General remarks

Thanks to the valuable comments of the three reviewers and the editor, I have revised the manuscript as explained below. I have also followed the requests of the editorial office to check and correct typos, phrasing, figure and table captions, formulas, as well as texts and legends in figures and tables.

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.

Changes: Text improved.

Assessments of annual water balance in the semi-dry and endorheric 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.

Changes: Text improved; further references added.

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 $\boldsymbol{x}$ 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.

Changes: Text improved.

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

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.

Changes: Text improved; further references added.

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

Changes: Text improved; terminology and formula adopted; further references added.

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 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 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.

Changes: Text improved; further references added.

2) There is a huge time scale gap between the 10 years time slice for present climate (2001-2014) and a time slice of Midïij 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).

Changes: Text improved; further references added.

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.

Changes: Text improved.

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.

Changes: Text improved.

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.

Changes: Text improved; terminology changed; further references added.

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.

Changes: Text improved; further references added.

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.

Changes: Text improved; subsections added to Results and Discussion sections to improve the structure and readability of the manuscript.

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.

Changes: Paragraph summarizing the main findings of this study added to the Conclusions section; text in Conclusions section improved; text parts shifted to the Discussion section.

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

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 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.

Changes: Text improved; terminology changed; further references added; HAR 30 km results better explained.

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 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.

Changes: Text improved.

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).

Changes: Text improved.

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.

Changes: Figure caption improved.

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.

Changes: Reference to Fig. 3 removed in the Data and methods section.

P4L91 climate driver -> variables/elements ?

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

Changes: Term climate driver is kept but better explained.

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.

Changes: Text improved.

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.
Changes: Text improved.

P7L210 Some papers show that climate in Mid-Pilocene is warm and wet (e.g. by Zhang).
Reply: Yes, and I have referenced the studies in P6 L175-188.
Changes: None.

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 in the introduction part (P1 L19-24). I will add further studies to the introduction.
Changes: Text improved; further references added.

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.
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.
Changes: Text improved; further references added; HAR 30 km results better explained.

Replies to Reviewer 2

The author carried out a study about the survival of the Qaidam mega-lake system in Pliocene by analyzing the modern water balance of the basin. The author finds that the water balance of Qaidam basin is nearly zero under present climate condition and believes that Qaidam basin may switch from negative to positive in the near future.
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. I as the author do not believe anything; I am just reporting and interpreting the results of the study, which is based on data that has been rigorously validated against independent observations. In particular, I do not speculate on the evolution of the Qaidam basin under future climates, moreover I showed that the basin’s water balance is highly sensitive to changes in mean annual air temperature and specific humidity such that it is physically possible that the mega-lake system could be restored on geological time scales, as it has happened several times in the past as independent proxy-based studies have revealed.
Changes: Text improved.

Although the story is quite interesting, there is a lack of robust evidence. In particular, the time scale of data used in the analysis is so different from a geological epoch, and therefore their connection is reluctant.

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 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).

Changes: Text improved; further references added.

I do not know how robust this linear speculation between the current and past lake conditions could be. As far as my knowledge, there are several fundamental flaws.

Reply: I don't speculate but carried out a study that strictly follows the principles of transparency and reproducibility. If the reviewer questions the correctness of my analyses he/she might download the freely available data and check my statistical analyses. The reviewer might also give reference to studies that contradict my findings. Again, it is important to recognise that the study does not try to reconstruct the water balance of the mid-Pliocene epoch. In this case, I would, indeed, have to prove that the current sensitivity would have been the same in the past. I only showed with my study, that the current sensitivity, which is statistically significant and in accordance with findings from independent studies, would be able to explain how the mega-lake system has survived under the still very dry climates of the mid-Pliocene epoch. I also discussed the limitations of this approach, but I realise from the comments of the reviewers that the whole concept behind the study needs to be better explained, and that the results need to be further substantiated by adding more references.

Changes: Text improved; further references added.

1. Line 32, lake evaporation is missing in the equation. Lake evaporation is very different from land evaporation. Although it is very small in modern time because the lake area is small (only ~1000 km2), it can be much large when the lake area is hundred times (~120, 000 km2) in Pliocene. Moreover, it is hard to derive the water balance in such a case from current HAR data, considering very different effects of a large lake area that is not included in HAR data. Lake evaporation is neither considered in the remaining discussion. For example, in line 227-231, the author did not consider the impact of lake evaporation.

Reply: Evaporation 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 L116-125. In addition, I stated in P8 L242-243 "…*Since lakes tend to reduce precipitation while concurrently showing high actual evaporation, there should be an upper limit for lake growth, which is, however, not yet known*…" If the reviewer is aware of any study that quantifies lake evaporation of the mega-lake system of the Qaidam basin (or a mega-lake in any other basin) during the Pliocene, I would be very happy to get knowledge about the results. There must definitely be such a negative feedback mechanism limiting lake growth, and it would be of utmost importance for reconstructing the evolution the mega-lake system to know more about the details. I have also mentioned in P8 L243-246 that regional water recycling could counteract this feedback, but the quantitative role of this process is also still unknown. Thus, I concluded that further studies are required on these topics.

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, which also comprises lake evaporation. Thanks to the comments of reviewer 1, 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. I will also change the terminology in the revised manuscript, such that the term water balance is only used when 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.

Changes: Text improved; terminology changed; formulas and symbols adopted.

In fact, when the lake continues to increase, lake evaporation increases and an equilibrium between input and output will be reached. Therefore, lake water level would not rise by 400 m over the basin within only 10 ka, even there is a positive long-term mean annual water balance.

Reply: See my comments above. Since lake evaporation is included in the water balance, a positive water balance would in fact result in an increase in terrestrial water storage (TWS) and subsequent recharge of the reservoirs including the lakes as stated in P8 L227-231. As proxy-based studies have shown, lake levels in the Qaidam basin have indeed shown drastic changes in the past during the Pleistocene glacial cycles. The interglacial periods have usually been shorter than the glacial periods, lasting for about 10 to 15 ka. So, the question arises how the mega-lake system could have been restored, at least partially, during such comparably short time periods. The findings of my study imply that lake restoration could take place within such short time periods without requiring drastic climatic changes, for which there is no evidence. I do not say that the sensitivity of the water balance of the Qaidam basin has been the same as today. But as Dowsett et al. (2010); cited in the manuscript, have stated that the paleogeographic situation of the mid-Pliocene epoch has been similar to the presence, this holds even more true for the Pleistocene, and definitely true for the near future. I am not aware of any study that has shown that the sensitivity of the water balance to changes in air temperature and humidity has been different than today. So far, this remains to be an unproven hypothesis. Therefore, I do not understand, why my approach, i.e., applying the physically based sensitivities as shown in Table 2 to estimates of the plausible range of changes in air temperature and precipitation during the mid-Pliocene as inferred from independent studies, both proxy-based and model results, should be scientifically wrong.

Changes: Text improved; feedbacks better discussed.

2. Line 166-174, as the author said, both lake area and lake number in the Qaidam basin have increased from the last two decades. The groundwater in the Qaidam basin was recharged between 2003 and 2012 due to changes in terrestrial water storage of 20.6 km3 at rate of 8 mm/a. These studies indicate that there should be considerable positive water balance during the last two decades in Qaidam basin, which contrasts with the main conclusion of the study, which shows the water balance of the basin is almost zero (Line 174).

Reply: I discussed that the results from GRACE satellite-based analyses are also showing that the hyperaridity of the low-lying regions of the Qaidam basin is misleading, when water balance of the entire basin including the high-altitude regions is to be assessed. For the same time period, the GRACE data show +8 mm/a while the HAR data set indicates 0 mm/a. Unfortunately, I could not find a specification of the error of the GRACE-based results in the publication of Jiao et al. (2015), but it is obvious that the error is in the order of at least ±10 mm/a. The uncertainty of the water balance as derived from the HAR data set is ±34 mm/a for the entire study period as specified in P4 L94. So, both results are not in contradiction. I also discussed further results from independent studies that clearly indicate that the water balance of the Qaidam basin has been positive during this period which showed warmer and less dry climate conditions. There is no study that is in contradiction to the results derived from the HAR data set for the recent time period.

Changes: Text improved; further references added.

3. L194-197: “the estimated changes in precipitation due to changes in air temperature would be 52 to 105 mm/a. The mean change in water balance as inferred from the changes in air temperature would lead to a positive mean annual water balance of 49 mm/a.” I cannot believe this derivation. The positive water balance is too big, because most of precipitation would be lost through evaporation in such a dry environment.

Reply: It is not a matter of belief but just the result of a computation using a) the present-day sensitivity of mean annual precipitation to changes in mean annual air temperature, and b) the present-day sensitivity of mean annual water balance to changes in mean annual precipitation, all quantities spatially averaged over the entire Qaidam basin, i.e., including the less dry and colder high-mountain regions. The starting point of this computation is the range of plausible changes in mean annual air temperature relative to the present-day situation, which has been taken from the literature, and is conservatively set to 1 to 2 K in my study. Applying a) gives 52 to 102 mm/a more presentation than today. This range of precipitation change is in accordance with the paleoclimate studies I have cited in the manuscript. Taking these values as input in b) leads to 42 to 84 mm/a higher values for the water balance than today. In absolute terms, i.e., taking the value of -14 mm/a as the current estimate, the water balance would be between +28 and + 70 mm/a, i.e., +49 mm/a on average. Please regard that any kind of evaporative water losses are in fact included in the sensitivity of b).

Changes: Text improved; sensitivity study better explained; feedbacks better discussed.

4. The main conclusion of the study is ‘near-future climates not much different from present conditions could cause rising lake levels and expanding lake areas, and may result in restoration of the Qaidam mega-lake system over geological time scales’ (line12-14). Although I am not a paleo-climatologist, I guess the formation of megalake system over geological time scales might have underwent special climate conditions (e.g. different scales of lake-air interaction, different land cover condition), and this speculation is quite uncertain. Even current climate yields positive mass balance, this positive balance would be lost soon due to the increase of lake evaporation when lake expands.
Reply: As discussed above, my study results are neither a reconstruction of the water balance of the mid-Pliocene nor a projection of the future water balance. I only conclude that there is no need for drastic climatic or environmental changes to explain the existence of a mega-lake system in the Qaidam basin. Using the results from the scientific literature that I have referenced in the manuscript, there is proven evidence that the mega-lake system has actually existed in the Pliocene. So, there must have been a physical mechanism that has allowed the mega-lake system to sustain such a large lake surface (about 120.000 km²) for long time without losing more water by lake evaporation and evapotranspiration over land than gaining by precipitation. The feedback mechanism that limits lake growth has been prominently mentioned in the conclusions part of my manuscript to make clear that the positive water balance will not be able to persist over unlimited time, and finally must reach an equilibrium. However, I stated that we do not yet have enough knowledge on this mechanism to use it for quantifying the effect, which would be prerequisite for any attempt to reconstruct the paleo-lake evolution in the Qaidam basin.
Changes: Text improved; further references added; text parts shifted from the Conclusions to the Discussion section.

Replies to Reviewer 3

The paper provides a nice straightforward estimation of the regional water balance of the Qaidam basin. It is interesting to observe that the water balance calculations confirm that the balance is near zero. It implies that although parts of the basin has hyper arid conditions, there is apparently a zero balance. This as such answers the question: can a lake exist for prolonged periods in this basin under arid conditions.
Reply: This is exactly the main focus of the study. I will need to make this much better visible than in the current version of the manuscript.
Changes: Text improved.

I am struggling with the way this is framed. We have no future time series so we can only speculate what will happen in the future. It is interesting that the current trends of climate change seems to lead to a positive water balance. The problem I have is that this does not automatically imply that the lake level will rise.
Reply: Any kind of projection, e.g. the climate projections used by the IPCC or studies of future changes of the Asian monsoon system, would then be purely speculative. As the formulations in the first paragraph of the Conclusions section (lines 223-231)

clearly indicates, I don’t make any predictions but only refer to the consequences of a slightly positive water balance. All sentences are written as conditional statements, which means that I am fully aware that we don’t know how the situation of the basin’s water balance will develop in the future. If the long-term mean water balance of the Qaidam basin would be positive, then (and only then) the consequence would be that reservoirs would start to restore. I described this in the first paragraph, and I also stated that the first response would be that the groundwater reservoirs would be recharged, and then the lakes would also start to restore, which seems to be happening already now (see literature review in lines 162-174).

Changes: Text improved; further references added.

I think the claim of a tipping point (line 15) is not substantiated, it could be a threshold but a tipping point suggest a complete new system equilibrium. This can not be predicted with linear regressions based on the current system dynamics.

Reply: That is correct; I will use the term “threshold” in a revised version of the manuscript.

Changes: Term “tipping point” replaced by “threshold”.

The link with the Mega Lake is also unclear. No information of its extent, depth etc is given. The existence of such a lake would invalidate many of the assumptions now made to calculate the water balance.

Reply: There is no spatially explicit information on the mega-lake system existing from the literature. But the geological evidence of its existence is referenced in the manuscript. The intention of the manuscript is not to reconstruct the mid-Pleistocene conditions of the mega-lake system but only to find a physical explanation for the existence of such a mega-lake system. The main answer is that the high-mountain parts of the Qaidam basin could have acted as regional water towers under slightly wetter and warmer climates that prevailed during the mid-Pliocene epoch (as indicated by the literature referenced in my study) such that the long-term water balance would not have been negative. In an (unknown) equilibrium state, water balance would have been zero, and positive during time periods when the mega-lake system would have been restored after periods of lake shrinkage, which have occurred several times in geological history.

Changes: Text improved.

Please discuss possible feedbacks in the studied system. You now seem to assume they dot not exist, which I consider unlikely.

Reply: In the last paragraph of the Conclusions section (lines 241-246) I discussed feedbacks that need to be addressed in future studies. I mentioned the most important negative feedback, i.e., increasing lake evaporation, that would finally lead to zero water balance even when precipitation would be higher than today due to changes in atmospheric circulation. There must be an upper, yet unknown limit for lake growth, which is, however, not subject of this study. I will make this point even more explicit in a revised version of the manuscript. I also mentioned the feedback that local recycling of water could be intensified when lake surface increases. Higher lake evaporation could potentially result in more precipitation within the boundaries of the Qaidam basin, which is large enough to support local recycling. This is, however, not yet quantifiable. I also discussed feedbacks due to orographic changes (see replies below), which would be relevant for the mid-Pliocene epoch but not for the next hundred thousand years.

Changes: Text improved; feedbacks better discussed.

Minor comments:

Line 7: the phrase increasingly arid climates is confusing given the fact that the analysis is not suitable to deal with large long term climate changes.

Reply: This sentence in the abstract is referring to the scientific literature that forms the motivation and background of my study. As it is part of the abstract, no references to scientific studies are given there. This is done in the Introduction section.

Changes: None.

Line 14: the restoration of the mage-lake is very speculative given the fact that the calculations are based on 14 years of data. Such a restoration would need ten thousands of years.

Reply: See my replies above. I don't speculate on the future development of the basin but only describe what would happen if long-term mean water balance would become positive, which is a realistic scenario as my study reveals. My study shows that this could happen (or may even have already started to happen) under subtle changes in the regional atmospheric circulation. Using the results from my study, I made an example calculation (lines 223-231) to illustrate that even a slightly positive, physically realistic water balance would have a huge cumulative effect over ten thousand years. This is, of course, not a prediction since no feedbacks are considered in the example calculation, and future changes in atmospheric circulation are not known!

Changes: Text improved.

Line 24: the disappearance of the lake during the last 100 ka is intriguing. What was different?

Reply: This is a very interesting question but not part of my study. The disappearance of the mega-lake system is described in the scientific literature. However, the details of the lake and climate conditions are not well constrained by observational data. I would regard to find an answer to this question as a highly ambitious but valuable goal for future research. My study reveals that climates colder and drier than today would probably drop the water balance due to reduction in precipitation. Although the mega-lake system disappeared there are nevertheless substantial variations in lake levels during this period. Such lake-level variations have been reported even for the Holocene, showing that the remaining lakes are highly sensitive to small changes in climate conditions, as revealed in my study for present-day geographic conditions.

Changes: Text improved.

Line 30-40: please provide units and support (10*10 km for example)

Reply: I will need to reformulate the manuscript regarding the terms "net precipitation" and "water balance", as already mentioned in my replies to the other reviewers. The term "water balance shall only be used when net precipitation is integrated over the entire basin. I will add suitable references as support. However, I don't understand, in which context units are missing.

Changes: Text improved; terminology changed; formulas and symbols adopted; information on units added.

Line 45-50: please formulate a concrete testable hypothesis. I propose that within the Qiadam basin the water balance is near zero.

Reply: In fact, this was not the starting point of my study. I didn't expect a near-zero water balance. Moreover, the original hypothesis was that increasing air temperatures would make the water balance less negative under present-day conditions. The results of my study showed that this is indeed happening, but the statistical analysis showed that not air temperate but specific humidity and the combined effect of air temperature and specific humidity are driving annual water balance variations. I will explicitly formulate this in a revised version of the manuscript.

Changes: Text improved; hypotheses explicitly formulated.

Line 74: what are valid data? How is this supported by evidence?

Reply: The expression "valid data" refers to the fact that meteorological data are existing for the time period and are not flagged as invalid by the data provider.

Changes: Text improved.

Line 82-84: is there possibly spatial autocorrelation in your analysis?

Reply: The results presented in Figure 4 are spatially averaged pairs of annual values for the entire Qaidam basin, thus there are no problems with spatial autocorrelation.

Changes: None.

Line 103: are you implying that there are feedbacks in the system? If this is the case, it implies that you should be very carful to use your regression relationship outside current conditions.

Reply: There are definitely feedbacks in the system when paleographic or future geographic conditions (especially total lake surface) would change. For this reason, I always use the term "sensitivity" and refer to the present-day geographic conditions. All statements referring to the mid-Pleistocene epoch or to the future are thus conditional, indicating that they are only simplified projections, and shall in no way be regarded as predictions.

Changes: Text improved; feedbacks better discussed.

Line 120: an important conclusion. Please emphasize this more in abstract and conclusions

Reply: I will consider this in a revised version of the manuscript.

Changes: Text improved.

Line 134: same as above important insight in current system

Reply: I will consider this in a revised version of the manuscript.

Changes: Text improved.

Line 174: how sensitive is your study for spatial resolution?

Reply: Interestingly and surprisingly, the results did not substantially differ between the 30 km and 10 km gridded HAR data (see lines 218-221 and the results presented in the supplement). As long as major features of the orography of the Qaidam basin are present in the dynamical downscaling runs, and thus, the mesoscale atmospheric processes induced by orography are resolved by the model, then the results are similar. I will add more details on this topic in a revised version of the manuscript (see also my reply below).

Changes: Text improved; HAR 30 km results better explained.

Line 197: how long would it take to fill up the whole mage-lake (with this rate of 49 mm/a).

Reply: I have made an example calculation using 40 mm/a as long-term mean value for the water balance (see lines 227-231). Since no feedbacks are included and no differentiation between the reservoirs (groundwater, lakes, …) has been made, the result (400 m rise of the water table in any of the reservoirs averaged over the entire basin within ten thousand years) is only illustrating that huge lakes could form within a geologically short time period. This calculation serves to show that ‘rapid’ (time scales of thousands to hundred thousand years) lake-level changes as reported in the scientific literature are not physically unfeasible. Since there is no spatially explicit information on area, depth or volume of the mega-lake system available from the literature, a spatially explicit computation would be impossible, even when feedbacks would be included (making the water balance time dependent).

Changes: Text improved.

Line 238: how important can the orographic precipitation be? You now assume this not to happen. Ad how does the presence of a big lake affect this effect?

Reply: My study shows that orographic precipitation is one of the most important processes with respect to basin-wide water balance. As Figure 3 shows and is discussed in the manuscript (see e.g. lines 111-115), precipitation increases with altitude, which is a direct consequence of orographic precipitation. It is not altitude itself but relief that induces precipitation in the mountain ranges. The results of my study only show the sensitivity of water-balance components to variations of climate conditions under present-day geographic conditions. A changed orography and the existence of a mega-lake system would induce additional feedbacks (as discussed in my manuscript; see my replies above). This could also affect orographic precipitation. The effect of lower altitudes is partly captured by the HAR 30 km data set, since highest altitudes in the 30 km gridded topography are lower by a few hundred meters than in the HAR 10 km data set (see lines 220-221). This has two counteracting effects as discussed in the manuscript (see lines 210-221): precipitation would tend to decrease since orographic precipitation would possibly be weakened, but blocking of atmospheric water transport to the Qaidam basin by high mountain ranges would also be reduced. The latter effect seems to be stronger than the first one, since mean water balance of the Qaidam basin is +3 mm/a in the HAR 30 km data set while it amounts to -14 mm/a in the HAR 10 km data set.

Changes: Text improved; HAR 30 km results better explained.

Survival of the Qaidam Mega-Lake System under Mid-Pliocene Climates and its Restoration under Future Climates

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Abstract. The Qaidam ~~b~~Basin in the north of the Tibetan Plateau~~,~~ has undergone drastic environmental changes during the last millions of years. During the Pliocene, the Qaidam ~~b~~Basin contained a freshwater mega-lake system although the surrounding regions showed increasingly arid climates. With the onset of the Pleistocene glaciations, lakes began to shrink, and finally disappeared almost completely. Today, hyperarid climate conditions prevail in the low-altitude parts of the ~~b~~Qaidam Basi~~asi~~n. The question, how the mega-lake system was able to withstand the regional trend of aridification for millions of years, remained enigmatic, so far. This study reveals that the mean annual water balance, i.e., the mean annual change in terrestrial water storage ~~of~~in the Qaidam B~~b~~asin, is nearly zero under present climate conditions due to positive values of net precipitation in the high mountain ranges, and shows positive annual values during warmer, less dry years. This finding provides a physically based explanation, how mid-Pliocene climates could have sustained the mega-lake system, and that near-future climates not much different from present conditions could cause water storage in reservoirs, rising lake levels and expanding lake areas, and may even result in restoration of the ~~Qaidam~~ mega-lake system over geological time scales. The study reveals that a region discussed as being an analogue to Mars due to its hyperarid environments is at a t~~ipping~~hreshold ~~point~~ under present climate conditions, and may switch from negative values of long-term mean annual ~~values~~water balance that have prevailed during the last 2.6 million years to positive ones in the near future.

1 Introduction

Paleogeographic studies (Chen and Bowler, 1986; Huang et al, 1993; Mischke et al., 2010; Wang et al., 2012, Fang et al., 2016) on the intermontane endorheic Qaidam B~~b~~asin (QB), located in China's desert region in the north of the Tibetan Plateau (TP), revealed that it once contained a ~~freshwater~~ mega-lake system~~ of ca. 120,000 km^2 lake surface~~ during the mid-Pliocene (ca. 3.3-3.0 Ma BP) and before. Although spatial details of the mega-lake system are not known, Chen and Bowler (1986) have reported that total lake surface was about 59.000 km^2 during the early Pleistocene. The onset of the Pleistocene glaciations at ca. 2.6 Ma BP marked a period of increased variability of climate, lake level and extent, as well as changes in salinity (Huang et al, 1993; Wang et al., 2012; An et al., 2001; Heermance et al., 2013, Fang et al., 2016). The mega-lake system finally disappeared during the last 100 ka (Madsen et al., 2014; Yu et al., 2019). Today, only few saline lakes and playas exist, and the low-altitude parts of the QB~~basin~~ are hyper-arid deserts (Chen and Bowler, 1986; Huang et al, 1993; Wang et al., 2012).

Paleoclimate studies (e.g. An et al., 2001; Fang et al., 2007, 2016; Miao et al., 2013; Koutsodendris et al., 2019) could prove that climates in the region have become increasingly dry throughout the Pliocene. However, the existence of a mega-lake system during this period implies that long-term mean annual water balance ~~ΔS~~ΔS, i.e., the total ~~c~~annual change in terrestrial water storage within the basin's reservoirs (aquifers, soils, lakes, rivers, permafrost, snow covers, glaciers, etc.), was zero or even positive, and did not show, on average, negative values over time periods of thousands of years or longer, because otherwise, the mega-lake system would have temporarily dried out and produced layers of evaporites.

The water balance equation of a drainage basin ~~is~~can be written ~~given by~~as

$$\Delta S = P - ET - R \qquad (1)$$

~~$\Delta S = P - ET + \Delta Q_{sfc} + \Delta Q_{sub}$, (1)~~

where P ~~P~~ is precipitation and~~,~~ ~~ET~~ ET is actual evapotranspiration, both quantities spatially averaged over the area of the drainage basin. ~~, while~~Total runoff is indicated by R ~~ΔQ_{sfc} and ΔQ_{gw} are~~ , which is the sum of surface and groundwater runoff~~net influx of surface and ground water into~~ leaving the drainage basin~~.~~. In this study, all quantities in Eq. (1) are expressed as volume water equivalent per area and time interval (in mm/month or mm/a).

