002, Che et al. 2005, Qian et al. 2006, Wang et al. 2012b). Human activities release anthropogenic particles into the atmosphere that alter aerosol density in the immediate sphere above the earth (Coe 2011). Due to the nature of their composition, aerosols (which are particles <1 μm in diameter) can directly scatter and/or absorb surface solar radiation in a process known as 'direct radiative forcing'. Increasing atmospheric aerosol density enhances the formation of clouds (as particles act as cloud condensation nuclei) that in turn increase the reflection of solar radiation in a process known as 'first indirect radiative forcing'. Pollution expands cloud lifetime and suppresses precipitation, which in turn leads to a significant reduction in global radiation in a process known as 'second indirect radiative forcing' (Charlson et al. 1992, Ramanathan et al. 2001). Furthermore in heavily polluted regions, absorbing aerosols in pollution layers could heat and stabilize the atmosphere, and thereby inhibit cloud formation or even dissolve existing clouds in a process known as 'semi-direct radiative forcing' (Wild 2009). All the radiative forcings of aerosols act towards attenuating surface solar radiation and sunshine hours. Global brightening has been widely related to anthropogenic efforts, which has resulted in strict regulations on reducing aerosol emissions and air pollution (Che et al. 2005, Streets et al. 2006, Wild 2009). In big Chinese cities, it remains inconclusive as whether clouds or aerosols are the main driver of recent change in sunshine trend.

The objectives of this study are (1) to spatially and temporally examine the dimming/brightening phenomenon in sunshine hours in 42 big cities across China for the period 1955–2011, and (2) to identify the prime driver of sunshine hour variations in China based on cause–effect analysis between sunshine hours and the 2 most likely driving factors: total cloud cover (TCC) and air pollution index (API).

2. DATA AND METHODS

2.1. Data and analysis

Data were collected in 42 cities mainly at provincial-level and 42 nearby counties across China within longitudes 87° 39′ to 128° 44′ E and latitudes 19° 02′ to 45° 58′ N (Fig. 1). All the investigated cities have available State Environmental Protection Administration (SEPA) monitored pollution data. All the selected counties are the nearest ones to the cities with reliable meteorological data.

Daily meteorological data of sunshine hours and TCC for 1955 to 2011 were derived from the China Meteorological Data Sharing Service System (CMDS) via the portal http://cdc.cma.gov.cn/. Routine monitoring methods and instrumentation of the datasets are documented by Tao et al. (1997). Sunshine hours were measured by the Campbell–Stokes sunshine recorder. TCC data were based on subjective estimates. All the meteorological observations were done in accordance with the specifications for surface meteorological observations authorized by the China Meteorological Administration (CMA). Quality assurance checks were performed for gross errors, time consistencies and rectifications of all detected errors in the datasets (see interpretation of data quality in section 3.7 of the meteorological data). Daily API data for 2001–2011 were obtained from the China National Environmental Monitoring Center (CNEMC) at www.cnemc.cn/, managed by the SEPA. API was calculated by computing the sub-indices of air pollutants in each monitoring station on 24 h average concentrations of principal pollutants SO_2, NO_2 and inhalable particulates (PM_{10}). Hence API is defined as the maximum index for I_{PM10}, I_{SO2} and I_{NO2}, where the factor I is the API 24 h score for pollutants PM_{10}, SO_2 and NO_2 in a range of 0–500. Note that PM_{10} is the predominant air pollutant in China.

