Weekend effect in summertime temperature and precipitation over the Yangtze River Delta region

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Research Article

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Abstract

The Yangtze River Delta (YRD) region located over East China, is an international urban agglomeration radiating Asia-Pacific with convenient transportation, advanced manufacturing industry and modern service industry. The rapid urbanization and intensive human activities have exerted substantial effects on the weather and climate over the YRD region during the past decades, thus bringing more challenges to accurate weather and climate forecasting. However, the weekly cycles of surface air temperature and precipitation linked closely to human activities and their corresponding physical processes remain insufficiently understood. Here, we investigate the weekly cycles of summertime surface air temperature and precipitation and the weekend effect over the YRD region for the period of 2008–2019 using high-resolution observational data and reanalysis data. The results demonstrate that lower surface air temperature and higher precipitation generally manifest during weekends compared to weekdays over the YRD region particularly over the areas with intensive human activities. The further analysis of the underlying physical processes points to that the aerosol-cloud-radiation interaction can largely explain the weekend effect in summertime temperature and precipitation over the YRD region.

1. Introduction

For the past several decades, rapid urbanization and increasing human activities have affected the weather and climate variations by changing the atmospheric composition, radiation and cloud processes, land surface conditions and so on (Ramanathan et al. 2001; Kalnay and Cai 2003; Zhou et al. 2004; Wu et al. 2013; Li et al. 2016), thus bringing more challenges to accurate forecasting of weather and climate. Closely linked to the weekly cycles of human activities, the meteorological variables also show obvious weekday-weekend differences or weekend effect, providing evidence that human influence does play substantial roles in regulating the variations of weather and climate (Cerveny and Balling 1998; Forster and Solomon 2003; Sanchez-Lorenzo et al. 2012). However, the weekend effect and associated complex physical mechanisms remain insufficiently understood.

Weekend-weekday differences in surface air temperature and precipitation have been evidenced in many places of the world, though their magnitudes vary with region and season (Zhou et al. 2004; Gong et al. 2006; Kim et al. 2009; Kim and Roh 2010; Sanchez-Lorenzo et al. 2012). For the corresponding physical mechanisms, previous studies found that weekend-weekday differences in aerosol-cloud-radiation interaction related to human activities may play critical roles (Dai et al. 1997; Zhou et al. 2004; Gong et al. 2007; Sanchez-Lorenzo et al. 2008). Besides, the anthropogenic heat release also contributes to the weekend effect in some areas (Fujibe 1987, 1988a, b; Simmonds and Keay 1997).

Over China, previous studies have detected the weekend effect in surface air temperature and precipitation, corresponding to the direct and indirect effects of aerosols on radiation and cloud processes, and associated modified regional atmospheric circulations (Gong et al. 2006, 2007; Zhao et al. 2006; You et al. 2009; Li et al. 2011; Zhu et al. 2014). For example, Gong et al. (2007) demonstrated that weekday-weekend differences are obvious in summertime solar radiation, daily maximum temperature, diurnal temperature range and precipitation over East China.

The Yangtze River Delta (YRD) region is located over East China, covering Anhui, Jiangsu and Zhejiang provinces and Shanghai municipality. The YRD region is an international urban agglomeration which is home to more than 220 million people. The rapid urbanization and intensive human activities over the YRD region have exerted certain effects on local and regional weather and climate (Chen et al. 2003; Gong et al. 2007; Zhang and Liang 2018). These previous studies are mainly based on observational data at relatively limited stations or remote sensing data.

Recently, China Meteorological Administration (CMA) developed a high-resolution (0.1°) gridded hourly precipitation dataset of China based on 30000–40000 automatic meteorological station observations across China and the CMORPH (Climate Prediction Center (CPC) morphing technique, Joyce et al. 2004) precipitation data from the National Oceanic and Atmospheric Administration (NOAA). In this study, we use the new hourly precipitation dataset combined with the high-resolution ERA5 reanalysis data provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) to investigate the weekend effect during summertime over the YRD region for 2008–2019 and further discuss associated underlying physical mechanisms.

