Structural time series analysis of meteorological data: In search of weekly cycles in Europe

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Abstract

There have been many reports on the subject of weekly periodicity in meteorological variables; they are an indication of anthropogenic influence on (short term) climate.

For Europe, it was found that, for a period from 1946 to 2006, the beginning of the week is warmer than the end of the week. Divided across Europe, this pattern is not as uniform though; the end of the week is the coldest period of the week across Europe, but the warmest period of the week varies; an indication of a regional pattern.

Over time, there is a shift of the general weekly pattern of the warmest period at the beginning of the week to the end of the week (and vice versa for the coldest period of the week). For the different areas in Europe there is also a shift visible, but not as clear as the general shift. The reasons for this shift remain unclear.

Over time the influence of maximum temperature on the weekly pattern seems to have decreased, while the influence of minimum temperature has increased.

In sunshine and precipitation it is harder to distinguish a weekly pattern, due to the different mechanism influencing these variables.

These results indicate that weekly periodicity is present in Europe, and is most likely to be influenced by anthropogenic emissions. A change in these emission patterns seems to also have influence on weekly meteorology.

More research is necessary to get a clear idea of the connection between aerosols and meteorology.

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Introduction

Currently, climate and climate change are important topics. There is more and more evidence of anthropogenic influence on climate (IPCC, 2007), though there is still no conclusive evidence on how large this influence is (IPCC, 2007; Gong, 2006).

One of these anthropogenic influences will be discussed here: the weekly cycle. Often the term weekend effect is used, which means that temperatures during the weekend are lower than those during weekdays (for explanation see below). However, this term does not clearly cover the whole topic of weekly pattern: What if there are statistical anomalies on e.g. Wednesday and not during the rest of the week? Therefore the term weekend effect is mentioned with respect to other articles, but it is not used in this report.

A week is a completely anthropogenic phenomenon; nature itself does not recognize any weekly timeframes (Bäumer and Vogel, 2007; Forster and Solomon, 2003; Cerveny and Coakly, 2002; Cerveny and Balling, 1998). However, weekly patterns in meteorological variables have been described by, i.e., Bäumer and Vogel (2007), Forster and Solomon (2005), Dessens (2001), Simmonds and Keay (1997), Fujibe (1987), and Lawrence (1971). Evidence of a weekly cycle in meteorological values would thus be good evidence that man is influencing climate.

The idea is that these weekly patterns are connected to anthropogenic emissions; During the week, as anthropogenic activity is at its largest, aerosols and greenhouse gases (GHG) build up in the atmosphere. During the weekend anthropogenic activity, and thus the amount of anthropogenic emissions, decreases, and is at its lowest on Sunday (in the western world) (Bäumer and Vogel, 2007; Beirle et al., 2003; Cerveny and Coakly, 2002). This is believed to affect meteorology, though the exact mechanism is not known yet (Schultz, 2007; Jin et al, 2005; Forster and Solomon, 2003; Dubovik et al., 2002).

However, a distinction must be made to whether a significant weekly cycle can be seen, or whether one or more days per week is/ are significantly warmer or colder than the rest of the week. A significant weekly cycle means that distinct cycle with a seven day period can be found in the data (mathematically speaking, some kind of sine or cosine function with a period of seven days). A weekly cycle may not show a clear warmer or colder period with significantly warmer or colder days; a seven-day cycle with small amplitude may not show a specific day as warmer or colder. However, in general, if a significant weekly cycle can be found, so can at least one significantly warmer or colder day.

It is also possible to look at the seven days of the week separately, and determine whether one (or more) of these days is significantly different from the weekly average. There does not necessarily have to be a significant seven-day cycle to display this difference.

For this reason I make a distinction between a seven day cycle, and a significantly different day. From hereon I will use the term weekly cycle for a seven day period, and the term weekly pattern in the case a significantly different day of the week is visible.

In the past few decades much research has been done on meteorological events on the weekly timescale. So far, no research has been done on the significance of cycles with a seven day period. Significantly different days of the week, or different periods of the week (three days, weekends) have been reported in the USA by, a.o. Cerveny and Balling (2005), Forster and Solomon (2003), and Coakley (1999), in Asia by Gong (2006) and Fujibe (1988, 1987), and in Australia by Simmonds and Keay (1997). In Europe, a significant difference between days of the week has been reported by Bäumer and Vogel (2007), Dessens (2001), and Lawrence (1971), but only locally. Hendricks Franssen (2008) found no evidence of a weekly cycle in Switzerland. Since all these authors emphasized on only a small part of Europe, it is not possible to say whether a weekly cycle or a weekly pattern is visible throughout Europe.

It is hard to believe that a weekly pattern can be found in Asia, the United States, and Australia, but not in Europe. There is not much research of this topic on a large area. Therefore it is not possible to see if this pattern is just locally influenced, or if perhaps there is a trend visible over a larger area (influenced by e.g. winds), of perhaps even globally (a week is a universal pattern, though the amount of activity per day is locally influenced (e.g. religion). Forster and Solomon (2003) found a spatial pattern in weekly temperatures in the USA, but further evidence is lacking. By looking at a large dataset, with locations spread around Europe, I hope to give a better overview of this topic. I will also look at temporal changes in mean temperature. So far, only Forster and Solomon (2003) found a change in long term temperature data fro some areas in the USA.

In this report, I will focus on three variables: temperature, precipitation, and sunshine. In chapter 2 an overview of the data is given. In chapter 3 the model used on these data is described. Chapter 4 shows the results of these data, with the discussion in chapter 5. Chapter 6 contains the conclusions of these findings.

Literature overview

In literature, much has been written on the subject of weekly patterns. Seven-day patterns have been reported in meteorological variables such as temperature (Bäumer and Vogel, 2007; Gong, 2006; Forster and Solomon, 2003; Coakley, 1999; Simmonds and Keay, 1997; Lawrence, 1971), precipitation (Bäumer and Vogel, 2007; Gong, 2006; Jin et al., 2005; Dessens, 2001; Fujibe, 1987), and sunshine (Bäumer and Vogel, 2007; Gong, 2006). Weekly patterns have also been found in aerosol data (Simmonds and Keay, 1997; Brönniman and Neu, 1997; Cerveny, 1998; van der A et al., 2008; de Meij et al., 2006). In this chapter follows a quick overview of the different data and time spans that have been used.

In the USA, weekly patterns have been found in meteorological variables by the following authors:

Coakley (1999) used daily maximum temperatures from 1949-1994 from San Francisco airport. He found that the warmest day of the week is more likely to occur on the first (or last) day of the week of the week, independent on which day is defined as the first day of the week. He proposed that this was due to air pollution.

Forster and Solomon (2003) found a weekly pattern in daily temperature range (DTR) for many stations in the USA, Mexico, Japan, and China. They found that for the USA Sunday and Monday to have consistently higher DTR than the other days, while Friday had one of the lowest DTRs of the week. Also, they found weekends to have a smaller DTR than midweek days. They used data for the last fifty years, but only if there were at least 52 consecutive full weeks of data available. They also found a similar trend in Mexico and Japan, but since data there where limited; they are not included in this overview.

Cerveny and Balling (2005) found significantly stronger nighttime winds on Saturday and stronger daytime winds on Sunday for the period 1970-2003 across the United States.

These data are corroborated with weekly patterns in anthropogenic emissions: Jin et al. (2005) found aerosol optical thickness in Houston and New York (USA) to be at a maximum on Wednesday, while they found no clear connection between aerosols and precipitation amount.

Beirle et al. (2003), found a decrease for NO_2 in the USA from Friday until Sunday. They used GOME measurements for the period 1996-2001.

Cerveny and Coakley (2002) found that in the weekend (Saturday-Sunday) there are significantly lower CO_2 concentrations in the air at Mauna Loa, Hawaii. They propose this is due to anthropogenic emissions.

Cerveny and Balling (1998) found a minimum of ozone and carbon monoxide concentrations early in the week, and higher concentrations later in the week in the Northeastern region of the United States. This corresponds with an increase in precipitation and tropical cyclones at weekends. They indicate that the influence of pollution-derived aerosols may drive weekly climate cycles.

For Asia, weekly patterns have been discovered by the following authors: Fujibe (1987) found weekday-weekend differences for temperature, wind speed, relative humidity, and solar radiation for the 1961-1985 period in Tokyo, (Japan). He found that temperatures on Sunday are lower than during the rest of the week, while cloud amount is also lower on Sunday. He found relative humidity to be higher on Sunday. The author did not find any difference in precipitation amount during the week.

Fujibe (1988) also found temperatures to be lower on Sundays for cities in Hokkaido. He used data from 1977 until 1985.

Gong (2006) found weekly patterns in China. They analyzed DTR, relative humidity, and solar irradiance for the period 1955-2000 in East

China. They found higher temperatures on weekdays than on weekends, and Wednesday to be drier than the rest of the week.

Beirle et al. (2003), found a decrease for NO_2 in the Japan on Saturday and Sunday. They used GOME measurements for the period 1996-2001. For China they found no difference.

In Australia, only one record for a weekly pattern was found: Simmonds and Keay (1997) found weekly patterns for temperature and precipitation in Melbourne for a period of 1856-1990. They found weekday temperatures to be significantly higher than weekend temperatures. They also found weekday rainfall to be significantly greater in winter. They compared these data with NO and NO_2 emissions at the airborne particle index (API) and found those to be lower in weekends than on weekdays. They thus hypothesize that an explanation must be sought in anthropogenic heat emissions.

In Europe, a little more research has been done, but only very locally: Bäumer and Vogel (2007) found a weekly cycle in temperature, precipitation, sunshine duration, and cloud amount for several stations in Germany for 1991-2005. He found weekdays to have higher temperatures than weekends, with a maximum on Wednesday and a minimum on Saturday. Sunshine duration was found to be maximum at the beginning of the week, and decrease until Saturday. There was an increase in rainfall in the course of the week, with a minimum on Monday, and a maximum on Saturday. Cloud amount was found to be higher at the second half of the week with a minimum on Tuesday and a maximum on Saturday. The authors imply that the atmosphere is forced to a 7-day period due to the anthropogenic weekly emission cycle.

Dessens (2001) analyzed hailstones for an 11 year period in southwestern France, and found an increase in the size of hailstones during the week, with the maximum size in the weekend. They concluded that this must be connected to the amount of NO_x particles in the atmosphere.

Lawrence (1971) suggests a weekly pattern in summer maximum temperatures in London for both the period 1949-1959 and 1959-1969. He found that for maximum temperature the maximum is on Sunday and minimum on Thursday for the summer months May, June, and July for 20 consecutive years. He suggests this could be due to variation of air pollution.

In anthropogenic emissions, Bäumer et al. (2007) found a weekly periodicity for aerosol data for twelve stations in France, Germany, Switzerland, and Italy. They found the lowest values on Sunday and Monday, and the largest values from Wednesday until Saturday.

de Meij et al. (2006) found, using the TM5 model, an increase in NO_2 and NH_3 at the beginning of the week in Europe.

Helmut Mayer (1999) found lower values of NO, NO_2, O_3 and O_x on Saturday and Sunday for the city of Stuttgart (Germany). He took the period 1975-1996 into account.

Brönniman and Neu (1997) found differences between weekend and weekday of near-surface ozone concentrations in Switzerland, depending on meteorological conditions: When the weather was favorable to ozone productions (high solar radiation, high temperatures, low wind speed) peaks were lower on Sunday compared to Thursday and Friday. When weather was not favorable for ozone production, weekends showed higher ozone peaks than weekdays.

There are also articles on the absence of a weakly pattern in meteorological values. Grant (2005), deLisi (2001), and Schultz (2007) found no such cycle in their data: deLisi, (2001) and Schultz (2007) both found no evidence significant weekly cycles in daily precipitation data at the northeast coast of the United States. deLisi (2001) used a time frame from 1973 to 1992, and Schultz (2007) used precipitation data from 1951-1992 across the United States (including Alaska and Hawaii).

Grant (2005) did not find a specific cycle for temperature data for the 1953-2003 temperature record from the summit of Mount Washington in the northwestern United States. He stated that this was because measurements were taken near the top of (or entirely above) the boundary layer (where most aerosols are located).

Hendricks Franssen (2008) looked at both precipitation and sunshine data in Lugano and Zurich (Switzerland) since 1864 (precipitation) and 1901 (sunshine), but did not find evidence for a weekly cycle. The main reason the author gives for this, is that spatial autocorrelation does not play a large role here.

Different methods used by the different authors to generate the weekly pattern varied largely between taking a t-test of values at the beginning and end of the week (Simmonds and Keay, 1997) to more advanced statistical methods as averaging of an autoregressive Gaussian process, random walk, and detrending (Coakley, 1999).

These many different locations, periods, and data are very confusing, and make it very difficult to say if a general weekly pattern is present, and how large it is. In general, there seems to be a positive correlation between aerosols and temperature. For precipitation and other variables, the connection with aerosols is less clear (Jin et al., 2005).

Very little is known for the European continent. So far, only local data for Switzerland (Hendriks Franssen, 2008), Germany (Bäumer and Vogel, 2007), France (Dessens, 2001), and London (Lawrence, 1971) have been investigated. Hopefully, it will be possible to draw some more conclusions from this report.

Despite many different approaches, some sort of weekly pattern seems to be present at different locations around the globe. However, the amplitude of this pattern may be different on different locations: All the different methods make it hard to compare the different weekly patterns one on one.

Data

The meteorological data in this report come from the European Climate Assessment & Dataset (ECA&D) project. This is a project of the European Climate Support Network (ECSN), in which meteorological data from different stations in Europe are collected. Some Northern African and Eurasian stations are taken into account too, to give a good idea of climate in the area around the Mediterranean Sea. These data were collected and checked by Klein Tank et al. (2002).

In this report surface temperature, precipitation amount, and sunshine duration are taken into account, because these data are present in many different locations, and do not contain too many missing values. Sunshine was also analyzed, but there are very few stations with continuous set of data.

In total 55 stations were taken into account, 46 for mean temperature, 34 for precipitation, and 18 for sunshine. Of these 55 stations, twenty are located in a rural area, and 35 are located in an urban area (according to 2008 observations). A map of all used stations can be found in figure 1, and a full list of the stations and data can be found in appendix A.
If possible daily data from 1946-01-01 to 2006-12-31 were used. However, for some locations (e.g. Ireland, Iceland) no such long series were available, or series contained many missing data (in the order of one subsequent year or more). Nevertheless, some of these series were used to get a good cover over Europe.

For all data, a continuous period was taken into account (with the exception of continuous missing values), and seasonal effects were not taken into account separately, even though Gong et al. (2005), Simmonds and Keay (1997), and Fujibe (1988b) found differences in the weekly pattern between summer and winter.

For the temperature data, daily data in ° C were taken into account.

For the rainfall amount, the log of daily rainfall (in mm) + 1 was taken. This was to prevent extreme values to influence the weekly pattern too much. For sunshine data, the amount of daily sunshine hours was taken into account.

For many locations it was not possible to get temperature, rainfall, and (especially) sunshine data. Other locations nearby were chosen if possible.

