Summary of the publication

# The role of increasing temperature variability in European summer heatwaves

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## 1 Introduction

Extreme climate events and their economic consequences can act as a catalyst for concern about the impacts of climate change. An extreme climate event can be defined as the exceedance of a certain threshold by a climate variable such as temperature or precipitation [1]. Instrumental records reveal an approximate 0.6°C increase in global surface temperature since the late 19th century [2]. This increase corresponds to a shift in mean towards warmer temperatures with regard to the empirical temperature distribution.

However, a mere change-in-mean framework might not be able to explain the occurence of extreme climate events. The following report summarizes Schär *et al.*, examining the warm 2003 summer temperatures [3]. Observing that such extreme temperatures are statistically very unlikely considering only a shift in mean temperature, the authors propose a regime with an additional increase in scale parameter. Support of this hypothesis is provided using simulations from a regional climate model.

## 2 Summary

### 2.1 Data and Methodology

Schär *et al.* conduct two main investigations [3]. In a first step, the statistical distribution of observed summer temperatures is analysed. This seeks to answer the question if the summer of 2003 constitutes an extreme event and can be explained by a shift in mean. In a second step, the authors simulate data from a regional climate model to investigate whether the 2003 temperatures are more in line with a distribution additionally increased in scale parameter.

**Empirical investigation** The empirical observation is conducted using a long-term temperature series at monthly resolution, representing Switzerland north of the Alps. The data stems from a Swiss climate measurement and observation network, providing at granular level daily homogenized time series starting 1864 [4].

For the outlier detection the authors examine the distribution of June, July, August (JJA) temperatures at both monthly and seasonal aggregation. This allows to compare normalized deviations from the observed mean using the empirical standard deviation. Moreover, the authors estimate the statistical return period (i.e. the inverse of expected frequency of threshold exceedance) of the observed temperatures. Assuming that summer temperatures are an independent, identically distributed gaussian time series the authors apply method of moments estimation to fit the distribution parameters.
To examine how sensitive tail behaviour is with respect to an increase in mean temperature the authors split the data excluding 2003 in two 60-year sub-periods and fit an empirical distribution for each period to the monthly observations. Thus the probability of temperature deviations can be compared between the two periods.

**Simulation** The simulated data (SCEN) is based on a climate change scenario defined by the Intergovernmental Panel on Climate Change (IPCC). The authors use the Special Report on Emissions Scenarios (SRES) A2 scenario together with a regional climate model (RCM) driven by 2071-2100 greenhouse-gas emissions. The SRES scenarios examine multiple possible evolutions of the main driving forces of future emissions. The A2 family corresponds to a scenario with high population growth, medium economic growth and high engery use [5]. As a reference a control integration is made over the period 1961-1090 (CTRL).
The evaluation of the simulated data is twofold. In a first descriptive step the authors examine the characteristics of the simulated distribution and theoretically discuss their validity. In a second step they analyse whether the observed JJA 2003 show similar characteristics to the simulated data. Therefore both temperature and precipitation anomalies are considered. Additionally, validity and robustness tests are conducted. To test the validity of the scenario integration the authors compare CTRL against the observed temperature data. To assess the robustness of the findings, the authors run alternative GCM and RCM models.

## 2.2 Results

**Empirical investigation** The empirical distribution of past summer temperatures show that 2003 constitutes an outlier with respect to the 1864-2003 time series. Considering the season as a whole, temperatures were 5.1°C (5.4 standard deviations) above average. Though the absolute deviation was higher in June (6.8°C), standard deviations are also higher for the individual month. Estimating the exceedance frequency using the 1864-2000 time period results in several million years, and using the 1990-2002 subsample in 46,000 years. The authors caution to interpret this stochastic concept as a prediction. However, they use the result to underline how, given the data, temperatures observed in summer 2003 are statistically highly unlikely. The sub-period comparison reveals that the tails of the temperature distribution are very sensitive to shifts in the mean, which was shifted by but 0.8°C.

