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Discussions

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Reply on RC1

Yongwei Liu et al.

Author comment on "Historical droughts manifest an abrupt shift to a wetter Tibetan Plateau" by Yongwei Liu et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2022-28-AC1, 2022

We appreciate the constructive criticisms and suggestions. We have addressed your concerns below.

Comments from Reviewers:

Reviewer Comments 1:

Comments on "Historical droughts manifest an abrupt shift to a wetter Tibetan Plateau" by Liu et al.
This study analyzed the climate wetting/drying of the Tibetan Plateau from variations of historical soil moisture droughts over 1961-2014, focusing on the spatiotemporal patterns, long-term variations of soil moisture, and the related climate causes of summer (May–September). Multiple observation and reanalysis data were used for the analysis. To this reviewer, these analyses are very important to quantify the various aspects of the soil moisture droughts and their causes. In reading through the manuscript, despite that fact that the authors have done a lots analyses, there seem some important technical issues that need to be considered carefully to ensure that the results of the study are reliable. Some of these issues are listed as follows:
1. The consistency of the used variables used in describing the water components. The study used different data sources for the analysis, e.g. the soil moisture is extracted from the GLDASv2.0/Noah dataset from the depth of 0-10cm, precipitation and air temperature from interpolation the gauge data provided by the Chinese Meteorological Administration, potential evapotranspiration, wind speed, radiation, vapour pressure deficit, latent heat flux, and net radiation flux again from the output and forcing datasets of GLDASv2.0/Noah. The authors need to consider if the relevant quantities are consistent before carrying out further analysis. Inconsistency in precipitation in the CMA data and that in GLDASv2.0/Noah can cause lots of inconsistencies in the derived soil moisture and its relationships to precipitation. See e.g. https://journals.ametsoc.org/view/journals/bams/99/2/bams-d-16-0074.1.xml for how to verify and ensure the consistency of the climate data records.

Response 1: Done. The consistency of precipitation and temperature from the gauge interpolation data provided by the Chinese Meteorological Administration (CMA) and the GLDAS forcing input data were evaluated. The precipitation and temperature of ERA5 and China Meteorological Forcing Dataset (CMFD) were incorporated for inter comparison (He et al., 2020). The temporal correlations between different data sources were analyzed.

The results in Figure R1 show that the precipitation of CMA and GLDAS have good consistency in large of east and south Tibetan Plateau (TP), but low consistency in the northwest. The precipitation of CMA presents better consistency with ERA5 and CMFD than GLDAS. The best consistency of precipitation is between CMA and ERA5. For the surface air temperature, both CMA, GLDAS, ERA5 and CMFD show quite high temporal consistency. The correlation coefficient between any two datasets is over 0.8 for the vast majority of the TP (Figure R2).

Figure R1. Pearson correlation coefficient between the precipitation of CMA and GLDAS, GLDAS and ERA5, CMA and ERA5, GLDAS and CMFD, CMA and CMFD, ERA5 and CMFD over summer periods of May-September. The black dots denote the significant ($p < 0.05$) correlations.

Figure R2. Pearson correlation coefficient between the surface (2 m) air temperature of CMA and GLDAS, GLDAS and ERA5, CMA and ERA5, GLDAS and CMFD, CMA and CMFD, ERA5 and CMFD. The black dots denotes the significant ($p < 0.05$) correlations.

2. GLDASv2.0/Noah data is strictly not a climate data record, the authors need to verify the temporal consistency of the used variables to make sure that the trends in the used variables are true reflection of the actual states of Tibetan Plateau and not caused by e.g. the change of the forcing data. A suggestion is compare the relevant variables with the ERA5 data and discuss the uncertainties. Some comparison to in-situ observation should also help to ensure the validity of the conclusions. Examples of such comparisons could be for precipitation (e.g. those from CMA and input to GLDASv2.0/Noah), soil moisture and evaporation from in-situ observation and remote sensing, e.g.
https://www.mdpi.com/2072-4292/13/18/3661/htm;
https://www.mdpi.com/2072-4292/12/3/509,
https://essd.copernicus.org/articles/13/3513/2021, among many others.

