Nat. Hazards Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/nhess-2020-69-AC2, 2020

Natural Hazards and Earth System Sciences
Open Access
Discussions

Interactive comment on "Attribution of the Australian bushfire risk to anthropogenic climate change" *by* Geert Jan van Oldenborgh et al.

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Received and published: 8 June 2020

1. *The analysis in this manuscript uses a range of observational data, reanalysis products and model simulations. The authors chose to include or exclude data sets based on criteria that are neither fully documented nor properly justified. A transparent approach would be most useful.*

   For example, two long observation-based datasets (Berkeley Earth analysis and ECMWF's coupled reanalysis of the 20th Century CERA-20C) were dismissed because of their performance during one particular week (in January 1939) out of the 110-year period dating back to 1910. The argument here was that the results were highly sensitive to that one week which might have seen very warm temperatures. CERA-20C is a reanalysis based on the latest state-of-the-art

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coupled assimilation techniques which aims to provide a physically consistent estimate of the coupled atmosphere-ocean state and has been demonstrated to perform in general very well. If the results of the presented attribution study crucially depend on a specific week in a specific year, that should warn us about the robustness of the findings and questions the brute dismissal of the CERA-20C data set altogether.

We thank the reviewer for their feedback and for the opportunity to expand on and clarify our dataset choices. We investigated the warm week in January 1939 extensively and are convinced that it is real: the station data (GHCN-D v2 and ACORN) also show the 10 to 15C anomalies that the Australian AWAP dataset shows in this region. There were also extensive bushfires in this region, the 'Black Friday' fires. As an extra check we did a comparison of the January 1939 monthly mean daily mean temperature, for which there are more data sources than daily maximum temperature. We compared the CERA-20C reanalysis with station data, the Australian ACORN analysis and the CRU TS 4.03 analysis. This shows that the CERA-20C land temperatures in this month are indeed unrealistic and should not be used for attribution in this region. We added a new figure showing this to the manuscript (also attached to this reply).

Because it is the warmest one-week event in our index region in the AWAP dataset and the extreme value fits have a negative shape parameter ξ, which implies an upper bound to the temperatures, the effect of this one week on the final results is indeed non-negligible. The 1939 value would be above the upper bound if this week were not included in the fit, so including it moves the upper bound up.

The absence of this event in the Berkeley Earth analysis can potentially be explained by the very large decorrelation lengths it employs, which dilute a relatively local anomaly such as this hot week in southeastern Australia (see our new Fig. 4, reproduced as the second figure at the end of this answer). Since the event mag-

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nitude is real and including the event is important for defining the GEV fit, we opted to not include datasets that do not show it.

The CERA-20C reanalysis also has an unrealistic cooling trend over 1900–1970 (defined as regression on global mean temperature) over the index region, counter to what the AWAP dataset shows, which points to more significant issues in the reanalysis. Note that the observations assimilated in CERA-20C are surface pressure, mean sea level pressures, surface marine winds, ocean temperature and salinity profiles. They do not include land surface temperature observations, which allows for discrepancies between the near-surface temperatures of the reanalysis and the observations. We added the time series of TX7x in CERA-20C to Fig. 3 to illustrate this issue (our new Fig. 3 attached at the end of this reply).

As a third check, we computed the correlation of the reanalysis time series with the AWAP estimate of observations. This correlation is quite low for CERA-20C at $r = 0.6 \pm 0.1$, contrary to the 20CRv3 reanalysis at $r = 0.8 \pm 0.1$ since 1910. This shows that the magnitude of one-week heat waves in the CERA-20C reanalysis does not correspond well with the magnitude in the observations, again making it unsuitable for attribution analysis. This explanation has been added to the text.

These three points, the value for January 1939, the long-term trends before 1970 and the poor synchronization of interannual variability with observations, all show that CERA-20C does not perform well enough for heat extremes in southeastern Australia to be included in this analysis.

To summarize, while we appreciate the concern for robustness of the presented analysis, we are convinced that the data issues discussed here provide ample justification to exclude certain datasets. We hope that the additional documentation of these data issues serves to convince the reviewer and reader of the validity of our approach and might even be of more general use to illustrate where reanalysis products could be improved for use in event attribution.

