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Weekend effect in diurnal temperature range in China: Opposite signals between winter and summer

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[1] Intense human activity can impact weather and climate in many ways. One possible important consequence is the weekly cycle (so-called weekend effect) in the diurnal temperature range (DTR). The weekend effect is defined as the average DTR for Saturday through Monday minus the average DTR for Wednesday through Friday. In the present study, the weekend effect in the DTR over east China combined with station observations of maximum and minimum temperatures, relative humidity, and total solar irradiance for the period 1955–2000 was analyzed. Results show that the weekend effect in the DTR has the opposite signal between winter (December, January, and February) and summer (June, July, and August). Wintertime DTR tends to have a positive weekend effect (i.e., larger DTR in weekend days compared to weekdays), in association with increased maximum temperature and total irradiance but decreased relative humidity. While summertime DTR displays a much stronger and significantly negative weekend effect (i.e., smaller DTR in weekend days), in association with decreased maximum temperature and total solar irradiance but increased relative humidity and a greater number of rainy days. This study indicates that the DTR difference between weekend and weekdays is predominantly related to weekly changes in the maximum temperature. The weekend effect in the DTR and maximum temperature is also found in the Reanalysis 2 data. The weekend effect in winter is supported by an analogous holiday (Spring Festival) effect. Since the late 1970s, the weekend effect has been enhanced in both winter and summer, concurrent with rapid development and enhanced human activity in China. The direct and indirect effects of human-related aerosols on radiation, cloud, precipitation, and so on, might play an important role in generating the opposite signal in the weekend effect for different seasons. During a dry winter, the reduction of aerosol concentrations may overwhelmingly impact on the DTR through a direct effect, i.e., by increasing total solar irradiance near the surface and raising the daytime temperature and maximum temperature and lowering relative humidity. By contrast, in summer the indirect effect of aerosols, i.e., reduction in precipitation efficiency caused by more numerous and smaller cloud droplets, would largely be responsible for the increased numbers of rainy days, the reduction of the total solar irradiance, and the lowering of the maximum temperature and DTR.

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1. Introduction

[2] In many ways, human activities have influenced climate change [*Intergovernmental Panel on Climate Change* (*IPCC*), 2001], while there are still large uncertainties how and to what extent they serve as an agent of climatic forcing. A well-known and frequently highlighted one is that weekly human activity exerts a notable impact on urban pollutants such as ozone, nitrogen oxide, and so on, as revealed in surface and satellite measurements [e.g., *Lebron*, 1975; *Marr and Harley*, 2002; *Beirle et al.*, 2003; *Jin et al.*, 2005]. The changing concentration of pollutants, as a consequence, may alter atmospheric physical characteristics such as the radiation and energy balance, properties of cloud condensation nuclei, and cloud forming in the local or regional domain [*Cerveny and Balling*, 1998; *Jin et al.*, 2005]. So, the question arises what impact weekly human activity exerts on the local and/or large-scale atmospheric circulation and climate, particularly on temperature.

[3] *Forster and Solomon* [2003] (hereinafter referred to as FS03) demonstrated a good example showing an evident weekly cycle in the diurnal temperature range (DTR) in

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many stations over the globe. They called this weekly cycle the 'weekend effect', defined as the average DTR for Saturday through Monday minus the average DTR for Wednesday through Friday. It was suggested that the most likely attributor to this phenomenon is anthropogenic aerosols. However, a puzzling fact is that positive DTR anomalies take place in some stations such as in the western United States of America, while negative DTR signals exist in others such as in central United States and Japan. Although the amplitude of the weekend effect and its spatial distribution are statistically significant, the reason for the opposite signs among different regions is not well understood yet.

[4] As the largest developing country in the world, China has experienced a rapid growth in its economy with considerable changes in the natural environment since the early 1980s. That exerts profound impact on weather and climate records, regarded as a contamination [e.g., *Kalnay and Cai*, 2003; *Zhou et al.*, 2004; *Richter et al.*, 2005]. Not surprisingly, FS03 found that there is an evident weekend effect over China (see Figure 5 of FS03), while its magnitude is somewhat smaller than that in United States. The aerosol types, emissions amount, geographical distribution and so on can play important roles for causing the difference in weekend effect among regions over the globe. In addition to these factors, here we suppose that climate and weather background (particularly the atmospheric moisture conditions) may also lead to various signals in the weekend effect in different regions as well as seasons, where different aerosol effect (direct or indirect) may be of different significance depending on the moistures. East Asia's climate is dominated by two extremely different modes, namely the dry, cold, and windy winter monsoon in the winter half year and the hot, moist summer monsoon in the summer half year. That provides us a good chance for checking whether there are different weekend effect signals between these two climate extremes.

[5] Thus, in the present study we aim to investigate a probable clue in the weekend effect in the DTR over China and its dependence on season. Our target region is limited to the east part of China where both intense human activity and tremendous seasonal climate contrast take place. More than 80% of China's population dwells in this region and dense station observations are available there, as well. The analysis season is the boreal winter (December, January, and February) and summer (June, July, and August), when the winter and summer monsoons reach their respective maximum strengths.

[6] Because this study is designed as a complement to the FS03 study, we exactly follow FS03's definition of the weekend effect. It is calculated each week, i.e., the average DTR for Saturday through Monday minus the average DTR for Wednesday through Friday. The annual mean is obtained by averaging the values for all 52 weeks in a specific year. Also, the winter and summer means are averaged from December to February and from June to August, respectively. Other variables are dealt with in the same way.

[7] Besides the DTR, we employed a couple of climate variables such as daily maximum and minimum temperature, relative humidity, and solar irradiance. Station observations are taken from 194 Chinese stations distributed by the China Meteorological Administration. In the present work, we used 171 stations located in the east portion of the country (east of 95°E). Also, much attention is focused on the time period 1979–2000 when the most rapid economic development has been taking place.

2. Results

2.1. Annual Mean

[8] First of all, we repeated FS03's work and examined the annual mean of the weekend effect in the DTR during the period 1979–2000 (here two more years are included) over China. Generally, the weekend effect shows large-scale characteristic signals, nearby stations tending to have the same signs (figure not shown). The negative sign prevails in northeast China and the west part of the target region, while the positive sign is dominant in central and north China. Interestingly, the major features are similar to SS03's results for the time period 1980–1999 (see Figure 5 of SS03). However, it is also noted that the weekend effect in the United States is stronger than that in China. The absolute difference in the DTR between weekend and weekdays is as large as 0.3–0.4°C in the United States, while the difference is less than about 0.2°C in China. Overall, FS03's findings are well reproduced over China, encouraging further analysis to investigate seasonal characteristics, i.e., winter and summer features. In fact, the FS03 analysis is on the basis of yearly averaged values. It may underestimate the amplitude of the weekend effect in the DTR over China if there exist opposite signals between winter and summer as we demonstrate in section 2.2.

