The Teddy-Tool v1.0: temporal disaggregation of daily climate model data for climate impact analysis

Dear Editor and Reviewers,

We thank you for your time to review our submitted paper and we greatly acknowledge your valuable comments, which help us to improve our paper.

In the following, we reply to your general and specific comments. Thereby, our reply is placed right below your comment and marked bold with red color.

Reviewer #1:

The authors present a tool for temporal disaggregation of daily climate model outputs to a sub-daily hourly time step. The tool covers the standard suite of meteorological driving variables required for land surface modelling, for example driving a distribution hydrological model or offline land surface scheme. Unlike many existing off-the-shelf approaches, Teddy-Tool is an empirical approach that searches for the best diurnal cycle analogue, matched based on a time window of daily outputs, using the globally available bias-corrected hourly reanalysis WFDE5 data (1980–2019) as the analogue pool. The approach is evaluated using a "perfect observation" approach where a single WFDE5 year is withheld from the analogue pool, hourly data are aggregated to daily, and performance of the method is assessed.

Reply: This is well summarized.

The tool is written in MATLAB and a full set of example data and source code are provided in a public repository.

Overall, my impression of the paper is positive. It fills a needed gap using an approach that is simple, provides physically-consistent inter-variable relationships, and makes sense for near-term future projections or seasonal to decadal climate predictions.

Reply: Thank you for your positive feedback and your note for the need and gap-filling of our approach, considering physically consistent inter-variable relationships.

My main concern is that the approach may lead to some pathological behavior when faced with strong climate change signals, for example end-of-century projections for moderate to high greenhouse gas emissions scenarios. Because the approach is built around the idea that the "diurnal profile of all variables is taken from the same, most similar meteorological day of the historical reanalysis dataset" it is conceivable that, under strong climate change, the same analogue day (or a very small number of analogue days, for example the hottest historical days for a given part of the annual cycle) will be sampled repeatedly, thus leading to a reduction in diversity of the diurnal profiles. Similar issues can exist, albeit on different time scales (e.g., monthly to daily disaggregation) for some downscaling algorithms like BCSD (Raff et al., 2009).

Reply: Regarding your concern of high warming end-of-century projections, we basically agree that this is a methodological constraint. We are aware of this limitation and already discuss

this issue in detail (see line 292ff). To address your concerns, we add a counter in the Teddy-Tool, which diagnoses the number of different historic diurnal profiles applied per year as shown in Fig. 1. So, the user is able to monitor this methodological constraint. In addition, we would like to put into perspective that a smaller size of the moving window (which can be set by the user) prevents that the same analogue day is chosen over a longer time period. This will increase the diversity of diurnal profiles at the expense of similarity. Further, since mass and energy are conserved within the disaggregation approach, the diurnal course, e.g. for temperature, might show variations (different offset and different amplitude) despite the diurnal profile are derived from the same analogue day.

From a broader perspective, it is also not clear whether the uncertainties resulting from this limitation are larger than the uncertainties within the climate model projections until the end of the century. Furthermore, in the long term, the basic population for finding analogue climates will continuously increase, since WFDE5 data, which are based on ERA5, are continuously updated.

We added these aspects to the discussion.

This is noted as a possibility, but the degree to which it is a problem is not tested. How many distinct analogue days are sampled in climate projections from SSP3-7.0 for the end of the 21st century? It would be nice to see this being evaluated, especially given that the stated goal is the disaggregation of climate model outputs. Similarly, how does the method compare with existing parametric approaches? Is there value added by this method? Is the performance comparable to Bennet et al. (2020) or Forster et al. (2016)?

Reply: Thanks a lot for this suggestion. It is a great idea to evaluate the number of analogue climate days. As suggested, we tested this in an additional analysis for SSP3-7.0 using the GFDL-ESM4 climate model (see Fig. 1). The result for 607 samples, distributed over the entire USA (including Alaska and Hawaii), shows that the number of unique analogue climate days are declining, as expected, but still the diversity of chosen days is above 300 at the end of the century for a chosen moving-window size of 11 days. We suppose that this is far away from a critical range. We included Fig. 1 to the results and refer to it in the discussion.