The magnitudes of sunshine trends over the 42 big cities across China were computed for the periods 1955–1989 and 1990–2011, and plotted on a GIS platform. Stepwise linear regression analysis was used to determine the significance of sunshine trends at the 95% confidence level. Based on the results, the investigated cities were divided into 3 groups: 42-C (total cities), 27-CDSH (cities with decreasing sunshine hours for 1990–2011) and 15-CISH (cities with increasing sunshine hours for 1990–2011). Next, annually averaged daily sunshine hours for each of the city groups were analyzed for the period 1955–2011 to isolate the time(s) with significant variation in sunshine hours. The magnitudes of sunshine trends over
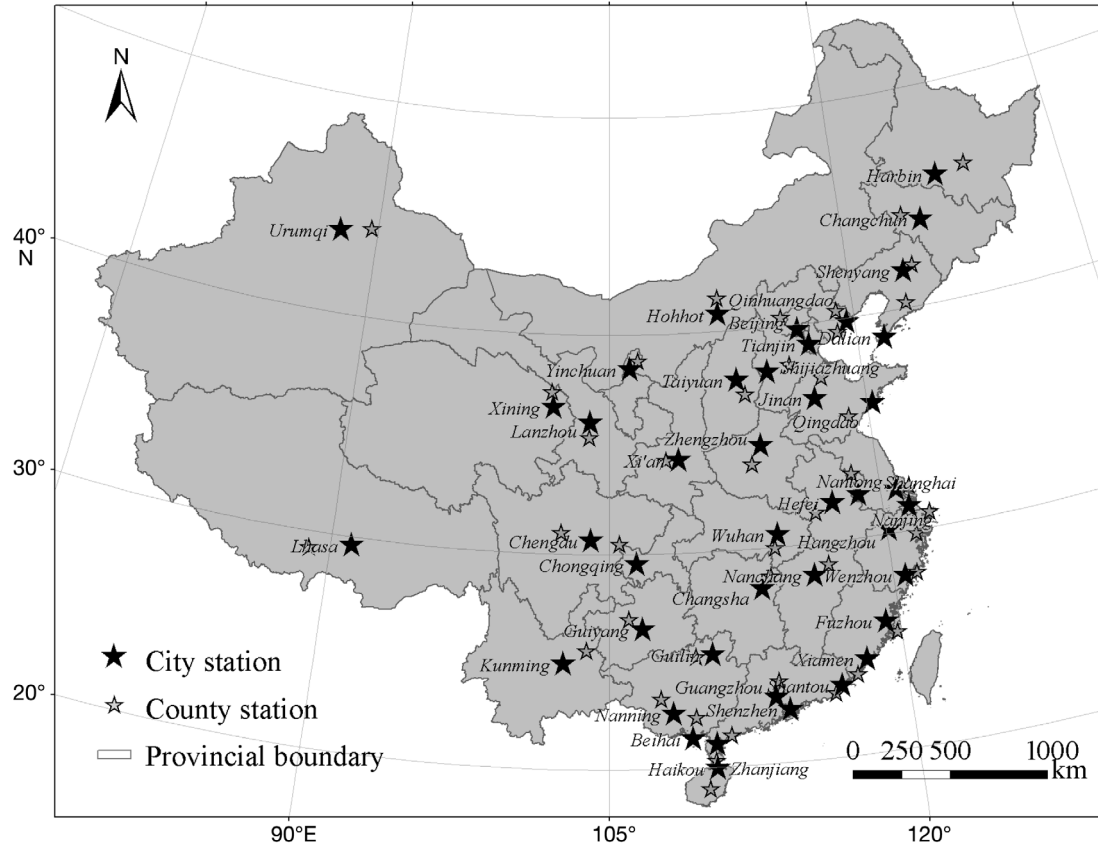
Fig. 1. Meteorological stations used in the study across China

the 42 big cities for 1990–2011 were further evaluated along seasons: spring (March to May), summer (June to August), autumn (September to November), and winter (December to February). And seasonally averaged daily sunshine hours for the 42 cities were analyzed for the period 1990–2011 to isolate the season(s) with sunshine hour recovery.

To identify the major driver of sunshine hour variation, first of all, annual fluctuations of sunshine hours were compared with those of TCC and API in the 3 city groups for the period 1955–2011. Grey relational analysis (GRA) was conducted to determine how significantly TCC influences sunshine hours for the periods 1955–1989 and 1990–2011. GRA was also used to determine the influences of TCC and API on sunshine hours for the period 2001–2011 in the 3 city groups. Second, annual fluctuations of sunshine hours and TCC for the 42 cities were compared with those for the 42 selected nearby counties for 1955–2011. The significance of the influence of TCC on sunshine hours for the 42 cities and 42 counties for the periods 1955–1989 and 1990–2011 was determined using GRA. Third, seasonal fluctuations of sunshine hours, TCC and API for the 42 cities were compared for the

period 1990–2011. GRA was applied to determine the significance of the influences of TCC and API on sunshine hours for different seasons in 2001–2011.

2.2. Grey relational analysis

GRA is an effective way to quantitatively analyze the closeness between objective factor and reference factors in a grey system, which can be used to judge key factors of an event (Deng 1989, 1990, 1992). Let the sequences of objective factor and reference factors respectively be:

$$x_0 = \{x_0(k),\ k = 1,\ 2,\ ...,\ n\} \tag{1}$$

$$x_i = \{x_i(k),\ k = 1,\ 2,\ ...,\ n;\ i = 1,\ 2,\ ...,\ m\} \tag{2}$$

where x_0 and x_i are elements of original sequences of objective factor and reference factors (from 1 to m), respectively, and k is a certain point in time.

In GRA, data pre-processing must be performed to transfer these original sequences into comparable ones. In this study, mean-value processing was chosen among various approaches for data pre-process-

ing. In the mean-value processing, elements in each sequence are divided by the mean value as:

$$x_0{}^* = \frac{x_0(k)}{\overline{x}_0} \text{ and } x_i{}^* = \frac{x_i(k)}{\overline{x}_i}, \; k = 1, 2, ..., n; \; i = 1, 2, ..., m \tag{3}$$

where $\overline{x}_0$ and $\overline{x}_i$ are the mean values of original sequences of objective factor and reference factors, respectively; and $x_0{}^*$ and $x_i{}^*$ are elements of normalized sequences of objective factor and reference factors, respectively.