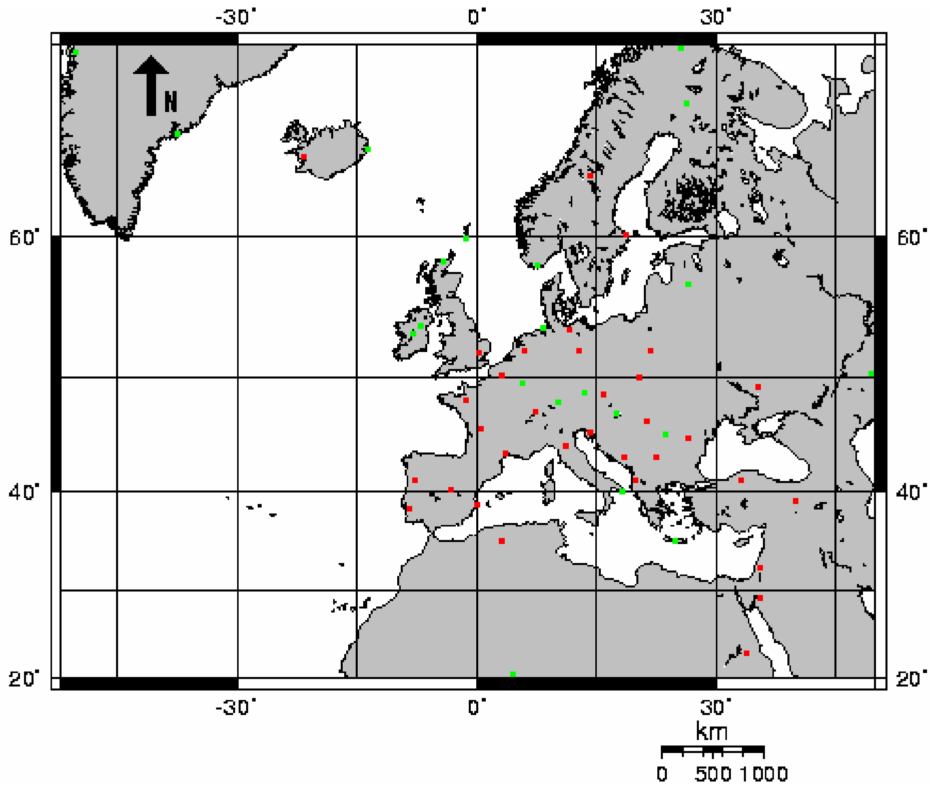


Figure 1. Map of all used stations, with urban locations (according to current day observations) in red and non-urban locations in green.

Model

To analyze the data, the program STAMP™ was used. This stands for "Structural Time series Analyser Modeller and Predictor". With this program time series with unobserved components can be analyzed. This means that it is relatively easy to find trends that can not be observed by looking at the original time series.

In this program a time series is broken up into components: A level, a slope, (together referred to as a trend). Two periodic functions can be added; a seasonal and a cycle. In the program the seasonal is referred to as a cyclical component that is allowed to change over time. A cycle is referred to as a cyclical component that is assumed to be stationary over time (such as a seasonal cycle). If necessary, an autocorrelation coefficient can be added.

In mathematical terms the model can be written as:

$$y_t = \mu_t + \gamma_t + \phi_t + \nu_t + \epsilon_t, \quad \epsilon_t \tilde{} NID(0, \sigma_\epsilon^2)$$

where μ_t is the trend component, γ_t is the seasonal component, ϕ_t is the cycle component, ν_t is the auto regression component, and ε_t is the irregular component. ε_t is assumed to be normally and independently distributed with mean zero and variance σ_ε^2.

The trend (both the level and the slope) and the seasonal can be set to stochastic or fixed. When they are set to be stochastic they are allowed to change from time point to time point. When they are fixed they remain the same throughout the time series.

The seasonal is often set as trigonometric, which allows for smoother changes in the seasonal (Lenten and Moosa, 2003).

At the base of this model lies the Kalman filter, together with some other smoothing algorithms. The model first analyzes every part of the time series separately, and than puts them together in a linear model.

Several advantages of STAMP are (i) that every part of the time series can be separately modeled and analyzed, (ii) that the model is good at handling missing values, (iii) it is easy to combine series, and (iv) parts of time series are allowed to change over time (Koopman, 2000).

Originally STAMP is an econometric program that has not been used much in other branches of science. In climatology STAMP has been used by Lenten and Moosa (2003) and Allen et al. (1999) to analyze long term time series in climate. More information on the program and its features can be found in Koopman (2007), Doornik (2005), and Koopman (1999).

To get a better example of the model, and the way it is used in this report, an example is given. The data used contain a cycle with a known period of 7, and amplitude of 0.1. Autocorrelation of these data is 4 and has a standard deviation of 3. The period of the time series is 1901-2008, and contains 39447 data.

These data where modeled using STAMP. To model these data no level and slope were used. The trigonometric seasonal was fixed, and has a 7-day period. Autocorrelation was modeled with a starting variance of 9 (3^2), but then allowed to vary.

The model automatically test whether a seasonal is present using a χ^2-value, with a null hypothesis of no seasonal. In this example the χ^2-value is 27.20512, which is well above a significance level of 99%.

To test for a significantly different day, the average for each day is tested against the weekly average, and both this value and its p-value are displayed. For this model, these values are displayed in table 1.

To get the best possible outcome, a model should show very strong convergence (as it did here), which means that the estimated values are as close to the observed values as possible.

Further more, the Akaike Information Criterion (AIC) and the Bayesian-Schwartz Information Criterion (BIC) can be used. These can be used to say how good a model is.

Unfortunately, there are no fixed values for these criteria: They must be as low as possible, but the lowest value may differ from model to model. In this example the AIC and BIC were 2.2429 and 2.2444 respectively, and it was not possible to generate any lower values if the model was adjusted.

Table 1. Periodic values for the data used to test the model.

Period	**Value**	**p-value**
1	0.06925	0.03203
2	0.05789	0.07310
3	-0.05129	0.11229
4	-0.10762	0.00086
5	-0.05021	0.12010
6	-0.02336	0.46955
7	0.10534	0.00111

Methods

The model used was different for each variable. Temperature data (mean, minimum, and maximum temperature) were measured using a trend consisting of a stochastic level, and a fixed slope, a cycle of 365.25, and a 7 day trigonometric seasonal. Although temperature is a highly auto correlated feature, removal of autocorrelation was not included in the model. First of all, when autocorrelation was included, the model did not perform better. Secondly, by removing autocorrelation, one could remove the signal: If temperature (for instance) is influenced anthropogenicly, one would expect it to build up or decrease as the week progresses. By removing the autocorrelation, one could also remove this increase in human activity, removing the weekly cycle (if present). To remove the annual influence on temperatures a cycle of period 365.25 (the 0.25 to account for leap years, (Harvey, 1997) was specified.

For precipitation a model with a stochastic level, a fixed trigonometric seasonal with a frequency of 7, and an irregular was used. However, not the direct precipitation was modeled, but the natural logarithm of precipitation + 1 was modeled. This is because precipitation data contain many extremes that might influence the significantly different days.

For sunshine a stochastic level, a fixed slope, a fixed trigonometric seasonal with a frequency of 7, a cycle of 365.25, and an irregular were used.

To test for the weekly cycle, the model provides a χ^2-test. This is tested against six degrees of freedom, and with a null-hypothesis of no seasonality. With a significance level of 90% the critical value lies at 10.6.

To test for a significantly different day, the average for each day is tested against the weekly average, and both this value and its p-value are displayed.

Results

Mean temperature

1946-2006

For mean temperature data from 46 locations were used. For these 46 locations only seven displayed a significant weekly cycle: Brindisi (Italy), Helsinki (Finland), Ilulissat (Greenland), Karasjok (Norway), Oestersund (Sweden), Rennes (France), and Tassilaq (Greenland). Of these seven stations, five are at a rural location, and two are at an urban location.

Though there are not many stations where data display a significant weekly cycle, there are many stations where the data do display at least one significantly warmer or colder weekday than the weekly average.

In Figure 2 the daily difference from the weekly average and its p-value are shown for each station. From this figure one can see that for the weekdays that show a significant difference from the weekly average, Monday and Tuesday are mainly above average, while Friday and Saturday are mainly below the weekly average.

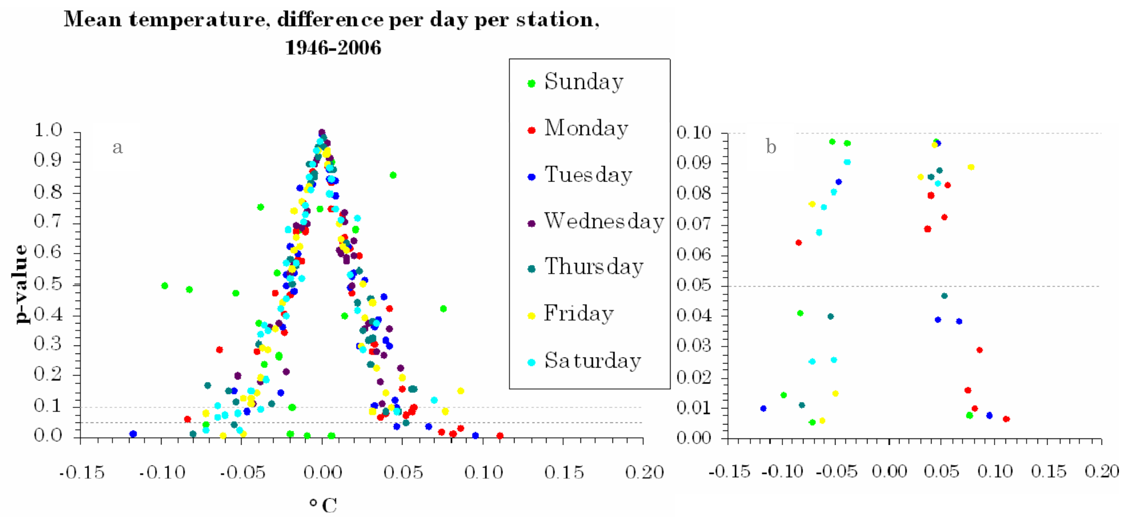


Figure 2. Scatter plot of daily mean temperature for the period 1946-2006 during the week for all stations where a shows all days for all stations, and b shows only the significant days for all stations. p-values are displayed on the y-axis, and temperature values (in °C) are displayed on the x-axis.

For the stations that do and do not display a significant weekly cycle, the average weekly pattern is displayed in figure 3. The black curve indicates days for stations with no significant weekly cycle, and the red curve displays days for stations with a significant weekly cycle. Both curves display the warmest day of the week on Monday, and the coldest day of the week on Saturday (black) and Sunday (red). This is similar to what Bäumer and Vogel (2007), Gong (2006), Forster, (2003), and Simmonds and Keay (1997) found.

To see if there is a spatial spread in the weekly pattern around Europe influenced by climatic region, Europe was divided into 4 areas: Southeast below 50 ° N and above 15 ° E, Northeast above 50 ° N and 15 ° E, Southwest below 50 ° N and below 15 ° E, and Northwest above 50 ° N and below 15 ° E. These areas were chosen just for convenience, and because this division gives a more or less equal spread of used stations (if possible). In figure 4 the averages of these different areas are displayed. For comparison, the overall average is displayed as the black dotted line.

As can be seen from figure 4 all areas display a clear weekly pattern. This is somewhat uniformly defined across Europe: the warmest period of the week falls on Monday and Tuesday, and the coldest period is mainly on Friday-Sunday. This is also indicated by the overall average, which is most similar to the Southeast. However, it must also be taken into account that the number of stations per area differed, For the Northeast the curve is very different. The amplitude for the Northeast is 0.12 °C, while for the Southeast, Northwest, and Southwest, these differences are approximately 0.05 °C. Negative values are much larger than positive values. The Northeast displays the warmest day of the week on Thursday, while the other three areas display the warmest day more at the beginning of the week. The coldest day of the week falls on Sunday, which is much more in line with the rest of Europe. This coldest day is, however, more than 0.02 ° C colder than in the rest of Europe.

In Southwestern Europe, the graph also deviates from the overall average: The warmest day falls on Thursday. However, the difference between Thursday as warmest day of the week, and Monday (like the rest of Europe) is only 0.005 ° C.

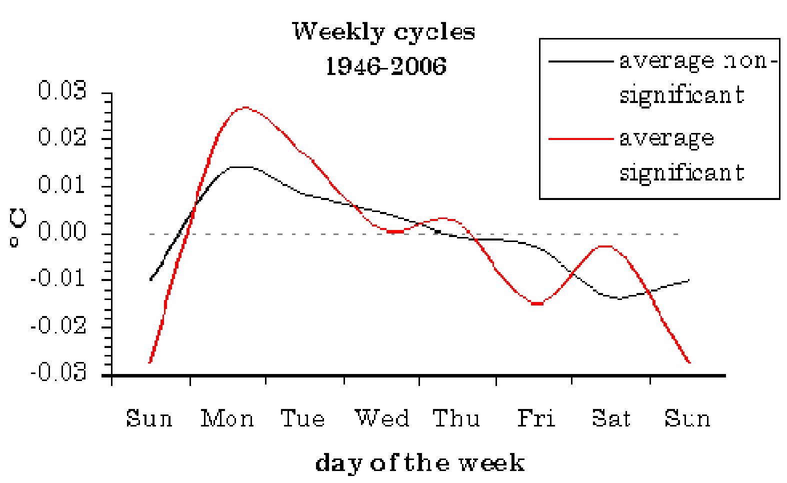


Figure 3. The weekly pattern of mean temperature for 61 years displayed for both stations that do (red) and do not (black) display a significant weekly cycle. The day of the week is on the x-axis, and the daily difference from the weekly average (in °C) is on the y-axis.