2.2. Opposite Signal Between Winter and Summer

[9] The same computation process is conducted but for winter and summer, separately. In addition, the statistical significance of the weekend effect is estimated using a t test under the following assumption: H0 is mean = 0, $\alpha = 0.1$ (i.e., the 90% significance level), the number of samples is 22 or 21 years for summer and winter, respectively.

[10] Figure 1 shows the weekend effect in the DTR for the two seasons. Generally, there is an obviously opposite signal: A positive weekend effect is overwhelming in winter, while a negative signal is predominant in summer. For winter, 117 of the total 171 stations show a positive value in the weekend effect (Figure 1a). On average the weekend effect is +0.06°C. On the contrary, it displays a much stronger negative weekend effect in summer (Figure 1b). Negative signals dominate in 123 stations, the average value over all stations yields a significant (at the $\alpha = 0.05$ level) negative value in the weekend effect, −0.10°C (see Table 1). In the statistical test it turns out that 11 stations are statistically significant in winter, and 36 stations significant in summer. Nevertheless, there are well-defined spatial features as seen in Figure 1. The large-scale spatial consistency should provide an additional confidence for the weekend effect.

[11] To evaluate the robustness of the spatial pattern, a Monte Carlo method is employed to simulate the weekend effect by locally randomizing the order of the days of the week using observational data for each of the 171 stations. Results show an obvious lack of similarity between observation and randomly simulated weekend effects either in spatial distribution or in magnitude (figures not shown). So,

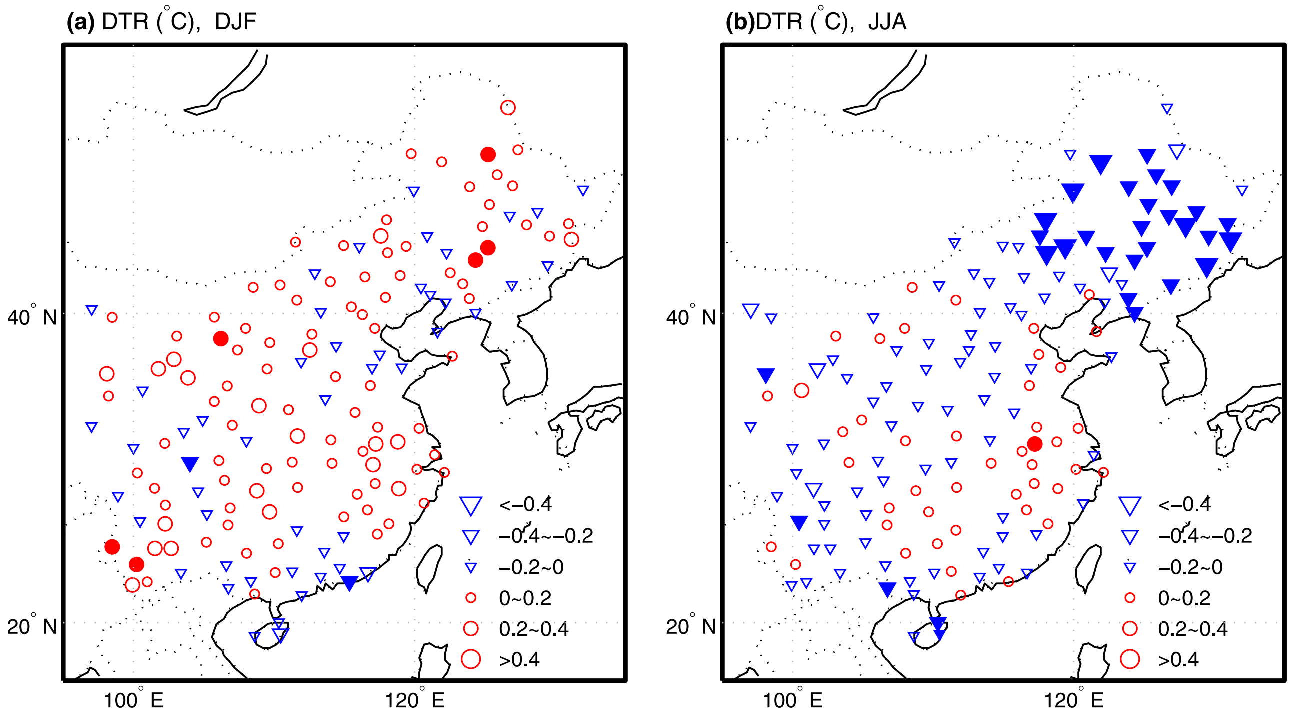

Figure 1. Weekend effect in DTR for (a) winter and (b) summer. Shown as the average for Saturday through Monday minus the average for Wednesday through Friday. Stations significant at α = 0.1 level are filled. Data period is from 1979 to 2000.

it is suggested that the above DTR patterns in China can hardly be reproduced by chance. It is also noted that the weekend effect and the difference between the two seasons are robust. Particularly, in summer the well-defined spatial distribution and high consistency among stations is most impressive over northeast China, and the average is as strong as −0.29°C (Table 1).

[12] The weekend effect in the DTR may occur due to changes in either the maximum temperature, the minimum temperature, or both. FS03 investigated the possible roles of the maximum and minimum temperatures in the United States, and demonstrated that the minimum temperature is more important compared to the maximum temperature in modulating the weekend effect. Here we examined the weekend effect due to these two variables for winter and summer, separately. In general, the weekend-weekday difference in maximum temperature shows a large-scale pattern, very similar to the DTR in both winter and summer (Figure 2 versus Figure 1). As seen in Figure 2a, the greatest maximum temperature north of about 30°N shows a positive signal for winter. For the summer case, the maximum temperature pattern is almost identical to the DTR (Figure 2b versus Figure 1b). In addition, the very strong negative value of −0.24°C in northeast China is the most outstanding, similar case of the DTR (Table 1).

