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Article

The hot summer 2003 in Germany. Some preliminary results of a statistical time series analysis

CHRISTIAN-D. SCHÖNWIESE*, TIM STAEGER and SILKE TRÖMEL

J.W. Goethe University, Institute for Meteorology and Geophysics, Frankfurt a.M., Germany

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Abstract

A statistical analysis of the summer (June, July, and August) surface air temperature, time series 1761–2003, representative of Germany, is presented. Rank statistics, where the 2003 value (3.4 K above the 1961–1990 average) appears to be by far the maximum on record, are listed as well as trend values for the whole and defined subperiods including the contributions of the individual summer months. The warming detectable since approximately 1900/1920 shows a progressive structure with highest values in recent decades. The month of August contributes much more to this warming than the other summer months. A time-dependent probability analysis of the 2003 event reveals an increasing probability, especially in recent decades. However, even under these assumptions, the 2003 event is very extreme.

Zusammenfassung

Eine statistische Analyse der Sommer-Reihe (Juni, Juli und August) der bodennahen Lufttemperatur 1761–2003, repräsentativ für das Flächenmittel Deutschland, wird vorgestellt. Rangstatistiken und Trendwerte für die gesamte Beobachtungszeit und einige Subintervalle, einschließlich der Beiträge der einzelnen Monate, werden aufgelistet, wobei der 2003-Wert (3,4 K über dem Mittel 1961–1990) bei weitem das bisher beobachtete Maximum ist. Die seit ungefähr 1900/1920 im Gang befindliche Erwärmung zeigt eine progressive Trendstruktur mit dem stärksten Anstieg in den letzten Dekaden. Dazu trägt der Monat August wesentlich mehr bei als die anderen Sommermonate. Eine zeitabhängige Wahrscheinlichkeitsanalyse des 2003-Ereignisses erbringt eine zunehmende Wahrscheinlichkeit, speziell in den letzten Dekaden; jedoch erscheint trotzdem dieses Ereignis als sehr extrem.

1 Introduction

In 2003 Germany experienced its warmest summer on record. Since 1761, the start of representative monthly surface air temperature assessments provided by RAPP, (2000; from 1999 updated by German Weather Service data; DWD, 2002, 2003; ULLRICH, 2002), such a high anomaly of the summer average of + 3.4 K related to the 1961–1990 CLINO normal (corresponding to a value of 19,6 °C; DWD, 2003) has not been observed. As far as the DWD daily maximum measurements are concerned, a value of 40.2 °C on 9 August 2003 in Karlsruhe and on 13 August 2003 again in Karlsruhe and in Freiburg was reached. However, the record maximum (same value) known on 27 July 1983 in Gärmersdorf (near Amberg, NE Bavaria) was not exceeded. Also on an European scale, based on multiproxy reconstructions since 1500, the year 2003 experienced by far the hottest summer (LUTERBACHER et al., 2004).

The synoptic situation in this summer was characterized by a pattern where a very stable high pressure system over Central Europe combined with low pressure systems westward and eastward of it appeared at a quasi-stationary Rossby wave meridional distance renewing again and again. In consequence a more or less continuous high temperature level was established accompanied by an unusual large number of hot days and high night minimum temperatures (27.6 °C at station Weinbiet, near Rhine Valley, 13 August 2003; earlier highest night minimum temperature was 26.0 °C on 5 July 1957 at Freiburg; for all related details see DWD, 2003).

In this study we briefly describe the structure of the representative Germany surface air temperature time series 1761–2003 with respect to summer data, contributions of the months June, July, and August included, in terms of extremes, rank statistics, trends, polynomial, and cyclical components. This implies also a spectral analysis. Furthermore, we assess the probability of the summer 2003 event and its evaluation in time. Finally, we add some conclusions and an outlook. The temperature data are based 1761–1890 on 4 stations, 1891–1951 on 31 stations, and 1951-1998 on 75 stations (details see RAPP, 2000). 1999–2003 we used the so-called raster data of the DWD (ULLRICH, 2002; MÜLLER-WESTERMEIER, 2002) which are based on much more stations. However, within the available overlap period 1985–1998 these two data sets are nearly identical (de-

*Corresponding author: Christian-D. Schönwiese, J.W. Goethe-Universität, Institut für Meteorologie und Geophysik, Postfach 11 19 32, D-60054 Frankfurt a.M., Germany, e-mail: schoenwiese@meteor.uni-frankfurt.de

