Replies to RC3

Please find below:

- *In black, original comments by RC3*
- *In green, replies by the authors*

Comments on "WFDE5: bias adjusted ERA5 reanalysis data for impact studies" by Cucchi et al.

This paper introduced the most advanced WFDE5 database for climatic usage. The performance of WFDE5 and its related WFDE5_CRU/GPCC are evaluated with site observations and spatial patterns. The results by driving a hydrological model also show improvements compared to its raw ERA5 data. In general, this paper is important for the community and should be published quickly. It is now well written and well structured. A few comments can be considered before the final acceptance.

Major comments:

As one of the previous referees mentioned, the ERA5 is already in 0.25o. But the authors aggregate them to 0.5 o for comparison with current 0.5o WFDEI. Some discussions should be added for this change.

Thanks for this observation. An additional paragraph has been added to the manuscript containing a more detailed discussion on the choice of generating WFDE5 with a 0.5° x 0.5° resolution.

2.3 Higher resolution WFDE5 data.

The WFDE5 has been provided at 0.5° x 0.5° resolution rather than at 0.25° x 0.25° in the original ERA5 data. There are several reasons for this. The project to generate WFDE5 was designed also to deliver open source software so that users could re-generate the data at the original or, eventually, higher resolution. Three main considerations influenced the initial generation of the WFDE5 dataset:

a) The need to generate data in time for ISIMIP3 and their reporting to the AR6 of IPCC in 2020;

b) The need to convert the existing WFDEI Fortran programs into CDS Toolbox workflows and easily test the output;

c) The requirement for appropriate, and freely-available, global land gridded observations for bias correction.

The first consideration meant that any procedures adopted had to be practical and fast. The simplest way to test whether the CDS Toolbox workflows programs were working was to apply them to ERA-Interim data and check that they correctly reproduced the WFDEI data. This implied generating output at the same resolution as the WFDEI and CRU. Additionally, ISIMIP3 only required data at 0.5 x 0.5o since their models were set up at that resolution.

The WFDE5 CDS workflows will eventually allow users to generate higher resolution data on their own. At the moment, this can only be done using interpolated CRU TS4.03 and GPCCv2018 datasets, copies of which are hosted on a dedicated CDS machine and made accessible through the CDS Toolbox. Another option would be to use higher-resolution observational datasets, such as quarter-degree GPCC or MSWEP (Beck et al., 2017; 2019b) for total precipitation. This option will be viable once additional datasets can be hosted on the C3S Climate Data Store.

New reference:

Beck, H.E., Vergoploan, N., Pan, M., Levizzani, V., van Dijk, A.I.J.M., Weedon, G.P., Brocca, L., Pappenberger, F., Huffman, G.J. and Wood, E.J.: Global-scale evaluation of 22 precipitation datasets using gauge observations and hydrological modelling, Hydrology and Earth System Sciences, 21, 6201-6217, https://10.5194/hess-21-6201-2017, 2017.

Compared to ERA-I/WFDEI, ERA5/WFDE5 has superiority in small-scale weather patterns (hourly compared to 3-hourly, 0.25o/0.5 o). However, this is not shown in the results. I think, one typical event over grids or regions with storm will be helpful to show this advantage. Is it has been included in Hersbach et al. (2020, under review)?

Thanks for your observation. To answer it, we added the following sentence at line 49:
'The increased level of detail of ERA5 compared to ERA-Interim has been reported in a growing number of publications. Several of these have been summarized in Hersbach et al. (2020), and the benefit of hourly resolution is illustrated for the December 1999 storm Lothar in that paper as well. Hersbach et al. (2019) shows the increased level in detail of precipitation over the North Atlantic.'

New reference:

Hersbach, H., Bell, B., Berrisford, P., Horányi, A., Sabater, J.M., Nicolas, J., Radu, R., Schepers, D., Simmons, A., Soci, C. and Dee, D., 2019. Global reanalysis: goodbye ERA-Interim, hello ERA5. ECMWF Newsl, 159, pp.17-24.

Although the hydrological model is not the core of this paper, some of the explanations are not convincing (please see the minor comments).

Minor comments:

Line 62, 21th should be 21st

Thanks. Done as suggested.