[13] Additional Monte Carlo experiments confirmed the robustness of the spatial pattern in the weekend effect in the maximum temperature. While minimum temperature shows somewhat similar features but the magnitude is weak and less significant in both winter and summer (figure not shown). As listed in Table 1, the mean weekend effect in the summer maximum temperature over east China is −0.09°C during the time period 1979–2000. Meanwhile the magnitude for the minimum temperature change is only 0.01°C, resulting in a DTR of −0.10°C. For winter (Table 2), the increase of 0.16°C in the maximum temperature is offset by the increase of 0.10°C in the minimum temperature, yielding 0.06°C in the DTR. Combining Figures 1 and 2 and Tables 1 and 2 altogether, it is demonstrated that maximum temperature, rather than minimum temperature, mainly determines the sign of the DTR. In other words, the positive weekend effect in the DTR in winter and the negative signal in summer are mainly contributed by changes in maximum temper-

Table 1. Statistics for Mean Time Series of Weekend Effect in Summer for Northeastern China and East China[a]

	Northeastern China, JJA			East China, JJA		
	1955–1978	1979–2000	Difference	1955–1978	1979–2000	Difference
Tmax, °C	0.16	−0.24[b]	−0.40[b]	0.05	−0.09[b]	−0.14[b]
Tmin, °C	0.16[c]	0.05	−0.11	0.10[c]	0.01	−0.09
DTR, °C	0.00	−0.29[b]	−0.30[b]	−0.05	−0.10[b]	−0.06

[a]Northeastern China is the area east of 115°E and north of 40°N, for an average of 41 stations, and east China is the area east of 95°E, for an average of 171 stations.
[b]Significant at α = 0.05 level.
[c]Significant at α = 0.1 level.

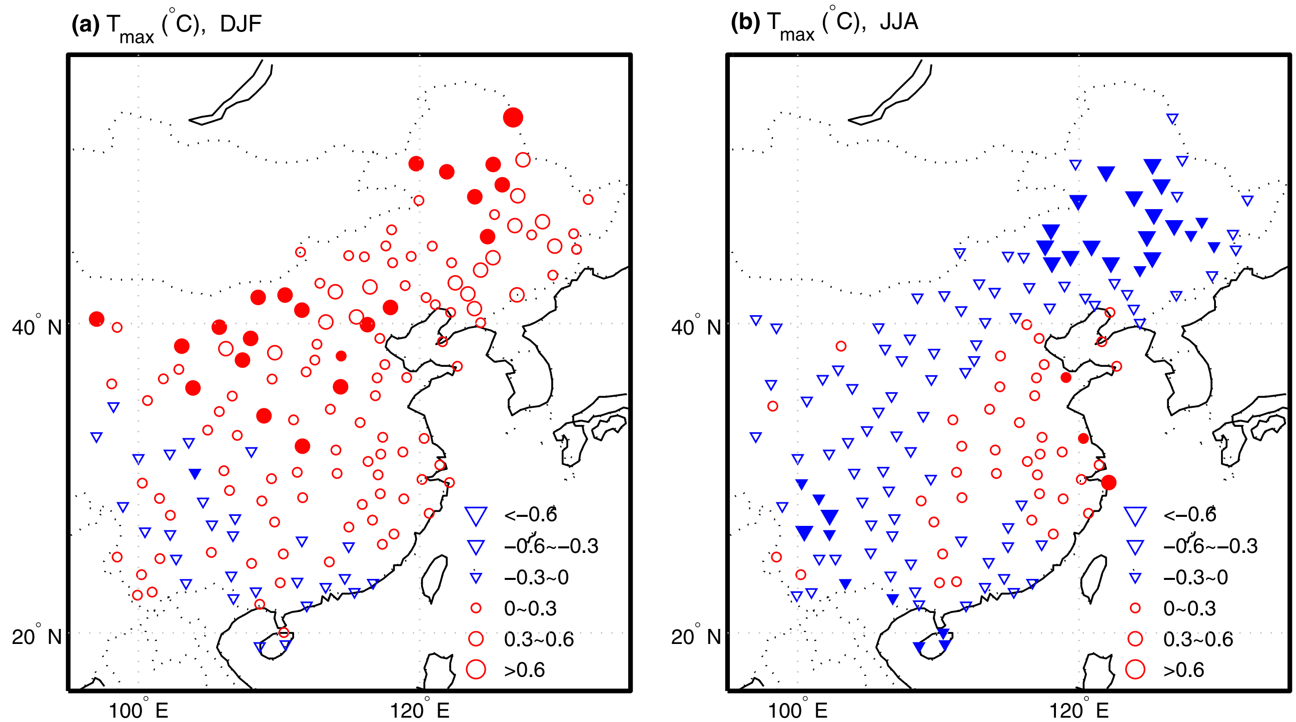

Figure 2. Weekend effect in maximum temperature for (a) winter and (b) summer. Stations significant at α = 0.1 level are filled. Data period is from 1979 to 2000.

atures: an increase in winter and a decrease in summer, respectively. These characteristics are different compared to the case for the United States where minimum temperature dominates the sign of the annual mean weekend effect in the DTR (see FS03 for details).

[14] Some studies indicated that a reduction in surface solar radiation during the last several decades dominated in large urban sites [e.g., *Alpert et al.*, 2005]. However, FS03 found no difference in the weekend effect in the DTR between urban and nonurban stations. To clarify this, we compared urban and nonurban stations by computing their weekend effect separately. For both urban and nonurban stations, major features remain almost identical to our aforementioned finding, suggesting the weekend effect in maximum temperature and DTR is a widely occurring phenomenon taking place not only in big cities over China. This can also be supported by further investigation using the gridded reanalysis data in section 2.3.

2.3. Weekend Effect in NCEP/DOE Reanalysis 2 Data

[15] The present analysis indicates that the weekend effect in China represents large-scale feature in its spatial distribution. So, the following question may be raised: Is this phenomenon reproducible in other somewhat independent data, say, the reanalysis data? To answer this question, we repeated the previous analysis but using the National Centers for Environmental Prediction/Department of Energy (NCEP/DOE) Reanalysis 2 data (R-2), which covers the period of 1979 to present at a spatial resolution about 1.9° [*Kanamitsu et al.*, 2002]. As shown in Figure 3, major features of the observed weekend effect in the DTR are well reproduced in the R-2 data. Overall, positive signals in winter and negative signals in summer agree well with the observations in both magnitude and spatial pattern.

[16] We also applied the same calculation using maximum and minimum temperatures and found that just as in the observations the maximum temperature plays a dominant role in determining the sign of the DTR. In addition, there are even higher similarities for the weekend-weekday difference in maximum temperature between the R-2 and the station data (Figure 4 versus Figure 2). The high reproducibility of the weekend effect in the R-2 data provides further support for our findings that there are opposite signals in the weekend effect between winter and summer over east China.

