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Extreme summer temperatures in Western Europe

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Abstract. We discuss the evolution of summer temperature extremes over Western Europe during 1961–2004 in the context of current climate warming. Using a parametric approach, we investigate the role of properties and changes in probability density functions of daily temperatures in modifying the frequency of severe, isolated events. In this perspective, the recent intensification of extremely warm events over Europe turns out to be well consistent with a pure, nonuniform shift of mean values, with no room for conjectures about increasing temperature variability.

1 Introduction

European temperatures have undergone a considerable rise in the recent past, accompanied by marked changes in the frequency and magnitude of warm and cold extremes (Alexander et al., 2006; Moberg et al., 2006). The way such changes are controlled by changes in mean climatic conditions still needs to be understood. Exceptionally warm events, for instance, are generally thought to be triggered by increasing temperature variability on the daily or annual timescale (Schär et al., 2004; Della-Marta et al., 2007). Likewise, modifications in the distributional shape of daily temperatures have been inferred from discrepancies between the observed behavior of moderate (so-called *soft*) extremes and that expected under a pure shift of mean temperatures (Klein Tank and Können, 2003; Klein Tank et al., 2005). Although such a climate shift seems inadequate to explain the recent intensification of unusually warm events, there is no clear observational evidence for changes in the statistical properties beyond the mean (e.g. Scherrer et al., 2005; Simolo et al., 2010, 2011).

A key-point is therefore to investigate the relationships between the behavior of severe, isolated events and the average distributional properties of daily temperatures. Here we provide an appropriate theoretical framework to determine the exact nature of these relationships, that is, for translating basic properties and long-term trends in the moments of probability density functions (PDFs) of daily temperatures into changes in the frequency of warm and cold extremes. This formalism is here used to examine the summer evolution of daily temperatures over a Western European subdomain, where the past decades have seen a strong warming that caused well-known record-breaking events, and is projected to be even more severe in the near future (e.g. Fischer and Schär, 2009; Hirschi et al., 2011). Using this case as a baseline, we show how the observed evolution of soft extremes can be understood in the light of a pure shift of mean temperatures, with no need for invoking more complicated changes in the second and higher moments. For further details see Simolo et al. (2011).

A brief description of the data used and their processing is given in Sect. 2. A model for time-evolving daily temperature PDFs and soft extremes is discussed in Sect. 3. Main results are then illustrated in Sect. 4 by direct comparison with observations. Conclusions are finally drawn in Sect. 5.

2 Observations

As discussed in detail in Simolo et al. (2011), analyses of changes in European temperature extremes during the past 50 yr are based on maximum (TX) and minimum (TN) daily records from the European Climate Assessment (ECA) dataset (Klein Tank et al., 2002), selected on the basis of strict quality and homogeneity criteria. Station series, re-expressed as anomalies relative to the base period 1961–1990, were gathered in three European sub-domains using a Principal Component Analysis, i.e. a southern area from the Alpine to the Carpathian Chain (AC), a Northern Sea (NS) and an

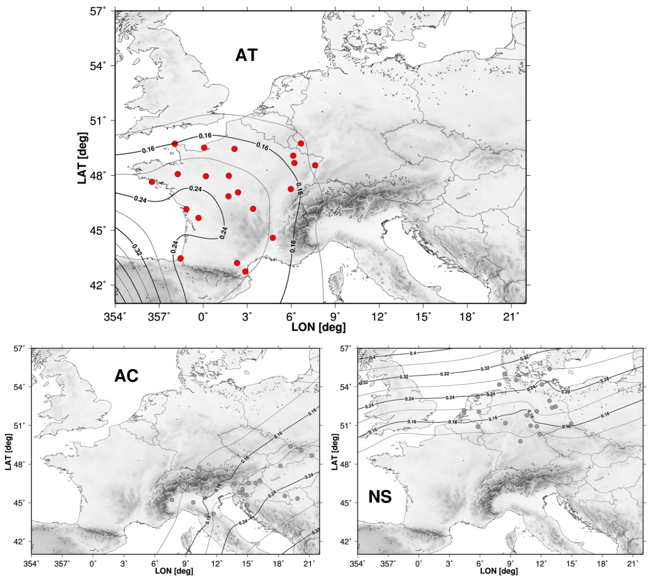

Figure 1. European areas (AT, AC and NS, see text) defined by Principal Component Analysis. Red dots in the upper panel denote locations of the 21 stations retained in the AT sub-domain. Loadings of Varimax rotated empirical orthogonal functions are also shown.

