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Weekly cycle of aerosol-meteorology interaction over China

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[1] Weekly cycles of the concentration of anthropogenic aerosols have been observed in many regions around the world. The phase and the magnitude of these cycles, however, vary greatly depending on region and season. In the present study the authors investigated important features of the weekly cycles of aerosol concentration and the covariations in meteorological conditions in major urban regions over east China, one of the most polluted areas in the world, in summertime during the period 2001–2005/2006. The PM10 (aerosol particulate matters of diameter < 10 μm) concentrations at 29 monitoring stations show significant weekly cycles with the largest values around midweek and smallest values in weekend. Accompanying the PM10 cycle, the meteorological variables also show notable and consistent weekly cycles. The wind speed in the lower troposphere is relatively small in the early part of the week and increases after about Wednesday. At the same time, the air temperature anomalies in low levels are positive and then become negative in the later part of the week. The authors hypothesize that the changes in the atmospheric circulation may be triggered by the accumulation of PM10 through diabatic heating of lower troposphere. During the early part of a week the anthropogenic aerosols are gradually accumulated in the lower troposphere. Around midweek, the accumulated aerosols could induce radiative heating, likely destabilizing the middle to lower troposphere and generating anomalously vertical air motion and thus resulting in stronger winds. The resulting circulation could promote ventilation to reduce aerosol concentrations in the boundary layer during the later part of the week. Corresponding to this cycle in anthropogenic aerosols the frequency of precipitation, particularly the light rain events, tends to be suppressed around midweek days through indirect aerosol effects. This is consistent with the observed anthropogenic weather cycles, i.e., more (less) solar radiation near surface, higher (lower) maximum temperature, larger (smaller) diurnal temperature range, and fewer (more) precipitation events in midweek days (weekend).

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1. Introduction

[2] During recent decades, China has become one of the heaviest sources of air pollutants in the world [*Qian et al.*, 2003, 2006; *Richter et al.*, 2005], and the climatic impact of anthropogenic aerosols emitted in this region has become a topic of intense study [*Qian and Giorgi*, 1999; *Menon et al.*, 2002; *Giorgi et al.*, 2002, 2003; *Cheng et al.*, 2005; *Qian et al.*, 2006; *Zhao et al.*, 2006; *Lau et al.*, 2006; *Rosenfeld et al.*, 2007; *Zhang et al.*, 2007; *Huang et al.*, 2007]. Most of previous studies attempted to relate the observed long-term trends in regional climate variables during the past decades to a concurrent increase in the anthropogenic aerosols in the region. Although these diverse studies provided valuable insights into the effects of increased concentrations of aerosols on the regional climate, large uncertainties regarding the underlying aerosol-meteorology feedback still exist. Analysis of day-to-day aerosol-meteorology interactions can help to improve our understanding of how weather and long-term climate respond to aerosol forcing. However, the effects of short-time variations in aerosol concentration and its interaction with the regional meteorology over heavily polluted China have not been investigated.

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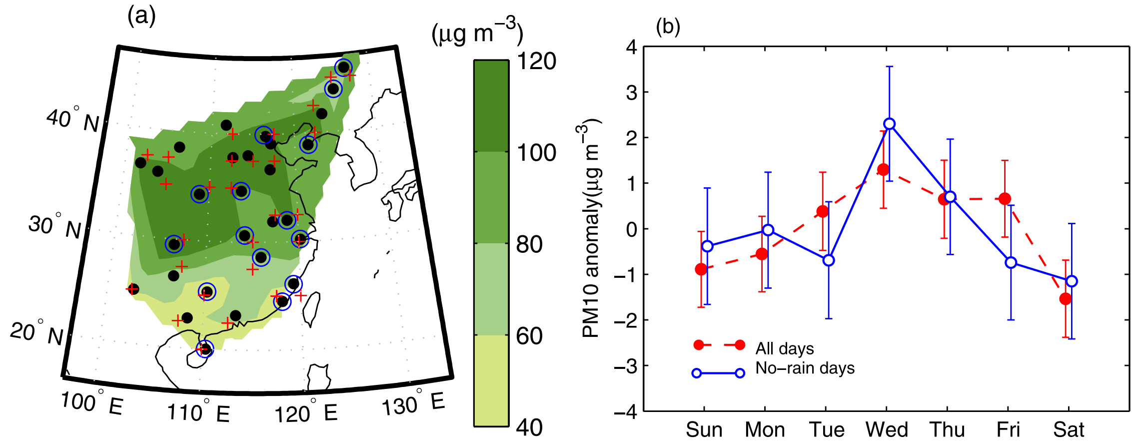

Figure 1. (a) Distribution of the mean PM10 concentration during June–August averaged over 2001–2006. The locations of the 29 pollution stations used are represented by solid circles, and R2 grids closest to the 29 stations are represented by red pluses. The 15 stations with radio-sounding temperature observations used during 2001–2005 are represented by large blue circles. (b) Weekly changes in the PM10 anomalies shown as the average values of the 29 stations. In order to remove the difference in the PM10 means among the stations, the anomaly is calculated for each station separately. The error bars correspond to a standard error of ±1 about the 29-sample mean.

