Winter "weekend effect" in southern Europe and its connections with periodicities in atmospheric dynamics

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Winter "weekend effect" in southern Europe and its connections with periodicities in atmospheric dynamics

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[1] Winter weekly cycles of different climatic variables have been detected over Spain during the 1961–2004 period. The 13 analyzed series come from stations placed on different climatological and geographical areas with different level of urban influence. Therefore, the weekly cycles can hardly be related with local effects. Contrarily, we suggest that the weekly cycles may be related with changes in the atmospheric circulation over Western Europe, which may be due to some indirect effect of anthropogenic aerosols. Particularly interesting is the observed increase in Sea Level Pressure over Southern Europe during the weekends and consequently a decrease of anticyclonic conditions during the central weekdays.
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1. Introduction

[2] According to the Fourth Assessment Report of the Intergovernmental Panel for Climate Change [*Intergovernmental Panel on Climate Change*, 2007] there are clear evidences of anthropogenic impact in the recent change of the Earth's climate. Since many natural factors may interact with anthropogenic causes, the study of weekly cycles has become an interesting way to establish links between the human activities and their influence on climate variables, because there is no evidence of natural processes that show constant cycles of 7 days during long time periods.

[3] The study of weekly periodicities has commonly addressed questions such as air pollution and aerosols concentrations [e.g., *Delene and Ogren*, 2002; *Bäumer et al.*, 2008]. In addition, some authors have reported weekend effects on local climate variables, as temperature or rainfall, and have related them to local heat and pollutants emissions [e.g., *Simmonds and Keay*, 1997; *Mullayarov et al.*, 2005]; other authors, however, have not found any significant weekly cycles [*DeLisi et al.*, 2001].

[4] Recently, *Bäumer and Vogel* [2007] detected unexpected weekly periodicities in different climatic variables in Germany, even at stations situated far away from urban areas (e.g. on Mount Zugspitze, 2960 m above sea level in the Alps region). They suggested the possibility of an important interaction between aerosols and atmospheric dynamics in order to explain the horizontal and vertical extent of the detected cycles. Also, other authors [*Cerveny and Balling*, 1998; *Forster and Solomon*, 2003; *Tesouro et al.*, 2005; *Gong et al.*, 2006, 2007] had previously detected significant weekly cycles in large domains that can hardly be related to local effects or emissions. For the U.S., *Bell et al.* [2008] found weekly cycles of precipitation for a period starting in 1998, while *Schultz et al.* [2007] did not detect such cycles, probably because the latter authors used a different period (1951–1992) as noted by *Bell and Rosenfeld* [2008].

[5] In this paper, we analyze different climatic variables in Spain trying to detect weekly cycles, which turn to be much more significant in winter. Then, we relate, for the first time, these results with a cycle in the atmospheric circulation over Western Europe.

2. Data and Methods

[6] For this study our database is constituted by daily series of 12 climatic variables: temperature (maximum -TMAX-, minimum -TMIN-, mean -TMEAN- and diurnal temperature range -DTR-), precipitation (PREC), air pressure (PRES), sunshine duration (SunDu), and cloudiness. For this later variable we considered the average total cloud cover (TCC), from the 3-daily observations, but also the relative frequency of overcast (OVER) and cloud free (FREE) days (which are more objectively determined by the observers), which are days with TCC greater or less than 6.5 and 1.5 oktas, respectively. Finally, we also used the relative frequencies of cloud types, and specifically of low level clouds since these are more reliable from surface observations, given the lower probability of being hidden compared with middle and high clouds. We split low clouds types in either low stratiform -STR- (St, Sc and Ns) clouds or vertical development clouds -VER- (Cu and Cb) because this grouping mitigates possible inhomogeneities coming from genera identification by the observers.