2.4. Enhanced Weekend Effect in Recent Two Decades

[17] If it is true that the observed weekend effect is mainly due to human activity, we should expect an enhanced trend in the last two decades because China is one of the most active nations in terms of economy as well as land use/cover change (LUCC) since the late 1970s. To clarify this, we examined long-term changes in the weekend effect in DTR, and maximum and minimum temperature since 1955. Inferred from Figures 1b and 3b, the most significant signals appear in northeast China for summer. So, we first averaged all 41 stations in this region (north of 40°N and east of 115°N) and plotted in Figure 5. Evidently, a

Table 2. Statistics for Mean Time Series of Weekend Effect in Winter for East China[a]

	1955–1978	1979–2000	Difference
Tmax(°C)	0.11	0.16	0.05
Tmin(°C)	0.13	0.10	−0.04
DTR(°C)	−0.02	0.06	0.09

[a]East China is area east of 95°E, for an average of 171 stations. No value is significant (at α = 0.1 level).

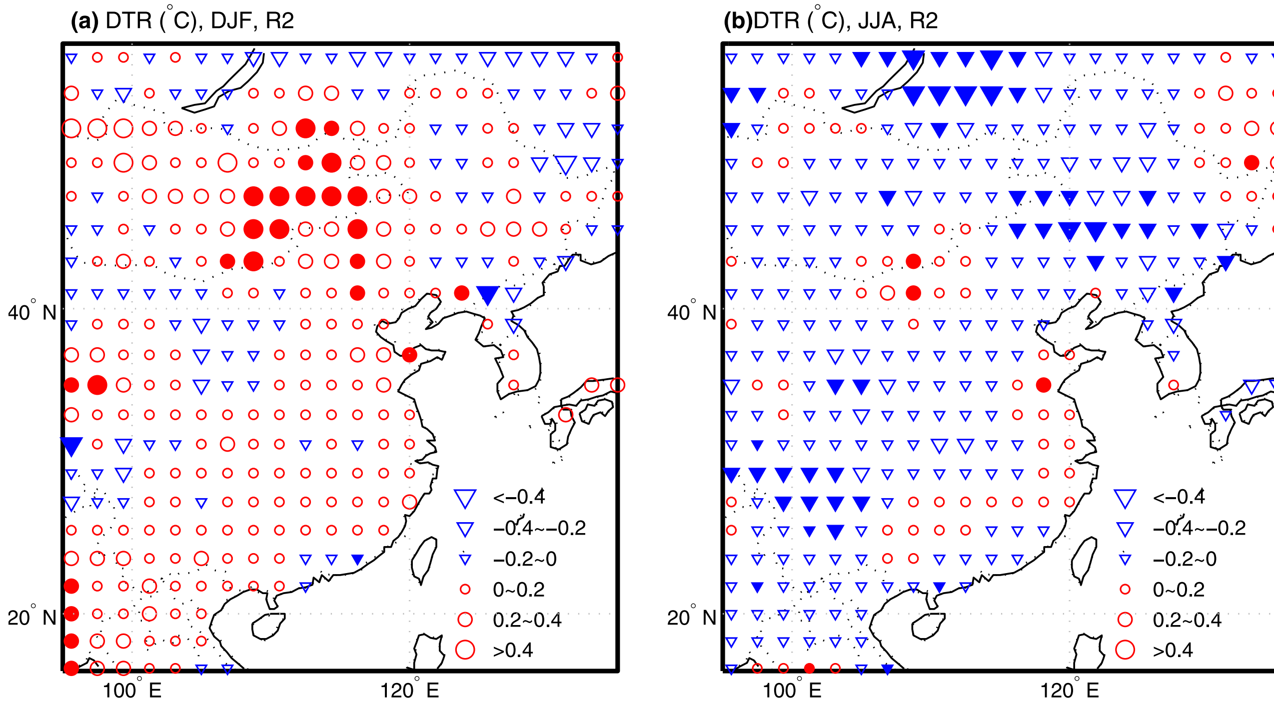

Figure 3. Same as in Figure 1, but based on R-2 data sets for the period 1979–2000.

remarkable drop in the summer DTR occurs in around the late 1970s (solid symbols). The mean weekend-weekday difference in DTR for the period 1955–1978 is 0.00°C, but drops to −0.29°C after 1979, making a considerable difference of about −0.30°C (significant at the $\alpha = 0.05$ level). East China as a whole, similar changing pattern can be found, too: The DTR difference decreases from −0.05°C for the period 1955–1978 to −0.10°C for the period 1979–2000 (Figure 5, open symbols).

[18] A comparison for maximum and minimum temperatures suggests that changes in maximum temperature are much more evident than in minimum temperature (figure not shown). In northeast China, the mean of summer maximum temperature for the period 1955–1978 is

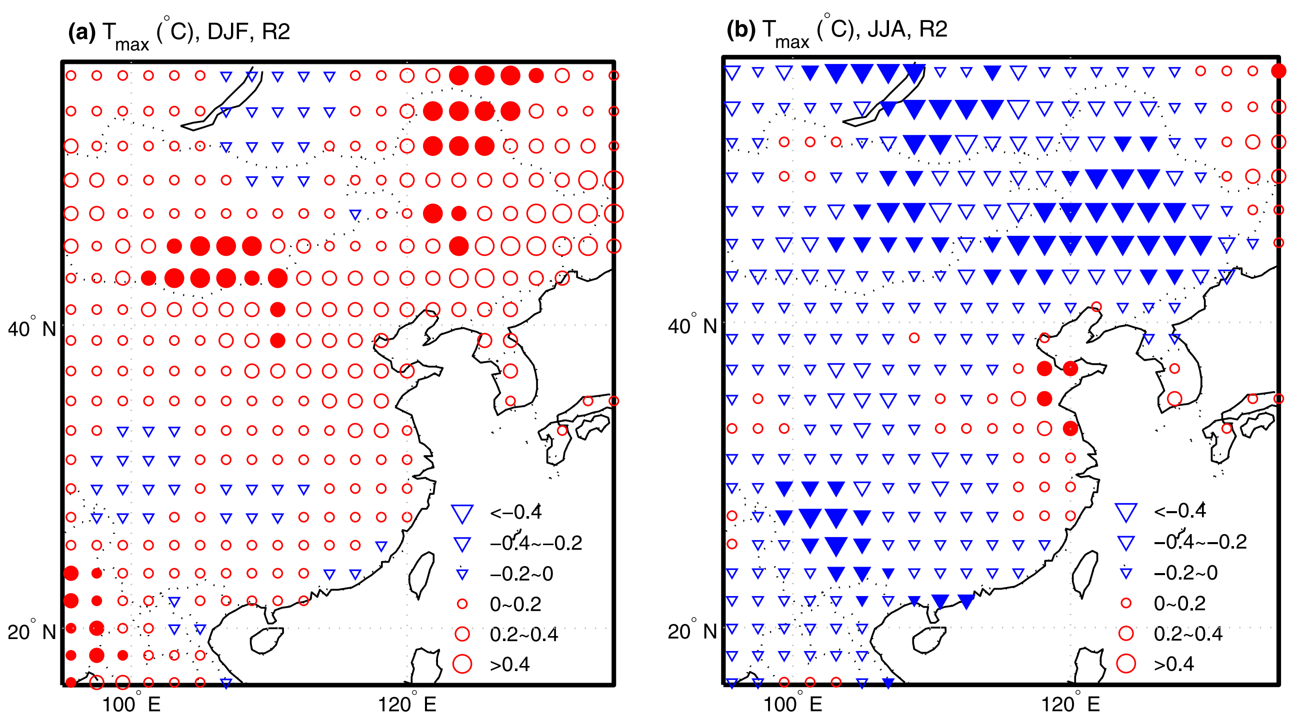

Figure 4. Same as in Figure 2, but based on R-2 data sets for the period 1979–2000.