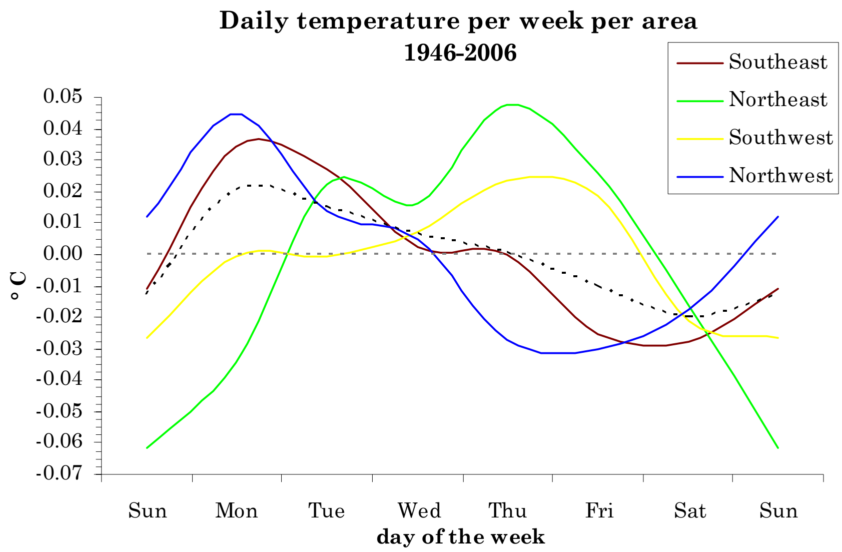
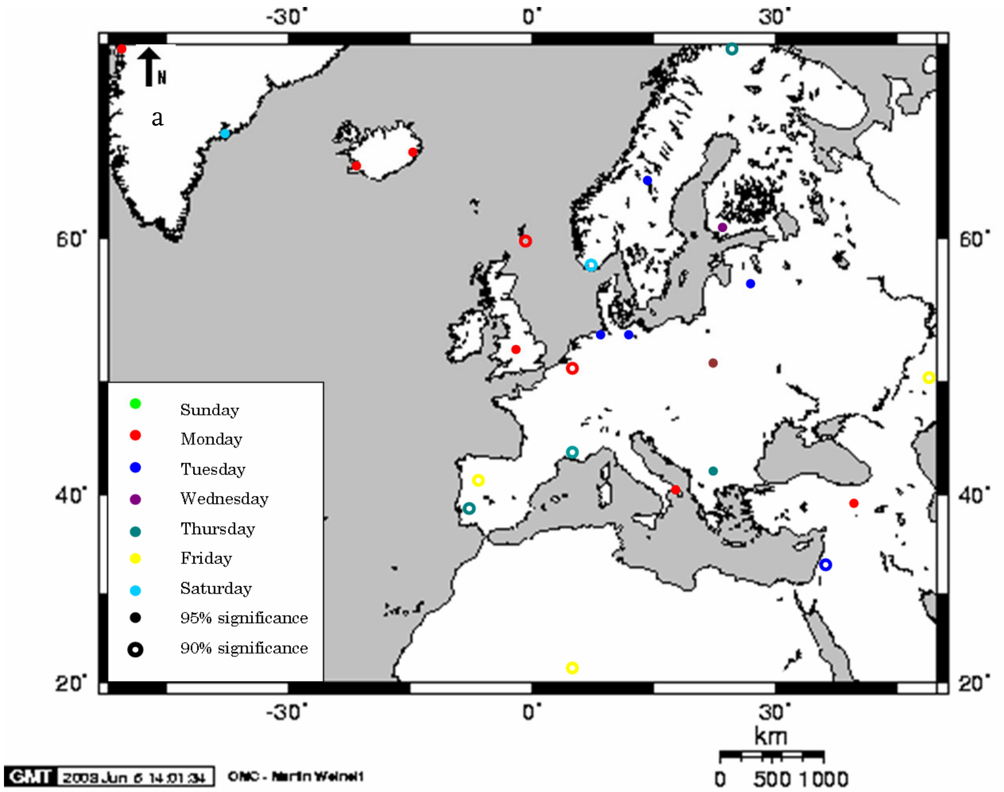


Figure 4. The weekly pattern of mean temperature for the four different regions in Europe for 61 years displayed for all stations where a significantly colder or warmer day of the week was found. The day of the week is on the x-axis, and the daily difference from the weekly average (in °C) is on the y-axis. The black dotted line indicates the overall average.

To get a better idea of the geographical spread of the warmest and coldest days of the week around Europe, and whether a spatial pattern exists, all stations that showed a significantly colder or warmer day of the week are plotted on a map of Europe. If more significantly warm or cold days occurred, the day with the highest significance was taken.

From figure 5a and b one can see that there are 24 stations that display a significantly warmer day of the week, and that there are 17 stations that display a significantly colder day of the week. Locations that display a warmer day are mainly located close to the coast, while the stations with a significantly colder day are mainly located further inland. Also, most stations with a significantly colder or warmer day are located in Northeastern and Northwestern Europe; there are very few stations in Southeastern Europe.

Of these 29 used stations, 13 are at a more rural location, and 16 are at an urban location. The amplitude is much smaller at non-urban locations. The warmest day of the week is in both cases on Monday, while the coldest day of the week is on Friday for the non-urban stations and on Saturday for the urban stations. In this graph no further difference can be seen between urban and non-urban areas.



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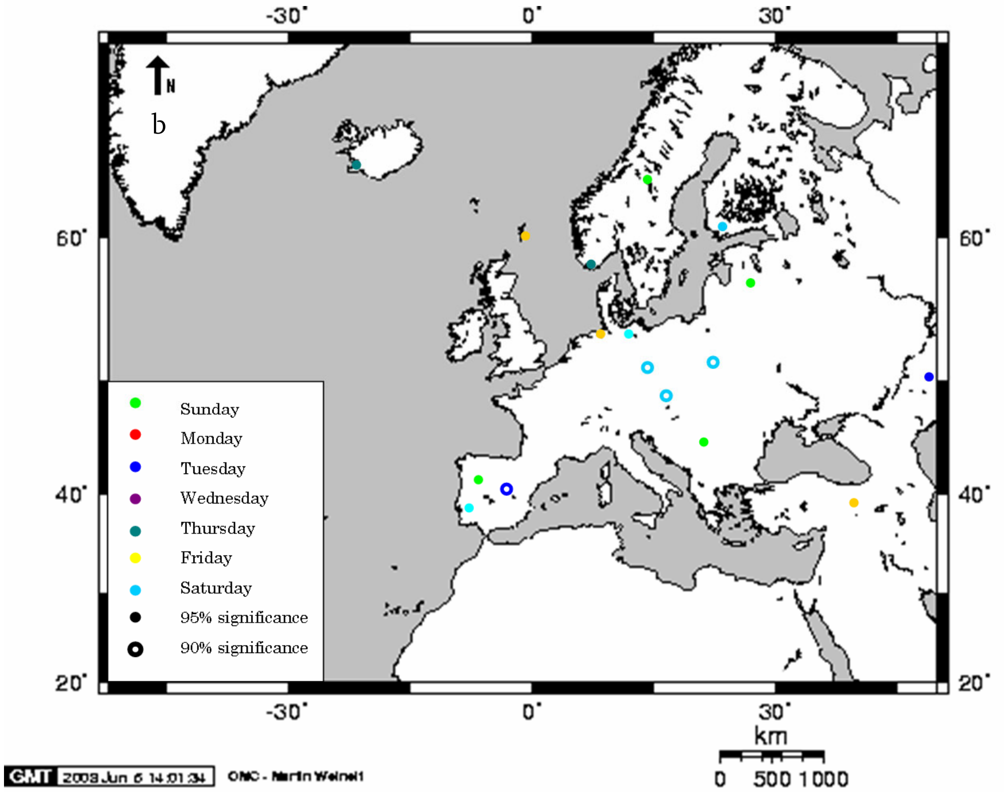

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Figure 5. Significantly (90% and 95%) warmer (a) and colder (b) days of the week around Europe for the 1946-2006 period.

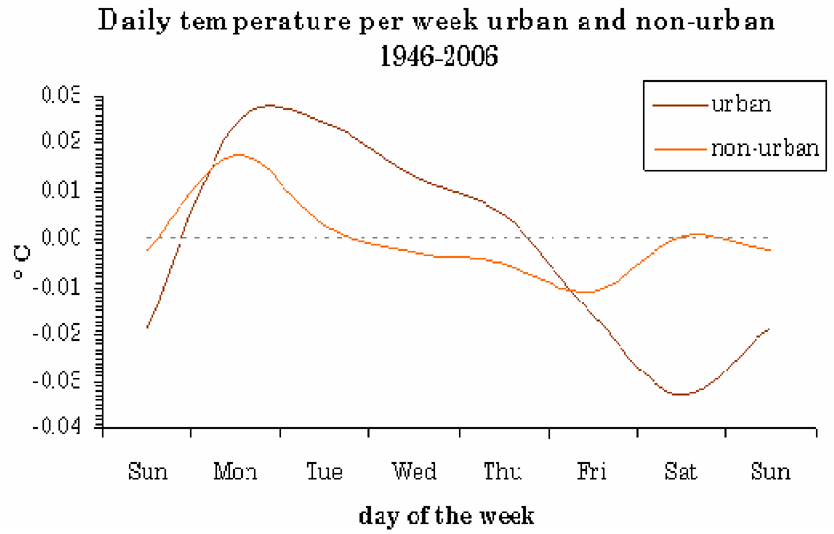

Figure 6. The weekly pattern of mean temperature for the urban (brown) and non-urban (orange) locations in Europe for 61 years displayed. Only locations where a significantly colder or warmer day of the week can be found were taken into account.

Other Periods

Since climate changed drastically during the last few decades (IPCC, 2007), the last ten years of the dataset (1997-2006) were considered separately.

This showed even less stations with significant weekly cycles: only Alger-Dar el Beida (Algeria), Nimes, and Rennes (both France). This time, all these three are more in the Southwest, and all three are at or near an urban location. There are also less significantly warmer or colder days for this period.

In contrast to the 1946-2006 period, significant and non-significant cycles (figure 7) show the warmest days of the week at the end of the week, while the coldest days of the week are at the beginning of the week. Though differences are larger, the significant and the non-significant graph show roughly the same weekly pattern.

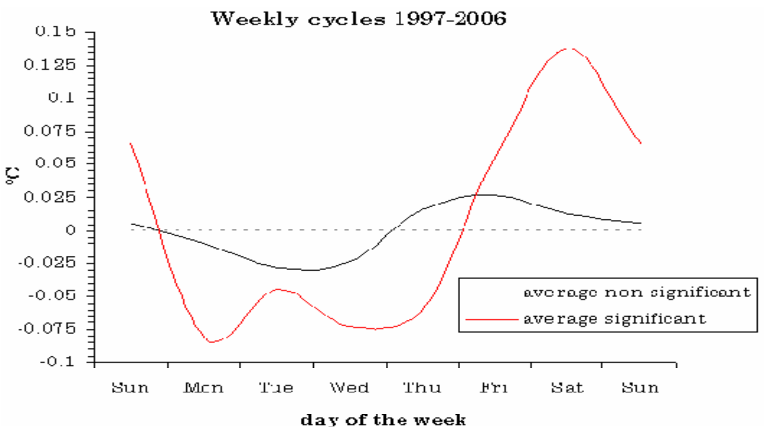

Figure 7. The weekly pattern of mean temperature for the 1997-2006 period displayed for both stations that do (red) and do not (black) display a significant weekly cycle. The day of the week is on the x-axis, and the daily difference from

To see whether this transition of the coldest and warmest period of the week occurs through time, and when, the 61-year period was further divided into five decades and one 11-year period; 1946-1956, 1957-1966, 1967-1976, and so on (hereafter referred to as six decades).

The average temperature for a week is shown per area per decade in Europe in figure 9. The overall average is shown as the black dotted line.

It is very difficult to distinguish a clear trend through time through Europe. The coldest and the warmest day of the week vary per area per decade. For all areas except Northeastern Europe the transition of the coldest period from the middle of the week to the beginning of the week is visible.

The differences in amplitude changed a lot per area and per decade. For the Northeast, there was a slight increase until 1997, and a decrease for the last decade. For the Southeast, values varied per decade, but were always lower than or similar to the other parts of Europe. For the Northwest, there was a decrease since 1947, than a sudden increase in 1987, and than an even larger decrease since 1997. For the Southwest, values remained more or less constant until 1997, when they rose again. So, since 1997, the largest extremes decreased for all areas except Southwestern Europe. In this area, extremes increased with approximately 0.15 ° C.

To summarize, it is difficult to find a consistent pattern through time that also indicates a spatial connection. Throughout Europe there is a transition from the warmest day of the week at the beginning of the week to the end of the week. However, this transition is not visible in the averages, only in single station data.

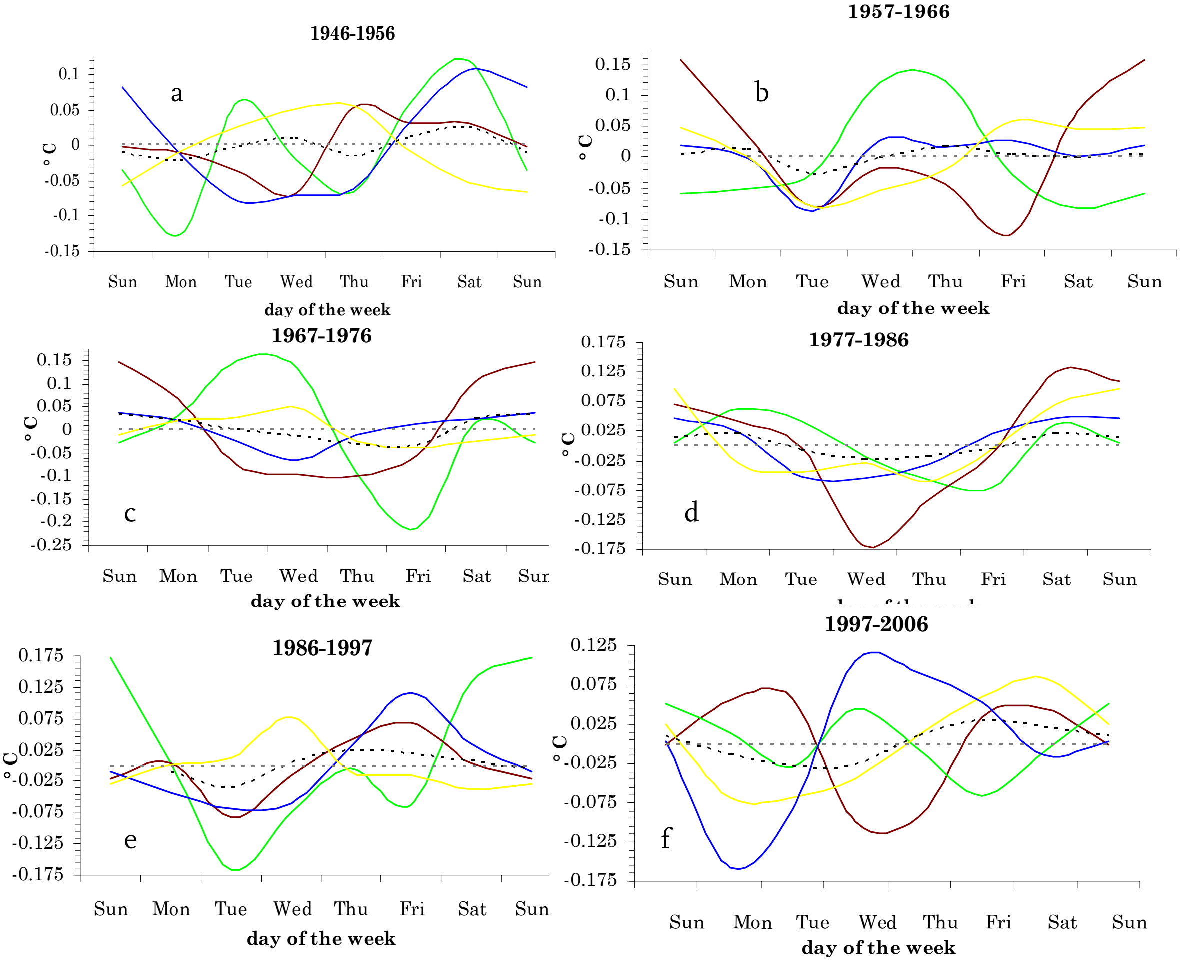

Figure 8. The weekly pattern of mean temperature for the four different regions in Europe for (a) 1946-1956, (b) 1957-1966, (c) 1967-1976, (d) 1977-1986, (e) 1987-1996, and (f) 1997-2006 displayed for all stations where a significantly colder or warmer day of the week was found. The day of the week is on the x-axis, and the daily difference from the weekly average (in °C) is on the y-axis. The black dotted line indicates the overall average for that period.