[7] We examined 44-year data (1961–2004 period) of 13 stations placed in Spain, namely Badajoz-Airport (Latitude 38°53′N, Longitude 06°48′W, 185 m above sea level), Madrid-Retiro (city) (40°25′N,03°39′W, 667 m), Malaga-Airport (36°40′N, 04°29′W, 7 m), Navacerrada (40°47′N, 03°59′W, 1890 m), Salamanca-Airport (40°57′N, 05°28′W, 790 m), San Sebastián-Igueldo (city) (43°18′N, 02°02′W, 259 m), Tortosa (40°47′N, 00°29′W, 50 m), Valencia (city) (39°29′N, 00°21′W, 11 m), Zaragoza-Airport (41°39′N, 00°59′W, 247 m), Alicante-Ciudad-Jardín (city) (38°22′N 00°30′W, 81 m), Barcelona-Airport (41°25′, 02°07′E,

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175 m), Albacete-Airport (38°57′N, 01°51′W, 702 m), and Cordoba-Airport (37°51′N, 04°51′W, 90 m). Most series were obtained from the European Climate Assessment & Dataset project (ECA&D) [*Klein Tank et al.*, 2002] but SunDu [*Sanchez-Lorenzo et al.*, 2007] and cloudiness series that were obtained directly from the Spanish National Institute of Meteorology. Navacerrada station did not have available series for PRES.

[8] Most analyzed variables were expressed, for a particular day, as the anomalies with respect to the corresponding winter average. However, the PREC anomaly (in mm) for a particular day was defined as the mean precipitation of this day minus the precipitation that would correspond to any day if it were evenly distributed during the week (computed by dividing the average weekly precipitation by seven). A similar procedure was applied for most cloudiness related variables (OVER, FREE, STRA, and VER) but the anomalies were expressed as relative (%) values. Finally, for the 12 climatic variables we computed the mean series for whole Spain starting from the weekly mean for each series and then by averaging all available series. Several ANOVAs and Bonferroni post-hoc tests were conducted to check the significance ($\alpha \leq 0.05$) of the weekly cycles and of the differences between each pair of weekdays, respectively.

3. Results

3.1. Winter Weekly Cycles of Climatological Variables in Spain

[9] The annual mean anomaly weekly series for different variables as TMEAN, TMAX, TMIN and PRES show slight weekly cycles with maximum or minimum anomalies centered in Wednesday or Thursday and the opposite anomalies between Saturday and Monday. These annual weekly cycles are significant but we do not further comment these annual results because we focus this work on the discussion of the clear weekly cycles that appear in the winter (December, January and February). Note that during this season the atmospheric boundary layer is usually thinner (i.e, there is less mixing within the lower troposphere), allowing a higher effect of pollutants on atmospheric variables. Our analyses detected also that other seasons (spring and summer) show opposite weekly cycles (compared with winter), like in *Gong et al.* [2006]. This fact can produce the missing or low signal in annual basis, although the magnitude and significance of these spring or summer cycles are lower and more confusing than in winter.

[10] Thus, in Figures 1a–1l we show the mean anomalies for winter, for the 12 considered variables, averaged over the 13 Spanish series in the 1961–2004 period. TMEAN shows a constant increase from Monday (minimum) to Saturday (maximum) with clear lower values during the first half of the week and greater during the second one. The absolute range between the extreme values is 0.17°C. Post-hoc comparisons indicate that Saturday TMEAN is significantly different than Monday, Tuesday, Wednesday, and Sunday. Thus, there is a significant weekly cycle but without a clear "weekend effect" because Sunday shows a significant cooling in comparison with Saturday.

[11] The mean TMAX anomaly shows a clear weekly cycle with a minimum from Tuesday to Thursday and a strong increase during Friday and the weekend. The absolute range between the extreme values is 0.28°C, slightly greater than the value obtained for TMEAN. The post-hoc comparisons confirmed this weekly cycle with significant TMAX differences between Monday, Tuesday, Wednesday, and Thursday respect Saturday. Also Friday and Sunday show significant differences with Wednesday. In disagreement with TMAX, TMIN shows positive anomalies during the second half of weekdays and Saturday, with clear minimum negative anomalies during Sunday and Monday, and an absolute range of 0.21°C. Thus, TMIN shows a "weekend effect" clearly displaced to Sunday and Monday. This later behavior is consistent with the idea of a weekly cycle because TMIN is normally recorded during the first hours of the day, and consequently, Monday TMIN is influenced by the weekend cooling that prevails until the start of the activity on late Monday morning. The post-hoc analyses led to significant TMIN differences between Wednesday, Thursday, Friday, and Saturday with Saturday; Sunday TMIN is also significantly different from Wednesday and Thursday. Finally, weekly anomalies of mean DTR, a variable inversely correlated with cloudiness and precipitation [*Dai et al.*, 1997], show a deep cycle, with a clear minimum during Wednesday and Thursday and maximum during the weekend and Monday, resulting in an absolute range of 0.30°C. Post-hoc comparisons indicate that Wednesday and Thursday DTR are significantly lower than Saturday, Sunday, and Monday.