[3] On the short-term timescale, a recently highlighted phenomenon is the significant differences in atmospheric physical conditions between weekend and midweek days. Weekly cycles of the concentration of anthropogenic pollutants have been observed in many regions around the world [*Lebron*, 1975; *Brönnimann and Neu*, 1997; *Marr and Harley*, 2002; *Beirle et al.*, 2003; *Jin et al.*, 2005]. The phase and the magnitude of these observed weekly aerosol cycles and the associated changes in meteorological variables vary significantly, depending on geographical location [*Forster and Solomon*, 2003] and season [*Gong et al.*, 2006]. However, the details of the mechanisms associated with the weekly cycle remain to be understood. Anthropogenic emissions and the complex feedbacks between the aerosols and atmospheric processes (including temperature variation, cloud formation, precipitation, and radiation) play important roles in modulating the temporal features of the pollutant concentration [*Cerveny and Balling*, 1998; *Forster and Solomon*, 2003; *Jin et al.*, 2005; *Gong et al.*, 2006; *Bäumer and Vogel*, 2007]. In the present study the analysis of the surface and upper air sounding data, revealed for the first time a weekly cycle of PM10 (aerosol particulate matters having diameters < 10 μm) concentrations in the major urban areas in China. Accompanying the PM10 cycles, there are significant cochanges in a number of atmospheric variables including horizontal wind, vertical motion,and thermal structure. Presumably, these indicate a self-modulation mechanism in aerosol-meteorology interaction corresponding to the PM10 cycles.

2. PM10 Data

[4] The daily mean concentrations of PM10, a leading pollutant, in the major cities of China have been measured in the form of the ambient air pollution index (API). The daily API and the corresponding pollutants (PM10, SO_2, or NO_2) have been archived at the State Center of Environment Monitoring of China. The details of the API and PM10 are presented in Appendix A. In this study, we selected 29 stations located to the east of 100°E (Figure 1a) where the records of daily API, maximum and minimum temperatures, and precipitation are available from 1 June 2001 to 18 July 2006. The original API data for 29 stations used in the study can be found in online auxiliary material.[1] Only the months of summer (June–August) are considered in this study because PM10-polluted days and relatively clean days (characterized by daily PM10 < 50 μg m^{-3}, SO_2 < 50 μg m^{-3}, and NO_2 < 80 μg m^{-3}) account for 96% of the total days in these months. A polluted day means that the daily API is above 50 (see Appendix A for details). During the other three seasons, the influence of PM10 on short-term meteorology is less dominant since the number of days that are either heavily influenced by the PM10 or relatively clean is well below 90% of the total number of days. Furthermore, dust storms, which produce anomalously high PM10 concentrations of natural origin (largely mineral dusts), are less frequent in summer. A majority of PM10 in summer is in the form of fine particulates of diameters less than 2.5 μm (PM2.5) and the ratio of PM2.5 to PM10 is approximately 0.7 in most regions in China [*Shi et al.*, 2003; *Cao et al.*, 2004; *Wang et al.*, 2006; *Yu et al.*, 2006]. The aerosol size distribution over China is much more homogeneous during summer than during the rest of the year. Aerosol size distribution, particularly that of fine aerosols, plays a significant role in the nucleation of cloud particles which is one of the primary mechanisms of indirect aerosol effects [*Dusek et al.*, 2006]. The most important constituents of the fine fraction of PM are carbonaceous particles (black carbon and organic carbon), which account for 20–45% of the PM2.5 mass concentration in most regions in eastern China [*Ye et al.*, 2003; *Cao et al.*, 2004; *Wang et al.*, 2006; *Yu et*

[1]Auxiliary materials are available at ftp://ftp.agu.org/apend/jd/2007jd008888.

al., 2006]. Black carbon originating from fuel combustion is particularly important because of its strong ability to absorb solar radiation, resulting in local radiative heating of the atmosphere.

3. Significant Weekly Cycle of PM10

[5] To delineate the characteristics of the day-to-day changes in PM10 concentration during a week, the average values of the observed PM10 concentrations at individual stations were calculated for each day of the week over all the summer days during the period 2001–2006. Subsequently, anomalies of the PM10 concentration on each day of the week were calculated by subtracting the daily mean values from the mean values over the total summer days at each station. Finally, the anomalies at individual stations were averaged over all the 29 stations to obtain the mean anomalies of PM10 concentration on each day of the week (Figure 1b). The resulting daily PM10 anomalies show a well-defined weekly cycle: They increase from Sunday through Wednesday and decrease during the later part of the week.

[6] We tested the PM10 difference between the weekly maximum and minimum (i.e., Wednesday minus Saturday) at the 29 stations by using an ordinary two-tailed *t*-test; this difference was used as an indicator of the weekly cycle. The null hypothesis of the test is that the mean of the differences at the 29 stations is zero, i.e., the weekly cycle signals are randomly arranged among the stations. The results of the test show that the null hypothesis is rejected at the 1% confidence level.

