Nov 14, 2021

Thank you very much for your helpful and valuable comments on our manuscript entitled “The Spatiotemporal Regime of Glacier Runoff in Oases Indicates the Potential Climatic Risk in Dryland Areas of China” (ID: HESS-2021-377). After studying your comments carefully, we have made some corrections which we hope to meet with approval. First of all, we realize that there were many unclear expressions and wrong marks of parameters in the manuscript which confused you. Following your comments, we have modified the corresponding sentence in responding to each specific comment. We will ask a well-established expert to polish our paper in the revised manuscript. According to your all comments, we think the main corrections in the paper are as follows:

(1) Rewrite the Methods. We annotate parameters correctly, explain the meanings of parameters clearly, and supplement the calculations of ablation and positive-degree days. As for some details we have discussed too much, such as the reasons for choosing Shean Estimation and APHRODITE, we use charts and figures to illustrate them in supplementary materials.

(2) Check references to make sure they are referred to correctly. Adjust texts, legends, and parameters in each figure make them accurate and easy to read.

(3) Add the uncertainty analysis of glacier area change. We decided to use Landsat TM/ETIM+ scenes on GEE to obtain the changes of glacier area during each period of dryland areas of China from 1985 to 1995 and 1995 to 2005. Following your comment, glacier areas during 2005-2015 were represented by the second Chinese Glacier Inventory (CGI-2). We compare glacier areas from remote sensing imageries with RGI in each period to analyze uncertainties brought by glacier area change. If some input scenes are masked after the cloud algorithm, we use RGI instead in these regions. The codes for calculating glacier areas are attached at the end of the response.

(4) For the socio-economic results of glacier runoff, a specific analysis of the impacts of glacier runoff on oases (e.g. using hydrological models) can be supplemented to increase the persuasiveness of this paper.

A detailed point-by-point response to your comment and suggestion is as follows:

[Reviewer #2 Major Comment 1] Many methods are not well explained: I don’t understand how you get precipitation. You use the 0.25° spatial resolution daily precipitation datasets from the Asian Precipitation –

Highly Resolved Observational Data Integration Towards Evaluation Of Water Resources (APHRODITE). But then you state that you "Used the Shean estimation to optimize the precipitation gradient per glacier". Shean provides annual mass balance – not precipitation, and does not use any precipitation data, so how specifically are you using his method or data? Equations 2, 3 and 4 only use elevation data and APHRODITE precip and temperature data.. not glacier mass balance data.

[Response] We are sorry for our disordered structure in Methods which confused you so much. Since there were some mistakes in Equations 3 and 4 and omitting an Equation about calculating ablation on a glacier, correct and complete Equations on reconciling high-altitude precipitation are as follows:

"$$B_y = A_{b,y} + A_{c,y} = \int_{t_1}^{t} (A_b + A_c)dt \quad (1)$$

$$A_{b,y} = DDF \times PDD_y \quad (2)$$

$$A_{c,d} = \begin{cases} P_{cor,d}, T_a \le 0 \\ \left(1 - \frac{T_a}{T_1}\right) P_{cor,d}, 0 < T_a \le 4 \\ 0, T_a > 4 \end{cases} \quad (3)$$

$$\Delta H = H - H_{rmd} \quad (4)$$

$$P_{cor,d} = P_{rmd,d} \cdot \{1 + [\Delta H + (H - H_{map})] \cdot PG \cdot 0.01\} \quad (5)$$"

Eq.1 shows the mass balance (B_y) is the sum of accumulation ($A_{c,y}$) and ablation ($A_{b,y}$) at a yearly time step of each glacier. Eq.2 shows the yearly ablation is the product of degree-day factor (DDF) and positive-degree days (PDD_y) of each glacier obtained in the daily temperature dataset. While precipitation is separated into solid and liquid by temperature, only solid precipitation, snow, count as atmospheric mass accumulation. Eq.3 indicates the calculation about daily accumulation by corrected high-altitude temperature (T_a), which decreases 0.65 degrees per 100 m rise corrected by DEM data. Eq.4 and Eq.5 show the reconciled high-altitude precipitation ($P_{cor,d}$) was calculated as a function of original precipitation data from APHRODITE ($P_{rmd,d}$), the vertical precipitation gradient (PG), the mean terrain elevation from DEM (H), the aggregated elevation at a spatial resolution with 0.25 degrees consistent with APHRODITE (H_{rmd}), and maximum rainfall height (H_{map}) at a daily time step for each glacier.

