ATMOSPHERIC SCIENCE LETTERS
Atmos. Sci. Let. **13**: 238–243 (2012)
Published online 12 June 2012 in Wiley Online Library
(wileyonlinelibrary.com) **DOI:** 10.1002/asl.389

RMetS
Royal Meteorological Society

Are there weekly cycles in occurrence frequencies of large-scale circulation types?

Christoph Beck*
Institute of Geography, University of Augsburg, Universitätsstr. 10, D-86135 Augsburg, Germany

*Correspondence to:
C. Beck, Institute of Geography, University of Augsburg, Universitätsstr. 10, D-86135 Augsburg, Germany.
E-mail: christoph.beck@geo.uni-augsburg.de

Received: 26 January 2012
Revised: 20 April 2012
Accepted: 27 April 2012

Abstract

The existence of weekly cycles in occurrence frequency distributions of circulation types is examined on the basis of a comprehensive data base of automated circulation-type classifications for the greater North Atlantic European region and sub-domains during the period 1957–2002. The main result is that the percentage of circulation types for which a statistical significant weekly cycle (95% level of confidence) could be detected by a chi-square goodness-of-fit test does not exceed the number that would be expected by chance. Thus it is concluded that no consistent weekly cycles in occurrence frequencies of circulation types exist. Copyright © 2012 Royal Meteorological Society

Keywords: weekly cycles; atmospheric circulation; circulation types; North Atlantic; Europe

1. Introduction

In recent years the existence of weekly periodicities in various meteorological variables and atmospheric pollutants has been investigated in numerous studies. Evidence of weekly cycles in anthropogenic pollution has been shown for different regions in Europe (e.g. Bäumer *et al*., 2008; Barmet *et al*., 2009; Stjern, 2011), North America (e.g. Cerveny and Balling, 1998; Murphy *et al*., 2008) and Asia (e.g. Gong *et al*., 2007). Concerning different meteorological variables several investigations point to the presence of weekly periodicities in surface air temperature (e.g. Forster and Solomon, 2003; Bäumer and Vogel, 2007; Gong *et al*., 2007; Laux and Kunstmann, 2008; Sanchez-Lorenzo *et al*., 2008), precipitation (e.g. Cerveny and Balling, 1998; Bäumer and Vogel, 2007; Gong *et al*., 2007; Bell *et al*., 2008), wind speed (e.g. Cerveny and Balling, 1998) or cloudiness (e.g. Bäumer and Vogel, 2007; Sanchez-Lorenzo *et al*., 2008), just to name a few of the analysed variables. However, it has to be mentioned that the detected periodicities vary distinctly concerning their phase and amplitude among different regions, time periods and variables (e.g. Laux and Kunstmann, 2008). Moreover, serious doubts concerning the applied methods and the results achieved in some of these studies have been repeatedly raised (e.g. Hendricks Franssen, 2008; Hendricks Franssen *et al*., 2009). Also in contradiction to the above mentioned studies a number of studies did not find any proof for statistical significant weekly cycles in different meteorological variables in varying regions of the world (e.g. DeLisi *et al*., 2001; Schultz *et al*., 2007; Barmet *et al*., 2009; Stjern, 2011).

Given the absence of any known natural phenomena that may cause the weekly weather cycles several anthropogenic factors have been proposed as potential causes for the observed periodicities in meteorological parameters. In this context several authors (e.g. Cerveny and Balling, 1998; Bäumer and Vogel, 2007; Sanchez-Lorenzo *et al*., 2008) have supposed corresponding cycles in aerosol concentrations. Weekly cycles in greenhouse gases have been mentioned for example by Cerveny and Coakley (2002). Sanchez-Lorenzo *et al*. (2008) and Laux and Kunstmann (2008) found evidence for the relationship between weekly cycles in meteorological variables and corresponding periodicities in large-scale atmospheric circulation dynamics reflected by occurrence frequencies of objectively derived circulation types. These periodicities in large-scale circulation dynamics are supposed to be in turn triggered by air pollution effects in the lower troposphere (Laux and Kunstmann, 2009). Sanchez-Lorenzo *et al*. (2008) analysed occurrence frequencies of nine daily circulation types determined by an optimized cluster analysis (Philipp *et al*., 2007) for the period 1961–2003. A statistical significant weekly cycle turned out for one type during winter (December, January, February – DJF). However this finding has been brought into doubt by Hendricks Franssen *et al*. (2009). Laux and Kunstmann (2009) investigated weekly cycles in occurrence frequencies of objectively derived European circulation types according to Beck *et al*. (2007). By applying a robust bootstrap method they detected significant weekly cycles in occurrence frequencies of 10 out of 18 circulation types for the period 1991–2005.