Atlantic (AT) area (see Fig. 1). Unweighted spatial averages were then derived for each sub-domain and for both TX and TN anomalies. Data availability and quality allowed to cover 1961–2007 over AC and NS and 1961–2004 over AT. Here we focus on summer (JJA) temperature evolution across the AT sub-domain, and refer to Simolo et al. (2011) for a comprehensive discussion. The observed evolution of soft extremes, i.e. those events confined to the outermost few percent tails of daily PDFs, is conventionally measured as day-counts per year (or season) exceeding/not exceeding fixed thresholds. We consider percentile-based indicators (Alexander et al., 2006) for gradually smaller fractions of the cold and the warm tail in TX PDFs, i.e. TXN, with $N = 10, 5, 1$ and $N = 90, 95, 99$ respectively, and similar for TN.

3 PDFs and soft extremes

Potential variations in the second and higher moments of daily temperature PDFs, as already noted, are usually deduced indirectly from anomalous behaviors of distribution tails. Here, reversing the point of view, we determine the time evolution of cold and warm extremes from observed properties and changes in daily temperature distributions. A theoretical model is used for describing time-evolving PDFs and their basic features (Sect. 3.1). The ensuing changes in soft extremes can be determined within this framework in terms of time-dependent exceedance probabilities (EPs), i.e. total probabilities for events exceeding/not exceeding fixed thresholds (Sect. 3.2). As an example, the whole formalism is adjusted for the TX and TN summer evolution over the AT region, as will be discussed in Sect. 4.

3.1 A time-evolving skewed density (TESD) model

The most prominent changes in European temperatures concern the increase of the mean, whereas no significant trends during the recent past have been clearly detected in the second and higher moments, except only for weak seasonal effects (e.g. Scherrer et al., 2005; Moberg et al., 2006). This issue has been addressed in Simolo et al. (2011) by a moment-based analysis of the empirical PDFs, derived from single-year sub-samples of TX and TN anomalies for the three European areas over their respective periods (see Sect. 2). In all cases the time series of second and higher moments did not reveal significant trends, but random fluctuations only (Simolo et al., 2011). The strongest warming was detected over the AT region, with a marked summer trend in both TX and TN mean values, which is only approximately linear in time and best fitted by a second-degree polynomial (see Fig. 2a). Similar to the other European areas, either on the annual or seasonal timescale, the AT summer PDFs were found to be essentially stationary in shape, though the shape itself shows departures from normality that are related to the degree of asymmetry.

Modeling observed PDFs therefore requires a skewed extension of the normal density function, i.e.

$$f(z) = 2\phi(z)\Phi(\alpha z), \quad \text{where}$$
$$\phi(z) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{z^2}{2}\right), \quad \text{and} \quad \Phi(\alpha z) = \int_{-\infty}^{\alpha z} \mathrm{d}y \phi(y). \qquad (1)$$