Hence from the empirical observations, the authors can conclude that a shift in mean makes temperature deviations in the range of around 3°C much more likely, a deviation of up to 5.4°C as was observed in summer 2003 still constitutes an unlikely event.

**Simulation** The characteristics of the simulated data differ from the empirical observations. Not only is the shift in mean with approximately 4.6°C larger than observed in the sub-period analysis, but more importantly they show a statistically significant (at 99% confidence level) increase in standard deviation by 102%. Moreover, extreme events are found to be more sensitive with respect to an increase in variance, as they are to an increase in mean. In particular, this sensitivity is higher the larger the exceedance threshold of the temperature anomaly.

The authors investigate the validity of the simulation results in multiple ways. This includes an analysis of analyse of how the increased variance can be explained by climate processes. The authors explain that the scenario involves an increased occurrence of droughts in central Europe, which non-linearly amplify local temperatures anomalies. Moreover the increase in variance can be shown to be robust to alternative GCM and RCM scenarios of greenhouse-gas emissions. Regarding validity of the scenario integration, the statistical temperature distribution for CTRL agrees well with the empirical data.

In a final step, the authors analyse whether the simulations show similar characteristics to JJA 2003. They find that the observed temperatures no longer constitute an outlier with respect to the simulated data. Drawing additionally on precipitation data reveals that the simulate dataset preserves the relationship between temperature and precipitation that was observed in the empirical data.

**Outlook and Discussion** The summarized paper shows that while a shift in mean is well able to explain European temperature observations until 2000, this framework fails to account for the observations of summer 2003. The authors close this gap by simulating data in alignment with an IPCC SRES scenario, showing that an increase in scale parameter provides a better fit for the observed temperatures. Regarding the consequences for adaption the authors caution that these results would pose serious challenges to coping with climate change. Taking an increase variability in temperature distribution, the increase greenhouse-gas forcing would lead to an increased occurrence of extreme warm temperatures and droughts.

# 3 Discussion

This section discusses the above summarized paper. It addresses design and methodology of the publication, relevance and originality.

The design of the paper is meticulous. The research question is clearly stated and the two-step design underlines the relevance of using simulations. Each sub-question is investigated from multiple perspectives and robustness test are conducted. It is explained why the respective methodologies are chosen and the computations are provided in enough detail for the reader to follow the argumentation and to interpret the outcome. However, for a step-by-step reproducibility of the results, additional details might be of benefit that were probably excluded in favour of readability. This could include formulas for the threshold exceedance or a permanent link to a minimal working data set additional to the raw data accessible through the reference list. It is of course well understood that a correspondence mail is provided for further requests.

The main innovative idea of Schär *et al.* is to simulate scenario data to investigate their hypothesis. In 2001, the IPCC published the third assessment report, discussing an increase in variance of temperature distribution on both global and regional level. The literature reviewed in the report is, however, mostly of descriptive nature and and no clear picture can be drawn [2]. Moreover, the summarized publication is of high relevance, both 2003 and today. The occurrence of extreme temperature events has economic and health consequences, as argued by Easterling *et al.* [7].

Future research could aim to separate the effects of mean and variance increase. The data simulated by Schär *et al.* increases in variance ($\approx 100\%, p < 1\%$) as well as in mean ($\approx 475\%$ with a 4.6°C opposed to a 0.8°C shift), compared to the empirical data [3]. Katz & Brown show that the the tail behaviour of probability distributions is more sensitive with respect to the scale than to the mean using extreme value theory. However, the authors stress that this argument is only made in terms of sensitivity. Hence if the change in location parameter is large enough it could still dominate the effect induced by the scale parameter [1].

# Acronyms

**IPCC** Intergovernmental Panel on Climate Change

**JJA** June, July, August

**SRES** Special Report on Emissions Scenarios

**SCEN** simulated data

**CTRL** control integration

**RCM** regional climate model

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