No explanation has been given why ERA-20C, ECMWF's first atmospheric reanalysis of the 20th Century, has been excluded as a dataset.

Daily ERA-20C maximum temperatures were not available to us for this attribution study and we were advised to use CERA-20C instead. They are also not available from the ECMWF but have to be computed from 3-hourly data, which in turn have to be downloaded programmatically. The whole procedure is time-consuming and error-prone and hence incompatible with a rapid attribution study.

For the revision we did include it, but found that the interannual variability of TX7x averaged over our study region correlates with the AWAP observation-based analysis at only $r = 0.5$ (see attached figure). The January 1939 event is reproduced to some extent in ERA-20C, although the monthly mean of daily mean temperature anomaly during the event is only about half as large as in AWAP, thus showing a substantial underestimation of the event magnitude. We do not know what causes the incoherence of this reanalysis with the observations in this region, but this makes it clearly unsuitable to use as a proxy for the observed record.

Section 3.3. says that the ACORN-SAT station data were not available at the time of writing. But they are included in Figures 5-7. Clarifications should be given which data exactly are used in these figures and for which time periods.

Section 3.3 says that ACORN station data are available, but the daily gridded analysis based on the station data, ACORN-SAT, is not. (They are still not available at the time of revision.) We clarified this further in the text.

For the Fire Weather Index analysis, no other reanalysis products than ERA-5 from 1979 onwards have been used — why? This presents another non-transparent choice of data sets and time periods used.

The ERA5 reanalysis was the only one that had all the required data up to the end of 2019 at the time of the analysis. We added this explanation to the manuscript.

2. *A related question is that of common periods between the data sets. The time periods spanned by the data sets vary considerably with some temperature data starting in the mid-19th Century, some in the early decades of the 20th Century and some only after 1950, see Table 1. The data in the FWI analysis only start around 1980 though. It is not clear to me what the impacts on the results are that stem from artefacts due to analysing data over vastly different periods, e.g., in Figure 5. If temperature trends were calculated using GEV estimates with a linear covariate relationship with global mean temperature, for data like JRA-55 assumptions must have been made for periods before the 1950s — was the temperature increase from 1900 extrapolated? Given the nonlinear nature of the trends from 1900 to today, that seems an overly strong and questionable assumption to me. The finding that ACORN, CERA-20C and ASF-20C reveal a non-stationary relationship between TX7x and GMST (presumably the others don't?) is interesting and would be worth more investigations regarding possible implications. Perhaps the authors can comment on this.*

   There are two places in which the different time periods can play a role: in the model evaluation and in the attribution. For the model evaluation, as in Fig. 5, we compare the scale parameter σ and shape parameter ξ of a fit to the observations (or reanalysis) to fits to the model output. In this case the values hardly depend on the time period chosen, in fact we assume that σ and ξ are constant over time and check this assumption in the observations and models by comparing the values for different start dates (1910 and 1950).

   The differing time periods obviously play a much larger role in the attribution step, in which we estimate the Probability Ratio PR and change in intensity ΔI from the transient runs for models that do not simulate a counterfactual climate. For convenience we use the smoothed GMST value at 1900 as reference climate. If the data start later we indeed extrapolate from the start date backwards in time to 1900, using the same assumption that we used for the fit. Note that the

GMST trends for pre-1950 dates are small, in particular with regards to the full trend from 1900–2019; the percentage of the 1900–2019 trend value covered by the extrapolated time period is noted for each starting date below. One sees that the extrapolations are small, at most 14% of the full trend in case of JRA, and much smaller for the model data. The period 1902–1920 is cooler than 1900 due to volcanic eruptions of Santa Maria in 1902 and a series of smaller eruptions afterwards lowering the GMST. Extrapolating in time to 1900 involves an interpolation in GMST for starting dates in that interval.

In principle it is possible that the local response to global radiative forcing approximated by the global mean temperature is different for different time periods, as the rise in the early 20th century was due to a combination of increasing concentrations of greenhouse gases, decreasing volcanic activity and increasing solar activity, whereas the rise from the 1970s onward is mainly due to greenhouse gases minus aerosols. These different forcings may well have different footprints locally. However, the only observational datasets to show negative trends over 1910–1970 have been shown to be a bad representation of heat extremes in this region on other grounds (Berkeley Earth, ERA-20C, CERA-20C) or have differing numbers of stations over this time period (ACORN stations). The positive trends in heat extremes agree with summer (DJF) mean temperatures increasing in this region in other datasets (GISTEMP, CRU TS, Berkeley) at a slightly higher rate than global mean temperature over 1910–1970 as well as the full period. To conclude, there are no indications that the negative trends over this period are real.