2. Data And Methods

The hourly precipitation data at a resolution of 0.1° obtained from the National Meteorological Information Center of China Meteorological Administration (NMIC-CMA) for the period of 2008-2019 were used to investigate the weekend effect of summertime precipitation over the YRD region. The hourly high-resolution precipitation dataset was newly produced based on 30,000–40,000 automatic observation stations and the CMORPH dataset (Joyce et al. 2004; Janowiak et al. 2005; Buarque et al. 2011; Qian et al. 2015; Trenberth and Zhang 2018). To analyze the weekend effect in summertime surface air temperature, we adopted hourly 2-m temperature at a resolution of 0.25° from the ERA-5 reanalysis (Hersbach et al. 2018a; Bassett et al. 2021).

This study focuses on the summer season including June, July, and August for the period of 2008–2019. In total, there are 1677 (including 3 abnormal hourly data) missing hourly precipitation data over the YRD region for the study period. The missing rate of 6.33% is small, so we removed these days with missing data. Additionally, because the huge impact of Typhoon may weaken the effect of human activities on precipitation, according to the historical typhoon data provided by the Shanghai Typhoon Institute of China Meteorological Administration (Ying et al. 2014; Lu et al. 2021), we also removed the influence of typhoon precipitation associated with the YRD region (Table 1). For consistency, we also removed these days in the analysis of the weekend effect in surface air temperature and the discussion of the associated physical processes.

Table 1
The main typhoon events and their corresponding impact period during 2008-2019

Year	Typhoon number (name)	Impact period (LST)
2008	0807 (Kalmaegi)	7.18-7.20
2008	0808 (Fung-wong)	7.28-8.2
2009	0908 (Morakot)	8.8-8.11
2011	1105 (Meari)	6.23-26
2011	1109 (Muifa)	8.6-8.7
2012	1209 (Saola)	8.2-8.3
2012	1210 (Damrey)	8.2-8.3
2012	1211 (Haikui)	8.7-8.8
2012	1214 (Tembin)	8.28-8.29
2012	1215 (Bolaven)	8.26-28
2013	1307 (Soulik)	7.13-7.15
2013	1312 (Trami)	8.21-8.23
2014	1410 (Matmo)	7.23-7.25
2014	1412 (Nakri)	7.31-8.03
2015	1509 (Chan-hom)	7.10-7.12
2015	1513 (Soudelor)	8.08-8.11
2015	1515 (Goni)	8.21-8.24
2016	1601 (Nepartak)	7.09-7.12
2017	1709 (Nesat)/1710 (Haitang)	7.30-8.02
2018	1810 (Ampil)	7.21-7.23
2018	1812 (Jongdari)	8.2-8.3
2018	1814 (Rumbia)	8.12-8.19
2019	1909 (Lekima)	8.9-8.11

To describe the human activities over the YRD region, we applied the gridded population data of 2015 with a resolution of 1 km from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (RESDC-CAS), GTOPO30 topographical height data with a resolution of 30 seconds (about 1 km) from the US Geological Survey (USGS), and DMSP-OLS nighttime lights time data of 2013 with a resolution of 30 seconds (about 1 km) collected by US Air Force Weather Agency.

Hourly low, medium and high cloud cover, 850 hPa winds, vertically integrated moisture divergence, surface downward short-wave radiation, surface net short-wave radiation and surface net long-wave radiation at a resolution of 0.25° from the ERA5 reanalysis dataset (Hersbach et al. 2018a, b; Bassett et al. 2021), and three-hourly aerosol optical depth product at 550 mm at a resolution of 0.75° from the EAC4 reanalysis dataset (Inness et al. 2019) were also used to explore the possible physical mechanisms.

In this study, considering that Monday and Friday are transitional periods between weekdays and weekends, we define Tuesday through Thursday as the weekdays and Saturday through Sunday as the weekend. The weekend effect refers to their difference value (weekend minus weekdays).

3. Results

The YRD region is an alluvial plain before the estuary of the Yangtze River, which is intermittently distributed with low elevation (Fig. 1a). The YRD region is highly populated and urbanized, especially in the eastern coastal area, forming megacities centered on Shanghai radiating outward (Figs. 1b and c). Under the background of the East Asian monsoon, the southwest warm and humid airflow brings sufficient moisture to the region (Fig. 1d). As a result, the YRD region has generally higher surface air temperature and more precipitation during summertime (Figs. 1e and f).