Thus, so far all findings on possible weekly cycles in large-scale circulation dynamics are based on the analyses of occurrence frequencies of only two different circulation classifications applied to different data sets, for different regions and different time periods. Against this background it appears appropriate to analyse weekly cycles in occurrence frequencies of circulation types using a more comprehensive data base of circulation classifications in order to avoid the over interpretation of single results that are maybe due to inconsistencies in individual classifications.

In this contribution the existence of weekly periodicities in occurrence frequencies of circulation types is analysed on the basis of 231 different daily circulation-type classifications that were applied to varying spatial domains for the period 1957–2002. The basic idea behind this comprehensive approach is that any essential and realistic signal of a weekly cycle in large-scale circulation dynamics should be reflected in occurrence frequencies of circulation types derived from varying classification methods.

The paper is organized as follows. The data set of circulation-type classifications and the approaches towards the detection of weekly cycles in occurrence frequencies of circulation types are described in Section 2. The main results are presented in Section 3 and finally a brief discussion and conclusions are given in Section 4.

2. Data and methods

The data set of daily circulation-type classifications used in this study consists of 231 classifications, each of them applied to 1° × 1° gridded daily atmospheric data [exclusively sea level pressure (SLP) data in most cases] from ERA-40 reanalysis (Uppala *et al.*, 2005) covering the period from September 1957 to August 2002. All classifications have been applied to 12 spatial domains of varying size and location within the greater North Atlantic European area (Figure 1) resulting in an overall number of 2772 circulation-type classifications. This comprehensive data base of circulation-type classifications has been developed

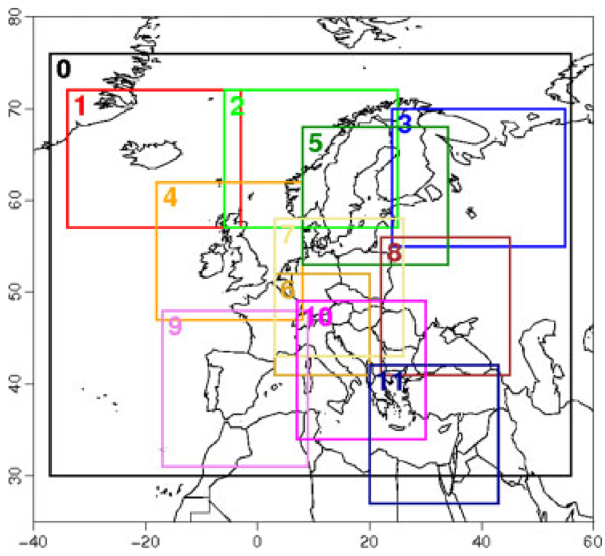

Figure 1. Location and size of spatial domains for which circulation-type classifications are available.

within the framework of the European COST733 Action "Harmonisation and Application of weather-types classifications in Europe" (e.g. Beck and Philipp, 2010; Huth *et al.*, 2010; Philipp *et al.*, 2010) by means of the freely available cost733cat software for weather- and circulation-type classification (Philipp *et al.*, 2010). The automated (or objective) classifications selected from this data set for use in this study are based on varying basic methodological approaches (see also Table I) including optimization algorithms (mainly non-hierarchical cluster analysis), principal component analysis (applied in S- or T-mode), leader algorithms (e.g. pattern correlation) and methods that are based on pre-defined thresholds (e.g. for categorizations according to the main wind directions). The number of circulation types varies among classifications between 4 and 38 with maximum frequencies

Table I. Overview of basic methodological approaches used for performing the circulation-type classifications used in this study.

