Replies to Reviewer 1

This paper assessed the water balance in Quaidam basin, where the mega-lake existed in mid-Pliocene, using High Asia Refined analysis data during 2001-2014. The results showed almost zero annual balance with positive during warmer and negative during dry years. Also the altitudinal tendencies of climate parameters with their contribution to the water balances are diagnosed by simple regression (scattering) analysis.

Reply: The study addresses both the state of the Qaidam basin's water balance during present-day conditions, and its sensitivity to variations in mean annual near-surface air temperature and humidity spatially averaged over the basin. These physical quantities are addressed in regional paleoclimate studies where uncertainties in global-scale forcing of regional climates and in paleogeographic data do not allow for spatially detailed (high-resolution) analyses of climate and hydrology. This holds particularly true for orographically induced precipitation which is not resolved by coarse grids used in paleo-climate modelling but is of utmost importance as my study reveals.

Assessments of annual water balance in the semi-dry and endorheic basin behind TP, using comprehensive data based on satellite estimates and numerical model, are challenging. If the trend shown in Fig.2 could be verified by independent data or evidences in the social activities, the budget assessments would be reliable and useful in the present climate condition.

Reply: I did not analyse trends. Moreover, I examined how variations in the basin's water-balance relate to its components, i.e., precipitation and actual evaporation, and to variations in near-surface air temperature and specific humidity. All physical quantities are resolved by the High Asia Refined analysis data set (HAR) on a strict physical basis using observational data that have been thoroughly examined and widely used in a multitude of independent scientific studies. All data including the HAR data set are freely available to the public, such that reproducibility of the results of this study is ensured. The discussion part comprises various studies which are compared with my own results. I will add more references to scientific articles showing that the results of this study are not in contradiction to other, independent studies.

Also, in the scattering diagram in Fig. 4, years with far from linier regression should be diagnosed intensively as Fig. 3 to know the factors in HAR data that caused positive or negative budget (e.g. as mentioned in P6L175).

Reply: I don't understand what is requested by the reviewer. The sensitivity of a dependent variable y on variations of one of the independent variables x is given by the partial derivative $\partial y/\partial x_i$ where x_i denotes the independent variable to be analysed while all the other independent variables are held constant. This is exactly what simple linear regressions provide as result, since the regression coefficient is the partial derivate. Statistical significance testing is a common method to ensure that the probability that a correlation could be purely by chance is below a certain threshold (here 0.05). I only showed sensitivities that are statistically significant. Of course, correlation is not causation. But the physics in the WRF model allows for in-depth analyses of the reasons behind correlations.

Besides, there are many fundamental unintelligible and not logical parts as following comments.

35   Reply: This statement indicates that a revised version of the manuscript should better explain the concepts and methods behind the study, and that additional studies should be added to the text.

    1) Mountain water (including from glaciers) are accumulated in the underground, and foster the society and ecosystem (used by human or biosphere/agriculture) in the semi-arid basins by pumping up especially during non-rainy season. This part is

40   ignored in (1) and flowing analysis.

    Reply: I have explained in the manuscript that the study addresses water balance in total but not the individual storage systems separately. The latter would be beyond the scope of my study, and would not be feasible to analyse just by any atmospheric data set. As shown in Eq. (1), the water balance of a large endorheic basin can be approximated by net precipitation, i.e., the difference between precipitation and actual evapotranspiration, since lateral fluxes of surface water and groundwater at the

45   basin's borders are excluded by definition ($\Delta Q_{sfc} = 0$), or are negligible when compared to net precipitation integrated over the entire basin. Thanks to the reviewer's comment, I detected an error in Eq. (1) that needs to be corrected in a revised version of the manuscript: the term ΔQ_{sub} (indicating subsurface) in the equation must be replaced by ΔQ_{gw}, which is the term used in the text for changes in groundwater storage.

    In addition, I will change the terminology in the revised manuscript, such that the term water balance is only used when

50   referring to the spatial average of net precipitation over the entire basin. Net precipitation shall be used when referring to individual grid points or areas within the basin, because then, lateral fluxes inside the basin are correctly treated.

    Many studies use the term terrestrial water storage (TWS), which also does not differentiate between different hydrological subsystems. As long as water that is exchanged between subsystems (glaciers, lakes, groundwater, etc.) resides inside the basin it does not change TWS. Thus, changes in TWS of the Qaidam basin are directly caused by the spatial average of net

55   precipitation, i.e., water balance. I will add further studies and revise the text to make the concept better understandable.

    Lake is the ground water level over the surface, but it is very strange that author neglected the groundwater matter (P2L34) and discusses about the lake existence in the past.