For endorheic basins like the QB surface runoff~~ΔQ_{sfc}~~ is zero by definition. Groundwater entering or leaving a basin is generally difficult to quantify but can be neglected for the water balance of large intermontane basins like the Q~~aidam b~~B~~asin~~, which ~~extends over~~has an area of ca. 254,000 km^2. Thus, the change in terrestrial water storage ΔS~~ΔS~~ of the Q~~aidam b~~B~~asin~~ can be approximated by

$$\Delta S = P - ET \qquad (2)$$

~~$\Delta S = P - ET$. (2)~~

The term ~~$P - ET$~~$P - ET$ is, as in this study, ~~als~~often referred to as net precipitation (Morrow et al., 2011), and sometimes called~~,~~ effective precipitation (Pritchard et al., 2019)~~,~~ or water availability (Greve et al., 2018)~~, which is particularly relevant for studies of river basins where ΔQ_{sfc} is generally negative, and thus $P - ET$ is not equal to the water balance~~. In this study, ΔS is called water balance and refers to the spatial average of net precipitation over the total area of the QB by applying Eq. (2).

This study addresses the research question how mean annual water ~~balance~~balance in the Q~~aidam b~~B~~asin~~ could have been zero or even positive over millions of years under very dry climates such that a mega-lake system could have been sustained. I hypothesise that the high mountain ranges in the Q~~aidam b~~B~~asin~~ receive sufficient precipitation such that negative values of net precipitation at lower altitudes due to very low amounts of precipitation ~~at lower altitudes and water losses by actual evapotranspiration~~ are compensated by positive values of net precipitation at high altitudes~~when both physical quantities are spatially averaged over the basin's entire area~~. A second hypothesis that is tested in this study is that annual ΔS of the QB is positively sensitive to warmer climates, i.e., that positive anomalies in spatially averaged annual air temperature T cause positive anomalies in annual ΔS under present geographic conditions. Knowing the value of the sensitivity $\frac{\partial \Delta S}{\partial T}$ of annual ΔS to changes in annual T would allow for a first-order estimate of the water balance under different climates like those in the mid-Pliocene or the future. This approach follows the general idea underlying studies that have linked climates of the past with those projected for the near future using the concept of climate sensitivity (e.g. Chandar and Peltier, 2018).

~~-~~This study does, however, n~~o~~either intend to reconstruct the climates or the hydrology of the past nor to make predictions for the future. So far, paleogeographic data like paleo-altitudes or paleo-hydrographic conditions of the QB, or past large-scale atmospheric circulation patterns in High Mountain Asia are not well constrained by observational data, making it difficult to use them as input in spatially detailed hydrological models. It is also not yet possible to quantify feedbacks in the hydrological cycle of the QB like an increase of ET due to increased lake area, changes in blocking of air masses under different orography, or changes in water recycling within the QB under more humid atmospheric conditions. ~~–~~Moreover, a physically based explanation for the proven long-term existence of the mega-lake system in the QB under dry climate conditions is sought. Since the mid-Pliocene is often regarded as past analogue for modern climate changes (Zubakov and Borzenkova, 1988; Haywood et al., 2016; Chandar and Peltier, 2018), this study also intends to provide a rational basis for assessing environmental changes that might be caused by climate changes as projected in this region for the future (Burke et al., 2018; Gu et al., 2018; Hui et al., 2018).

2 Data and methods

Fig. 1 provides an overview on the Q~~aidam~~B~~basin~~ and its surrounding regions in the north of the TP. The boundary of the Q~~aidam~~B~~basin~~ was delineated by Lehner and Grill (2013) from a digital elevation model (DEM) derived from data of the Shuttle Radar Topography Mission (SRTM).

2.1 Meteorological data from the High Asia Refined analysis (HAR)

Meteorological data for 14 hydrological years (2001-2014) covering the period from 10/2000 to 09/2014 were taken from the first version ~~(V1)~~ of the High Asia Refined analysis (HAR) data set (Maussion et al., 2011~~;~~, 2014)~~ for the model domain of 10 km grid spacing~~. In ~~High Asia~~the study region, hydrological years start in October, and are numbered by the calendar year to which January belongs (i.e., the hydrological year 2001 starts in October 2000). The HAR ~~V1~~ data set was produced by dynamical downscaling of global gridded atmospheric data of the National Centers for Environmental Prediction (NCEP) Operational Model Global Tropospheric Analyses (FNL) with the Weather Research and Forecasting (WRF) model version 3.3.1 to two regional domains of 30 km and 10 km grid spacing as described by Maussion et al. (2011, 2014)~~ and 20~~. In contrast to regional climate simulations, the WRF model is re-initialised every day, and integrated only over 36 hours. Data of the first twelve hours are discarded to avoid artefacts eventually caused by model spin-up. The resulting data covering a full day are thus strongly constrained by the observed large-scale state of the atmosphere. Temporal resolution of the HAR ~~V1~~ 10 km data set is one hour (three hours for the HAR 30 km data set). HAR ~~V1~~ data used in this study were aggregated to monthly values.

Monthly data for air temperature T ~~T~~ (2 m above ground) and specific humidity q ~~q~~ (2 m above ground), which are called climate drivers in this study, are monthly means, while monthly data of ~~P~~ P, which comprises both rainfall P_{rain} ~~P_{rain}~~ and snowfall P_{snow} ~~P_{snow}~~, and of ET ~~ET~~ are monthly sums. Monthly values for ΔS ~~ΔS~~ were computed from monthly values of ~~P~~ P and ~~ET~~ ET spatially averaged over the QB by applying Eq. (2). Data were further aggregated to annual means and sums for each hydrological year, and to mean monthly and annual values for the 14-year study period, both for each of the 2543 grid points of the HAR ~~V1~~ 10 km data set (280 grid points in the HAR 30 km data set) and the spatial averages over the QB. ~~Data were also spatially averaged for the entire Qaidam basin (2543 grid points in the HAR V1 10 km domain).~~

2.2 Meteorological data from the Global Summary of the Day

The National Centers for Environmental Information (formerly known as National Climatic Data Center) of the National Oceanic and Atmospheric Administration (NOAA) provide the Global Summary of the Day (GSOD), which is a collection of meteorological data from numerous weather stations all over the world. Eight GSOD stations providing meteorological ~~valid~~ data for the entire study period are located within or nearby the Q~~aidam basin~~B as shown in Fig. 1. Only GSOD data that are not flagged as invalid were used in this study.

2.3 Data on actual evapotranspiration

A data set of annual ~~ET~~ ET values for the Q~~aidam basin~~B and eight hydrological subregions covering the time period from 2001 to 2011 (Jin et al., 2013) was used in this study for assessing the results based on the HAR ~~V1~~ 10 km data set. The data set was derived from various data sources, especially from space-borne remote sensing data from the Moderate Resolution Imaging Spectroradiometer MODIS, by applying the Surface Energy Balance System (SEBS) algorithm (Su, 2002).

2.4 Statistics

Regression analyses as performed in this study are simple linear regressions and one multiple linear regression using the ordinary least squares method. Simple linear regressions, in which altitude h ~~h~~ was used to as predictor variable x ~~x~~, were performed both by using $x = h$ ~~$x = h$~~ directly (in m a.s.l.), and by $x = e^{h^*}$ ~~$x = e^{h^*}$~~, where $h^* = \frac{h}{h_{scl}}$ ~~$h^* = h/h_{scl}$~~ (~~h_{scl}~~ h_{scl} = 1000 m). The respective result with the highest effect size is ~~shown in each panel of Fig. 3~~ used in this study. Probability values p ~~p~~ for significance testing of the regression results were computed from double-sided ~~t~~ t-tests. Statistically significant results are assumed for p ~~p~~ < 0.05. The effect size of the regressions is specified by the coefficient of determination r^2 ~~r^2~~, which is the fraction of variance in the dependent variable y ~~y~~ that is explained by the linear model of the predictor variable(s) x ~~x~~. The effect size is further specified by the adjusted r^2 ~~r^2~~ (r_{adj}^2 ~~r^2_{adj}~~):

$$r_{adj}^2 = 1 - (1 - r^2)\frac{N-1}{N-k-1}$$

~~$r^2_{adj} = 1 - (1-r^2)\cdot(N-1)/(N-k-1)$,~~

–Eq. (3)

w~~W~~here N ~~N~~ is the number of observations (i.e., years; N ~~N~~ $= 14$), while k ~~k~~ is the number of predictor variables.

3 Results

In the following subsections, the study results are presented. First, annual values of the water balance of the QB are shown for the 14 years. Then, altitude dependencies of each quantity are presented for each grid point of the HAR 10 km data set within the QB. Finally, the results of a sensitivity study relating the water balance components with the climate conditions are shown.

3.1 Water balance

Table 1 lists mean monthly and annual values for the water balance components and the~~ir~~ climate drivers, while Fig. 2 presents time series of the annual values of ~~P~~ P, ~~ET~~ ET, and ~~ΔS~~ ΔS for the 14 years covered by this study. The results show that the Q~~aidam basin~~B's water balance is nearly zero (ΔS ~~ΔS~~ = -14±34 mm/a) under present climate conditions. From 2005 to 2012, all years except 2011 show above-average annual values for the water balance due to increased annual precipitation. Rainfall is the main driver of interannual variability of both precipitation and water balance, while snowfall and actual evapotranspiration are less variable. The first year (2001) was the one with the by far most negative water balance (~~ΔS~~ ΔS = -94 mm/a), and was also the coldest (T ~~T~~ = -1.6 °C) and driest (q ~~q~~ = 2.2 g/kg) year, and received the lowest amount of precipitation (~~P~~ P = 122 mm/a), rainfall (P_{rain} ~~P_{rain}~~ = 45 mm/a), and snowfall (P_{snow} ~~P_{snow}~~ = 77 mm/a) (see Tables S1-S7 in the Supplement for monthly and annual values for each quantity and year).

Mean monthly values for the quantities shown in Table 1 illustrate strong differences in their seasonality. While T ~~T~~, q ~~q~~, P ~~P~~, P_{rain} ~~P_{rain}~~, P_{snow} ~~P_{snow}~~, and to a lesser extend also ~~ET~~ ET, show strong variations over the year with slightly displaced winter minima and summer maxima, ~~ΔS~~ ΔS is less variable during the course of the year. This indicates complex interdependencies between the climate drivers ~~air temperature and specific humidity of~~and the water balance components, which lead to partial compensatory effects. Concurrence of the summer maxima of air temperature and precipitation in July leads to a shift of the maximum of snowfall to May, since higher air temperatures during summer reduce the fraction of precipitation falling as snow. The cold months are connected with slightly negative monthly water balance due to sublimation of snow exceeding snowfall. The concurrently higher values of precipitation and actual evapotranspiration during summer mostly compensate each other such that monthly water balance is only slightly positive during early summer. In August monthly water balance even shows small water losses since precipitation decreases faster than actual evapotranspiration.

3.2 Altitude dependencies

Altitude dependencies of the annual water balance components and the~~ir~~ climate drivers are presented in Fig. 3. While T ~~T~~, P ~~P~~, P_{snow} ~~P_{snow}~~, and $P - ET$ ~~ΔS~~ show strong correlations with altitude h ~~h~~ within the Q~~aidam basin~~B, ~~ET~~ ET is only weekly correlated with h ~~h~~, and q ~~q~~ is not dependent on h ~~h~~. At altitudes of 4000 m a.s.l. and higher, ~~water balance~~net precipitation becomes positive on average, and none of the HAR ~~V1~~ 10 km grid points shows negative values above 4700 m a.s.l., which demonstrates the importance of high mountains as water towers (Xu et al., 2008) for the hydrology of the ~~a basin~~QB, especially under arid climates like those in the desert zones of High Mountain Asia.

Fig. 3 illustrates that the air over the lakes (ten grid points in the HAR ~~V1~~ 10 km data set) is generally warmer and less dry than over land, which is the result of high actual evapotranspiration due to lake evaporation. Although there are a few low-lying areas with very high actual evapotranspiration, the majority of land areas shows increasing actual evapotranspiration with altitude, while air temperature strongly decreases with altitude (following the mean annual moist-adiabatic lapse rate). This indicates that abundance of water but not available energy for latent heat is the main limiting factor for actual evapotranspiration in the Q~~aidam basin~~B. In fact, the areas showing high actual evapotranspiration are mainly saline lakes that are not indicated as lakes in the HAR ~~V1~~ 10 km data set, such that water is available for actual evapotranspiration. Lakes tend to suppress rain- and snowfall such that their annual values are markedly lower over lakes. In consequence, most lakes (seven of ten grid points) show strongly negative net precipitation~~water balance~~. Further details and maps of the spatial patterns of the water balance components and the~~ir~~ climate drivers are presented in Fig. S1 to S7 in the Supplement.

3.3 Sensitivity study

Fig. 4 presents results of simple linear regression analyses between annual values of the spatially averaged quantities for the entire Q~~aidam basin~~B for the 14 hydrological years, which reveal that annual variability of water balance is driven by precipitation but not by actual evapotranspiration. Both precipitation and water balance are themselves driven by air temperature and specific humidity, the latter showing much stronger effect sizes in the simple linear regressions.

Since annual air temperature and specific humidity are themselves correlated (r^2 ~~r^2~~ = 0.571; r^2_{adj} = ~~r^2_{adj} =~~ 0.535; p ~~p~~ < 0.01; see Fig.~~ure~~ S8 in the Supplement), the problem of multicollinearity of the two climate drivers was addressed in this study by an additional multiple linear regression, in which both annual T ~~T~~ and q ~~q~~ serve as predictor variables, while annual ΔS ~~ΔS~~ is taken as the dependent variable. Both predictors together explain more than 85 % of the variance in annual ~~ΔS~~ΔS (~~r^2~~r^2 = 0.852; r^2_{adj} ~~r^2_{adj}~~ = 0.825; p ~~p~~ < 0.001). However, the analysis revealed that the unique contribution of annual air temperature to the variance in the annual water balance is not significant. Air temperature alone uniquely explains only 0.25 % (p_T ~~p_T~~ = 0.67) of the variance in water balance, while the unique variance explanation by specific humidity is 31.96 % (p_q ~~p_q~~ < 0.001). The combined effect of air temperature and specific humidity explains 52.97 %. Thus, the simple linear regression between specific humidity and water balance as shown in Fig. ~~3~~4 (lower right panel) account~~ain~~s for both ~~the~~ direct and indirect effects of variations in annual specific humidity on annual water balance of the QB.

The results show that a change in ~~mean~~ annual specific humidity of 1.0 g/kg would lead to an estimated change in ~~mean~~ annual water balance of 131 mm/a. Since the standard error of the estimate for annual water balance is 14.0 mm/a, even a slight change in ~~mean~~ annual specific humidity of e.g. 0.2 g/kg would have a strong, significant effect such that ~~the~~ annual water balance of the Q~~aidam basin~~B would become positive.

4 Discussion

4.1 Errors and uncertainties

Physical consistency of the results obtained from the HAR ~~V1~~ data set is ensured by the fact that the WRF model is physically based, and HAR ~~V1~~ data have been comprehensively analysed, particularly with respect to precipitation and atmospheric water transport (~~Pritchard et al., 2019;~~ Maussion et al., 2011, 2014; Curio et al., 2015; Pritchard et al., 2019; Yoon et al., 2019). HAR ~~V1~~ data have been successfully utilised for e.g. studying glacier mass balance on the T~~ibetan~~ P~~lateau~~ (Mölg et al., 2014), in which independent data sets from global reanalysis data and field measurements have also been included to ensure validity of the results. Pritchard et al. (2019) showed for the upper Indus basin that the HAR ~~V1~~ 10 km data set is particularly applicable in studies on water availability.

Since the HAR ~~V1~~ data set, as any data set, comes with errors and uncertainties, the question arises how they would influence the results of the study. Fig. 3 illustrates that at six of the eight GSOD stations within or nearby the Q~~aidam basin~~B the HAR 10 km ~~V1~~ precipitation data are well according to the measurements, while ~~at two GSOD stations~~ precipitation might be slightly underestimated at two GSOD stations by the HAR 10 km ~~V1~~ data. The altitudinal changes of both air temperature and precipitation as documented by the GSOD data are well captured by the HAR 10 km. A comparison of HAR ~~V1~~ 10 km results for actual evapotranspiration with those from the SEBS-based study by Jin et al. (2013) indicates higher actual evapotranspiration in the HAR 10 km ~~V1~~ data. During the calendar years from 2005 to 2011, mean annual actual evapotranspiration is 218 mm/a in the HAR 10 km ~~V1~~ data, while SEBS data show 153 mm/a. Both annual time series are well correlated during this time period (r^2 ~~r^2~~ = 0.733; r^2_{adj} ~~r^2_{adj}~~ = 0.679; p ~~p~~ < 0.05; see Fig. S9 and Table S8 in the Supplement). SEBS shows inconsistent, even lower actual evapotranspiration values during the calendar years 2001 to 2004 (HAR ~~V~~10 km: ~~ET~~ ET = 202 mm/a; SEBS: ~~ET~~ ET = 77 mm/a; see Table S8 in the Supplement). These findings reveal that there is no evidence that the HAR ~~V1~~10 km data set would overestimate ~~the~~annual water balance of the Q~~aidam basin~~B. On the contrary, if SEBS values for annual actual evapotranspiration would be considered to be more accurate than HAR ~~V~~10 km data, then annual water balance would have been positive throughout all years.

4.2 Comparison with other studies

The results of this study are in ~~line~~accordance with results from other studies. A number of studies (Liu and Chen, 2000; Kang et al., 2010; Li et al., 2010; Zhang et al., 2013b) revealed that the TP experiences general, but spatially and temporally varying trends to higher air temperatures, increasing humidity, and precipitation, which are also found in the Q~~aidam basin~~B (Whang et al., 2014). The regions in the Qinghai province, to which the Q~~aidam basin~~B belongs, show trends to warmer and wetter climates while those regions belonging to Tibet tend to warmer but dryer climates (Zhang et al., 2013b).

Several studies (Zhang et al., 2011; Zhang et al., 2013a; Lei et al., 2014; Zhang et al., 2017; Li et al., 2019) reported on rising lake levels and expanding lake areas on the TP. Besides enhanced glacier melt, increasing precipitation is regarded as main driver of rising lake levels (Zhang et al., 2013a; Lei et al., 2014; Zhang et al., 2017). The total lake area in the Q~~aidam basin~~B has increased from 994 km^2 in the 1960s to 1046 km^2 in 2014 (Wan et al., 2016), and the number of lakes has increased (Li et al., 2019) by 18 from 1977 to 2015.

~~-~~Increased terrestrial water storage in the Q~~aidam basin~~B does not only affect lakes but also groundwater reservoirs. Jiao et al. (2015) showed for the Q~~aidam basin~~B that aquifers were recharged between 2003 and 2012 due to changes in terrestrial water storage of 20.6~~-~~ km^3, which is equivalent to a slightly positive mean annual water balance of 8 mm/a during this time period, while the mean value from the HAR ~~V1~~ 10 km data set for the ~~corre~~s~~ponding~~ame time period is only slightly lower and amounts to 0 mm/a. This result is also confirmed by the study of Loomis et al. (2019) who show zero to slightly positive mass trends in the northern TP.

4.3 Implications for the mid-Pliocene and the future

During the mid-Pliocene, climates have been generally warmer and less dry (or wetter) than today in many regions of the world (Haywood et al., 2013, 2016). The studies of Zhang et al. (2013c) and Mutz et al. (2018) provide quantitative estimates of mid-Pliocene changes in mean annual air temperature and precipitation with respect to preindustrial climates from various global paleoclimate simulations. The study of Zhang et al. (2013c) is based on a multi-model ensemble, which showed approx. 2 to 4 K higher mean annual air temperature in the Q~~aidam basin~~B during the mid-Pliocene as inferred from their Fig.~~-~~ 6. The same Fig. 6 indicates 100 to 300 mm/a higher values for mean annual precipitation. The study of Mutz et al. (2018) is based on simulations by a single global model, showing 2 to 6 K higher mean annual air temperature in the high mountains, while it was approx. 2 to 4 K cooler in the lower parts of the Q~~aidam basin~~B as inferred from their Fig. 4. Mean annual precipitation was approx. 100 to 300~~-~~ mm/a higher as shown in the same Fig. 4. Both studies did not present data on differences between preindustrial and present times. Nevertheless, the values for mean annual air temperature and precipitation as presented by Fig. 4 in Mutz et al. (2018) are generally comparable to those from the HAR ~~V1~~ 10 km data set. Thus, present mean annual air temperature is assumed to be slightly higher (about 1 K) than during preindustrial times, such that changes in air temperature between the mid-Pliocene and present times are slightly lower but still positive (at least 1 K higher than today). Analogously, changes in precipitation are assumed to follow the same pattern (at least 50 mm/a higher than today).

Table 2 presents estimates for mean annual changes in the water balance of the Q~~aidam basin~~B due to climate changes with respect to present conditions. The first three rows (marked in red) indicate changes ~~in q~~Δq, ~~P~~ ΔP, and $\Delta(\Delta S)$~~$\Delta S = P - ET$~~ for estimates of minimum and maximum changes of annual air temperature ΔT ~~in T~~. As conservative estimates, ~~the~~ minimum and maximum changes in annual air temperature were set to 1 ~~K~~ and 2 K, respectively, which can be used as estimates for the air temperature range representing both mid-Pliocene climates and those projected for the end of the 21st century (Burke et al., 2018; Gu et al., 2018; Hui et al., 2018). Applying the results from the simple linear regressions (Fig. ~~Table 2~~4) providing estimates for the sensitivities $\frac{\partial q}{\partial T}$, $\frac{\partial P}{\partial T}$, and $\frac{\partial \Delta S}{\partial T}$~~-~~, the estimated changes in annual precipitation due to changes in annual air temperature would be 52 to 105 mm/a, which are compatible with the values modelled for the mid-Pliocene by Zhang et al.

(2013c) and by Mutz et al. (2018). The ~~mean~~estimated change in annual water balance as inferred from the changes in mean annual air temperature would lead to a positive mean annual water balance of 49 mm/a.

Based on the same estimates for changes in annual air temperature and the sensitivity of annual specific humidity to changes in annual air temperature, the resulting changes in annual specific humidity would be between 0.3 and 0.6 g/kg.

Applying the sensitivities of annual precipitation $\frac{\partial P}{\partial q}$ and water balance $\frac{\partial \Delta S}{\partial q}$ with respect to changes in annual specific humidity (fourth and fifth row in Table 2; marked in blue), the resulting changes in annual precipitation and water balance would be almost identical (values differ only by 3 mm/a or less) to those directly estimated from the changes in annual air temperature. The sixth row of Table 2 (marked in black) shows the results for changes in annual water balance $\Delta(\Delta S)$ for given changes in annual precipitation ΔP. ~~The m~~Minimum and maximum values for the changes in annual precipitation (50 to 100 mm/a) are conservative estimates but also compatible with the studies of Zhang et al. (2013c) and Mutz et al. (2018). The mean change in annual water balance as inferred from the changes in annual precipitation by applying the sensitivity of annual water balance to changes in annual precipitation $\frac{\partial \Delta S}{\partial P}$ would lead to a positive mean annual water balance of 40 mm/a.

Warmer and less dry conditions in the Q~~aidam basin~~B are also confirmed from geological evidence (Miao et al., 2013; Wu et al., 2011; Cai et al., 2012). The very high sensitivity of annual water balance to changes in annual air temperature and specific humidity as revealed in this study would explain that even slightly warmer and less dry climates ~~w~~could result in positive long-term mean annual water balance such that the mega-lake system ~~w~~could have been able to exist in this still very dry region for long time. It must, however, be noted that these estimates do not consider feedbacks that will have additional effects on the water balance of the QB. At a certain yet unknown point, lake area will not be able to increase further since increasing lake evaporation would lead to a zero mean annual water balance.

Since the high mountain ranges are of utmost importance for ~~in~~ th~~is~~e ~~respect~~water balance of the entire QB, the question arises, how different the paleogeographic situation has been in the Q~~aidam basin~~B as compared with today. Although the details of tectonics are not yet finally clarified, and vertical movements of the lithosphere have certainly influenced the basin's orography (Fang et al., 2007) and hydrography, the results of this study are considered to be generally applicable to the mid-Pliocene, since the paleogeographic situation ~~of this epoch~~ has been generally similar to the presence (Dowsett et al., 2010). Since the mid-Miocene, elevations of the QB and surrounding mountain ranges are comparable to today (Wang et al., 2008; Yuan et al., 2013). If altitudes of the high mountain ranges in the Q~~aidam basin~~B would have been a few hundred~~ths~~ meters lower than today as indicated by Fang et al. (2007), then the negative effect of lower altitudes on annual water balance would be accompanied by the counteracting effect that blocking of humid air masses by the high mountain ranges in the fringes of the Q~~aidam basin~~B would have been less strong, a fact also studied for the entire TP (Broccoli and Manabe, 1992).

This statement is also justified by the results obtained by applying the same methodology ~~as used in this study~~ to the HAR ~~V1~~ data set for the 30 km domain (see Table S9, Fig~~ures~~. S10 and S11 in the Supplement). Due to the coarser model grid, the altitudes of the highest mountains are lower in the 30 km grid (h_{max} ~~h_{max}~~ = 5.136 m a.s.l.) than in the 10 km grid (~~h_{max}~~ h_{max}

= 5.433 m a.s.l.), and ~~the~~ mean annual water balance rises from -14 mm/a (10 km grid) to 3 mm/a (30 km grid). This indicates that less blocking of humid air inflow to the QB (due to lower altitudes) overcompensates reduction in orographic precipitation in the HAR 30 km data set (due to the coarser grid) as compared to the results for the HAR 10 km data set (higher altitudes and finer grid).