Here, the shape parameter α controls the degree of asymmetry, with a left (right) skewed density defined by $\alpha < 0\ (> 0)$ and the usual normal density by $\alpha = 0$. A location ξ and a scale parameter ω are restored by setting $z = (x - \xi)/\omega$. Model parameters can be estimated, e.g., by the method of moments. The performance of the skewed density (Eq. 1) in fitting daily temperature data was thoroughly assessed in previous works (Simolo et al., 2010, 2011), and is here illustrated in Fig. 2b, c for TX and TN summer anomalies of the AT regional series. Since, as stated above, time averages of second and higher moments are preserved by the evolution of European temperatures, the skewed density (Eq. 1) can be assumed as the fixed-shape PDF underlying daily anomalies. Time dependence can be then imposed on the model PDF through a change in the location parameter ξ only, while keeping the scale and shape parameters constant across the full period and equal to their long-term averages. Hence,

$$z \to z - \frac{\Delta\xi(t)}{\omega}, \quad \Delta\xi(t) = \xi_1 t + \xi_2 t^2, \quad \omega = \bar{\omega} \quad \text{and} \quad \alpha = \bar{\alpha}, \qquad (2)$$

where t is the time lapse and a second order term in $\Delta\xi(t)$ accounts for the nonuniform shift of the mean, consistently with observations (see Fig. 2a).

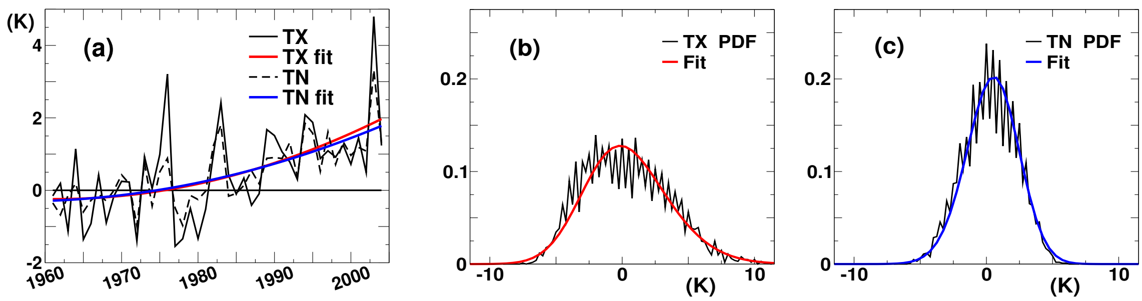

Figure 2. (a) Time evolution of mean summer anomalies for TX (black solid line) and TN (black dashed line) over the AT region, together with their second order polynomial fits (red and blue lines respectively). **(b–c)** Empirical versus model PDFs for detrended summer **(b)** TX anomalies altogether, and similar for **(c)** TN. Model parameters are given in Sect. 4.

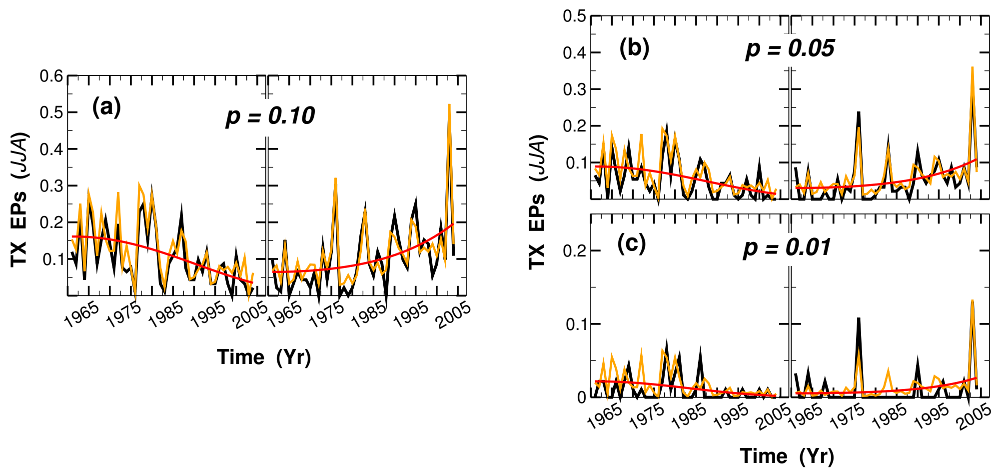

Figure 3. Modeled and observed evolution of TX EPs for AT summer anomalies and probabilities **(a)** $p = 0.10$, **(b)** $p = 0.05$ and **(c)** $p = 0.01$. In all cases, black lines denote the observed frequencies of (left) cold and (right) warm extremes, i.e. TX10 and TX90, and similar. Red lines are expected EPs with location parameter given by Eq. (2), and yellow lines are point-wise, expected EPs (see text).