Next, the grey relational coefficient $\xi_i(k)$ is calculated to express the correlation between normalized objective sequence and reference sequences at the time point k as:

$$\xi_i(k) = \frac{\min_i \min_k \left| x_0{}^*(k) - x_i{}^*(k) \right| + \rho \max_i \max_k \left| x_0{}^*(k) - x_i{}^*(k) \right|}{\left| x_0{}^*(k) - x_i{}^*(k) \right| + \rho \max_i \max_k \left| x_0{}^*(k) - x_i{}^*(k) \right|},$$

$$k = 1, 2, ..., n; \; i = 1, 2, ..., m \tag{4}$$

where $\rho \in [0.1]$ is the distinguishing coefficient that controls the resolution scale and is generally assigned the value of 0.5 (which in fact was the exact value used in this study).

After the weighted summing of grey relational coefficients, grey relational grade is obtained to represent the level of correlation between normalized objective sequence and reference sequences at all time points. The grey relational grade γ_i is defined as follows:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k), \; i = 1, 2, ..., m \tag{5}$$

The grey relational grade $\gamma_i \in [0.1]$ can numerically measure the influence of reference factors on the objective factor. The higher a grey relational grade is, the closer the factors are correlated. In general, $\gamma_i > 0.9$, > 0.8, > 0.7 and < 0.6 indicate marked, relatively marked, noticeable and negligible influences, respectively (Fu et al. 2001).

3. RESULTS

3.1. Spatial/temporal sunshine trends in China since 1955

Fig. 2 shows the trends in decadal average daily sunshine hours in the 42 big cities for the periods 1955–1989 (Fig. 2A) and 1990–2011 (Fig. 2B). In 1955–1989, a decline in sunshine hours occurs in 41 cities at an average rate of 0.27 h d^{-1} decade^{-1}. Of the 41 cities, 31 show significant sunshine hour declines at the 95% confidence level while 21 show declines
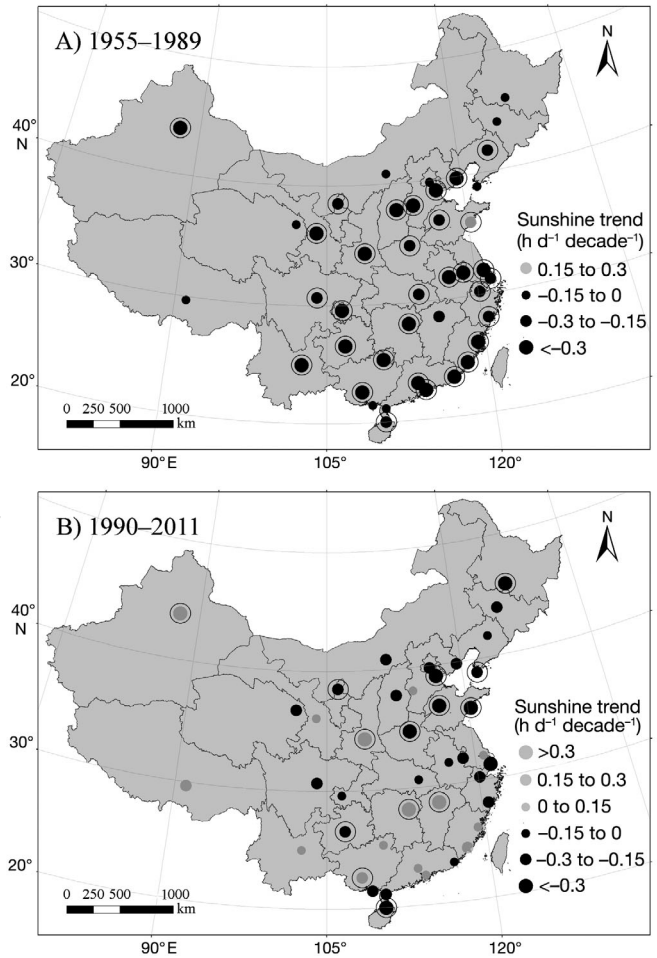

Fig. 2. Spatial patterns of sunshine trends over the 42 big cities across China for the periods (A) 1955–1989 and (B) 1990–2011. Circles: upward trend (grey); downward trend (black); significant trend at the 95% confidence level (open)

of > 0.3 h d^{-1} decade^{-1}. Qingdao is the only city with increasing sunshine hours in 1955–1989. After 1990, the spatial extent of sunshine hour decline shrinks to 27 cities. The average decline after 1990 is 0.25 h d^{-1} decade^{-1}, occurring mainly in areas around North China. About 5 of the cities have significant sunshine hour declines and 7 have declines > 0.3 h d^{-1} decade^{-1}. Sunshine hours in the other 15 cities (mainly distributed in South China) rebound by 0.22 h d^{-1} decade^{-1} for the 22 yr. Significant ($p < 0.05$) sunshine hour recovery occurs in the cities of Xi'an (0.80 h d^{-1} decade^{-1}), Urumqi (0.66), Changsha (0.39), Nanchang (0.35) and Nanning (0.29). Of these cities, 4 have declines of > 0.3 h d^{-1} decade^{-1} in sunshine hours for 1955 to 1989.

To further isolate the period with notable change in sunshine hours, the cities were analyzed after grouping into 42-C, 27-CDSH and 15-CISH city groups.

