Theoretical and Applied Climatology manuscript No.
(will be inserted by the editor)

Influence of circulation types on temperature extremes in Europe

E.J.M. van den Besselaar · A.M.G. Klein Tank · G. van der Schrier

May 6, 2009

Abstract The aim of this study is to determine the influence of atmospheric circulation on the recently observed changes in the number of warm days and cold days in Europe. The temperature series for stations in the European Climate Assessment and Dataset project and the Grosswetterlagen (GWL) were used here. The temperature series were first adjusted for global warming before determining the indices for cold and warm extremes.

The 29 GWLs were grouped in ten circulation types. Then the number of days a certain circulation type occurred was determined for each winter (December, January and February) and summer (June, July and August). The relation between the circulation type frequencies and the temperature indices was modelled with a multi-regression fit over the period 1947–1974 and tested for the period 1974–2000.

The difference between the observed indices and the calculated indices in the second period (using the fit coefficients for the first period) shows a warming effect for both winter and summer, and for at least the warm day index, which is unaccounted for by the global warming trend. A simple snow model shows that variations in the European snow cover extent is likely influencing the cold and warm day indices in winter: there is a correlation between the decreasing trend of the snow cover extent in Europe and the increasing (decreasing) trend of the number of warm (cold) days for stations throughout Europe.

1 Introduction

Surface air temperatures in most European regions have increased during the last century. This warming is projected to continue and it is likely to be accompanied by changes in extreme weather and climate events (Cubasch et al 2001; Christensen et al 2007), although little is known about the nature of the changes in the associated temperature extremes. For a better understanding of these changes, it is relevant to learn which mechanisms are affecting the temperature extremes, which is an issue under increased attention (Klein Tank and Können 2003; Tebaldi et al 2006; Scaife et al 2008; Jones et al 2008).

Several groups analysed the observed changes in temperature extremes for individual stations or countries (see e.g. Tuomenvirta et al 2000; Moberg et al 2000; Yan et al 2002; Moberg et al 2006), but it is not known how the trends in extremes are related to large-scale circulation over Europe. With the start of the European Climate Assessment (ECA) daily dataset the spatial coverage of high-resolution time series has increased (Klein Tank et al 2002; Klok and Klein Tank 2008). The daily resolution, the large number of stations and its nine climate variables make the ECA dataset an excellent dataset to be used in studies on climate extremes over the whole European region.

Changes in large-scale circulation patterns over Europe influence the temperatures (see e.g. Bárdossy and Caspary 1990; Werner and von Storch 1993; Corti et al 1999; Chen 2000; Xoplaki et al 2003; Cahynová and Huth 2009). Perhaps the best known example is the influence of the North Atlantic Oscillation (NAO, traditionally characterized by the sea-level pressure difference between Iceland and the Azores) on European temperatures, which has been studied by, e.g. Dorn et al (2003), Rauthe and Paeth (2004), and Stephenson et al (2006).

Baur et al (1944) defined a circulation type as a mean air pressure distribution over an area at least as large as Europe. Any given circulation type occurs normally for at least three days during which the main weather features remain mostly constant over Europe. After this there is a rapid transition to another circulation type. These Grosswetterlagen (GWL)

Royal Netherlands Meteorological Institute (KNMI), PO Box 201, 3730 AE De Bilt, The Netherlands E-mail: besselaar@knmi.nl

Table 1 The GWLs belonging to a certain circulation type (Circ)

Circ	GWL	Circ	GWL	Circ	GWL
W	Wa	Low	TM	E	HFa
	Wz	N	Na		HFz
	Ws		Nz		HNFa
	Ww		HNa		HNFz
SW	SWa		HNz	SE	SEa
	SWz		HB		SEz
NW	NWa		TrM	S	Sa
	NWz	NE	NEa		Sz
High	HM		NEz		TB
	BM				TrW

can therefore be used for weather regimes for the whole of Europe and the North-East Atlantic. This classification system was later revised and updated by Hess and Brezowsky (1952, 1969, 1977) and Gerstengabe et al (1999).

In this paper we will use the GWLs in combination with the number of warm and cold days in a season at stations in the ECA dataset as indices for temperature extremes. The aim of our study is to determine how the large-scale circulation influences the reported trend patterns of temperature extremes over Europe. To do this we will derive a relation between the temperature indices and the frequency of the GWLs for one period, and we will apply this to a second period to see if this relation still holds and explains the observed changes in the temperature indices, or if other factors than circulation play a role. We will account for the influence of global warming by first adjusting for this before starting our analysis. Section 2 describes the data and methods used, Sect. 3 shows the results and Sect. 4 gives the conclusion and discussion including a short study on the influence of the snow cover extent in Europe.

2 Data and methods

2.1 Circulation

In this study we made use of the GWLs for the period 1947–2000. The GWLs classification system consists of 29 types and are given as one type per day. For the purpose of our study, we grouped them to ten so-called circulation types in the same way as the major types in Bárdossy and Caspary (1990), see Table 1. For each winter (December, January and February (DJF)) and each summer (June, July and August (JJA)) we determined the number of days each circulation type occurred.