1. We use the Shean Estimation of the mass balance and their uncertainties as annual mass balance (B_y) while Shean Estimation showed the average mass balance from 2000 to 2018 for each glacier.
2. Using the product of the distribution map of DDF and PDD_y to obtain the yearly ablation ($A_{b,y}$) at a grid scale with a spatial resolution of 100 m. For each glacier, yearly ablation ($A_{b,y}$) was calculated on values within the zones of RGI shapefiles.
3. The annual accumulation ($A_{c,y}$) on each glacier was calculated based on 1 and 2.
4. The annual accumulation ($A_{c,y}$) of each glacier calculated in 3 was substituted into Eq. 3-5, the vertical precipitation gradient (PG) of each glacier was obtained by combining elevation data, corrected high-altitude temperature data (T_a), and the maximum rainfall height (H_{map}) of each glacier region.
5. As the spatial resolution of the temperature and precipitation dataset from APHRODITE is 0.25°, which is quite different from the area of glaciers, the vertical precipitation gradient between nearby glaciers may be quite different. We interpolated each glacier's precipitation gradient to smooth the errors caused by the boundary of the raster data.
6. In Step 5, the map of interpolated vertical precipitation gradient (PG) was obtained. Using original temperature and precipitation ($P_{rmd,d}$) from APHRODITE according to Eq.3-5 to calculate corrected high-altitude precipitation ($P_{cor,d}$) and accumulation ($A_{c,d}$) at a daily step on a grid cell. The daily ablation ($A_{b,d}$) on a grid cell could be calculated by Eq. 2, and then the daily mass balance (B_d) on a grid cell could be obtained according to Eq. 1. The grid cell is unified at a spatial resolution with 100 m in this step.

The above six steps are the complete process of the raster dataset of regional glacier mass balance obtained after high-altitude precipitation correction by Shean Estimation in this paper.

[Reviewer #2 Major Comment 1. a] In the next line you state that you are using a precipitation gradient to correct the original APHRODITE data. You then use this gradient "PG" in equations but then never state how you get the gradients until L253-254: "PG in this paper was obtained by interpolation using the mass balance algorithm and geostatistics method". This is an important point and should be introduced together and fully described, currently this line doesn't tell us how you get the PG. (Also, is PG a widely used abbreviation for precipitation gradient? I haven't seen this used).

[Response] We are sorry again for the unclear narrative structure in Methods. Vertical precipitation gradients (PG) were calculated after obtaining accumulation (A_c) (corrected high-altitude precipitation relevant to high-altitude temperature, P_{cor}) by subtracting mass balance (B_y) from Shean Estimation to ablation (A_b) for each glacier. The PG is just an abbreviation for precipitation gradients and a parameter in equations in this paper but not a widely used abbreviation. We got a map of interpolated precipitation gradients (PG) to smooth the errors caused by the boundary of the raster data at a spatial resolution of 0.25 degrees. Then, using original temperature and precipitation ($P_{rmd,d}$) from APHRODITE to calculate corrected high-altitude precipitation ($P_{cor,d}$) and accumulation ($A_{c,d}$) at a daily step on a grid cell. Daily ablation ($A_{b,d}$) on a grid cell could be calculated by Eq.2 and we obtained map of daily mass balance for glacier regions at a spatial resolution of 100 m.

[Reviewer #2 Major Comment 1. b] L214, "The precipitation was corrected by the Shean estimation for high-altitude precipitation gradients…", again, what is this correction, I can't find any precipitation gradient work in Shean et al. (2020). You have annual mass balance from Shean et al. (2020), precipitation data from APHRODITE, and then estimate ablation with a PDD model. How you use these three datasets in conjunction is not clear.