Basic classification approach	**Specific classification schemes**	**Number of individual classifications (per domain)**
Threshold-based classifications	Objective grosswettertypes Litynski advection and circulation types Jenkinson-Collison types Objective Wetterlagen	22
Leader-based	Lund types Kirchhofer types Erpicum classification Petisco types	71
Principal Component Analysis (PCA)-based	PCA in *t*-mode P27 PCA extreme scores	50
Optimization	*K*-means by dissimilar seeds *K*-means by seeds from hierarchical cluster analysis of principal components *K*-means using PCA-derived seeds Simulated annealing and diversified randomization clustering Neural network classification	88

See Philipp *et al.* (2010) for a detailed description of the COST733 data base of circulation-type classifications and respective references.

for 9, 18 and 27 types. A more detailed description of the individual classification methods that are provided by COST733 can be found in the study by Philipp *et al*. (2010).

From this data set occurrence frequencies on a daily basis for the period 1957–2002 are available for all in all around 40 000 individual circulation types (from 2772 classifications with approximately 15 circulation types on average).

For each of these circulation types a test on the existence of a significant weekly cycle in occurrence frequencies has been performed. To this end type frequencies have first been grouped according to weekdays (Monday to Sunday). The chi-square goodness-of-fit test (e.g. Wilks, 1995) was then applied to test each sample of seven daily circulation-type frequencies against the null hypothesis of uniform distribution of occurrence frequencies among weekdays. The chi-square goodness-of-fit test has been already used in other studies on weekly cycles in occurrence frequencies (DeLisi *et al*., 2001). Compared to t-tests that may be used to check for significant differences between weekdays with maximum and minimum frequencies (Laux and Kunstmann, 2008) the chi-square test has the advantage of considering the whole weekly frequency distribution.

To take into account possible decadal scale variations in weekly frequency characteristics all tests have been performed on the basis of six temporal sub-periods that have been defined as: 1957–2002, 1957–1980, 1981–2002, 1961–1975, 1976–1990 and 1991–2002. Furthermore, tests have been applied for the whole year (January to December) and as well separately for the 3-month seasons winter (DJF), spring (March, April, May – MAM), summer (June, July, August – JJA) and autumn (September, October, November – SON) to consider potential inter-seasonal differences. Chi-square tests yielding p-values less than 0.05 were interpreted as indicators of significant weekly cycles in occurrence frequencies of individual circulation types. However for the overall interpretation of results it is important to keep in mind that given the chosen confidence level of 95% one would expect that when applying the chi-square test to around 1.2 million weekly frequency distributions of circulation types the null hypothesis is rejected purely by chance in around 60 000 cases.

In order to check how far the varying circulation types from different classifications for which weekly cycles appear evident (rejection of the null hypothesis of the preceding chi-square test) reflect consistent circulation features or not, two subsequent analyses have been performed.

Firstly, the coherence of the spatial structures (represented by type specific SLP composites) of circulation types featuring similar weekly cycles (e.g. frequency minimum on Tuesday, frequency maximum on Saturday) has been analysed. To this end pairwise spatial correlations (Pearson's R correlation coefficient) have been estimated among all circulation types exhibiting similar weekly cycles. The mean of all resulting Pearson's R correlation coefficients gives an indication on the degree of similarity of circulation characteristics among circulation types with similar weekly cycles. As a reference the mean of all spatial correlation coefficients between all pairs of circulation types – not accounting for weekly frequency distributions – has been also determined.

Secondly for each circulation type featuring a significant weekly cycle (according to the preceding chi-square test) all circulation types with a similar circulation pattern (spatial Pearson correlation coefficient greater than 0.9) have been selected. Then the respective mean weekly occurrence frequency distributions have been estimated (via averaging for all similar circulation types) and tested – using the chi-square test – against the null hypothesis of uniform distribution.

Both approaches have been applied separately to each of the 6 temporal samples, the 12 spatial domains and the 5 seasonal subsets. The motivation for these additional analyses is that if any realistic weekly cycles in circulation dynamics exist, the following two assumptions should be fulfilled. (1) The similarity between spatial patterns of circulation types featuring similar weekly frequency distributions is distinctly higher than the average similarity among all available circulation types. (2) A distinct weekly cycle in occurrence frequencies of one circulation type is detectable not only for this individual type but also for circulation types with very similar spatial patterns.