[12] The mean PREC series shows a clear weekly cycle with maximum anomalies in Wednesday and Thursday and lower values centered during the weekend, producing an absolute range of 4.1 mm. The post-hoc analyses confirmed that Wednesday PREC is significantly different than Monday, Saturday, and Sunday. Moreover, Thursday PREC shows significant differences only with Monday and Saturday.

[13] Another variable with interesting results is PRES, which also shows a clear weekly cycle with maximum positive and minimum negative anomalies during the weekends and the central weekdays, respectively. The absolute range is greater than 0.76 hPa. For PRES, the post-hoc comparison indicated a strong difference between the weekdays and the weekends, with significant differences between the Saturdays and Sundays and the other five weekdays.

[14] Sunshine duration (and TCC) shows lower (higher) values in the central weekdays, particularly on Wednesday, and maximum (minimum) anomalies during the weekend, particularly on Saturday. The absolute range is 0.37 hours (0.22 oktas). The post-hoc analyses applied to both variables confirms the significance of these differences. In order to complete the previous analysis we checked the weekly cycles in the frequency of OVER and FREE days, and the results clearly indicate a weekly cycle in both variables, with maximum positive (minimum negative) anomalies of OVER (FREE) days during the central weekdays and minimum negative (maximum positive) values in the weekend and Monday. The absolute range is 14.2% (13.3%) for the OVER (FREE) frequency days. These differences are again confirmed by the post-hoc test. Finally the findings for the low cloud types are coherent with the previous results, obtaining a clear and significant increase in STR and VER types during the central weekdays (with clear maximum on Wednesday) and minimum frequencies in the weekend.

