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Earth System Dynamics Discussions

Interactive comment on "Storylines of the 2018 Northern Hemisphere heat wave at pre-industrial and higher global warming levels" *by* Kathrin Wehrli et al.

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We thank Geert Jan for his evaluation of our manuscript and helpful comments, especially on observed trends. We have done additional analyses and update Figure 7 in the manuscript to follow the recommendations. Below we will answer the specific questions of the reviewer, addressing the major comment first and then the minor comments. For readability the questions are shown in black *and answers are shown in* blue.

There is only one major comment I have on the analysis, namely that it is only analyses climate model data and does not make any connection to observations beyond showing

the patterns agree. Trends in heat waves are notoriously badly simulated by climate models and some comparisons of the modelled trends to the observed trends would make the paper and a discussion on possible discrepancies and how these would affect future trends much more useful for readers who want to apply the results to the real world rather than the model world.

We agree that observed trends should be discussed in the paper. Therefore, we made additional analyses using maximum daily temperatures for CRU TS4.03 and the Berkeley Earth Surface Temperature (BEST) project. As a reference for global mean temperature change (land+ocean) we used HADCRUT4 and GISTEMP. We estimated the slope using a linear regression for the years 1901-2017 from all data sets. The uncertainty of the fit for the slope is estimated using the covariance matrix. The results are shown in Figs. 1 and 2 given at the end of this comment, which will both be included in the manuscript (the latter in the appendix). The results indicate that, especially for CNA and ENA, the CMIP5 models overestimate the regional warming compared to observations, as documented in previous articles (e.g. Alter et al., 2017; Donat et al. 2017). Further articles also showed that the CMIP5 models tend to overestimate soil moisture-temperature coupling (Sippel et al. 2017, Vogel et al. 2018), which can lead to an overestimation of projected changes in temperature extremes (Vogel et al. 2018). These biases appear smaller in the newer CMIP6 models (Seneviratne and Hauser 2020). On the other hand, there can be large differences of the observed trend for some of the regions depending on the observational data sets used (e.g. MED and CEU; see Fig. 1 at the end of this comment). We discuss the systematic biases in CMIP5 models together with the differences and uncertainties of the observational data sets in the revised paper.

We are not sure which exact method the reviewer used to estimate observed scaling factors, i.e. which reference he used for global mean temperature, whether linear regression was used, which time periods were considered, and whether he included ocean grid points within the given SREX regions (which we do not for the regional temperatures). Therefore, our results differ from the numbers given in the reviewer comment (see Fig. 2 at the end of this comment), although they agree on a general overestimation of regional warming per degree of global warming in the CMIP5 models for North America.

Both global temperature data sets (GISTEMP and HadCRUT4) merge near-surface temperatures over land with SSTs over the ocean, which leads to an inconsistency with how global mean temperature is commonly determined for models by taking near surface temperature over ocean and land (as is also done here; see also Cowtan et al., 2015). Therefore, 1 degree of global mean temperature increase in the observations does not correspond to 1 degree from the models (see also IPCC, 2018). We discuss this issue in the paper.

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Donat, M.G., A.J. Pitman, and S.I. Seneviratne (2017). Regional warming of hot extremes accelerated by surface energy fluxes, Geophys. Res. Lett., 44, https://doi.org/10.1002/2017GL073733.

IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable

development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. P.rtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. P.an, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press. Available from https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf.

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Vogel, M. M., J. Zscheischler, and S. I. Seneviratne (2018). Varying soil moisture-atmosphere feedbacks explain divergent temperature extremes and precipitation projections in central Europe. Earth Syst. Dynam., 9, 1107-1125, https://doi.org/10.5194/esd-9-1107-2018.

Minor comments

l.16 The Koreas were also very badly affected.

We included the Korean Peninsula in the list of affected regions.

l.78 How does the end date of July 27 affect the results? Although this captures the largest area with heat, individual regions had heat waves after this date: North Korea experienced its worst heat the first days of August. The Benelux had a second heat-wave in early August and the heat on the North American west coast was most severe during the second week of August.

We agree that with the presented study we cannot make statements about heat waves after 27 July 2018, which were more intense in some locations. The choice was also made due to the availability of input files for the atmospheric nudging. Therefore, we cannot provide numbers on how the results are affected by the chosen time period. We changed the text in the results and discussion as well as the conclusions sections of the manuscript to mention the regions affected by heat waves after July 27 and to discuss this shortcoming of our study.

l.162 I would propose “almost simultaneous”, there were weeks differences between these heat waves. Please also mention that there were severe heat waves after the cut-off date.

We agree and use the term “almost simultaneous” as suggested. Also we mention that some regions experienced severe heat waves after the cut-off date (see also previous answer).

l.174 My Newfie friends prefer "Newfoundland".

We thank the reviewer for spotting and correcting this.

l.201 Please mention that in contrast to the CMIP5 model simulations, observed precipitation has increased in CNA over the last century.

We added that the simulated trends are of different sign than the observed summer precipitation trends for CNA.

l.221 Why do you switch from a two-week period to a monthly period? The properties of short-duration heat waves are different from monthly anomalies. Please justify this

choice.