Line 88-91 & line 97-99 repeated sentences about the bias correction.
Thanks for this suggestion, there's a bit of overlapping between the two paragraphs indeed. Lines 86-99 will be replaced by the following:

Here we describe the WFDE5 (i.e. "WATCH Forcing Data methodology applied to ERA5 reanalysis data", C3S, 2020), a new meteorological forcing dataset for land surface and hydrological models based on the ERA5 reanalysis (Copernicus Climate Change Service, 2017). It consists of eleven variables (see Table 2) with an hourly temporal resolution on a regular longitude-latitude half-degree grid, with global spatial coverage and values defined only for land and lake points. The dataset was derived by applying the sequential elevation and monthly bias correction methods described in Weedon et al. (2010, 2011) to half-degree aggregated ERA5 reanalysis products. The monthly observational datasets used for bias correction are CRU TS4.03 from CRU (Harris et al., 2014) for 1979 to 2018 for all variables and the GPCCv2018 full data product (Schneider et al., 2018) for rainfall and snowfall rates for 1979 to 2016. In addition, as described below, the aerosol correction step for shortwave radiation has been revised with respect to WFD and WFDEI. For an outline of the methodology applied and a reference to the observation datasets used see Tables 1 and 2.

Line 97-99 how the monthly values are applied to bias correction for hourly data. What are the differences in the methods for old 3-hourly and for the hourly data here?
Thank you for your question. As mentioned at the beginning of section 2.2, the bias-correction methods used for the generation of the WFDE5 dataset are exactly the same which had been previously used for WFD and WFDEI datasets (except for Qair variable), and which are thoroughly described in Weedon et al. (2010, 2011). These methods are not impacted by the change in temporal resolution of the input datasets, so there's no significant difference to be mentioned.

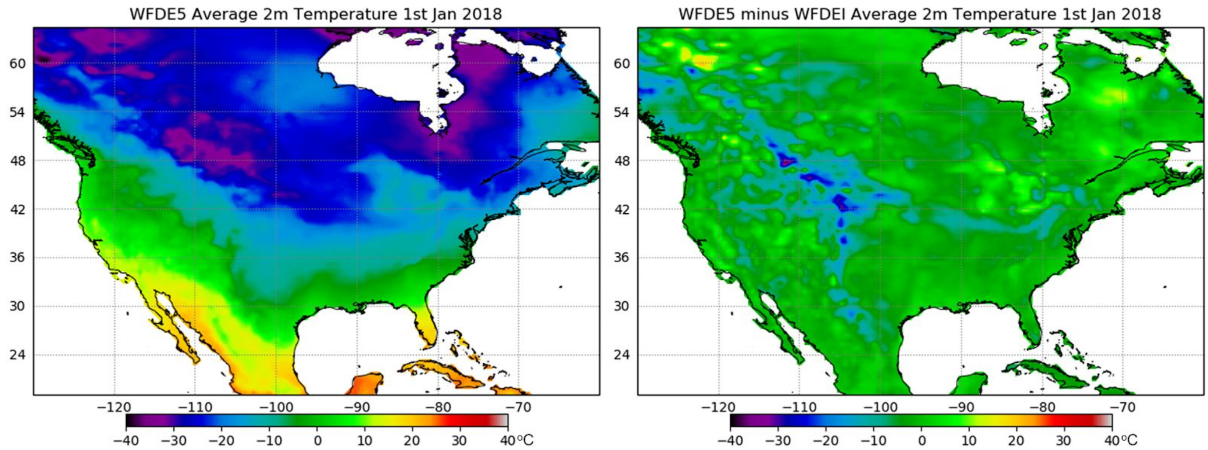
References:

- Weedon, G. P., Gomes, S., Viterbo, P., Österle, H., Adam, J. C., Bellouin, N., Boucher, O., and Best, M.: The WATCH Forcing Data 1958–2001: A meteorological forcing dataset for land surface- and hydrological-models, Tech. rep., WATCH Technical Report 22, http://www.eu-watch.org/publications/technical-reports, 2010.
- Weedon, G. P., Gomes, S., Viterbo, P., Shuttleworth, W. J., Blyth, E., Österle, H., Adam, J. C., Bellouin, N., Boucher, O., and Best, M.: Creation of the WATCH Forcing Data and Its Use to Assess Global and Regional Reference Crop Evaporation over Land during the Twentieth Century, Journal of Hydrometeorology, 12, 823–848, https://doi.org/10.1175/2011JHM1369.1, 2011.

