Nonstationarity of the summer extreme temperatures in Neuchâtel during 1901-2006

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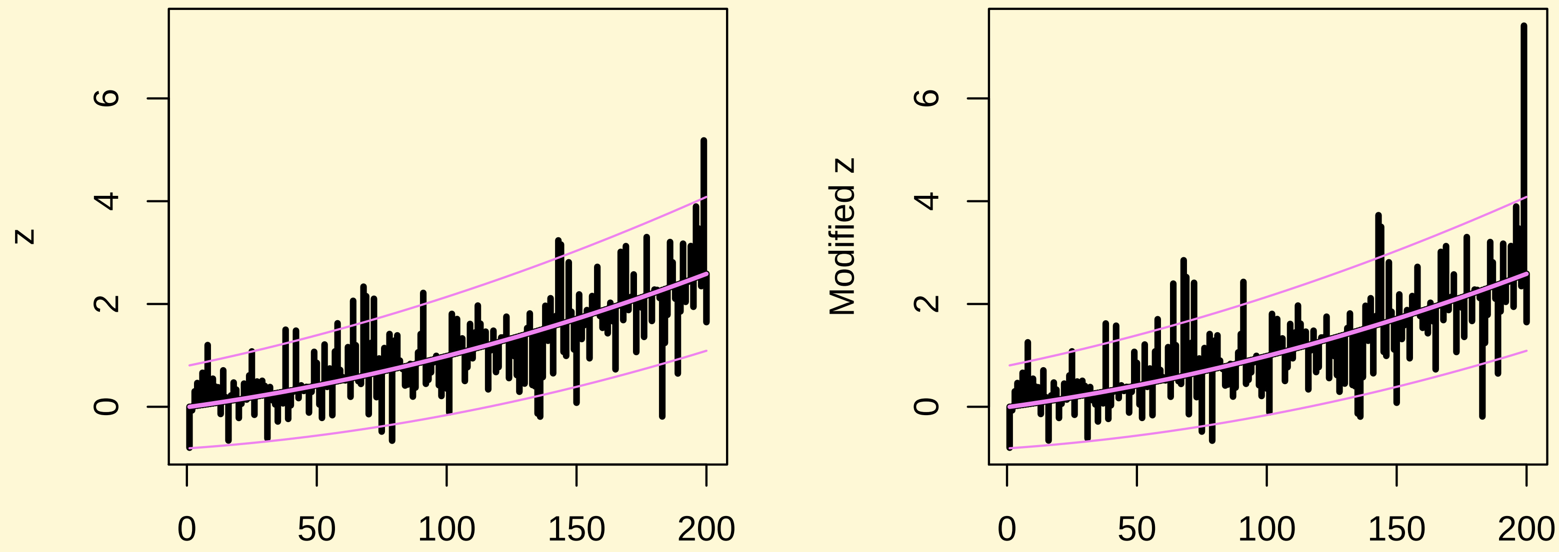
How do extremes change with climate change?

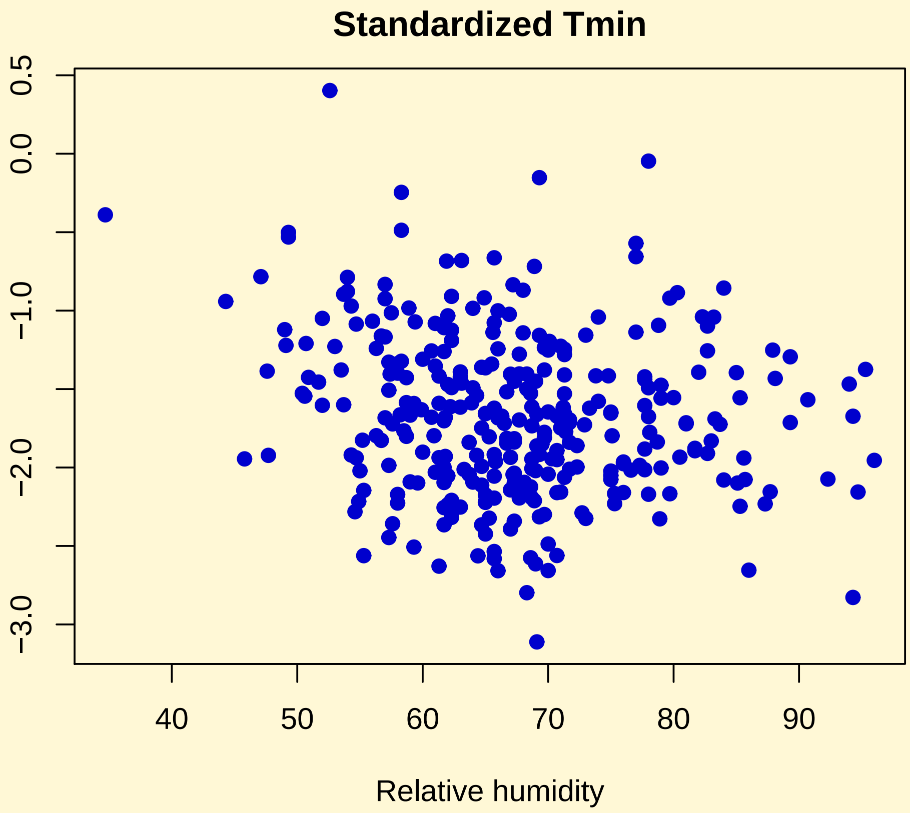
Do extreme observations move together with the complete data set, or do they have a behaviour of their own?