2.2 Temperature indices

From the ECA daily dataset we have determined the cold day and warm day indices. The cold day index is calculated as the number of days per season that the temperature is below the 10th percentile of the temperature distribution for the station under consideration (T10p). This distribution was determined over the time period 1961–1990. The warm day index is the number of days the temperature is above the 90th percentile of this distribution (T90p). We have used the minimum (TN), mean (TG) and maximum (TX) temperature distributions to calculate the six indices per station and per season.

The ECA dataset consists at present of over 400 stations for each temperature series, which are quality controlled (Klein Tank et al 2002; Klok and Klein Tank 2008). To determine the time period for our research, we determined the number of stations that have more than 80% non-missing temperature indices in each interval. Furthermore, we are interested in trends in recent decades, so therefore we decided to take the period 1947–2000 in which the number of good stations is approximately constant.

2.3 Method

The temperature series in the ECA dataset are, of course, not adjusted for global warming. Because we would like to determine the influence of the circulation types on temperature extremes excluding the effect of global warming, we needed to adjust the temperature series for this component before starting our research. To do this, we have taken the HadCRUT3 monthly global temperature anomalies from Brohan et al (2006). For each day we have subtracted the corresponding global monthly temperature anomaly from the minimum, mean and maximum temperature. Due to the temporal variability of the global temperature anomalies on short time scales, we assume that it is justified to use the monthly average for correcting daily observations. These adjusted temperature series were then used as input for the calculation of the adjusted cold day and warm day indices. The name ”adjusted indices” is used to refer to the indices based on the temperatures adjusted for global warming.

These series are fit with a multi-parameter linear fit to the circulation types. This was done separately for the winter and summer seasons, and also separately for each station. The equation used is

$$\begin{aligned} \mathrm{T} = {} & c0 \cdot \mathrm{W} + c1 \cdot \mathrm{SW} + c2 \cdot \mathrm{NW} + c3 \cdot \mathrm{N} + c4 \cdot \mathrm{NE} + \\ & c5 \cdot \mathrm{E} + c6 \cdot \mathrm{SE} + c7 \cdot \mathrm{S} + c8 \cdot \mathrm{Low} + c9 \cdot \mathrm{High}, \end{aligned} \tag{1}$$

where T stands for the (adjusted) temperature index anomaly with respect to the period 1961–1990 (one value per station per year per season), $c0$–$c9$ are the coefficients (one value per coefficient per station per season) and the number of days the indicated circulation type occurred (one value per year per season).

A weighted function (using one or zero) was used to derive the best fit coefficients. If an index value for a certain