3. Results

Figure 2 summarizes the results of the chi-square tests that have been applied to the weekly frequency distributions of individual circulation types. It is obvious from Figure 2 that only for a relatively small number of all tested circulation types a rejection of the null hypothesis of uniform distribution of weekly occurrence frequencies can be stated on the 95% level of confidence. The percentage of rejections ranges between around 0.5 and 3%. Percentage values vary considerably among spatial domains, seasonal subsets and temporal samples. In most cases these variations appear to be unsystematic with the only exception of considerably lower percentages of positive test results in the largest spatial domain 0 compared to the smaller domains. With regard to the overall significance of the applied chi-square tests the most important finding that can be deduced from Figure 2 is that for no case the percentage of rejections of the null hypothesis is higher than 5%. Against the background that 5% of positive test results (for alpha = 0.05) are expected purely by chance when performing multiple chi-square tests this result can be interpreted as a clear indication of

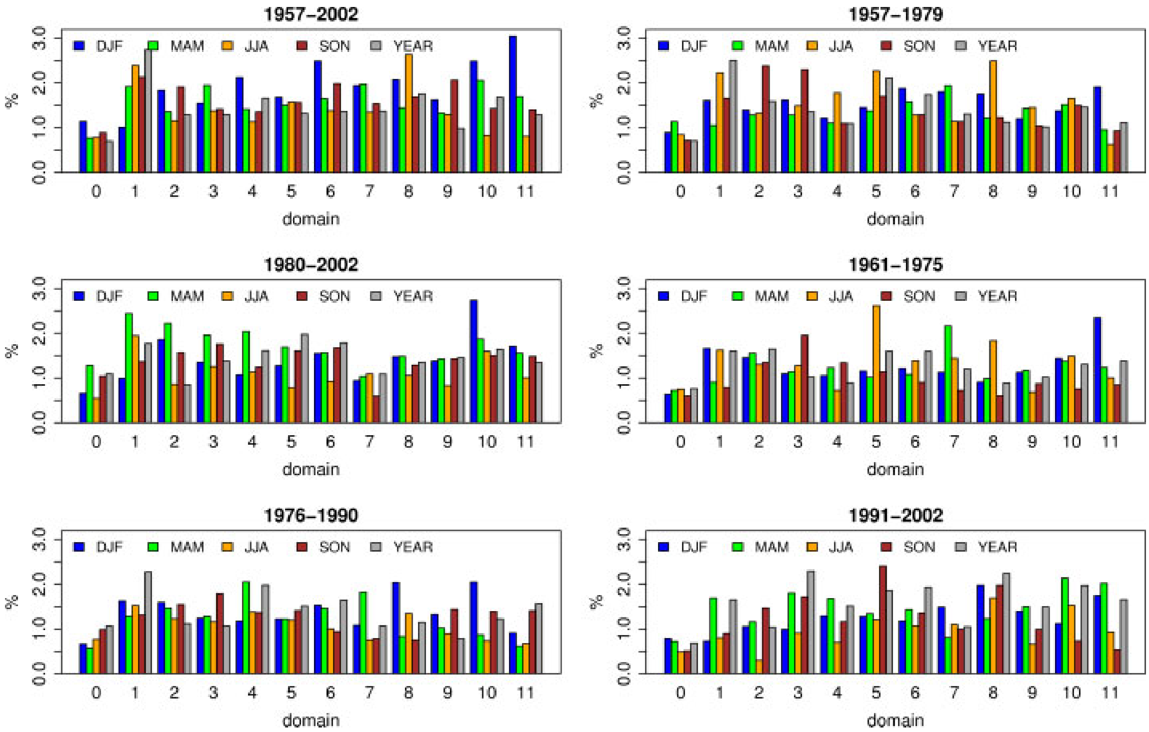

Figure 2. Percentages of circulation types for which the null hypothesis of uniform distribution of occurrence frequencies among weekdays is rejected – on the basis of a chi-square test – for a confidence level of 95%. Percentages are given for 6 temporal sub-samples, 12 spatial domains and 5 seasonal subsets.

the non-existence of weekly cycles in circulation-type frequencies.