Response 2: Done. ERA5 data was incorporated to verify the temporal consistency of the used variables to make ensure that the trends or shifts in the used variables are true reflection of the actual states of the TP. Moreover, multi-sources of reanalysis, in-situ and remote sensing data were utilized to ensure the reliability of the results. Specifically, the CMFD data were incorporated in precipitation verification. The precipitation of CMA, ERA5, GLDAS and CMFD were inter compared. The results show that CMA and ERA5 precipitation present high consistency. CMA precipitation has higher consistency with CMFD than ERA5 and GLDAS (see Figure R1).

To verify the validity of the soil moisture data, the in situ soil moisture observations from the International Soil Moisture Network (ISMN; https://ismn.geo.tuwien.ac.at/en/) were used. Figure R3 shows the location of the available 111 ISMN soil moisture stations from three (NGARI, CTP-SMITN, and MAQU) observation networks in this region. We subdivided the 111 ISMN stations into 0.25° × 0.25° grids (26 grids in total: 5 in NAGARI; 12 in CTP-SMITN; 9 in MAQU). The mean soil moisture value of each grid was obtained by averaging all stations falling within that grid pixel. The GLDAS and ERA5 monthly soil moisture were compared with the ISMN measurements over summer periods (from May to September) of 2008-2014 on 25 grids (with 1 grids in NAGARI has no ISMN observation records during 2008-2014). Generally, GLDAS shows lower bias and root mean square error (rmse), but higher unbiased rmse (ubrmse) and lower Pearson correlation coefficient (r) than ERA5 (Figure R4). In terms of the temporal consistency with in situ observations, ERA5 seems better than GLDAS soil moisture. Specifically, for MAQU (in humid region), GLDAS soil moisture performs better in bias, but ERA5 is better in r and ubrmse. For NGARI (in arid region), ERA5 is better in bias, r, and rmse, but worse in ubrmse than GLDAS. For CTP-SMTMN (in semi-arid and dry sub-humid region), GLDAS performs better in bias and rmse, but ERA5 is better in r and ubrmse (Figure R5). ERA5 soil moisture over May to September in MAQU and CTP-SMTMN is superior to GLDAS if the system biases were not considered.

To understand the reliability of the evapotranspiration data, the monthly average actual evapotranspiration developed by Han et al. (2020, 2021) from 2001 to 2018 were incorporated in the inter comparison of the GLDAS and ERA5 evapotranspiration. This dataset is calculated using the surface energy balance system model (SEBS) based on the satellite remote sensing (MODIS) and reanalysis meteorological data (CMFD), and agrees well with the observations of flux towers in the validation of Han et al. (2021). The results (Figure R6) show that the actual evapotranspiration of GLDAS and ERA5 have high temporal consistency in most regions, and the low consistency mainly in northwest and south fringe of the TP. The ERA5 evapotranspiration agrees better with the dataset of Han et al. (2020, 2021) than GLDAS. The evapotranspiration in northwest and north TP present large uncertainty among the aforementioned three datasets.

Based on the above verification and analysis, the ERA5 dataset were incorporated into our analysis of the climate wetting of the TP in the updated manuscript. The performance of ERA5 and GLDAS datasets were inter compared and the uncertainties were discussed.

Figure R3. Location of the in situ soil moisture observations from the International Soil Moisture Network and the Aridity index for the TP (from http://ref.data.fao.org/map?entryId=221072ae-2090-48a1-be6f5a88f061431a&tab=about).

Figure R4. Comparisons of the bias, Pearson correlation coefficient (r), root mean square error (rmse) and unbiased rmse (ubrmse) for GLDAS and ERA5 soil moisture in summer periods of May-September over 2008-2014 based on the soil moisture measurements from ISMN.