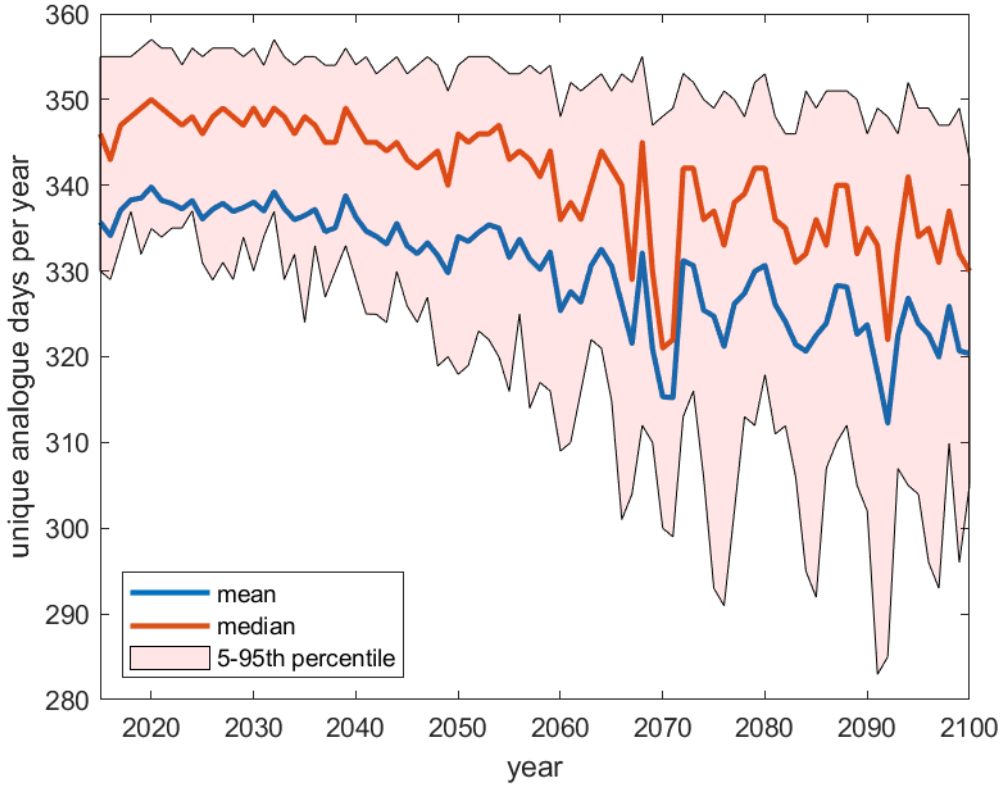

Figure 1: Number of unique analogue climate days per year for the GFDL-ESM4 climate model under SSP 3-7.0 for the years 2015-2100 and a selected moving window size of 11 days, showing the mean (blue) and median (orange), as well as the range between the 5th and 95th percentile for a number of 607 samples in the USA.

Regarding the suggestion for comparing our method with other approaches, please see the next reply.

Noted above is the similarity of the method to existing empirical disaggregation schemes, like the one in BCSD, but there are also others like the method of fragments (Li et al., 2018) or the historical analog (Chen, 2016) approach. An expanded literature review that covers existing analogue or k-nearest neighbour approaches in climatology would be useful.

Reply: The intention of this publication is not a model comparison, although we agree that this would be really interesting for a follow-up publication. In a follow-up publication, also the performance in terms of computational demand and computing time can be compared. In this context, we would like to mention that in the meantime of this review process, we parallelized the Teddy-Tool and thus significantly decreased the computing time. The parallelized version of Teddy is uploaded to Zenodo and provided Open Source under CC-BY license.

Thanks a lot for the suggested additional publications. We already refer to several different and similar disaggregation approaches (see line 46-60) and already refer to Li et al. (2018) in line 121 and Förster et al. (2016) in line 49 and 57. We complemented our description with Chen (2016), and Bennet et al. (2020) as you suggested.

One more minor concern is that the software is written in MATLAB, which is a proprietary, commercial software package. Will the method run with a free and open source alternative like Octave?

Reply: Matlab is platform independent and a precompiled version is provided, which can be used without any license. Therefore, a redistributional package of Matlab must be installed before running the executable file. Since the code is provided open source, anyone can translate the code into other languages as preferred.

We included this information to the data availability statement, also mentioning the availability of a parallelized version.