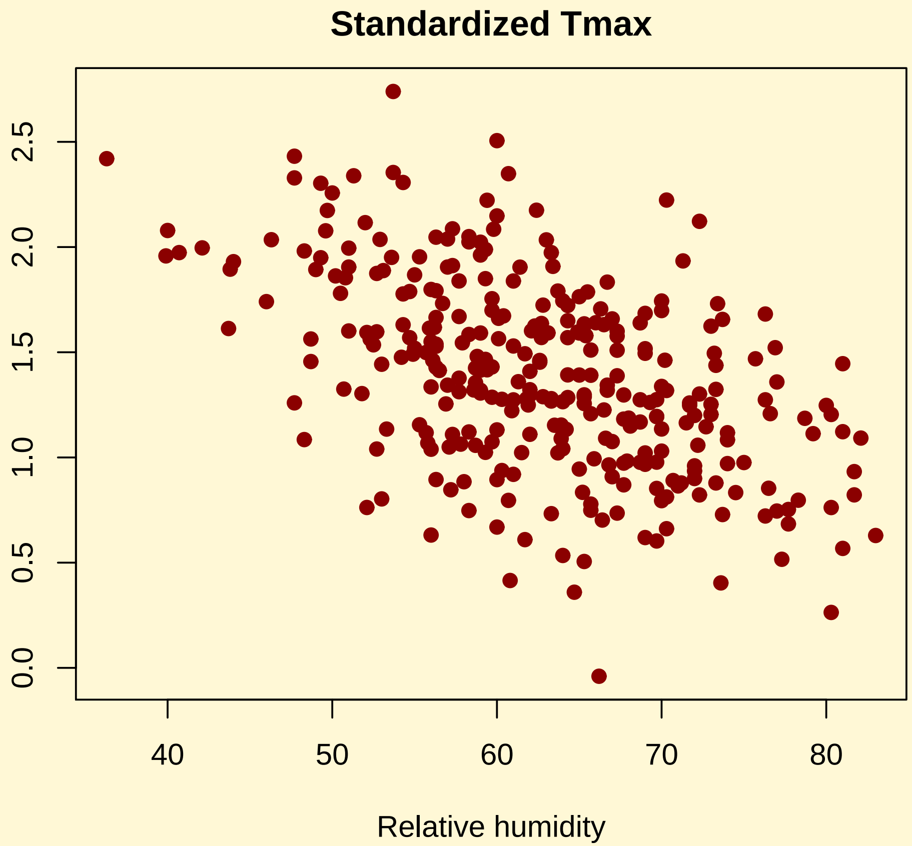


Relation to other climatic variables

Can links to other variables be useful in statistical analysis?

Daily maximum (Tmax) temperatures, daily minimum (Tmin) temperatures and daily mean relative air humidity from Neuchâtel, 1 January 1901 – 31 December 2006.





Summary

Main differences from other studies:

- a standardization procedure;
- the inclusion of humidity into the statistical modeling.

Results on the monthly hottest and coldest summer temperatures at Neuchâtel:

- We found strong stochastic association between the monthly extremal temperatures and the relative humidity at that day, different for Tmin and Tmax, that might be used to improve the quality of statistical analysis.
- After removing the common trend-like changes of the complete data series, a residual change in the lower tail of the Tmin series is found. This affects the symmetry of the distribution of Tmin.

Standardization

X_i: a random sequence with finite means m_i and variances s_i^2.

Standardization:

$$X_i^* = \frac{X_i - m_i}{s_i};$$

then $\mathrm{E}(X_i^*) \doteq 0$ and $\mathrm{Var}(X_i^*) \doteq 1$.

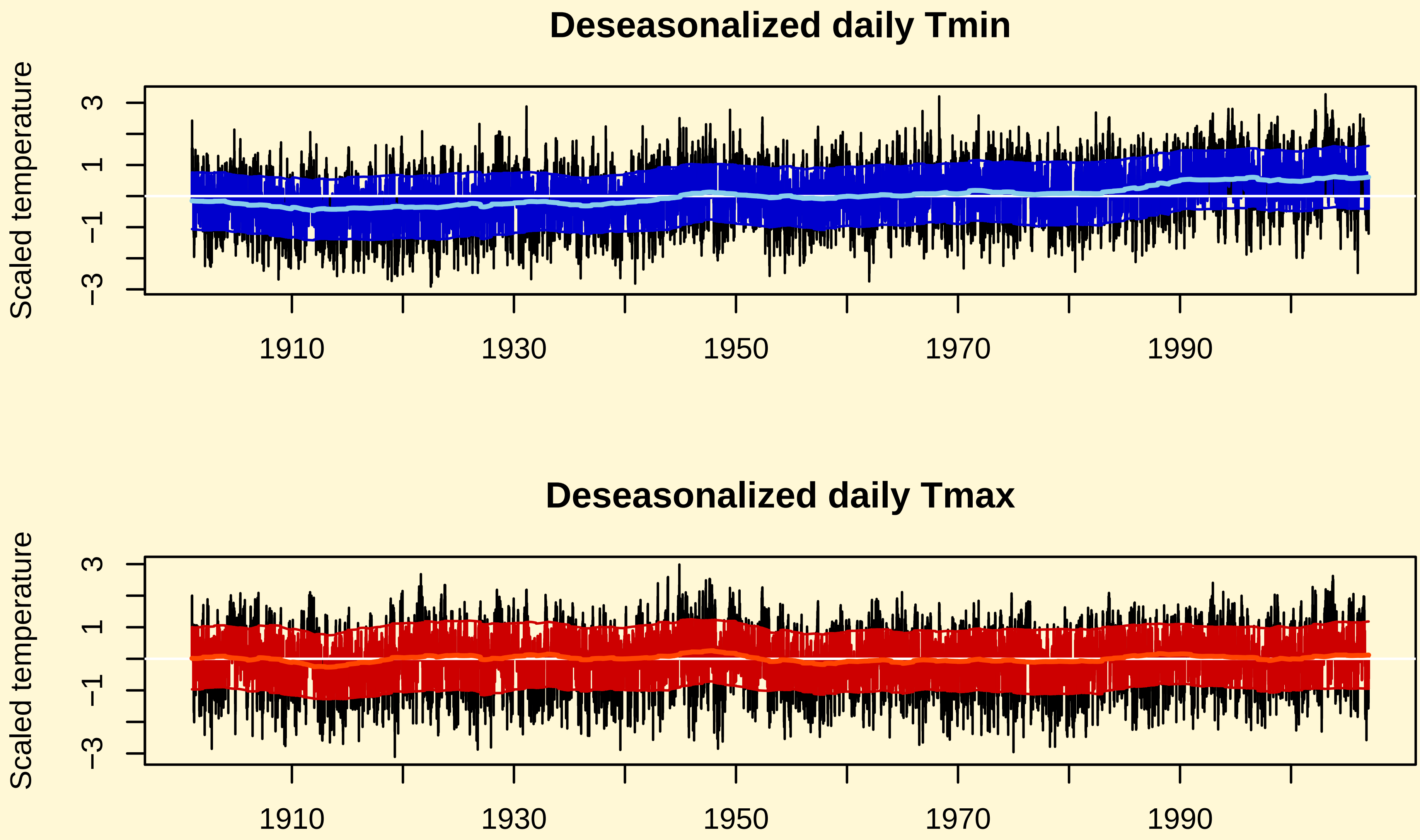
Two main sources of variation in the temperatures:

- seasonal changes in the mean and the variance;
- slow trend-like change in the mean and the variance.

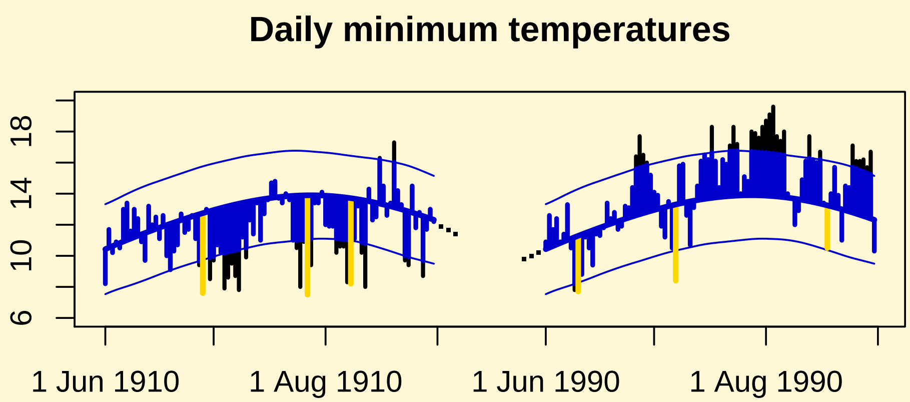
Accordingly, two steps of standardization:

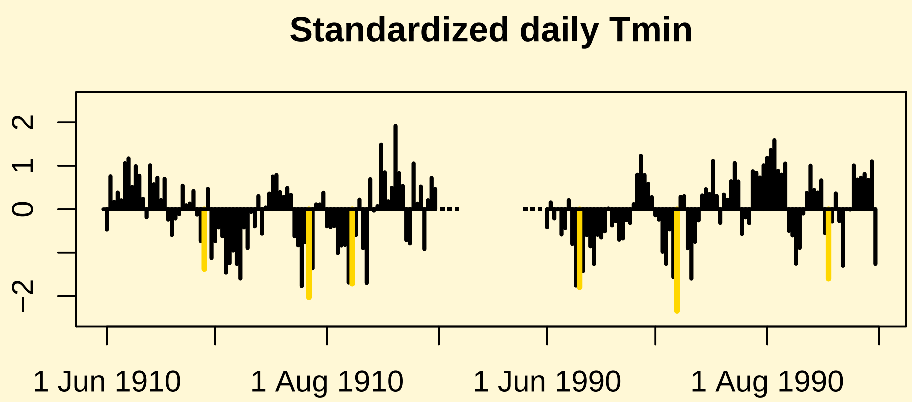
- standardization with respect to a common seasonal mean and variance pattern;
- standardization with respect to the slow trend in mean and variance.

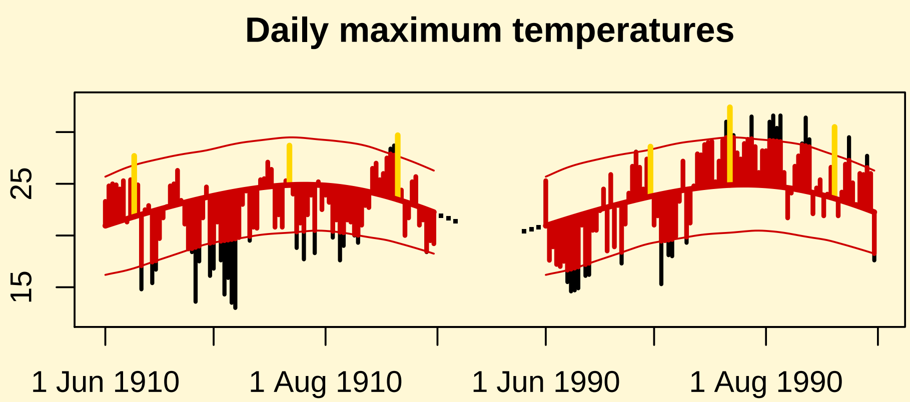
The removed trend component

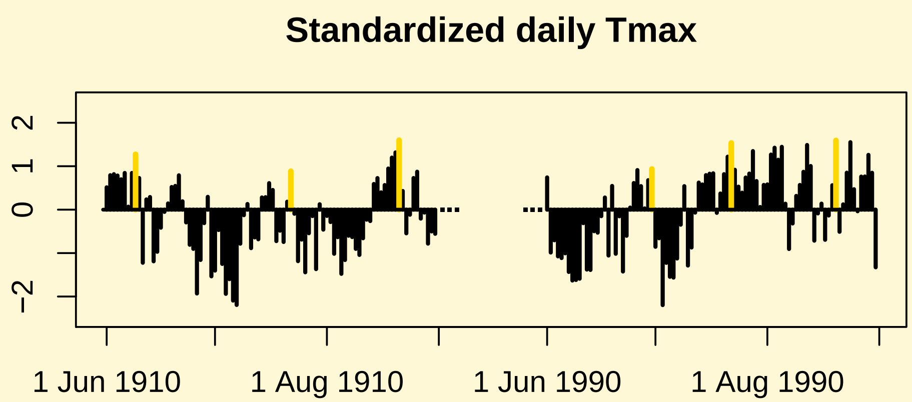


The standardized sequences









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Extreme-value model with covariates