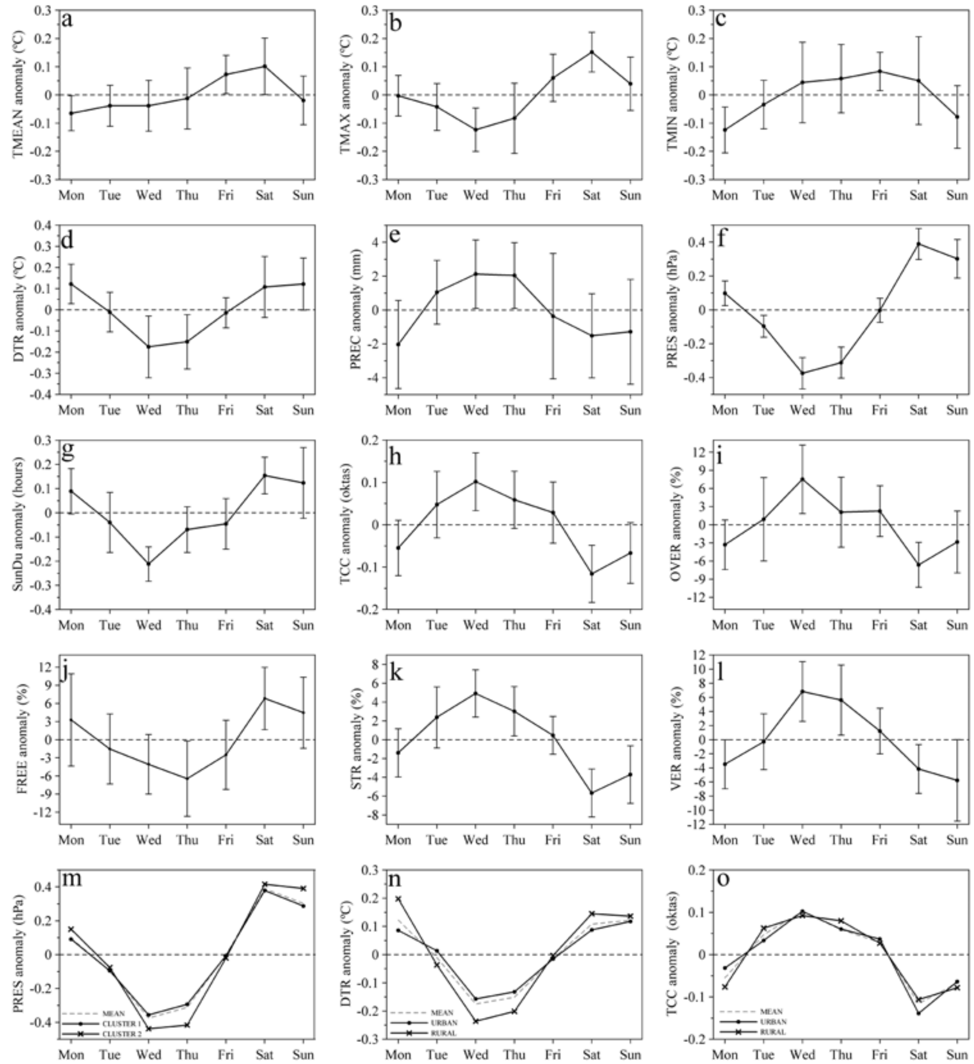

Figure 1. (a–l) Mean week anomalies, for the 12 considered variables, averaged over the 13 Spanish series in the 1961–2004 period. Error bars show the standard deviation of the everyday mean. (m) Mean PRES weekly anomalies for the stations grouped in the two clusters obtained by means of CA techniques. (n–o) Mean DTR and TCC weekly anomalies for the urban and rural stations.

[15] To verify that these mean weekly periodicities are not exclusively caused by stations placed in congested urban areas, we clustered the 13 stations by means of a Cluster Analysis (CA). We started from a matrix where the columns are the stations and the rows are the values for each day of the week of all the analyzed variables, and then we applied a hierarchical CA using the Ward's method as clustering criterion. The results is that two clusters can be clearly differentiated: Cluster 1 with 11 series including stations at or near big cities as Madrid, Barcelona or Valencia, but also extra-urban (airports) and middle-sized city stations as Tortosa, Albacete, Badajoz and Salamanca, and even a mountain station as Navacerrada. Cluster 2 only includes Zaragoza and San Sebastian (both middle-sized cities) stations. In some of the analyzed variables Cluster 2 shows a different behavior than Cluster 1, normally without a clear weekly cycle (e.g. DTR). Nevertheless, there are other variables, as PRES (Figure 1m), that show similar weekly cycles for the 2 clusters. Furthermore, a manual grouping of urban (Madrid, Malaga, Valencia, Zaragoza, and Barcelona) and rural or semi-rural (Badajoz, Navacerrada, Salamanca, Tortosa and Albacete) stations did not reveal any significant difference between both categories (e.g. PRES); in fact, some of the analyzed variables, as DTR (Figure 1n) or TCC (Figure 1o), showed more marked weekly cycles for the rural stations group. Thus, we can conclude that the detected weekly cycles in the mean winter series are not caused only by stations situated in or near the largest and congested Spanish cities.

3.2. Possible Atmospheric Dynamics Periodicities Over Western Europe

[16] One of the most important findings of our results is that, like *Forster and Solomon* [2003] or *Bäumer and Vogel* [2007], the detected weekly cycles are not only caused by series from large cities where it is more plausible to expect some anthropogenic signal. From our previous results we can conclude that a weekly cycle is also detected in areas situated far away from the most important sources of pollutants and anthropogenic activities in Spain, also including a surprising "weekend effect" in Navacerrada