Figure 2 shows spatial distributions of the weekday with maximum and minimum 2m surface air temperature and precipitation over the YRD region in the summertime of 2008–2019. The surface air temperature is maximal on Tuesday and Thursday from South to North of the YRD region and consistent minimal on Sunday throughout the YRD region except few locations. Compared with temperature, precipitation exhibits less spatial consistency. Saturday and Sunday are wetter than other weekdays over most areas of the southern and northern part, while Thursday is the driest day of the week over most areas of the YRD region. In general, weekend has relatively lower surface air temperature and stronger precipitation compared to weekdays over the YRD region in summertime of 2008–2019.

Figure 3 shows weekly cycles of regional mean 2m surface air temperature and precipitation over the YRD region in summertime for 2008–2019. There are clear weekly cycles in 2m surface air temperature and precipitation. Surface air temperature increases from Sunday to Thursday and then decreases with a maximum on Thursday and minimum on Sunday. Comparatively, precipitation has an opposite pattern of weekly cycle. The precipitation decreases from Sunday to Thursday as a whole and then increase with peaks on weekend. In general, both surface air temperature and precipitation exhibit distinct weekend-weekday differences.

Figure 4 shows the weekend effect in surface air temperature and precipitation over the YRD region in summertime of 2008–2019. The surface air temperature has a negative weekend effect all over the YRD region, with the average value of -0.22°C. On contrary, precipitation exhibits a positive weekend effect over most areas of the YRD region, and the average value is 0.05 mm/h. It is worth noting that the areas where relative large weekend effect in surface air temperature and precipitation mainly occurred are consistent with those of large population density and nighttime lights (Figs. 1a and b). These results imply that the weekend effect in surface air temperature and precipitation are tightly associated with intensified human activities, which is also revealed in the previous research of other areas (Rosenfeld 2000; Gong et al. 2006).

Further, we explore the possible interpretation responsible for the colder and wetter weekend compared to weekdays over the YRD region in summertime of 2008–2019. Aerosol-cloud-radiation interaction and land-air interaction are considered to be the main reasons affecting regional temperature and precipitation. Cloud development related to aerosols is beneficial to more precipitation, while the reduction of downward short-wave radiation flux may decrease the surface air temperature (Gong et al. 2006; Ekman et al. 2007). Figure 5a indicates that more aerosols are released into the atmosphere during the weekend. Consequently, the concentration of aerosols serving as cloud condensation nuclei (CCN) increases the regional cloud cover (Figs. 5b, c, and d), especially in the low and medium cloud cover (Twomey 1977; King et al. 1993; Zhao et al. 2014), which provides a good background for more precipitation during the weekend (Fig. 4b). Meanwhile, the increase in aerosols during the weekend leads to less surface downward short-wave radiation, decreasing the surface air temperature (Fig. 5e, Fig. 4a).

4. Conclusions And Discussion

Using the 0.1° high-resolution hourly observational precipitation data from CMA and the 0.25° hourly surface temperature from ERA5 reanalysis data provided by ECMWF, we investigate the weekend effect in summertime surface air temperature and precipitation over the YRD region for 2008–2019. The results show that lower surface air temperature and higher precipitation generally appear during weekends compared to weekdays over the YRD region. Moreover, strong spatial differences in the weekend effect in summertime surface air temperature and precipitation are clearly identified.

Further, we explain the possible physical processes explaining the weekend effect in surface climate over the YRD region. The results show that the aerosol-cloud-radiation interaction may make a critical contribution to the weekend effect over the YRD region. Under the increasing urbanization, more aerosol emissions associated with intense human activities tend to increase the cloud cover amount and decrease the net radiation reaching the surface (Fig. 5), which may subsequently lead to more precipitation and lower surface air temperature during weekends.

Some previous research demonstrated that the pollutant accumulation was less during weekend than weekdays due to some reasons such as motor vehicles and factories emitting fewer pollutants at weekends (e.g., Gong et al. 2007). However, as shown in this study and other work (Xia et al. 2008; Song et al. 2018), over the YRD region the AOD magnitudes are larger during weekend than weekdays. Here the question raises, what mechanisms are responsible for the increased aerosols during the weekend over the YRD region?

The East Asian summer monsoon is mainly the prevailing southeast wind driven by the land-sea thermal contrast. However, the rapid urbanization makes the regional weekend temperature generally lower than weekdays (Fig. 4a), which reduces the land-sea thermal difference and further weakens the monsoon, resulting in northerly wind anomalies (Fig. 6). Due to the different urbanization levels, the inhomogeneous distribution of thermal anomalies leads to convergence and divergence of northerly winds, which makes the AOD accumulation (Fig. 5 and 6). In addition, there are other factors linked to the surface wind over the coastal area of the YRD region. For example, the lake-air interaction may lead to strong local divergence anomalies.