Global climate change as projected for the future and its consequences for the regional climates of China (Burke et al., 2018; Gu et al., 2018; Hui et al., 2018) could lead to strengthening of the East Asian Summer Monsoon (Wang et al., 2008), which could also affect the Q~~aidam basin~~B such that both annual specific humidity and precipitation ~~w~~would further increase. This would then lead to continued recharge of groundwater reservoirs and, at a later stage, to rising lake levels or formation of new lakes, as already observed today. In a long-term perspective, even the ~~Qaidam~~ mega-lake system may be restored. Assuming a slightly positive long-term mean annual water balance of 40 mm/a as discussed above, lake water levels would rise by 400 m averaged over the entire Q~~aidam basin~~B within only 10 ka, which is, in a geological perspective, a very short time period. Since water would preferentially accumulate in the low-lying areas due to surface and groundwater flows within the QB, the effect would be even stronger in those areas, which have formerly been part of the ~~Qaidam~~ mega-lake system. Partial restoration of the mega-lake system during former Pleistocene interglacial periods as reported by Wang et al. (2012) among others, indicates that this mechanism has probably taken place several times in Earth history.

5 Conclusions

This study could show that the mean annual water balance of the QB was close to zero during the 14 hydrological years from 2001 to 2014. Negative values of net precipitation prevail in the low-lying desert regions while the high mountain regions within or at the border of the drainage basin show positive values compensating the water losses at lower altitudes. Orographic precipitation is strongly increasing total precipitation at higher altitudes, while actual evapotranspiration is also increasing with altitude but less strong. The latter fact, combined with high values of actual evapotranspiration over lakes, indicates that availability of water but not energy for latent heat is the main driver of actual evapotranspiration in the QB.

Annual water balance of the QB was positive during warmer years, since these years showed higher-than-normal precipitation. Annual water balance variations in the QB are driven by variations in annual precipitation while variations in annual actual evapotranspiration showed no statistically significant effects on annual water balance. The study revealed that not air temperature alone but specific humidity is the main climate driver of annual water balance. Inflow of moister-than-normal air to the QB takes place during warmer-than-normal years and increases both precipitation and water balance.

~~Global climate change as projected for the future and its consequences for the regional climates of China (Burke et al., 2018; Gu et al., 2018; Hui et al., 2018) could lead to strengthening of the East Asian Summer Monsoon (Wang et al., 2008), which could also affect the Qaidam basin such that both specific humidity and precipitation would increase. This would then lead to continued recharge of groundwater reservoirs and, at a later stage, to rising lake levels or formation of new lakes. In a long-~~

~~term perspective, even the Qaidam mega-lake system may be restored. Assuming a slightly positive long-term mean annual water balance of 40 mm/a as discussed above, lake water levels would rise by 400 m averaged over the entire Qaidam basin within only 10 ka, which is, in a geological perspective, a very short time period. Since water would preferentially accumulate in the low-lying areas, the effect would be even stronger in those areas, which have formerly been part of the Qaidam mega-lake system.~~

Future research could target on acquisition of additional or improved spatially distributed data sets for water balance components and climate drivers at even higher spatial resolution to capture the details of the high mountain topography of the Q~~aidam basin~~B, and for longer time periods to improve assessments of environmental changes related to changes in water balance. The new global ERA5 reanalysis data set, as well as the transferability of the methods applied in this study to other regions offer new options in this respect. Other lines of research could focus on dynamical downscaling of paleoclimate simulations for Pliocene time slices or global climate projections for the future. Both kind of data sets are, in general, spatially too coarse to fully resolve atmospheric processes like orographic~~ally induced~~ precipitation or actual evapotranspiration in high mountain ranges (Gu et al., 2018), such that regional water balance computations based on coarse data would, most likely, come with high uncertainties. Thus, dynamical downscaling of global atmospheric data is regarded to be essential.

Dynamical downscaling could also be used to study changes in the statistical relations as revealed in this study by artificially modified (paleo-)geographies. Since lakes tend to reduce precipitation while concurrently showing high actual evaporation, there ~~should~~must be an upper limit for lake growth, which is, however, not yet known. On the other hand, it is theoretically also possible that a mega-lake system effectively recycles its own water, i.e., that atmospheric moisture stemming from lake evaporation precipitates within the basin’s catchment area. Water recycling is highly important for the entire TP (Curio et al., 2015), and might also play an important, yet unknown role for the Q~~aidam basin~~B’s water balance.

Data availability. The HAR ~~V1~~ data set is freely availability at http://www.klima.tu-berlin.de/HAR.

Supplement. The supplement related to this article is available online at:

Author contribution. Dieter Scherer carried out the analyses and wrote the paper.

Competing interests. The author declares that he has no conflict of interest.

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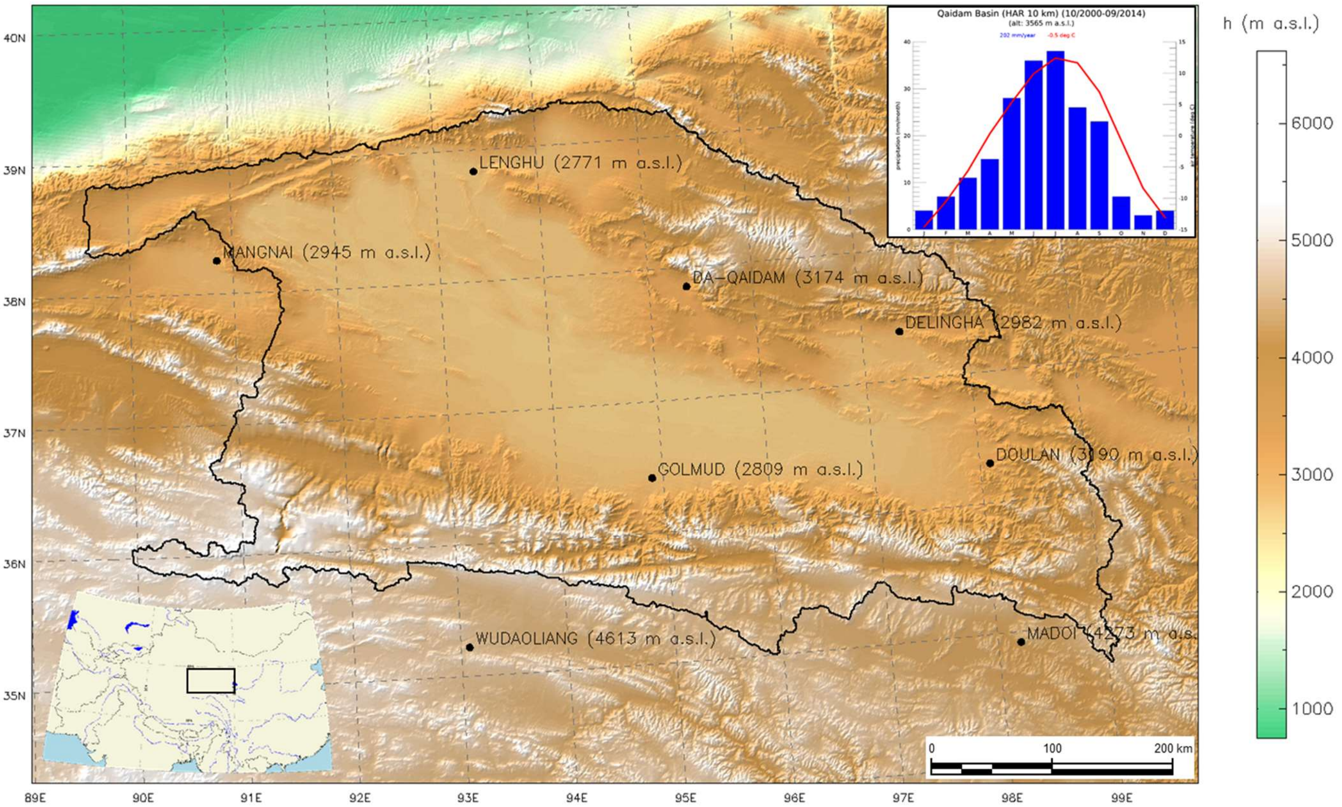

Qaidam Basin (HAR 10 km) (10/2000-09/2014)
(alt: 3565 m a.s.l.)
202 mm/year
-0.5 deg C
precipitation (mm/month)
air temperature (deg C)
J F M A M J J A S O N D
0 10 20 30 40
-15 -10 -5 0 5 10 15
h (m a.s.l.)
1000 2000 3000 4000 5000 6000
LENGHU (2771 m a.s.l.)
MANGNAI (2945 m a.s.l.)
DA-QAIDAM (3174 m a.s.l.)
DELINGHA (2982 m a.s.l.)
DOULAN (3190 m a.s.l.)
GOLMUD (2809 m a.s.l.)
WUDAOLIANG (4613 m a.s.l.)
MADOI (4273 m a.s.l.)
40N 39N 38N 37N 36N 35N
89E 90E 91E 92E 93E 94E 95E 96E 97E 98E 99E
0 100 200 km

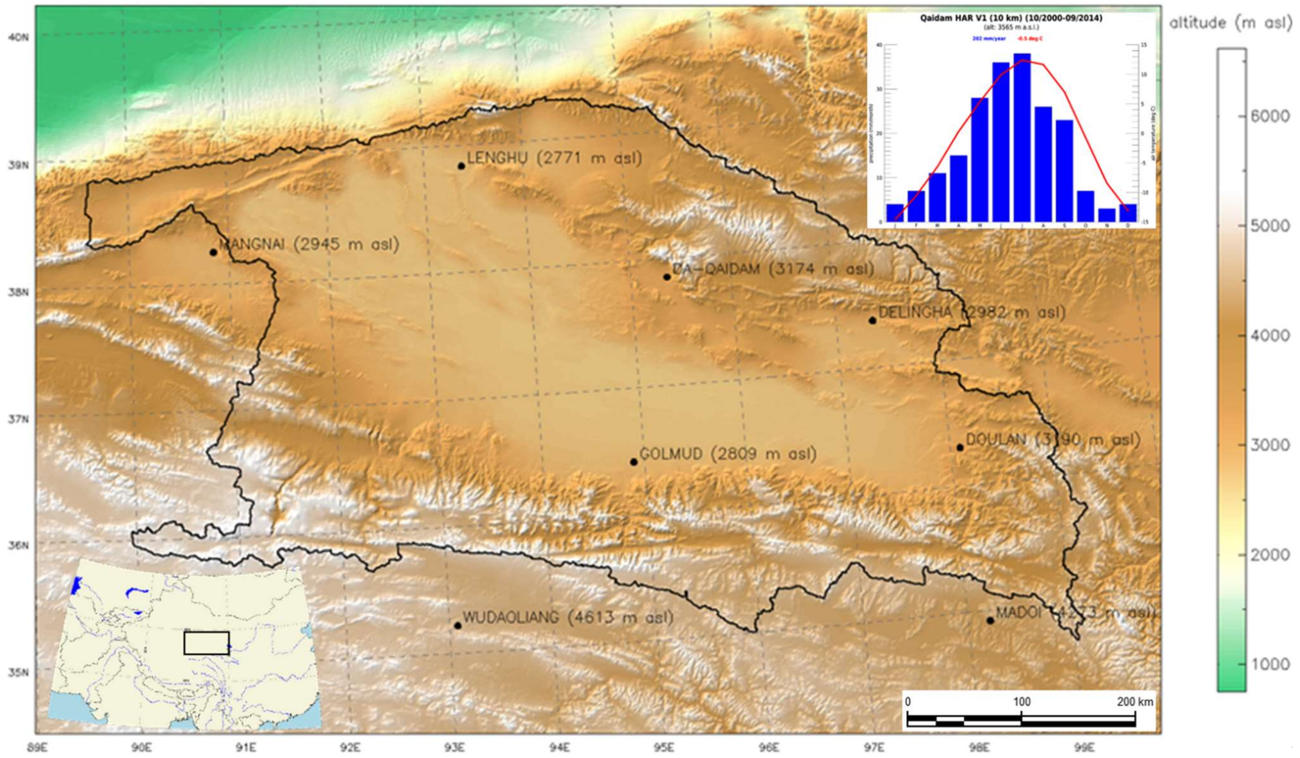
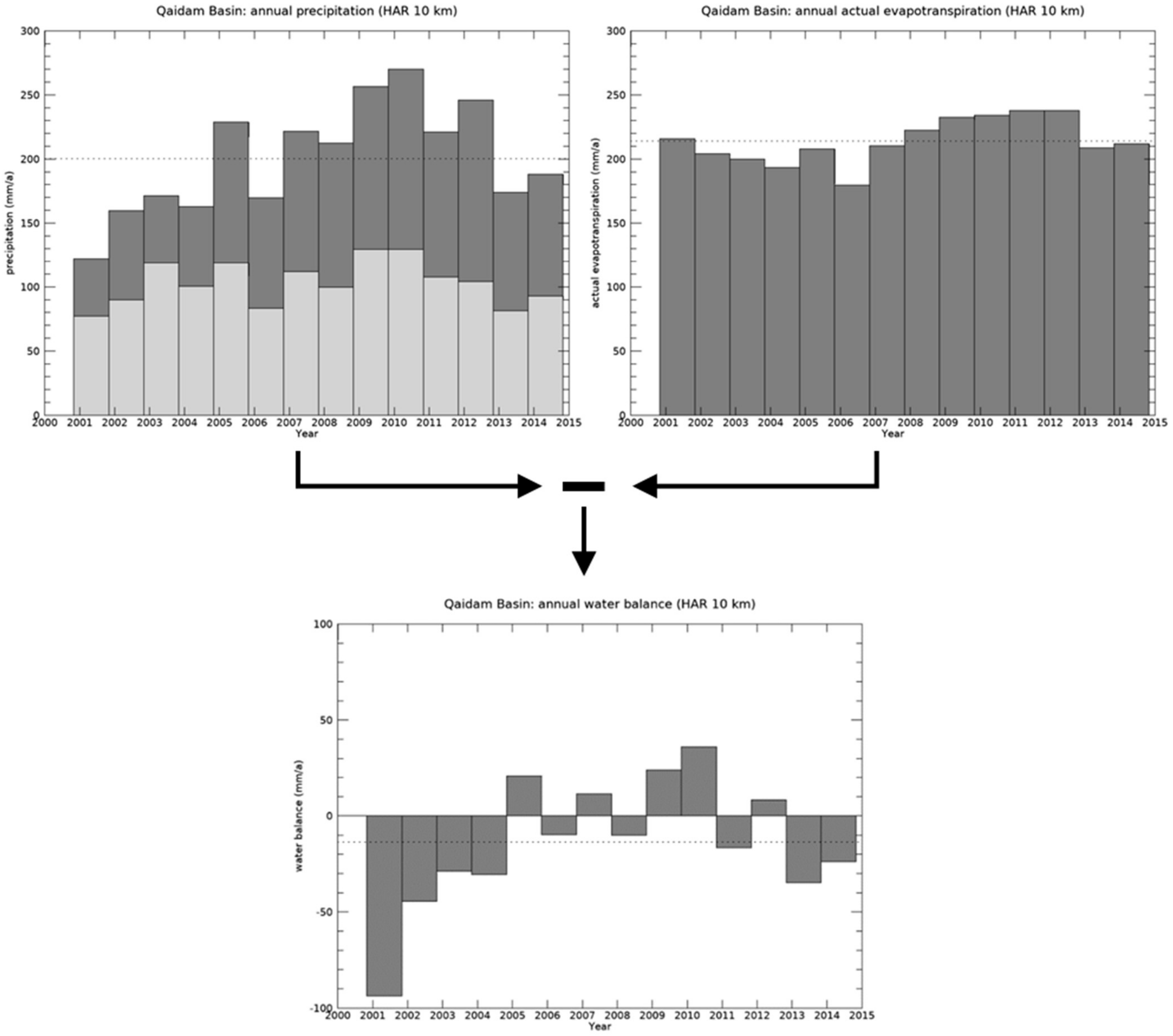


Figure 1: Overview on the Qaidam ~~b~~Basin (QB), including a spatially averaged climate diagram for the Q~~aidam b~~B~~asin~~ derived from the HAR ~~V1 (~~10 km~~)~~ data set for the study period of 14 hydrological years (2001-2014). Black line: boundary of the Q~~aidam b~~B~~asin~~ (Lehner and Grill, 2013). Topographic shading is based on DEM data from the SRTM. Black dots indicate the locations of the eight GSOD stations within or nearby the QB.


Qaidam Basin: annual precipitation (HAR 10 km)
precipitation (mm/a)
Year
Qaidam Basin: annual actual evapotranspiration (HAR 10 km)
actual evapotranspiration (mm/a)
Year
Qaidam Basin: annual water balance (HAR 10 km)
water balance (mm/a)
Year
0
50
100
150
200
250
300
-100
-50
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

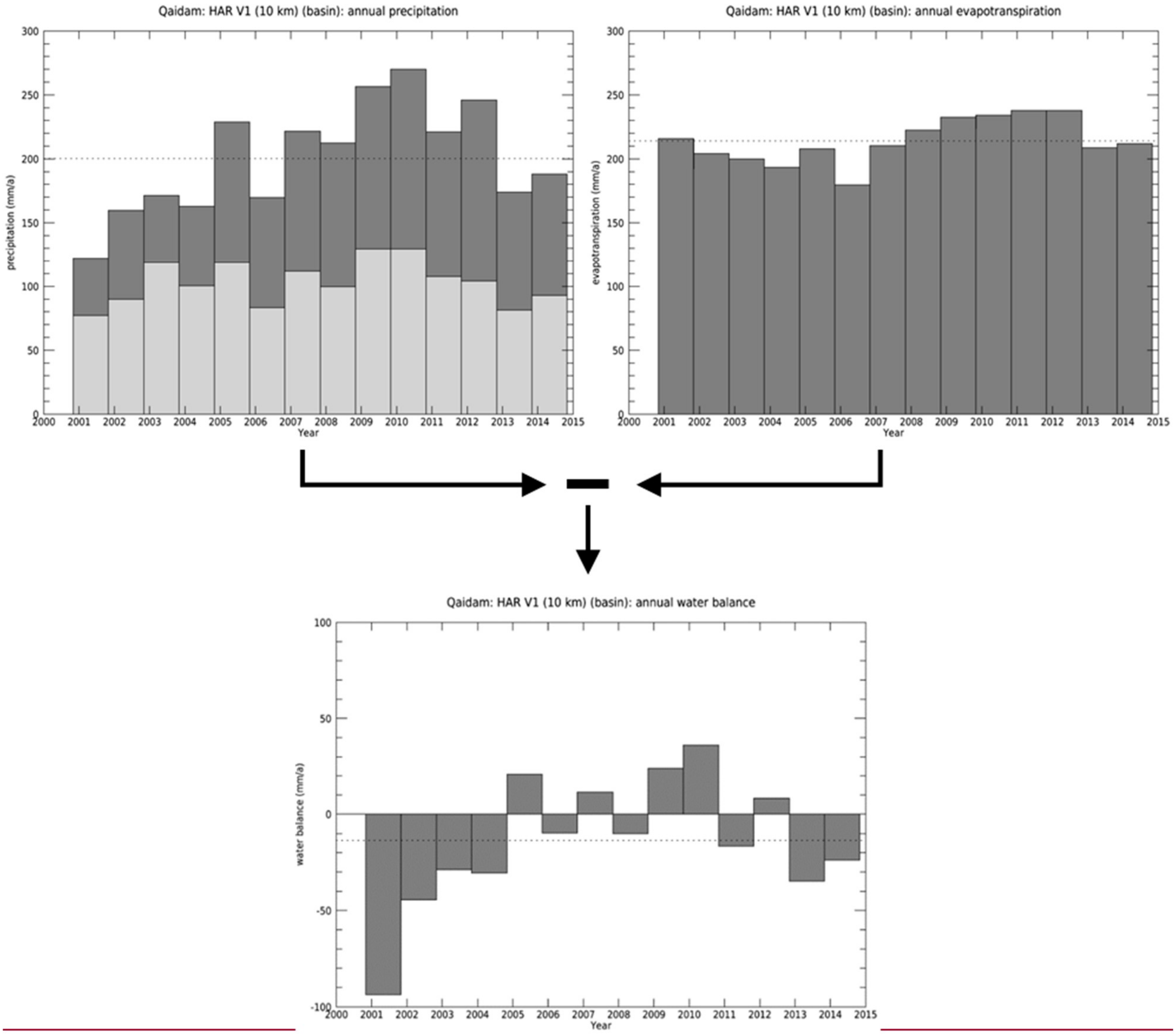
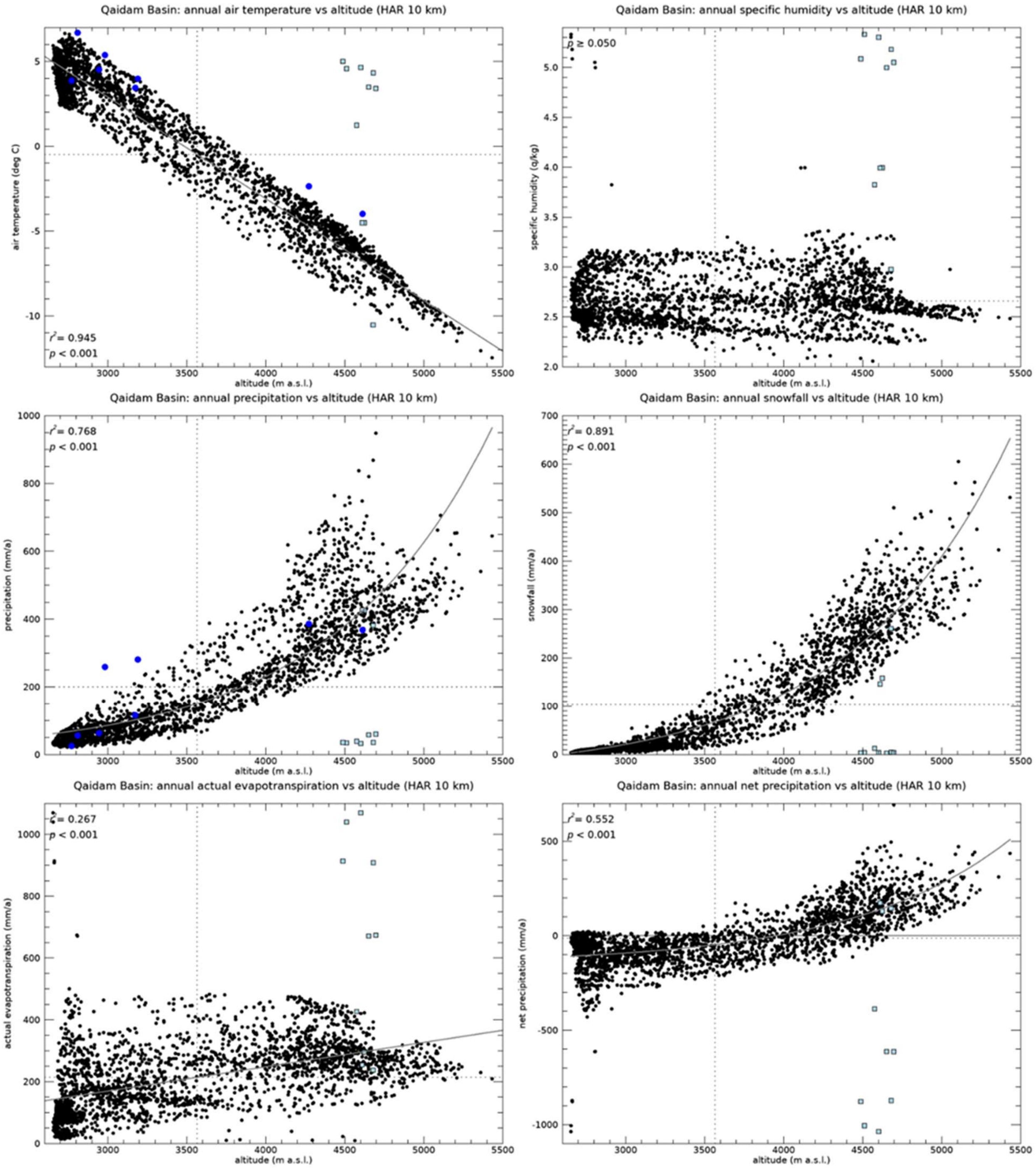


Figure 2: Annual precipitation ~~P~~ (upper left panel), actual evapotranspiration ~~ET~~ (upper right panel), and water balance ~~$\Delta S = P - ET$~~ (lower panel) in the Qaidam B~~b~~asin (QB) during the hydrological years 2001 to 2014 derived from the HAR 10 km data set. Upper left panel: light grey bars: annual snowfall ~~P_{snow}~~; dark grey bars: annual rainfall ~~$P_{rain} = P - P_{snow}$~~. Dotted lines: mean annual values.