[Response] Thanks for your comment and we apologize for the unclear paragraphs in Methods. We will rewrite the method section to avoid confusion and make it clearer. As mentioned in the previous responses, mass balance with uncertainties for each glacier from Shean Estimation provided annual mass balance (B_y). Positive-degree days (PDD) are accumulated by daily temperature from APHRODITE corrected by DEM (0.65°C/100 m). Ablation ($A_{b,y}$) is calculated by the product of PDD and map of DDF provided by Zhang et al. After subtracting mass balance to ablation, annual accumulation ($A_{c,y}$) from 2000-2018 (Shean et al., 2020) for each glacier could be obtained. According to Eq.3-5, the precipitation gradient for each glacier could be calculated with the help of original precipitation ($P_{rmd,d}$) from APHRODITE. Substituting the map of interpolated precipitation gradient and precipitation from APHRODITE into Eq.1-5, yearly maps of mass balance for glaciers in dryland areas of China could be obtained.

[Reviewer #2 Major Comment 2] L153-156 The PDD values must be stated, what is the range of values? Perhaps show a map of them as a supplemental figure. Further, the uncertainty around these values should be quantified.

[Response] Thanks for your suggestion and following your comment, we add a description of positive-degree days as follows:

"Monthly positive-degree days ($\mathrm{PDD_m}$) were chosen instead of absolute PDD (Braithwaite & Olesen, 1993) which were summed positive daily average temperatures:

$$PDD = \sum_{t=1}^{n} H_t \cdot T_{a,t},$$

$$H_t = \begin{cases} 1.0, T_{a,t} \geq 0 \\ 0.0, T_{a,t} < 0 \end{cases}$$

where $\mathrm{H_t}$ is a logistic variable, $\mathrm{T_{a,t}}$ is corrected temperature by DEM."

However, as we used temperature from APHRODITE, uncertainties around temperature and PDD_m could not be quantified. We could add a map of PDD_m as a supplemental figure.

[Reviewer #2 Major Comment 3 a] The terms monthly delayed runoff and meltwater runoff are poorly defined.

Is monthly delayed runoff a mix of seasonal snow melt runoff and rainfall over the glacier?

[Response] We are sorry for missing detailed and accurate definitions of delayed runoff and meltwater runoff. Delayed runoff is defined in lines 178-181 as "Based on the definition of glacier runoff, the runoff includes two parts. One is the precipitation on glaciers stored in the non-melting season and released in the melting season, which is called delayed runoff (Kaser et al., 2010; Pritchard, 2019; Shean et al., 2020)". Actually, glacier runoff in this paper refers to the runoff generated in glacier regions. According to Eq.1, mass balance (B_y) is the sum of accumulation ($A_{c,y}$) and ablation ($A_{b,y}$) at a yearly time step of each glacier. While mass balance is a positive value, it means there is accumulation caused by precipitation on the glacier, and the amount greater than 0 forms runoff according to the PDD of each month. So, delayed runoff refers to the amount of precipitation accumulated at high altitudes after offsetting by the ablation and stored in the mountains as snow in the cold seasons and discharged in the warm seasons, not including meltwater runoff.

[Reviewer #2 Major Comment 3 b] In lines 184-186 is Ta meant to be T1?

[Response] We are sorry for these mistakes. In lines 184-186, what T_a meant to say is T_1, which is 4 °C in this paper. We will replace T_1 in the original text with 4 °C used in the actual calculation to avoid confusion.

[Reviewer #2 Major Comment 3 c] In lines 290-292 you better clarify the terms, which should not be occurring in the results, and still leave the reader confused: "Glacier runoff included delayed runoff that was stored rainfall in the cold seasons and released rainfall in the ablation seasons, while meltwater runoff was caused by glacier mass balance, which was also called excessive meltwater runoff or the imbalanced part of glacial runoff". Do you mean stored snowpack in the cold season? Or both stored seasonal snowpack and stored

rainfall in the cold season? Released rainfall in the ablation seasons?