[7] Usually, the significance of the weekly cycle and the means for each day of the week can also be estimated from their error bars. It should be noted that the calculation of the error bars using all the stations as independent data points may overestimate the significance if these stations are intercorrelated. Since some of the stations used here are closely located, and some weather variables such as temperature, pressure are of large spatial scale, the estimated significance of their weekly changes is most likely biased. In the present study, we employed a Monte Carlo approach to yield a better estimation. We randomly changed the order of the day of the week. To simulate the possible intercorrelations of PM10 and meteorological variables among stations, we applied the same order to all of the 29 stations each once. Then we got a simulated mean for each day of the week and the corresponding standard errors of the means. This process was repeated 1000 times, yielding 1000 standard errors. The 95th percentiles of the simulated standard errors are used as the significance criteria in our analysis and plotted together with the observed means. Error bars for other variables analyzed in the following sections are all estimated using the same method. These error bars all are moderately larger than the standard errors estimated from 29 observations, thus they are somewhat stricter standards. These tests confirm that the weekly cycle of the PM10 concentration is statistically significant.

[8] Precipitation can wash out tropospheric aerosols effectively. To examine the impact of wet scavenging on the PM10 weekly cycle, we repeated the above analysis by using the data from only the days when there was no rain. The weekly cycle of the PM10 concentration observed for these days is very similar to that for all days (Figure 1b). Thus the weekly cycles of aerosol concentrations observed in this study are most likely robust signals.

4. Associated Wind Changes

[9] Wind is a critical variable for near-surface ventilation condition, which greatly impacts the pollutant concentration. At first, it is reasonable to detect possible changes in wind speed in lower troposphere in the context of weekly cycle. Here we investigated the weekly cycles of wind speed constructed in the same manner as the PM10. We found that there are detectable wind changes even though the daily winds are highly variable and noisy. Surface wind speed measured at 29 stations shows a tendency to increase after Wednesday with higher values in Thursday to Friday (see also Discussion and Conclusion). It is worthy to note that in regular observations at meteorological stations in China, the surface wind records are observed four times every day (0200 h, 0800 h, 1400 h, and 2000 h, Beijing local time). The wind speed is the average value of each observing time for a 2-min period. The surface wind in such a short time period could be heavily impacted or contaminated by the transient turbulence relating to the diverse microenvironments and atmospheric chaos. As height rises, the noise would drops. Therefore the daily mean low-level wind fields were examined using the relatively less noisy Reanalysis 2 (R2) data of 925 hPa and 850 hPa pressure levels, which are obtained from the National Centers for Environmental Prediction/Department of Energy (NCEP/DOE) with a resolution of 2.5 [*Kanamitsu et al.*, 2002]. Compared to surface wind observations, the R2 wind used in the present study is on a much larger spatial scale and the influence of noisy turbulence should be suppressed or reduced. We selected R2 grid points that are closest to the 29 pollution stations (Figure 1a). The resulting low-level wind anomalies show that the horizontal wind speed below the 2-km level, in which high aerosol concentration occurs, is relatively weak during the period from Saturday to Wednesday (Figure 2a). This is consistent with the continuous accumulation of PM10 during the same period because poor ventilation favors the occurrence of higher pollutant concentrations in urban areas (Figures 1b and 2a). The wind speed anomalies during the later part of the week are positive with a maximum of about +0.2 m s^{-1} on Thursday–Friday.

[10] It should be pointed that some of the R2 grid points, selected in this study, are located approximately 100–150 km away from the corresponding pollution stations. For a typical horizontal wind speed of 4–6 m s^{-1} in the boundary layer, the timescales for the advection of PM10 over the distance between the stations and the R2 grid points are less than 6–8 h. Furthermore, the distribution of large cities (population > 0.5 million) in east China is on average twice as dense as the R2 grid resolution, implying that there is a much smaller distance between the R2 grids and the cities located nearby. Therefore the distances between the stations and the R2 grids may not be a major concern in our analysis regarding the pollution advection.

[11] In addition to the R2 data, we also examined the upper air sounding data of the wind that are available at 16 of the 29 pollution stations considered in this study [*Durre et al.*, 2006]. We used the sounding data only at 1100 UTC