A final, obvious effect is that shorter time series sample less of the natural variability and give larger uncertainties per ensemble member.

The differing start dates are as follows:

- Observational analyses (AWAP, ACORN stations): 1910, introduction of Stevenson screens. Due to the volcanic eruptions, 1910 is below the full

GMST trend line of 1900–2019, so the interval 1920–2019 covers 126% of the full warming over 1900–2019.

- Reanalyses that do not assimilate land temperature observations (20CRv3): includes 1900, the results do not look reliable in this region for the 19th century so we only use the period 1900-2019.
- The JRA starting data is 1958, the period 1958—2019 covers 86% of the full warming over 1900–2019.
- For EC-EARTH, which has data starting in 1860 we use data from the beginning of the GISTEMP series (1880) and interpolate to 1900.
- The GFDL-CM3 model starts in 1920. This is still below the full GMST trend line of 1900–2019, so the interval 1920–2019 covers 109% of the 1900–2019 warming.
- The CanESM2, GFDL-ESM2M and IPSL-CM6A ensembles start in 1950, this covers 96% of the 1900–2019 warming.
- The ASF20C model starts in 1901, which is very close to 1900.

One sees that the extrapolations are small, at most 14% for JRA and much smaller for the model data. We added a sentence to the text 'The value for 1900 is determined by extrapolating the statistical fit to the data available. Note that this extrapolation represents a small fraction of the total trend due to the majority of GMST change between 1900 and the present day occurring after 1970.'

Note that we already included an analysis with an equal start date of 1950 and thus less sensitive to the potential different effects of GMST changes due to different drivers. The results are very similar to the analysis of the full period, except of course with larger uncertainties due to the shorter time period (see our Fig. 7).

3. *As the main author of the ASF-20C atmospheric seasonal hindcast data set that has been used in this manuscript, I should clarify that the statements made*

around line 303 about ASF-20C are not correct. ASF-20C is not initialised from ocean reanalysis. Instead, it uses prescribed SST fields and is an atmosphere-only forecast product.

Our excuses, this has been corrected.

The subsequent sentences are misleading at best and provide no justification for the non-stationary relationship between TX7x and GMST, as mentioned in line 300.

These lines have been deleted and replaced by 'ASF-20C is initialised from ERA-20C and run with the same SST dataset as boundary forcing (HadISST.2.1.0.0) (Weisheimer et al., 2017) and hence shows similar weaknesses as this reanalysis. It agrees well with the observations over the satellite era, but has an unrealistic negative temperature trend over the whole century. This is heavily influenced by the too warm years at the beginning, but in fact the trend is negative for start dates as late as 1935 and only becomes comparable to the observations and reanalysis from around 1960 onwards (not shown). We do not know what causes the long-term trends to be at odds with observations.'

In line 370 it is argued that ASF-20C cannot be used for the drought analysis as the data cannot provide annual mean precipitation nor the driest month in a fire season. This is also not correct; ASF-20C does exist for all months of the year (although originating from different initialisation months).

Our original text was maybe not precise enough and we have now attempted to further clarify the reasons for our choices. The description of ASF-20C (Weisheimer et al., 2017) does not specify how the reinitialisation works for every month, but we assumed that the new ensemble was not a continuation of the old one. This implies that there are no continuous runs covering a whole or half a year. This might imply discontinuity in slowly varying land boundary conditions such as soil moisture, making the analysis of annual mean or fire season minimum precipitation challenging. We made the text around our argument more precise: 'The ASF-20C model only has 4-month runs starting four times per year and therefore cannot provide continuous and physically consistent annual or 6-month fire season precipitation, as slowly varying land boundary conditions such as soil moisture are discontinuous every three months when a new ensemble is initialised. Using this dataset without significant further investigation is therefore not straightforward and led us to exclude it from our analysis.'