Besides, the rapid urbanization and human activities also exert effects on land surface processes such as soil types (Thielen et al. 2000; Hu et al. 2017; Song and Zhang 2020), soil moisture (Douville et al. 2001; Koster et al. 2010; Sun and Wang 2012; Wei and Dirmeyer 2012), soil temperature (Zhang and Wu 2014), the vegetation (Lee et al. 2012; Wei and Dirmeyer 2012), leading to changes in aerosol-cloud-climate interaction and land-air interaction (Rosenfeld 2000; Jin et al. 2005; Menon et al. 2008; Rosenfeld et al. 2014). These changes can influence radiation, energy balance, moisture, atmospheric boundary layer and regional atmospheric circulations, and further modulate temperature and precipitation variations over the YRD region. It also needs to note that weekday-weekend differences in anthropogenic heat release may play an important role in highly urbanized areas (Simmonds and Keay 1997). These complex physical progresses involved should be explored by combined diagnosis methods and numerical simulations in the future.

Declarations

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Competing Interests

The authors declare no competing interests.

Author Contributions

Jingyong Zhang and Ziyi Song conceived the study. Ziyi Song performed the data analysis and prepared the first draft. Ziyi Song and Jingyong Zhang revised the manuscript. All authors contributed to the writing of the paper.

Data Availability

The hourly high-resolution precipitation data is available at http://data.cma.cn/site/showSubject/id/101.html. The historical typhoon data is stored at https://tcdata.typhoon.org.cn/dlrdqx_zl.html. The gridded population data is available at https://doi.org/10.12078/2017121101. GTOPO30 topographical height data is stored at https://doi.org/10.5066/F7DF6PQS and DMSP-OLS nighttime lights time data is from https://www.ngdc.noaa.gov/eog/dmsp/downloadV4composites.html. The hourly ERA-5 reanalysis variables of low cloud cover, medium cloud cover, high cloud cover, 2m temperature, vertically integrated moisture divergence, surface downward short-wave radiation flux, surface net short-wave radiation flux, surface net long-wave radiation flux and 850 hPa wind flows are available at https://doi.org/10.24381/cds.adbb2d47 and https://doi.org/10.24381/cds.bd0915c6 respectively. The three-hourly aerosol optical depth product at 550 mm of the EAC4 reanalysis dataset is stored at https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-reanalysis-eac4?tab=overview.

Code Availability

All the figures were produced using NCL. The code used in this study will be available on reasonable request.

Ethics approval

The authors paid attention to the ethical rules in the study. There is no violation of ethics.

Consent to participate

All the authors admitted that they have contributed to the study.

Consent for publication

All the authors agree with the publication of the content of the manuscript.

Conflict of interest

The authors declare no competing interests.

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Figures

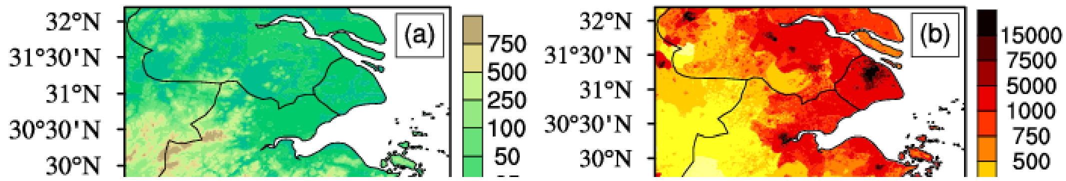

Figure 1

Spatial distributions of (a) topographical height (unit: m), (b) population density (unit: people/km^2), (c) nighttime lights (representing urbanization rate) and climatic patterns of summer (d) 850hPa wind field (vector, unit: m/s) and vertically integrated moisture divergence (shaded, unit: 10^{-5} kg•m^{-2}•s^{-1}), (e) 2m mean surface air temperature (unit: ℃), (f) precipitation (units: mm/h) over the YRD region for 2008–2019.