Qaidam Basin: annual air temperature vs altitude (HAR 10 km)
air temperature (deg C)
5
0
-5
-10
r^2= 0.945
p < 0.001
altitude (m a.s.l.)
3000
3500
4000
4500
5000
5500
Qaidam Basin: annual specific humidity vs altitude (HAR 10 km)
specific humidity (g/kg)
p ≥ 0.050
2.0
2.5
3.0
3.5
4.0
4.5
5.0
altitude (m a.s.l.)
Qaidam Basin: annual precipitation vs altitude (HAR 10 km)
precipitation (mm/a)
r^2= 0.768
p < 0.001
0
200
400
600
800
1000
altitude (m a.s.l.)
Qaidam Basin: annual snowfall vs altitude (HAR 10 km)
snowfall (mm/a)
r^2= 0.891
p < 0.001
0
100
200
300
400
500
600
700
altitude (m a.s.l.)
Qaidam Basin: annual actual evapotranspiration vs altitude (HAR 10 km)
actual evapotranspiration (mm/a)
r^2= 0.267
p < 0.001
0
200
400
600
800
1000
altitude (m a.s.l.)
Qaidam Basin: annual net precipitation vs altitude (HAR 10 km)
net precipitation (mm/a)
r^2= 0.552
p < 0.001
500
0
-500
-1000
altitude (m a.s.l.)

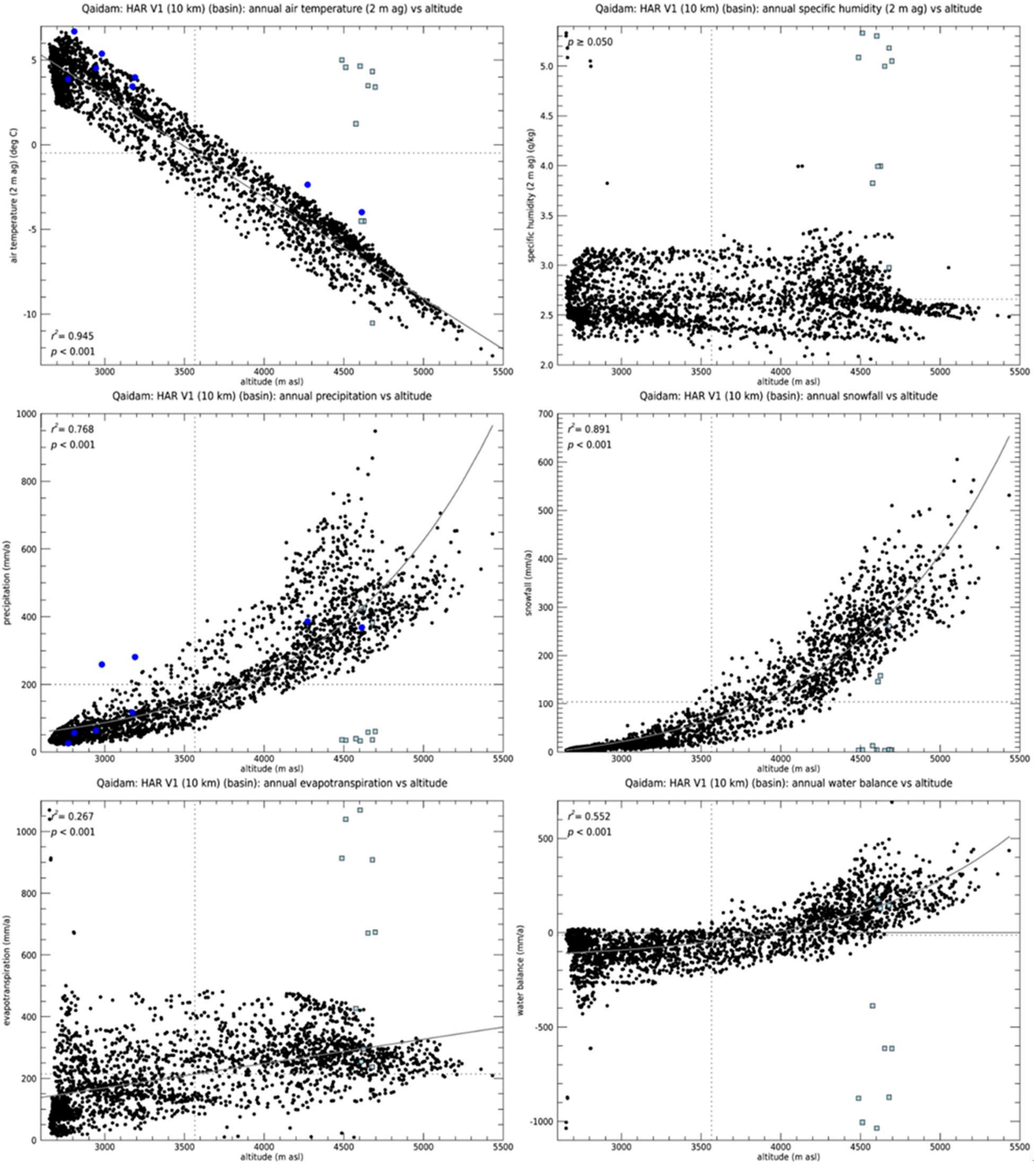
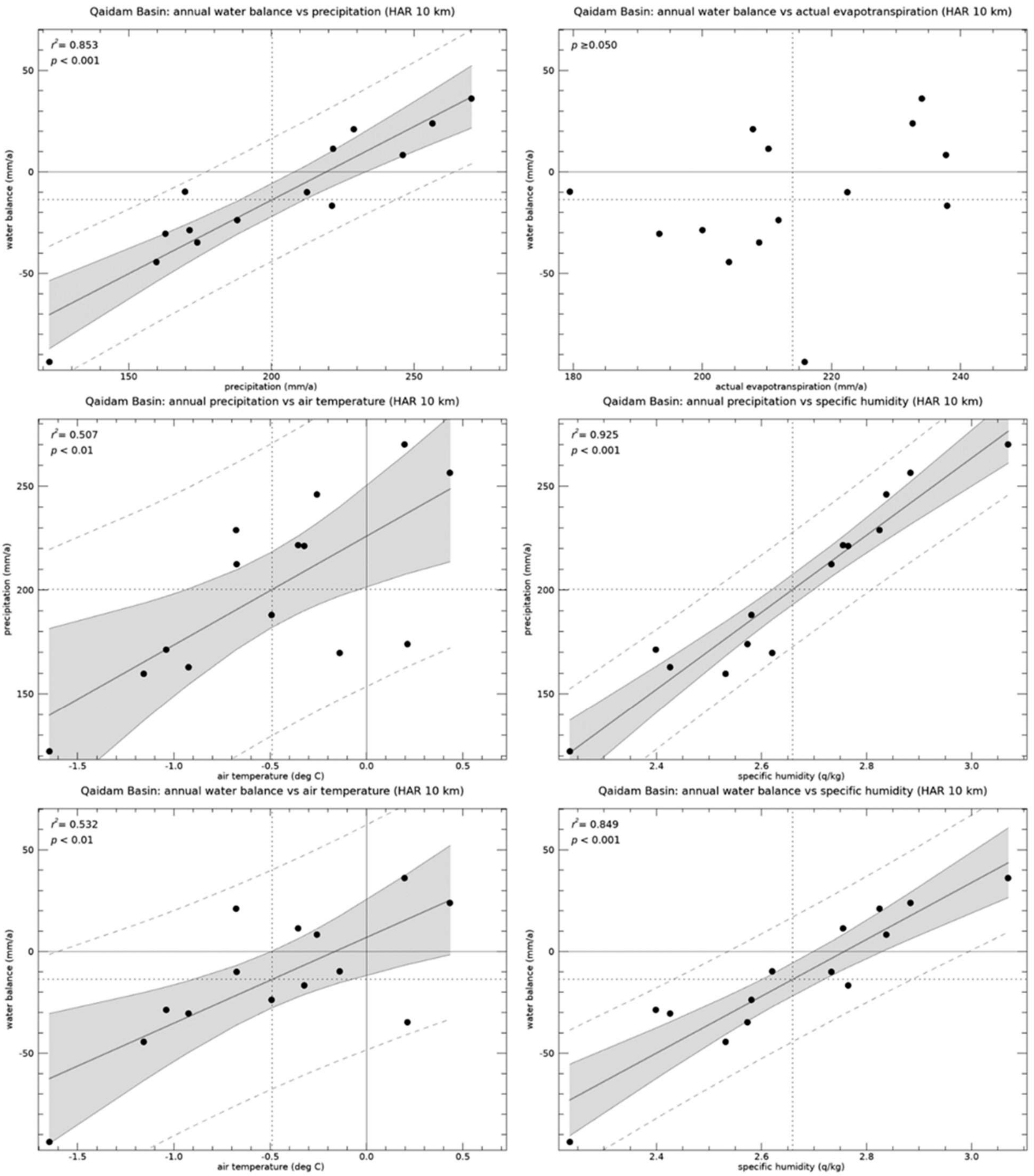


Figure 3: Mean annual air temperature ~~*T*~~ (upper left panel), specific humidity ~~*q*~~ (upper right panel), precipitation ~~*P*~~ (middle left panel), snowfall ~~P_{snow}~~ (middle right panel), actual evapotranspiration ~~*ET*~~ (lower left panel), and ~~water~~net ~~balance ΔS =~~ precipitation ~~*P* – *ET*~~ (lower right panel) versus altitude in the Qaidam ~~b~~Basin (QB) during the hydrological years 2001 to 2014 derived from the HAR 10 km data set. Black dots: ~~terrestrial~~land grid points; light blue squares: grid points covered by lakes in the HAR ~~V1 (~~10 km~~)~~ land cover data; blue dots: data from eight GSOD stations; dotted lines: mean annual values.


Qaidam Basin: annual water balance vs precipitation (HAR 10 km)
$r^2 = 0.853$
$p < 0.001$
water balance (mm/a)
precipitation (mm/a)
Qaidam Basin: annual water balance vs actual evapotranspiration (HAR 10 km)
$p \geq 0.050$
water balance (mm/a)
actual evapotranspiration (mm/a)
Qaidam Basin: annual precipitation vs air temperature (HAR 10 km)
$r^2 = 0.507$
$p < 0.01$
precipitation (mm/a)
air temperature (deg C)
Qaidam Basin: annual precipitation vs specific humidity (HAR 10 km)
$r^2 = 0.925$
$p < 0.001$
precipitation (mm/a)
specific humidity (q/kg)
Qaidam Basin: annual water balance vs air temperature (HAR 10 km)
$r^2 = 0.532$
$p < 0.01$
water balance (mm/a)
air temperature (deg C)
Qaidam Basin: annual water balance vs specific humidity (HAR 10 km)
$r^2 = 0.849$
$p < 0.001$
water balance (mm/a)
specific humidity (q/kg)

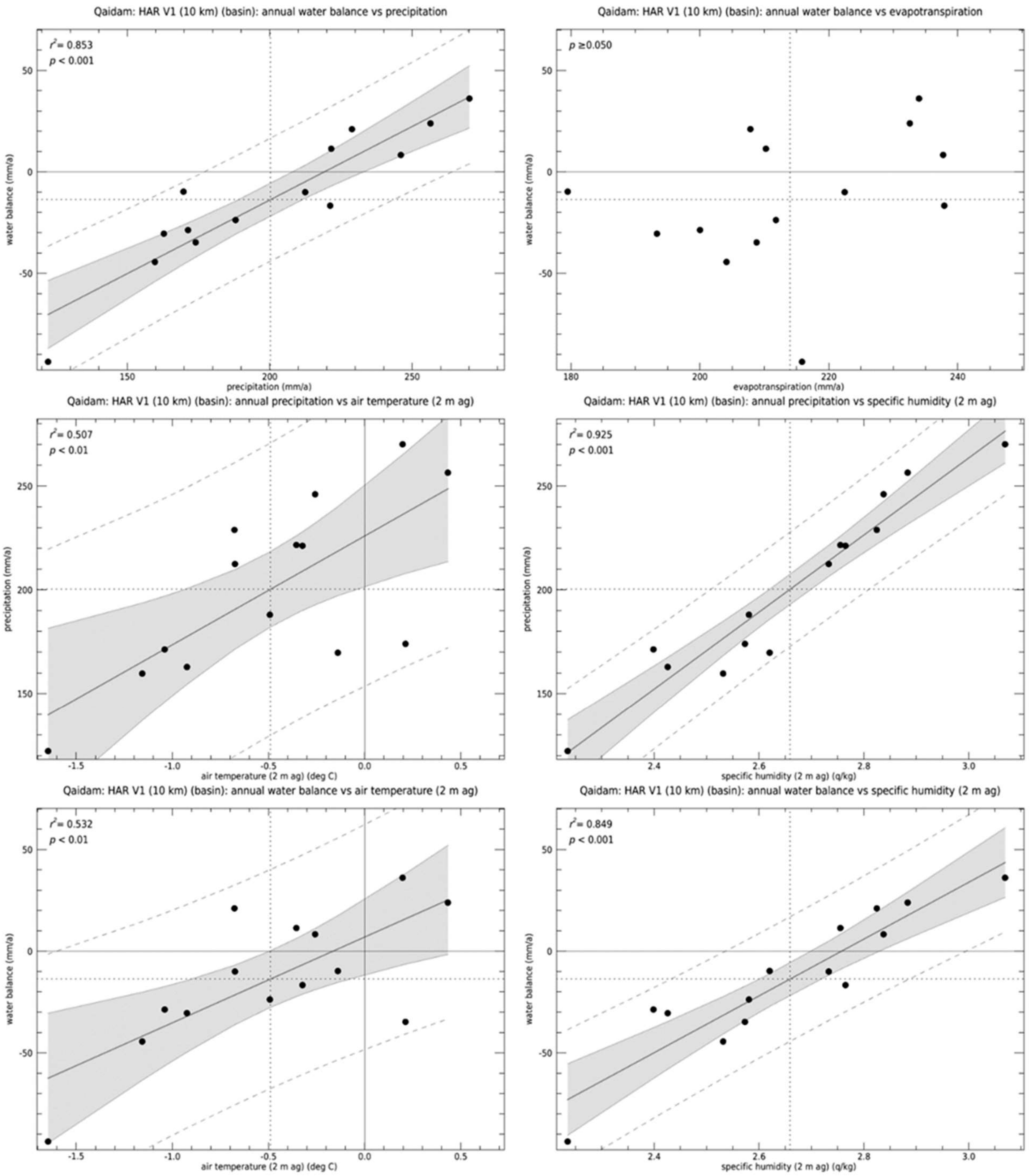


Figure 4: ~~W~~Water balance ~~$\Delta S = P - ET$~~ versus precipitation ~~P~~ (upper left panel) and actual evapotranspiration ~~ET~~ (upper right panel); ~~P~~precipitation versus air temperature ~~T~~ (middle left panel) and specific humidity ~~q~~ (middle right panel); ~~ΔS~~ water balance versus ~~T~~ air temperature (lower left panel) and ~~q~~ specific humidity (lower right panel) in the Qaidam ~~b~~Basin (QB) during the hydrological years 2001 to 2014 derived from the HAR 10 km data set. Dotted lines: mean annual ~~me~~va~~n~~lues; solid lines: regression lines; light grey shades: confidence intervals; dashed lines: prediction intervals.

Table 1: Mean monthly and annual air temperature T (in deg C) ~~T~~, specific humidity q (in g/kg) ~~q~~, precipitation P (in mm/month or mm/a) ~~P~~, rainfall P_{rain} (in mm/month or mm/a)~~P_{rain}~~, snowfall P_{snow} (in mm/month or mm/a) ~~P_{snow}~~, actual evapotranspiration ET (in mm/month or mm/a)~~ET~~, and water balance ~~$\Delta S = P - ET$~~$\Delta S = P - ET$ (in mm/month or mm/a) in the Qaidam ~~b~~Basin (QB) derived from the HAR 10 km data set; sigma: standard deviations of annual values for each quantity during the hydrological years 2001 to 2014~~during the 14-years study period~~.

month	10	11	12	1	2	3	4	5	6	7	8	9	**year**	sigma
T	-0.7	-8.4	-13.1	-14.6	-10.5	-5.6	0.3	5.3	9.9	12.4	11.6	7.0	**-0.5**	0.6
q	2.2	1.4	1.0	0.9	1.2	1.5	1.9	2.8	4.3	5.6	5.1	3.9	**2.7**	0.2
P	7	3	4	4	7	11	15	28	36	38	26	23	**200**	43
P_{rain}	1	0	0	0	1	1	4	9	21	30	19	12	**97**	31
P_{snow}	6	3	4	4	6	10	11	19	15	8	7	11	**103**	17
ET	13	8	5	5	9	15	18	25	29	34	31	21	**214**	18
ΔS	-6	-4	-1	-2	-2	-4	-4	2	7	4	-5	1	**-14**	34

month	10	11	12	1	2	3	4	5	6	7	8	9	**year**	sigma
T (deg C)	-0.7	-8.4	-13.1	-14.6	-10.5	-5.6	0.3	5.3	9.9	12.4	11.6	7.0	**-0.5**	0.6
q (g/kg)	2.2	1.4	1.0	0.9	1.2	1.5	1.9	2.8	4.3	5.6	5.1	3.9	**2.7**	0.2
P (mm)	7	3	4	4	7	11	15	28	36	38	26	23	**200**	43
P_{rain} (mm)	1	0	0	0	1	1	4	9	21	30	19	12	**97**	31
P_{snow} (mm)	6	3	4	4	6	10	11	19	15	8	7	11	**103**	17
ET (mm)	13	8	5	5	9	15	18	25	29	34	31	21	**214**	18
P-ET (mm)	-6	-4	-1	-2	-2	-4	-4	2	7	4	-5	1	**-14**	34

~~T~~Table 2: Estimated changes in ~~long-term mean~~ annual air temperature ΔT (in deg C) ~~T~~, specific humidity Δq (in g/kg) ~~q,~~, precipitation ΔP (in mm/a) ~~P~~, and water balance $\Delta(\Delta S)$ (in mm/a) ~~$\Delta S = P - ET$ (actual evapotranspiration)~~ in the Qaidam ~~b~~Basin (QB) with respect to present conditions, and resulting estimated annual water balance ΔS (in mm/a) for the mid-Pliocene ~~or for future climates due to anthropogenic climate change~~. Red colours: estimates based on changes ΔT ~~T~~; blue colours: estimates based on changes Δq ~~q~~; black colours: estimates based on changes ΔP ~~P~~. Input values for ΔT ~~T~~ (magenta shades) and ΔP ~~P~~ (grey shades) are estimates based on the studies of Zhang et al. (2013c) and Mutz et al. (2018), while present values and sensitivities are derived from the HAR 10 km data set during the hydrological years 2001 to 2014 as discussed in the text.

sensitivity	value	unit	ΔT		Δq		ΔP		$\Delta(\Delta S)$		ΔS		
			min	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**mean**
$\frac{\partial q}{\partial T}$	0.288	g kg^{-1} K^{-1}	**1.0**	**2.0**	0.3	0.6							
$\frac{\partial P}{\partial T}$	52.40	mm a^{-1} K^{-1}					52	105					
$\frac{\partial \Delta S}{\partial T}$	42.17	mm a^{-1} K^{-1}							42	84	28	70	**49**
$\frac{\partial P}{\partial q}$	185.6	mm a^{-1} g kg^{-1}			0.3	0.6	53	107					
$\frac{\partial \Delta S}{\partial q}$	139.7	mm a^{-1} g kg^{-1}							40	81	26	67	**46**
$\frac{\partial \Delta S}{\partial P}$	0.725	mm a^{-1} mm^{-1} a^{-1}					**50**	**100**	36	73	22	59	**40**

			ΔT		**Δq**		**ΔP**		**$\Delta(P\text{-}ET)$**		**$P\text{-}ET$**		
sensitivity	**value**	**unit**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**min**	**max**	**mean**
$\partial q/\partial T$	0.288	g/(kg·K)	**1.0**	**2.0**	0.3	0.6							
$\partial P/\partial T$	52.40	mm/(a·K)					52	105					
$\partial(P\text{-}ET)/\partial T$	42.17	mm/(a·K)							42	84	28	70	**49**
$\partial P/\partial q$	185.6	mm·kg/(a·g)			0.3	0.6	53	107					
$\partial(P\text{-}ET)/\partial q$	139.7	mm·kg/(a·g)							40	81	26	67	**46**
$\partial(P\text{-}ET)/\partial P$	0.725	mm/mm					**50**	**100**	36	73	22	59	**40**

Supplement to

Survival of the Qaidam Mega-Lake System under Mid-Pliocene Climates and its Restoration under Future Climates

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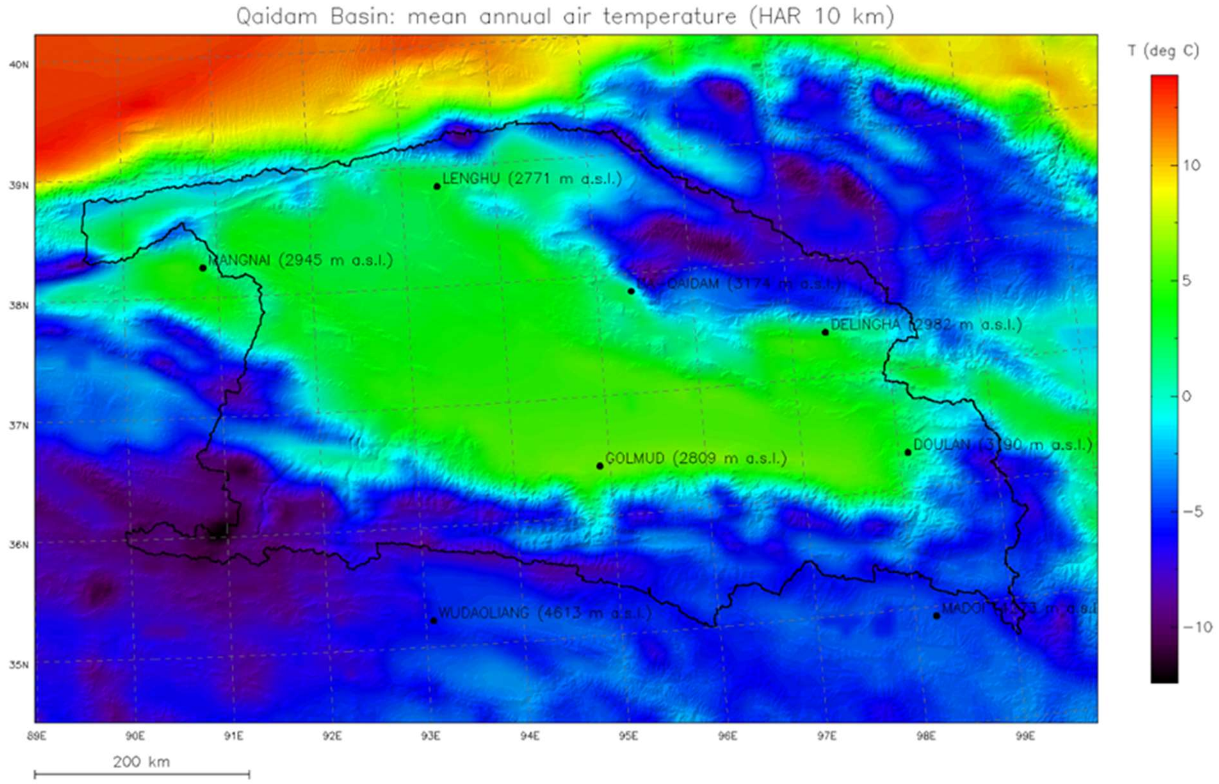
1 Supplementary Figures


Qaidam Basin: mean annual air temperature (HAR 10 km)
T (deg C)
10
5
0
−5
−10
40N
39N
38N
37N
36N
35N
89E
90E
91E
92E
93E
94E
95E
96E
97E
98E
99E
200 km
LENGHU (2771 m a.s.l.)
MANGNAI (2945 m a.s.l.)
DA-QAIDAM (3174 m a.s.l.)
DELINGHA (2982 m a.s.l.)
GOLMUD (2809 m a.s.l.)
DOULAN (3190 m a.s.l.)
WUDAOLIANG (4613 m a.s.l.)
MADOI (4273 m a.s.l.)