Figure 2. typo. a) FN205 missing '1' in FN2015 Figure 2. In table 2, rainf_CRU and rainfall_CRU+GPCC are introduced. So here Precipitation_GPCC is with CRU or not?
thanks for the observation. In the figure "Precipitation_GPCC" was actually meant to be "Precipitation_CRU+GPCC", so a consistent naming has been applied.

Table A17. Some shades in cells are useful if we compare the relative results between WFDEI and WFDE5. The cell can be with light gray if it shows a better performance. Also applicable to other Tables.
Thank you for this observation, but we have decided to leave the Tables as they are.

Figure 3 make a map of difference will be more straightforward for discussion. In general, the description of the spatial pattern of WFDE5 is not as solid as the discussions on point observations and later global assessment of water balance.
Thanks for your observation. Fig. 3 was actually intended to show superiority of WFDE5 versus WFDEI just in terms of spatial resolution, and as such we believe that the current figure is better suited than a map of differences. For completeness, we attach here the alternative option we considered:



Line 241. No evidence shows that WFDE5 performs better without comparison to observations, even though we see the high-resolution features in WFDE5. A comparison on dense gauge observations over the US could be helpful if the author would like to do so. (or including the topography will be helpful for the discussion on the topographic effect on temperature.) How about precipitation, its spatial characteristics could be more obvious with topographic effects.
Thanks for your comment. We agree that demonstrating that WFDE5 leads to better model performance requires comparison to observations. This is why we adopted a dual approach: a) assessment of the individual variables against FLUXNET2015 site observations (Section 4.2) and b) using WaterGAP to utilize all variables together and assessing the performance against observed river flows via the GRDC gauge data (Section 4.3). Extending the latter assessment to a dense gauge network across the USA is beyond the scope of this paper.

Table 6, caption should mention that the results are for global scale.
Thank you for your suggestion. In Table 6 caption, “WaterGAP 2.2c and for 1981-2010.” has been replaced by “WaterGAP 2.2c for 1981-2010 and for global land area (except Antarctica and Greenland).”

Line 261. Not significantly higher, <5% for AET; but ~13% for discharge.

Thanks for your suggestion, on which we agree. In line 261 the word “significantly” has been removed.

Line 263 (previous estimates, better to use some values rather than only mentioning Table 2). Why for this comparison, in Muller Schmied et al., 2014, the STANDARD is results for WFD+WFDEI (111070), and CLIMATE scenario is WFDEI_CRU/GPCC (112969). When you do same routines to ERA5 (bias correction with CRU/GPCC), you must have this result.
Thank you for the suggestion. We intended to argue here that using ERA5 precipitation directly leads to much higher global sums compared to those global sums that are reached when monthly scaling to observation datasets (as GPCC and CRU) has been done. The references here should show only the link to those tables. But yes, indeed the numbers are not completely similar (which has to do with a different land-sea mask used in Müller Schmied et al., 2014 (plus a different GPCC version used) and also due to a different time span used within Müller Schmied et al., 2014, 2016 (1971-2000) and this study (1981-2010). Furthermore, the CLIMATE experiment in Müller Schmied et al., 2014 is using monthly climate input from CRU TS 3.2 but GPCC v6 for precipitation and a slightly different snow undercatch routine. We agree that providing all those details is not meaningful here. Hence, to not overcomplicate our message (the reduction of global mean precipitation to plausible ranges that are based on observation-based datasets), we modified this sentence to:

“The general reduction of mean global precipitation from 120000 km3/yr for ERA5 to observation-based datasets with around 111000 km3/yr for WFDE5 is consistent to previous estimates (109631 to 111050 km3/yr for the time span 1971-2000 for the snow undercatch corrected climate forcings in Table 3 and 4 of Müller Schmied et al., 2016).”