For the CMIP5 models the monthly period was chosen for two reasons: First, as the CMIP5 models do not have a prescribed ocean or nudged atmosphere, there is more variability which is better represented using a longer sample and it is also not necessary to have the exact days as every day of July matches conditions of the study time period. Secondly, it is more practicable to process the monthly instead of the daily data. For the nudged experiments in our study we agree that the choice of the time period and its length could have been expected to affect the results, although we find that the effects are actually very small. To assess this point, we repeated the analysis plotting only July 13-27 for CESM nudged. The results show that changing the monthly to a two-week period for the nudged experiments does not substantially impact the results (see Fig. 3 at the end of this comment). The change is largest for ENA where a reduction of the slope can be found. However, results are still qualitatively the same.

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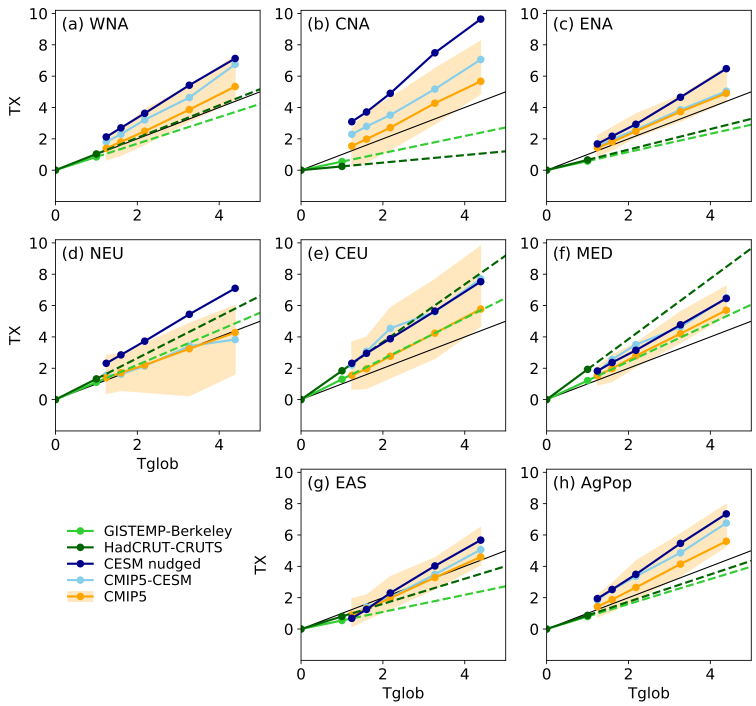

Fig. 1. As Fig. 7 in the paper but added observed trends. The solid green lines correspond to the approximate observed warming while dashed green lines indicate the extrapolation beyond the observed warming.

TXreg	**CRUTS**		**BEST**	
Tglob	**GISTEMP**	**HadCRUT**	**GISTEMP**	**HadCRUT**
WNA	0.85 ± 0.21	1.03 ± 0.24	0.85 ± 0.22	1.04 ± 0.25
CNA	0.16 ± 0.30	0.24 ± 0.34	0.55 ± 0.31	0.68 ± 0.35
ENA	0.56 ± 0.22	0.65 ± 0.25	0.58 ± 0.21	0.68 ± 0.23
CEU	1.52 ± 0.30	1.84 ± 0.33	1.30 ± 0.30	1.60 ± 0.34
NEU	1.13 ± 0.31	1.32 ± 0.35	1.11 ± 0.29	1.29 ± 0.33
MED	1.67 ± 0.15	1.93 ± 0.16	1.21 ± 0.16	1.40 ± 0.18
EAS	0.61 ± 0.16	0.80 ± 0.18	0.55 ± 0.19	0.75 ± 0.21
AgPop	0.72 ± 0.12	0.87 ± 0.14	0.80 ± 0.13	0.96 ± 0.14

Fig. 2. The slopes for all combinations of the observational data sets and their uncertainties (one standard deviation).

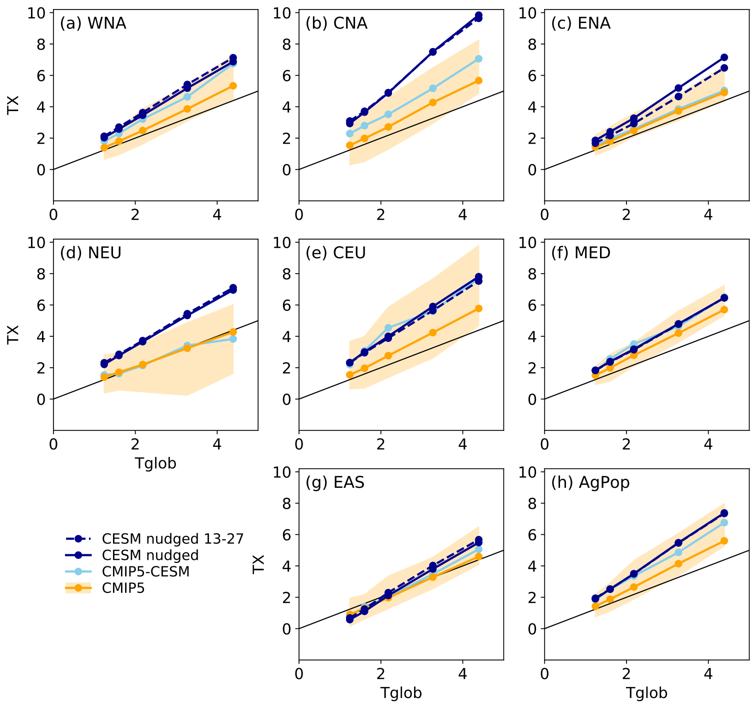

Fig. 3. Same as Fig. 7 in the paper but showing July 13-27 for the nudged simulations (dark blue; stippled) and July 1-27 (dark blue; solid).