3.2 Expected EPs

Time-varying frequencies of cold and warm extremes, as measured by the percentile indicators (e.g. TX10 and TX90), have a straightforward, theoretical representation as EPs, respectively

$$F_-(\bar{z}_p, t) = \int_{-\infty}^{\bar{z}_p} \mathrm{d}z\, f(z,t), \qquad \text{and}$$

$$F_+(\bar{z}_{1-p}, t) = \int_{\bar{z}_{1-p}}^{+\infty} \mathrm{d}z\, f(z,t) \tag{3}$$

for a defined probability p (e.g. $p = 0.10$ for, say, TX10 and TX90). The fixed thresholds, $\bar{z}_p$ and $\bar{z}_{1-p}$ are climatological values, uniquely determined by the condition $F_-(\bar{z}_p, t_0) = F_+(\bar{z}_{1-p}, t_0)$ at a given initial time t_0. In practice, changes over time in the frequency of soft extremes can be explicitly predicted within this framework from observed changes in the distributional properties of daily anomalies, by estimating the appropriate TESD model parameters defined by Eqs. (1)–(2). The inherent nonlinearity between changes in PDF moments and tails becomes apparent in this formalism, since the time evolution of EPs is controlled by the behavior of the underlying density function. For normal distributed data, for instance, rates of change in EPs scale exponentially in time, even for a uniform shift of the mean, as can be easily proved using Eqs. (1)–(3) with $\alpha = \xi_2 = 0$ (see Simolo et al., 2011 for details).

4 Comparing modeled and observed changes

Warm extremes (i.e. TX > 90th percentile, etc.) have increased at an average rate of several days per decade over all the European areas, and cold extremes (TX < 10th percentile, etc.) correspondingly decreased. Although rates of change in soft extremes are far from being constant over the whole period, linear trends in the AT region amount to, e.g. $+3.1 \pm 0.9$ (-0.3 ± 0.2) summer day-counts per decade in TX90 (TX10), and $+5.2 \pm 0.9$ (-0.5 ± 0.1) in TN90 (TN10).

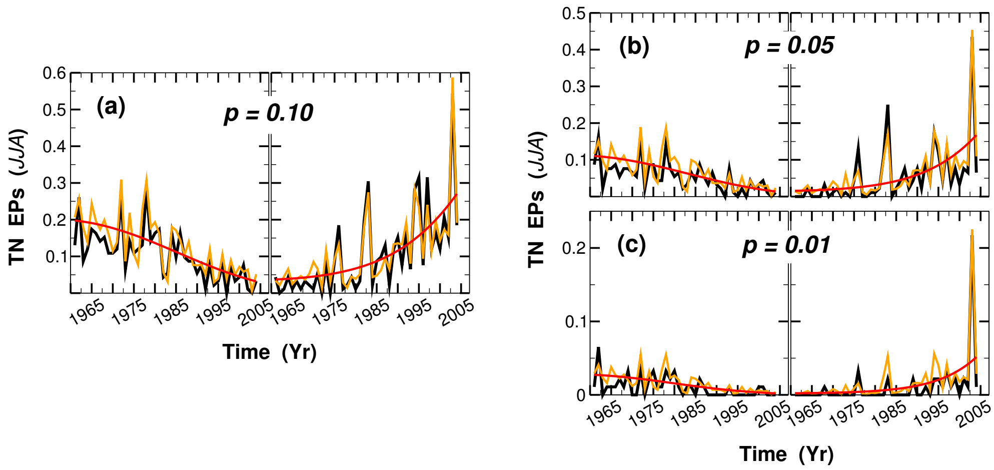

Figure 4. Same as Fig. 3, but for TN EPs.