Similar in Line 265 for AET and Q, some numbers are helpful for the conclusion.
Thank you for the suggestion. We have modified the sentence in line 265 to: “...AET and Q are well within the estimates of other models or datasets (AET 62800-75981 km3/yr and Q 34400-44560 for most assessments according to Müller Schmied et al., 2014, Table 5)”
Furthermore, we have deleted the long bracket regarding the model parameter gamma (note that…) because we think that even though this is important from a model perspective, it is an unnecessary detail for the general message and does not influence the assessment.

Line 267-269, please specify that 1825 and 768 is for river discharge.
Thank you for the observation, done as suggested.

Line 269, Differences between ERA5 and ERA-I could also lead to the difference in estimated discharge. But a more straightforward comparison is that WFDEI-CRU is 573 larger than WFDE5-CRU which can be explained by the CRU versions.
Thank you for the suggestion. We agree that this part can lead to confusion and thus we have modified the sentences starting in line 267 and ending in line 269 by: “The differences in GPCC and CRU dataset versions to adjust ERA5 (ERA-Interim) precipitation for WFDE5 (WFDEI) is substantially smaller for GPCC (precipitation difference: 87 km3/yr for WFDE5-GPCC vs. WFDEI-GPCC) compared to CRU (precipitation difference: 573 km3/yr for WFDE5-CRU vs. WFDEI-CRU). Consequently, differences in simulated river discharge are higher for WFDE5-CRU vs. WFDEI-CRU (1010 km3/yr) compared to WFDE5-GPCC vs.

WFDEI-GPCC (47 km3/yr). This implies that the choice of precipitation bias adjustment target (CRU or GPCC) impacts water balance components. Water consumption ...

Line 270-272. Not agree. How did you explain AET in WFDE5-GPCC is less than that in WFDEI-GPCC. Abstraction goes to the river discharge rather to the AET, so I would attribute the difference to the water use schemes in hydrological model which are associated with the variabilities of forcing in ERA5 and ERA-I. If the model estimates the PET, you can list it in the Table as well.

Thank you for this observation. Indeed, AET is lower for WFDE5-GPCC compared to WFDEI-GPCC. Please note that AET in Table 6 contain already Total (actual) water consumptions as the water consumption can be understood as evaporated (hence "lost" water). AET differences (excluding row 4 in Table 6) are 72247 km3/yr for WFDE5-GPCC and 72437 km3/yr for WFDEI-GPCC. It is a nice idea to look at PET as well. In WaterGAP, PET is calculated by using the Priestley-Taylor algorithm with varying the alpha parameter in dependence of aridity of the grid cell (1.26 for humid grid cells and 1.74 for (semi)arid grid cells, respectively). The resulting global scale PET values are: 149880 km3/yr (ERA5), 151545 km3/yr (WFDE5-GPCC), 151428 km3/yr (WFDE5-CRU), 151104 km3/yr (WFDEI-GPCC) and 150964 km3/yr (WFDEI-CRU). Here, WFDE5-GPCC is calculated to have 441 km3/yr more PET compared to WFDEI-GPCC, which is, however translated to 190 km3/yr less AET for WFDE5-GPCC (excluding water consumption) but 80 km3/yr more actual water consumption for WFDE5-GPCC. Of course these numbers are averaging regional differences between the datasets. The inclusion of PET would add another complexity to the description which might lose the purpose of this assessment. However, we agree that it is too speculative to reduce the difference in global water consumption to the difference in global net radiation without a sufficient spatial analysis. In addition, taking into account the overall relatively small deviations between the water balance components mentioned here, we decided to delete the sentence starting in line 269.

Line 270, any reference for the net radiation difference in WFDE5 than in WFDEI (or ERA5 to ERA-I? Regarding the comparison between WFDE5 and ERA5, a global map of the differences between the precipitation and SWdown (which has been modified according to Table 2) is recommended.

Thank you for the suggestion. Based on your important comment, we re-thought our argument here. The WFDE5 only provides downward radiation fluxes. Net radiation simulated with WaterGAP depends on both, downward radiation input from the meteorological forcing and assumptions in the model about land cover-dependent emissivity and albedo. Hence, net radiation as simulated by WaterGAP cannot easily be used to evaluate WFDE5 radiation fluxes. To avoid over-complications in the assessment for the readers, we decided to delete the part with the net radiation (see our comment above). However, the suggestion to show maps with spatial differences is a very good idea which we followed. The new Fig. 1 (below) shows the differences in precipitation, whereas the Figs. A1, A2, A3 (below) show differences in shortwave downward radiation, longwave downward radiation and temperature. We believe that those figures can improve the understanding of the differences between ERA5 and WFDE5.