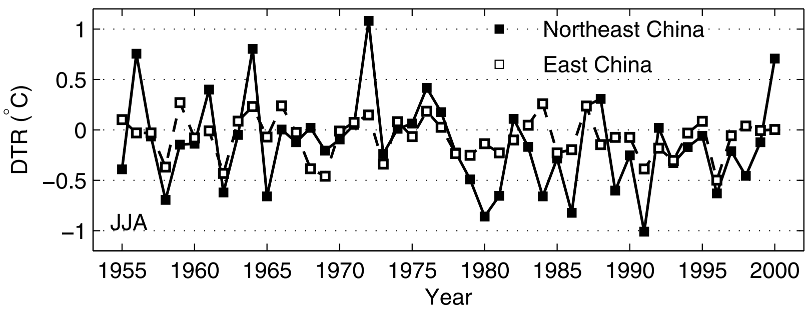

Figure 5. Regional averages of summer weekend effect in DTR for northeast China and whole east China.

0.16°C, while it drops to −0.24°C after 1979, being a significant (at the $\alpha = 0.05$ level) difference of −0.40°C.

[19] On the contrary, in winter, the weekend effect in the DTR generally tends to rise, i.e., a larger positive value is detected in the 1980s and 1990s. The mean weekend effect in DTR averaged over all 171 stations is −0.02°C for the period 1955–1978 and increases to 0.06°C after 1979, making a rise of about 0.09°C. Statistical analysis for northern stations (north of 30°N) shows an even stronger increase of 0.12°C from −0.05°C (1955–1978) to 0.07°C (1979–2000). At the same time, the maximum temperature has increased by 0.05°C though this change is not statistically significant. This demonstrates that the enhancement of the weekend effect in DTR during the last two decades is largely due to the enhancement of the weekend effect in the maximum temperature in both summer and winter (see Tables 1 and 2).

2.5. Comparison With a Holiday Effect in the DTR

[20] In this section, we examined the analogous holiday effect in the DTR, i.e., the DTR difference between nation-wide holidays and nonholidays. The lunar calendar New Year (i.e., Spring Festival) season is the most important traditional Chinese holiday, lasting for about one week every year. Similar to the weekend effect, DTR changes during the holidays may be notable if underlying causes indeed exist. The dates of all lunar New Years from 1955 to 2000 are identified as follows: 24 January 1955; 12 February 1956; 31 January 1957; 18 February 1958; 8 February 1959; 28 January 1960; 15 February 1961; 5 February 1962; 25 January 1964; 13 February 1964; 2 February 1965; 21 January 1966; 9 February 1967; 30 January 1968; 17 February 1969; 6 February 1970; 27 January 1971; 15 February 1972; 3 February 1973; 23 January 1974; 11 February 1975; 31 January 1976; 18 February 1977; 7 February 1978; 28 January 1979; 16 February 1980; 5 February 1981; 25 January 1982; 13 January 1983; 2 February 1984; 20 February 1985; 9 February 1986; 29 January 1987; 17 February 1988; 6 February 1989; 27 January 1989; 15 February 1991; 4 February 1992; 23 January 1993; 10 February 1994; 31 January 1995; 19 February 1996; 7 February 1997; 28 January 1998;

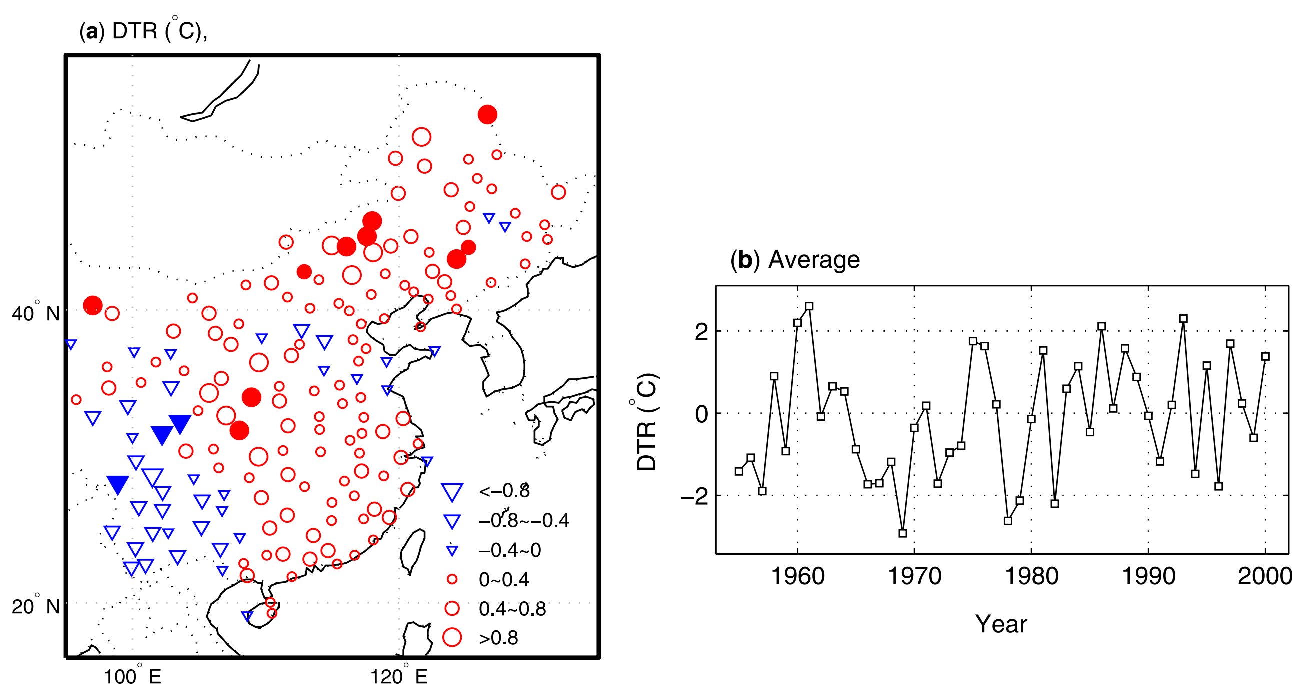

Figure 6. (a) DTR difference shown as the average for 7 days after the lunar new year minus the average for 7 days before that. Time period is 1980–2000. Values significant at the $\alpha = 0.1$ level are filled. (b) Time series of regional mean for all 171 stations since 1955.