Minimum and Maximum temperature

1946-2006

To further investigate the weekly pattern in mean temperature in the weekly pattern and weekly cycle, minimum and maximum temperature were compared for all stations that displayed a significantly warmer or colder day of the week in mean temperature (for the 1946-2006 period). For the minimum temperature, four stations showed a significant weekly cycle: Ilulissat (Greenland), Ni (Serbia), Oestersund (Sweden), and Tassilaq (Greenland), while for maximum temperature, five stations displayed a significant weekly cycle: Brest Zonalya (Belarus), Brindisi (Italy), Oestersund (Sweden), Porto (Portugal), Reykjavik (Iceland), and Rostock (Germany).

Three of the four stations with a significant weekly cycle for minimum temperature, also have a significant weekly cycle for mean temperature (Ilulissat, Oestersund, and Tassilaq).

There were also three stations that displayed a weekly cycle in both mean and maximum temperature (Brindisi, Oestersund, and Reykjavik).

Only for Oestersund mean temperature, minimum temperature, and maximum temperature displays a significant weekly cycle.

For maximum and minimum temperature a scatter plot of the daily values per station is shown in figure 9. From this figure it can be seen that significant values of the minimum temperature are mainly positive on Monday and Tuesday, while they are mainly negative on Saturday and Sunday. For maximum temperature, most significantly negative values fall on Saturday and Sunday, while most values for Monday are positive. However, there are very few values for Monday, and other days do not clearly show positive values.

When looking at the averages of the weekly pattern for all the stations with significant days for maximum, minimum, and mean temperature (figure 10), the values in the scatter plots in figure 9 are confirmed by this figure. The

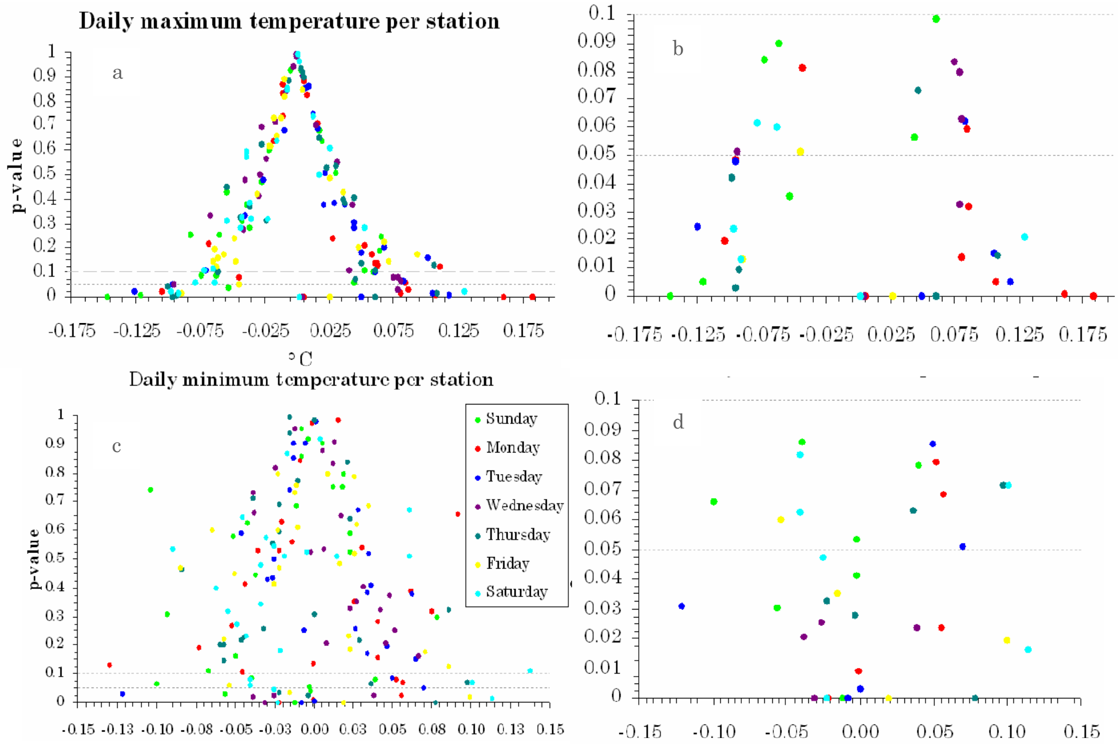

Figure 9. Scatter plot for the period of 1946-2006 of daily minimum (a) and(b) and maximum (c) and (d) temperature during the week for all stations, where (a) and (c) show all days for all stations, and (b) and(d) shows only the significant days for all stations. p-values are displayed on the y-axis, and temperature values (in °C) are displayed on the x-axis.

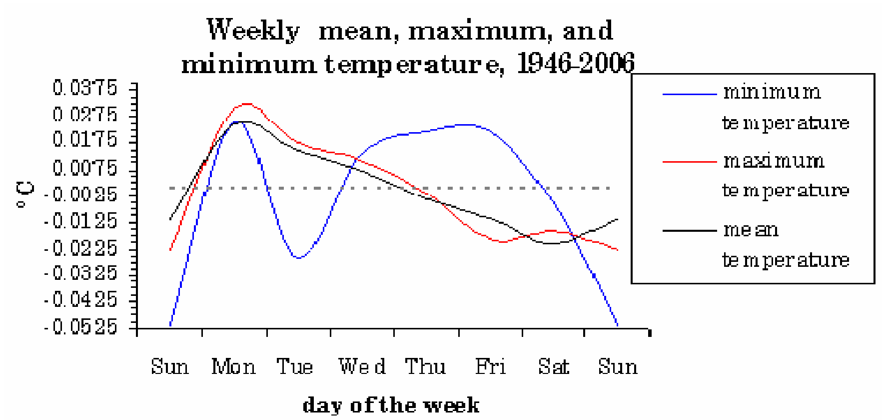

Figure 10. The weekly pattern of minimum (blue), maximum (red), and mean (black) temperature for the locations in Europe for 61 years. Only locations where a significantly colder or warmer day of the week can be found were taken into account.

average of maximum temperature follows the average of mean temperature much closer than does the average for the minimum temperature, indicating a large influence of maximum temperature on mean temperature.

Furthermore, for maximum temperature the warmest day is displayed on Monday, and the coldest day is displayed on Saturday. For minimum temperature the warmest day is displayed on Wednesday, with the coldest day on Saturday. However, the warmest day for the minimum temperature is still similar to the mean temperature on the same day.

Comparing urban and non-urban areas for minimum, maximum, and mean temperature (figure 11), minimum temperature is approximately one day ahead of mean temperature in urban areas, and approximately one day behind in non-urban areas. Maximum temperature is much more similar to mean temperature in both urban and non-urban areas.

Comparing different regions around Europe (the same regions as above), the trend differs largely per area (figure 12). In Southeastern Europe, maximum temperature shows a somewhat similar curve to that of average temperature in that region, though approximately one to two days earlier, especially near the end of the week. In Southwestern Europe, maximum temperature shows an exact opposite trend from mean temperature, with the warmest part of the week at the beginning of the week, and the coldest part at the end of the week.

In Northeastern and Northwestern Europe, maximum temperature is very similar to mean temperature on every day of the week. For minimum temperature a different pattern is visible. In the Northeast, minimum temperature leads mean and maximum temperature by approximately one day, while in the Northwest, minimum temperature is, except on Tuesday and Wednesday, very similar to mean and maximum temperature. For the Southeast, minimum temperature shows a very different trend from mean or maximum temperature; especially the maxima on Wednesday and Friday are

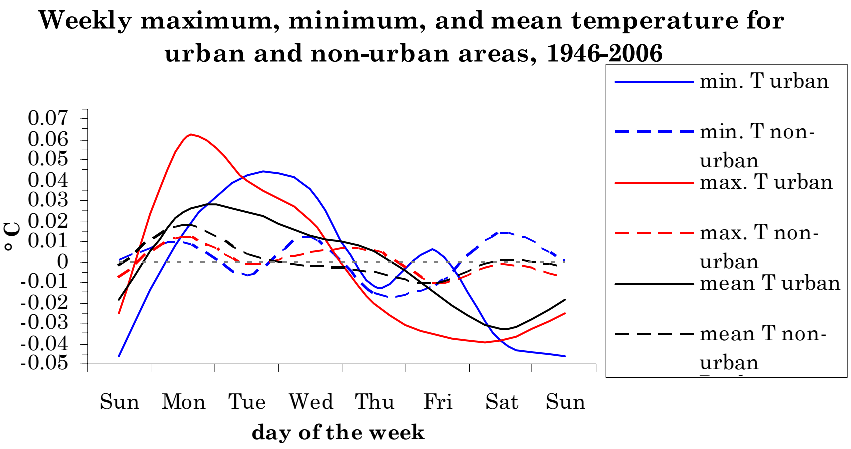

Figure 11. The weekly pattern of minimum (dotted line), maximum (striped line) and mean (solid line) temperature for the urban (brown) and non-urban (orange) locations in Europe for 61 years displayed. Only locations where a significantly colder or warmer day of the week can be found were taken into account.

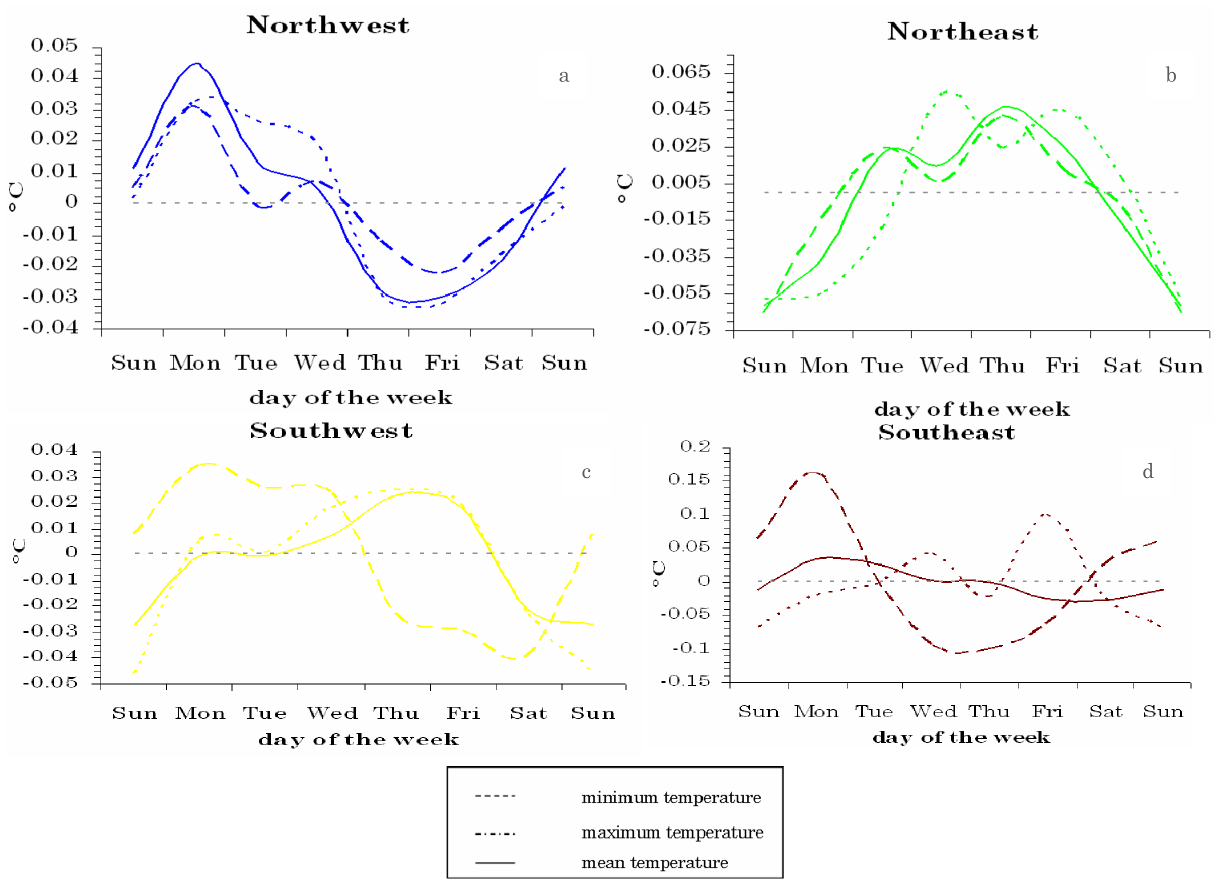

Figure 12. The weekly pattern of minimum (dotted line), maximum (striped line) and mean (solid line) temperature for the (a) Northwest, (b) Northeast, (c) Southwest, and (d) Southeast of Europe for 61 years . Only locations where a significantly colder or warmer day of the week can be found were taken into account.

peculiar. For the Southwest, minimum temperature is nearly identical to mean temperature.

1997-2006

Because of the large difference between the 61-year period and different decades, the last decade (1997-2006) was also reviewed for minimum and maximum temperature (figure 13). This gives an indication whether the connection between minimum and maximum temperature has changed over time.

It is very difficult to distinguish the main influence for the last decade. On Sunday, Monday, and Wednesday-Friday, the average daily minimum temperature is even higher than the average daily maximum temperature. The coldest day of the week for the mean temperature falls on the same day as the coldest day of the week for the minimum temperature, while the warmest day of the week for the mean temperature falls on the same day as the warmest day for the maximum temperature.

For the urban and non-urban areas, it is also impossible to distinguish a clear trend. Mean and maximum temperature show the same coldest day of the week for the urban areas, while minimum temperature leads by one day. For the warmest day of the week, maximum temperature lags mean temperature by one day, while minimum temperature lags mean temperature by three days. Minimum, mean, and maximum temperature do follow a similar trend through the week, in that they display a minimum, increase a little, decrease a little, and increase again, to go back to their minimum. However, the timescale on which this happens is different.

For the non-urban areas, mean and minimum temperature display the same coldest day (Tuesday), but mean temperature has its warmest day on Saturday, while minimum temperature has its warmest day on Monday.

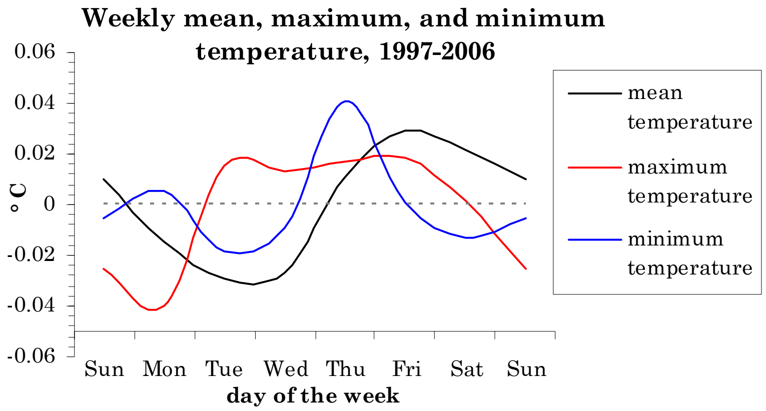

Figure 13. The weekly pattern of minimum (dotted line), maximum (striped line) and mean (solid line) temperature for the urban (brown) and non-urban (orange) locations in Europe for the last ten years displayed. Only locations where a significantly colder or warmer day of the week can be found were taken into account.