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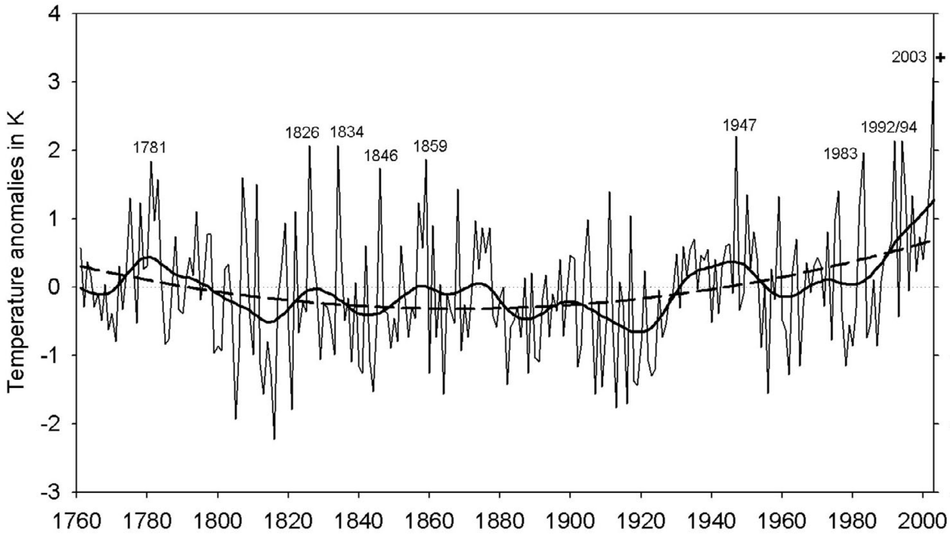

Figure 1: German summer (average of June, July, and August) surface air temperature anomalies as deviations from the 1961–1990 average. Years of outstanding extremes indicated (+, see right edge, denotes the year 2003 event). Polynomial component (dashed heavy line) indicates cooling in the first and warming in the second subperiod, and 30 yr Gaussian low-pass filtered data (heavy line). Original data from RAPP (2000; updated, DWD, 2002, 2003).)

Table 1: Ranks and related years of the summer such as June, July, and August monthly extremes, mean German surface air temperature, observational period 1761–2003. Rank 1 is the warmest season or month, respectively. In parantheses, for ranks 1–10, the related temperature anomalies in K (relative to 1961–1990) are also specified. (* 1.7–1.4 K).

Rank	*Summer*	*June*	*July*	*August*
1	**2003 (3.4)**	**2003 (3.9)**	1994 (4.6)	1807 (4.2)
2	1947 (2.2)	1917 (3.2)	1983 (3.4)	**2003 (4.2)**
3	1994 (2.1)	1858 (3.0)	1995 (3.2)	1997 (3.5)
4	1992 (2.1)	1811 (2.9)	1834 (3.0)	1826 (3.0)
5	1826/1834 (2.1)	1930 (2.8)	1859 (2.9)	1944 (2.9)
6	1826/1834 (2.1)	1889 (2.8)	1794 (2.8)	1911 (2.7)
7	1983 (2.0)	1822 (2.7)	1976 (2.4)	1781 (2.6)
8	1859 (1.9)	1947 (2.4)	1959 (2.4)	1992 (2.6)
9	1781 (1.8)	1877 (2.3)	1991 (2.3)	1842 (2.5)
10	1846 (1.7)	1950 (2.3)	1826 (2.3)	1947 (2.4)
11	2002*	1775/1781/1866	1783/1874/2003	1975
12	1807*	1775/1781/1866	1783/1874/**2003**	2002
13	1783*	1775/1781/1866	1783/1874/2003	2001
14	1811*	1976/1992	1778	1802
15	1868*	1976/1992	1911	1932

viations of monthly data between 0.0 and 0.3 K, on average 0.1 K; no inhomogeneities detectable).

2 Results of the summer temperature time series analysis

Fig. 1 shows the mean German surface air temperature summer (mean of months June, July, and August) anomalies 1761–2003 (deviations from the average of the recent CLINO period 1961–1990). Some extremes are denoted: 2003 (+3.4 K, maximum so far), 1947 (+2.2 K, maximum before 2003), 1994 and 1992 (+2.1 K) and so on. Rank statistics for both summer and individual summer months are listed in Table 1. 2003 was also the warmest June month; in August only the value in 1807 was warmer. Considering again Fig. 1 and Table 1, it is worth noting that the summer extreme values, roughly first 10 ranks, differ relatively little from each other so that the 2003 value appears as a unprecedented ‘jump’ (1.2 K above previous warmest summer, 1947).

