Weekend effect: Anthropogenic or natural?

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[1] Human activities have been suggested to result in weekly changes of meteorological variables, called the “weekend effect.” Recent debates on its statistical significance, however, reveal that there still remain huge uncertainties as to the anthropogenic origin of the weekend effect. We show that atmospheric Rossby waves induce the “natural” weekend effect, which is much stronger than the “anthropogenic” weekend effect. The “natural” weekend effect does not completely disappear even with averaging over 61 years of data; as a result, true “anthropogenic” weekend effect is obscured by the natural component. We attempted to remove the “natural” component in the diurnal temperature range and the resulting pattern is an overall positive weekend effect over North America.


1. Introduction

[2] Weekly cycles of pollution and heat release due to human activities [Cleveland et al., 1974; Gordon, 1994; Cerveny and Balling, 1998] have led to extensive studies on anthropogenic weekly cycles of various climatological variables. Observational evidence includes temperature anomalies [Gordon, 1994; Tesouro et al., 2005] and diurnal temperature range (DTR) differences [Forster and Solomon, 2003; Gong et al., 2006; You et al., 2009] between weekends and weekdays. Meteorological variables such as precipitation, wind, cloud, solar irradiance and convective storm were also shown to have weekly cycles in many locations worldwide [Cerveny and Balling, 1998; Gong et al., 2007; Bell et al., 2008; Ho et al., 2009]. Aerosol-cloud interactions and related atmospheric circulation change are suggested to induce weekly cycles in DTR and precipitation [Cerveny and Balling, 1998; Forster and Solomon, 2003; Gong et al., 2007; Bell et al., 2008; Ho et al., 2009].

[1] However, recent debates on their statistical significance [Bäumer and Vogel, 2007; Schultz et al., 2007; Bäumer and Vogel, 2008; Bell and Rosenfeld, 2008; Hendricks Franssen, 2008; Sanchez-Lorenzo et al., 2008; Barmet et al., 2009; Hendricks Franssen et al., 2009; Sanchez-Lorenzo et al., 2009] aroused hypothesis that anthropogenic weekly effect interacts with large scale atmospheric dynamics. In this study, we show that the naturally occurring weekly cycle in DTR is stronger than the “weekend effect” in many midlatitude regions. After removing the natural cycle, we obtain a more accurate pattern of the weekend effect.

2. Data and Method

[4] We used maximum and minimum temperatures for a 51-year period (1950–2000) from the Global Daily Climatology Network (GDCN) dataset [Easterling et al., 2003] as observational data. We also used daily 2 m maximum and minimum temperatures for a 61-year period (1948–2008) from the NCEP/NCAR dataset [Kalnay et al., 1996] as reanalysis data. A summer period (May 19–September 15) was analyzed since a stronger “weekend” effect may be visible in variables associated with convection, which, together with the radiative effects of aerosols, is considered a principal mechanism for the weekend effect. Observational data quality check has been performed for each station in terms of outliers (>3 standard deviations), missing values and the minimum record length of 30 years; only the stations passing a quality criterion have been used in this study. Long-term fluctuations were removed by subtracting the weekly mean value from each week. Thus, the resulting data represent variability on a weekly time scale or less. Since the reanalysis dataset derives fairly reasonable results in comparison with the results from the observational dataset (Figure 1), we used the reanalysis dataset to understand natural and anthropogenic characteristics in the weekly cycles of the DTR.

[5] Cyclostationary EOF (CSEOF) analysis [Kim et al., 1996; Kim and North, 1997] was conducted on the DTR with the nested period of 7 days:

$$DTR(r, t) = \sum_{n} DTR_n(r, t) PC_n(t),$$

where $DTR_n(r, t)$ are the CSEOF loading patterns and $PC_n(t)$ are the corresponding principal component (PC) time series, $n$ is the mode number, and $r$ and $t$ denote space and time. The purpose of CSEOF analysis is the decomposition of weekly variation into physically meaningful modes. The CSEOF loading patterns, $DTR_n(r, t)$, show space–time evolution of the DTR over a period of 7 days and the PC time series measures weekly fluctuations of $DTR_n(r, t)$. Other atmospheric variables including total cloud fraction, relative humidity, minimum temperature, 200–250 hPa potential vorticity (PV), net longwave radiation at surface, net shortwave radiation at surface, and precipitation rate from the NCEP/NCAR dataset were also analyzed in the same way. Then, physically consistent evolutions of the atmospheric variables (say, precipitation $P(r, t)$) are found in the form:

$$P(r, t) = \sum_{n} P_n(r, t) PC_n(t).$$
This can be accomplished via CSEOF analysis of \( P(r, t) \) followed by a regression analysis between principal components of \( DTR_n(r, t) \) and \( P(r, t) \) [Seo and Kim, 2003].

Physical consistency between \( DTR_n(r, t) \) and \( P_n(r, t) \) is argued that they have a common evolution history, \( PC_n(t) \), whereas the two space–time patterns, \( DTR_n(r, t) \) and \( P_n(r, t) \), may not be the same. The physical evolutions depicted in \( DTR_n(r, t) \) and \( P_n(r, t) \), in fact, should be such that they satisfy the governing equation of the physical process they represent. In this way, we produced space–time evolution patterns of atmospheric variables to be physically consistent with that of \( DTR \). That is,

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Data(r, t) = \sum \{ DTR_n(r, t), P_n(r, t), q_n(r, t), ..., PV_n(r, t) \} PC_n(t),
\]

where \( \{ DTR_n(r, t), P_n(r, t), q_n(r, t), ..., PV_n(r, t) \} \) denote physical evolution of variables we investigated; these spatial and temporal patterns of physical evolutions describe the detailed nature of the physical evolution.

3. Eastward Propagating Signal in Weekly Cycles

The weekly cycles of \( DTR \) in Figure 1 were derived from the GDCN dataset and the NCEP/NCAR reanalysis data, respectively. Figure 1a shows the weekend effect—\( DTR \) averaged over weekends (Saturday, Sunday, Monday) minus \( DTR \) averaged over weekdays (Wednesday, Thursday, Friday). It looks reasonably similar (pattern correlation = 0.51) to that based on the reanalysis product (Figure 1c) with positive \( DTR \) anomalies over the northwestern US (WA, OR), northeastern US (NC, VA, PA, NY) and southwestern US (NM, CO). While the weekend–weekday difference shown in Figure 1a is presumed to be anthropogenic, the corresponding weekly cycle along the 35°–45°N band shows a sign of eastward propagation specifically on the eastern side of the US (Figure 1b). The weekly cycle based on the NCEP/NCAR reanalysis data also shows a similar eastward propagating signal (Figure 1d). This over 10 m s\(^{-1}\) eastward propagating signal is not explained by anthropogenic causes primarily in the planetary boundary layer and suggests that the weekend effect is contaminated by natural components of variability even after a 51-year averaging of the observational data.

In order to understand the degree of contamination by natural variability in the weekly cycle of \( DTR \), the first two CSEOF modes were analyzed for the period of 1979–2008 (Figure 2). The two modes represent the dominant modes of natural variability in \( DTR \) and clearly depict eastward propagation; the two modes describe essentially the same physical evolution and are analogous to cosine and sine parts of Fourier decomposition due to the variable phase of propagating waves. These two CSEOF modes were multiplied by the respective amplitude time series and were then added together to reconstruct the data over the entire data period associated with the major component of the atmospheric waves. Then, weekly cycles of various atmospheric variables were obtained by averaging the entire record for each day of the week.
Holton, 1992]. Whereas the period and phase of Rossby waves are variable, a significant fraction of Rossby wave energy resides in the neighborhood of 7 days as suggested in Figure 2. Even after 30 years of averaging, these eastward moving Rossby waves with variable phase are not completely removed. A similar picture is obtained based on the 61-year reanalysis data, although the amplitude is reduced to 1/3 of that shown in Figure 2.