Figure 5. substantial changes from ERA5 to WFDE5 in Yangtze, what has resulted in the changes?

Thank you for your question. Indeed, large changes to see. For the period 1979-1988 (which is the major time series with discharge observation as plotted in the figure), basin-wide precipitation for ERA5 is 2543 km3/yr whereas for WFDE5-GPCC it is only 1779 km3/yr, which translates to discharge (AET) of 1303 (1240) for ERA5 vs. 584 (1194) for WFDE5-GPCC. Based on your earlier suggestion regarding the precipitation differences, we added Figure 1 below for differences in precipitation, plus figures for the other variables as used by WaterGAP.

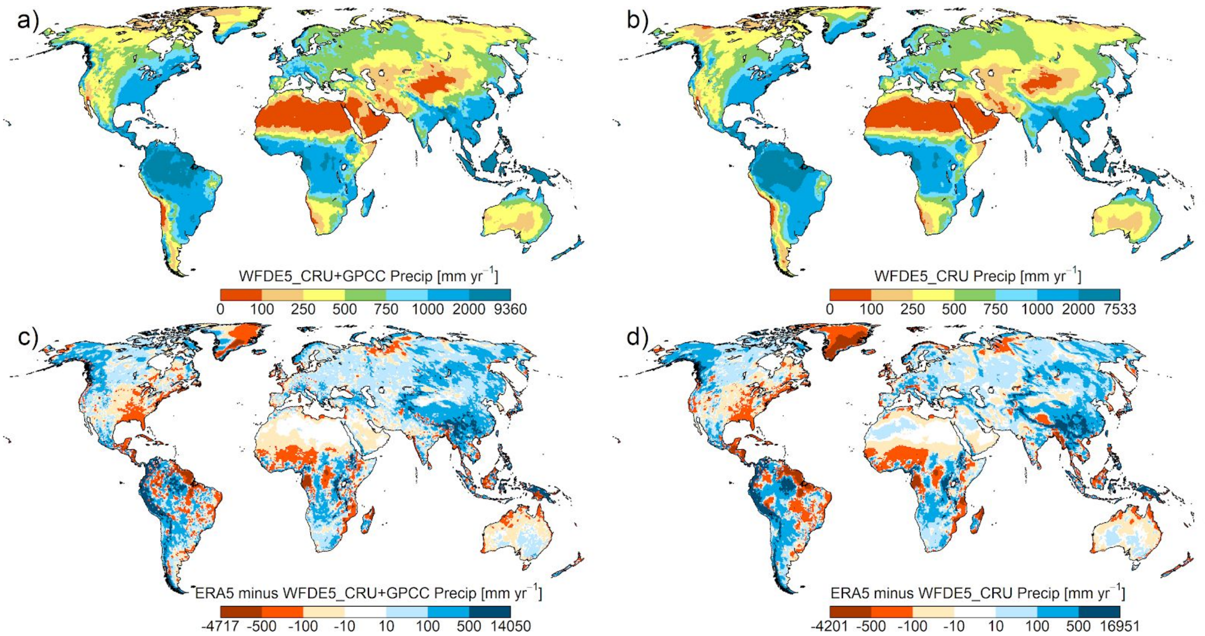


Figure 1: Long-term (1979–2016) average precipitation of the climate forcings, displayed as absolute number for WFDE5_CRU+GPCC (a), WFDE5_CRU (b) and differences to ERA5, computed as ERA5 minus WFDE5_CRU+GPCC (c) and ERA5 minus WFDE5_CRU (d). All units in mm yr^{-1}.