However results of additional analyses considering only those circulation types for which the preceding chi-square tests yield an individual p-value of less than alpha $= 0.05$ are depicted in Figures 3 and 4.

Figure 3 illustrates results of the analyses of the similarity of the spatial patterns of circulation types with similar weekly occurrence frequency distributions. The further interpretation of these results is based on the assumption that a considerable degree of similarity between circulation patterns can be stated for spatial correlation coefficients above 0.7 – this threshold (indicated by a horizontal line in Figure 3) is used for example in correlation based circulation-type classification methods for defining initial key patterns (Lund, 1963). First of all it can be stated that only for 29 of 360 cases the spatial correlation between circulation types featuring similar weekly cycles in occurrence frequencies reaches values above 0.7. For roughly the half of these 29 cases the mean pattern correlation estimated considering all circulation types (for the respective period, seasonal subset and domain) is even higher. Moreover, the comparison of results achieved for the six different temporal samples (six panels in Figure 3) reveals no temporal consistency. The few indications for consistent spatial characteristics of circulation types (mean spatial correlation >0.7) with similar weekly frequency cycles appear for varying domains and seasonal subsets during the six different periods.

Finally Figure 4 illustrates the main results of the analyses of weekly occurrence frequencies of circulation types with significant weekly cycles (according to the preceding chi-square test) and respective similar types (spatial Pearson correlation coefficient above 0.9). Depicted are the percentages of those types with significant weekly cycles for which a corresponding significant cycle (for alpha $= 0.05$) has also been detected for the mean weekly frequency distribution of all similar circulation types. Only in two cases – domain 6, JJA during 1957–1979; domain 0, year during 1976–1990 – the percentage of rejections of the null hypothesis exceeds the percentage that could be expected by chance.

4. Summary and conclusions

In this study, the existence of weekly cycles in occurrence frequencies of large-scale circulation types has been analysed on the basis of a comprehensive data set of automated circulation-type classifications for the period 1957–2002. Weekly frequency distributions have been determined for around 40 000 circulation types and chi-square tests have been applied to these data in order to test for the null hypothesis of uniform distribution of daily occurrence frequencies among days of the week. Overall results of this test strategy applied separately to 12 spatial domains, 5 seasonal subsets and 6 temporal sub-samples show no compelling evidence for the existence of statistically significant weekly cycles in circulation-type frequencies. This interpretation of test results is based