4. Natural Variability in Weekend Effect

[10] Figure 3 shows the weekend-weekday differences for DTR, total cloud fraction, relative humidity, precipitation, minimum temperature, 200–250 hPa PV, net longwave radiation at surface, and net shortwave radiation at surface based on the first two CSEOF modes. The passing of Rossby waves is clearly traced in the concerted changes of all variables considered here. Specifically, the surface response leads/lags Rossby waves by approximately a quarter of a cycle [Holton, 1992]. The increased PV in the upper atmosphere leads to a lower-level convergence and an upward motion to the east of the PV, as well as a low-level divergence and a downward motion to the west of the PV [Hoskins et al., 1985; Holton, 1992]. To the east of the PV, relative humidity and precipitation increases thereby increasing total cloud fraction; this is likely due to the upward motion in the atmospheric column associated with the positive vortex aloft. The increased total cloud fraction diminishes net shortwave radiation reaching the surface and longwave radiation leaving the surface thereby increasing minimum surface temperature and DTR. To the west of the PV, situation reverses. It is clear that the passing of Rossby waves results in a consistent change of atmospheric conditions, thereby affecting DTR.

[11] Although the spatial and temporal patterns of DTR in Figure 3 due to Rossby waves are different from the so-called “weekend” effect in Figure 1, the contribution of the first two Rossby waves is significantly larger in magnitude over much of the mid- to high-latitudes than the “weekend” effect derived from the data. Whereas the eastward propagation of Rossby waves is clear in Figure 2, it is not clearly seen in Figure 1 since other variabilities added on top of Figure 2 obscure this eastward propagation of Rossby waves. In Figure 1, there is, nevertheless, a hint of eastward propagation on the eastern side of the domain at relatively high latitudes, which is completely hidden in the weekend/weekday DTR difference. Further, this propagation yields a “natural” weekend effect upon weekend-weekday differencing [Sanchez-Lorenzo et al., 2008, 2009]. Consequently, the “natural” weekend effect may no longer be discernable from the “anthropogenic” weekend effect.

5. Conclusions

[12] Unfortunately, the “natural” weekend effect as shown in Figure 3 is much stronger than the overall “weekend effect” of natural and anthropogenic origins combined; the magnitude of the former is often 10–100 times stronger than the latter over the northeastern and midwestern US and several other places (Figure S1 of the auxiliary material), making an accurate estimate of anthropogenic effect nearly impossible without first removing the natural effect. In a simple averaging-and-differencing approach, the “true” weekend effect of anthropogenic origin will be seriously inflated or deflated and its sign will also be reversed in many places due to the natural effects.
weekend effect at several places, with a widespread positive weekend effect over the northeastern states and a much less remarkable weekend effect over WA, CO, NM, TX and Mexico [Forster and Solomon, 2003]. The region of positive weekend effect encompasses most of the cities with populations greater than a half million among the top 100 most populated US cities. Fujibe [2010] similarly showed that the weekend effect is generally stronger in more populated cities in Japan. The corresponding weekly cycle averaged over 35°–45°N also shows fairly consistent positive values during weekends and negative values during weekdays. Further, the sign of eastward propagation in Figure 1 is nearly gone in Figure 4. Similar patterns of the weekend effect and weekly cycle are obtained based on the 30-year reanalysis data, except for a somewhat stronger magnitude of the weekend effect. It implies that the weekend effect is more widely spread with the population growth. Correlation between the weekly cycle of DTR and those of other physical variables shows that there are also significant weekend effects in meteorological variables specifically on the northeastern part of U.S. (Figure S2).

Figure 3. Difference in meteorological variables between weekends and weekdays based on the first two CSEOFs. Weekend (Saturday–Monday) minus weekday (Wednesday–Friday) difference patterns of (a) 2m minimum air temperature, (b) 200–250 hPa potential vorticity, (c) net longwave radiation at surface, (d) net shortwave radiation at surface, (e) diurnal temperature range, (f) total cloud fraction, (g) relative humidity, and (h) precipitation rate derived from the first two CSEOFs of the NCEP/NCAR reanalysis data.
weekend effect due to Rossby waves does not disappear even with averaging over 61 years of summers (= 976 weeks). We crudely removed the “natural” component of the weekend effect and obtained a seemingly more reasonable pattern of the “anthropogenic” weekend effect (Figure 4). We feel that a firm conclusion on the anthropogenic origin of what we call the “weekend effect” requires more careful scrutiny of data.

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References


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