Fig. 3A illustrates the annual trends in average daily sunshine hours for the 3 city groups for 1955–2011. For the 42-C city group, there is an obvious decline in sunshine hours for 1955–1989 at a rate of 0.026 h d^{-1} yr^{-1}. Then, sunshine hour decrease tends to stabilize from 1990 with a negligible trend of −0.002 h d^{-1} yr^{-1}. For the 27-CDSH city group, sunshine hours show a continuous decline for the 57-yr period. The decreasing trend slightly slows down after 1990. For the 15-CISH city group, an obvious change exists in sunshine trend with a strong decline of 0.036 h d^{-1} yr^{-1} in 1955–1989 and a recovery of 0.019 h d^{-1} yr^{-1} in 1990–2011. Sunshine hours in the 15-CISH group are generally shorter than in other city groups. This suggests more intensive cloud cover in humid areas than in arid and semi-arid areas.

Seasonal sunshine trends in the 42 big cities for 1990–2011 are shown in Fig. 4. Compared with other seasons, it is obvious that the extent and magnitude of sunshine hour increases are highest in spring, covering 29 cities and increasing on average by 0.44 h d^{-1} decade^{-1}. The rate of sunshine hour increase in 17 cities is >0.3 h d^{-1} decade^{-1}, of which 10 cities have a significant increase at the 95% confidence level. In winter, sunshine hour recovery (average 0.19 h d^{-1} decade^{-1}) occurs in 26 cities. Of these cities, 3 have a sunshine hour increase >0.3 h d^{-1} decade^{-1}. However, only one of these cities has a significant sunshine hour increasing trend. For the total 42 cities, sunshine hours rebound average by 0.27 and 0.08 h d^{-1} decade^{-1} in spring and winter of 1990–2011 (Fig. 5), respectively. In summer and autumn, however, decreasing trends still dominate the sunshine hour dynamics. Sunshine hours decline by 0.55 h d^{-1} decade^{-1} in 30 cities during summer. This trend is significant in 9 cities, with over 0.3 h d^{-1} decade^{-1} declines in 22 cities. In autumn, 34 cities have decreasing trends in sunshine hours, occurring at an average of 0.40 h d^{-1} decade^{-1}. Sunshine hour declines in 14 cities are significant and in 23 cities are >0.3 h d^{-1} decade^{-1}. On average, sunshine hours in the 42 cities decrease by 0.23 and 0.18 h d^{-1} decade^{-1} in the summer and autumn of 1990–2011, respectively (Fig. 5). Therefore, the slowdown in sunshine hour decline in 1990–2011 mainly occurs in spring and winter.
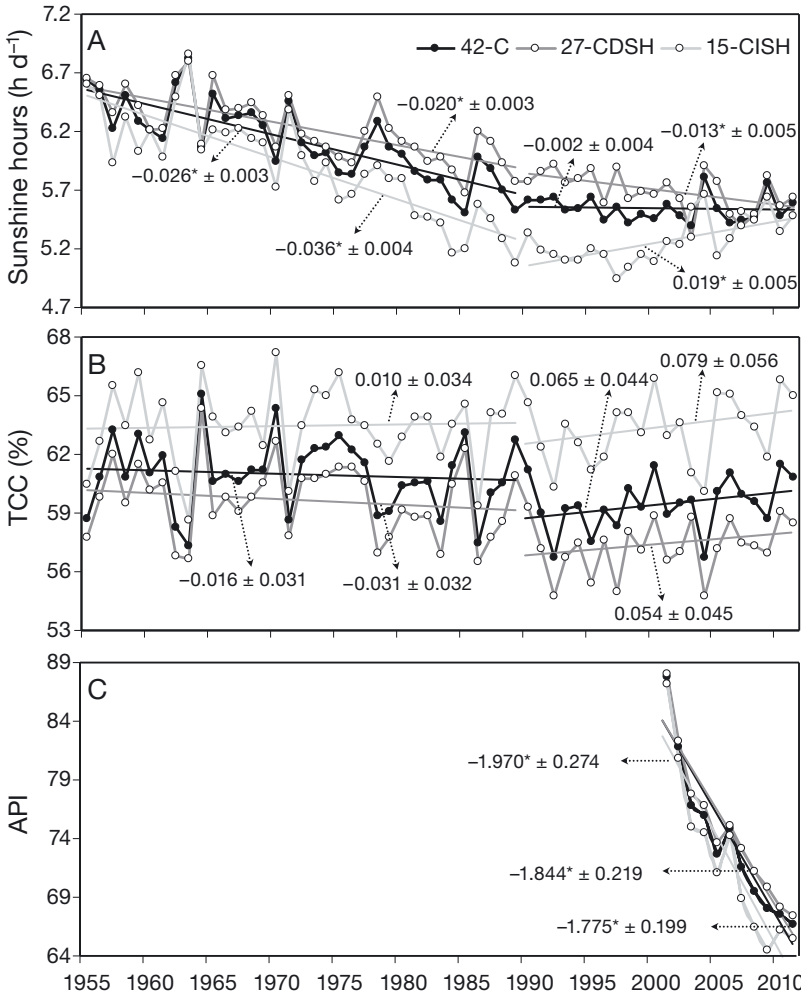