    Reply: I do, of course, know the definition of a lake. I have discussed groundwater in general, and changes in groundwater

60   storage in particular, in the manuscript, e.g. in Eq. (1); see above. In the discussion part (P6 L171-174), I discussed changes in groundwater reservoirs, and I referred to a study from Jiao et al. (2015) that showed the accordance of my results with those from an analysis of GRACE satellite data. I will give more details on this study and add further studies like the study of Loomis et al. (2019) to the discussion part:

    Loomis BD, Richey AS, Arendt AA, Appana R, Deweese Y-JC, Forman BA, Kumar SV, Sabaka TJ, and Shean DE, 2019. Water Storage

65   Trends in High Mountain Asia. *Front. Earth Sci.* 7, 235. doi: 10.3389/feart.2019.00235.

    Over long time periods, positive changes in TWS will result in rising groundwater levels, and subsequently, in rising lake levels. Both phenomena are currently taking place in the Qaidam basin as reported in the literature referenced in the manuscript. My study does, however, not address the timing of storage changes in the different reservoirs.

2) There is a huge time scale gap between the 10 years time slice for present climate (2001-2014) and a time slice of Mid-Pliocene (3.3-3.0 Ma=30,000,000 years). Author also recognized this issue in P8L234. I can not understand the logic of such comparison. It is very nonsense to compare 10 years/annual average to the paleo climate time scale.

Reply: The study does not intend to reconstruct the water balance of the Qaidam basin during the mid-Pliocene epoch. This is indeed impossible since no suitable paleogeographic or paleoclimate data required for detailed hydrological analyses or modelling studies are available, today. Moreover, I analysed the sensitivity of the present-day water balance (14 hydrological years) of the entire Qaidam basin to variations in spatially averaged mean annual near-surface air temperature and specific humidity. Then, I used results from independent paleoclimate studies on the Qaidam basin for the mid-Pliocene epoch (both from proxy-based and numerical modelling studies) to illustrate that the long-term mean water balance would have been positive during this period. The rationale behind this approach is given by the fact that physical laws do not change over time, and the results are in accordance to independent findings by the proxy-based studies that show the existence of a mega-lake system during a period of intensifying aridification of the region. I will add further details and additional references on this topic. I also discussed the assumptions and limitations of this approach (P7 L210-221).

If your focus is the mechanism of mega-lake formation and maintenance for several millions of years, water budget simulation during the mid-Pliocene is necessary with boundary condition that fits proxy data.

Reply: As stated above, this study is not targeting on reconstruction of the water balance, and, even more, not on modelling the hydrology of the Qaidam basin during the mid-Pliocene epoch.

Also, the evaporation over the lake water is quite different from the desert surface that is not considered in your study. Dry soil/sand at the skin surface blocks soil moisture movement from the underground.

Reply: Actual evapotranspiration of lake water is included in the study. Spatial averages of all physical quantities also comprise grid points indicated as lakes in the HAR data set. I also discussed the specific role of lakes in P4 L116-119. In addition, I stated in P8 L242-246 that there are processes related to evaporation of lake water and its consequences for water balance and lake-level changes not yet solved, and thus require further studies. Evaporation of the desert surfaces are also included in the study. Soil moisture is one of the input variables provided by the global operational FNL data set. Even if soil properties would not be accurately represented in the WRF model, the very low soil moisture values nevertheless limit evaporation. If aridity resistances would be larger as indicated by the reviewer, then net precipitation would be even higher (less negative or more positive), and thus supporting the findings of this study.

3) I could not understand that what and how the author estimates in P7L193. I speculated that statistical relations between altitude and meteorological parameters derived in Fig. 3 was performed as functions of future or passed expected temperature differences. If so, the methods are wrong.

Reply: The values for minimum and maximum changes in long-term mean annual air temperature (1 and 2 K) are taken from the literature as referenced in the manuscript. These values are relative to recent mean annual air temperature, and are conservative estimates for both the mid-Pliocene and for future climate conditions. They are not reconstructions or projections in a strict sense, moreover they show the range of possible changes in mean annual air temperature that are generally compatible with the results from various independent studies. I will revise the text to make the approach better understandable, and I will add further studies.

Altitude is not explicitly considered in this part of the study. All values are spatial averages for the respective quantities, thus representing the whole spectrum of altitudes in the basin. Also, the sensitivities are derived from the simple regressions for spatial averages of mean annual values of the respective quantities.

Relations in Fig. 3 was derived from the dynamical downscaling in the present climate condition, and does not work in the passed or future climate condition without simulating the similar dynamical downscaling under Mid-Pilocene global climate condition (see PlioMIP2 project etc.).

Reply: As stated above, the study does not intend to reconstruct past and future climates and water balance.

4) Paper structure is very strange. Results (figures) are only limited in the statistical relations and data aggregation using the 10 years HAR data, without clear figures to explain that why the mega-lake could form/sustain during the mid-Pliocene.