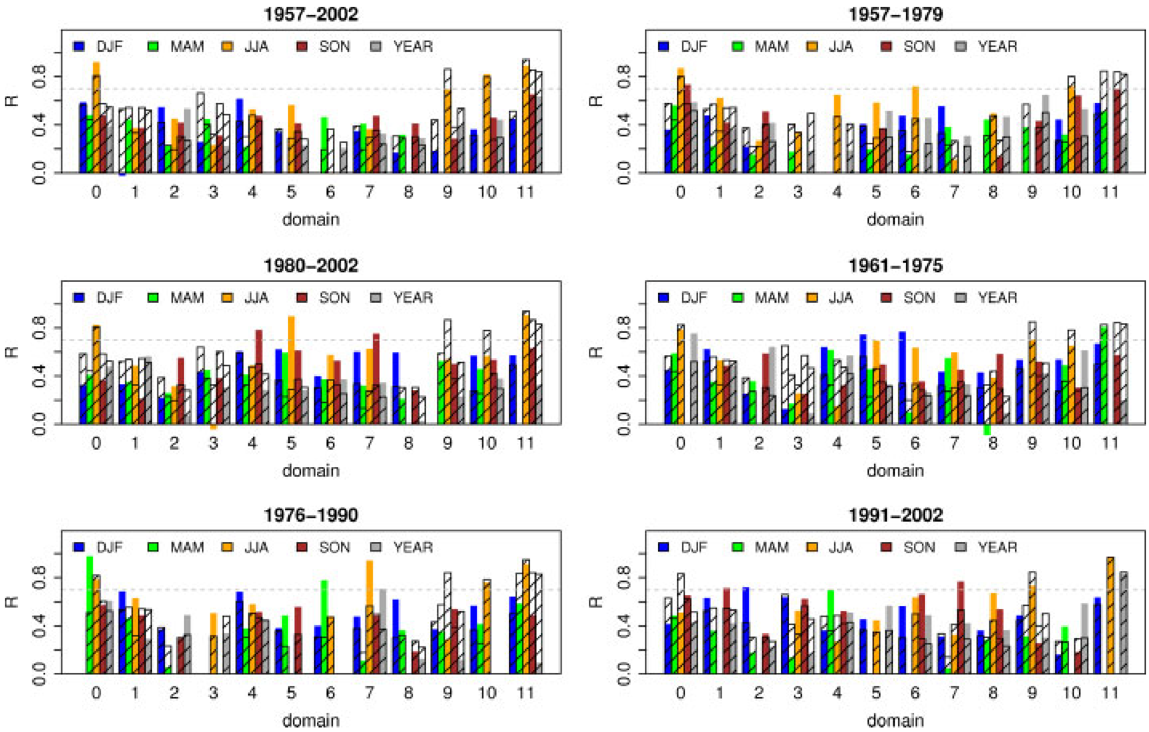

Figure 3. Mean spatial Pearson correlation coefficients among circulation types with frequency minima and maxima on similar weekdays. Estimated for those circulation types for which preceding chi-square tests resulted in the rejection of the null hypothesis of uniform distribution of occurrence frequencies at the 95% level of confidence. For comparison, respective mean Pearson correlation coefficients estimated on the basis of all available circulation types are indicated by the hatched bars. Values are given for 6 temporal sub-samples, 12 spatial domains and 5 seasonal subsets.