Fig. 3. Time series of annually averaged (A) daily sunshine hours, (B) total cloud cover (TCC) and (C) air pollution index (API) in the 3 city groups: 42-C (total cities), 27-CDSH (cities with decreasing sunshine hours for 1990–2011) and 15-CISH (cities with increasing sunshine hours for 1990–2011), respectively, for the period 1955–2011. Values: trend slopes and corresponding SEs. *Significant trend at 95% confidence level

3.2. Driving factors of sunshine hours

To determine the main stabilizing factor of sunshine trends in China, variations in sunshine hours were analyzed and compared against those in TCC and API along the city groups (42-C, 27-CDSH and 15-CISH; Fig. 3) and seasons (spring, summer, autumn and winter; Fig. 5). GRA analysis gave the degree of interrelatedness of sunshine hours with the potential driving factors.

Results of GRA reveal that TCC exerts a non-negligible (grey relational grade $\gamma_i > 0.6$) influence on sunshine hours at all temporal and spatial scales
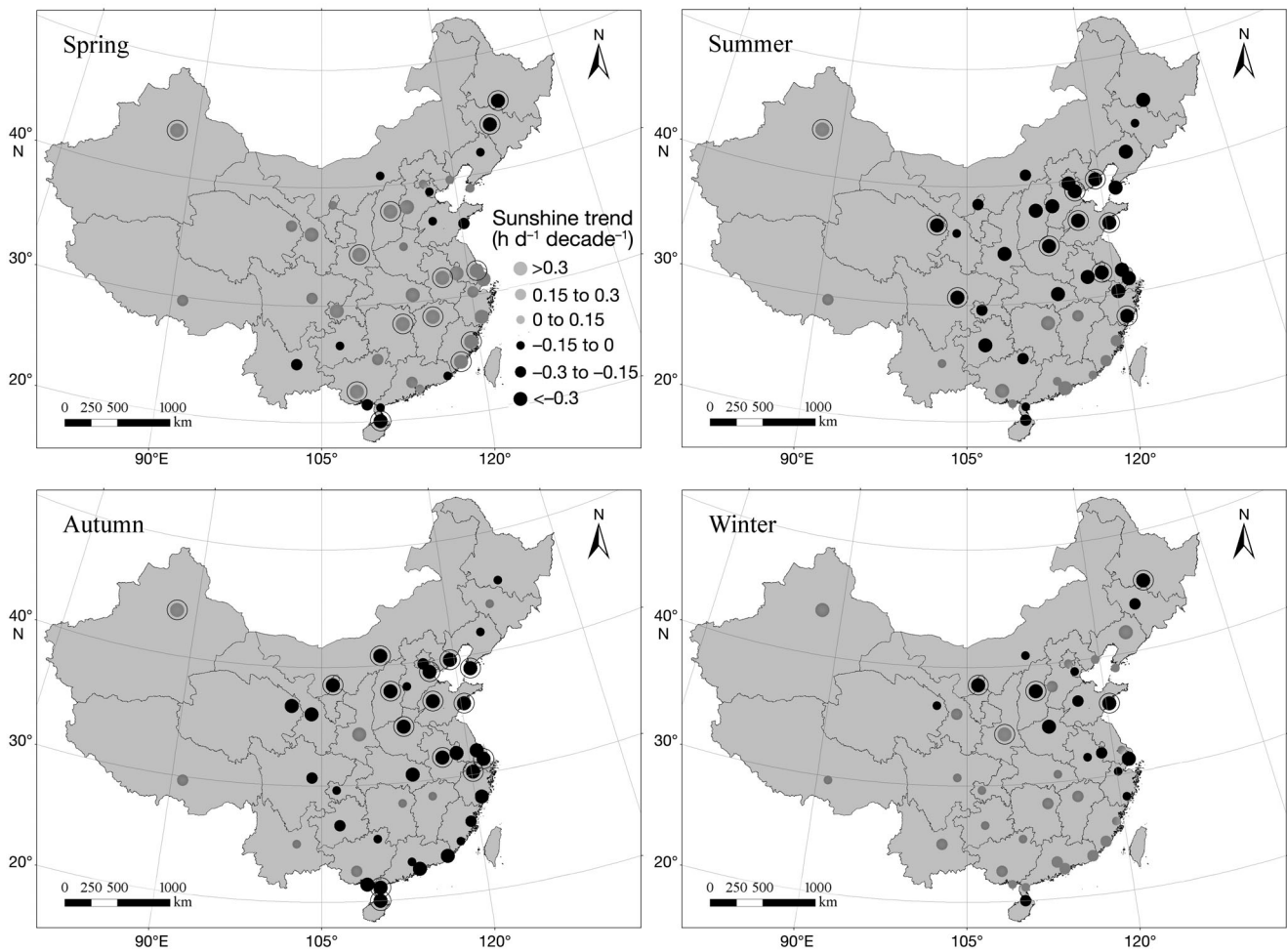
Fig. 4. Spatial patterns of sunshine trends over 42 big cities across China for the period 1990–2011 at seasonal time scales. Circles: upward trend (grey), downward trend (black) and a significant trend at 95% confidence level (open)