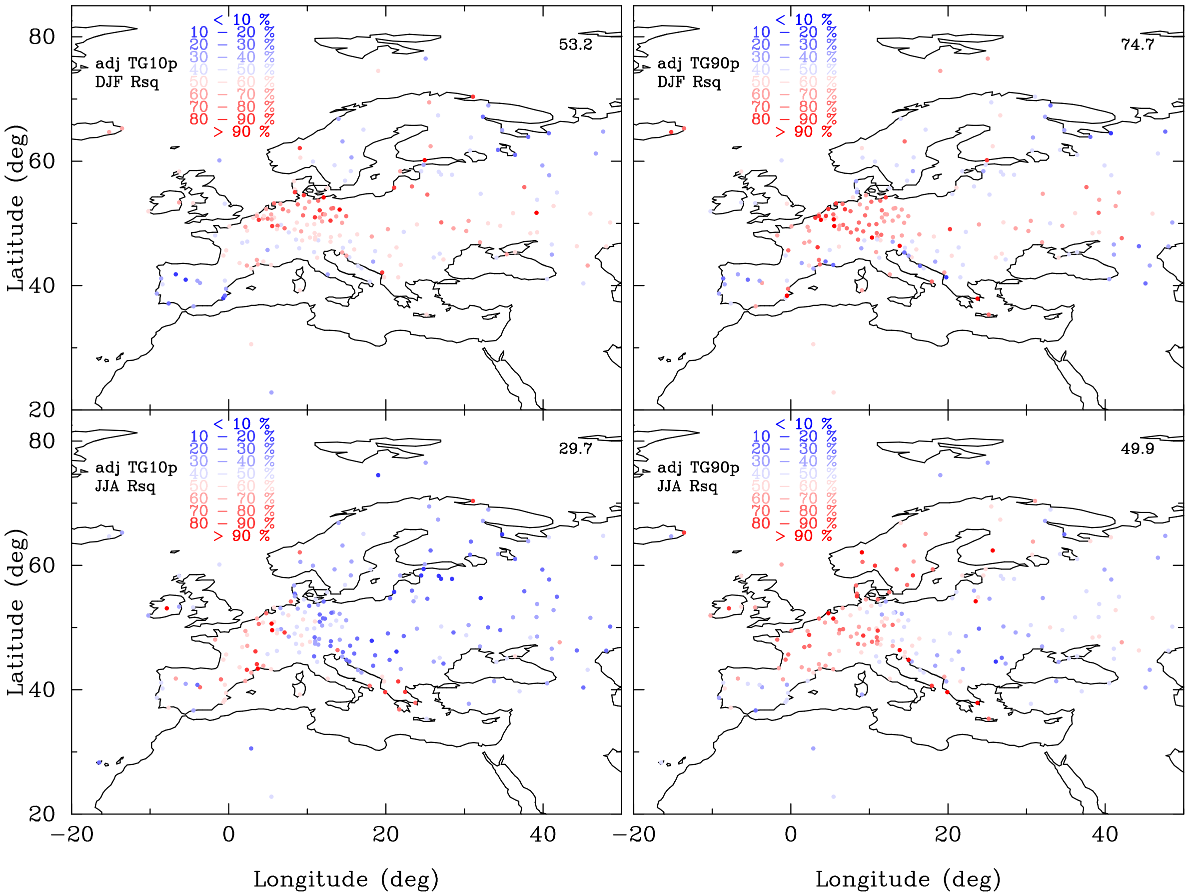

Fig. 1 Patterns of explained variance by the fit over 1947–1974 (R^2) in winter (DJF) and summer (JJA) by using the adjusted indices TG10p and TG90p. Red points indicate an explained variance higher than 50%, while blue points indicate an explained variance lower than 50%. The values in the upper right corners are the explained variances of the European averaged series

station was missing, that year was excluded from the least-square analysis for the best coefficients determination of that station.

The time period under consideration was split in two. The first half (1947–1974, calibration period) was used to determine the above mentioned multi-parameter linear fit between the circulation types and the (adjusted) indices series. We have varied the break year 1974 between 1970 and 1980 and the fit results are approximately the same, so we decided to use two almost equal length periods. The second interval (validation period) was used as a testing period to determine if the influence of the separate circulation types on the temperature indices determined for the first period still holds and thus explains the changes in the indices. This was done by determining a possible trend in the difference between the observed adjusted indices and the fitted adjusted indices over the second period which would indicate a change in the influence of the circulation types. The significance of the resulting trends is shown by taking the ratio between the slope of the fitted linear line and the standard deviation of the slope.

3 Results

We use equation (1) on the temperature extremes and determined the coefficients for the adjusted temperature indices of TN, TG and TX for both the winter and summer periods. The European averaged index series were used as input as well.

All the patterns for the indices based on TN, TG and TX are approximately the same, so therefore we only show the ones for the indices based on TG. Figure 1 shows the explained variance by the fit (period 1947–1974), which is in general better for the winter season than for the summer season. The values of the explained variance for the European averaged adjusted TG10p series are 53.2% (winter) and 29.7% (summer), and for the European averaged adjusted TG90p series 74.7% (winter) and 49.9% (summer). It can also be noted that the adjusted warm day index (TG90p) can be explained better by circulation type frequencies than the adjusted cold day index (TG10p). For the winter season, the explained variance is highest in the central European re-