Observations: X_i, a random sequence satisfying a weak condition requiring asymptotic independence on extreme levels.

Modeled variable: $M_n = \max_i\{X_i\}$, the maximum of the sequence $X_1, \ldots, X_n$.

Probabilistic model: Generalized extreme-value (GEV) model for M_n, with parameters depending on other variables $\mathbf{z}$:

$$\Pr(M_n < x) = \exp\left\{ -\left(1 + \xi(\mathbf{z})\frac{x - \mu(\mathbf{z})}{\sigma(\mathbf{z})}\right)_+^{-1/\xi(\mathbf{z})} \right\},$$

with $\xi(\mathbf{z}), \mu(\mathbf{z}) \in \mathbb{R}$ and $\sigma(\mathbf{z}) > 0$ for all admissible $\mathbf{z}$.

Examples for $\mathbf{z}$: time, humidity, North Atlantic Oscillation Index, ...

Need an initial idea about the $\xi(t,h)$, $\sigma(t,h)$ and $\mu(t,h)$ functions: what mathematical form is appropriate for the models?

Initial model

Problem:

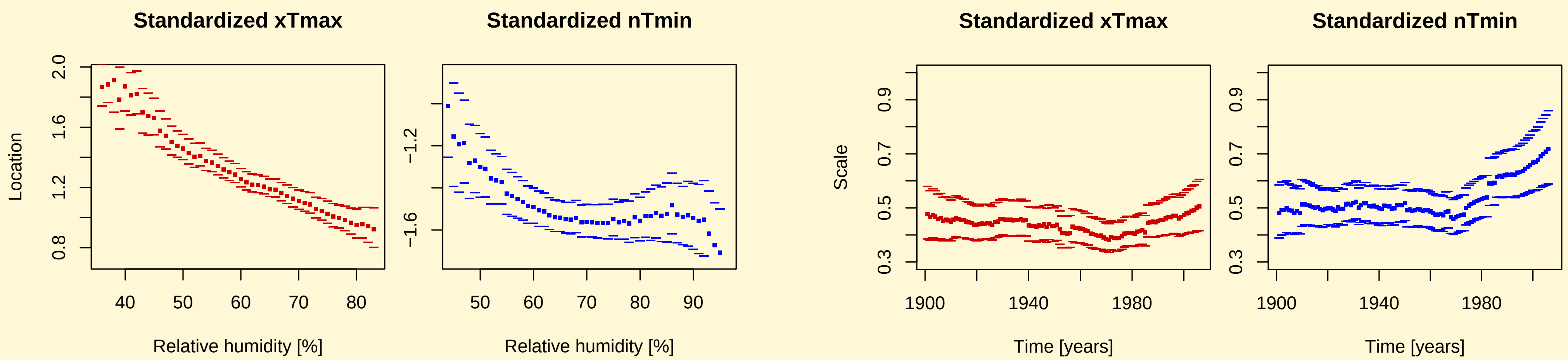
We want to decide about the existence or not of a time- or humidity-dependence of unknown form.

Solution:

Stationary GEV fits with constant parameters within fixed-length moving windows, both with respect to time and to humidity.

The most interesting dependencies:

Location: Scale:



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Mathematical formulation and model fitting

- **Initial model**

  A combination of quadratic and linear models for the parameters $\xi(t, h)$, $\sigma(t, h)$ and $\mu(t, h)$, with breakpoints at t = 1970 and h = 75% for nTmin.

- **Model fitting**

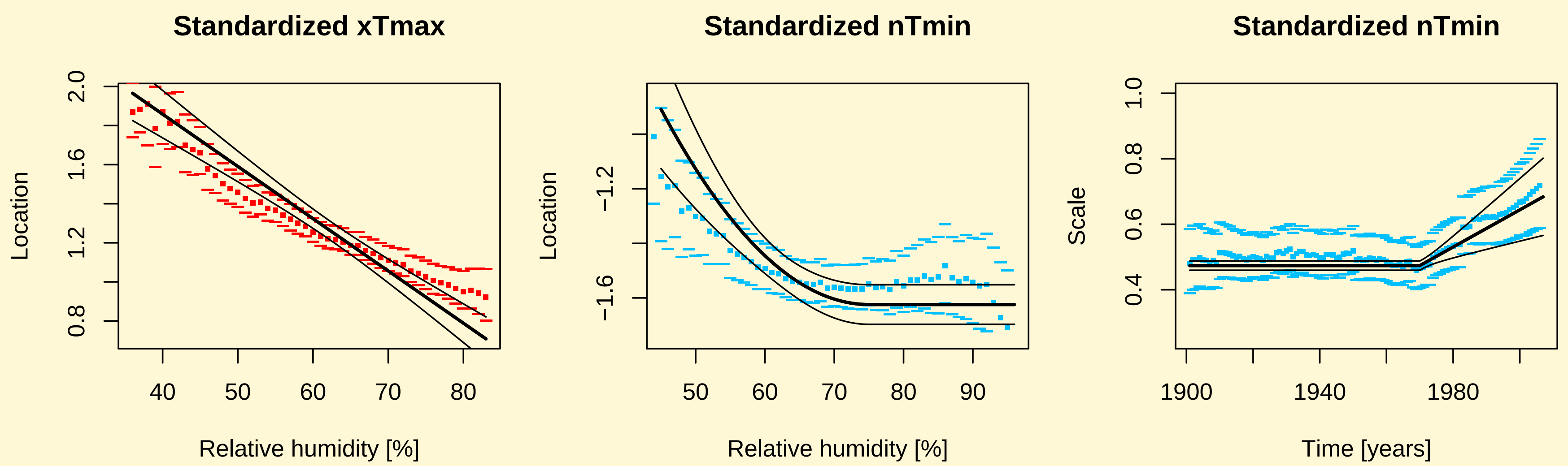
  Method of maximum likelihood.