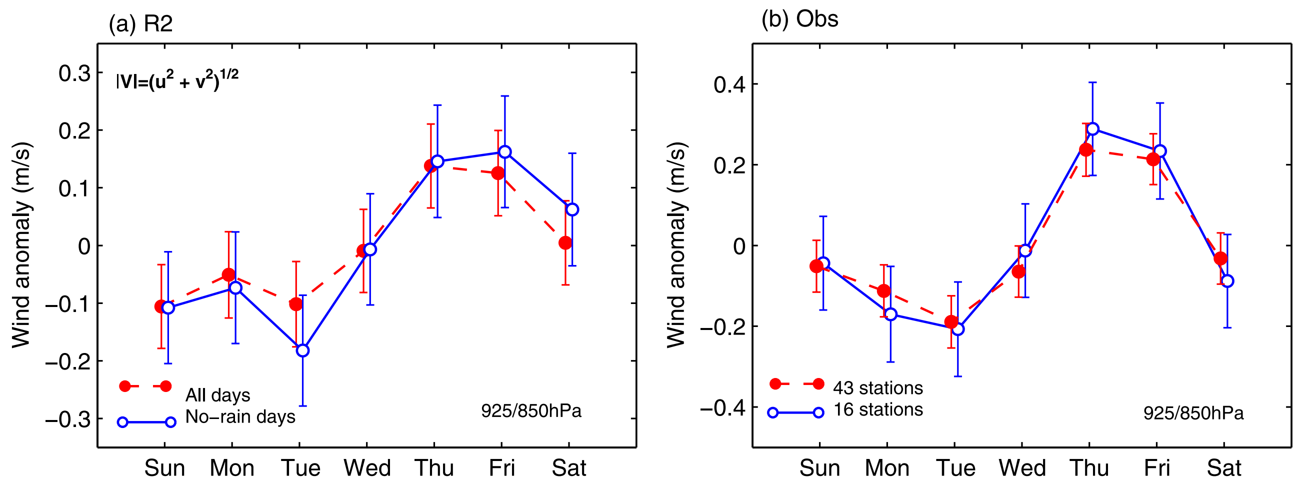

Figure 2. Anomaly of the horizontal wind velocity in the lower troposphere between 925 and 850 hPa levels shown as (a) the average from 29 R2 grids and (b) means from 16 and 43 radio-sounding stations for June–August from 2001 to 2005. The error bars correspond to a ±1 standard error about the sample means. For the locations of 16 and 43 radio-sounding wind stations, refer to Figure 3.

since soundings at 1100 UTC are available for more than 90% of the total number of days during summer in the period 2001–2005. In order to reduce the influence of the outlier observations, at each station all data beyond $\pm 3\sigma$ (standard deviation) range are excluded. About 1.24% of the total records were removed by this criterion. The patterns are almost identical when a different criterion of $\pm 2\sigma$ is used. Sounding data also shows an evident weekly cycle (Figure 2b) with negative (positive) wind speed anomalies during the earlier (later) part of the week with a maximum of +0.2 to +0.3 m s^{-1} occurring on Thursday and Friday; this is similar to the results based on the R2 data. The weekly cycle calculated using all 43 upper air stations in China, of which 27 stations are not colocated with the aerosol measurement stations (Figure 3), produced an almost identical weekly cycle as that obtained from the 16 colocated stations (Figure 2b). Since almost all of the upper air sounding stations are located in considerably populated areas, we conclude that the weekly cycle of the low-level wind speed is a common feature in the urbanized areas in China. We also checked the observed wind at 700 hPa, and found that the wind cycle is almost identical in phase.

[12] The positive wind speed anomalies may cause a decline in the PM10 concentrations during the later part of the week due to improved ventilation, at least partially. Furthermore, we checked the horizontal wind using only data for no-rain days and found an almost identical cycle. This is in good agreement with the PM10 cycle for no-rain days (Figures 1b and 2a) too.

5. Changes in the Vertical Thermal Structure

[13] The temperature anomaly in the low and middle troposphere provides important information for the atmospheric thermal structure and stability, which are indicative of anomalous winds. In order to investigate the weekly variations in the tropospheric thermal structure, we analyzed the temperature sounding data [*Durre et al.*, 2006] in 15 of the 29 stations where the temperature sounding data are available for more than 90% of the total summer days during the period 2001–2005 (on average, there are 4.3 missing days per station per summer). The resulting weekly atmospheric temperature cycle shows considerably positive values below the 850 hPa level (at approximately 1.5–2 km) from Monday to Wednesday, followed by negative values in the later part of the week (Figure 4a). The weekly cycle of the temperature anomalies in the lower troposphere also appears in the middle and upper troposphere with phase lags. The low-level positive temperature anomalies during the earlier part of the week steadily propagate upward during the course of the week. The anomalous +0.05 K isotherm is situated below approximately 900 hPa (about 1 km) on Monday, but it appears on the 850 hPa level in two days. Positive temperature anomalies in the middle to high troposphere appear from Wednesday to the weekend. To

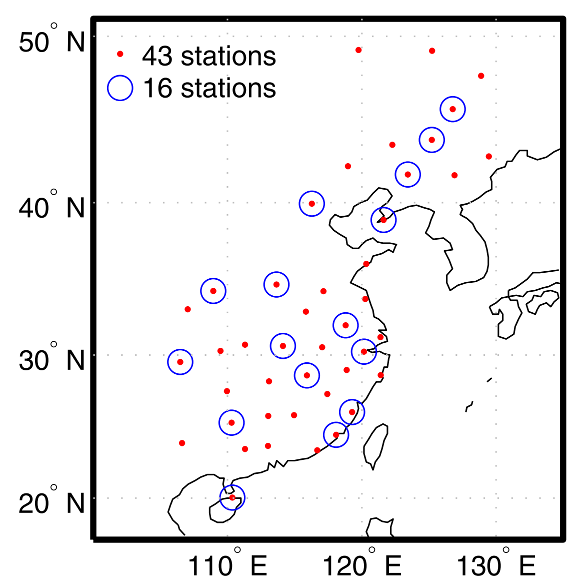

Figure 3. Locations for the radio-sounding wind stations used in Figure 2b.