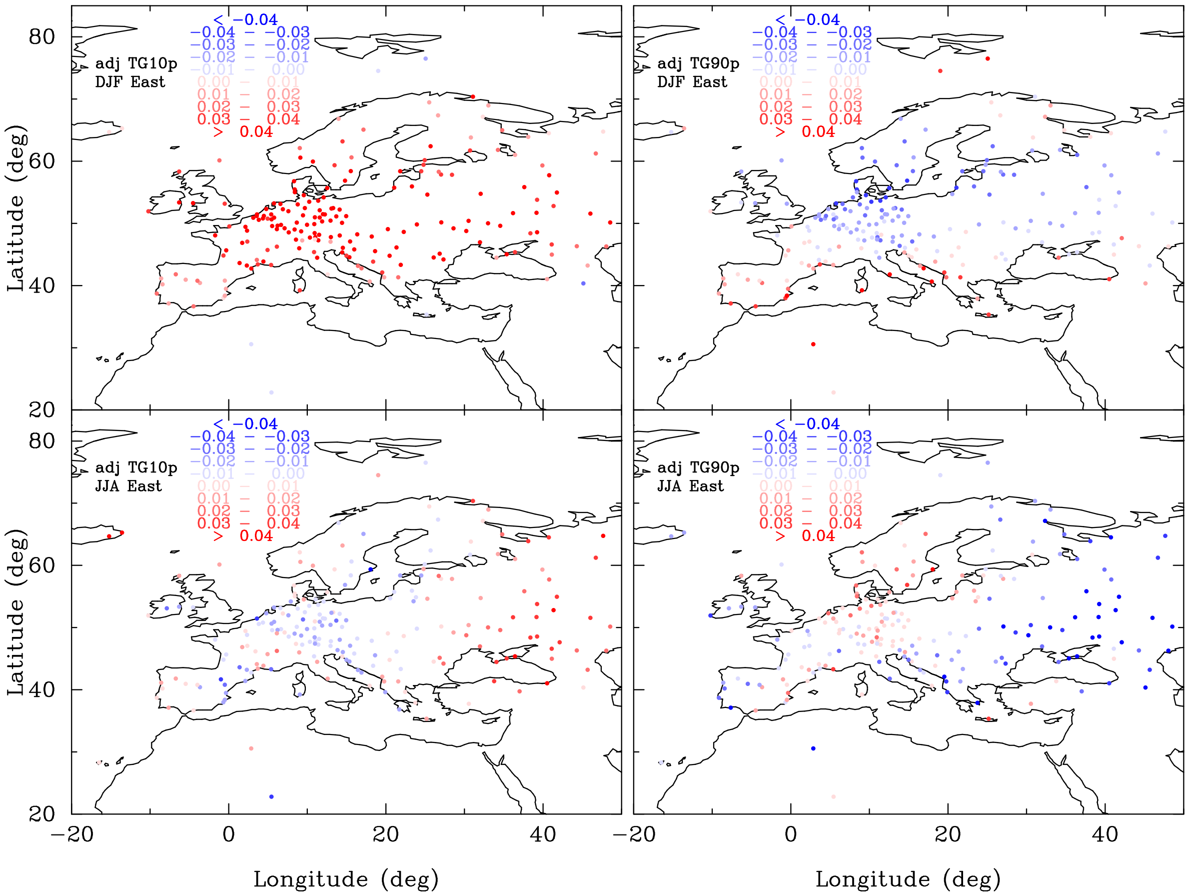

Fig. 2 Patterns of coefficients for circulation type East in winter (DJF) and summer (JJA) by using the adjusted indices TG10p and TG90p. Red points indicate a positive influence of the circulation type on the adjusted cold day or warm day index, while blue points indicate a negative influence

gions, while lower in the southern and northern regions. This division is less pronounced or even absent in summer.

Figure 2 shows the values of the fit coefficient corresponding to circulation type East ($c5$) over Europe using the adjusted TG10p and TG90p series. This figure demonstrates how circulation type East is contributing to the adjusted cold day and warm day indices in both winter and summer. This shows that in case of an increase in frequency of the occurrence of circulation type East there will be more cold days in winter. This can be understood because the air transported by circulation type East originates from polar regions (so cold air) in Russia (Scherhag 1949).

Over southern Europe the number of warm days will increase in winter, while for the northern part the number will decrease. In summer, the number of warm days will increase over central Europe, but decrease over eastern Europe by circulation type East.

For circulation type West, almost the opposite result is seen for the largest part of Europe in winter (not shown). This type will result in less cold days and more warm days in winter, which is not surprising from air transported over a relatively warm North Atlantic Ocean onto the continent. In summer this circulation type will result in slightly less cold days and warm days over central Europe.

In the same way we established that circulation type South decreases the number of cold days in winter and that circulation type North decreases the number of warm days in summer.

The regression coefficients of eq. (1) are based on the period 1947–1974. To determine the extent to which this relation can reproduce the adjusted indices over the period 1974–2000, we have taken the difference between the observed adjusted indices and the calculated adjusted indices. These differences show an increase with time for nearly all stations over the 1974–2000 period. A linear line was fitted to these differences and the trend of this line divided by the standard deviation is shown in Fig. 3. The weighting of the trend with the standard deviation gives the significance of this trend, with values >1 (<-1) corresponding to confidence levels of $>68\%$ that the null-hypothesis of a trend by chance can be rejected. Almost all points in Fig. 3 are red, indicating a warming effect. This means that the observed