Reply: As stated above, the study does not intend to reconstruct past and future climates and water balance. The main part of the study is to analyse 14 years of spatially and temporally detailed data from the HAR10 to quantify water balance of the entire basin, the importance of the high-altitude parts for the water balance of the entire basin, and the sensitivity of the water balance of the entire basin to variations in mean annual air temperature and specific humidity spatially averaged over the entire basin as presented in the results part. Results are then discussed with respect to uncertainties, and compared to results from other independent studies.

If requested by the reviewer, I could move the results of the sensitivity study to the results part. However, I put this into the discussion part in order to first discuss that the results of the HAR-based analyses are consistent with the findings from independent studies and thus applicable, before using them for assessing potential changes of the water balance in the past and the future.

Conclusion do not contain the main results but his own theory (idea) was extended, and abstract mentioned that analogue of Mars could fit to the study results without any analysis in the main contents.

Reply: I will repeat the main results in the conclusions part in more detail in a revised version of the manuscript. The reference to the Qaidam basin discussed as analogue to Mars is just illustrating the discrepancy between the hyper-aridity of the low-altitude parts of the basin and the water balance of the entire basin, which is an integral over the low- and high-altitude parts.

There are many studies that focus just on the low-altitude parts disregarding the importance of the high-mountain regions for the water balance.

Minor comments P2L42ã ˘A ˘AWhich is the "high mountain range in the Qaidam basin"? Is this for Midïij Pliocene?

140   Reply: As shown in Fig. 3 and discussed in text (P4 L113-115), net precipitation is positive, on average, at altitudes above 4000 m asl. The term water balance will be avoided in a revised version of the manuscript since it is misleading as discussed above. The sensitivity computations do not consider changes in altitudes, but the discussion part contains a paragraph (P7 L210-221) that refers to Fang et al. (2007) who report on paleo-altitudes of the Qaidam basin slightly lower than today. In addition, I have included results based on HAR30 data, in which altitudes are lower than in the HAR10 data due to the coarser

145   grid. These results show that lower altitudes lead to less blocking of atmospheric water transport, and thus, to slightly higher water balance values. I will add further studies on this topic in a revised version of the manuscript.

P2L47-50 Is this objective parts? Can not understand the discussion.

Reply: The last sentence of this paragraph (P2 L46-49) is one of the main motivations behind this study. The literature

150   referenced in this sentence essentially says that environmental changes that could eventually take place in the future due to global climate change could be also studied by investigations that address the mid-Pliocene epoch. The proxy-based studies showed that a mega-lake was present during this time, thus the objective of the study was to identify a physically based mechanism that could explain the existence of the mega-lake in the past, and could also assist to estimate potential future environmental changes.

155

P3L74 How many GSOD stations in the target area ? Quite few? Or many?

Reply: As written in the text, there are eight GSOD stations within or nearby the basin. None of them is located at very high altitudes, i.e., the altitude of the highest GSOD station (Wudaoliang; see Fig. 1) is just 4613 m asl. Data scarcity was one of the major reasons for developing the HAR data set as explained by Maussion et al. (2011, 2014).

160

Black point in Fig. 1?

Reply: Thank you! The black points are the eight GSOD stations (with names and altitudes) within or nearby the Qaidam basin. I will add this information to the figure caption.

165   P3L85 Fig. 3 comes before Fig. 2 ?

Reply: Thank you! I overlooked that I mentioned Fig. 3 before Fig. 2 in the data and methods part. I will change the sequence of the figures accordingly.

P4L91 climate driver -> variables/elements ?

170   Reply: In the text, climate drivers are air temperature and humidity. I will revise the text such that the term climate driver is avoided.

P6L164-175 Is this review ? Then better to move in Chapter 1.

Reply: This paragraph belongs to the discussion, because the results of this study are compared to findings from other studies.

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P7L199ã ˘A ˘A"comparative with,," L205ã ˘A ˘A"almost identical", very vague terms and I cannot understand.

Reply: This text shall be revised to better explain the results shown in Table 2.

P7L210 Some papers show that climate in Mid-Pilocene is warm and wet (e.g. by Zhang).

180   Reply: Yes, and I have referenced the studies in P6 L175-188.

Celements et al. (1996) shows that nonstationary phase of Asian monsoon during Plio-Pleistoce, so is it sure that mega-lake was stable for several Ma years?

Reply: I only refer to the mid-Pliocene epoch but not to later stages, where the mega-lake system started to shrink, as described

185   in the introduction part (P1 L19-24). I will add further studies to the introduction.

P7L220 "blocking humidity" Thermal effect of TP causes subsidence around the northeast Asian area to form dry climate including around Qaidam basin. See Sato and Kimura, 2005, GRL for instance. Uplift of northwestern Tibet in the target era may also effect to this effect and also changes intensity/route of westerly disturbances.

190   Reply: As noted above, I will add further studies on this topic in a revised version of the manuscript, and I will better explain the findings from the HAR30 analysis.