- **Variable selection**

  Likelihood ratio tests.

Best models

Summary:



- We found negative shape parameters: temperatures are bounded (in a statistical sense).
- Only the location parameters of both nTmin and xTmax are influenced by humidity, and the form of dependence is different.
- Only the scale parameter of nTmin changed in time from around 1970.

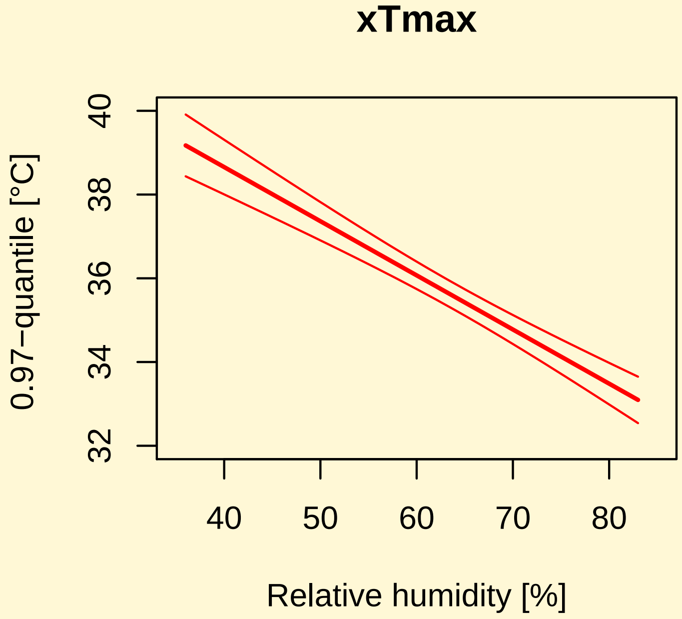
What does this mean on the original temperature scale?

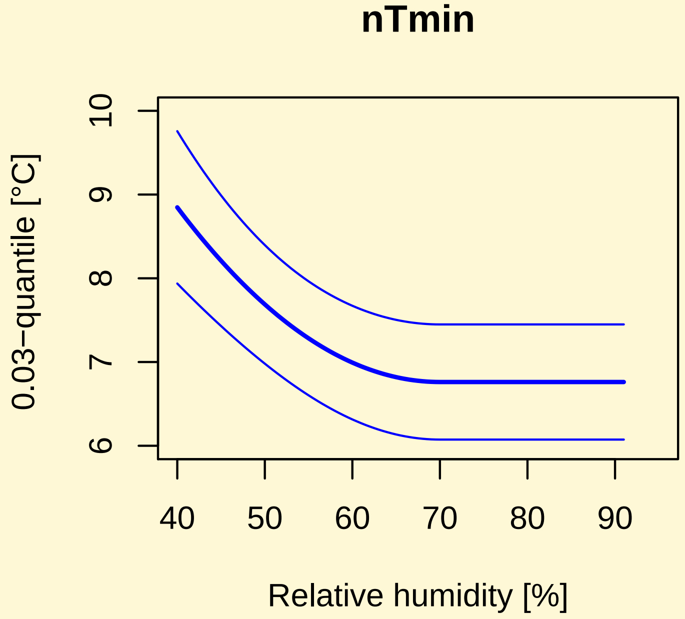
Humidity dependence of quantiles

p-quantile: The level which is exceeded with probability $1 - p$.

- For Tmax: choose the 0.97-quantile; 3% probability that the monthly maximum will be larger than this level.
- For Tmin: choose the 0.03-quantile; 3% probability that the monthly minimum will be lower than this level.