Figure R5. The bias, Pearson correlation coefficient (r), root mean square error (rmse) and unbiased rmse (ubrmse) for GLDAS and ERA5 soil moisture in summer periods of May-September over 2008-2014 based on the ISMN station measurements from the MAQU, NGARI and CTP-SMTMN observation network.

Figure R6. Pearson correlation coefficient between the actual evapotranspiration of (a) GLDAS and ERA5, (b) GLDAS and the dataset developed by Han et al.(2020,2022), and (c) ERA5 and the dataset developed by Han et al.(2020, 2022) over summer periods of May-September.

3 Changes in vegetation coverage is closely related to the changes in soil moisture and temperature, this seems completely neglected by the authors. See e.g. https://link.springer.com/article/10.1007/s10584-009-9787-8.

Response 3: Done. The vegetation coverage changes were investigated based on the AVHRR GIMMS NDVI3g during the period of 1982-2015. The vegetation coverage presents an increasing trend for the whole TP (Figure R7a) and this trend is significant for large regions of north and west TP (Figure R7b). The results generally support the wetting of soil moisture and the overall warming of temperature. The partial correlation analysis between the NDVI and soil moisture of GLDAS and ERA5 shows that vegetation coverage changes in east TP tend to be more impacted by temperature, while the changes in middle and west TP tend to be jointly impacted by temperature and soil moisture, more by soil moisture in some regions, e.g. the large regions around 90°E both indicated in GLDAS and ERA5 (Figure R8). The vegetation changes analysis were incorporated in the wetting shift exploration in the revised manuscript as important supports.

Figure R7. Variations of the (a) yearly average NDVI over summer periods of May–September from 1982 to 2015, and the (b) variation trends of NDVI on the Tibetan Plateau. Note that the greed/brown ☐/☐ denote the significant ($p < 0.05$)

increasing/decreasing trends.

Figure R8. Spatial distribution of the partial correlations between the NDVI and soil moisture (SM)/surface air temperature (Temp) over summer periods of May–September from 1982 to 2015 for GLDAS and ERA5 respectively. The black dots denote the significant correlations.

4. Figure 4 is rather difficult to comprehend, perhaps a Hovmöller diagram is more effective.
Response 4: We tried to use the Hovmöller diagram, but it cannot reflect the spatial distribution and the location changes or the spatiotemporal evolution of soil moisture drought clusters over time. So, Figure 4 was revised as follows, which more clearly shows the spatiotemporal dynamics of soil moisture drought clusters and the development process of the drought event, as well as the impacts from precipitation and potential evapotranspiration.

Figure 4. Spatiotemporal dynamic patterns of the most severe SM drought event over 1961–2014 (a), and the monthly standard anomaly maps of Prep (b) and PET (c) before (1 month) and during the drought duration over the drought cluster affected area. In (a), the yellow dots in subgraph "Dynamics from May to Sep" are the centroids of the drought clusters. The black arrow lines show the migration/evolution direction and trajectory of the drought clusters.

5 Trend lines and designated changes in Figures 5, 9 and 11 appear arbitrary, unless the authors can provide more details in trend detection that identifies 1995 as the year of abrupt change. Such a change in Fig. 5 is also not observed nor explained by the monsoon indices, AMO, PDO and ISM. These relationships should be explored more in detail. Does ENSO have any impact on the precipitation and circulation patterns? How about the solar cycles?
Response 5: We incorporated more data sources to investigate the abrupt wetting of the TP. The abrupt wetting was detected in both the soil moisture, precipitation, and actual evapotranspiration of GLDAS, ERA5 and CMA dataset (Figure R9). Almost all the aforementioned variables show abrupt changes in mid to late 1990s at the significance level of $p < 0.05$ based on pettitt diagnosis (pettitt, 1979) (Figure R10). Supports of the abrupt wetting of the TP can also be drawn from the researches of Zhou et al. (2022), Sun et al. (2019), Ma and Zhang, 2022.