Next, it is of interest to look at trends to assess whether there is a tendency for summer seasons to be-

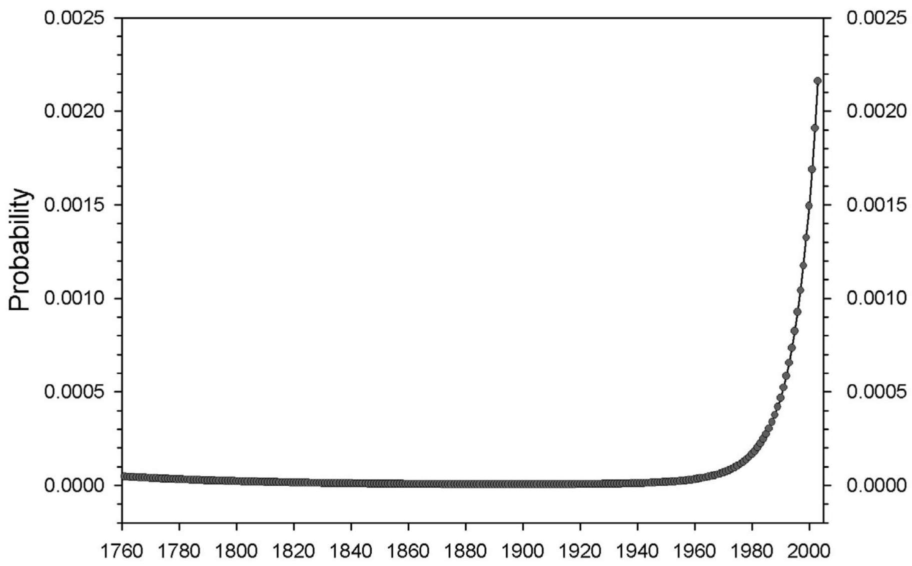

Figure 2: Evaluation of the probability that a ≥ 3.4 K summer anomaly event occurs based on a Gaussian distribution of the data shown in Fig. 1.

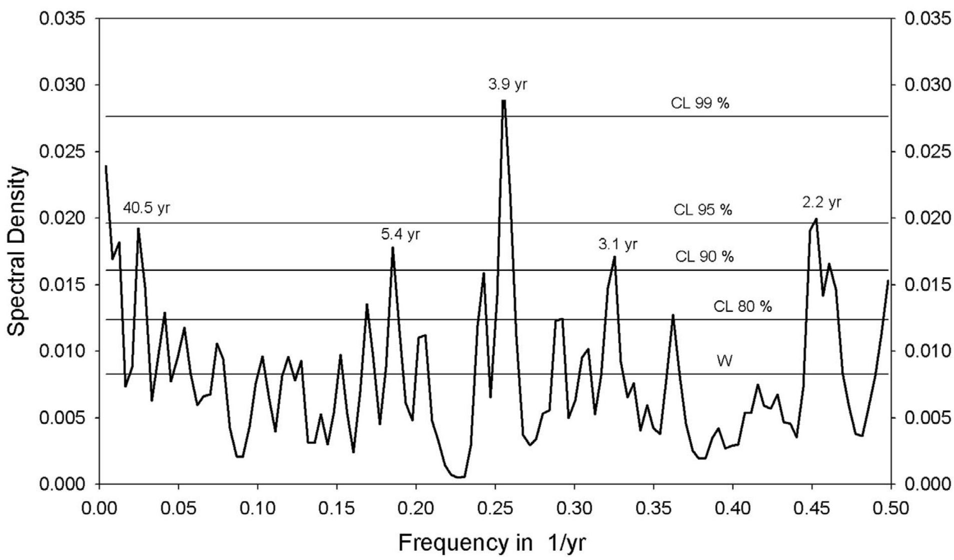

Figure 3: Autocorrelation spectral analysis (ASA, method see SCHÖNWIESE, 2000) of the data shown in Fig. 1. W is the white background noise spectrum, CL are confidence levels. Some outstanding peaks are denoted by their period values.

come systematically warmer. A related analysis of the whole summer temperature series (1761–2003) reveals that, in the long-term there was first a cooling trend and later on, roughly since 1900–1920, a warming trend. Both can be combined in a second order polynomial component plotted in Fig. 1 by means of a heavy dashed line. The related linear trends amount to –0.5 K for 1761–1913 and + 1.3 K for 1913–2003. The linear trend 1901-2000 is somewhat smaller: 1.0 K (very similar to the annual data trend amounting to + 0.9 K; RAPP, 2000). Table 2 reveals that the summer trend is dominated by the August data. Moreover, it appears, comparing the 30 yr trend values 1961–1990, 1971–2000, 1973–2002, and 1974–2003, that the maximum trend value is reached in the most recent subperiod (summer + 1.8 K, June 1.5 K, July 1.5 K, with August, again dominating, 2.4 K). However, just this trend value is strongly influenced by the 2003 extreme event. More general, extremes and fluctuations are the reasons of trend instabilities. Due to the relative large superimposed variations the confidence of these trend values is rather small in most cases, see Table 2 (where only confidence levels

Table 2: Linear trends and related confidence levels of the observed mean German surface air temperature time series for different periods as denoted. Note that the 1974–2003 trends are strongly influenced by the 2003 extreme event.