(Table 1). The level of significance of the effect of TCC on sunshine hours is weakened for 1990–2011 in all the city groups. From Fig. 3B, it is noted that TCC slightly increases in the 15-CISH city group for 1990–2011, which apparently cannot explain sunshine hour increase. Among all the city groups, annual average daily API for the 15-CISH city group decreases the most in 2001–2011 by 1.970 yr^{-1}. The corresponding effect of API on sunshine hours is a little stronger than that of TCC in the 15-CISH city group for 2001–2011 (see GRA results in Table 1). Therefore, the most plausible explanation for sunshine hour recovery in the 15 cities (mainly around South China) is the gradual decline in API. In other words, regulated anthropogenic aerosol emission is the possible driver of recent leveling off in sunshine trend in the 42 big cities.

To confirm the important role of air pollution in altering sunshine hour variation in big cities of

China, fluctuations of sunshine hours in the 42 big cities were compared with those in 42 nearby counties for 1955–2011 (Fig. 6A). A widening gap (starting somewhere in 1978) is depicted in annual average daily sunshine hours between the 42 cities and 42 surrounding counties. It was in 1978 that the policy of reform and openess was adopted in China. This policy brings accelerated not only economic growth, but also industrial emissions across China. Sunshine hour decline in cities is greater than that in the neighboring counties. By contrast, TCC change averaged over the 42 cities is very similar to the one averaged over the 42 counties (Fig. 6B). It is therefore improbable that TCC meaningfully contributes to the widening gap in sunshine hours between cities and counties. GRA analysis further shows that while the effect of TCC on sunshine hours for 1990–2011 weakens in the 42 cities, it strengthens in the 42 counties (Table 1). The much stronger sunshine hour
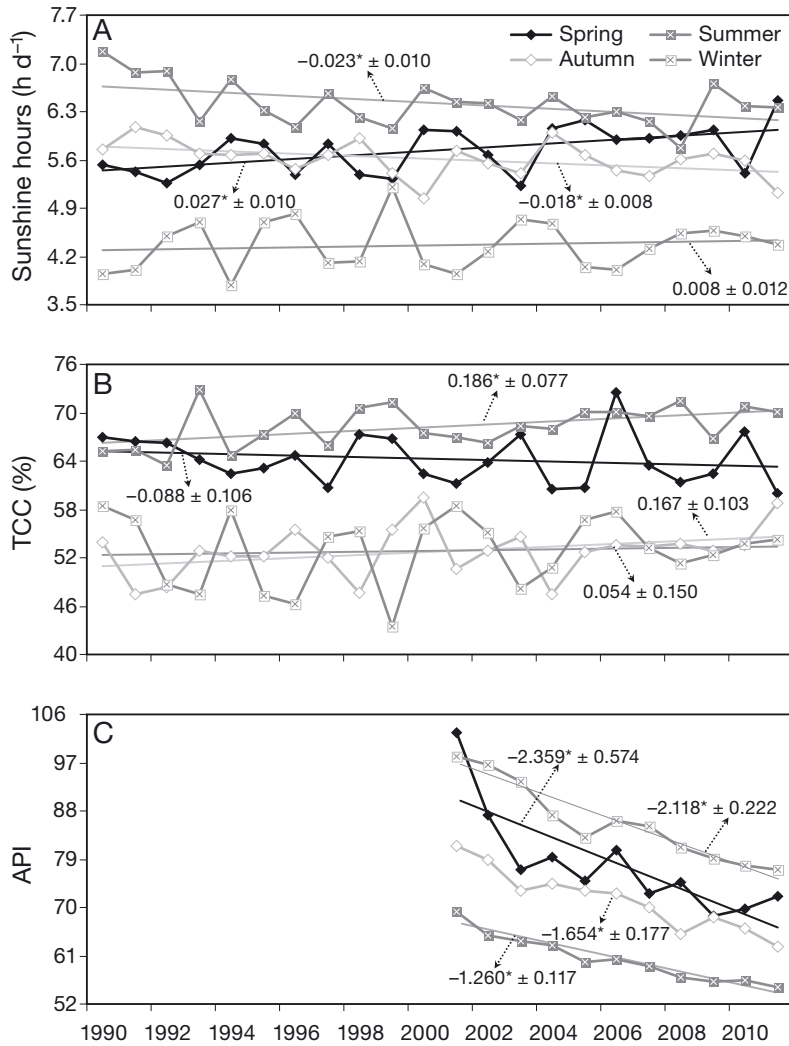
Fig. 5. Time series of seasonally averaged (A) daily sunshine hours, (B) total cloud cover (TCC) and (C) air pollution index (API) in the 42 big cities for the period 1990–2011. Values: trend slopes and corresponding SEs. *Significant trend at 95% confidence level

Table 1. Grey relational grades $\gamma_i \in [0.1]$ measuring the influences of total cloud cover (TCC, %) and air pollution index (API) on sunshine hours (h d^{-1}) in the 42-C (total cities), 27-CDSH (cities with decreasing sunshine hours for 1990–2011) and 15-CISH (cities with increasing sunshine hours for 1990–2011) city groups and 42 counties across China for the periods 1955–1989, 1990–2011 and 2001–2011

Period	42-C	27-CDSH	15-CISH	42 counties
TCC				
1955–1989	0.691	0.645	0.705	0.663
1990–2011	0.688	0.611	0.675	0.710
2001–2011	0.771	0.695	0.674	–
API				
2001–2011	0.696	0.686	0.687	–

decline in the big cities could be due to city-based API as opposed to regional-based climate changes.