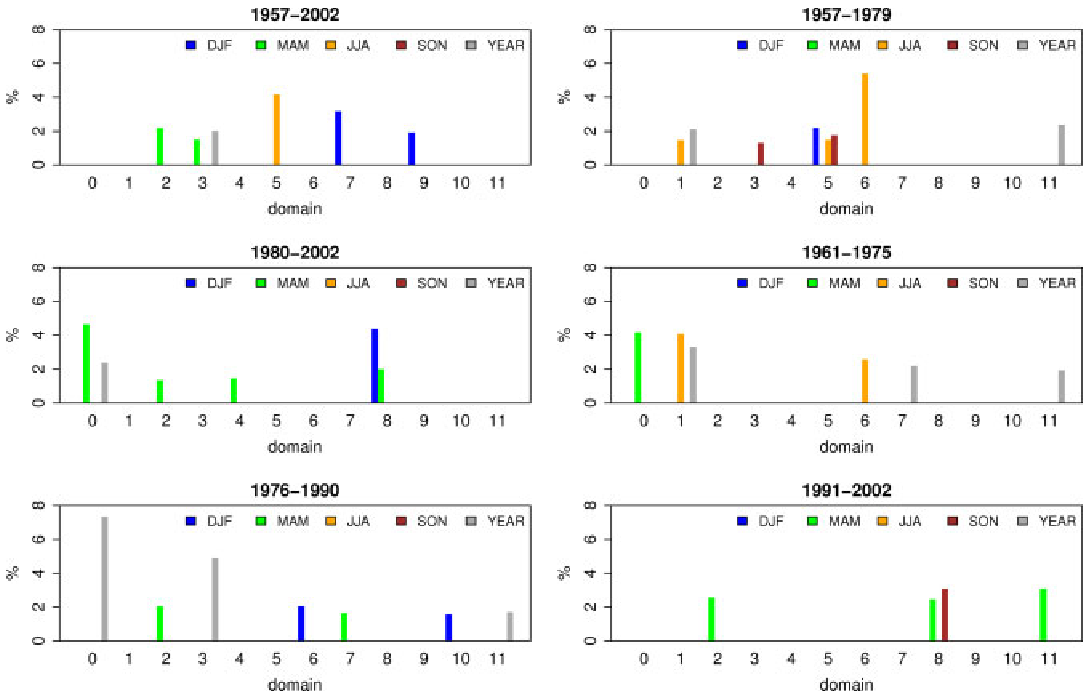

Figure 4. Percentages of circulation types with significant weekly cycles (according to chi-square tests of weekly occurrence frequencies) for which significant weekly cycles (rejection of the null hypothesis of the chi-square test for alpha = 0.05) have also been detected when considering mean weekly occurrence frequencies averaged for all similar (spatial Pearson correlation coefficient above 0.9 to the respective circulation type) circulation types. Percentages are given for 6 temporal sub-samples, 12 spatial domains and 5 seasonal subsets.

on the fact that for none of the tested samples the number of rejections of the null hypothesis of uniform distribution of samples exceeds the number of rejections which could be expected purely by chance when applying the chi-square test as often as in this study.

Two subsequent analyses have been applied to only those circulation types that feature positive test results from the preceding analyses in order to detect

- in how far circulation types with similar distinct maxima and minima in their weekly frequency distributions reflect respective consistent circulation characteristics and
- in how far detected significant weekly cycles in occurrence frequencies of circulation types are reflected when considering occurrence frequencies of all circulation types featuring very similar circulation patterns.

The comparison of spatial Pearson correlation coefficients determined between patterns of circulation types with similar weekly cycles and between all circulation types respectively, for one temporal sample, one spatial domain and one seasonal subset shows that circulation types with similar weekly frequency cycles only in a very few cases feature distinct similarity between circulation patterns higher than the average degree of similarity between all circulation types.

Furthermore, it could be shown that distinct weekly cycles detected for circulation characteristics reflected by individual circulation types – in the overwhelming number of cases – could not be verified when taking into consideration the weekly frequency distributions of all circulation types with highly similar circulation patterns.

Thus in contradiction to the findings presented by Sanchez-Lorenzo *et al*., (2008) and Laux and Kunstmann (2008) the here presented analyses provide no evidence for any consistent weekly cycles in occurrence frequencies of circulation types in the different spatial domains within the greater North Atlantic European region.

References

Barmet P, Kuster T, Muhlbauer A, Lohmann U. 2009. Weekly cycle in particulate matter versus weekly cycle in precipitation over Switzerland. *Journal of Geophysical Research* **114**: DOI: 10.1029/2008JD011192.

Bäumer D, Vogel B. 2007. An unexpected pattern of distinct weekly periodicities in climatological variables in Germany. *Geophysical Research Letters* **34**: DOI: 10.1029/2006GL028559.

Bäumer D, Rinke R, Vogel B. 2008. Weekly periodicities of aerosol optical thickness over Central Europe – evidence of an anthropogenic direct aerosol effect. *Atmospheric Chemistry and Physics* **8**: 83–90.

Beck C, Jacobeit J, Jones PD. 2007. Frequency and within-type variations of large scale circulation types and their effects on low-frequency climate variability in Central Europe since 1780. *International Journal of Climatology* **27**: 473–491.

Beck C, Philipp A. 2010. Evaluation and comparison of circulation type classifications for the European domain. *Physics and Chemistry of the Earth* **35**: 374–387.

Bell, TL, Rosenfeld D, Kim KM, Yoo JM, Lee MI, Hahnenberger M. 2008. Midweek increase in U.S. summer rain and storm heights suggests air pollution invigorates rainstorms. *Journal of Geophysical Research* **113**: D02209, DOI: 10.1029/2007JD008623.

Cerveny RS, Balling RC. 1998. Weekly cycles of air pollutants, precipitation and tropical cyclones in the coastal NW Atlantic region. *Nature* **394**: 561–563.

Cerveny RS, Coakley KJ. 2002. A weekly cycle in atmospheric carbon dioxide. *Geophysical Research Letters*. **29**: 1028, DOI: 10.1029/2001GL013952.

DeLisi MP, Cope AM, Franklin JK. 2001. Weekly precipitation cycles along the Northeast corridor? *Weather and Forecasting* **16**: 343–353.

Forster PM, Solomon S. 2003. Observations of a 'weekend effect' in diurnal temperature range. *Proceedings of the National Academy of Sciences USA* **100**: 11225–11230.