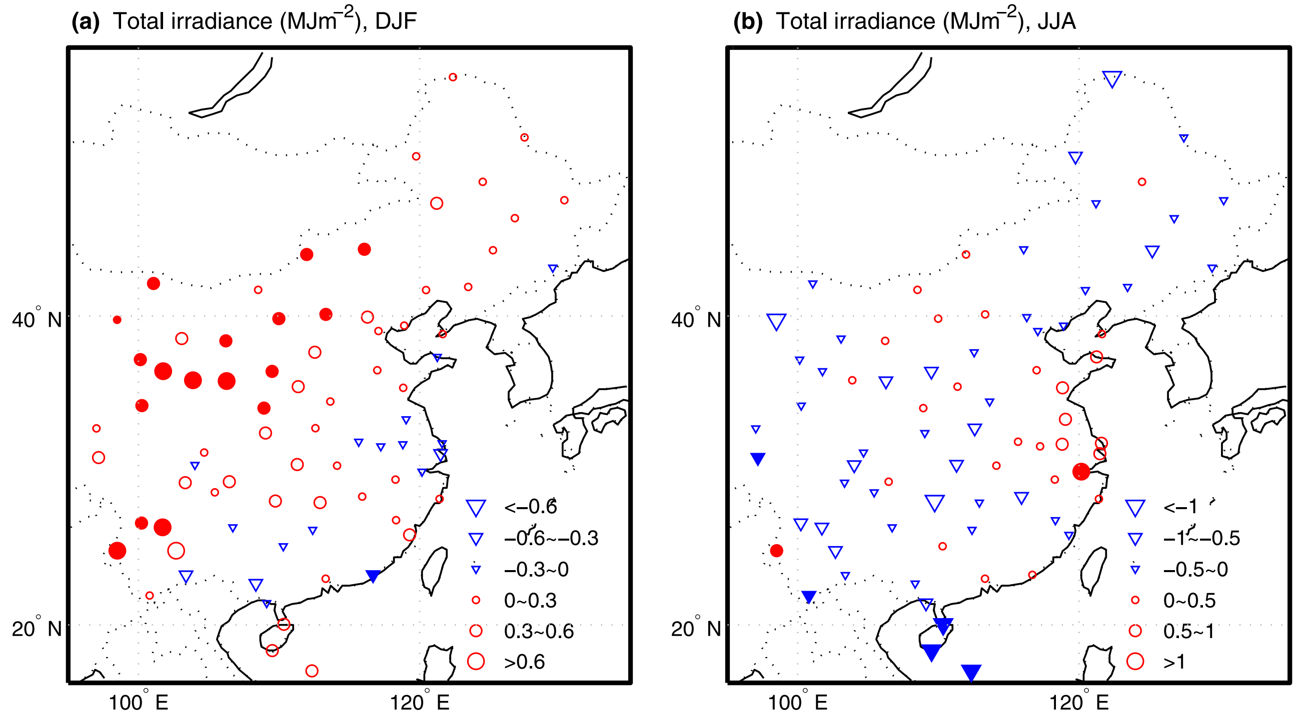

Figure 7. Weekend effect in total solar irradiance for (a) winter and (b) summer. Stations significant at $\alpha = 0.1$ level are filled. Time period is 1993–2000.

16 February 1999; 5 February 2000. We gathered the DTRs in the New Year day and the following 6 days, then made an average for these 7 days. The mean for nonholiday DTRs is obtained by averaging 7 days before the New Year day. The nonholiday mean subtracted from the holiday mean gives the holiday effect in DTR (Figure 6). As seen in Figure 6a, most of the stations (134 among the total 171 stations) show positive anomalies in the last two decades, except for some negative DTRs taking place in the southwest region. This implies that DTRs in the New Year holidays tend to get larger in comparison with the days before the holiday. Since the lunar New Year day varies from mid January (the earliest is 13 January 1983) to late February (the latest is 20 February 1985), the holiday effect can be regarded as a duplication of the wintertime weekend effect but with an enlarged signal.

[21] In addition, we found that temporal features of the New Year effect in the DTR since 1955 are very similar to and consistent with the wintertime weekend effect (Figure 6b). Interestingly, average DTRs for two subperiods 1955–1979 and 1980–2000 are different. The increasing trend since the early 1980s leads to an obvious higher DTR during the last two decades, resulting in a significant (at the $\alpha = 0.059$ level) increase of 0.80°C. Again, this is consistent with the enhancement of the weekend effect in the DTR during winter.

3. Possible Interpretation and Discussion

[22] FS03 supposed that human-related aerosols are most likely responsible for generating the weekend-weekday difference in the DTR. Aerosols in China consist of a variety of components spanning from natural mineral fine dust, associated with land cover and land use changes, to chemical pollutants released by industrial factories and vehicles. In fact, China's rapid development is accompanied by appreciably enhanced aerosol emission [*Luo et al.*, 2001; *Richter et al.*, 2005]. As a natural consequence, the amount of solar radiation at the surface would be changed. Over all China, a notable long-term decreasing trend in the total irradiance, the direct and diffuse radiation, and the sunshine duration percentage has been reported [*Kaiser and Qian*, 2002; *Che et al.*, 2005] and this is consistent with an increasing trend in the aerosol concentration. In addition, a decreasing trend in cloud amount is observed over much of China, and a remarkable drop occurred in 1978 [*Kaiser*, 2000]. It is interesting to note that these notable changes in all the aforementioned variables occurred in the late 1970s and coincided with the enhancement of the weekend effects in the DTR. Although no authors have ever made a reliable estimation of how large the difference in aerosol concentrations is between weekends and weekdays over China, the enhanced aerosol forcing might exert an apparent influence on the weekend effect in association with changes in the solar irradiation. Other studies [e.g., *Kaiser and Qian*, 2002; *Qian et al.*, 2003, 2006] reported that there is a notable rend toward more frequent cloud-free sky and less surface solar radiation during the recent decades in China, suggesting the important roles of aerosols in influencing meteorological variables. However, these studies did not explicitly consider possibly different importance of direct and indirect effect between winter and summer.