The relationships between precipitation of the TP and the AMO, PDO, EASM, ISM were further investigated. ENSO and solar cycles were incorporated in the analysis of their influences on precipitation and circulations using the Niño 3.4 and solar radiation flux indices (SRF, http://www.esrl.noaa.gov/psd/data/correlation/solar.data). The interdecadal correlation analysis of the aforementioned factors suggests that EASM is significantly related to AMO, PDO and ENSO. ISM is significantly related to AMO and PDO. The correlation analysis based on 11-year running average statistics shows that solar circles have significant ($p<0.05$) impacts on ENSO and ISM. Considering the complex cross-impacts among the oscillation and circulation indexes and the subsequent multiple effects on precipitation, the partial correlation between these indexes and precipitation were analyzed. Figure R11 shows that the interdecadal variations of summer precipitation of the TP are largely impacted by AMO and PDO, and with some local influences from ENSO. The ISM has significant positive influence on the precipitation of south TP, while negative impacts on the precipitation of north TP. The EASM has positive impacts on the precipitation of south east TP, while negative influences on the precipitation of central north TP.

The phase transition of AMO from cold (negative) to warm (positive) in mid 1990s (Figure R12c) tend to weaken the westerly winds near the TP through a wave train of cyclonic and anticyclonic anomalies over Eurasia in summer (Sun et al., 2020). The weakened westerlies would reduce the water vapor transport beyond the eastern TP boundary and facilitate the convergence of water vapor (i.e., Prep formation) over the west and central TP (Wang et al., 2017; Zhou et al., 2019). On the other hand, the phase transition of AMO from cold to warm are inclined to cause the weakening of ISM and EASM due to the significant negative correlations between AMO and the ISM and EASM. This impact seems more pronounced on ISM with obvious decreasing tendency after mid 2000s (Figure R12b). The weakened ISM would contribute to the wetting of north TP, while slow down the wetting of central south TP through its impacts on the water vapor transport from south boundary (Figure R11e). The PDO seems mainly in its cold (negative) phase after mid to late 1990s (Figure R11d) on interdecadal scale. The negative PDO tend to slow down/alleviate the weakening of EASM and contribute to the weakening of ISM through its significant negative correlation with EASM and positive correlation with ISM. The weakening of the EASM tend to contribute to the wetting in north central and the drying in southeast of the TP (Figure R11f).

Figure R9. Variations of the total annual soil moisture (SM) drought severity of (a) GLDAS and (b) ERA5, the average SM of (c) GLDAS and (d) ERA5, the yearly average precipitation (Prep) of (e) CMA, (f) GLDAS, and (g) ERA5, and the yearly average actual evapotranspiration (ET) of (h) GLDAS and (i) ERA5 over summer periods (May**–**September) from 1961 to 2014. The dotted black lines are the mean values over different periods.

Figure R10. Pettitt statistics for the total annual soil moisture (SM) drought severity of GLDAS and ERA5, the average SM of GLDAS and ERA5, the yearly average precipitation (Prep) of CMA, GLDAS, and ERA5, and the yearly average actual evapotranspiration (ET) of GLDAS and ERA5 over summer periods (May–September) from 1961 to 2014. The red dotted lines represent the statistics at the significance level of p = 0.05.

Figure R11. Spatial distribution of the partial correlation coefficients between the precipitation and the (a) AMO, (b) PDO, (c) ENSO (nino 3.4), (d) SRF, (e) EASM and (f) ISM index on interdecadal scale.

Figure R12. Interdecadal variations of the (a) EASM, (b) ISM, (c) AMO, (d) PDO, (e) ENSO (nino 3.4), and (f) SRF index.

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Please also note the supplement to this comment:
https://hess.copernicus.org/preprints/hess-2022-28/hess-2022-28-AC1-supplement.zip