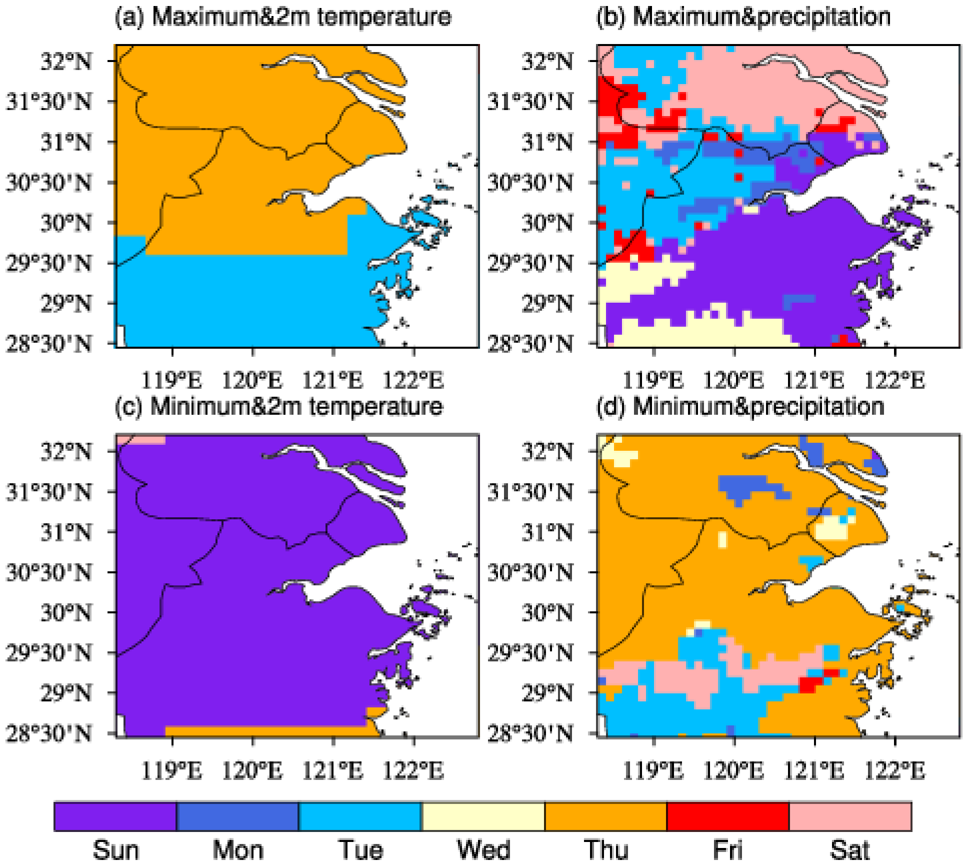

Figure 2

Spatial distributions of day-of-week with maximum (a, b) and minimum (c, d) summertime 2m surface temperature (left panel) and precipitation (right panel) over the YRD region for 2008–2019.