The frequency of day-counts with JJA anomalies exceeding/not exceeding percentile thresholds are shown as a function of time in Figs. 3–4 (black lines), for both TX and TN in the AT regional series and gradually less moderate extremes.

The expected time-dependent EPs are obtained from Eq. (3) with $p = 0.10$, 0.05, and 0.01, and the same choice of the TESD model parameters defined by Eqs. (1)–(2), derived from observations. That is, the location ξ of the AT summer skewed density is let vary nonlinearly in time with coefficients obtained from fits of TX and TN mean anomalies (see Fig. 2a); estimates of average scale and shape parameters are given by $\overline{\omega}_{\mathrm{TX}} = 3.9\,\mathrm{K}$, $\overline{\alpha}_{\mathrm{TX}} = 1.3$, $\overline{\omega}_{\mathrm{TN}} = 2.4\,\mathrm{K}$, and $\overline{\alpha}_{\mathrm{TN}} = -1.1$ (Fig. 2b–c). As seen in Figs. 3–4, theoretical EPs (red lines) nicely fit the observed evolution of both cold and warm extremes, in both TX and TN anomalies, down to $p = 0.01$, thereby outlining the actual rates of change. This, in turn, implies that the observed changes in the frequency of soft extremes are in fact those expected from a forward, nonuniform shift of mean temperatures. This is even more clear if the prescription in Eq. (2) for a continuous time-evolution of the location parameter is replaced with point-wise, annual averages, obtained e.g. by adding back the residuals from the fits of mean anomalies. In all cases the observations are faithfully reproduced by the corresponding point-wise EPs (yellow lines in Figs. 3–4), as witnessed by the large fraction of the variance explained by the model, i.e. $R^2 \sim 0.86, 0.77, 0.49$ (0,88, 0.79, 0.68) for TX (TN) and $p = 0.10$, 0.05, 0.01 respectively, averaging over cold and warm tails. Several unusually intense anomalies in either TX or TN (e.g. the 1976 and 2003 heatwaves) are predicted with values of probabilities very close to the observed ones. This fact again stresses the prominent role of the mean, both long-term trends and fluctuations, in the time-evolution of soft extremes.

Small discrepancies between model predictions and observations can be ascribed to fluctuations in the second and higher moments, not accounted for by the choice of average scale and shape parameters in the TESD model. Nevertheless, these discrepancies are quite small throughout the period, with no pattern, signifying that predictions are not plagued by underestimated trends in variability and skewness.

5 Conclusions

To summarize, we illustrated a simple, theoretical model for predicting changes in the frequency of cold and warm extremes from average distributional properties and changes in daily temperatures. The key-strength of the present approach is its ability to account explicitly for the inherent nonlinearity between PDF moments and tails. A detailed comparison of model predictions and observations over the past decades puts forward the prominent role of the mean in explaining the evolution of extreme summer temperatures over Western Europe, including the occurrence of unusually intense events. In view of this, hypothesis of ongoing changes in the higher moments appear to be neither supported by the data, nor even required.

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References

Alexander, L. V., Zhang, X., Peterson, T. C., Caesar, J., Gleason, B., Klein Tank, A. M. G., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F., Tagipour, A., Rupa Kumar, K., Revadekar, J., Griffiths, G., Vincent, L., Stephenson, D. B., Burn, J., Aguilar, E., Brunet, M., Taylor, M., New, M., Zhai, P., Rusticucci, M., and Vazquez-Aguirre, J. L.: Global observed changes in daily climate extremes of temperature and precipitation, J. Geophys. Res., 111, D05109, doi:10.1029/2005JD006290, 2006.

Della-Marta, P. M., Haylock, M. R., Luterbacher, J., and Wanner, H.: Double length of western European summer heat waves since 1880, J. Geophys. Res., 112, D15103, doi:10.1029/2007JD008510, 2007.