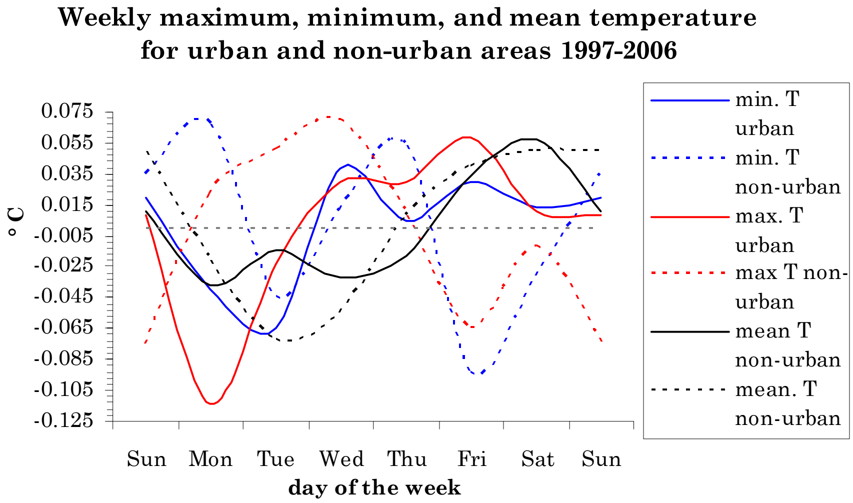

Figure 14. The weekly pattern of minimum (dotted line), maximum (striped line) and mean (solid line) temperature for the urban (brown) and non-urban (orange) locations in Europe for the period 1997-2006 years displayed. Only locations where a significantly colder or warmer day of the week can be found were taken into account.

Maximum temperature shows an almost opposite trend to mean temperature, with its maximum on Wednesday, and its minimum on Sunday. Perhaps maximum temperature can be seen as leading mean temperature by two to three days, but this does not explain the increase in temperature on Saturday.

If minimum- and maximum temperature are divided into the four regions in Europe, the graph (figure 15) becomes even more complicated. In the Northeast, the curve for mean temperature is similar to that of minimum temperature during the beginning of the week and similar to that of the maximum temperature during the end of the week. In the Northwest there seems to be a similar trend. In the Southeast however, the shape of the curve for the mean temperature is somewhat similar to that for the minimum temperature. The day for the minimum and maximum temperature of the week is not similar for these curves however. But, it is also not for mean and maximum temperature. For the Southwest, finally, both minimum- and maximum temperature show a very similar curve to the mean temperature, though perhaps maximum temperature is the best fit.

When compared to the 61-year period, the minimum temperature in the Northeast can be seen as shifted one or two days, and with some larger extremes. For the maximum temperature no clear change can be detected from this figure. In the Northwest, minimum temperature also seems to have shifted to days, and now lag mean temperatures by one or two days. For the maximum temperature, again it is difficult to see a clear pattern. In the Southeast, a similar pattern can be seen for both minimum and maximum temperature, though with larger extremes. In the Southwest, maximum temperature seem to have shifted approximately two days, while minimum temperatures seem to have shifted approximately one day, and are more evenly distributed among the week.

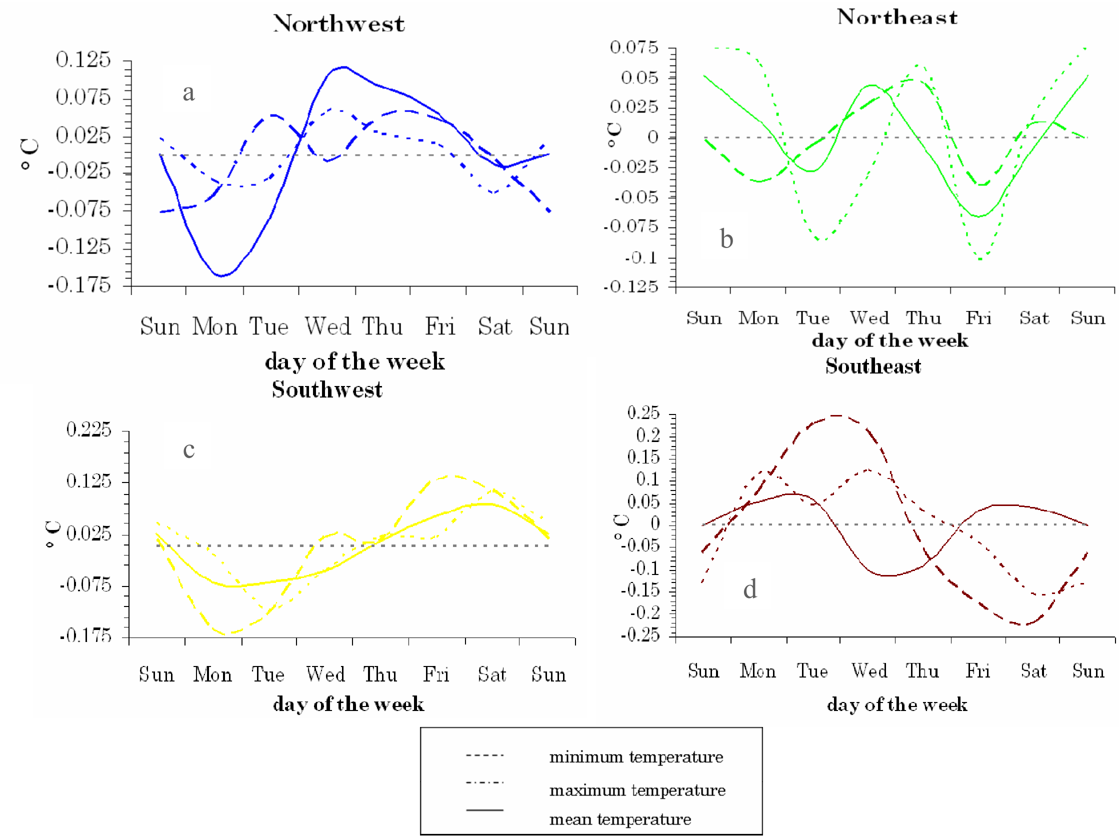

Figure 15. The weekly pattern of minimum (dotted line), maximum (striped line) and mean (solid line) temperature for the (a) Northwest, (b) Northeast, (c) Southwest, and (d) Southeast of Europe for the 1997-2006 period . Only locations where a significantly colder or warmer day of the week can be found were taken into account.

Sunshine

1946-2006

To see how and if aerosols might influence temperature, daily sunshine duration (in hours) was taken into account: Aerosols affect cloud formation, and clouds affect sunshine. However, not many stations have sunshine data, so a one on one comparison of temperature/ precipitation and sunshine was difficult. Also, the time for which these data exists in the used stations varies from 61 to five years. Nevertheless, sunshine was taken into account for thirteen stations around (mainly Western) Europe, but a comparison with temperature was not attempted.

For the thirteen selected locations none displayed a significant weekly cycle. Nine displayed one or two days that were different from the average. There are more stations that display a significantly cloudier day, than there are stations that display a significantly sunnier day.

Figure 16 shows that there is quite a clear weekly pattern, though the amplitude is not large. Sunshine decreases from Tuesday until Friday, and increases from Friday until Tuesday.

Comparing urban and non-urban locations shows large amplitude for the non-urban graph (0.386), and very week amplitude for the urban graph (0.032). For the urban graph the sunniest day on Monday and the cloudiest day on Saturday, while for the non-urban graph Tuesday is the sunniest day, while Friday is the cloudiest day.

1997-2006

To see if sunshine displays a similar trend as temperature data, the same model was run for the 1997-2006 period. Again no significant weekly cycles could be found, but there are nine locations that display a significantly cloudier or sunnier day.

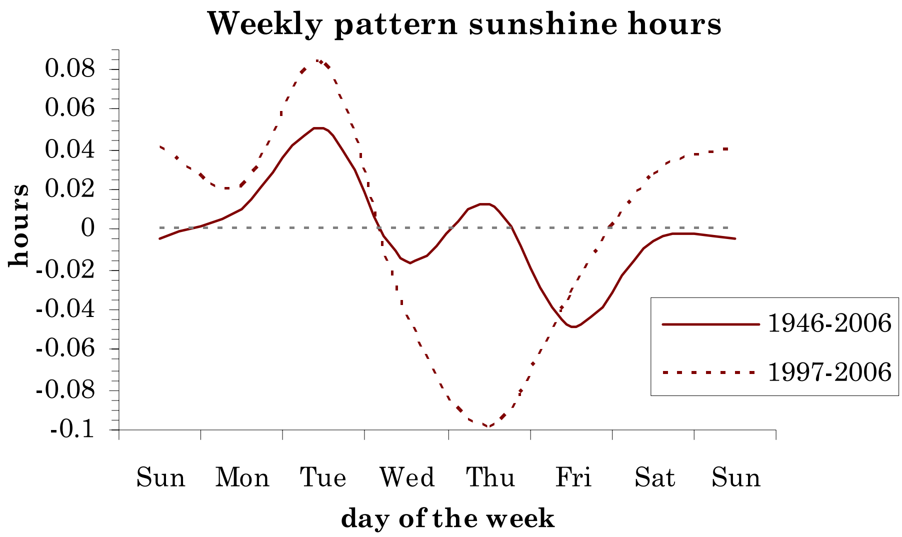

Figure 16. The weekly pattern of sunshine hours for the 1946-2006 period (solid lines), and the 1997-2006 period (dotted lines) displayed per day of the week. The day of the week is on the x-axis, and the daily difference from the weekly average (in hours) is on the y-axis.

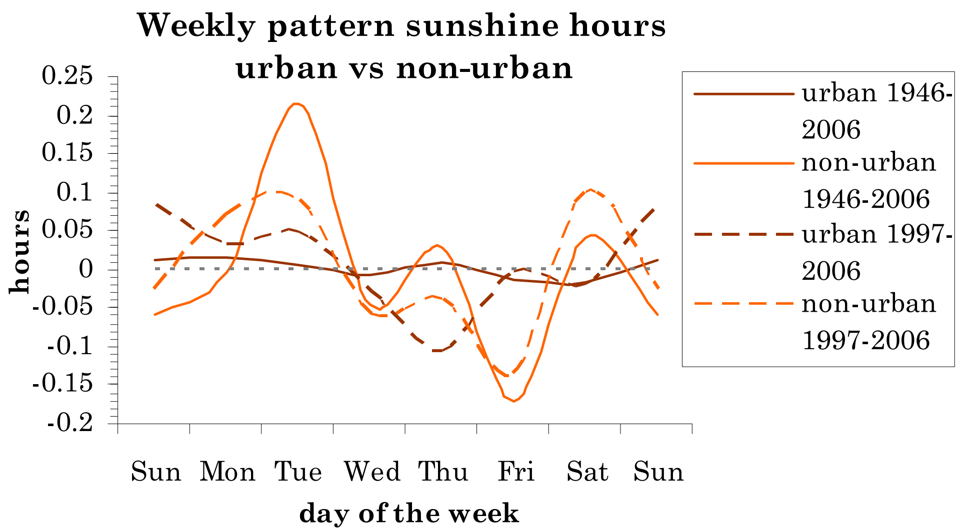

Figure 17. The weekly pattern of sunshine hours for the 1946-2006 period (solid lines), and the 1997-2006 period (dotted lines) displayed for both stations that at an urban (brown) and at a non-urban (orange) location. The day of the week is on the x-axis, and the daily difference from the weekly average (in hours) is on the y-axis.

The amplitude of the weekly pattern has increased largely, but the sunniest and cloudiest days are still in the same period of the week (Tuesday being the sunniest and Friday being the cloudiest).

Comparing urban and non-urban areas for sunshine for the 1997-2006 and 1946-2006 (figure 17) shows an increase in sunshine hours for the urban areas, and a decrease for the non-urban areas. For the urban locations, the sunniest day of the week is Sunday, and the cloudiest day is Thursday. For the non-urban locations, Saturday is the sunniest day of the week, while Friday is the cloudiest day of the week.

Precipitation

1946-2006

For precipitation, it is very hard to detect a pattern at all. Out of 32 stations, only two stations with a significant weekly cycle can be detected: Ni (Serbia) and Brest Zonalya (Belarus). Fourteen out of 32 displayed a day with significantly more or less precipitation. At these fourteen stations, there are twelve days with significantly less precipitation, and six days with significantly more precipitation.

In figure 18a and b, a scatter plot of precipitation per day per station is displayed, showing very little significant values. Thursday and Saturday seem to be the wettest, but this figure shows no further results.

For the two stations with a significant weekly cycle, Thursday is the driest day of the week, and Monday is the wettest day of the week (figure 18). Thursday is much drier than Monday is wetter. For stations with no significant weekly cycle, the difference during the week is very small, with an amplitude of only 0.007 mm. Tuesday is the driest day of the week, while Wednesday is the wettest day of the week.

Comparing urban and non-urban areas, Thursdays are driest in urban areas, and Wednesdays are wettest. In non-urban areas Saturdays are driest, and Wednesdays are wettest. However, the difference is not very large, and

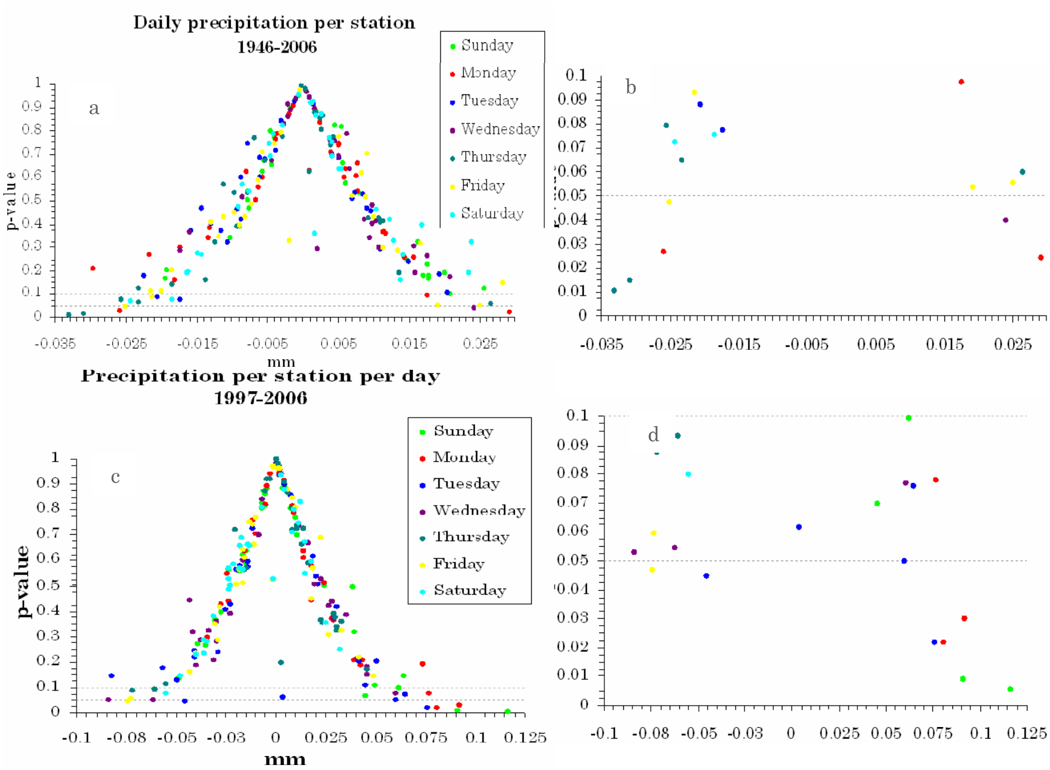

Figure 18. Scatter plot of precipitation amount (mm) for the period of 1946-2006 (a) and (b), and 1997-2006 (c) and (d) during the week for all stations, where (a) and (c) show all days for all stations, and (b) and(d) shows only the significant days for all stations. p-values are displayed on the y-axis, and temperature values (in °C) are displayed on the x-axis.