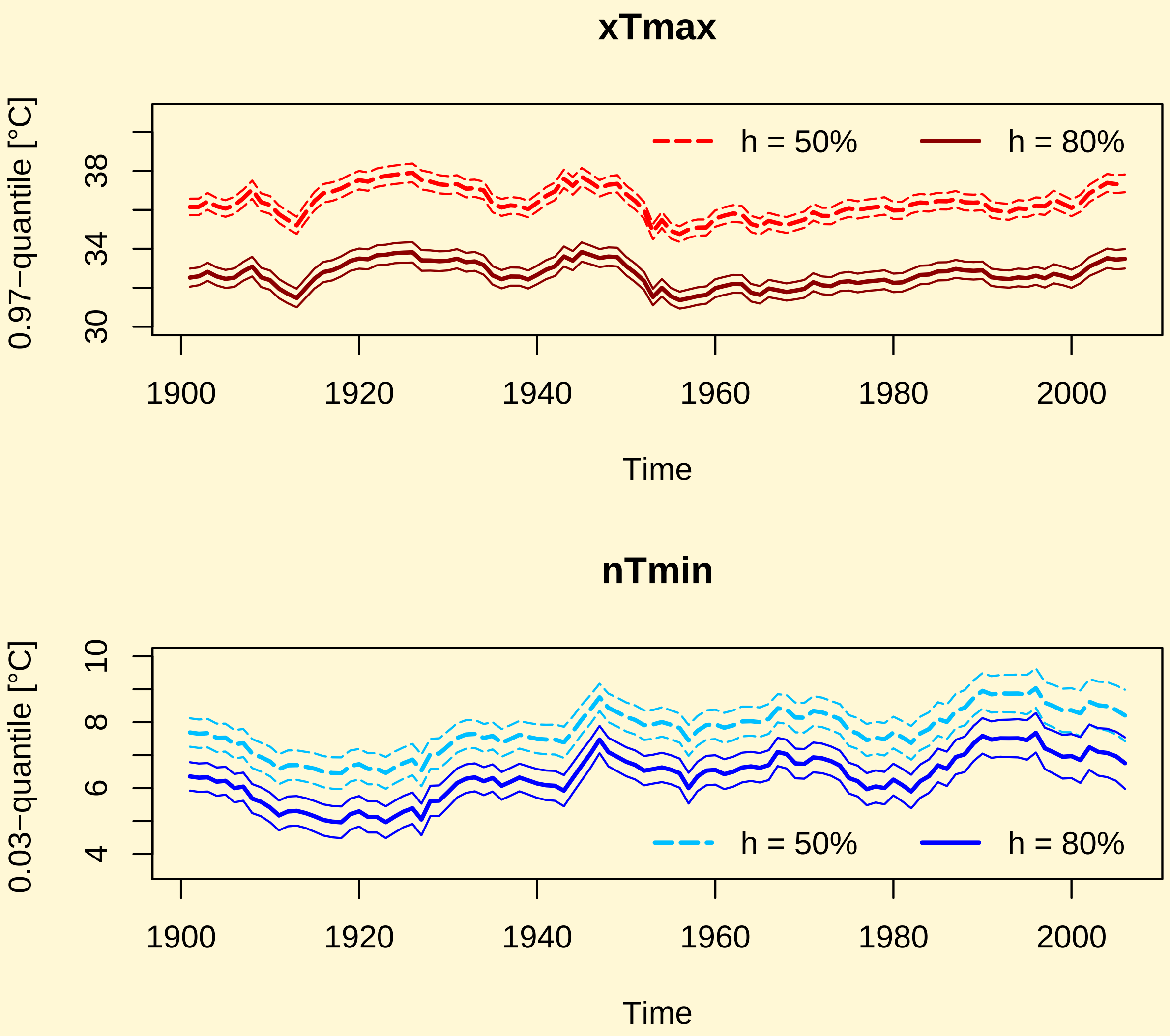
0.97- and 0.03-quantiles (with 20 July 2006 trend and seasonal values):



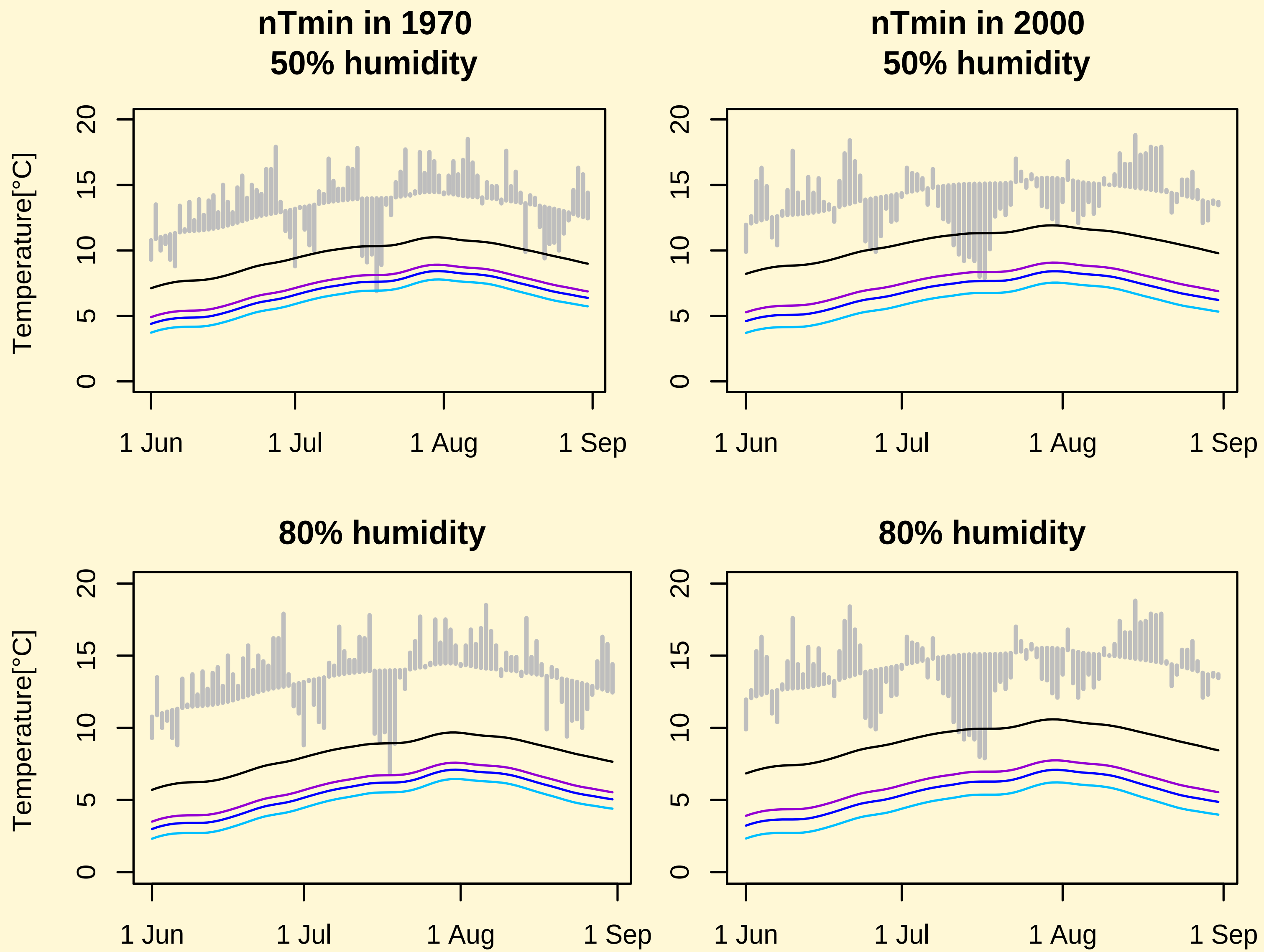


0.97 and 0.03-quantiles on 20 July over 1901–2006

How did the quantiles change during the 20th century?