From the GRA results in Table 2, the effect of TCC on sunshine hours is negligible ($\gamma_i < 0.6$) for seasons with increasing sunshine hours (spring and winter) while it is noticeable ($\gamma_i > 0.7$) for seasons with decreasing sunshine hours (summer and autumn) of 2001–2011. API effectively affects sunshine hour variations in all seasons, except autumn ($\gamma_i < 0.6$). Therefore, strong recovery in sunshine hours during spring could largely be due to the steepest decline in API (Fig. 5C), irrespective of the slight decline in the negligible driver of TCC (Fig. 5B, Table 2). Similarly, the slight sunshine hour recovery in winter could be driven by the second steepest decline in API (Fig. 5C). It is further clear that API decline has contributed in slowing down sunshine hour decline in the 42 big cities across China during the past decades.

4. DISCUSSION AND CONCLUSIONS

The sunshine trend in 42 big cities across China almost levels off at a negligible rate of −0.002 h d^{-1} yr^{-1} in 1990–2011, following a steady decline of 0.026 h d^{-1} yr^{-1} in 1955–1989. A severe decreasing trend in sunshine hours over China during the latter half of the 20th century has also been reported by Che et al. (2005), Kaiser & Qian (2002), and Xia (2010b). With quality-controlled data, Tang et al. (2011) pointed out a stable state in solar radiation in China since the 1990s. Sunshine hours in 15 cities (which cover ~1/3 of China, mainly South China) recover at 0.019 h d^{-1} yr^{-1} for 1990–2011. An increasing trend in solar radiation has also been noted in South China after 2000 (Xia 2010a), and across most of China after 1990 (Wang et al. 2011). In the other 27 cities, sunshine hours keep decreasing with a weakened rate of 0.013 h d^{-1} yr^{-1} after 1990. For the seasons, the extent and magnitude of sunshine hour recovery are highest in spring, fol-
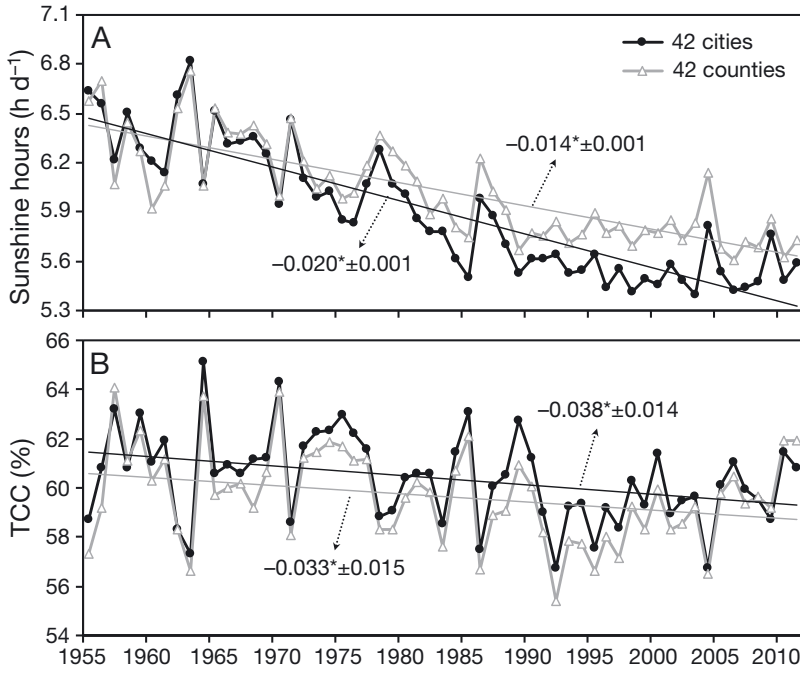
Fig. 6. Time series of annually averaged (A) daily sunshine hours and (B) total cloud cover (TCC) in the 42 cities and 42 counties, respectively, for the period 1955–2011. Values: trend slopes and corresponding SEs. *Significant trend at 95% confidence level

Table 2. Grey relational grades $\gamma_i \in [0.1]$ measuring the influences of total cloud cover (TCC, %) and air pollution index (API) on sunshine hours (h d^{-1}) in the 42 big cities across China for 2001–2011 for each season

Variable	Spring	Summer	Autumn	Winter
TCC	0.592	0.741	0.713	0.580
API	0.687	0.639	0.585	0.630

lowed by winter. In China, low rates of sunshine hour decline have been noted in the springs of 1954–2005 (Xia 2010b) and 1960–2009 (Wang et al. 2012b). While in summer and autumn, the sunshine trend mainly decreases for 1990–2011.