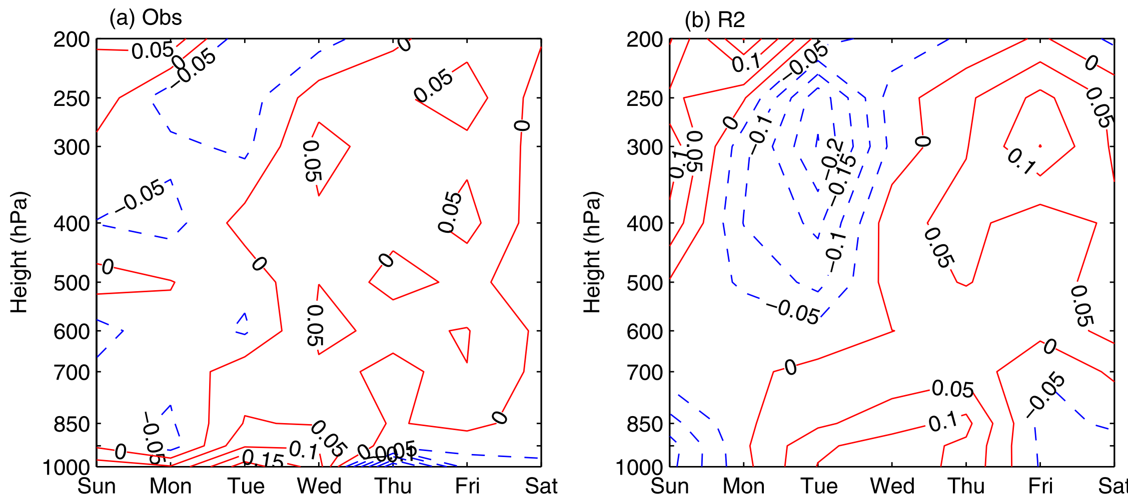

Figure 4. Temperature anomaly profile from Sunday through Saturday in the troposphere during June–August over 2001–2005. (a) Means of 15 radio-sounding station observations at 1100 UTC, see Figure 1a for their locations, and (b) means of 29 R2 grids. Contour intervals are 0.05 K.

examine the robustness of the weekly atmospheric temperature anomaly cycle, we repeated the analysis using the R2 data at all the 29 grid points that correspond to the PM measurement stations (Figure 4b). The R2 temperature data essentially generates the same weekly cycle as the upper air sounding data. The characteristics of the weekly cycle of atmospheric temperatures, such as the occurrence of the positive and negative temperature anomalies in the lower troposphere during the earlier and later parts of the week, respectively, and the vertical propagation of these low-level temperature anomalies into the middle and upper troposphere during the course of the week, are more clearly identified from the R2 data with slightly larger amplitudes than from the upper air sounding data.

6. Aerosol-Meteorology Interaction: A Hypothesis

[14] Anthropogenic aerosol emissions from the household sector and power generation are relatively steady throughout a week; however, other sources such as motor vehicles and factories emit less pollutants during weekends than during weekdays. Limited observations available in a few urban areas in eastern China show that the traffic related PM and black carbon concentrations are lower in weekend at fixed observation sites [*Li et al.*, 2005; *Liu et al.*, 2006]. However, sufficient data are not available for clarifying how emission impacts PM10 concentrations during a week. Comprehensive air pollution modeling in conjunction with observed emission will be useful for examining the details in the observed weekly cycle, a subject of future study.

[15] Since the typical residential timescales of aerosols with a diameter in the range 0.1–10 μm are several days in the lower troposphere [*Brasseur et al.*, 1999], PM10 should gradually accumulate in the lower troposphere if it is generated faster than it is removed by dry deposition and/or wet scavenging. Thus the corresponding PM10 concentration would acquire its peak on Friday. However, our results show that the maximum (minimum) concentration of PM10 occurs on Wednesday (Saturday). We hypothesize that the phase of the weekly PM10 cycle is associated with changes in the atmospheric circulation that might be triggered by the accumulation of PM10 through diabatic heating of lower troposphere.

[16] Previous measurements showed that absorbing aerosols warm the lowest 2–4 km of the atmosphere during the periods of heavy aerosol concentration over the Indian Ocean and the Amazon Basin [*Eck et al.*, 1998; *Satheesh and Ramanathan*, 2000; *Ramanathan et al.*, 2001]. The radiative heating in the boundary layer and cooling at the surface increase the static stability near the surface however, would destabilize the atmosphere in the upper part of the boundary layer and the midtroposphere [*Koren et al.*, 2004]. The increased instability in the low and middle troposphere can enhance vertical motions. Our analysis shows that gradual warming of lower troposphere occurs from weekend to midweek. For measuring the atmospheric instability, we used the total totals index (TT) [*Miller*, 1967], which is defined as $TT = T_{d850} + T_{850} - 2 \times T_{500}$, where T_{d850} is the dew point temperature at 850 hPa, T_{850} and T_{500} are temperatures at 850 and 500 hPa, respectively. $TT > 44$ indicates a high possibility of the occurrence of strong convections. The R2 data show that the frequency of events where $TT > 44$ increases after Wednesday and reaches a maximum on Thursday, suggesting that the anomalously enhanced vertical air motions can occur during this period. This is supported by the changes of vertical motion.