Different quantiles of nTmin in 1970 and 2000



Black: median, violet: 0.03-quantile, dark blue: 0.01-quantile, light blue: endpoint.

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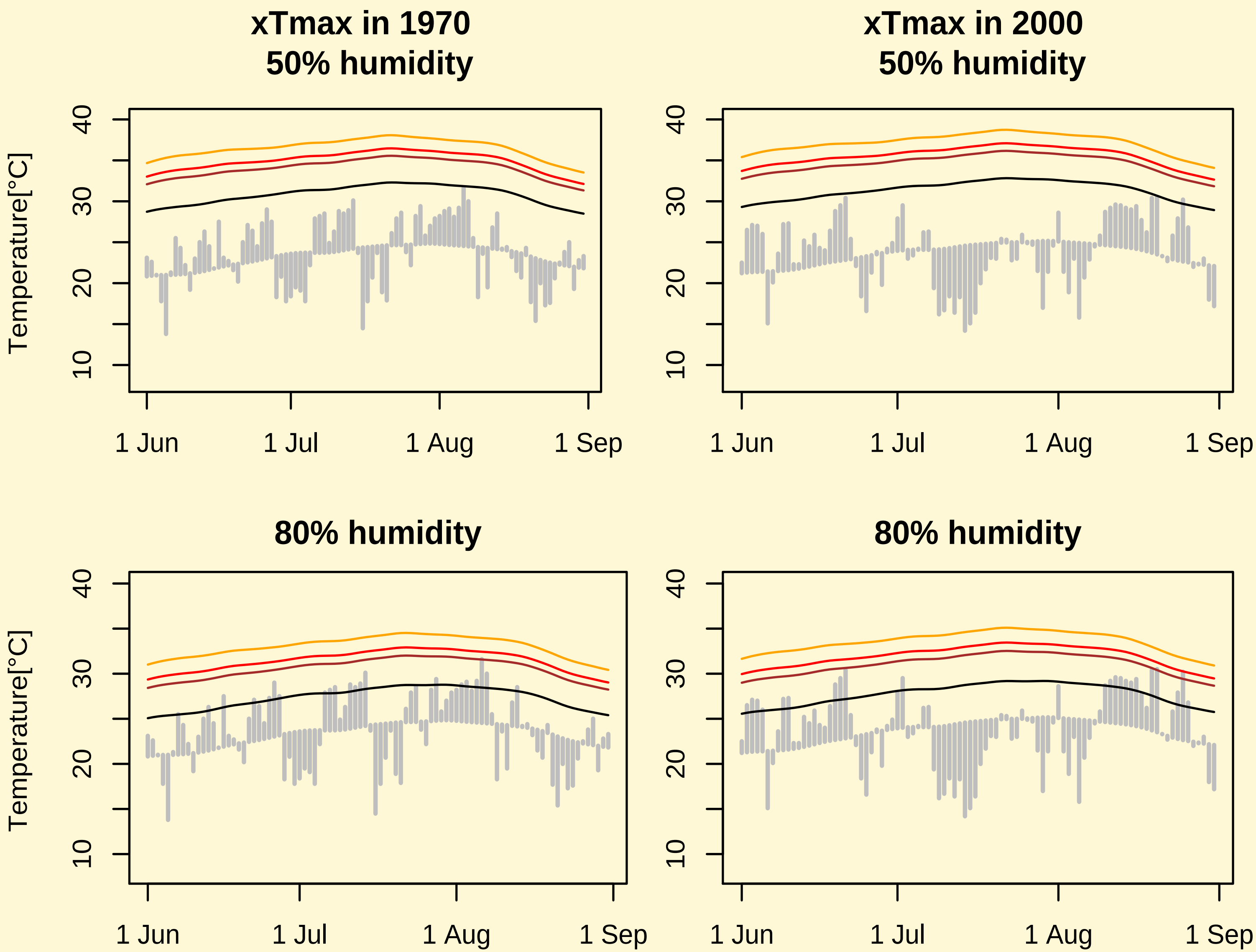
Different quantiles of xTmax in 1970 and 2000



Black: median, brown: 0.97-quantile, red: 0.99-quantile, orange: endpoint.