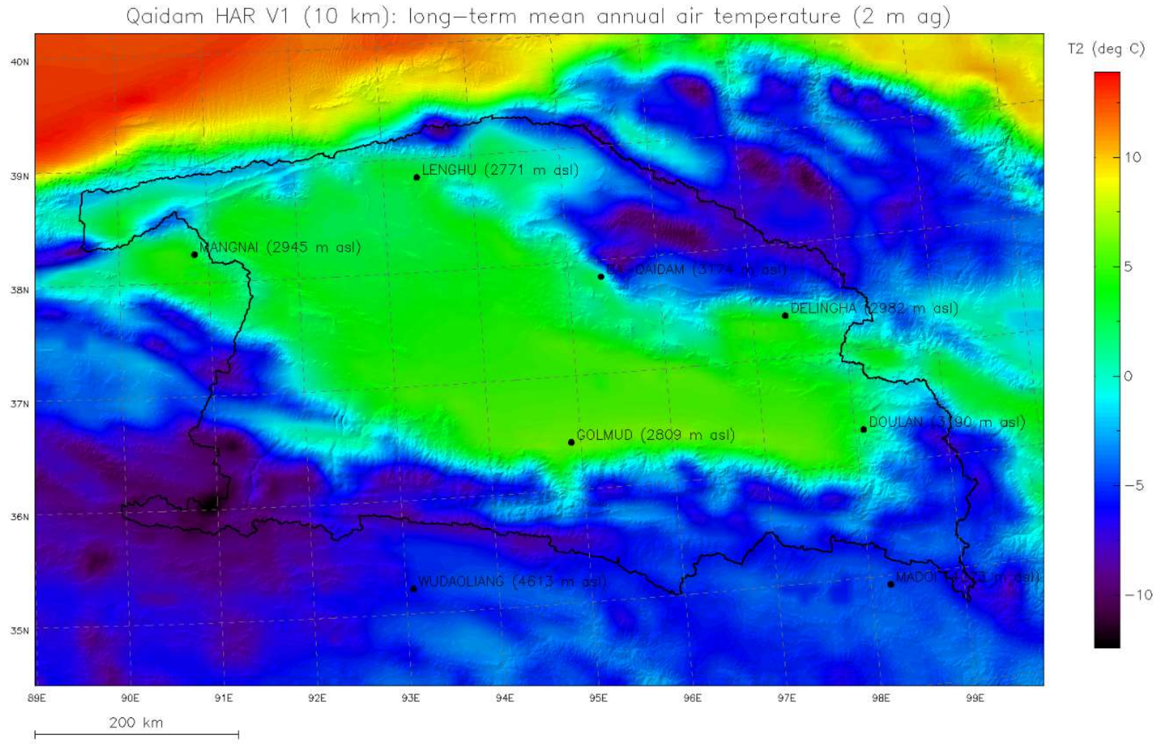
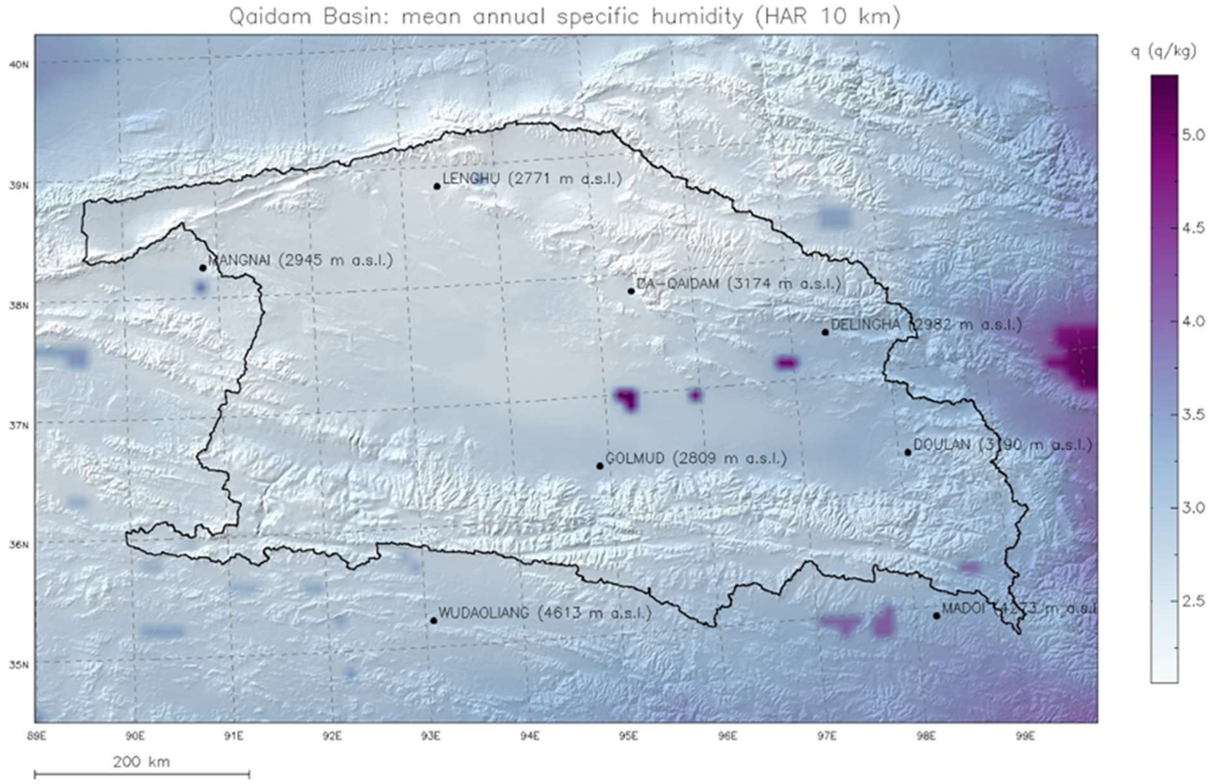

Qaidam HAR V1 (10 km): long−term mean annual air temperature (2 m ag)
T2 (deg C)
10
5
0
−5
−10
40N
39N
38N
37N
36N
35N
89E
90E
91E
92E
93E
94E
95E
96E
97E
98E
99E
200 km
LENGHU (2771 m asl)
MANGNAI (2945 m asl)
DA-QAIDAM (3174 m asl)
DELINGHA (2982 m asl)
GOLMUD (2809 m asl)
DOULAN (3190 m asl)
WUDAOLIANG (4613 m asl)
MADOI (4273 m asl)

Figure S1: Mean annual air temperature (2 m above ground) ~~derived from the HAR V1 (10 km) data set for~~during the study period of 14 hydrological years (2001-2014) for the Qaidam ~~b~~Basin (QB) and its surrounding regions derived from the HAR 10 km data set. Black line: boundary of the Q~~aidam basin~~B (Lehner and Grill, 2013). Topographic shading is based on DEM data from the SRTM. Black dots indicate the locations of the eight GSOD stations within or nearby the QB.


Qaidam Basin: mean annual specific humidity (HAR 10 km)
q (g/kg)
5.0
4.5
4.0
3.5
3.0
2.5
LENGHU (2771 m a.s.l.)
MANGNAI (2945 m a.s.l.)
DA-QAIDAM (3174 m a.s.l.)
DELINGHA (2982 m a.s.l.)
GOLMUD (2809 m a.s.l.)
DOULAN (3190 m a.s.l.)
WUDAOLIANG (4613 m a.s.l.)
MADOI (4273 m a.s.l.)
40N
39N
38N
37N
36N
35N
89E
90E
91E
92E
93E
94E
95E
96E
97E
98E
99E
200 km

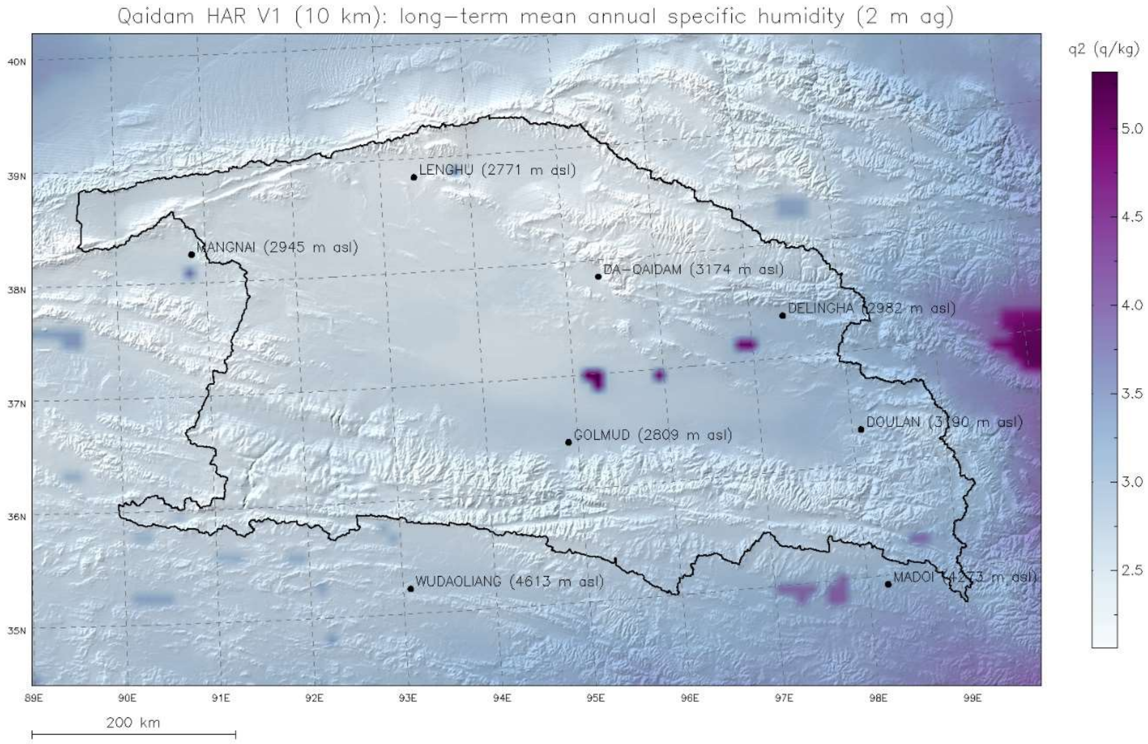
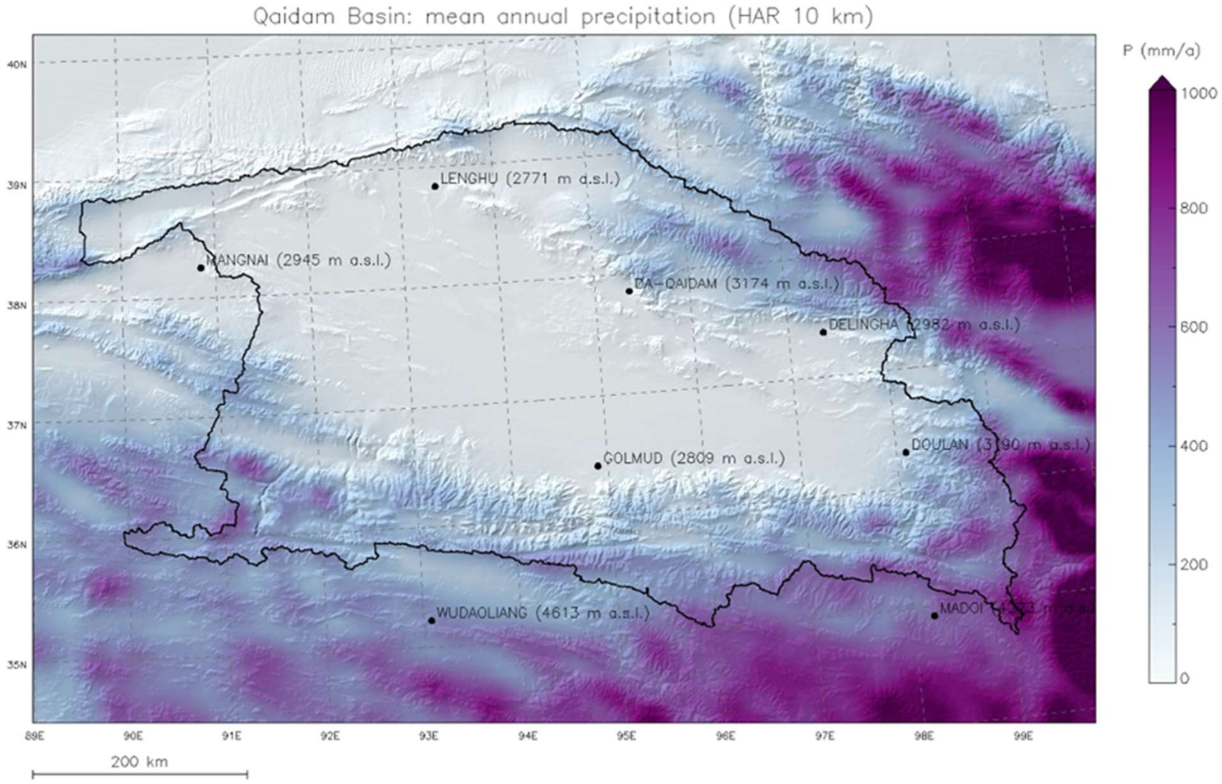

Qaidam HAR V1 (10 km): long-term mean annual specific humidity (2 m ag)
q2 (g/kg)
5.0
4.5
4.0
3.5
3.0
2.5
LENGHU (2771 m asl)
MANGNAI (2945 m asl)
DA-QAIDAM (3174 m asl)
DELINGHA (2982 m asl)
GOLMUD (2809 m asl)
DOULAN (3190 m asl)
WUDAOLIANG (4613 m asl)
MADOI (4273 m asl)
40N
39N
38N
37N
36N
35N
89E
90E
91E
92E
93E
94E
95E
96E
97E
98E
99E
200 km

Figure S2: Mean annual specific humidity (2 m above ground) ~~derived from the HAR V1 (10 km) data set for~~during the study period of 14 hydrological years (2001-2014) for the Qaidam ~~b~~Basin (QB) and its surrounding regions derived from the HAR 10 km data set. Black line: boundary of the Q~~aidam basin~~B (Lehner and Grill, 2013). Topographic shading is based on DEM data from the SRTM. Black dots indicate the locations of the eight GSOD stations within or nearby the QB.


Qaidam Basin: mean annual precipitation (HAR 10 km)
P (mm/a)
1000
800
600
400
200
0
LENGHU (2771 m a.s.l.)
MANGNAI (2945 m a.s.l.)
DA-QAIDAM (3174 m a.s.l.)
DELINGHA (2982 m a.s.l.)
DOULAN (3190 m a.s.l.)
GOLMUD (2809 m a.s.l.)
WUDAOLIANG (4613 m a.s.l.)
MADOI
40N
39N
38N
37N
36N
35N
89E
90E
91E
92E
93E
94E
95E
96E
97E
98E
99E
200 km

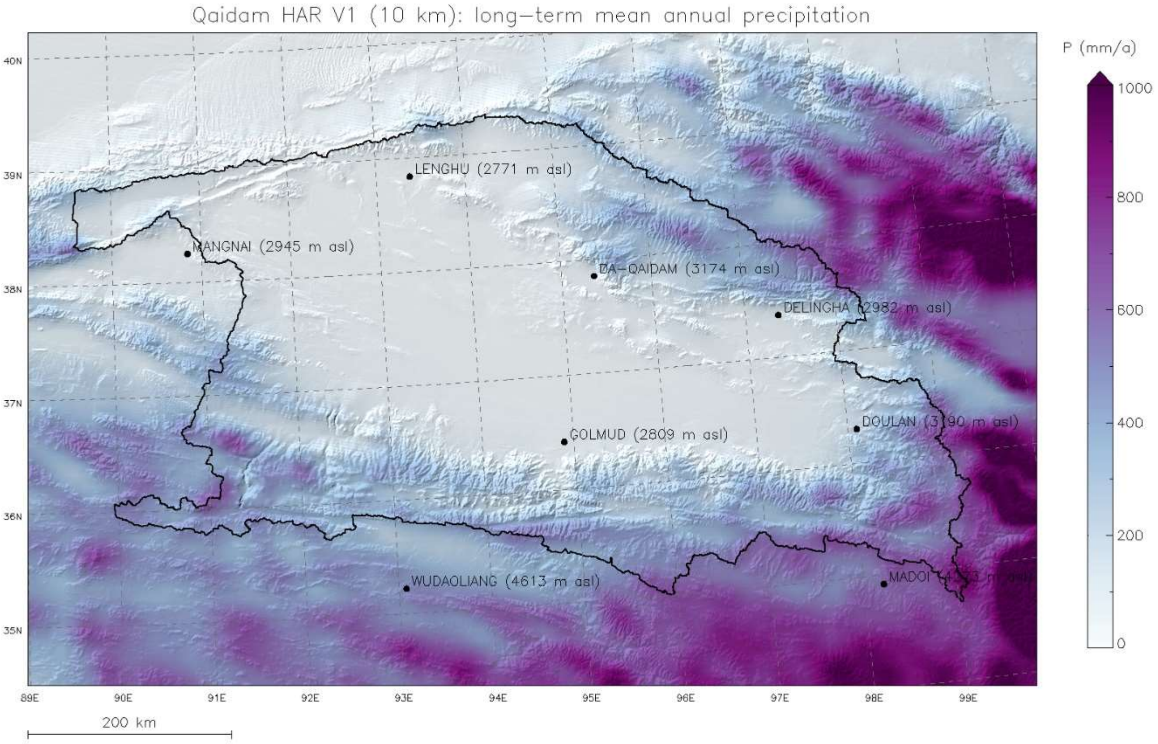
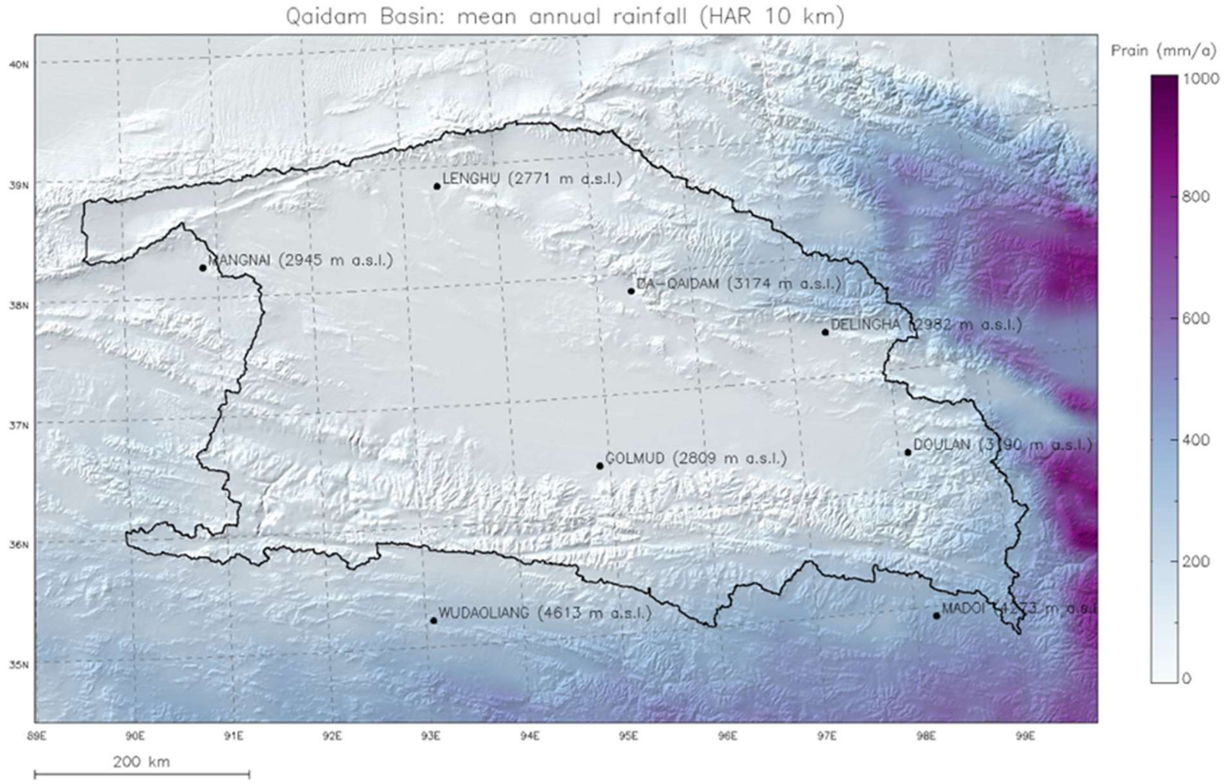

Qaidam HAR V1 (10 km): long-term mean annual precipitation
P (mm/a)
1000
800
600
400
200
0
LENGHU (2771 m asl)
MANGNAI (2945 m asl)
DA-QAIDAM (3174 m asl)
DELINGHA (2982 m asl)
DOULAN (3190 m asl)
GOLMUD (2809 m asl)
WUDAOLIANG (4613 m asl)
MADOI
40N
39N
38N
37N
36N
35N
89E
90E
91E
92E
93E
94E
95E
96E
97E
98E
99E
200 km

Figure S3: Mean annual precipitation ~~derived from the HAR V1 (10 km) data set for~~during the study period of 14 hydrological years (2001-2014) for the Qaidam ~~b~~Basin (QB) and its surrounding regions derived from the HAR 10 km data set. Black line: boundary of the Q~~aidam basin~~B (Lehner and Grill, 2013). Topographic shading is based on DEM data from the SRTM. Black dots indicate the locations of the eight GSOD stations within or nearby the QB.


Qaidam Basin: mean annual rainfall (HAR 10 km)
Prain (mm/a)
1000
800
600
400
200
0
40N
39N
38N
37N
36N
35N
89E
90E
91E
92E
93E
94E
95E
96E
97E
98E
99E
LENGHU (2771 m a.s.l.)
MANGNAI (2945 m a.s.l.)
DA-QAIDAM (3174 m a.s.l.)
DELINGHA (2982 m a.s.l.)
GOLMUD (2809 m a.s.l.)
DOULAN (3190 m a.s.l.)
WUDAOLIANG (4613 m a.s.l.)
MADOI (4273 m a.s.l.)
200 km

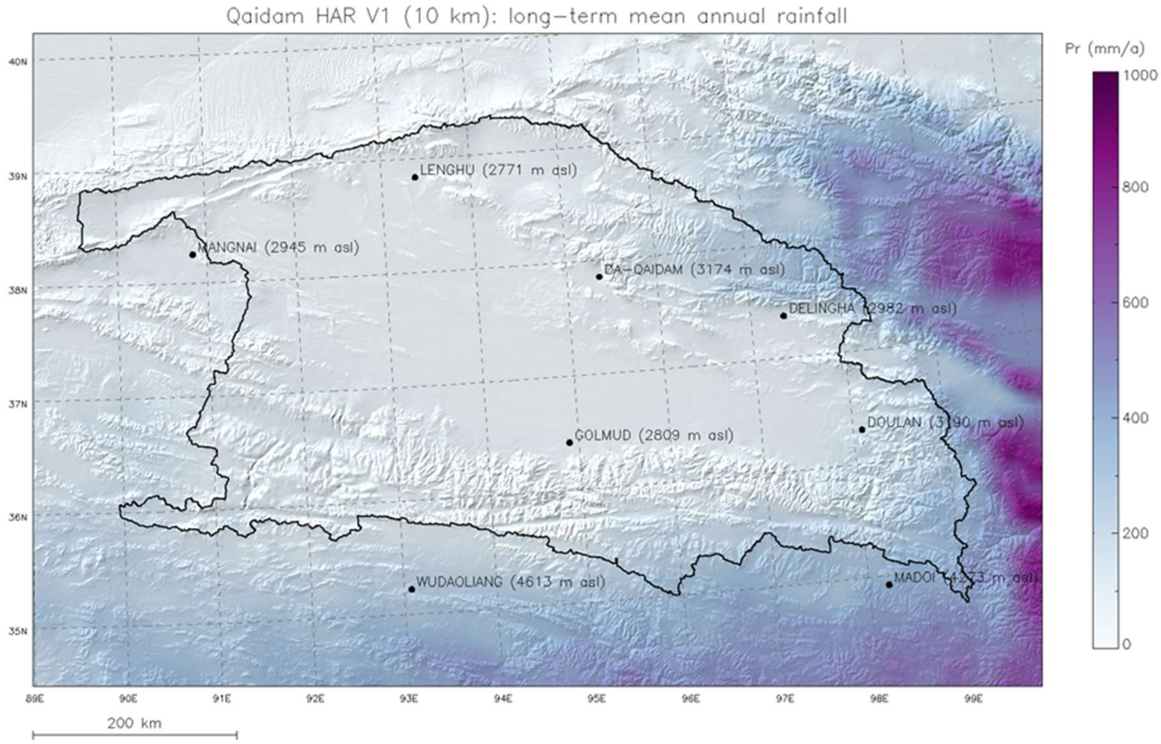
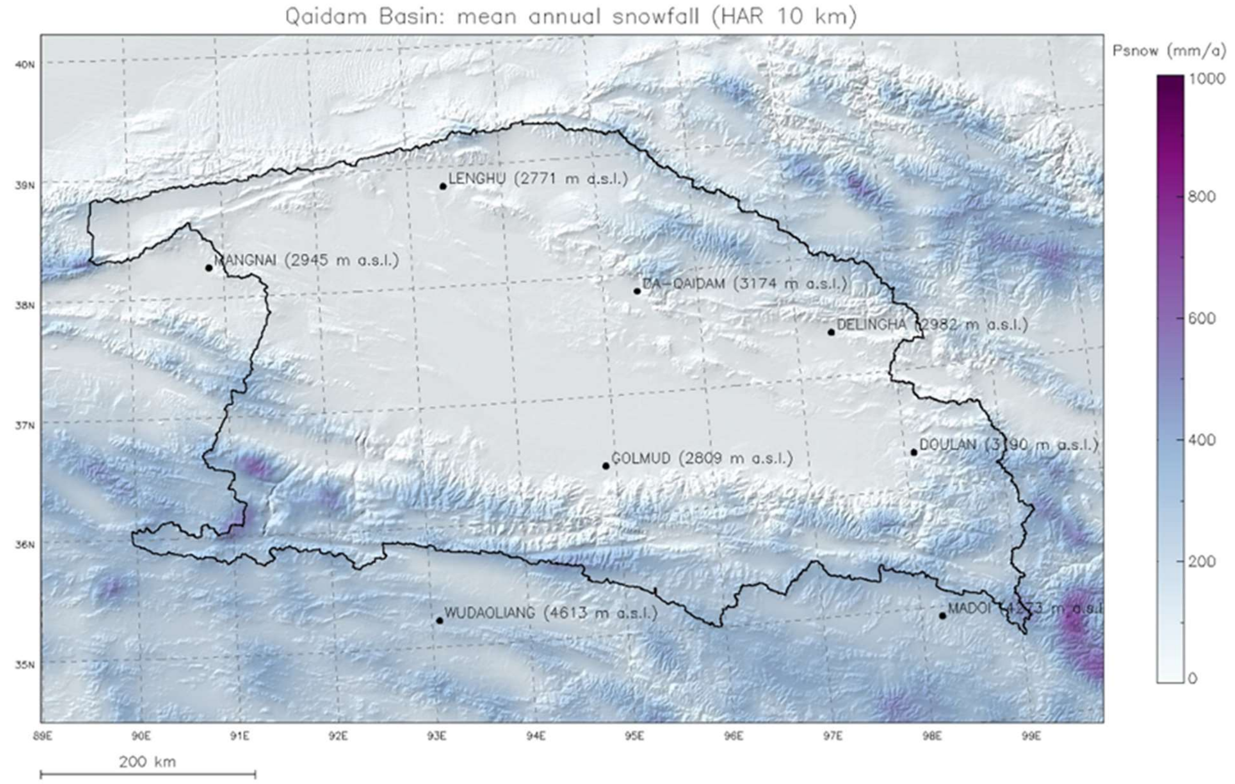

Qaidam HAR V1 (10 km): long-term mean annual rainfall
Pr (mm/a)
1000
800
600
400
200
0
40N
39N
38N
37N
36N
35N
89E
90E
91E
92E
93E
94E
95E
96E
97E
98E
99E
LENGHU (2771 m asl)
MANGNAI (2945 m asl)
DA-QAIDAM (3174 m asl)
DELINGHA (2982 m asl)
GOLMUD (2809 m asl)
DOULAN (3190 m asl)
WUDAOLIANG (4613 m asl)
MADOI (4273 m asl)
200 km

Figure S4: Mean annual rainfall ~~derived from the HAR V1 (10 km) data set for~~during the study period of 14 hydrological years (2001-2014) for the Qaidam ~~b~~Basin (QB) and its surrounding regions derived from the HAR 10 km data set. Black line: boundary of the Q~~aidam basin~~B (Lehner and Grill, 2013). Topographic shading is based on DEM data from the SRTM. Black dots indicate the locations of the eight GSOD stations within or nearby the QB.