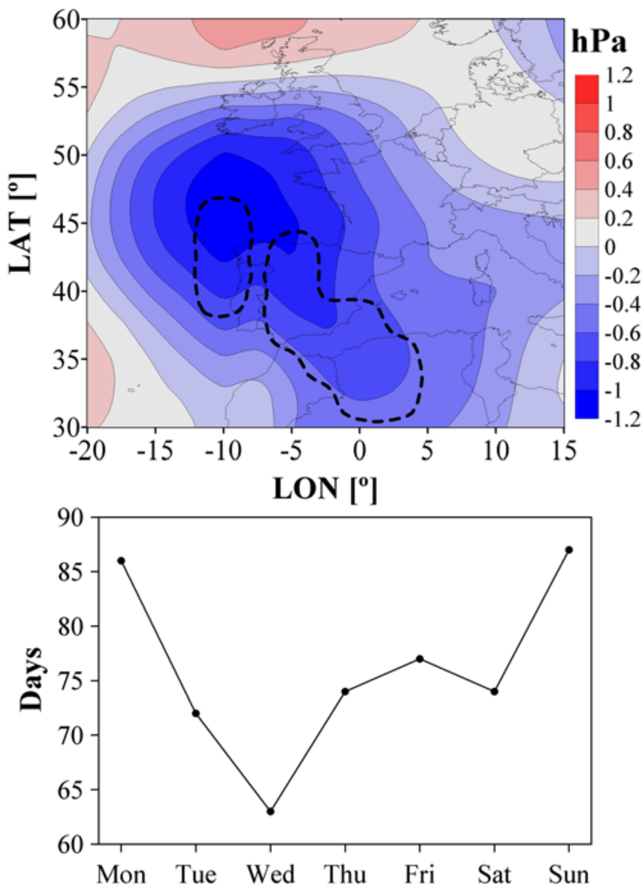

Figure 2. (top) Composite of the winter SLP anomalies (1961–2004 period) of Wednesday minus Saturday. The continuous lines indicate positive (red) or negative (blue) anomalies, and the dashed lines indicates statistical significance ($\alpha \leq 0.05$). (bottom) Absolute frequency by day of the week for Cluster 3 obtained using the EMULATE dataset [*Philipp et al.*, 2007].

station, situated near 2000 m above sea level in the Central System mountain range. As suggested by *Bäumer and Vogel* [2007], a possible hypothesis arises from relating the weekly anthropogenic emission cycle (maybe not only from Spanish local sources) and the subsequent aerosol cycle interaction with the atmospheric circulation at a mesoscale or synoptic scale.

[17] In order to verify this hypothesis we checked the possible periodicities in the atmospheric circulation using the daily sea level pressure (SLP) data from the NCEP/NCAR reanalysis [*Kalnay et al.*, 1996] at a resolution of 2.5° × 2.5° over Western Europe and part of the Atlantic Ocean (30°W–20°E longitude; 30°–70°N latitude). We calculated the differences between Wednesday and Saturday SLP winter anomalies from 1961 to 2004 and then we applied a one-tailed t-test in order to verify the significance ($\alpha \leq 0.05$) of the obtained differences between these two days. Figure 2 (top) shows SLP significant negative anomalies greater than −1 hPa in an area centered on the NW border of the Iberian Peninsula; this area spreads across Spain with values ranging from −1 hPa to −0.5 hPa. These values are in agreement with the mean absolute range obtained for the PRES series (0.67 hPa). This SLP pattern suggests an increase in the frequency of low (high) relative pressure systems in the Southern part of Europe during the central weekdays (weekend). We repeated the analysis (not shown) considering the difference between the average of Wednesday and Thursday minus that of Saturday and Sunday and obtained similar results. Finally, we also checked the differences between two consecutive days that do not show differences in the climatic variables analyzed (e.g. Wednesday and Thursday, see Section 3.1) and obtained, coherently, SLP non significant differences.