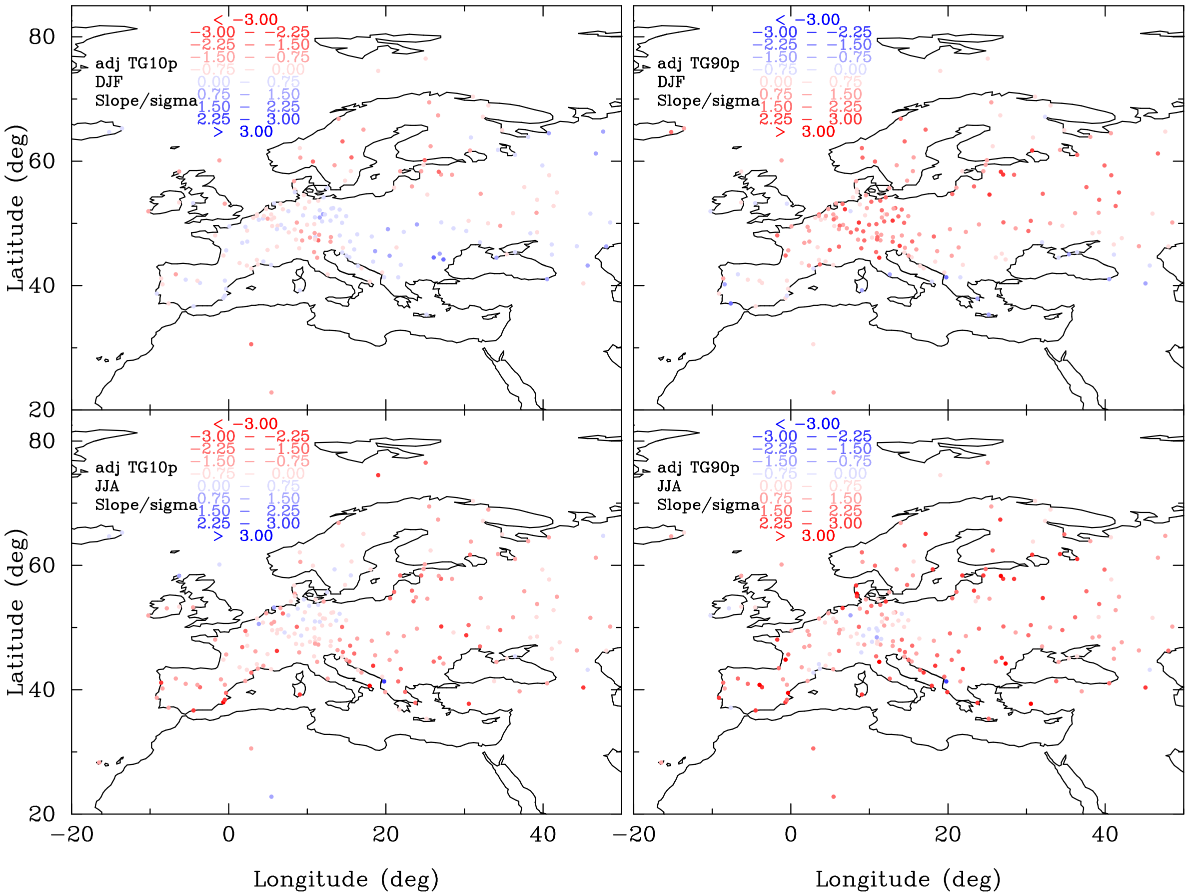

Fig. 3 Patterns of coefficients for the ratio of the slope and the uncertainty on the slope for the linear fit to the index minus the calculated index from the fit results for winter (DJF) and summer (JJA) and the adjusted indices TG10p and TG90p. The colour coding is such that red indicates a warming trend

trends in the number of warm days and cold days, even when adjusted for the rise in global mean temperature, cannot be explained by a changing frequency in the occurrence of circulation types only. One or more other mechanisms are influencing the temperature indices as well.

4 Conclusion & Discussion

The daily temperature series from the ECA dataset (Klein Tank et al 2002) were used in this study. To adjust for the trend due to global warming, the corresponding monthly global temperature anomaly (Brohan et al 2006) was subtracted from each daily temperature. These adjusted series were used to calculate the number of cold days and warm days per season (index) based on minimum, average and maximum temperature series. Because the fit results for minimum, average and maximum index series are approximately the same, we decided to concentrate on the average temperature indices (TG10p and TG90p).

The adjusted indices per season were fitted with a multi-parameter linear model to the frequency of the circulation types in that season. The patterns of the values of the coefficients (e.g. Fig. 2) show how the corresponding circulation type influences the adjusted indices. The fit was determined per station and per season over the period 1947–1974.

For the period 1974–2000 we have analysed the value of the adjusted index minus the calculated index using the fit coefficients for the period 1947–1974. A linear trend was fitted to this difference. To determine how significant the trend is, the ratio between the slope and the standard deviation of the slope of the linear line is shown in Fig. 3. Over almost entire Europe, the analysis for both adjusted TG10p and adjusted TG90p, and for both seasons indicates a warming trend. These results indicate a warmer climate than what would be expected on the basis of the frequency of the circulation types alone, even when the global warming effect is accounted for. This suggests one or more additional effects which increase the European temperatures.

This warming trend is most likely due to a different response of the circulation types to the adjusted indices for the second period than for the first period. One hypothesis that may explain the different relation between circulation types and temperature extremes in these two periods is that a smaller snow cover extent in northern and eastern Europe will lead to less cold air for circulation types transporting air originating from the north and east compared to a situation with a large snow cover extent. Brown (2000) has studied the snow cover extent over Eurasia in October, March, and April over the period 1915–1997 and concluded that there is indeed evidence for a decrease in March and April snow cover extent over the last decades. Also, Dye (2002) concluded that the snow-free period in the Northern Hemisphere is increasing over the period 1972–2000. This might contribute to the warming trend seen in Fig. 3.

In Fig. 4 we have shown Europe average trends to give an idea about the influence of the frequency of circulation types on the observed trends in temperature extremes in winter, assuming that before 1974 everything could be explained completely. To derive these trends, we have determined the average cold day and warm day indices over Europe for which the whole procedure described above was done as well. The lines above zero correspond to the warm day index (increasing trends) and the lines below zero to the cold day index (decreasing trends). The 1σ uncertainty bars are for the year 2000 which are slightly shifted for clarity. The green, solid lines show the trends in the indices themselves, without any adjusting or fitting. The red, dotted lines show the trend in the indices due to global warming. This trend is determined by taking the difference between the non-adjusted and adjusted European averaged indices and derive a linear line from that. The blue, dashed lines show the accumulated trend of our fit and global warming combined. The difference between the green and blue trends show the remaining trend which is unexplained by global warming and our fit.

From this figure, it is seen that the trends for the cold day index (TG10p) are much smaller than for the warm day index (TG90p). Furthermore, the trend in TG10p itself is very sensitive for the exact period over which it is calculated (the lower green, solid line). For example, using a starting year between 1970 and 1980, and keeping the ending year constant at 2000, results in trends between -0.157 and $+0.028$ for TG10p. Together with the uncertainties on the cold day trends, we can conclude that the trends in the number of cold days are too small for any conclusions. For the warm day index this is not the case. Using the same range for the trend calculation for TG90p results in trends between 0.221 and 0.348, i.e. much more stable. In this case, the unexplained, remaining trend is most likely true.