[17] We further analyzed the R2 vertical velocity (ω) and compared with the horizontal wind. Note that ω is a diagnostic variable in reanalysis, here we used daily mean data (the average of four time slices) to reduce the possible random biases. On the basis of the same time period 2001–2005 and same method, we got the weekly changes. As shown in Figure 5, daily mean ω in R2 are clearly lower in Thursday and Friday, with a significant minimum in Thursday. This implies existence of an anomalous ascending motion on Thursday and Friday although the statistical significance of the vertical velocity anomalies is smaller than the horizontal wind anomalies (compare Figures 2 and 5). It is well known that ascending air is often accompanied by

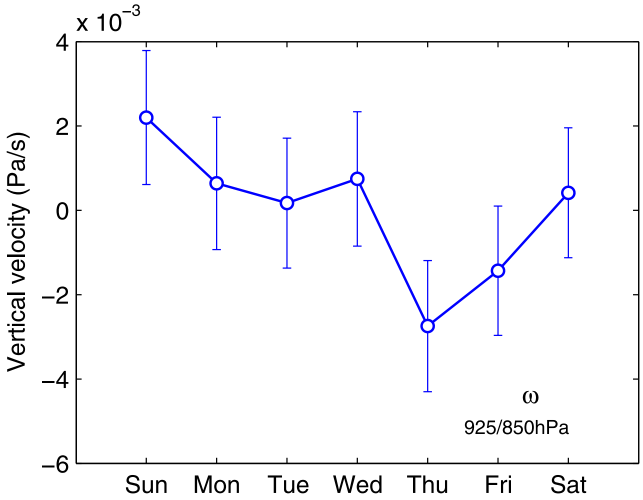

Figure 5. Anomaly of the daily mean vertical air velocity (ω) in the lower troposphere between 925 and 850 hPa levels at 29 R2 grids during 2001–2005.

low-level convergence which often brings stronger wind near surface and that the increases in vertical fluxes in association with the enhanced vertical wind can help transfer the faster air in the upper down to the low level. Thus the positive horizontal wind speed anomalies in near surface to lower troposphere in the later part of the week are associated with the anomalous ascending motions in the same period.

[18] The occurrence of the positive temperature anomalies in the middle to high troposphere from Thursday to Sunday (Figure 4) is concurrent with the enhanced vertical motion. Either dry or wet convections can result in the heating of the upper level layers because of (1) the vertical transport of the warmer low-level air into the middle and high troposphere and (2) the heating effect of the absorbing aerosols in PM10 transported from the boundary layer into the upper troposphere. The heating of the upper levels can serve as a "heat pump," which in turn can enhance the ascending motions in the lower troposphere [*Lau et al.*, 2006]. Consequently, the stronger winds and the enhanced vertical motions most likely generated in response to the radiative heating by the absorbing aerosols helps to disperse the aerosols, resulting in the decrease in the PM10 concentration during the later part of the week.

[19] These analyses suggest that there may exist a self-modulation mechanism in aerosol-meteorology interaction at a weekly timescale in China. Further understanding of the mechanism, however, needs more elaborate study.

7. Implications for Temperature and Rain Frequency

[20] Aerosols are known to have a considerable impact on the atmospheric energy balance and the temperature [*Bellouin et al.*, 2005; *Kaufman et al.*, 2005; *Kaufman and Koren*, 2006]. However, this impact may significantly vary from region to region, depending on whether the direct or indirect effect of aerosols or other mechanisms is dominant [*Lohman and Feichter*, 2005; *Kristjánsson et al.*, 2005; *Gong et al.*, 2006; *Huang et al.*, 2006]. In China, both the station observation and upper air sounding data show that the highest (lowest) daily mean temperature occurs on Wednesday (Saturday) in the lower troposphere during summer. Similar weekly variations are also observed in the daily maximum temperature and the diurnal temperature range (DTR, defined as the maximum temperature minus the minimum temperature) on Wednesday, both the daily maximum temperature and the DTR are approximately 0.25 K higher than those on Saturday (Figure 6a). However, the daily minimum temperature anomalies do not show a clear weekly signal. This suggests that the daytime radiative heating plays a dominant role in determining the daily mean temperature and DTR signals as supported by an in-phase relationship between the weekly cycles of aerosol concentrations and low-level temperatures. The increased total solar irradiance received at the surface in midweek days [*Gong et al.*, 2006] implies that the suppression of cloud cover/precipitation by aerosol indirect effects roughly on Wednesday may additionally play an important role in causing temperature cycles.

[21] The impact of aerosols on clouds and precipitation characteristics is an important issue in the climate research [*Kristjánsson et al.*, 2005; *Kaufman and Koren*, 2006]. The

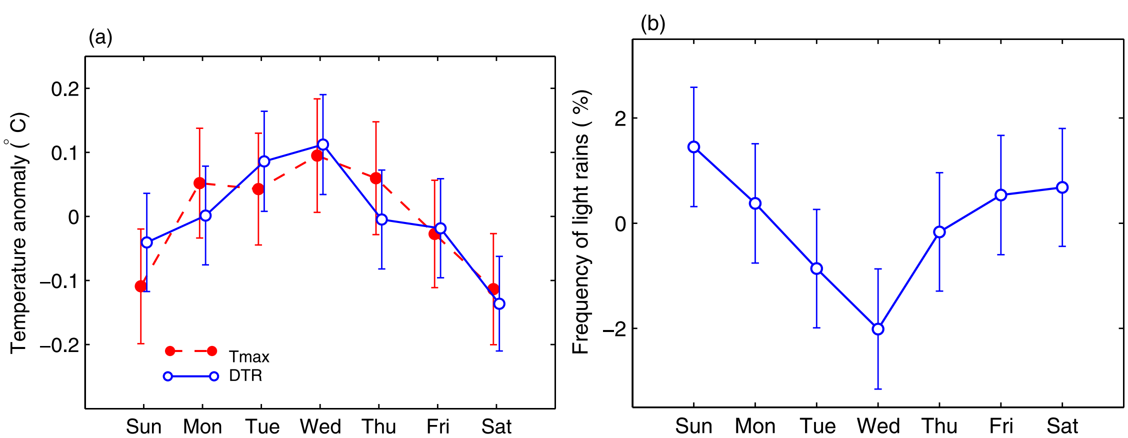

Figure 6. Weekly changes in (a) diurnal temperature range (DTR) and maximum temperature and (b) frequency of light rains ($\leq$5 mm day^{-1}) during the months of June–August over 2001–2006. The results are averaged over 29 stations, and the $\pm$1 standard errors about the mean are plotted together.