Figures:

1. The highest 7-day running mean of daily maximum temperature of the July–June year in a) the AWAP analysis, b) Berkeley Earth, c) 20CRv3 reanalysis, d) CERA-20C ensemble mean (DJF maximum) and d) ERA-20C ensemble mean (DJF maximum). The green line indicates a 10-yr running mean. (Expanded Fig. 3 of the original manuscript).

2. The Australian monthly mean daily mean temperature anomalies relative to 1981–2010 in a) GHCN-M v3 station data, b) the ACORN-SAT analysis, c) the CRU TS 4.03 analysis, d) the Berkeley Earth analysis, e) the 20CRv3 reanalysis, f) the CERA-20C reanalysis (ensemble mean) end g) the ERA-20C reanalysis. (New figure 4).

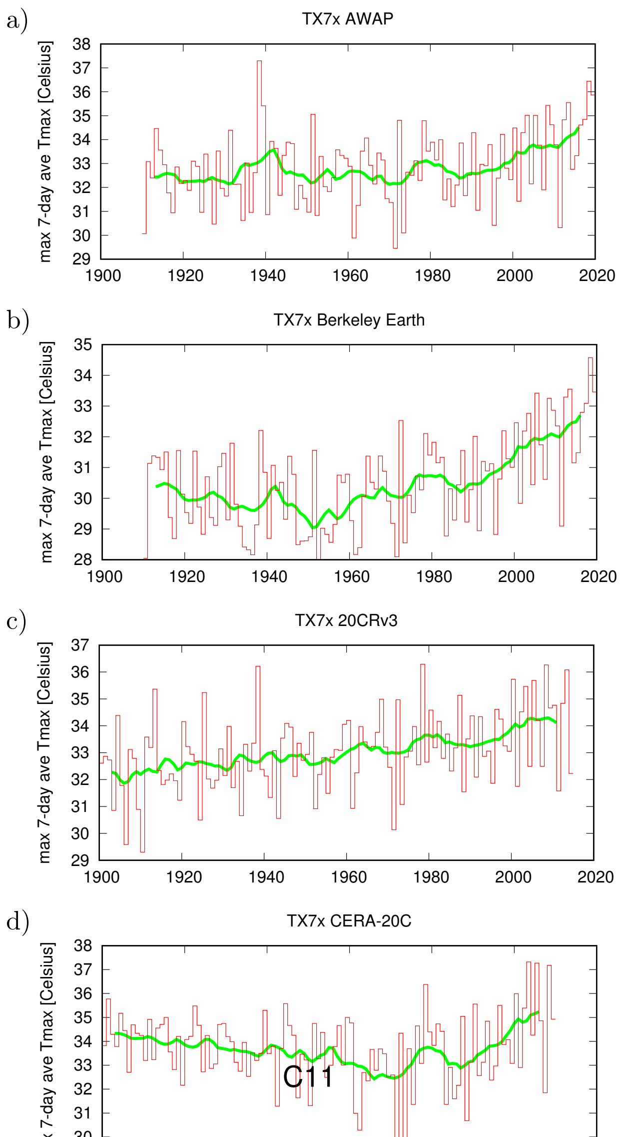
3. Running start date regressions of AWAP, ERA-20C and ASF-20C trends as a regression on smoothed GMST. (Not included in the manuscript.)

References

Weisheimer, A., Schaller, N., O'Reilly, C., MacLeod, D. A., and Palmer, T.: Atmospheric seasonal forecasts of the twentieth century: multi-decadal variability in predictive skill of the winter North Atlantic Oscillation (NAO) and their potential value for extreme event attribution, Quarterly Journal of the Royal Meteorological Society, 143, 917–926, https://doi.org/10.1002/qj.2976, 2017.

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2020-69, 2020.