4.1 Snow cover extent

As a possibility for the unexplained, remaining trend, we investigate here the influence of snow cover extent in Europe. To do this, we decided to use a simple model for a snow cover proxy to estimate the snow cover extent in Europe by using the available temperature and precipitation information, due to the lack of long time series of snow cover extent in Europe. We used the ENSEMBLES gridded dataset (E-Obs) produced from the ECA station data which covers the period 1950–2006 (Haylock et al 2008; Hofstra et al 2008).

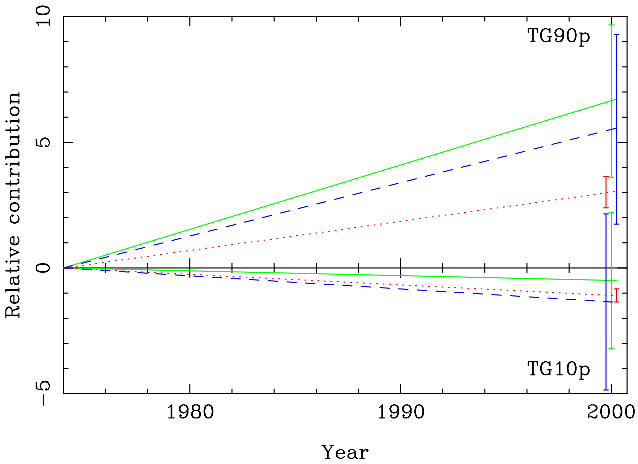

Fig. 4 The relative contributions of several factors to the observed trend in the number of cold days (below zero) and in the number of warm days (above zero). The green, solid lines show the trend as observed in the non-adjusted index. The red, dotted lines show the trend contribution due to global warming. The blue, dashed lines show the accumulated contributions of global warming and our fit to the circulation types. The uncertainties are for 2000, which are slightly shifted for clarity

For each grid box the water equivalent of the snow depth was determined by the following simple relations. When the daily mean temperature was below 0 °C and the daily precipitation was above 0 mm, it is assumed that all precipitation falls as snow, and the amount of precipitation was taken as the water equivalent of the snow for that grid box and added to the amount of the previous day. If on a following day the temperature was still below 0 °C, but with no precipitation, the snow amount was unchanged. When the temperature rose above 0 °C, we let the snow melt with a rate of 4.5 mm water equivalent day^{-1} °C^{-1} (Braithwaite and Zhang 2000). Although the melt rate is dependent on several factors, such as elevation, wind, age of the snow, humidity, cloud cover, etc. (Greuell and Genthon 2003), we decided to use this simple model and to keep the melt rate constant over time and location.

To determine the snow cover extent per day, we added the area of the grid boxes in which there was snow present for that day. This extent was then averaged over the winter period. The normalised time series of the snow cover extent is shown in Fig. 5. We compared the snow cover extent over the area between -20° to 50°E and 20° to 70°N with the snow cover extent over the same area in the weekly data set from the National Snow and Ice Data Center (Armstrong and Brodzik 2005, updated 2007). This data set gives

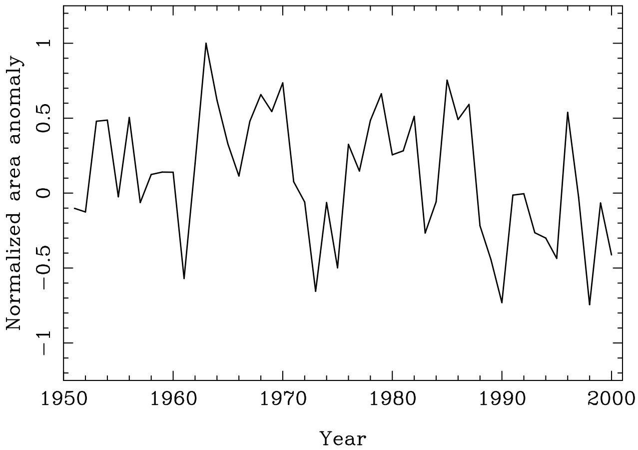

Fig. 5 Anomaly of the snow cover extent for the European region in winter

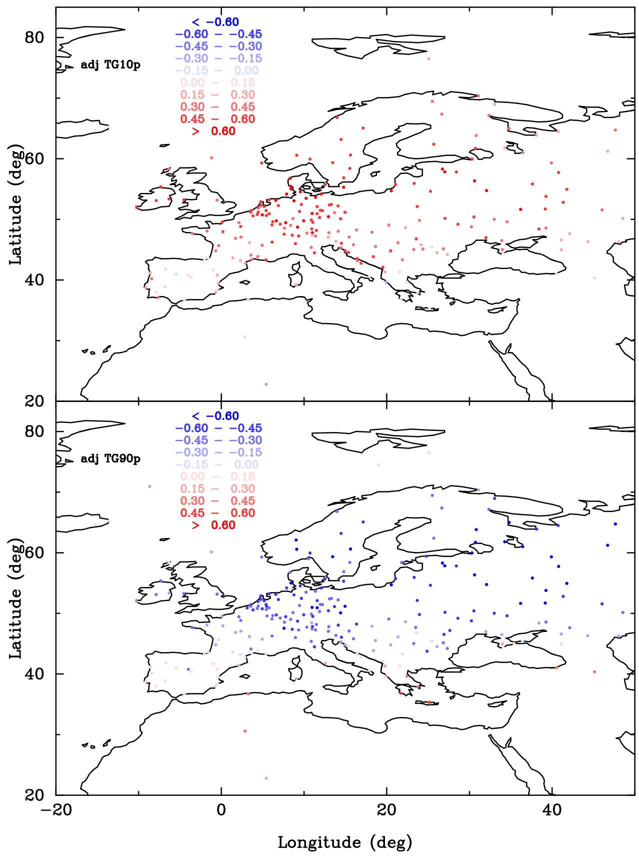

Fig. 6 Correlation of adjusted TG10p and adjusted TG90p with the snow cover extent in Europe in winter