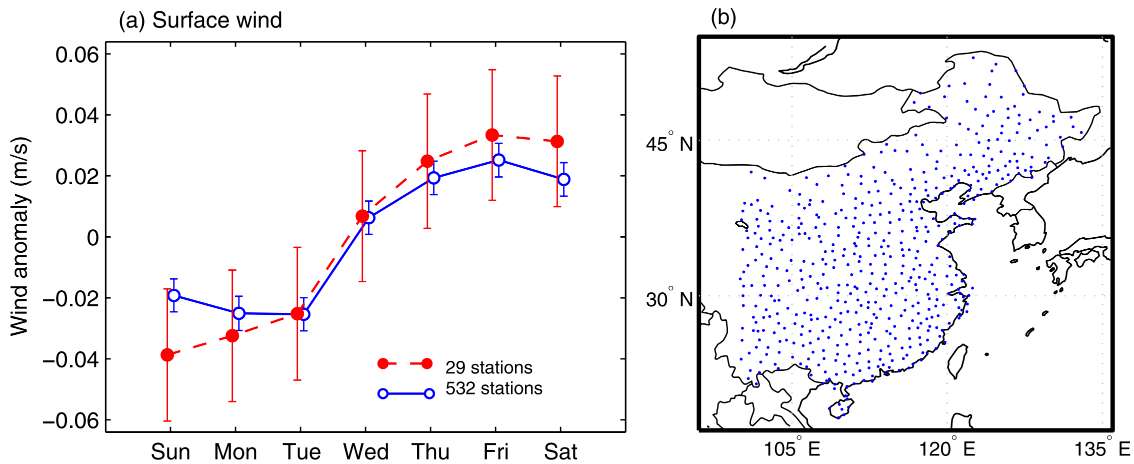

Figure 7. Weekly changes in surface wind during the months of June–August over 2001–2005. (a) Results as estimated from 29 colocated stations and from all 532 stations plotted together for comparison. (b) Location of 532 stations.

response of clouds and precipitation to aerosols depends on the large-scale environment particularly relative humidity, the characteristics of the clouds formed in those environments, and the physical nature of aerosols. Aerosols affect the clouds and precipitation in a number of ways (e.g., direct, first and second indirect, semi-indirect and so on). To produce rain, cloud droplets need to grow to radii greater than about 14 μm. With too many cloud condensation nuclei (CCN), a majority of cloud droplets fail to acquire the critical radius, resulting in the suppression of rainfall. This is the so-called second aerosol indirect effect. We believe that under a particular circumstance (e.g., warm stratus cloud), the second indirect effect is dominant for the frequency of light rain, i.e., more aerosol particles and less frequent rainfall (especially light rain), under a given atmospheric condition. This effect could be enhanced by atmospheric heating by absorbing aerosols and the reduction in albedo [*Krüger and Graßl*, 2004].

[22] We investigated the frequency of light rain days, which include trace precipitation (between 0 and 0.1 mm day^{-1}) and <5mm day^{-1} events. The light rain days by this definition account for 31% of the total summer days and 62% of the total summer rainy days. Figure 6b shows the changes in the frequency of light rains from Sunday to Saturday. A weekly cycle of light rain frequency is evident, showing a maximum on Sunday and a minimum on Wednesday, where the difference between the maximum and minimum is approximately 3%. The higher concentration of PM10 on Wednesday seems to reduce the precipitation frequency, which is consistent with the previous findings that the aerosol loading caused by humans, particularly the fine particles, suppress the warm rain processes [*Rosenfeld*, 2000; *Koren et al.*, 2004; *Rosenfeld et al.*, 2007]. We repeated this analysis using different threshold values up to 10 mm day^{-1} for the definition of light rain, resulting in the same conclusion.

[23] A recent analysis of ground temperature, radiation, and humidity observations and reanalysis data [*Gong et al.*, 2006] reveals that in China in summer this effect allows relatively more sunlight to reach the surface during midweek than during the weekend; this occurs in conjunction with the increase in the PM10 concentration and leads to a higher maximum temperature and a larger DTR in the low troposphere. The increase in the temperature in turn can reduce the relative humidity and suppress cloud formation and light precipitation.