Interactive comment



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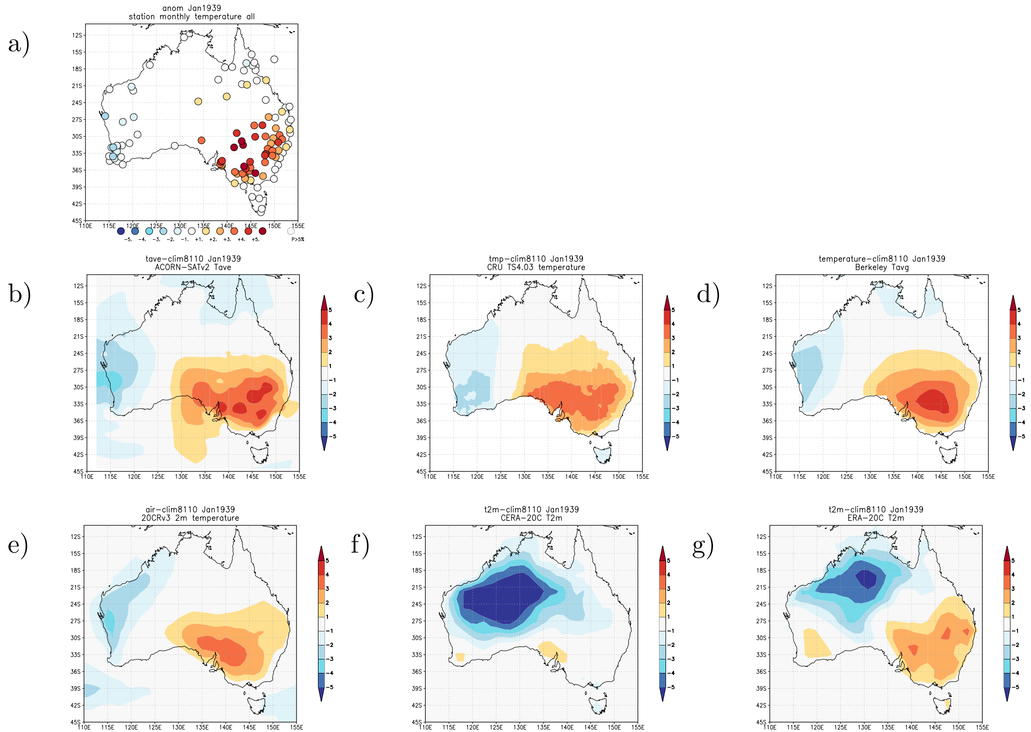

Fig. 2.

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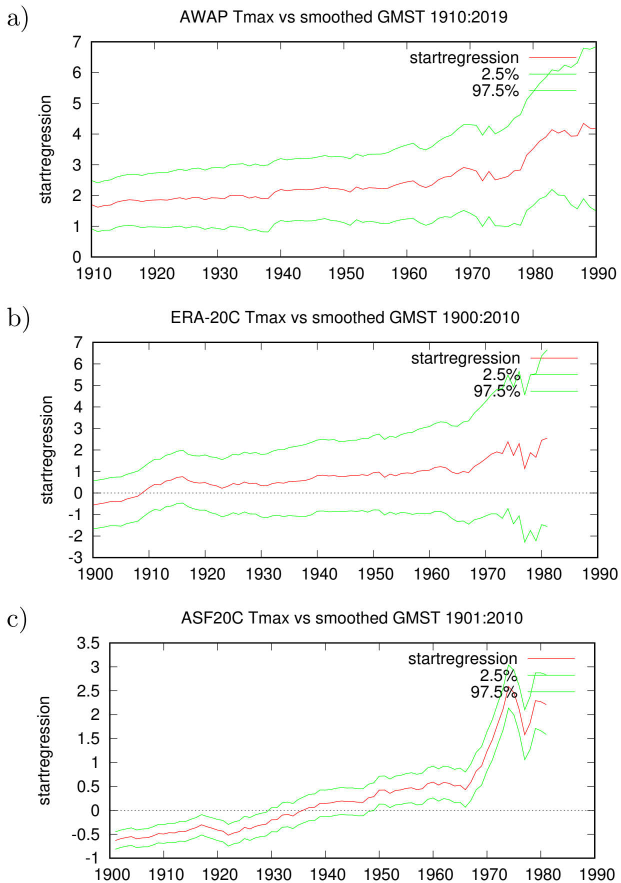
a)
AWAP Tmax vs smoothed GMST 1910:2019
startregression
2.5%
97.5%
b)
ERA-20C Tmax vs smoothed GMST 1900:2010
startregression
2.5%
97.5%
c)
ASF20C Tmax vs smoothed GMST 1901:2010
startregression
2.5%
97.5%

Fig. 3.