only binary data indicating snow or no snow. Although the dataset itself is on a high resolution grid, the underlying source grid boxes are much larger. The correlation for the weekly averages for the winter periods of 2004–2006 is >0.9. This gives us enough confidence for using our snow cover proxy in this work.

Table 2 Correlation of the snow cover extent over Europe in winter with the European averaged adjusted and non-adjusted indices for cold and warm days

Index	Correlation
adjusted TG10p	0.731
adjusted TG90p	-0.783
TG10p	0.754
TG90p	-0.824

The corresponding time series was correlated with the adjusted index series over the correlation period 1951–2000 for each station as well as for the European averaged series. For comparison we have given the correlations for the non-adjusted indices also. The results for the European averaged indices are given in Table 2. As an example for the variation of the correlations over Europe we have shown in Fig. 6 the correlation of the adjusted cold day and warm day indices with the snow cover extent over Europe in winter. From this figure it is seen that the snow cover extent is most likely influencing the cold and warm day indices over the whole European region, so snow cover extent might indeed be a mechanism responsible for the observed trends in the number of warm and cold days in Europe. We note that the correlation factors for the non-adjusted indices are slightly higher than for the adjusted indices (Table 2). From this, we can assume that the influence of the snow cover extent is already partly accounted for by the removal of the global warming trend. Although it seems that the snow cover extent has an influence on the temperature extremes, a more detailed study including possible other causes, such as sea surface temperature or soil moisture, is necessary to determine if these mechanisms might explain the unexplained trend described before.

Acknowledgements We acknowledge the E-Obs dataset from the EU-FP6 project ENSEMBLES (http://www.ensembles-eu.org) and the data providers in the ECA&D project (http://eca.knmi.nl).

References

Armstrong R, Brodzik M (2005, updated 2007) Northern Hemisphere EASE-Grid weekly snow cover and sea ice extent version 3. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media

Bárdossy A, Caspary H (1990) Detection of Climate Change in Europe by Analyzing European Atmospheric Circulation Patterns from 1881 to 1989. Theor Appl Climatol 42:155–167

Baur F, Hess P, Nagel H (1944) Kalendar der Grosswetterlagen Europas 1881–1939. Bad Homburg (Deutscher Wetterdienst)

Braithwaite R, Zhang Y (2000) Sensitivity of mass balance of five Swiss glaciers to temperature changes assessed by tuning a degree-day model. J Glaciol 46:7–14

Brohan P, Kennedy J, Harris I, Tett S, Jones P (2006) Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. Geophys Res Lett 111:D12,106