[Response] We apologize for the unclear sentence. We divided glacier runoff into two parts in this paper while one is delayed runoff, the other is meltwater runoff. As mentioned in the former response, delayed runoff refers to the amount of precipitation accumulated at high altitudes after offsetting by the ablation and stored in the mountains as snow in the cold seasons and discharged in the warm seasons, not including meltwater runoff. Meltwater runoff, which is also called excessive meltwater runoff or the imbalanced part of glacier runoff, is caused by glacier mass balance. While mass balance is a negative value, glaciers recede during warm seasons. Delayed runoff emphasizes the release of precipitation offsetting ablation stored in cold seasons on glaciers during warm seasons, while meltwater runoff emphasizes the amount of melting of the glacier itself due to its mass balance during warm seasons. The corrected sentence reads as:

> "To be precise, glacier runoff in this study is runoff generated in glacier regions, including meltwater runoff and delayed runoff. Delayed runoff was caused by remaining precipitation which stored in cold seasons and discharged in warm seasons after offsetting ablation. Meltwater runoff, which was also called excessive meltwater runoff or the imbalanced part of glacier runoff, was caused by mass loss of glaciers when atmospheric accumulation cannot offset ablation on glaciers."

[Reviewer #2 Major Comment 4] Many other terms are undefined, e.g.: L347 What is "glacier runoff recharge"?

[Response] We apologize for the undefined term "glacier runoff recharge" in lines 347-348 "The percentage of glacier runoff recharge calculated by the DDF model was between 5% and 15% based on the first Chinese inventory and monthly precipitation and temperature data from the National Meteorological Centre (Gao et al., 2010)". Glacier runoff recharge here refers to glacier runoff as a percentage of surface runoff recorded by hydrological stations. The corrected sentence reads as:

> "The percentage of glacier runoff calculated by the DDF model was between 5% and 15% based on

the first Chinese inventory and monthly hydrothermal data from the National Meteorological Centre (Gao et al., 2010)."

[Reviewer #2 Major Comment 5 a] Some references are inappropriate. E.g. in your submission you do not cite the information stated in L597-598 about California, then in your response to Reviewer 1 you state: "For example, due to increased temperature and reduced snowmelt or precipitation, California, in the United States, experienced a severe drought from 2011 to 2015 where hydroelectric power decreased by two-thirds due to declining runoff, including glacier runoff (Gonzalez et al., 2018; Rasul & Molden, 2019)." --- Rasul and Molden (2019) merely reference the Gonzalez work, and do not offer any data on this so is not suitable to be referenced here. The Gonzalez work can be found here: https://nca2018.globalchange.gov/downloads/NCA4_Ch25_Southwest_Full.pdf, and does not ever mention glaciers.

[Response] In the response to Reviewer #1, we only added references neglecting to check the contents of them. Following your comments, we recognize no matter Gonzalez et al. (2018) or Rasul & Molden (2019) are inappropriate referred here. Thanks again for providing the Gonzalez work and your valuable comments. Here we would like to state the impact of glacier shrinkage on hydropower as follows:

"Some countries where the main source of electricity is hydropower, glacier runoff contributed significantly to its origination such as France (Milner et al., 2017) and Norway (Andreassen et al., 2005). 19 hydropower plants in the glacier-fed Rhone River supplied 25% of French hydropower and 15% of hydropower used runoff comes from glacierized basins in Norway."

[Reviewer #2 Major Comment 5 b] Some references are inappropriate. An additional example is in L341 Barnett et al. (2005) is a review paper and did not "simulate glacial runoff" as you claim.

[Response] We apologize for the misquotation of Barnett et al. (2005) which is a review paper not mentioning glacier runoff simulation. Even the contents in Section "Impacts on regional water supplies" were about Himalaya-Hindu Kush region not dryland areas of China. So we delete this reference here and add a new one. The corrected complete sentence with references reads as:

> "Some studies (Hussain et al., 2019; Li et al., 2018; Shen et al., 2004; Wang et al., 2015; Wu et al., 2018; Yang et al., 2015; Ye et al., 2017) simulated glacial runoff in the DAC by qualitative or semi-quantitative methods or by using models."