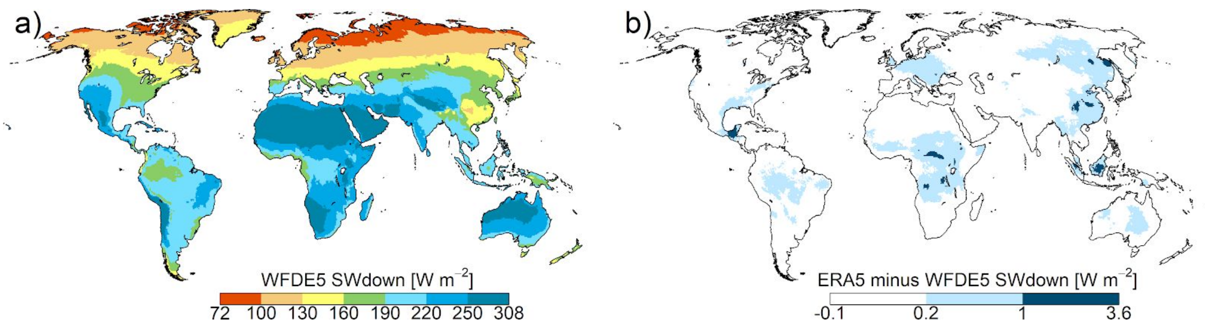


Figure A1: Long-term (1979–2016) average shortwave downward radiation of the climate forcings, displayed as absolute number for WFDE5 (a) and differences to ERA5, computed as ERA5 minus WFDE5 (b). All units in W m^{-2}.

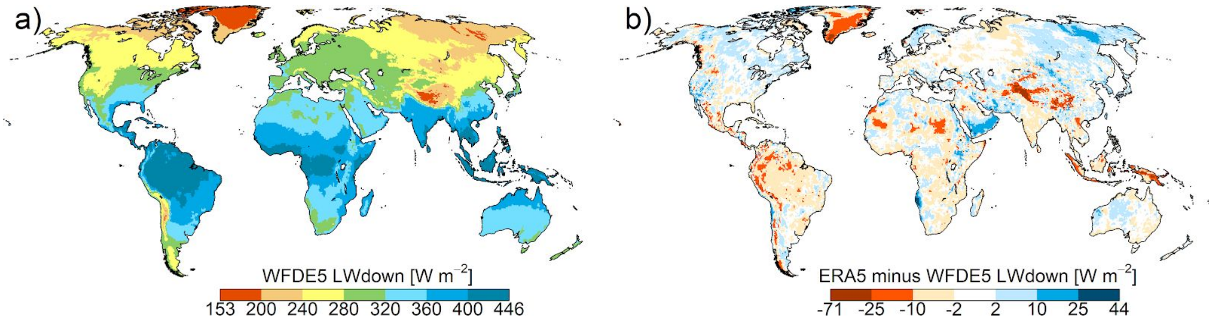


Figure A2: Long-term (1979–2016) average longwave downward radiation of the climate forcings, displayed as absolute number for WFDE5 (a) and differences to ERA5, computed as ERA5 minus WFDE5 (b). All units in W m^{-2}.

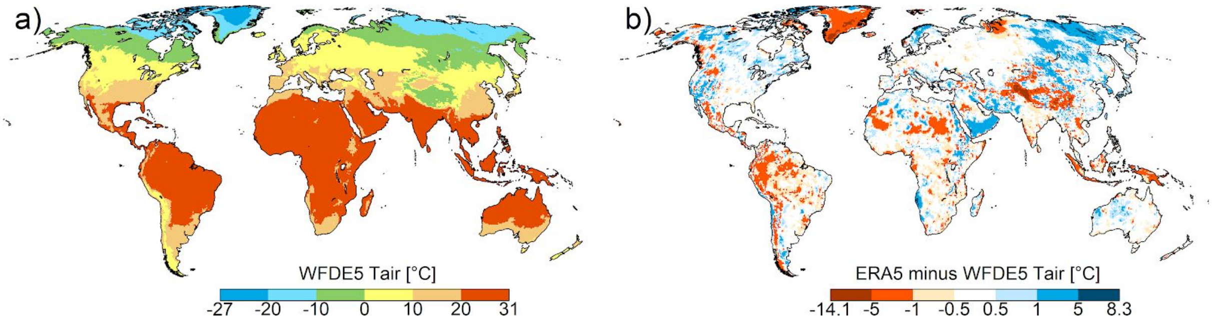


Figure A3: Long-term (1979–2016) average temperature of the climate forcings, displayed as absolute number for WFDE5 (a) and differences to ERA5, computed as ERA5 minus WFDE5 (b). All units in °C.