Qaidam Basin: mean annual snowfall (HAR 10 km)
Psnow (mm/a)
1000
800
600
400
200
0
LENGHU (2771 m a.s.l.)
MANGNAI (2945 m a.s.l.)
DA-QAIDAM (3174 m a.s.l.)
DELINGHA (2982 m a.s.l.)
DOULAN (3190 m a.s.l.)
GOLMUD (2809 m a.s.l.)
WUDAOLIANG (4613 m a.s.l.)
MADOI (4273 m a.s.l.)
40N
39N
38N
37N
36N
35N
89E
90E
91E
92E
93E
94E
95E
96E
97E
98E
99E
200 km

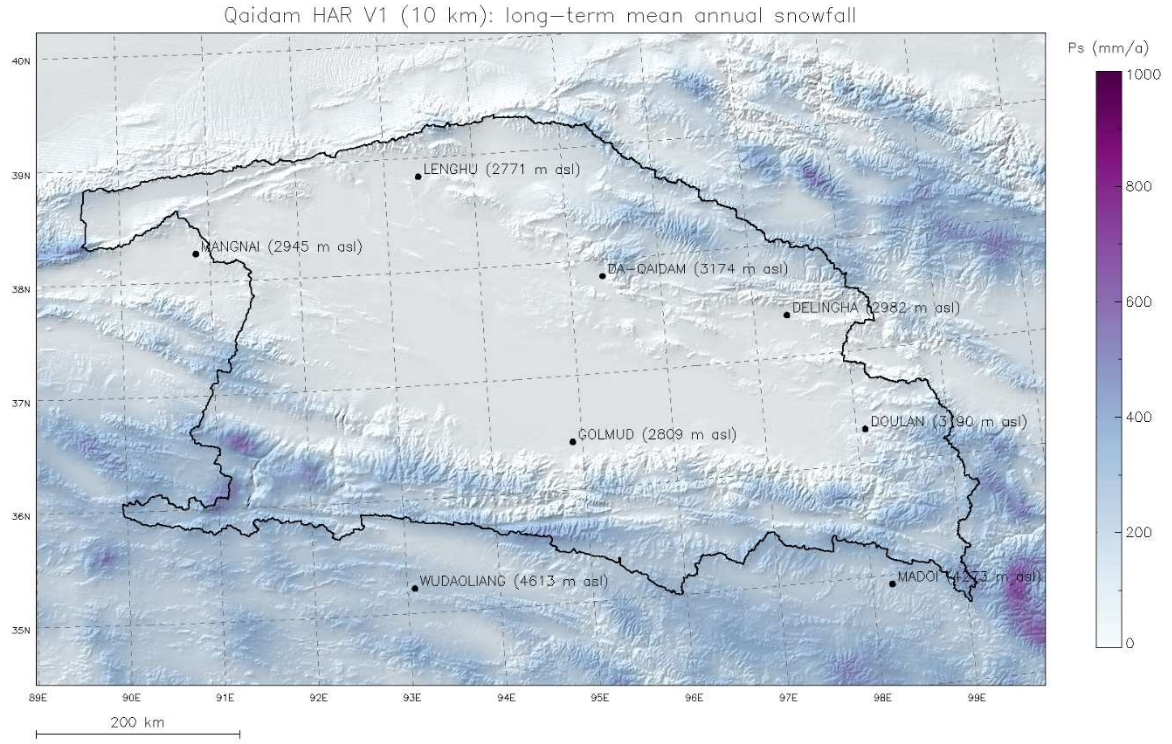
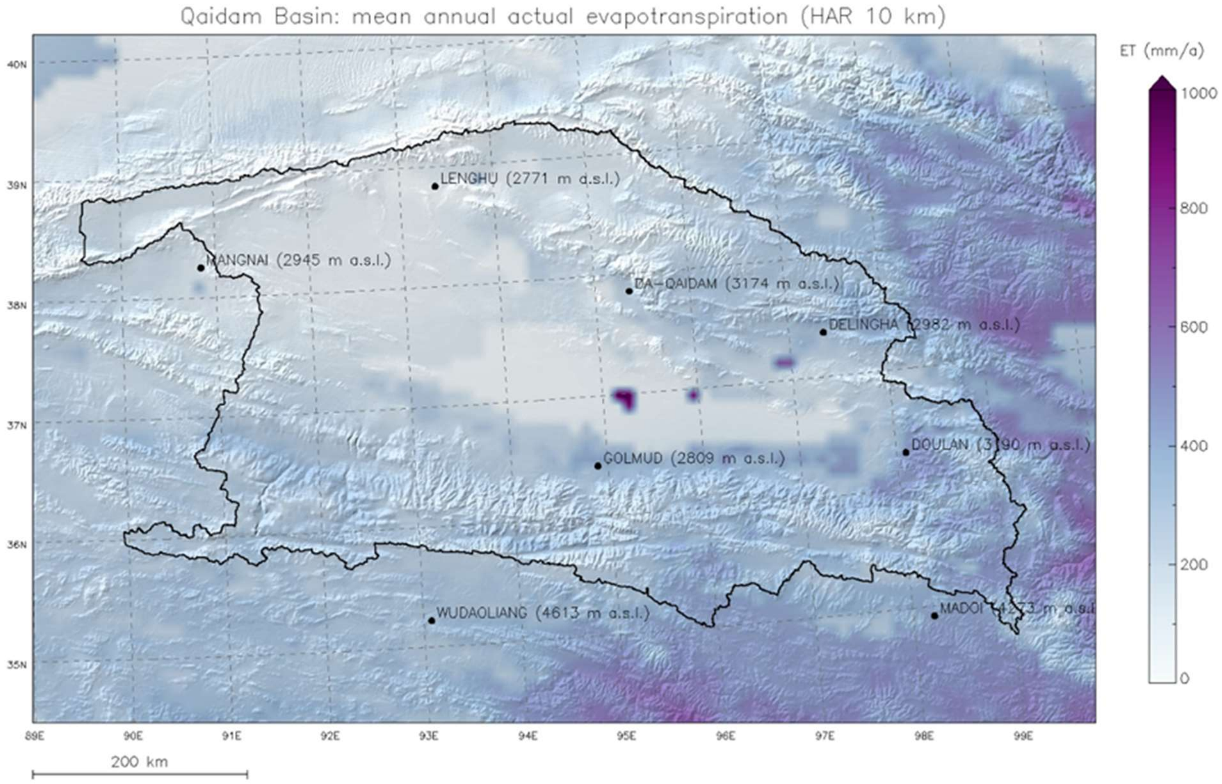

Qaidam HAR V1 (10 km): long−term mean annual snowfall
Ps (mm/a)
1000
800
600
400
200
0
LENGHU (2771 m asl)
MANGNAI (2945 m asl)
DA-QAIDAM (3174 m asl)
DELINGHA (2982 m asl)
DOULAN (3190 m asl)
GOLMUD (2809 m asl)
WUDAOLIANG (4613 m asl)
MADOI (4273 m asl)
40N
39N
38N
37N
36N
35N
89E
90E
91E
92E
93E
94E
95E
96E
97E
98E
99E
200 km

Figure S5: Mean annual snowfall ~~derived from the HAR V1 (10 km) data set for~~during the study period of 14 hydrological years (2001-2014) for the Qaidam ~~b~~Basin (QB) and its surrounding regions derived from the HAR 10 km data set. Black line: boundary of the Q~~aidam basin~~B (Lehner and Grill, 2013). Topographic shading is based on DEM data from the SRTM. Black dots indicate the locations of the eight GSOD stations within or nearby the QB.


Qaidam Basin: mean annual actual evapotranspiration (HAR 10 km)
ET (mm/a)
1000
800
600
400
200
0
40N
39N
38N
37N
36N
35N
89E
90E
91E
92E
93E
94E
95E
96E
97E
98E
99E
LENGHU (2771 m a.s.l.)
MANGNAI (2945 m a.s.l.)
DA-QAIDAM (3174 m a.s.l.)
DELINGHA (2982 m a.s.l.)
DOULAN (3190 m a.s.l.)
GOLMUD (2809 m a.s.l.)
WUDAOLIANG (4613 m a.s.l.)
MADOI (4273 m a.s.l
200 km

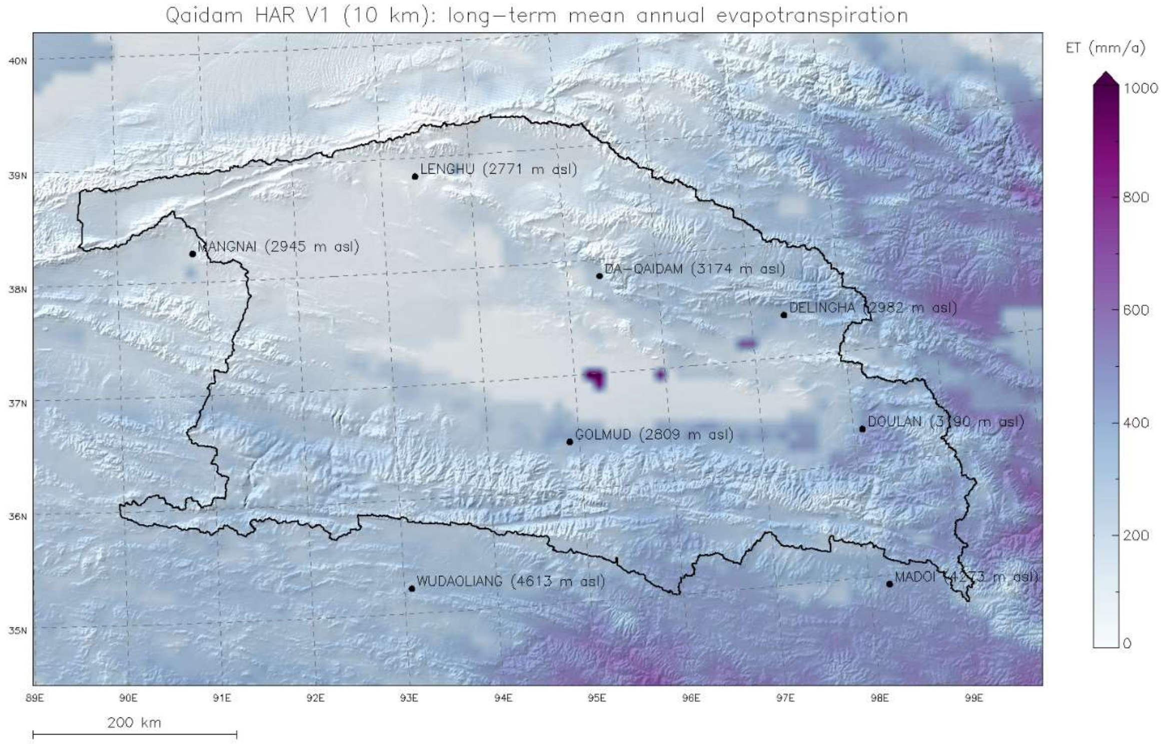
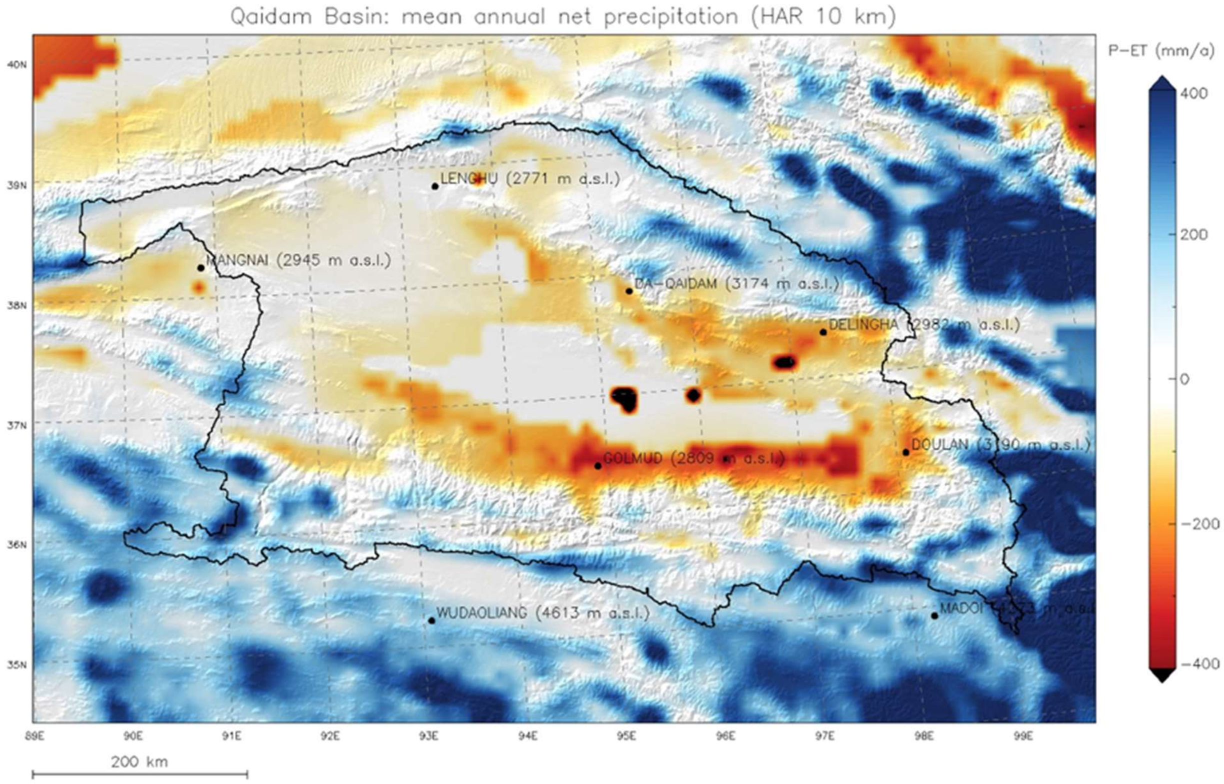

Qaidam HAR V1 (10 km): long-term mean annual evapotranspiration
ET (mm/a)
1000
800
600
400
200
0
40N
39N
38N
37N
36N
35N
89E
90E
91E
92E
93E
94E
95E
96E
97E
98E
99E
LENGHU (2771 m asl)
MANGNAI (2945 m asl)
DA-QAIDAM (3174 m asl)
DELINGHA (2982 m asl)
DOULAN (3190 m asl)
GOLMUD (2809 m asl)
WUDAOLIANG (4613 m asl)
MADOI (4273 m asl)
200 km

Figure S6: Mean annual actual evapotranspiration ~~derived from the HAR V1 (10 km) data set for~~during the study period of 14 hydrological years (2001-2014) for the Qaidam ~~b~~Basin (QB) and its surrounding regions derived from the HAR 10 km data set. Black line: boundary of the Q~~aidam basin~~B (Lehner and Grill, 2013). Topographic shading is based on DEM data from the SRTM. Black dots indicate the locations of the eight GSOD stations within or nearby the QB.


Qaidam Basin: mean annual net precipitation (HAR 10 km)
P-ET (mm/a)
400
200
0
-200
-400
LENGHU (2771 m a.s.l.)
MANGNAI (2945 m a.s.l.)
DA-QAIDAM (3174 m a.s.l.)
DELINGHA (2982 m a.s.l.)
DOULAN (3190 m a.s.l.)
GOLMUD (2809 m a.s.l.)
WUDAOLIANG (4613 m a.s.l.)
MADOI
40N
39N
38N
37N
36N
35N
89E
90E
91E
92E
93E
94E
95E
96E
97E
98E
99E
200 km

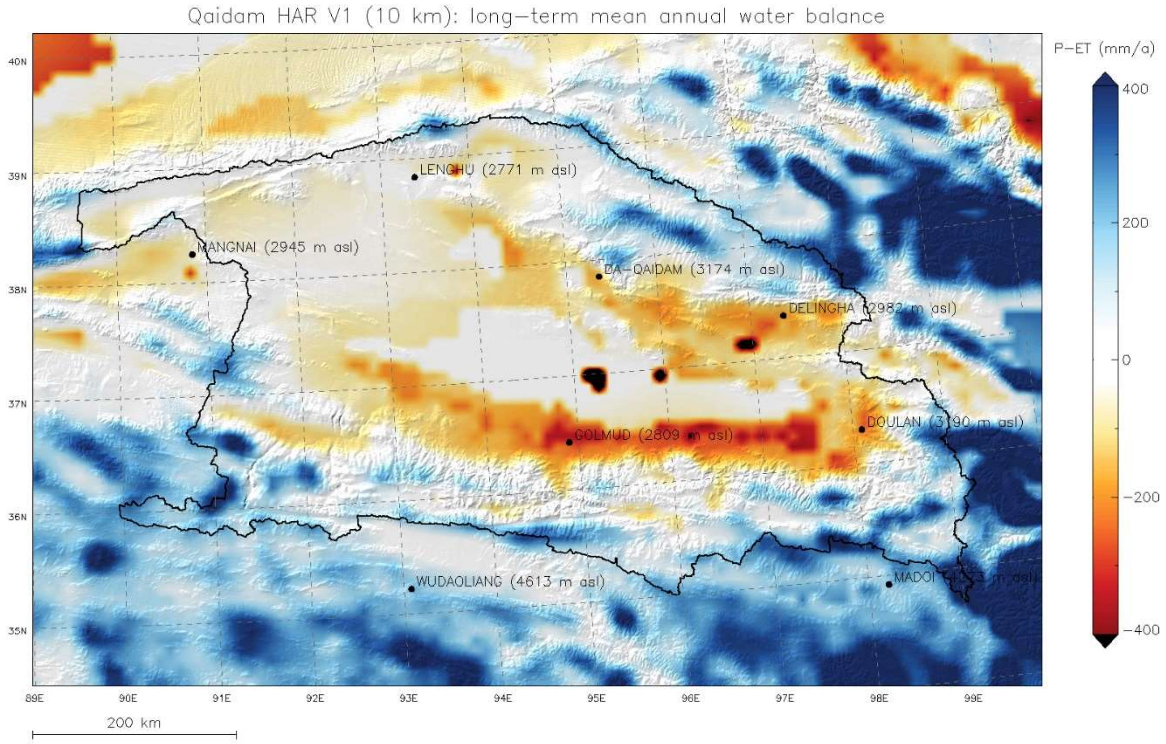

Qaidam HAR V1 (10 km): long-term mean annual water balance
P-ET (mm/a)
400
200
0
-200
-400
LENGHU (2771 m asl)
MANGNAI (2945 m asl)
DA-QAIDAM (3174 m asl)
DELINGHA (2982 m asl)
DOULAN (3190 m asl)
GOLMUD (2809 m asl)
WUDAOLIANG (4613 m asl)
MADOI
40N
39N
38N
37N
36N
35N
89E
90E
91E
92E
93E
94E
95E
96E
97E
98E
99E
200 km

Figure S7: Mean annual ~~water balance~~net precipitation, i.e., precipitation P minus actual evapotranspiration ET, ~~derived from the HAR V1 (10 km) data set for~~during the study period of 14 hydrological years (2001-2014) for the Qaidam ~~b~~Basin (QB) and its surrounding regions derived from the HAR 10 km data set. Black line: boundary of the Q~~aidam basin~~B (Lehner and Grill, 2013). Topographic shading is based on DEM data from the SRTM. Black dots indicate the locations of the eight GSOD stations within or nearby the QB.

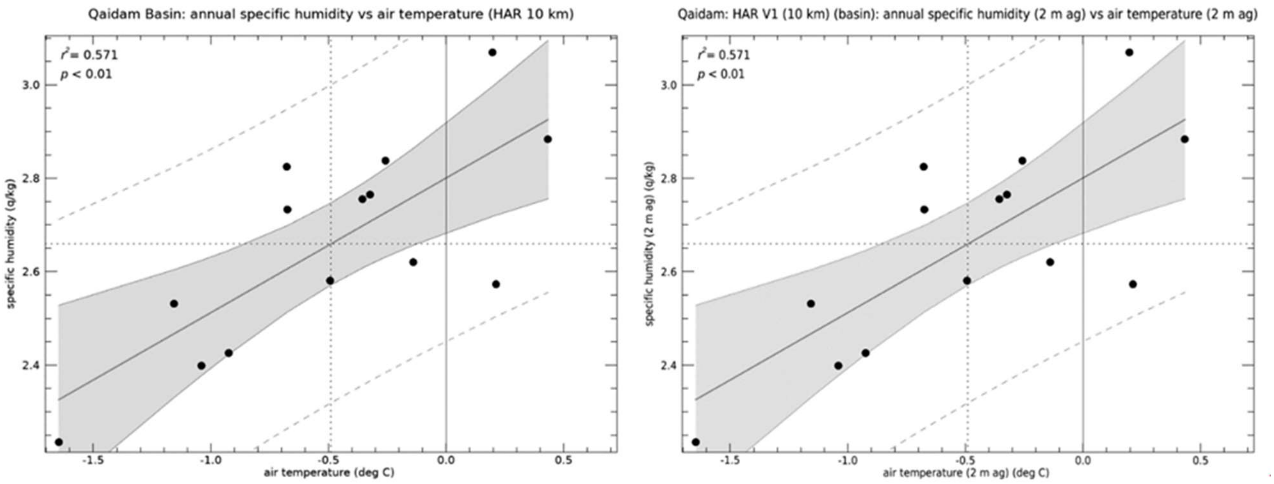


Figure S8: Specific humidity ~~*q*~~ versus air temperature ~~*T*~~ in the Qaidam ~~b~~Basin (QB) during the hydrological years 2001 to 2014 derived from the HAR 10 km data set. Dotted lines: mean annual ~~mean~~values; solid lines: regression lines; light grey shades: confidence interval; dashed lines: prediction interval.