A critical finding in this study is that decreasing air pollution largely explains recent leveling off in sunshine hours in the 42 big cities across China. The contributions of decreasing API to the slowdown in sunshine hour decline are visible in 3 ways. (1) It is likely that the gradual decrease in API drives sunshine hour recovery in the 15 cities with sunshine hour increase. This is because in the 15 cities, increasing TCC could not explain sunshine hour increase. (2) GRA analysis shows that TCC has a negligible effect on sunshine hours for seasons with

increasing sunshine hours (spring and winter). Steep declines in API lead to sunshine hour recovery in spring and winter seasons. (3) While the gap in sunshine trends between the 42 cities and 42 nearby counties grows after the 1980s, in TCC trends, it is stable for most of 1955–2011. Therefore the variations in sunshine hours in the big cities across China could be due to city-based variations in API and not so much of regional-based variations in TCC. Despite the fact that decreasing API has been widely speculated to be the main driver of recent recoveries in sunshine hours, it is difficult to establish a simple correlation between API and sunshine hours at an annual scale. This is because of the complexity of the composition and mixing of aerosols and the subsequent scattering/absorption of solar radiation and sunshine hours (Qian et al. 2006, 2007). Aerosols determine the variability of solar radiation at a decadal time scale, but clouds play a more important role in changing solar radiation at an annual scale (Wang et al. 2012a). The degree of API is largely a function of industrial emissions and economic growth (Lin et al. 2010, Shaw et al. 2010, Lei et al. 2011). Notwithstanding the fact that interannual variations in sunshine hours and API are not strongly correlated, the trends in sunshine hours are in inverse correlation with those in API. Grouping the 42 cities according to the API trends, sunshine hours increase by 0.009 h d^{-1} yr^{-1} in 35 API decreasing cities but decrease by 0.018 h d^{-1} yr^{-1} in the other 7 API increasing cities for 2001–2011 (Fig. 7, Table 3).
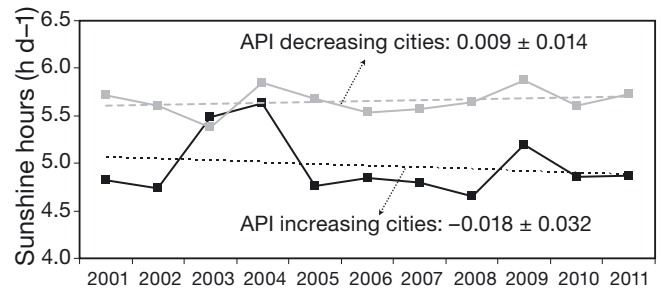

Fig. 7. Time series of annually averaged daily sunshine hours in cites with increasing and decreasing air pollution index (API), respectively, for the period 2001–2011. Values: trend slopes and corresponding SEs

Table 3. Number of cities with decreasing ($\downarrow$) or increasing ($\uparrow$) air pollution index (API) trends for 2001–2011 in 3 city groups: 42-C (total cities), 27-CDSH (cities with decreasing sunshine hours for 1990–2011) and 15-CISH (cities with increasing sunshine hours for 1990–2011). Parentheses: number of cities with significant ($p < 0.05$) API trends

API	42-C	27-CDSH	15-CISH
$\downarrow$	35 (30)	22 (20)	13 (10)
$\uparrow$	7 (3)	5 (2)	2 (1)

Air quality in the big cities across China has been gradually improving since the 2000s (Figs. 3C & 5C). A large proportion (≈71%) of the cities shows significant ($p < 0.05$) decline in API (Table 3). Previous studies by Lin et al. (2010), Shaw et al. (2010) and Lei et al. (2011) have also referred to the improving air quality in China since the beginning of the 21st century. This favorable development is due to various efforts including cleaner industrial production (Chen 2004), strict air pollution control policies (Gao et al. 2009), utilization of renewable energy sources (Shi et al. 2010), and less occurrence and intensity of dust-storms (Gu et al. 2010). Besides the optimistic trend, one fact that cannot be ignored is the transfer of pollution emission industries from big cities to the surrounding underdeveloped regions in China (Li 2010). However, API data availability restricted further analysis of air quality trends in these underdeveloped regions.

Sunshine hour recovery mainly started since the late 1970s in industrialized regions of the world (Angell & Korshover 1978, Streets et al. 2006, Sanchez-Lorenzo et al. 2008, Stanhill & Cohen 2008). This occurred concurrently with strong declines in the emissions of sulphur and black carbon or carbon soot in response to air pollution regulations and slowing economic growth (Streets et al. 2006, Wild 2009). Similarly in China, sunshine hour increase in the early 21st century mainly occurs in South China, a region that is relatively developed and has good air quality. Behind the marginal increase in sunshine hours is a generally steep dip in anthropogenic aerosol emissions.

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