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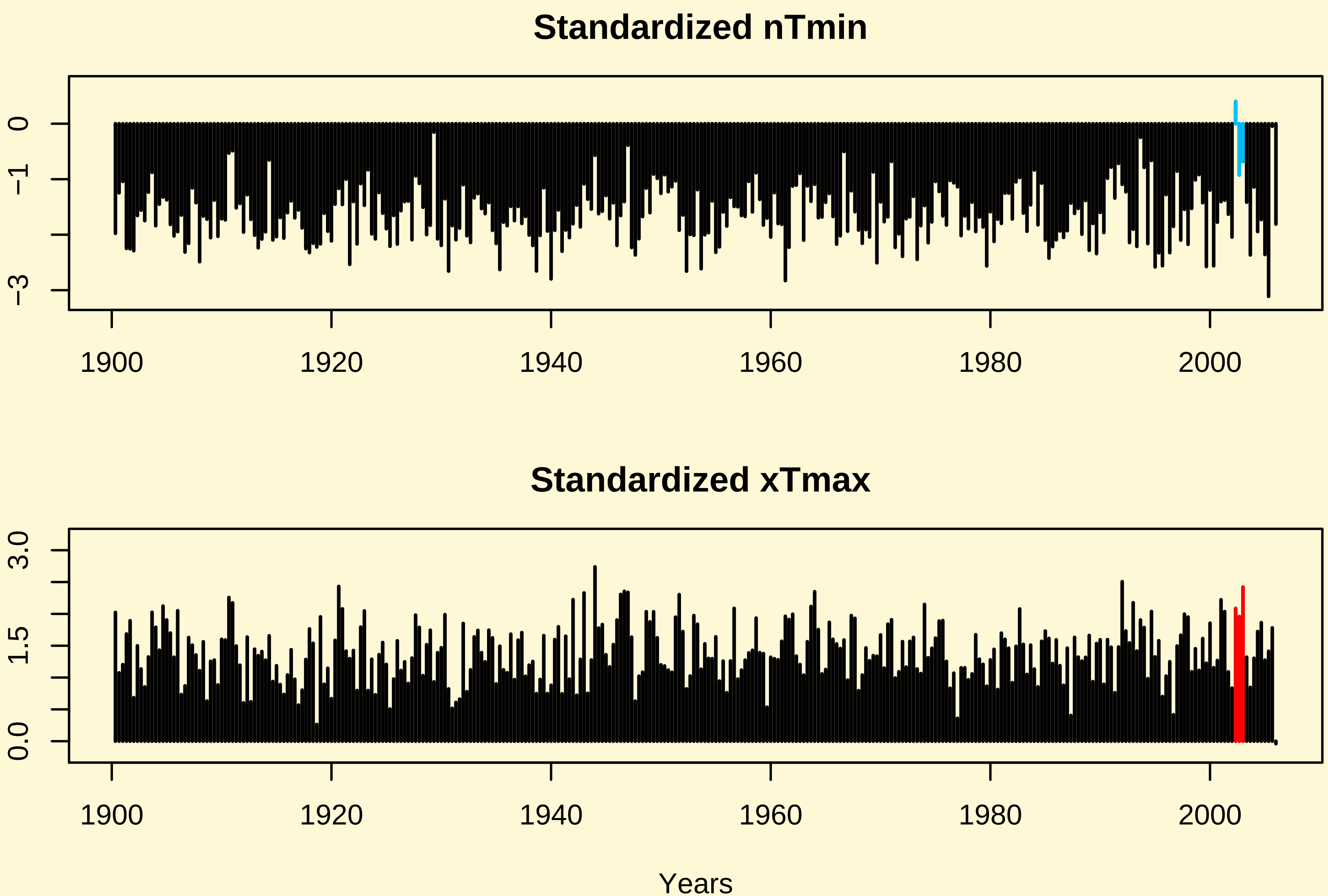
2003: outlier?



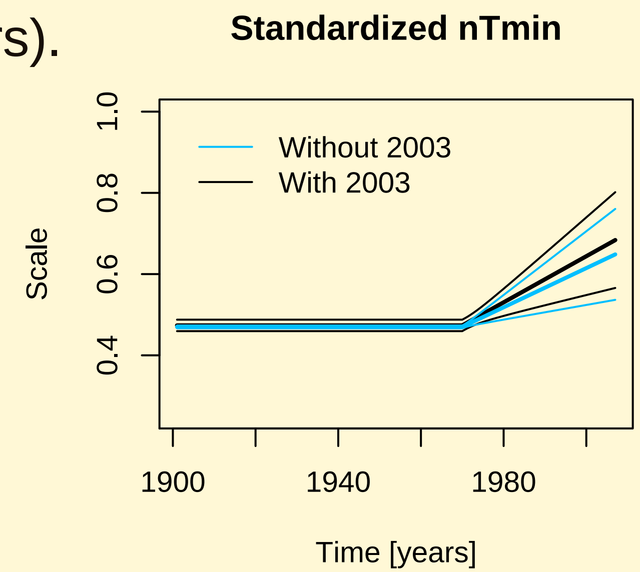
How unusual was 2003?

We refit the models without the observations in 2003.

Tmax: No change (less than 1% in all parameters).

Tmin: Only the slope of the scale changes.

The slope is still statistically significant – this is not a false trend in the variance due to the single outlier 2003!



$T_{\text{Jun 03}}$ = the smallest Tmin in June 2003.

$$\begin{aligned}
\Pr(T > T_{\text{Jun 03}}) &= 0.0027\ (0.0015) \\
\Pr(T > T_{\text{Jul 03}}) &= 0.16\ (0.15) \\
\Pr(T > T_{\text{Aug 03}}) &= 0.065\ (0.055)
\end{aligned}$$

Conclusions 1

- Strong association to humidity:
  - By including air humidity as a covariate, we isolated a major source of variability; with its inclusion, we can explain part of the variability of extremes by varying air humidity, and can draw a clearer picture of temporal changes.
  - Thus, an extremal trend additional to the overall trend is detected in Neuchâtel.
  - Can humidity dependence be related to some physical model?
  - Importance of any factors that influence air humidity (vegetation type, soil moisture, land-atmosphere coupling,...)

- Distributional changes in time:
  - For Tmin, the median line of the distribution of the complete data set is shifted upwards (with most change during the 80s), but the lowest quantiles of the extreme-value distribution remained near-constant.
  - For Tmax, we found stable temporal behaviour both for the bulk and the extremes.

Conclusions 2

- Use in forecasts:
  - Need assumptions for humidity dependence in the future: maybe from models?
  - Need assumptions for the trend and the seasonal component in the future: maybe from global/regional models?
  - Need assumptions to extrapolate the changes in extremes: maybe the use of other covariates (global mean temperature,...)?

Thank you!