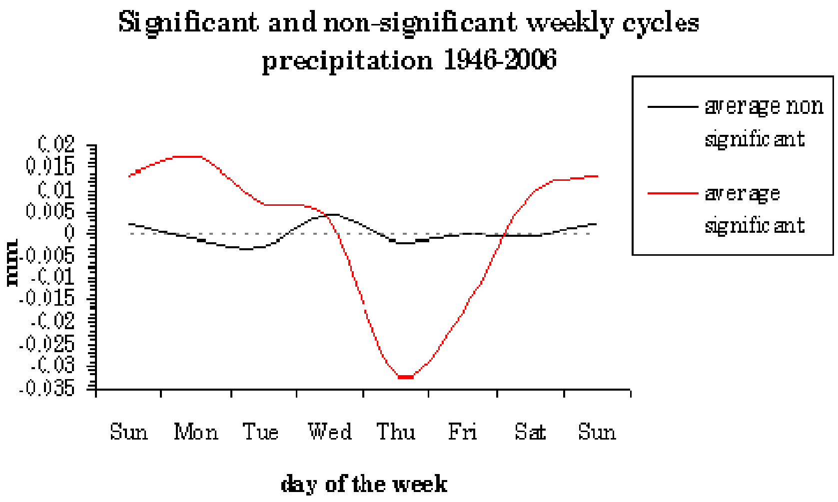

Figure 20. The weekly pattern of precipitation for 61 years displayed for both stations that do (red) and do not (black) display a significant weekly cycle. The day of the week is on the x-axis, and the daily difference from the weekly average (in mm) is on the y-axis.

there seems no further pattern between urban and non-urban areas (see figure 21).

In figure 22 weekly precipitation per area in Europe is displayed. The wettest day is on Thursday, Thursday, Saturday, and Tuesday for respectively Northeastern, Southeastern, Northwestern, and Southwestern Europe, while the driest day is on respectively Wednesday, Monday, Wednesday and Friday.

1997-2006

For 1997-2006 , there is only one station that displayed a significant weekly cycle: Zürich (Switzerland). There are again fourteen stations that display at least one day with a significant difference in precipitation. Of these differences, twelve are above the weekly average, and six are below. For 1997-2006 the extremes have become larger (figure 18): Between -0.1 and 0.1mm instead of between -0.035 and 0.035mm. There are a little more significantly drier or wetter day, with most wet days on Sunday-Tuesday, and most dry days on Wednesday-Saturday.

Looking at weekly precipitation for Zürich and at the average for the non-significant weekly cycles it becomes clear that the middle part of the week is wettest for Zürich, with the wettest day on Thursday (figure 23). The driest part of the week is the weekend, with the driest day on Sunday. The driest days are much drier than the wettest days are wet. For the non-significant stations the driest period of the week is on Sunday and Monday, and the wettest period of the week is on Friday and Saturday.

For the urban and non-urban areas for the 1997-2006 period (figure 21), both the urban and the non-urban graph show a much higher amplitude than the urban and non-urban graph for the 1946-2006 period (0.051 (1997-2006) vs. 0.012 (1946-2006) for the urban graph, 0.035 (1997-2006) vs. 0.13 (1946-2006)

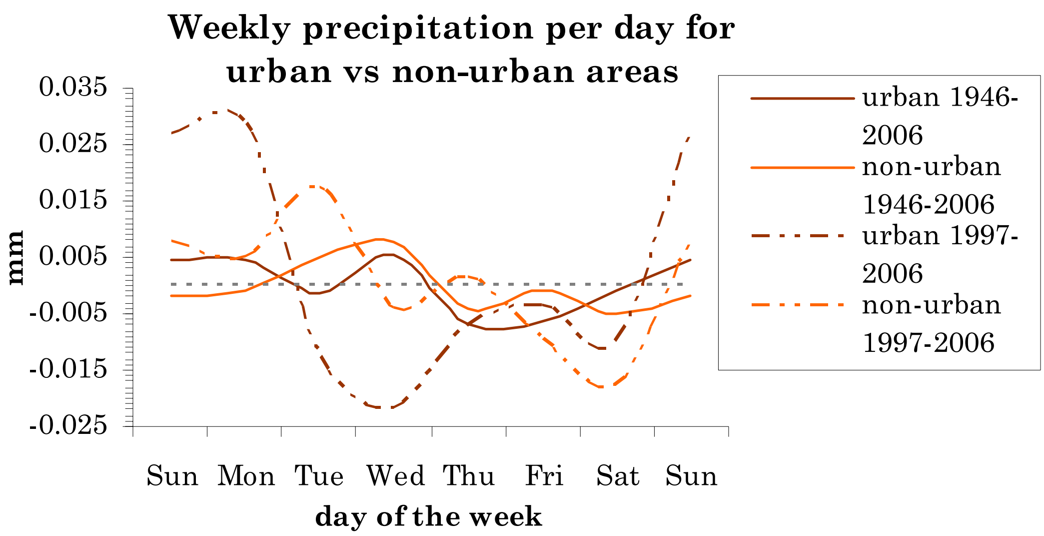

Figure 21. The weekly pattern of precipitation for the urban (brown) and non-urban (orange) locations in Europe for 1946-2006 (solid lines) and 1997-2006 (dashed lines). Only locations where a significantly colder or warmer day of the week can be found were taken into account.

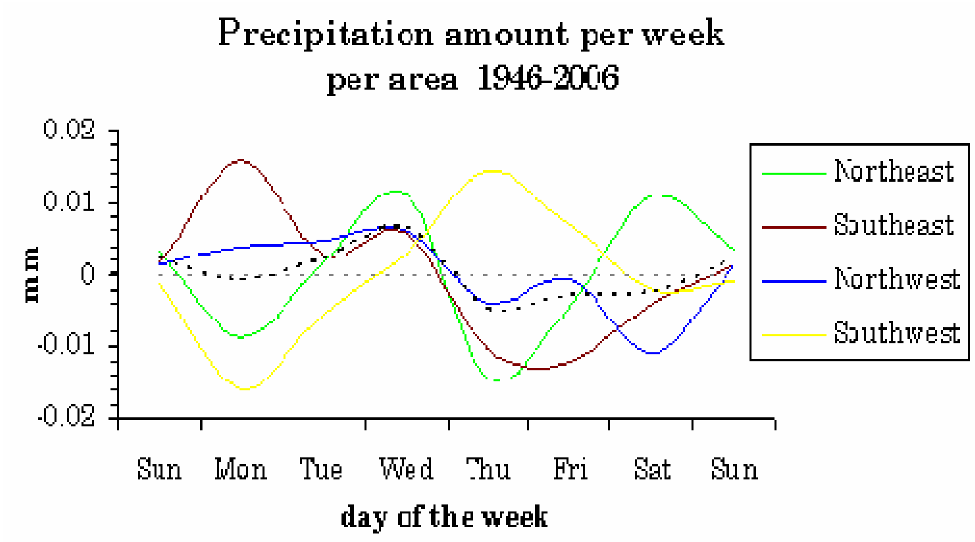

Figure 22. The weekly pattern of precipitation for the four different regions in Europe for 61 years displayed for all stations where a significantly wetter or drier day of the week was found. The day of the week is on the x-axis, and the daily difference from the weekly average (in mm) is on the y-axis. The black dotted line indicates the overall average.

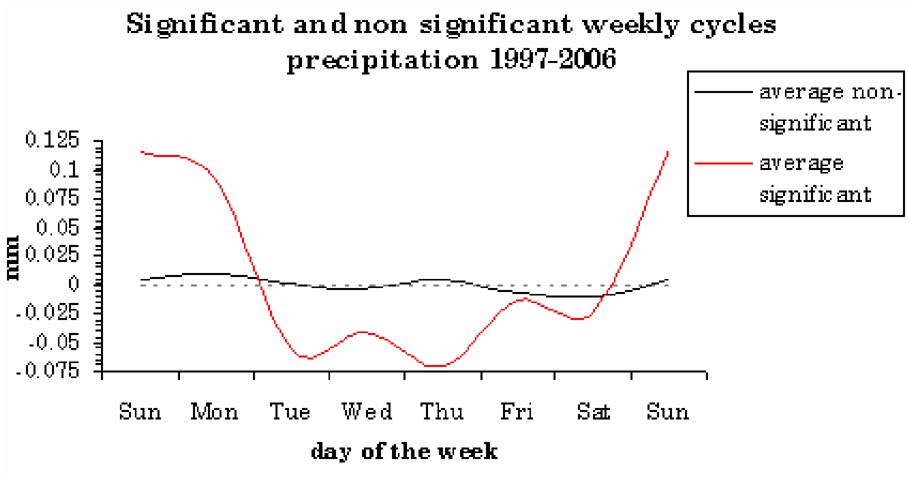

Figure 23. The weekly pattern of precipitation for 1997-2006 displayed for both the stations that do (red) and do not (black) display a significant weekly cycle. The day of the week is on the x-axis, and the daily difference from the weekly average (in mm) is on the y-axis.

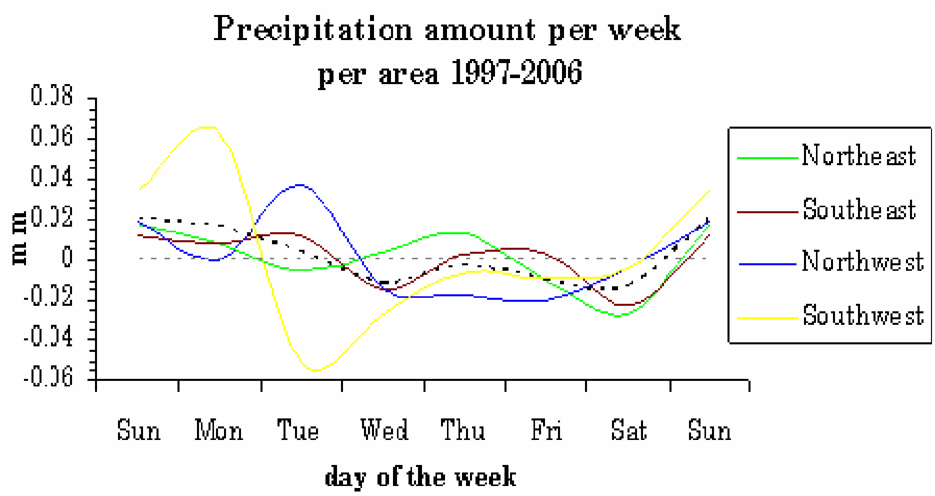

Figure 24. The weekly pattern of precipitation for the four different regions in Europe for the 1997-2006 period displayed for all stations where a significantly wetter or drier day of the week was found. The day of the week is on the x-axis, and the daily difference from the weekly average (in mm) is on the y-axis. The black dotted line indicates the overall average.

for the non-urban graph). For the urban areas precipitation increases from Wednesday until Monday, and displays a sharp decrease from Monday until Wednesday. For the non-urban areas precipitation increases from Saturday until Tuesday, and decreases from Tuesday until Saturday.

Comparing the different areas around Europe (figure 24), the Northeast is no longer the area that shows the largest differences. Both the Northeast and the Northwest are very similar to the average weekly pattern (the Northwest is a little more similar than the Northeast). The Southeast also shows a good weekly pattern, with a lead of one day for the driest day, and the wettest day on the same day as the overall average. The Southwest, however, shows a completely different pattern with much larger extremes. The driest day is also at the beginning of the week, but the wettest day is now at Tuesday (though this is similar to the wettest day for the Southwest for the 61-year period).

Discussion

Mean temperature

1946-2006

Table 2.Summary of mean temperature results 1946-2006

Graph	Colder	Warmer	Amplitude
Significant weekly cycles	Saturday	Monday	0.052
Non-significant weekly cycles	Saturday	Monday	0.027
Pattern with significant days	Saturday	Monday	0.033
Northeast	Sunday	Friday	0.109
Southeast	Saturday	Monday	0.062
Northwest	Friday	Monday	0.072
Southwest	Sunday	Friday	0.050

Of the six stations where a significant weekly cycle is visible, four are located in Northern Europe 50°N. One would not expect weekly cycles to be significant there, because human influence is minimal, and thus so is air pollution (EEA, 2007). An explanation might be that at these locations, due to the relatively clean air, small scale cycles and patterns, such as the weekly cycle are easier to detect.

Another possibility is that of advection. Because Europe is mainly influenced by southeastern winds aerosols from southwestern Europe are transported northwards, perhaps enhancing weekly pattern in the north.

In figure 3 both the curves that do and do not display a significant weekly cycle have roughly the same shape. The amplitude between the curves differs 0.035 °C. This is not only because the red curve displays the average for locations with a significant weekly cycle (red), but also because the black curve is an average of 39 stations, and the red curve is an average of 7 stations. This automatically leads to a much smoother average for the black curve. Another factor might be that nearly all stations that do display a significant weekly cycle are located in Northern Europe.

The shape of the curve might be (partly) explained by the geographical location of these stations: e.g. wind and advection.

The different areas around Europe display large differences in the weekly pattern, with both the Northwest and the Southeast showing a similar pattern to the overall average, but the Northeast and Southwest show a different graph. The cold days are quite similar around Europe, but the warmest period of the week differs. This is an indication that there is some difference between the different locations.

For instance, the influence of the, mainly southwestern, winds in Europe. This would mean that, assuming a positive correlation with aerosols from North- and Southwestern Europe are transported to the Northeast during the week. That the coldest day of the week falls on nearly the same day as for the rest of Europe can in that case perhaps be explained by the fact that anthropogenic emissions in this area are larger than in the rest of Europe. With the rise and fall of the Soviet Union, and the sudden rise of capitalism, this might be true. Also, mainly in winter, there is little oceanic influence in this area of Europe. This might affect winter temperatures, that in turn might affect the average for this area. However, an exact mechanism for this idea remains to be seen. Another possible explanation could be the difference in aerosol type and amount in Europe (Querol et al., 2004).