[18] Finally, we checked how the weekly cycle detected in the SLP over Western Europe may affect synoptic patterns. For this purpose we used the winter (December, January and February) daily patterns (1961–2003 period) recently obtained by means of the SANDRA scheme clustering [*Philipp et al.*, 2007], developed in the framework of the EMULATE project (http://www.cru.uea.ac.uk/projects/emulate/), that considers SLP gridded data obtained from instrumental series (independent of the SLP reanalysis data above analyzed by us). We considered the recommend solution for 9 clusters -circulation patterns- and distributed them by day of the week. In order to detect weekly cycles we selected the days with maximum and minimum frequencies for every cluster and applied a χ^2 test to verify the statistical significance of these frequencies differences. Only Cluster 3 (http://www.cru.uea.ac.uk/projects/emulate/emslp3_pattern_classification/emslp3_pattern_classification/annealing/l03-m12/ncl09/index.html), which is a pattern with a strong anticyclone centered over the Southern British Islands, shows a significant difference ($\alpha \leq 0.05$) between Wednesday and Sunday (days with minimum and maximum frequencies, respectively). This pattern has a clear weekly cycle (Figure 2, bottom), with maximum frequencies during Sunday and Monday and minimum in the central weekdays. Actually, Monday has also a significant difference respect Wednesday. The weekly cycle and spatial configuration of the pattern are coherent with the previous results. Specifically, this pattern weekly cycle is consistent with the decrease in PREC and cloudiness detected in the weekend over Spain, and with the increase in DTR, PRES and SunDu.

4. Discussion and Conclusions

[19] Recently *Bäumer and Vogel* [2007] also detected significant weekly cycles in many climatological variables in Germany in the 1991–2005 period, suggesting the possibility of mesoscale changes in order to explain the detected periodicities that are not determined only by local pollution or population density modifications. In a comment to the previous paper, *Hendricks Franssen* [2008], however, affirmed that the weekly cycles observed in Germany are random since they are not consistent with results obtained with long-term series of sunshine duration and precipitation variables in two Swiss stations. The former authors have responded [*Bäumer and Vogel*, 2008] arguing that if it is assumed that the weekly cycle is induced by anthropogenic activities, then it is understandable not to detect these periodicities over the last centuries and contrarily it is more likely that the weekly cycle has become more intense since the second half of the 20th century. Similarly, *Gong et al.* [2006] detected in China that the weekly cycle is clearer

since the late 1970s. Over Spain, we tried to detect changes in the weekly signal over two 22 year sub-periods (1961–1982 and 1983–2004) but we obtained significant and similar weekly cycles in both time periods.

[20] Thus, *Bäumer and Vogel* [2007, 2008] argue that it is possible to explain weekly cycles from the interaction of the aerosol cycle [*Bäumer et al.*, 2008] with the atmospheric dynamics. In fact, there are evidences of aerosol impacts on cloud properties and precipitation forming processes [*Lohmann and Feichter*, 2005; *Rosenfeld*, 2007; *Bell et al.*, 2008].

[21] Except the lunar phases with a period of 7.38 days, negligible in terms of the day of the week for 44 years, there is no other known natural periodicity that can generate a weekly cycle. Thus, it is plausible to relate the detected weekly periodicities with the human activity cycle and consequently it is possible to argue that the anthropogenic disturbances (such as pollutant emissions) may interact with local or larger scales affecting the atmospheric dynamics.

[22] From our results we can speculate that some areas over Western Europe show a significant weekly cycle in the winter SLP that – at least partly – appears to be linked with frequency changes in one atmospheric circulation pattern obtained from a daily synoptic classification. Thus, our results suggest that the frequency of winter anticyclonic conditions over the British Isles (covering all the central and southern areas of Western Europe) is higher during the weekend than in central weekdays. Meanwhile, in the northernmost areas of the North Atlantic-European region an opposite behavior is expected: more (less) low pressure systems frequency during the weekend (weekdays). To check this later hypothesis we briefly analyzed four PRES series from sites in this area (Ammasalik in Eastern Greenland; Reykjavik and Stykkisholmur in Iceland, and Torshavn in the Faroe Islands) obtained from the EMULATE data set. Their winter mean week series (not shown) exhibit clear maximum anomalies during the second half of the week and an important drop during the weekend, with an absolute range of 0.89 hPa. A post-hoc test confirms that there is a significant cycle, with weekend PRES significantly different than Thursday and Friday.

[23] In the future, research will be performed to overcome possible limitations of the present work. In particular, in order to verify the presented initial findings concerning the weekly periodicities in large scale circulation further analyses will make use of different available SLP data sets and will include the application of different circulation classification methods as well. An attempt will be made to check the physical mechanisms that may produce the weekly cycles in the large-scale SLP as a result of anthropogenic disturbances.

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