Season/ Month	*Period*	*Trend*	*Confidence level*
Summer	1901 –2000	1.01	> 90 %
	1961–1990	0.38	-
	1971–2003	0.93	> 80 %
	1973–2002	1.16	> 80 %
	1974–2003	1.82	> 95 %
June	1901–2000	0.57	-
	1961–1990	-0.89	-
	1971–2000	0.85	-
	1973–2002	0.59	-
	1974–2003	1.49	> 80 %
July	1901–2000	0.79	-
	1961–1990	0.87	-
	1971–2000	0.69	-
	1973–2002	1.18	-
	1974–2003	1.49	> 80 %
August	1901–2000	1.68	> 90 %
	1961–1990	2.51	> 99 %
	1971–2000	0.12	-
	1973–2002	1.74	> 90 %
	1974–2003	2.44	> 95 %

> 80% are indicated, assessments based on the trend-to-noise values and z-test).

Temperature data are often Gaussian distributed. (Note that here, as well as in the following, all data and not only extremes are considered.) A related analysis of the German summer data shows that such an assumption of a Gaussian distribution is justified (no rejection using both the χ^2 and the Kolmogoroff-Smirnoff test at all confidence levels 80...99.9 %, although a Weibull distribution fits insignificantly better; methods see textbooks, e.g. SCHÖNWIESE, 2000). So assessing trends using a z-test as mentioned above is correct. Under this Gaussian assumption (implying a stationary process) one may ask for the probability that a summer anomaly of + 3.4 K, corresponding to 3.8 s (s = standard deviation), as observed in summer 2003 appears. The answer is: p = 0.7 $\cdot$ 10^{-6}, i.e. nearly impossible. Note that in Switzerland the summer anomaly of + 5.1 K, corresponding to 5.4 s, was even more extreme (SCHÄR et al., 2004).

However, due to a changing climate, in particular a warming trend, such probabilities may change (non-stationary process). In consequence, based on an advanced technique of time series decomposition which allows (inter alia) time-dependent probability assessments (TRÖMEL and SCHÖNWIESE, 2004; see also GRIESER et al., 2002) we have applied this technique on the German summer temperature series and asked for the probability that a $\geq$ 3.4 K event like in summer 2003 can be statistically expected. The result is shown in Fig. 2: Starting with a probability p $<$ 0.0001 (corresponding to a statistical return period of 1/p = 10.000 years), due to the progressive warming trend in recent decades, this probability amounts now approximately to p = 0.0022 (return period of c. 455 years). This means that the probability of warm summer seasons in Germany has dramatically increased, however, even under such findings, the 2003 summer event is very extreme.

Fig. 1 shows, in addition to the summer time series and the polynomial component also a 30 yr low-pass filtered fluctuation (heavy line) which can be identified as a quasi-40 yr – cycle by means of spectral analysis, see Fig. 3. This Figure indicates also some more cycles above or near the 95 % confidence level (2.2 yr = QBO and outstandingly 3.9 yr), however, the spectrum does not very significantly differ from a white one. The quasi-40 yr cycle may be of special interest in context with trends. It has reached its maxima, in addition to some earlier ones, roughly in 1900, 1945, 1970 and, hypothetically, in the near future. Since c. 1980, however, it cannot be discerned from a linear trend. This may mean that just within the recent two decades this cycle and the long-term trend are superimposed leading to a very pronounced warming. However, this assumption is speculative and the physical origin of the quasi-40 yr cycle is unknown (although in earlier literature it appears as "Brückner cycle", c. 35 yr; see e.g. von RUDLOFF, 1967).

3 Conclusions

Similar to other European countries, the hot summer 2003 in Germany has to be seen as a very extreme event. Although the warming trend observed especially within the recent decades, in turn, leads to an increasing probability of hot summers taking place, the 2003 event, in the moment, can be characterized by a returning period of only 455 years (probability 0.0022). Simultaneously, the summer 2003 was also relatively dry (as expected in case of high pressure influence), however this related dryness event was not as outstanding as in case of temperature (since 1901 rank 5, driest summer so far 1911; temperature-precipitation correlation 1901–2003 r = –0.46). For a more detailed analysis including daily data and precipitation see SCHÖNWIESE et al., 2004; BECK et al., 2004.

Based on IPCC (2001) SRES scenarios and using a regional climate model, SCHÄR et al. (2004) found that a probable reason for the observed European summer warming is the enhanced anthropogenic greenhouse effect. Their projection until 2071–2100 leads to an outstanding increase of both summer temperature average and standard deviation in Switzerland and, in consequence, of the return period of the 2003 hot summer event by a factor of roughly 150. Note that the coolest summer in Germany appeared in 1816 (see Fig. 1), just one year after the Tambora eruption.

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