[23] In the following, we simply investigated changes in the total solar irradiance in 79 stations in east China. Because there was a nation-wide change in pyranometer measurements and instrument type in 1993, the observational error in the solar irradiance has been controlled within in a very low level (less than 0.5% relative error) since then.

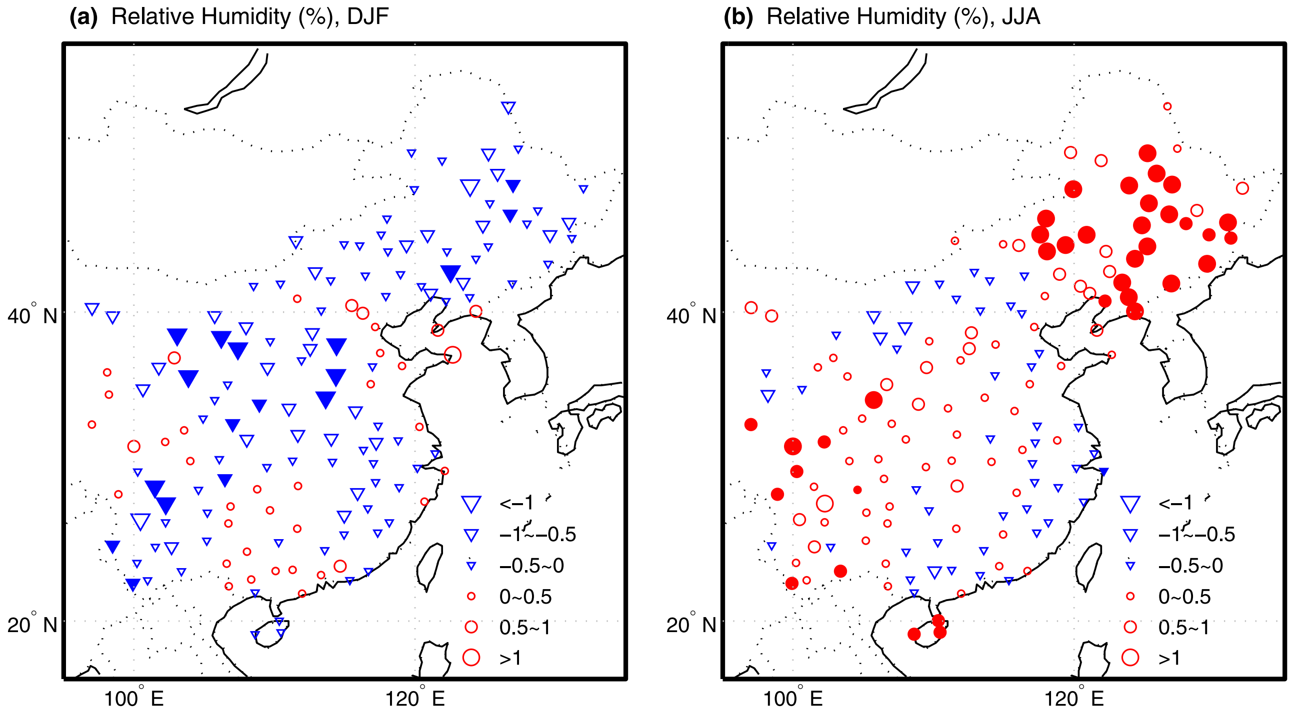

Figure 8. Weekend effect in relative humidity for (a) winter and (b) summer. Stations significant at α = 0.1 level are filled. Time period is 1979–2000.

So, we used only data set for the period 1993–2000. Corresponding to the above analysis, we plotted the distribution of the weekend effect in total solar irradiance for winter and summer, respectively (Figure 7). Signals are clearly different from winter to summer: Positive values are overwhelming in winter while negative values dominate in summer. This indicates that more total solar irradiance reaches the surface in weekends compared to weekdays during winter, while less solar irradiance reaches the surface during summer. We suggest that these results may explain features in the DTR and maximum temperature (see Figures 1 and 2).

[24] The different signals in total solar irradiance between winter and summer may arise from the difference in how aerosols impact on the radiation, depending on whether by direct effect or by indirect effect. Generally, the direct effect is to make a net increase in the total solar irradiance [*Tegen et al.*, 1996] if less aerosols are released into the atmosphere at the weekend, while the indirect effect, involved with aerosol-cloud interaction, is much more complicated [*Ramanathan et al.*, 2001; *Liepert et al.*, 2004; *Lohman and Feichter*, 2005]. With regard to the positive weekend effect during winter, the direct effect of aerosols seems to dominate, because the east Asian winter monsoon is controlled by cold, dry air and there is very little atmospheric moisture content compared to summer. A reduction of aerosol concentration on weekend days leads to more irradiance reaching the surface, raising the daytime temperature and the maximum temperature. This can consequently result in a larger DTR. In addition, the increased temperature tends to cause a lower relative humidity as the relative humidity depends heavily on temperature (Figure 8a). A lower relative humidity in turn can suppress cloud development. Hence the aerosol-cloud process, the indirect effect, in winter is likely not as important as the direct effect.

[25] In the moist and hot summer, atmospheric boundary conditions are quite different from those in winter. Reduced values in the DTR, maximum temperature, and total solar irradiance during the weekend likely result from the indirect effect, i.e., the aerosol-cloud interaction. Previous studies found that urban and industrial air pollution may result in a reduction in precipitation [*Rosenfeld*, 2000; *Lohman and Lesins*, 2002]. Recent satellite measurements show that major kinds of aerosols such as smoke, dust, and pollution aerosols all affect the droplet size [e.g., *Kaufman et al.*, 2005]. Other observed data and modeling approaches also support the view that an increase in cloud condensation nuclei can substantially reduce rain efficiency in the convective clouds [*Rosenfeld*, 2000; *Nober et al.*, 2003; *Jin et al.*, 2005]. Therefore, if this mechanism does work in summer over east China, we can expect drier weekdays when the aerosol concentration reaches its maximum and relatively wetter weekend days as aerosol concentration drops.

[26] Figure 8b likely verifies the above hypothesis: An increased relative humidity in weekend days is evident, particularly in the northeast and southwest of the research region. Relative humidity would be a key factor modulating cloudiness. However, cloud is so highly variable that its possible weekly cycle can hardly be distinguished from randomly fluctuating weather events, particularly in the local and regional domain. Rather than cloudiness, we checked the distribution of the number of rainy days, using daily rainfall data for the period 1979–2002. In general, the results show that most of the stations tend to have a less-than-normal number of rainy days in midweek, and an above normal number of rainy days during the weekend.