In southwestern Europe, Europe's main mountain ranges (such as the Alps, the Pyrenees, and the Apennines) can be found. Together with these mountain ranges come climate effects such as the Föhn and the Mistral. Perhaps their occurrence interferes with the weekly pattern. If (many parts of) the weekly pattern are influenced, the averages could be affected in such extend that another pattern is visible.

Another, more likely, possible reason could be that, in the Mediterranean area, high levels of solar irradiation in combination with biogenic and anthropogenic ozone precursors favor photochemical ozone production (Filella and Peñuela, 2006). The weekly pattern for ozone produces, in favorable meteorological conditions and in Switzerland, peaks on Thursday and Friday, and a lower value on Saturday (Brönnimann, 1997). This is similar to the pattern temperature displays in the Southwest. Since photochemical ozone production depends on aerosols, there seems to be a positive correlation here between aerosols and temperature

The geographical spread around Europe in figure 5 further confirms the idea that there is a difference between oceanic and continental locations; stations with a significantly colder day of the week are mainly continental, and stations with a significantly warmer day of the week do have a more coastal location. The mechanism behind this is not clear, however.

That there are more stations with a significantly different day in northwestern Europe can be partly understand by the idea that northwestern Europe is (and especially was, compared to 1946 standards) a much denser populated area, and thus much more anthropogenic emissions (Mayer, 1999).

For urban versus non-urban stations it can only be seen that the amplitude of non-urban stations is lower, and that the coldest day of the week falls a day earlier at non-urban stations. This is probably due to the lower amount of aerosols in the air at non-urban areas. That the coldest day of the week is a day earlier at non-urban areas might be explained by the fact that there are so many aerosols in the air at urban locations that there is some kind of delay in displaying the coldest day. Why this effect is only visible on Friday is not clear though.

Other periods

Table 3.Summary of mean temperature results decades.

Period	Graph	Colder	Warmer	Amplitude
1946-1956	Northeast	Monday	Thursday	0.188
	Southeast	Wednesday	Thursday	0.123
	Northwest	Tuesday	Sunday	0.163
	Southwest	Sunday	Thursday	0.112
	Overall average	Monday	Saturday	0.053
1957-1966	Northeast	Saturday	Thursday	0.205
	Southeast	Friday	Sunday	0.282

	Northwest	Tuesday	Friday	0.115
	Southwest	Tuesday	Saturday	0.136
	Overall average	Tuesday	Sunday	0.091
1967-1976	Northeast	Thursday	Tuesday	0.242
	Southeast	Thursday	Wednesday	0.246
	Northwest	Thursday	Sunday	0.104
	Southwest	Friday	Wednesday	0.086
	Overall average	Friday	Monday	0.06
1977-1986	Northeast	Friday	Monday	0.135
	Southeast	Wednesday	Sunday	0.279
	Northwest	Wednesday	Saturday	0.103
	Southwest	Thursday	Sunday	0.157
	Overall average	Wednesday	Saturday	0.118
1987-1996	Northeast	Tuesday	Sunday	0.337
	Southeast	Tuesday	Friday	0.151
	Northwest	Tuesday	Saturday	0.185
	Southwest	Wednesday	Saturday	0.117
	Overall average	Tuesday	Friday	0.155
1997-2006	Northeast	Friday	Sunday	0.117
	Southeast	Wednesday	Tuesday	0.157
	Northwest	Monday	Wednesday	0.263
	Southwest	Saturday	Monday	0.153
	Overall average	Wednesday	Saturday	0.111
	Significant weekly cycles	Monday	Saturday	0.219
	Non-significant weekly cycles	Tuesday	Friday	0.055

That for the period 1997-2006 there are less stations that displayed a significant weekly cycle or a significantly different day of the week in mean temperature is not completely as expected: Since 1946 a lot of areas around Europe have developed, and anthropogenic emissions have enhanced (IPCC, 2007).

On the other hand, the air has also become a lot cleaner in the last few decades; due to an increase in energy efficiency and a switch from coal and oil to lighter oil and gas, there was a drop of PM_{10} of 44% and a reduction of emissions of fine particulates and particulate precursor gases of 36% from 1990-2004 (EEA ,2007). Van der A (2008) found a reduction of NO_2 of up to 7% per year in Europe for the last ten years. All this may have affected the weekly cycle negatively.

Comparing the graphs in figure 9, the trend for the different decades is quite consistent throughout the six decades, with a decrease at the beginning of the week, and an increase near the end of the week. However, comparing the graphs with figure 4, the trend is almost exactly opposite. A similar trend was found by Lawrence (1971) with Sundays to be warmer and Thursdays to be cooler in London for the period 1949-1968. However, other authors do not mention a similar pattern. However, Forster and Solomon (2003) do mention a change in the weekend effect through time for the USA.

Exactly how or why this opposite pattern occurs is unclear, but it seems to be due to averaging. When looking at data for single locations, there is a transition visible (though not very clearly) from, the first three or four decades to the last three to two decades (figure 25).

Perhaps an explanation for this transition in the weekly cycle can be found in aerosols. Many environmental rules and regulations have been implemented in the last decades. This changed the type of aerosols in the air IPCC (2007) and the way they influence meteorology. For instance, the amount of aerosols in the air has decreased, while the amount of GHG has increased (IPCC, 2007; see above). If one assumes that aerosols have a cooling effect, and greenhouse gases have a warming effect (Ramanathan, 2001), this could explain the transition of the warmest and the coldest period of the week.

In figure 9, the change in amplitude of the weekly pattern in the Northeast and Southeast might be partly explained by the falling apart of the Soviet Union: this caused many polluting factories to close, and a more uniform environmental policy around Europe.

In the Southwest, the increase in extremes can perhaps be seen as a change of being more influenced by ozone (Filella and Peñuela, 2006; Brönniman, 1997).

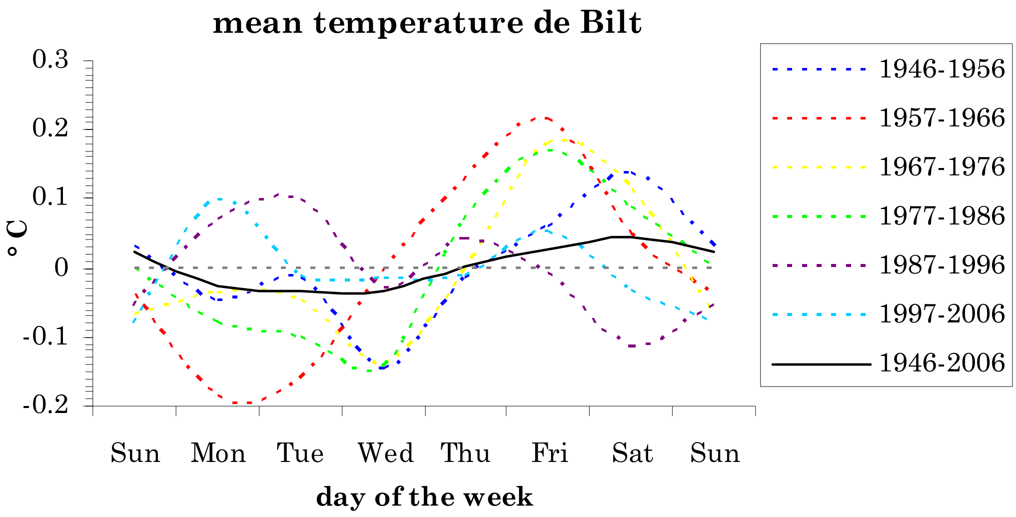

Figure 25. Average weekly mean temperature for station the Bilt (Netherlands) for all reviewed periods.

Minimum and maximum temperature

1946-2006

Table 4.Summary of minimum and maximum temperature results 1946-2006

	Graph	Colder	Warmer	Amplitude
Pattern	TN	Sunday	Monday	0.076
	TX	Sunday	Monday	0.053
	TG	Saturday	Monday	0.045
Urban	TN	Sunday	Tuesday	0.088
	TX	Saturday	Monday	0.099
	TG	Saturday	Monday	0.057
non-urban	TN	Friday	Saturday	0.030
	TX	Friday	Monday	0.023
	TG	Thursday	Monday	0.023
Northeast	TN	Sunday	Wednesday	0.112
	TX	Sunday	Thursday	0.107
	TG	Sunday	Thursday	0.109
Southeast	TN	Sunday	Friday	0.167
	TX	Wednesday	Monday	0.256
	TG	Saturday	Monday	0.062

Northwest	TN	Friday	Monday	0.065
	TX	Friday	Monday	0.053
	TG	Friday	Monday	0.075
Southwest	TN	Sunday	Thursday	0.071
	TX	Monday	Saturday	0.074
	TG	Sunday	Thursday	0.050

For minimum temperatures, three out of four of all locations displaying a significant weekly cycle are in Scandinavia. For maximum temperature, two out of five locations displaying a significant weekly cycle are located in Scandinavia. Oestersund even shows a significant weekly cycle in mean, minimum, and maximum temperature (figure 26). All this supports the idea that at more Northern locations temperatures show a better weekly cycle, perhaps due to advection from the more Southern parts of Europe.

Comparing the weekly pattern for mean, minimum, and maximum temperatures (figure 11), showed that mean temperature is much more influenced by maximum temperature than by minimum temperature. On Wednesday and Thursday, mean- and maximum temperature are even almost identical, indicating that the influence of minimum temperature on those days can be neglected. Perhaps an explanation is that both men and maximum temperature are (usually) measured during day time, while minimum temperatures usually occur during night time.

Comparing urban versus non-urban values, minimum temperature displays an extra increase on Friday in urban areas. Why is unclear; There are no clear events that take place on Friday. Perhaps this is due to the fact that the mean temperature of the previous day is higher than the minimum temperature.

For the different regions around Europe, minimum- and maximum temperature behave differently per region. Maximum temperature throughout Europe is much more uniform than minimum and mean temperature (figure 13), perhaps because during the day the boundary layer is in an unstable condition that can be locally influenced, while during the night boundary layer is much more stable.

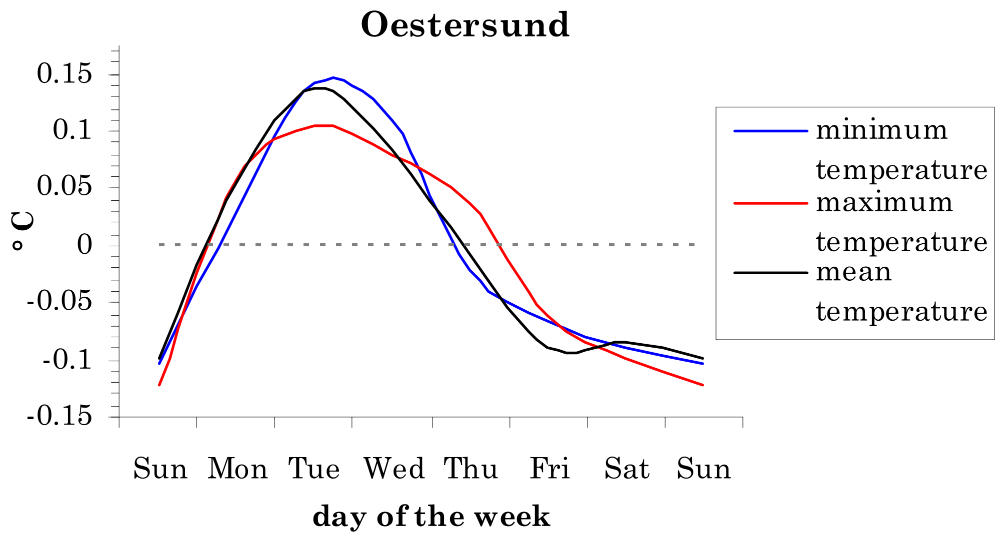

Figure 26. Average weekly minimum, maximum, and mean temperature for station Oestersund (Sweden).

1997-2006

Table 5.Summary of minimum and maximum temperature results 1997-2006

	Graph	Coldest	Warmest	Amplitude
Pattern	TN	Tuesday	Friday	0.059
	TX	Monday	Friday	0.058
	TG	Tuesday	Friday	0.058
Urban	TN	Tuesday	Wednesday	0.102
	TX	Monday	Friday	0.173
	TG	Monday	Saturday	0.094
Non-urban	TN	Friday	Monday	0.161
	TX	Sunday	Wednesday	0.145
	TG	Tuesday	Saturday	0.122
Northeast	TN	Friday	Sunday	0.087
	TX	Friday	Thursday	0.085
	TG	Friday	Sunday	0.117
Southeast	TN	Saturday	Wednesday	0.279
	TX	Saturday	Tuesday	0.450
	TG	Wednesday	Tuesday	0.157
Northwest	TN	Saturday	Wednesday	0.110
	TX	Sunday	Tuesday	0.130
	TG	Monday	Wednesday	0.263

Southwest	TN	Tuesday	Saturday	0.229
	TX	Monday	Friday	0.288
	TG	Monday	Saturday	0.153

For the 1997-2006 period, it is difficult to determine the influence of minimum and maximum temperature on mean temperature (figure 14). The influence of maximum temperature seems to have decreased, while the influence of minimum temperature has increased. This is supported by the IPCC (2007) and Vose (2005), who found that the increase of minimum temperature increased almost twice as fast as maximum temperature. This change is probably due to changes in cloud cover, precipitation, soil moisture, and atmospheric circulation (Vose, 2005).

From figure 14 it seems that the influence of the minimum temperature is greater in the colder period of the week, while the influence on the maximum temperature is greater in the warmer period of the week. If this is true, and if so how is unclear.

The data for urban and non-urban areas, and for different areas around Europe all show a decrease of the influence of maximum temperature, and an increase of the influence on minimum temperature, as found by Vose (2005).

Sunshine

1946-2006

Table 6.Summary of sunshine duration results 1946-2006 and 1997-2006

Period	**Graph**	**Colder**	**Warmer**	**Amplitude**
1946-2006	Weekly Pattern	Friday	Tuesday	0.097
	Urban	Saturday	Monday	0.032
	Non-urban	Friday	Tuesday	0.3896
1997-2006	Weekly Pattern	Thursday	Tuesday	0.181
	Urban	Thursday	Sunday	0.188
	Non-urban	Friday	Saturday	0.234

For sunshine, only nine stations displayed a significantly cloudier or sunnier day. And contrary to what Hendricks Franssen (2008) found, a significantly sunnier day on Wednesday at Zürich was found for the 1946-2006 period. However, the significance level was only 91%, and not 95%, what the author looked for. And perhaps taking data from 1901 (as H. Franssen did), no significantly different days can be found.

For Germany, the station of Nurnberg displayed one significantly cloudier day, while the station of Helgoland did not. This is contrary with Bäumer and Vogel (2007), who found significantly cloudier and sunnier days in many stations around Germany, i.e. Helgoland. According to the authors, the weekly cycle is small, however, and only the period 1991-2005 was taken into account.