8. Discussion and Conclusion

[24] Uncertainties in the aerosol-meteorology relations still exist. By simulation, *Jacobson and Kaufman* [2006] reported that aerosol particles may reduce near-surface wind speed and enhance the wind aloft because of the momentum conservation. They assumed that the increasing in air pollution in China may, at least partly, responsible for the significant reduction in surface wind speed observed there [*Xu et al.*, 2006]. This is apparently different from our analysis, where we found that stronger wind in Thursday and Friday follows the PM10 maximum of Wednesday. For clarification we rechecked the surface wind. Since the surface wind observation at each single station contains very high noise, we analyzed 532 stations with daily mean wind observations available (missing days less than 10 during the time period of 2001–2005). Compared to the results from 29 stations, the much larger number of samples yields smaller standard errors and gives us higher confidence on the estimation of means. As shown in Figure 7, the weekly cycle in surface wind speed is evident, and the increases in wind speed in Thursday-Friday are significant. There are about 0.04–0.08 m/s difference between the minimum and maximum during the week, that is 2–4% of the mean surface wind speed in summer. These apparent discrepancies might be caused by the following reasons. First, our results focus on observations from individual stations in seriously polluted east China, while *Jacobson and Kaufman*'s [2006] results are of simulation over regional, costal California. In the two regions the emission are notably different. Whether/how the wind anomaly depends on aerosol emission amount and/or types are not yet clear. Also, the timescale is different. Our study focuses on day-to-day changes within one week. *Jacobson and Kaufman*'s [2006] simulations are monthly anomalies with respect to

specific aerosol forcing. The possibility of larger wind in some days due to strong heating effect by aerosols cannot be ruled out, even though the monthly-seasonal mean wind declines in association with increase in the atmospheric stability. Checking the weekly aerosol-wind relations in station observations over California and simulating weekly wind changes forced by emission inventory over China would help reduce the uncertainties in our understanding of aerosol-meteorology interactions.

[25] Our analysis is based on local observations. It is an interesting question that whether the aerosol-induced diabatic heating due to local aerosol concentrations influence large-scale meteorological conditions. Some studies analyzed the large-scale influence of the aerosols [e.g., *Giorgi et al.*, 2002, 2003], but few focused on the weekly timescale. Previous observation analysis [*Forster and Solomon*, 2003; *Gong et al.*, 2006; *Bäumer and Vogel*, 2007] and our results here suggest that the weekly change seems not solely a local phenomenon, though it could be local in origin. Comprehensive analysis of large-scale circulation changes from the surface to upper levels in association with the weekly cycle would provide an insight into this question. This is a subject of future investigation.

[26] China has been experiencing rapid urbanization; as of 2003 there are over 660 large cities: 448 of them with population >0.5 million and 174 cities with population >1 million. Most of these large cities are densely located in the eastern parts of the country [*National Bureau of Statistics of China*, 2004]. PM concentration in urban areas can be quickly spread to neighboring regions [e.g., *Xu et al.*, 2003; *Zhang et al.*, 2004]. This results in relatively homogeneous PM10 concentration over eastern China despite the fact that emissions are essentially local. Thus the aerosol-meteorology interaction is most likely a nationwide phenomenon beyond the 29 stations analyzed in the present study. Although a similar aerosol cycle corresponding to a Wednesday maximum and a weekend minimum has been observed in other parts of the world, such as New York [*Jin et al.*, 2005], it remains to be determined if this is a worldwide phenomenon and/or is independent of location, aerosol types and weather background.

[27] In conclusion, our analysis of the spatiotemporal variations in PM10 and atmospheric variables at 29 air pollution stations in China show significant weekly cycle of PM10 concentration and meteorological variables during summer. In association with the PM10 cycle, atmospheric circulation, temperature and precipitation frequency vary in a physically consistent manner, very likely implying a self-modulating mechanism at weekly timescales through the aerosol concentration-meteorology feedback.

Appendix A: Aerosol Concentration Data

[28] All pollutant data used in the present study are available in the form of the air pollution index (API). The daily API and the corresponding pollutants (PM10, SO_2, or NO_2) have been archived at the State Center of Environment Monitoring of China and available online via http://www.sepa.gov.cn/quality/air.php3. The daily API is defined by two key parameters: the API type, which indicates the type of the leading pollutant (SO_2, NO_2, or PM10) and the API value, which represents the concentration of the leading pollutant. The API values are transformed from the pollutant concentration according to the national standard of ambient air quality (see Table A1). If the API is below 50, it is defined as a clean day and no pollutant type is set.

Table A1. National Standard of the Ambient Air Quality in China

Index (API)	Concentration, μg m^{-3} SO_2 (Daily Mean)	NO_2 (Daily Mean)	PM10 (Daily Mean)
50	50	80	50
100	150	120	150
200	800	280	350
300	1600	565	420
400	2100	750	500
500	2620	940	600

[29] Given an observed daily mean pollutant concentration (C) along with the upper (C_U) and lower (C_L) standard values where C corresponds to, the pollution index is calculated as $API = (I_U - I_L)(C - C_L)/(C_U - C_L) + I_L$, where I_U and I_L are the upper and lower standard API values, respectively, corresponding to C_U and C_L in that order. Three types of pollutants yield three APIs. Finally, the maximum API value is defined as the daily API, i.e., API = max(API_{SO2}, API_{NO2}, API_{PM10}), which varies between 0 and 500. Similarly, the concentration of the major pollutant can be derived from the API by using the formula: $C = C_L + (I - I_L)(C_U - C_L)/(I_U - I_L)$. In the present study, the PM10 concentration is determined from the API in this manner, and the major pollutant on clean days is assumed to be PM10. In order to avoid the impact of outlier data, 6 d with API > 250 are excluded in the analysis for summer. The original API data for 29 stations are provided as online auxiliary material.

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