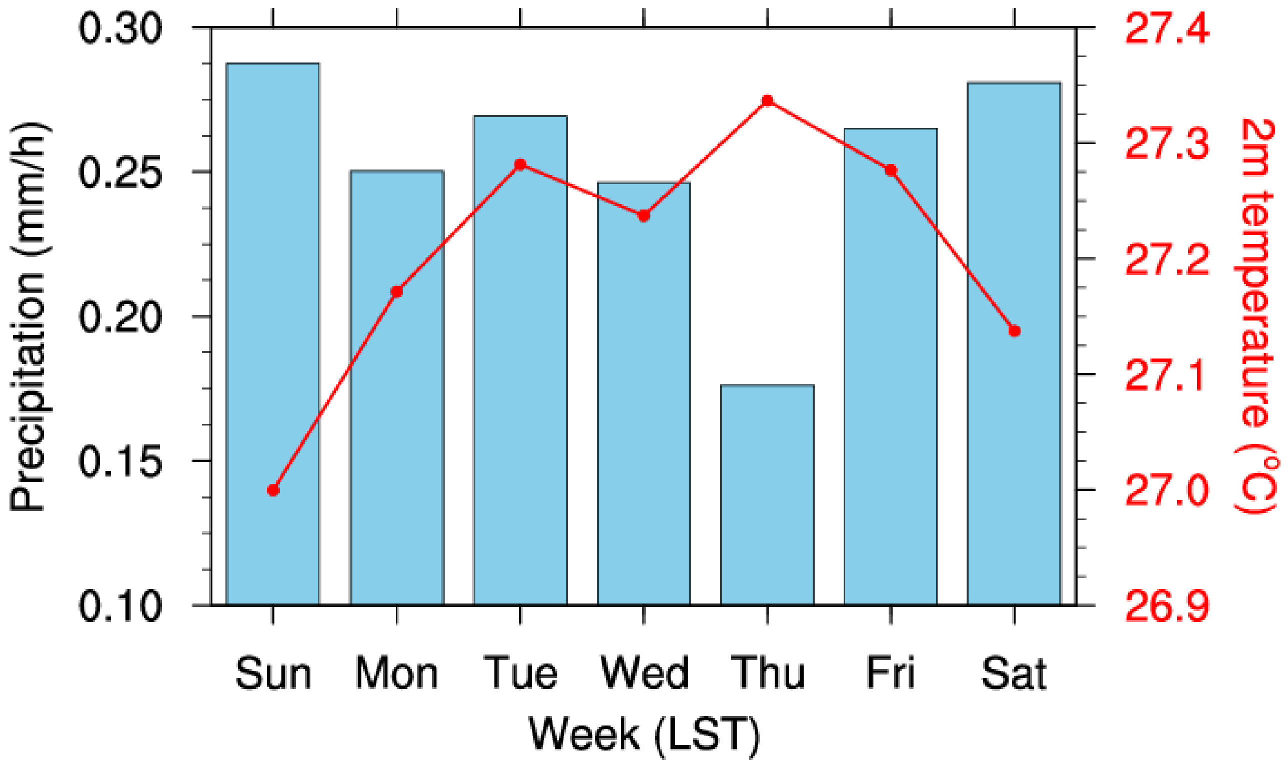

Figure 3

Weekly cycles of regional mean summertime 2m surface air temperature (red solid line, unit: °C) and precipitation (blue histogram, unit: mm/h) over the YRD region for 2008–2019.

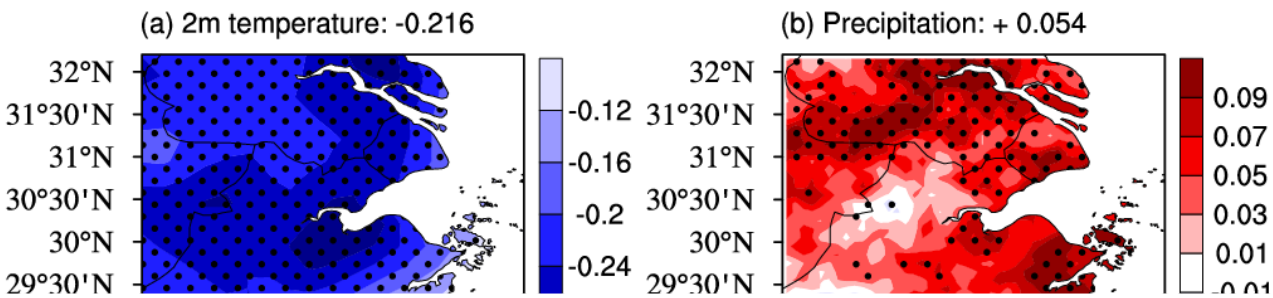

Figure 4

Weekend effect in (a) 2m surface air temperature (unit: °C) and (b) precipitation (unit: mm/h) over the YRD region for 2008–2019. The stippling areas are significant at the 99% confidence level by Student's t-test. The weekend effect is calculated by subtracting the average for Tuesday through Thursday from the average for Saturday through Sunday.

Figure 5

Weekend effect in summertime (a) aerosol optical depth at 550mm (, (b) low cloud cover, (c) medium cloud cover, (d) high cloud cover, (e) surface downward short-wave radiation (unit: W•m^{-2}), and (f) surface net radiation (unit: W•m^{-2}) over the YRD region for 2008–2019. The stippling areas are significant at the 90% confidence level with Student's t-test.

Figure 6

Distributions of summertime10m surface wind (vector, unit: m/s) and its divergence (unit: $10^{-6}s^{-1}$) during (a) weekend (Saturday through Sunday) and (b) weekdays (Tuesday through Thursday) and (c) their difference field (weekend minus weekdays) over the YRD region for 2008–2019. The areas passing the 99% confidence level are shown.