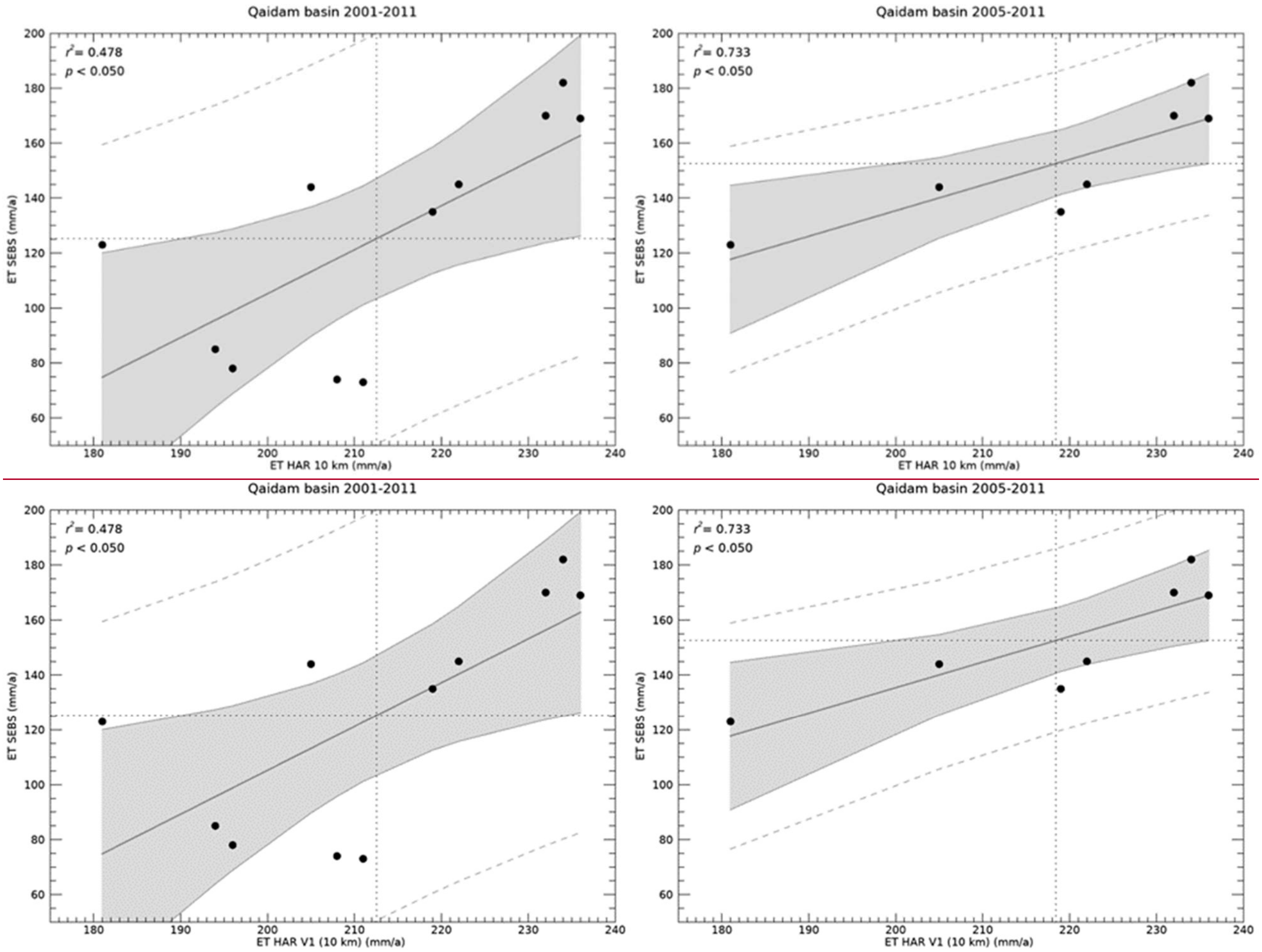
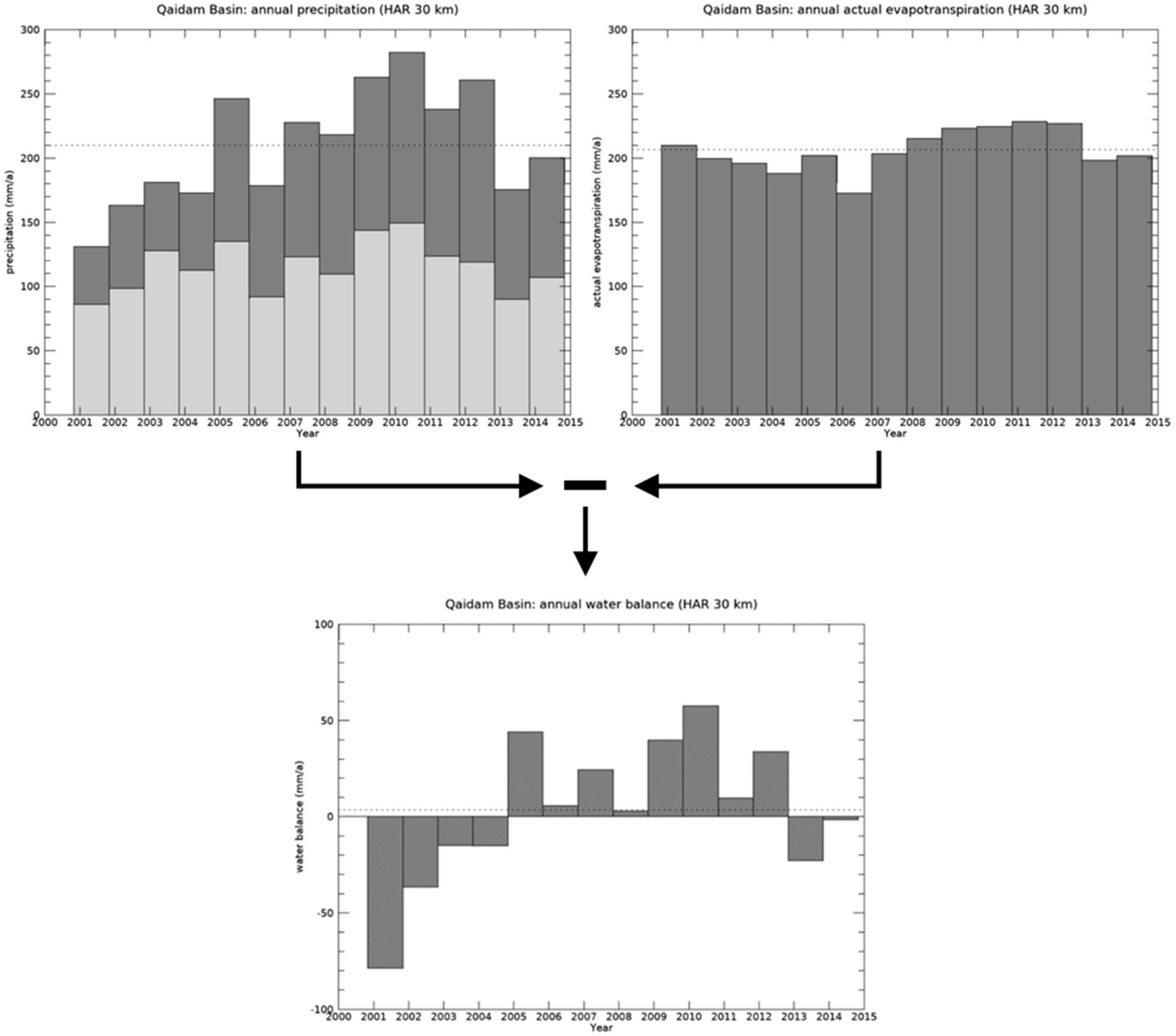


Figure S9: Annual actual evapotranspiration *ET* determined by the SEBS-based study of Jin et al. (2013) versus *ET* of the HAR ~~V1 (~~10~~-~~ km~~)~~ data set in the Qaidam ~~b~~Basin (QB) for the calendar years 2001-2011 (left panel) and 2005-2011 (right panel). Dotted lines: mean annual ~~mean~~values; solid lines: regression lines; light grey shades: confidence intervals; dashed lines: prediction intervals.


Qaidam Basin: annual precipitation (HAR 30 km)
precipitation (mm/a)
0
50
100
150
200
250
300
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year
Qaidam Basin: annual actual evapotranspiration (HAR 30 km)
actual evapotranspiration (mm/a)
0
50
100
150
200
250
300
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year
Qaidam Basin: annual water balance (HAR 30 km)
water balance (mm/a)
-100
-50
0
50
100
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year

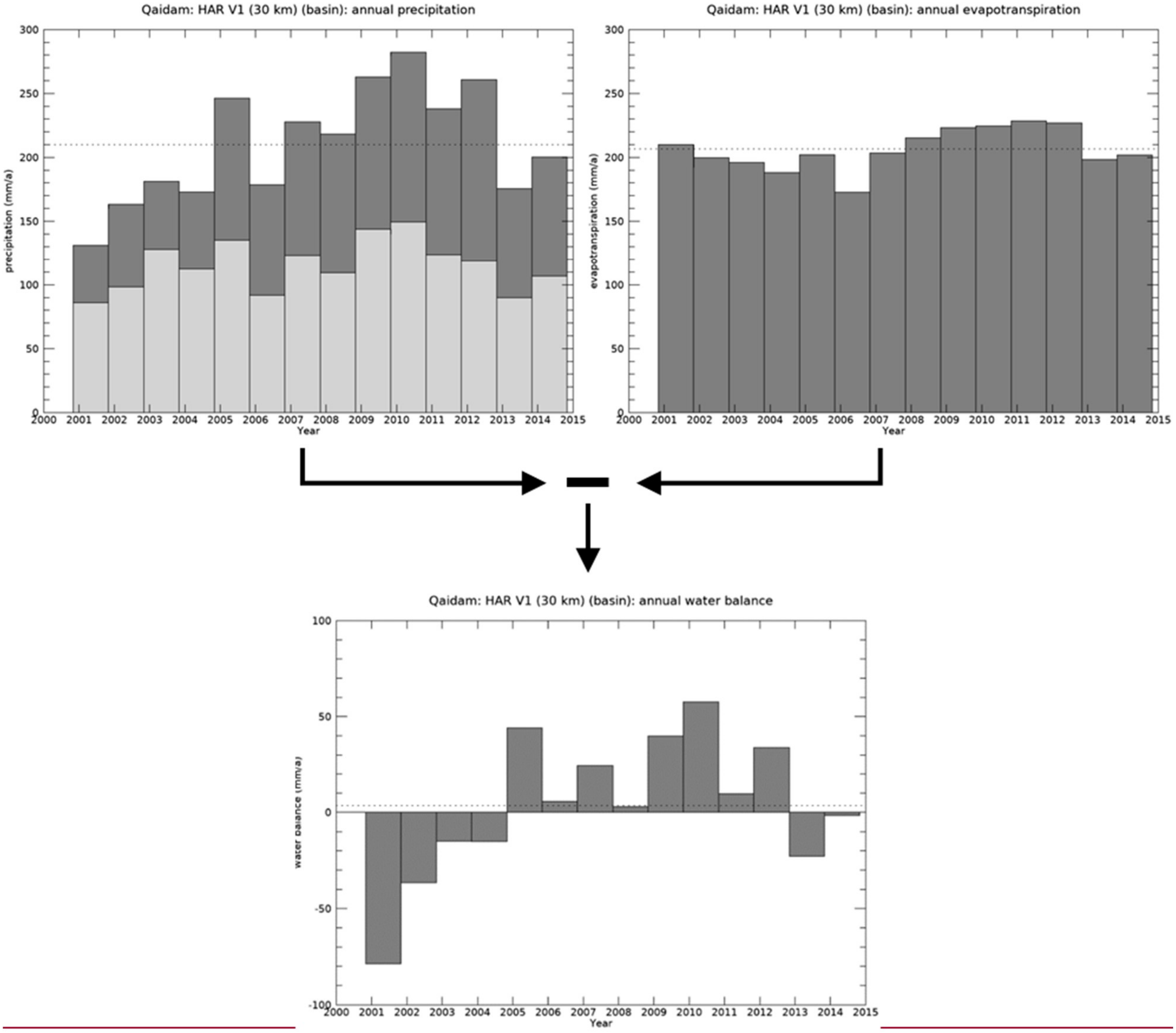
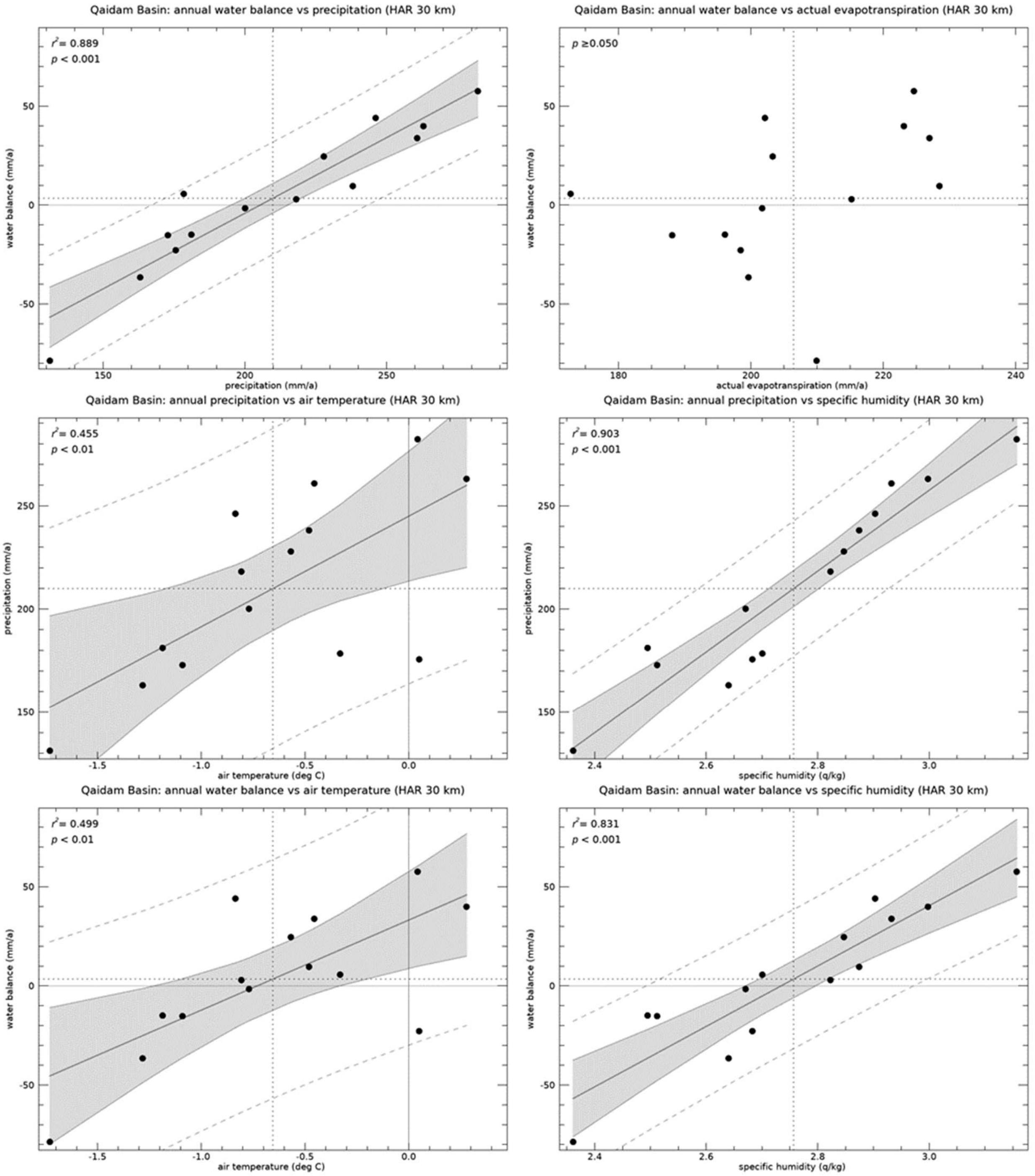


Figure S10: Annual precipitation ~~P~~ (upper left panel), actual evapotranspiration ~~ET~~ (upper right panel), and water balance ~~$\Delta S = P - ET$~~ (lower panel) in the Qaidam ~~b~~Basin (QB) during the hydrological years 2001 to 2014 as in Fig. 2 but derived from the HAR 30 km ~~model domain of the HAR V1~~ data set. Upper left panel: light grey bars: annual snowfall ~~P_{snow}~~; dark grey bars: annual rainfall ~~$P_{rain} = P - P_{snow}$~~. Dotted lines: mean annual values.


Qaidam Basin: annual water balance vs precipitation (HAR 30 km)
r^2 = 0.889
p < 0.001
water balance (mm/a)
precipitation (mm/a)
50
0
-50
150
200
250
Qaidam Basin: annual water balance vs actual evapotranspiration (HAR 30 km)
p ≥0.050
water balance (mm/a)
actual evapotranspiration (mm/a)
180
200
220
240
Qaidam Basin: annual precipitation vs air temperature (HAR 30 km)
r^2 = 0.455
p < 0.01
precipitation (mm/a)
air temperature (deg C)
150
200
250
-1.5
-1.0
-0.5
0.0
Qaidam Basin: annual precipitation vs specific humidity (HAR 30 km)
r^2 = 0.903
p < 0.001
precipitation (mm/a)
specific humidity (q/kg)
2.4
2.6
2.8
3.0
Qaidam Basin: annual water balance vs air temperature (HAR 30 km)
r^2 = 0.499
p < 0.01
water balance (mm/a)
air temperature (deg C)
Qaidam Basin: annual water balance vs specific humidity (HAR 30 km)
r^2 = 0.831
p < 0.001
water balance (mm/a)
specific humidity (q/kg)

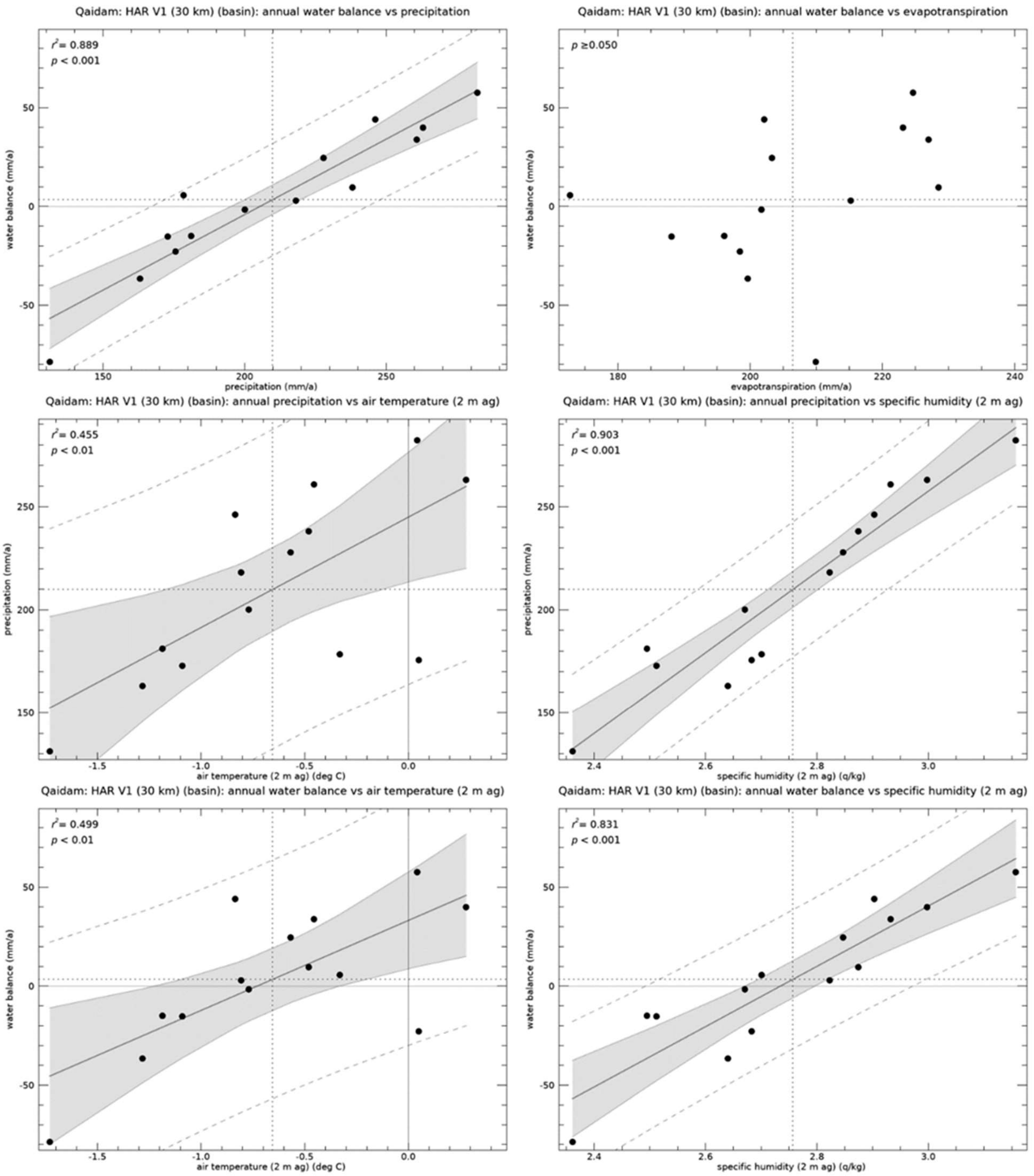


Figure S11: Water balance ~~$\Delta S = P - ET$~~ versus precipitation ~~P~~ (upper left panel) and actual evapotranspiration ~~ET~~ (upper right panel); ~~P~~precipitation versus air temperature ~~T~~ (middle left panel) and specific humidity ~~q~~ (middle right panel); ~~ΔS~~ water balance versus ~~T~~air temperature (lower left panel) and specific humidity ~~q~~ (lower right panel) in the Qaidam Basin (QB) during the hydrological years 2001 to 2014 as in Fig~~ure~~. 4 but derived from the HAR 30 km ~~model domain of the HAR V1~~ data set. Dotted

lines: mean annual ~~mean~~values; solid lines: regression lines; light grey shades: confidence intervals; dashed lines: prediction intervals.

2 Supplementary Tables

Table S2: Monthly and annual air temperature *T* (in deg C) ~~*T*~~ in the Qaidam ~~b~~Basin (QB) ~~for~~during the 14 hydrological years (2001-2014) covered by the HAR ~~V1 (~~10 km~~)~~ data set.

T	10	11	12	1	2	3	4	5	6	7	8	9	**year**
2001	-2.0	-10.3	-14.2	-16.1	-11.5	-7.7	-1.8	3.5	9.4	13.3	10.6	6.5	**-1.6**
2002	-1.5	-8.3	-14.5	-16.7	-10.8	-6.6	1.0	4.1	9.9	12.4	11.6	5.1	**-1.2**
2003	-3.1	-9.5	-12.3	-13.2	-10.2	-5.9	0.2	3.9	9.2	11.2	10.6	6.1	**-1.0**
2004	-1.2	-7.4	-12.7	-14.9	-11.6	-4.3	1.4	4.1	8.4	11.2	10.3	5.3	**-0.9**
2005	-2.0	-10.6	-11.8	-13.1	-10.4	-4.8	-0.5	5.1	9.6	11.6	10.9	7.3	**-0.7**
2006	-0.9	-8.7	-13.4	-11.5	-8.5	-6.6	-0.7	5.1	9.7	13.0	12.9	7.7	**-0.1**
2007	0.8	-7.3	-13.7	-16.2	-10.0	-5.8	0.9	7.0	9.4	11.5	12.0	6.6	**-0.4**
2008	-0.6	-7.2	-11.7	-14.8	-14.9	-5.4	0.1	7.1	10.0	11.7	9.8	7.2	**-0.7**
2009	0.3	-7.3	-11.0	-12.8	-8.4	-5.0	2.6	5.3	10.2	12.1	10.7	8.0	**0.4**
2010	-0.6	-8.2	-12.6	-11.5	-8.9	-5.3	-0.8	5.4	9.8	13.9	12.8	7.7	**0.2**
2011	-0.2	-8.1	-14.3	-16.5	-8.8	-7.7	0.8	6.4	10.7	12.9	12.8	7.7	**-0.3**
2012	0.9	-5.6	-12.3	-17.9	-11.9	-6.8	0.1	6.4	10.7	12.7	12.6	7.6	**-0.3**
2013	-1.0	-9.1	-13.7	-15.2	-9.6	-2.5	1.3	6.3	11.5	12.9	13.8	7.4	**0.2**
2014	0.8	-10.3	-15.2	-14.1	-11.3	-4.4	-0.1	5.0	10.2	13.4	11.6	7.9	**-0.5**
mean	**-0.7**	**-8.4**	**-13.1**	**-14.6**	**-10.5**	**-5.6**	**0.3**	**5.3**	**9.9**	**12.4**	**11.6**	**7.0**	**-0.5**

***T* (deg C)**	10	11	12	1	2	3	4	5	6	7	8	9	**year**
2001	-2.0	-10.3	-14.2	-16.1	-11.5	-7.7	-1.8	3.5	9.4	13.3	10.6	6.5	**-1.6**
2002	-1.5	-8.3	-14.5	-16.7	-10.8	-6.6	1.0	4.1	9.9	12.4	11.6	5.1	**-1.2**
2003	-3.1	-9.5	-12.3	-13.2	-10.2	-5.9	0.2	3.9	9.2	11.2	10.6	6.1	**-1.0**
2004	-1.2	-7.4	-12.7	-14.9	-11.6	-4.3	1.4	4.1	8.4	11.2	10.3	5.3	**-0.9**
2005	-2.0	-10.6	-11.8	-13.1	-10.4	-4.8	-0.5	5.1	9.6	11.6	10.9	7.3	**-0.7**
2006	-0.9	-8.7	-13.4	-11.5	-8.5	-6.6	-0.7	5.1	9.7	13.0	12.9	7.7	**-0.1**
2007	0.8	-7.3	-13.7	-16.2	-10.0	-5.8	0.9	7.0	9.4	11.5	12.0	6.6	**-0.4**
2008	-0.6	-7.2	-11.7	-14.8	-14.9	-5.4	0.1	7.1	10.0	11.7	9.8	7.2	**-0.7**
2009	0.3	-7.3	-11.0	-12.8	-8.4	-5.0	2.6	5.3	10.2	12.1	10.7	8.0	**0.4**
2010	-0.6	-8.2	-12.6	-11.5	-8.9	-5.3	-0.8	5.4	9.8	13.9	12.8	7.7	**0.2**
2011	-0.2	-8.1	-14.3	-16.5	-8.8	-7.7	0.8	6.4	10.7	12.9	12.8	7.7	**-0.3**
2012	0.9	-5.6	-12.3	-17.9	-11.9	-6.8	0.1	6.4	10.7	12.7	12.6	7.6	**-0.3**
2013	-1.0	-9.1	-13.7	-15.2	-9.6	-2.5	1.3	6.3	11.5	12.9	13.8	7.4	**0.2**
2014	0.8	-10.3	-15.2	-14.1	-11.3	-4.4	-0.1	5.0	10.2	13.4	11.6	7.9	**-0.5**
mean	**-0.7**	**-8.4**	**-13.1**	**-14.6**	**-10.5**	**-5.6**	**0.3**	**5.3**	**9.9**	**12.4**	**11.6**	**7.0**	-0.5