Fischer, E. M. and Schär, C.: Future changes in daily summer temperature variability: driving processes and role for temperature extremes, Clim. Dynam., 33, 917–935, doi:10.1007/s00382-008-0473-8, 2009.

Hirschi, M., Seneviratne, S. I., Alexandrov, V., Boberg, F., Boroneant, C., Christensen, O. B., Formayer, H., Orlowsky, B., and Stepanek, P.: Observational evidence for soil-moisture impact on hot extremes in southeastern Europe, Nat. Geosci., 4, 17–21, doi:10.1038/ngeo1032, 2011.

Klein Tank, A. M. G. and Können, G. P.: Trends in indices of daily temperature and precipitation extremes in Europe, J. Climate, 16, 3665–3680, 2003.

Klein Tank, A. M. G., Wijngaard, J. B., Können, G. P., Böhm, R., Demaree, G., Gocheva, A., Mileta, M., Pashiardis, S., Hejkrlik, L., Kern-Hansen, C., Heino, R., Bessemoulin, P., Muller-Westermeier, G., Tzanakou, M., Szalai, S., Palsdottir, T., Fitzgerald, D., Rubin, S., Capaldo, M., Maugeri, M., Leitass, A., Bukantis, A., Aberfeld, R., Van Engelen, A. F. V., Forland, E., Mietus, M., Coelho, F., Mares, C., Razuvaev, V., Nieplova, E., Cegnar, T., Antonio Lopez, J., Dahlstrom, B., Moberg, A., Kirchhofer, W., Ceylan, A., Pachaliuk, O., Alexander, L. V., and Petrovic, P.: Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment, Int. J. Climatol., 22, 1441–1453, 2002.

Klein Tank, A. M. G., Können, G. P., and Selten, F. M.: Signals of anthropogenic influence on European warming as seen in the trend patterns of daily temperature variance, Int. J. Climatol., 25, 1–16, 2005.

Moberg, A., Jones, P. J., Lister, D., Walther, A., Brunet, M., Jacobeit, J., Alexander, L. V., Della-Marta, P. M., Luterbacher, J., Yiou, P., Chen, D., Klein Tank, A. M. G., Saladie, O., Sigro, J., Aguilar, E., Alexandersson, H., Almarza, C., Auer, I., Barriendos, M., Begert, M., Bergstrom, H., Bohm, R., Butler, C. J., Caesar, J., Drebs, A., Founda, D., Gerstengarbe, F. W., Micela, G., Maugeri, M., Osterle, H., Pandzic, K., Petrakis, M., Srnec, L., Tolasz, R., Tuomenvirta, H., Werner, P. C., Linderholm, H., Philipp, A., Wanner, H., and Xoplaki, E.: Indices for daily temperature and precipitation extremes in Europe analyzed for the period 1901–2000, J. Geophys. Res., 111, D22106, doi:10.1029/2006JD007103, 2006.

Schär, C., Vidale, P. L., Lüthi, D., Frei, C., Häberli, C., Liniger, M. A., and Appenzeller, C.: The role of increasing temperature variability in European summer heatwaves, Nature, 427, 332–336, 2004.

Scherrer, S. C., Appenzeller, C., Liniger, M. A., and Schär, C.: European temperature distribution changes in observations and climate change scenarios, Geophys. Res. Lett., 32, L19705, doi:10.1029/2005GL024108, 2005.

Simolo, C., Brunetti, M., Maugeri, M., Nanni, T., and Speranza, A.: Understanding climate change-induced variations in daily temperature distributions over Italy, J. Geophys. Res., 115, D22110, doi:10.1029/2010JD014088, 2010.

Simolo, C., Brunetti, M., Maugeri, M., and Nanni, T.: Evolution of extreme temperatures in a warming climate, Geophys. Res. Lett., 38, L16701, doi:10.1029/2011GL048437, 2011.