Brown R (2000) Northern Hemisphere Snow Cover Variability and Change, 1915–97. J Climate 13:2339–2355
Cahynová M, Huth R (2009) Changes of atmospheric circulation in central Europe and their influence on climatic trends in the Czech Republic. Theor Appl Climatol 96:57–68
Chen D (2000) A monthly circulation climatology for Sweden and its application to a winter temperature case study. Int J Climatol 20:1067–1076
Christensen J, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli R, Kwon WT, Laprise R, na Rueda VM, Mearns L, Menéndez C, Räisänen J, Rinke A, Sarr A, Whetton P (2007) Regional Climate Projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt K, Tignor M, Miller H (eds) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 847–940
Corti S, Molteni F, Palmer T (1999) Signature of recent climate change in frequencies of natural atmospheric circulation regimes. Nature 398:799–802
Cubasch U, Meehl G, Boer G, Stouffer R, Dix M, Noda A, Senior C, Raper S, Yap K (2001) Projections of Future Climate Change. In: Houghton J, Ding Y, Griggs D, M Noguer Pv, Dai X, Maskell K, Johnson C (eds) Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, United Kingdom and New York, NY, USA, pp 525–582
Dorn W, Dethloff K, Rinke A, Roeckner E (2003) Competition of NAO regime changes and increasing greenhouse gases and aerosols with respect to Arctic climate projections. Clim Dynam 21:447–458
Dye D (2002) Variability and trends in the annual snow-cover cycle in Northern Hemisphere land areas, 1972–2000. Hydrological Processes 16:3065–3077
Gerstengabe FW, Werner P, Rüge U (1999) Katalog der Grosswetterlagen Europas 1881–1998 nach P. Hess und H. Brezowsky. 5. Aufl. Potsdam-Inst F Klimafolgenforschung, Postdam, Germany p 138
Greuell W, Genthon C (2003) Modelling land-ice surface mass balance. In: Bamber J, Payne A (eds) Mass balance of the Cryosphere: Observations and Modelling of Contemporary and Future Changes, Cambridge University Press, pp 117–168
Haylock M, Hofstra N, Klein Tank A, Klok E, Jones P, New M (2008) A European daily high-resolution gridded dataset of surface temperature and precipitation. J Geophys Res 113:D20,119
Hess P, Brezowsky H (1952) Katalog der Grosswetterlagen Europas. Berichte des Deutschen Wetterdienstes in der US-Zone 33
Hess P, Brezowsky H (1969) Katalog der Grosswetterlagen Europas, 2. neu bearbeitete und ergänzte Aufl. Berichte des Deutschen Wetterdienstes 113, offenbach am Main
Hess P, Brezowsky H (1977) Katalog der Grosswetterlagen Europas 1881–1976, 3. verbesserte und ergänzte Aufl. Berichte des Deutschen Wetterdienstes 113, offenbach am Main
Hofstra N, Haylock M, New M, Jones P, Frei C (2008) Comparison of six methods for the interpolation of daily, European climate data. J Geophys Res 113:D21,110
Jones G, Stott P, Christidis N (2008) Human contribution to rapidly increasing frequency of very warm Northern Hemisphere summers. J Geophys Res 113:D02,109
Klein Tank A, Können G (2003) Trends in Indices of Daily Temperature and Precipitation Extremes in Europe, 1946–99. J Climate 16:3665–3680
Klein Tank A, Wijngaard J, Können G, Böhm R, Demarée G, Gocheva A, Mileta M, Pashiardis S, Hejkrlik L, Kern-Hansen C, Heino R, Bessemoulin P, Müller-Westermeier G, Tzanakou M, Szalai S, Pálsdóttir T, Fitzgerald D, Rubin S, Capaldo M, Maugeri M, Leitass A, Bukantis A, Aberfeld R, van Engelen A, Forland E, Mietus M, Coelho F, Mares C, Razuvaev V, Nieplova E, Cegnar T, Antonio López J, Dahlström B, Moberg A, Kirchhofer W, Ceylan A, Pachaliuk O, Alexander L, Petrovic P (2002) Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. Int J Climatol 22:1441–1453
Klok E, Klein Tank A (2008) Short communication: Updated and extended European dataset of daily climate observations. Int J Climatol DOI: 10.1002/joc.1779
Moberg A, Jones PD, Barriendos M, Bergström H, Camuffo D, Cocheo C, Davies T, Demarée G, Martin-Vide J, Maugeri M, Rodriguez R, Verhoeve T (2000) Day-to-day temperature variability trends in 160- to 275-year-long European instrumental records. J Geophys Res 105:849–868
Moberg A, Jones P, Lister D, Walther A, Brunet M, Jacobeit J, Alexander L, Della-Marta P, Luterbacher J, Yiou P, Chen D, Klein Tank A, Saladié O, Sigró J, Aguilar E, Alexandersson H, Almarza C, Auer I, Barriendos M, Begert M, Bergström H, Böhm R, Butler CJ, Caesar J, Drebs A, Founda D, Gerstengarbe F, Micela G, Maugeri M, Österle H, Pandzic K, Petrakis M, Srnec L, Tolasz R, Tuomenvirta H, Werner P, Linderholm H, Philipp A, Wanner H, , Xoplaki E (2006) Indices for daily temperature and precipitation extremes in Europe analyzed for the period 1901–2000. J Geophys Res 111:D22,106
Rauthe M, Paeth H (2004) Relative Importance of Northern Hemisphere Circulation Modes in Predicting Regional Climate Change. J Climate 17:4180–4189
Scaife A, Folland C, Alexander L, Moberg A, Knight J (2008) European Climate Extremes and the North Atlantic Oscillation. J Climate 21:72–83
Scherhag R (1949) Neue Methode der Wetteranalyse und Wetterprognose. Quart J Roy Meteor Soc 75:442–444
Stephenson D, Pavan V, Collins M, Junge M, Quadrelli R, Participating CMIP2 Modelling Groups (2006) North Atlantic Oscillation response to transient greenhouse gas forcing and the impact on European winter climate: a CMIP2 multi-model assessment. Clim Dynam 27:401–420
Tebaldi C, Hayhoe K, Arblaster J, Meehl G (2006) Going to the extremes: An intercomparison of model-simulated historical and future changes in extreme events. Climate Change 79:185–211
Tuomenvirta H, Alexandersson H, Drebs A, Frich P, Nordli P (2000) Trends in Nordic and Arctic Temperature Extremes and Ranges. J Climate 13:977–990
Werner P, von Storch H (1993) Interannual variability of Central European mean temperature in January-February and its relation to large-scale circulation. Clim Res 3:195–207
Xoplaki E, González-Rouco J, Luterbacher J, Wanner H (2003) Mediterranean summer air temperature variability and its connection to the large-scale atmospheric circulation and SSTs. Clim Dynam 20:723–739
Yan Z, Jones PD, Davies TD, Moberg A, Bergström H, Camuffo D, Cocheo C, Maugeri M, Demarée GR, Verhoeve T, Thoen E, Barriendos M, Rodríguez R, Martín-Vide J, Yang C (2002) Trends of Extreme Temperatures in Europe and China Based on Daily Observations. Climate Change 53:355–392