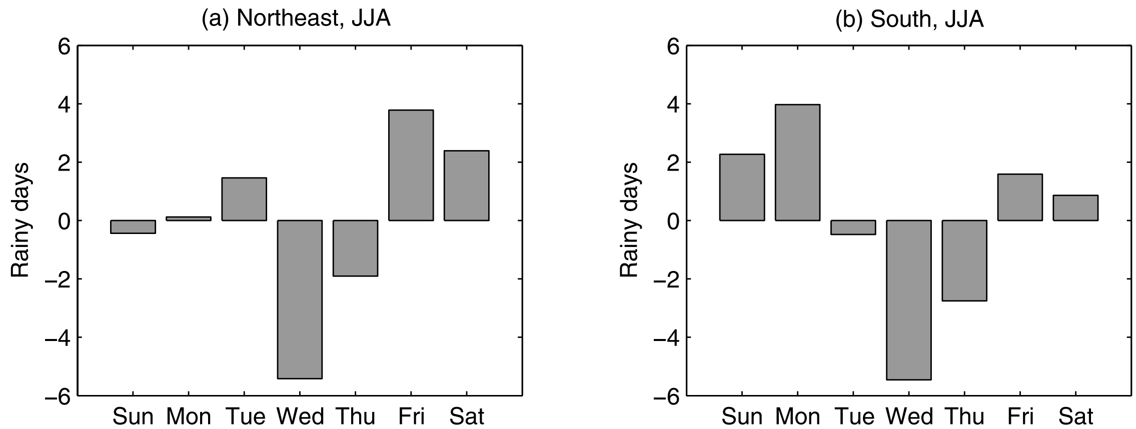

Figure 9. Number of rainy days as a function of day of week in summer. Shown as departures from the climatological mean. Averaged for (a) northeast, north of 40°N and east of 115°E; and (b) south China, south of 30°N and east of 95°E. Data period is from 1979 to 2002.

As an example, we depicted the distribution of rainy days in two subregions: one in the most southerly portion and another in the farthest northeasterly portion of China (Figure 9). Interestingly, the two regions show similar characteristics: A minimum takes place on Wednesday while a higher number of rainy days is observed from Friday to the following Monday. *Cheng et al.* [2005] also found that the increasing aerosol and cloud cover in early summer (May and June) over southern China might cause reduced rainfall. We examined the precipitation amount and found no evident weekend effect. This suggests that the changes in rainfall amounts caused by indirect effects were negligible, while the changes in cloud lifetime that is altered by precipitation efficiency may be more important. On the contrary, there are many factors that can significantly impact the precipitation. Compared to the weekend effect they play dominant roles in altering precipitation amount/intensity. That also makes it difficult to identify the possible weekend effect in precipitation amount. In addition, climate model simulations taking into account of the direct, semidirect, and indirect aerosol effects indicate that decreasing precipitation, less solar radiation reaching the surface, more liquid water path, and larger aerosol optical depth would be expected in a warmer, moist climate with more aerosols [*Liepert et al.*, 2004, Figure 3], providing insightful clues to better understanding of weekend effect in summer over east China.

[27] Research focused on the U.S. rainfall showed similar results: *Jin et al.* [2005] reported that the summer aerosol optical thickness reaches maximum on Wednesday and a minimum over the weekend, while the cloud-integrated water path becomes small on Wednesday and large at the weekend near New York city (see their Figures 7 and 9). *Cerveny and Balling* [1998] also found there is a so-called "wet Saturday" phenomenon over northeast United States and surrounding ocean regions. Therefore the aerosol indirect effect (i.e., reduction in precipitation efficiency caused by more numerous and smaller cloud droplets), as a worldwide phenomenon, might largely be responsible for the enhanced number of rainy days, the reduction in the total solar irradiance, and the lower maximum temperature and DTR at the weekend during summer over east China. However, it should be noted that other possible reasons, for example, the chemical pollutants and their many accompanying processes, aircraft contrail, troposphere ozone, and random chance are able to impact the estimation of weekly cycle in meteorological variables. Possible influences by these factors have not been ruled out in this study. Detailed investigation for aerosol-cloud interaction and other possible mechanisms is beyond the scope of the present study.

[28] An interesting phenomenon is that the weekend effect during summer has a robust signal in northeast and southwest China. Intense human activity and topography would play important roles. Red Basin (centered about 30°N and 105°E) and northeast China are two regions known as the highly polluted areas and include important industrial branches based on coal, oil, and natural gas. Furthermore, Red Basin is surrounded by high mountains; northeast China is also surrounded by mountains opening only to the sea in the southwest. The combination of high-emission source strength and topography favors the accumulation of pollutants in the lower troposphere, the so-called basin effect [*Luo et al.*, 2001; *Krüger and Graßl*, 2004], likely resulting in a larger weekend effect.

4. Concluding Remarks

[29] This study indicates that the weekend effect in the DTR shows an opposite signal between winter and summer in east China. It tends to have a positive weekend effect during winter, i.e., larger DTR on weekend days. While summer DTR displays a much stronger and more significant negative weekend effect, i.e., smaller DTR in weekend days. The DTR difference between weekdays and the weekend days is predominantly associated with weekly changes in the maximum temperature. Besides, the total solar irradiance and relative humidity have consistent signals corresponding to the weekend effect in the DTR in both winter and summer. Similar

features in the maximum temperature and DTR are also reproduced in the R-2 data.

[30] The weekend effect in the DTR is getting stronger since the late 1970s. In summer, the mean of the DTR difference over east China is −0.05°C for the period 1955–1979, while it drops to −0.10°C after 1979. The most significant signals appear in northeast China, where a significant drop of −0.30°C takes place. On the other hand, in winter, the weekend effect in the DTR generally tends to rise in the 1980s and 1990s. The mean of 171 stations increases from −0.02°C for the period 1955–1979 to 0.06°C after 1979. In addition, the analogous holiday (Spring Festival) effect in the DTR is quite similar to the weekend effect in winter months, increasing evidently during the last two decades. The intense human activities may play essential roles for the enhancement of the weekend effect.

[31] The direct and indirect effects of human related aerosols on radiation, cloud, precipitation, and so on, would play important roles in generating the weekend effect in the DTR. During a dry winter, the reduction of aerosol concentration might overwhelmingly impact DTR through the direct effect, i.e., reducing the total solar irradiance near the surface and raising the daytime temperature, maximum temperature, and lowering relative humidity. By contrast, in summer the indirect effect of aerosols would largely be responsible for the increased number of rainy days, the reduction in the total solar irradiance, and the lower maximum temperature and DTR.

[32] However, other possible mechanisms have not been ruled out in this study. The different signals of the weekend effect on temperature provide helpful clues for better understanding and modeling human impact on weather and climate, with respect to differences in season and region.

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