Table S2: Monthly and annual specific humidity ~~*q*~~ *q* (in g/kg) in the Qaidam ~~b~~Basin (QB) ~~for~~during the 14 hydrological years (2001-2014) covered by the HAR ~~V1 (~~10 km~~)~~ data set.

q	10	11	12	1	2	3	4	5	6	7	8	9	year
2001	1.9	1.2	1.0	0.8	0.9	1.0	1.8	2.3	3.1	4.2	4.7	3.8	**2.2**
2002	1.7	1.3	1.0	0.9	1.1	1.4	2.2	2.7	4.0	5.5	4.4	4.0	**2.5**
2003	2.0	1.4	1.3	1.1	1.4	1.7	2.4	2.5	3.5	4.0	4.3	3.1	**2.4**
2004	1.8	1.6	1.1	1.1	1.3	1.7	1.9	2.7	3.3	4.5	5.0	2.9	**2.4**
2005	2.0	1.4	1.3	1.1	1.2	1.9	1.9	2.8	4.2	6.2	5.7	4.0	**2.8**
2006	2.0	1.2	0.8	1.1	1.5	1.1	1.7	2.4	4.3	6.4	5.1	3.5	**2.6**
2007	2.2	1.5	1.0	0.7	1.2	1.7	2.0	2.5	4.4	5.5	5.9	4.3	**2.8**
2008	2.7	1.3	1.0	1.0	1.1	1.5	1.8	3.0	4.2	6.1	4.6	4.5	**2.7**
2009	2.6	1.6	1.2	1.1	1.3	1.5	2.0	2.9	4.1	6.1	4.8	5.3	**2.9**
2010	2.4	1.4	1.1	1.1	1.4	1.7	2.0	3.1	5.6	7.1	5.1	4.7	**3.1**
2011	2.6	1.3	0.9	0.7	1.3	1.3	2.0	3.2	4.8	5.4	5.6	4.0	**2.8**
2012	2.3	1.7	0.9	0.8	1.2	1.5	1.7	3.4	5.0	6.5	6.0	3.1	**2.8**
2013	1.9	1.1	0.9	0.9	1.2	1.2	1.6	3.2	4.5	5.9	5.2	3.3	**2.6**
2014	2.0	1.2	0.9	0.8	1.1	1.5	2.0	2.1	4.6	5.4	5.0	4.2	**2.6**
mean	**2.2**	**1.4**	**1.0**	**0.9**	**1.2**	**1.5**	**1.9**	**2.8**	**4.3**	**5.6**	**5.1**	**3.9**	**2.7**

q **(g/kg)**	10	11	12	1	2	3	4	5	6	7	8	9	year
2001	1.9	1.2	1.0	0.8	0.9	1.0	1.8	2.3	3.1	4.2	4.7	3.8	**2.2**
2002	1.7	1.3	1.0	0.9	1.1	1.4	2.2	2.7	4.0	5.5	4.4	4.0	**2.5**
2003	2.0	1.4	1.3	1.1	1.4	1.7	2.4	2.5	3.5	4.0	4.3	3.1	**2.4**
2004	1.8	1.6	1.1	1.1	1.3	1.7	1.9	2.7	3.3	4.5	5.0	2.9	**2.4**
2005	2.0	1.4	1.3	1.1	1.2	1.9	1.9	2.8	4.2	6.2	5.7	4.0	**2.8**
2006	2.0	1.2	0.8	1.1	1.5	1.1	1.7	2.4	4.3	6.4	5.1	3.5	**2.6**
2007	2.2	1.5	1.0	0.7	1.2	1.7	2.0	2.5	4.4	5.5	5.9	4.3	**2.8**
2008	2.7	1.3	1.0	1.0	1.1	1.5	1.8	3.0	4.2	6.1	4.6	4.5	**2.7**
2009	2.6	1.6	1.2	1.1	1.3	1.5	2.0	2.9	4.1	6.1	4.8	5.3	**2.9**
2010	2.4	1.4	1.1	1.1	1.4	1.7	2.0	3.1	5.6	7.1	5.1	4.7	**3.1**
2011	2.6	1.3	0.9	0.7	1.3	1.3	2.0	3.2	4.8	5.4	5.6	4.0	**2.8**
2012	2.3	1.7	0.9	0.8	1.2	1.5	1.7	3.4	5.0	6.5	6.0	3.1	**2.8**
2013	1.9	1.1	0.9	0.9	1.2	1.2	1.6	3.2	4.5	5.9	5.2	3.3	**2.6**
2014	2.0	1.2	0.9	0.8	1.1	1.5	2.0	2.1	4.6	5.4	5.0	4.2	**2.6**
mean	**2.2**	**1.4**	**1.0**	**0.9**	**1.2**	**1.5**	**1.9**	**2.8**	**4.3**	**5.6**	**5.1**	**3.9**	**2.7**

Table S3: Monthly and annual precipitation *P* (in mm/month or mm/a) ~~*P*~~ in the Qaidam ~~b~~Basin (QB) ~~for~~during the 14 hydrological years (2001-2014) covered by the HAR ~~V1 (~~10 km~~)~~ data set.

P	10	11	12	1	2	3	4	5	6	7	8	9	**year**
2001	5	4	6	3	3	3	19	16	17	11	20	15	**122**
2002	2	1	6	3	3	10	16	25	34	25	12	22	**160**
2003	5	3	6	4	8	17	28	23	19	21	26	10	**171**
2004	3	5	5	8	10	11	12	29	24	24	24	8	**163**
2005	6	4	8	3	7	13	9	27	29	55	39	26	**229**
2006	5	2	1	3	12	4	16	16	37	39	23	12	**170**
2007	8	3	2	1	5	14	14	20	59	35	28	33	**222**
2008	7	2	1	6	6	7	13	24	26	60	25	35	**212**
2009	13	5	6	6	9	14	11	44	20	57	33	38	**256**
2010	12	5	4	5	7	21	14	39	77	42	18	26	**270**
2011	11	1	3	3	6	12	14	35	49	29	35	22	**221**
2012	7	5	1	3	6	10	10	44	46	60	40	14	**246**
2013	12	4	4	3	7	2	7	30	24	41	18	23	**174**
2014	5	3	2	1	5	9	19	14	41	31	27	30	**188**
mean	**7**	**3**	**4**	**4**	**7**	**11**	**15**	**28**	**36**	**38**	**26**	**23**	**200**

***P* (mm)**	10	11	12	1	2	3	4	5	6	7	8	9	**year**
2001	5	4	6	3	3	3	19	16	17	11	20	15	**122**
2002	2	1	6	3	3	10	16	25	34	25	12	22	**160**
2003	5	3	6	4	8	17	28	23	19	21	26	10	**171**
2004	3	5	5	8	10	11	12	29	24	24	24	8	**163**
2005	6	4	8	3	7	13	9	27	29	55	39	26	**229**
2006	5	2	1	3	12	4	16	16	37	39	23	12	**170**
2007	8	3	2	1	5	14	14	20	59	35	28	33	**222**
2008	7	2	1	6	6	7	13	24	26	60	25	35	**212**
2009	13	5	6	6	9	14	11	44	20	57	33	38	**256**
2010	12	5	4	5	7	21	14	39	77	42	18	26	**270**
2011	11	1	3	3	6	12	14	35	49	29	35	22	**221**
2012	7	5	1	3	6	10	10	44	46	60	40	14	**246**
2013	12	4	4	3	7	2	7	30	24	41	18	23	**174**
2014	5	3	2	1	5	9	19	14	41	31	27	30	**188**
mean	**7**	**3**	**4**	**4**	**7**	**11**	**15**	**28**	**36**	**38**	**26**	**23**	**200**

Table S4: Monthly and annual rainfall P_{rain} (in mm/month or mm/a) ~~P_{rain}~~ in the Qaidam ~~b~~Basin (QB) ~~for~~during the 14 hydrological years (2001-2014) covered by the HAR ~~V1 (~~10 km~~)~~ data set.

P_{rain}	10	11	12	1	2	3	4	5	6	7	8	9	**year**
2001	1	0	0	0	0	1	3	3	7	10	13	8	**45**
2002	0	0	0	0	0	0	4	8	19	19	9	10	**70**
2003	0	0	0	0	0	1	7	5	8	12	15	3	**52**
2004	0	0	0	0	0	1	3	7	14	16	18	3	**62**
2005	0	0	0	0	1	1	2	8	15	42	28	12	**110**
2006	0	0	0	0	0	0	5	5	19	36	16	6	**87**
2007	2	1	0	0	0	1	5	5	31	26	24	16	**110**
2008	1	0	0	0	0	1	3	10	16	46	15	19	**112**
2009	3	0	0	0	0	1	3	13	11	44	23	27	**126**
2010	1	0	0	0	1	1	2	14	54	36	14	17	**141**
2011	1	0	0	0	1	1	3	10	33	22	30	12	**113**
2012	2	1	0	0	0	0	2	17	28	51	35	5	**142**
2013	2	0	0	0	0	1	2	11	18	33	16	9	**93**
2014	1	0	0	0	0	1	4	4	24	26	20	14	**95**
mean	**1**	**0**	**0**	**0**	**1**	**1**	**4**	**9**	**21**	**30**	**19**	**12**	**97**

P_{rain} (mm)	10	11	12	1	2	3	4	5	6	7	8	9	**year**
2001	1	0	0	0	0	1	3	3	7	10	13	8	**45**
2002	0	0	0	0	0	0	4	8	19	19	9	10	**70**
2003	0	0	0	0	0	1	7	5	8	12	15	3	**52**
2004	0	0	0	0	0	1	3	7	14	16	18	3	**62**
2005	0	0	0	0	1	1	2	8	15	42	28	12	**110**
2006	0	0	0	0	0	0	5	5	19	36	16	6	**87**
2007	2	1	0	0	0	1	5	5	31	26	24	16	**110**
2008	1	0	0	0	0	1	3	10	16	46	15	19	**112**
2009	3	0	0	0	0	1	3	13	11	44	23	27	**126**
2010	1	0	0	0	1	1	2	14	54	36	14	17	**141**
2011	1	0	0	0	1	1	3	10	33	22	30	12	**113**
2012	2	1	0	0	0	0	2	17	28	51	35	5	**142**
2013	2	0	0	0	0	1	2	11	18	33	16	9	**93**
2014	1	0	0	0	0	1	4	4	24	26	20	14	**95**
mean	**1**	**0**	**0**	**0**	**1**	**1**	**4**	**9**	**21**	**30**	**19**	**12**	**97**

Table S5: Monthly and annual snowfall P_{snow} (in mm/month or mm/a) in the Qaidam Basin (QB) during the 14 hydrological years (2001-2014) covered by the HAR 10 km data set~~P_{snow} in the Qaidam basin for the 14 hydrological years (2001-2014) covered by the HAR V1 (10 km) data set~~.

P_{snow}	10	11	12	1	2	3	4	5	6	7	8	9	year
2001	4	4	6	3	3	2	16	13	10	1	7	7	**77**
2002	2	1	6	3	3	10	12	17	15	6	3	12	**90**
2003	5	3	6	4	8	16	21	18	11	9	11	7	**119**
2004	3	5	5	8	10	10	9	22	10	8	6	5	**101**
2005	6	4	8	3	6	12	7	19	14	13	11	14	**119**
2006	5	2	1	3	12	4	11	11	18	3	7	6	**83**
2007	6	2	2	1	5	13	9	15	28	9	4	17	**112**
2008	6	2	1	6	6	6	10	14	10	14	10	16	**100**
2009	10	5	6	6	9	13	8	31	9	13	10	11	**130**
2010	11	5	4	5	6	20	12	25	23	6	4	9	**129**
2011	10	1	3	3	5	11	11	25	16	7	5	10	**108**
2012	5	4	1	3	6	10	8	27	18	9	5	9	**104**
2013	10	4	4	3	7	1	5	19	6	8	2	14	**81**
2014	4	3	2	1	5	8	15	10	17	5	7	16	**93**
mean	**6**	**3**	**4**	**4**	**6**	**10**	**11**	**19**	**15**	**8**	**7**	**11**	**103**

P_{snow} (mm)	10	11	12	1	2	3	4	5	6	7	8	9	year
2001	4	4	6	3	3	2	16	13	10	1	7	7	**77**
2002	2	1	6	3	3	10	12	17	15	6	3	12	**90**
2003	5	3	6	4	8	16	21	18	11	9	11	7	**119**
2004	3	5	5	8	10	10	9	22	10	8	6	5	**101**
2005	6	4	8	3	6	12	7	19	14	13	11	14	**119**
2006	5	2	1	3	12	4	11	11	18	3	7	6	**83**
2007	6	2	2	1	5	13	9	15	28	9	4	17	**112**
2008	6	2	1	6	6	6	10	14	10	14	10	16	**100**
2009	10	5	6	6	9	13	8	31	9	13	10	11	**130**
2010	11	5	4	5	6	20	12	25	23	6	4	9	**129**
2011	10	1	3	3	5	11	11	25	16	7	5	10	**108**
2012	5	4	1	3	6	10	8	27	18	9	5	9	**104**
2013	10	4	4	3	7	1	5	19	6	8	2	14	**81**
2014	4	3	2	1	5	8	15	10	17	5	7	16	**93**
mean	**6**	**3**	**4**	**4**	**6**	**10**	**11**	**19**	**15**	**8**	**7**	**11**	**103**

Table S6: Monthly and annual actual evapotranspiration ~~ET in the Qaidam basin for the 14 hydrological years (2001-2014) covered by the HAR V1 (10 km) data set~~ET (in mm/month or mm/a) in the Qaidam Basin (QB) during the 14 hydrological years (2001-2014) covered by the HAR 10 km data set.

ET	10	11	12	1	2	3	4	5	6	7	8	9	**year**
2001	13	7	5	5	8	16	22	30	28	32	31	20	**216**
2002	10	5	4	4	8	14	18	26	33	34	27	20	**204**
2003	12	7	5	5	9	17	21	26	25	28	27	18	**200**
2004	10	6	4	5	8	14	17	25	25	30	32	17	**193**
2005	10	6	5	6	8	14	20	23	27	34	31	21	**208**
2006	11	6	4	6	7	10	13	19	27	34	25	17	**179**
2007	11	7	5	4	8	16	15	20	31	38	32	24	**210**
2008	17	8	6	5	7	13	18	22	30	35	37	23	**222**
2009	17	9	6	6	9	16	18	27	29	37	32	26	**233**
2010	16	10	6	7	9	17	20	23	36	39	30	20	**234**
2011	18	10	7	6	11	16	18	28	33	34	34	23	**238**
2012	16	10	5	4	9	17	20	32	32	34	36	21	**238**
2013	13	8	5	5	9	11	12	29	29	35	30	22	**209**
2014	14	8	4	6	8	13	24	21	24	34	31	23	**212**
mean	**13**	**8**	**5**	**5**	**9**	**15**	**18**	**25**	**29**	**34**	**31**	**21**	**214**

***ET* (mm)**	10	11	12	1	2	3	4	5	6	7	8	9	**year**
2001	13	7	5	5	8	16	22	30	28	32	31	20	**216**
2002	10	5	4	4	8	14	18	26	33	34	27	20	**204**
2003	12	7	5	5	9	17	21	26	25	28	27	18	**200**
2004	10	6	4	5	8	14	17	25	25	30	32	17	**193**
2005	10	6	5	6	8	14	20	23	27	34	31	21	**208**
2006	11	6	4	6	7	10	13	19	27	34	25	17	**179**
2007	11	7	5	4	8	16	15	20	31	38	32	24	**210**
2008	17	8	6	5	7	13	18	22	30	35	37	23	**222**
2009	17	9	6	6	9	16	18	27	29	37	32	26	**233**
2010	16	10	6	7	9	17	20	23	36	39	30	20	**234**
2011	18	10	7	6	11	16	18	28	33	34	34	23	**238**
2012	16	10	5	4	9	17	20	32	32	34	36	21	**238**
2013	13	8	5	5	9	11	12	29	29	35	30	22	**209**
2014	14	8	4	6	8	13	24	21	24	34	31	23	**212**
mean	**13**	**8**	**5**	**5**	**9**	**15**	**18**	**25**	**29**	**34**	**31**	**21**	**214**

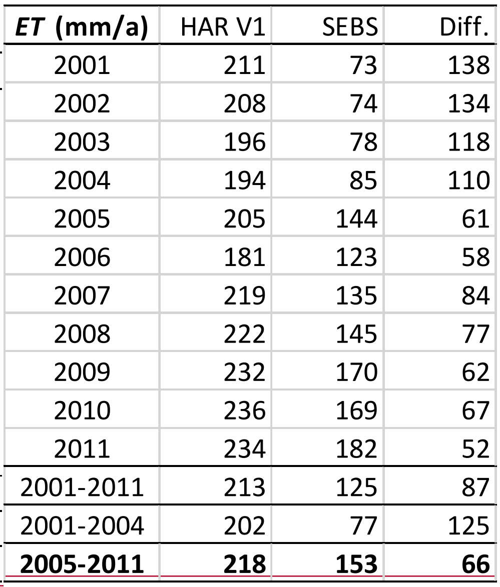
Table S7: Monthly and annual water balance ΔS (in mm/month or mm/a) in the Qaidam Basin (QB) during the 14 hydrological years (2001-2014) covered by the HAR 10 km data set~~$\Delta S = P - ET$ (precipitation P minus actual evapotranspiration ET) in the Qaidam basin for the 14 hydrological years (2001-2014) covered by the HAR V1 (10 km) data set~~.

ΔS	10	11	12	1	2	3	4	5	6	7	8	9	year
2001	-8	-3	1	-2	-5	-13	-3	-13	-11	-21	-11	-5	**-94**
2002	-8	-4	2	-1	-4	-4	-2	-2	2	-9	-15	1	**-44**
2003	-6	-4	1	-1	-1	0	7	-2	-6	-7	-1	-8	**-29**
2004	-7	-1	1	3	2	-3	-5	3	-1	-6	-8	-9	**-30**
2005	-4	-2	3	-3	-2	-1	-11	4	2	21	8	5	**21**
2006	-6	-4	-2	-2	5	-6	3	-3	10	5	-3	-5	**-10**
2007	-3	-4	-3	-4	-3	-2	-2	0	29	-2	-4	10	**11**
2008	-10	-7	-4	1	-1	-7	-5	2	-5	25	-12	12	**-10**
2009	-5	-4	-1	0	0	-1	-7	17	-9	20	1	12	**24**
2010	-4	-5	-3	-2	-2	4	-6	16	42	3	-13	6	**36**
2011	-7	-9	-3	-3	-5	-4	-4	6	16	-5	1	-1	**-17**
2012	-9	-5	-4	-1	-3	-7	-10	12	14	26	3	-7	**8**
2013	-1	-4	-2	-2	-2	-9	-5	1	-5	6	-12	1	**-35**
2014	-9	-6	-3	-4	-3	-4	-5	-6	17	-3	-4	7	**-24**
mean	**-6**	**-4**	**-1**	**-2**	**-2**	**-4**	**-4**	**2**	**7**	**4**	**-5**	**1**	**-14**

***P-ET* (mm)**	10	11	12	1	2	3	4	5	6	7	8	9	**year**
2001	-8	-3	1	-2	-5	-13	-3	-13	-11	-21	-11	-5	**-94**
2002	-8	-4	2	-1	-4	-4	-2	-2	2	-9	-15	1	**-44**
2003	-6	-4	1	-1	-1	0	7	-2	-6	-7	-1	-8	**-29**
2004	-7	-1	1	3	2	-3	-5	3	-1	-6	-8	-9	**-30**
2005	-4	-2	3	-3	-2	-1	-11	4	2	21	8	5	**21**
2006	-6	-4	-2	-2	5	-6	3	-3	10	5	-3	-5	**-10**
2007	-3	-4	-3	-4	-3	-2	-2	0	29	-2	-4	10	**11**
2008	-10	-7	-4	1	-1	-7	-5	2	-5	25	-12	12	**-10**
2009	-5	-4	-1	0	0	-1	-7	17	-9	20	1	12	**24**
2010	-4	-5	-3	-2	-2	4	-6	16	42	3	-13	6	**36**
2011	-7	-9	-3	-3	-5	-4	-4	6	16	-5	1	-1	**-17**
2012	-9	-5	-4	-1	-3	-7	-10	12	14	26	3	-7	**8**
2013	-1	-4	-2	-2	-2	-9	-5	1	-5	6	-12	1	**-35**
2014	-9	-6	-3	-4	-3	-4	-5	-6	17	-3	-4	7	**-24**
mean	**-6**	**-4**	**-1**	**-2**	**-2**	**-4**	**-4**	**2**	**7**	**4**	**-5**	**1**	**-14**

Table S8: Annual actual evapotranspiration *ET* ~~ET~~ in the Qaidam ~~b~~Basin (QB) ~~for~~during the calendar years 2001 to 2011 covered by both the HAR ~~V1 (~~10 km~~)~~ data set and the SEBS data as published in Jin et al. (2013).

ET **(mm/a)**	HAR 10 km	SEBS	Diff.
2001	211	73	138
2002	208	74	134
2003	196	78	118
2004	194	85	110
2005	205	144	61
2006	181	123	58
2007	219	135	84
2008	222	145	77
2009	232	170	62
2010	236	169	67
2011	234	182	52
2001-2011	213	125	87
2001-2004	202	77	125
2005-2011	**218**	**153**	**66**



ET **(mm/a)**	HAR V1	SEBS	Diff.
2001	211	73	138
2002	208	74	134
2003	196	78	118
2004	194	85	110
2005	205	144	61
2006	181	123	58
2007	219	135	84
2008	222	145	77
2009	232	170	62
2010	236	169	67
2011	234	182	52
2001-2011	213	125	87
2001-2004	202	77	125
2005-2011	**218**	**153**	**66**

Table S9: Mean monthly and annual air temperature T (in deg C), specific humidity q (in g/kg), precipitation P (in mm/month or mm/a), rainfall P_{rain} (in mm/month or mm/a), snowfall P_{snow} (in mm/month or mm/a), actual evapotranspiration ET (in mm/month or mm/a), and water balance $\Delta S = P - ET$ (in mm/month or mm/a) in the Qaidam Basin (QB) as in Table 1 but derived from the HAR 30 km data set; sigma: standard deviations of annual values for each quantity during the hydrological years 2001 to 2014.~~Mean monthly and annual air temperature T, specific humidity q, precipitation P, rainfall P_{rain}, snowfall P_{snow}, actual evapotranspiration ET, and water balance $\Delta S = P - ET$ in the Qaidam basin as in Table 1 but derived from the 30 km model domain of the HAR V1 data set; sigma: standard deviations of annual values for each quantity during the 14-years study period.~~

month	10	11	12	1	2	3	4	5	6	7	8	9	**year**	sigma
T	-0.9	-8.6	-13.2	-14.8	-10.6	-5.9	0.1	5.2	9.8	12.3	11.5	6.7	**-0.7**	0.6
q	2.3	1.4	1.1	1.0	1.3	1.5	2.0	2.9	4.4	5.8	5.3	4.0	**2.8**	0.2
P	8	4	4	4	7	11	15	29	39	39	28	23	**210**	45
P_{rain}	1	1	0	0	0	1	4	8	22	29	19	11	**95**	30
P_{snow}	7	3	4	4	7	10	11	21	17	10	9	12	**115**	20
ET	13	8	5	6	9	14	18	24	28	32	29	20	**206**	16
ΔS	-5	-4	-1	-2	-1	-4	-3	5	11	7	-2	3	**3**	36

month	10	11	12	1	2	3	4	5	6	7	8	9	**year**	sigma
T (deg C)	-0.9	-8.6	-13.2	-14.8	-10.6	-5.9	0.1	5.2	9.8	12.3	11.5	6.7	**-0.7**	0.6
q (g/kg)	2.3	1.4	1.1	1.0	1.3	1.5	2.0	2.9	4.4	5.8	5.3	4.0	**2.8**	0.2
P (mm)	8	4	4	4	7	11	15	29	39	39	28	23	**210**	45
P_{rain} (mm)	1	1	0	0	0	1	4	8	22	29	19	11	**95**	30
P_{snow} (mm)	7	3	4	4	7	10	11	21	17	10	9	12	**115**	20
ET (mm)	13	8	5	6	9	14	18	24	28	32	29	20	**206**	16
P-ET (mm)	-5	-4	-1	-2	-1	-4	-3	5	11	7	-2	3	**3**	36