The amplitude of the weekly pattern for sunshine during the period 1946-2006 is quite small. Tuesday is the sunniest day, while Friday is the cloudiest day. This sunniest day is supported by Bäumer and Vogel (2007) who found sunshine duration to be higher on Tuesday. He found sunshine to be lower on Saturday, which is only one day away from Friday. However, Bäumer and Vogel (2007) used data from 1991-2005, so it might not be correct to make a one on one comparison.

Fujibe (1987) found a smaller cloud amount on Sunday in Tokyo, (Japan). Considering that this is in Asia, and subjected to different meteorological conditions, it would be reasonable that this is, somehow, two days earlier than Europe.

The urban graph for displays only a very small weekly pattern, while the non-urban graph gives a very clear weekly pattern. The pattern for non-urban location should, assuming a positive correlation with aerosols, show larger amplitude. However, the fact that the difference is this large is probably mainly due to the fact that there are only two non-urban locations. Both urban and non-urban areas do show a similar pattern.

1997-2006

For 1997-2006, again nine stations displayed a significantly cloudier or sunnier day. Contrary to Hendricks Franssen (2008) Lugano (Switzerland) showed a significantly sunnier day. However, significance was again only 90%, which is below the significance level what H. Franssen looked for.

The weekly pattern for 1946-2006 and 1997-2006 is very similar. The amplitude has increased largely, but this is expected, since the amount of aerosols in the air has decreased (again assuming a negative correlation with aerosols). This period is much more similar to the period taken into account by Bäumer and Vogel (2007), and still has Tuesday as the sunniest day. The cloudiest day of the week is now on Thursday however, which is not in line with Bäumer and Vogel (2005). However, with so few stations and such a large spatial spread, this is possible.

For the urban and non-urban locations, the amplitude has increased for the urban areas, and decreased for the non-urban areas. Of course, this is also due to the fact that there are now four non-urban stations with a significant day of the week, displaying a better average. However, it indicates again that the effect of aerosol reduction in urban areas is (relatively speaking) larger than in non-urban areas. Also, non-urban areas have developed more as well, increasing their anthropogenic emissions.

That there is not much change in the weekly pattern for sunshine, and there is for temperature is quite curious, since both are assumed to depend on aerosols. However, it is also an indication that the problem is not in the model.

A possible explanation is that the influence of aerosols on the different mechanisms that influence temperature and sunshine is not clear yet, so there can not be a one on one comparison of temperature-aerosol and sunshine-aerosol connections.

Precipitation

Table 7.Summary of sunshine precipitation amount results 1946-2006 and 1997-2006

Period	Graph	Driest	Wettest	Amplitude
1946-2006	Significant cycles	Thursday	Monday	0.049
	Non-significant cycles	Tuesday	Wednesday	0.007
	Urban	Thursday	Wednesday	0.012
	Non-urban	Saturday	Wednesday	0.013
	Northeast	Thursday	Wednesday	0.026
	Southeast	Friday	Monday	0.028
	Northwest	Saturday	Wednesday	0.017
	Southwest	Monday	Thursday	0.030
1997-2006	Significant cycles	Thursday	Sunday	0.193
	Non-significant cycles	Saturday	Monday	0.022
	Urban	Wednesday	Monday	0.051
	Non-urban	Saturday	Tuesday	0.035
	Northeast	Saturday	Sunday	0.044
	Southeast	Saturday	Sunday	0.034
	Northwest	Saturday	Tuesday	0.058
	Southwest	Tuesday	Monday	0.115

1946-2006

For precipitation, the significant weekly cycle is different from the non-significant weekly cycle. However, there are only two stations with a significant weekly cycle, so it is not possible to conclude that this is a regular weekly pattern for Europe. For the other stations, it is difficult to distinguish a clear trend. This means that either there is no clear difference throughout the week. However, when the wettest and the driest day directly follow each other up, this indicates that the presence of a smooth weekly pattern is not very likely.

That there is less precipitation in non-urban areas compared to urban areas agrees with the ideas described in Schultz (2007) and Ramanathan (2001) that more aerosols cause less precipitation.

For the different areas around Europe one could say that, with the exception on Southwestern Europe, the wettest day is more at the end of the week, and the driest day is more at the beginning of the week. However, the difference from day to day is quite large.

The curve for the Northwest is most similar to the overall curve. One part of this can probably explained by the fact that precipitation in northern Europe has decreased over the past 40 years, while it has decreased in the Mediterranean (IPCC, 2007). The other part can than be explained by the fact that Northwestern Europe receives much precipitation from the North Atlantic Ocean, and thus is wetter than Northeastern Europe, which is more influenced by continental climate.

1997-2006

That for this period Zürich displayed a significant weekly cycle and significantly wetter and drier days, is contrary to what Hendricks Franssen (2008) found for the same station for the period 1991-2005. However, he did find a similar weekly pattern.

Comparing the significant with non-significant weekly cycle for this period shows that the beginning of the week is drier, and the end of the week is wetter for the non-significant weekly cycle, but that the middle part of the week is driest for the significant cycle (figure 21). However, one station is compared with the average of 33. The significant weekly cycle one station might deviate from significant weekly cycles from other stations around Europe (which were not taken into account here). Also, a one on one comparison of weekly extremes between the two graphs does not show an accurate picture of weekly precipitation.

The difference between urban and non-urban areas has decreased (figure 22). Assuming there is a negative correlation between aerosols and precipitation this supports the idea that aerosols have (relatively seen) decreased more in urban than in non-urban areas.

For the urban areas, precipitation decreases during the week, and increases in the weekend. This is exactly opposite to what Bäumer and Vogel (2007) found for Germany; he found Mondays to be drier and Saturdays to be wetter. However, it is in concurrence with the idea that more aerosols in the air cause a decrease in precipitation (Jin et al., 2005; Schultz et al., 2007).

For the weekly pattern of precipitation around Europe amplitudes for all areas except for the Southwest have decreased. This is another indication that, meteorological values in Southwestern Europe are differently influenced than for the rest of Europe.

All in all, there are a lot of different weekly pattern visible for precipitation, but none of them is very consistent. It is therefore possible that there is no clear pattern visible in precipitation (Schultz, 2007; deLisi, 2001). Because there is no clear idea yet on the connection between aerosols and precipitation (Jin et al., 2005), it is hard to distinguish a clear weekly pattern; it could be that there is some kind of lead in aerosols.

Conclusions

Weekly cycles can be found around Europe in temperature and precipitation. However, they are not very common, and they do not show a clear spatial pattern throughout Europe. The only surprising feature of these weekly cycles is that for mean, minimum, and maximum temperature for 1946-2006, weekly cycles occur mainly in Scandinavia and Greenland. Since this is a relatively sparsely populated area, this is quite peculiar. An explanation might be found in advection; the main wind direction in Europe is southwest, and so aerosols that are exhausted in other parts of Europe all build up in the North, causing a weekly cycle.

Weekly patterns with one or more significantly different day, on the other hand, are more common, and can be found in temperature, sunshine, and precipitation. However, they again do not show a clear spatial pattern throughout Europe. The amount of these weekly patterns decreases through time, but there is an increase in amplitude. This is supported by Fujibe (1987), who found an increase in the weekend effect.

For the 1946-2006 period temperature displays a decrease during the week and an increase during the weekend. This is supported by i.e. Bäumer and Vogel (2007) in Germany, Gong (2006) in China, and Forster (2003) in the USA. For sunshine duration roughly the same weekly pattern can be seen, though not as clear. This is supported by Bäumer and Vogel (2007) and Fujibe (1987). For precipitation there is an increase from the middle of the week to the end of the week, end a decrease from the end of the week to the middle of the week. However, the amplitude is very small, so it is better to not assume a weekly pattern in precipitation for this period and these stations. An absence of a weekly pattern in precipitation was also found by Schultz (2007) and deLisi (2001).

Through time, for six decades, mean temperature displays a different weekly pattern for 1946-2006. The end of the week is now the warmest period

of the week, while the beginning is the coldest part of the week. This same pattern has been found by Lawrence (1971) in London (Great Britain) for the period 1949-1968, but not by any other authors. It is quite curious that the weekly pattern has changed, and that none of the six decades graphs resemble the 1946-2006 graph. When looking at single station data this transition of warm and cold periods is better visible. So, it can be concluded that this transition is real, but can not be seen in figure 9, because it is somehow averaged out. Also, Forster and Solomon (2003) found a change in the weekend effect through time for some areas in the USA.
A possible reason for this transition in temperature might me a difference in the type of human exhaustion (IPCC, 2007).

For the 1997-2006 period the transition that is visible in mean temperature is not (or not very strongly) visible in sunshine and precipitation. Both sunshine duration and precipitation display a stronger weekly pattern for this period. Sunshine duration show a decrease from Thursday until Tuesday increases, and decreases from Tuesday until Thursday. For precipitation there is a clear pattern throughout the week, with a decrease during the week, and an increase during the weekend. That there are changes in temperature, sunshine, and precipitation supports the idea of changes in human exhaustion. A reduction in aerosols and an increase in greenhouse gases is a possibility; aerosols have a cooling effect while greenhouse gases have a warming effect (Ramanathan, 2001). And, if assuming that fewer aerosols induce precipitation (the reduction in aerosols might have made a weekly pattern in precipitation visible) (Jin et al., 2005; Ramanathan, 2001).

For future research it might be interesting to look better into how this weekly cycle develops over time. Perhaps investigating different seasons might give a better clue. Gong (2006) and Simmonds and Keay (1997) found a difference in weekly patterns between summer and winter in China and

Australia. Also a better investigation of rural-urban relationships could give more information on the influence of wind action and other local influences.

It might be interesting to look at specific regions in Europe, or perhaps specific altitudes. It might also be interesting to further investigate the differences between rural and urban areas.

All in all, there is evidence of a weekly pattern in meteorological variables around Europe, but a spatial pattern can not be found. A connection with aerosols seems very likely, although the exact mechanism behind this connection is not clear (Jin, 2005).

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Appendix A, Extended list of stations

Number	Location	Country	Latitude	Longitude	Altitude	Temperature	Precipitation	Sunshine	Urban
153	Karasjok	Norway	+69:28:00	+25:31:00	129	yes	yes	no	no
254	Ilulissat	Greenland	+69:13:12	-51:06:00	39	yes	yes	no	no
27	Sodankyla	Finland	+67:22:00	+26:39:00	179	yes	yes	no	no
255	Tassilaq	Greenland	+65:36:00	-37:38:00	50	yes	yes	no	no
61	Dalatangi	Iceland	+65:16:00	-13:35:00	9	yes	no	no	no
62	Reykjavik	Iceland	+64:08:00	-21:54:00	52	yes	yes	no	yes
6	Oestersund	Sweden	+63:11:00	+14:29:00	376	yes	yes	no	yes
25	Helsinki	Finland	+60:10:00	+24:57:00	4	yes	no	no	yes
295	Lerwick	UK	+60:08:00	-01:11:00	82	yes	yes	no	no
278	Torungen Fyr	Norway	+58:24:00	+08:48:00	12	yes	yes	no	no
296	Stornoway	UK	+58:19:48	-06:19:12	9	no	yes	no	no
91	Pskow	Russia	+57:49:00	+28:25:00	45	yes	yes	no	yes
876	Ballyshannon	Ireland	+54:30:00	-08:10:44	38	no	no	yes	no
413	Helgoland	Germany	+54:11:00	+07:54:00	4	yes	yes	yes	no

Number	Location	Country	Latitude	Longitude	Altitude	Temperature	Precipitation	Sunshine	Urban
417	Rostock	Germany	+54:11:00	+12:05:00	4	yes	yes	no	yes
298	Waddington	UK	+53:10:00	-00:31:00	68	yes	no	no	yes
109	Birr	Ireland	+53:05:25	-07:52:35	70	yes	yes	no	no
32	Berlin	Germany	+52:27:00	+13:18:00	55	yes	yes	no	yes
594	Brest Zonalya	Belarus	+52:07:12	+23:42:24	141	yes	yes	no	no
128	de Bilt	Netherlands	+52:06:00	+05:11:00	2	yes	yes	yes	yes
14	Ukkel	Belgium	+50:48:00	+04:21:00	100	yes	yes	no	yes
430	Nurnberg	Germany	+50:22:00	+06:52:00	485	no	no	yes	yes
66	Aleksandrow	Russia	+50:09:00	+48:33:00	50	yes	yes	no	no
868	Luxembourg	Belgium	+49:37:24	+06:12:18	38	no	no	yes	no
217	Poltava	Ukraine	+49:36:00	+34:33:00	160	yes	yes	no	yes
13	Wien	Austria	+48:14:00	+16:21:00	198	no	no	yes	yes
269	Rennes	France	+48:04:00	-01:44:00	36	yes	yes	no	yes
8	Kremsmuenster	Austria	+48:03:00	+14:08:00	383	yes	no	no	no
190	Hurbanovo	Slovakia	+47:52:38	+18:12:04	115	no	no	yes	no
54	Zugspitze	Germany	+47:25:00	+10:59:00	2960	yes	yes	no	no
206	Zurich	Switzerland	+47:23:00	+08:34:00	556	yes	yes	yes	yes

Number	Location	Country	Latitude	Longitude	Altitude	Temperature	Precipitation	Sunshine	Urban
180	Arad	Romania	+46:08:00	+21:21:00	117	yes	yes	no	yes
189	Varfu Omul	Romania	+45:27:00	+25:27:00	2504	yes	no	no	no
1579	Rijeka	Croatia	+45:20:00	+14:27:00	120	no	no	yes	yes
132	Bologna	Italy	+44:29:00	+11:15:00	60	yes	yes	no	yes
184	Calarasi	Romania	+44:12:00	+27:20:00	19	yes	no	no	yes
722	Nimes	France	+43:51:30	+04:24:24	59	yes	yes	yes	yes
232	Sarajevo	Bosnia	+43:51:00	+18:23:00	277	yes	no	no	yes
224	Ni	Serbia	+43:20:00	+21:54:00	202	yes	yes	no	yes
291	Kastamonu	Turkey	+41:22:00	+33:47:00	800	yes	no	no	yes
233	Tirana	Albania	+41:20:00	+19:47:00	89	yes	yes	no	yes
178	Porto	Portugal	+41:08:00	-08:36:00	93	yes	yes	no	yes
137	Brindisi	Italy	+40:38:00	+17:56:00	10	yes	no	yes	no
193	Madrid	Spain	+40:24:40	-03:39:19	667	yes	yes	yes	yes
292	Sivas	Turkey	+39:45:00	+37:01:00	1285	yes	yes	no	yes
177	Lisboa	Portugal	+38:43:00	-09:09:00	77	yes	no	no	yes

Number	Location	Country	Latitude	Longitude	Altitude	Temperature	Precipitation	Sunshine	Urban
274	Souda	Greece	+35:29:00	+24:07:00	136	yes	yes	no	no
113	Tel Aviv	Israel	+32:06:00	+34:47:00	4	yes	yes	no	yes
118	Elat	Israel	+29:33:00	+34:57:00	12	no	no	yes	yes
262	Asswan	Egypt	+23:58:00	+32:47:00	200	yes	yes	no	yes
260	Tamanrasset	Algeria	+22:48:00	+05:26:00	1362	yes	yes	no	no