Gong DY, Ho CH, Chen D, Qian Y, Choi YS, Kim J. 2007. Weekly cycle of aerosol-meteorology interaction over China. *Journal of Geophysical Research* **112**: DOI: 10.1029/2007JD008888.

Hendricks Franssen HJ. 2008. Comment on "An unexpected pattern of distinct weekly periodicities in climatological variables in Germany" by Dominique Bäumer and Bernhard Vogel. *Geophysical Research Letters* **35**: DOI: 10.1029/2007GL031279.

Hendricks Franssen HJ, Kuster T, Barmet P, Lohmann U. 2009. Comment on "Winter weekend effect in southern Europe and its connection with periodicities in atmospheric dynamics" by A. Sachez-Lorenzo, *et al*. *Geophysical Research Letters* **36**: L13706, DOI: 10.1029/2008GL036774.

Huth R, Beck C, Tveito OE. 2010. Classifications of atmospheric circulation patterns – theory and applications – preface. *Physics and Chemistry of the Earth* **35**: 307–308.

Laux P, Kunstmann H. 2008. Detection of regional weekly weather cycles across Europe. *Environmental Research Letters* **3**: DOI: 10.1088/1748-9326/3/4/044005.

Lund IA. 1963. Map-pattern classification by statistical methods. *Journal of Applied Meteorology* **2**: 56–65.

Murphy, DM, Capps SL, Daniel JS, Frost GJ, White WH. 2008. Weekly patterns of aerosol in the United States. *Atmospheric Chemistry and Physics*. **8**: 2729–2739.

Philipp A, Bartholy J, Beck C, Erpicum M, Esteban P, Fettweis X, Huth R, James P, Jourdain S, Kreienkamp F, Krennert T, Lykoudis S, Michalides S, Pianko-Kluczynska K, Post P, Rassilla Álvarez D, Schiemann R, Spekat A, Tymvios FS. 2010. COST733 CAT – a database of weather and circulation type classifications. *Physics and Chemistry of the Earth* **35**: 360–373.

Philipp A, Della-Marta PM, Jacobeit J, Fereday DR, Jones PD, Moberg A, Wanner H. 2007. Long term variability of daily North Atlantic-European pressure patterns since 1850 classified by simulated annealing clustering. *Journal of Climate* **20**: 4065–4095.

Sanchez-Lorenzo A, Calbo J, Martin-Vide J, Garcia-Manuel A, Beck C. 2008. Winter, "weekend effect" in southern Europe and its connections with periodicities in atmospheric dynamics. *Geophysical Research Letters* **35**: DOI: 10.1029/2008GL034160.

Schultz DM, Mikkonen S, Laaksonen A, Richman MB. 2007. Weekly precipitation cycles? Lack of evidence from United States surface stations. *Geophysical Research Letters* **34**: DOI: 10.1029/2007GL0 31889.

Stjern CW. 2011. Weekly cycles in precipitation and other meteorological variables in a polluted region of Europe. *Atmospheric Chemistry and Physics*. **11**: 4095–4104.

Uppala SM, Kallberg PW, Simmons AJ, Andrae U, Da Costa Bechtold V, Fiorino M, Gibson JK, Haseler J, Hernandez A, Kelly GA, Li X, Onogi K, Saarinen S, Sokka N, Allan RP, Andersson E, Arpe K, Balmaseda MA, Beljaars ACM, Van De Berg L, Bidlot J, Bormann N, Caires S, Chevallier F, Dethof A, Dragosavac M, Fisher M, Fuentes M, Hagemann S, Holm E, Hoskins BJ, Isaksen L, Janssen PAEM, Jenne R, McNally AP, Mahfouf JF, Morcrette JJ, Rayner NA, Saunders RW, Simon P, Sterl A, Trenberth KE, Untch A, Vasiljevic D, Viterbo P, Woollen J. 2005. The ERA-40 re-analysis. *Quarterly Journal of the Royal Meteorological Society* **131**: 2961–3012.

Wilks DS. 1995. *Statistical Methods in the Atmospheric Sciences*. Academic Press: London.