[Reviewer #2 Major Comment 6] Using RGI glacier outlines for 1961-2018 is not appropriate for a 100m resolution study. At least an error analysis on the effect of not incorporating glacier area change should be added.

a. In response to Reviewer 1 you state that the RGI polygons were "All glacier extents were obtained started in the 1990s and finished in 2014 which is consistent with our research time." This is close to the case, but as pointed out by Shean et al. (2020)

b. source image timestamps used for RGI polygon digitization (~1998–2014) and the DEM timestamps. This means that the polygons were digitize ANY time between those dates, and contain information about the date.

c. So using a single polygon of 1998-2014 origin is either not appropriate, or requires an uncertainty analysis (which should be included regardless).

d. Also, as detailed by Guo et al. (2017) the first Chinese Glacier inventory was finished in 2002 and covered CGI-1 was compiled based on topographic maps and aerial photographs acquired during the 1950s–80s – so would be a potentially suitable starting outline for you study, then updating to the CGI-2 dating to 2006-2010, compiled by Guo et al. (2017): https://www.cambridge.org/core/journals/journal-of-glaciology/article/second-chinese-glacier-inventory-data-methods-and-results/386DAB512F4869D3335E2DE24B0F43EB

[Response] We note that both you and Reviewer #1 have put forward opinions on the change of glacier areas. In our response to reviewer 1, we explained that we thought uncertainties brought by areas were smaller than uncertainties brought by glacier mass balance (Shean Estimation) so changes in areas of glaciers were not taken into account in this article. However, following your and Reviewer #1's comments, we will add error analysis on the effect of neglecting areas change.

Thank you very much for providing the article about the second Chinese Glacier Inventory (CGI-2). We learned the CGI-2 was compiled based on 218 remote sensing imageries during 2006-2010 end of ablation seasons using band ratio segmentation method and corrected by field GPS investigation and outlines delineated from high-resolution Google Maps^{TM} images. The CGI-2 (Guo et al., 2015) was the most accurate glacier inventory in China since the 21st century. Based on it, we think about some strategies for analyzing uncertainties about area change of glaciers. Glacier outlines can be obtained from Landsat TM/ETM+ scenes in the two periods (Region$_{1985-1995}$ and Region$_{1995-2005}$) in each basin, respectively, in Google Earth Engine^{TM} (hereafter, GEE) based on band ratio segmentation method same as Guo et al. (2015) If scenes are limited by cloud cover or lack of data, we use RGI instead. Kappa coefficient is used to calculate the accuracy of comparison between Region$_{1985-2005}$ and Google Earth Map^{TM} for each similar scene time. Uncertainties due to area change during 1961-2015 in different basins brought by RGI can be calculated as following equations:

$$E_{RGI,i} = \frac{A_{RGI,i} - A_{GEE,i} \cdot K_i}{A_{RGI,i}} \times 100\%$$

Where $E_{RGI,i}$ is the glacier area error, $A_{RGI,i}$ is the glacier area provided by RGI, $A_{GEE,i}$ is the glacier area calculated by GEE, K_i is the Kappa coefficient between glacier areas calculated by GEE and outlines from Google Earth Map^{TM}, i indicates different basins. And the total glacier area error can be calculated using:

$$E_{RGI} = \sqrt{\sum_{i=1}^{n} (E_{RGI,i})^2}$$

The code of extracting glacier outline in GEE is attached in the supplementary materials. Hope this strategy can solve the problem of uncertainties analysis caused by area change and thanks again for providing references and suggestions.

[Reviewer #2 Specific Comment 1] Any use of numbers should spell out the number if below 10, e.g. 7 regions --> seven regions.

[Response] Thanks for your comments and we will exchange use of numbers below 10 in the whole paper. The corrected sentences read as:

> "two goals in the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Line 27)
>
> The seven glaciers affect 22 tertiary watersheds in the DAC, including six drainage basins which all originated directly from glaciers and across arid and hyper-arid regions (hereafter, AH). Two river basins were both completely in the arid zone while 11 drainage basins were in both semiarid and arid regions (hereafter, SA). (Lines 102-105)
>
> Based on the RGI 6.0, six glacier regions influence the DAC. (Line 136)"

[Reviewer #2 Specific Comment 2] Please use significant digits e.g. L107-108

[Response] We apologize for the unprecise expression. Following your comment, the corrected sentence reads as:

> "As Table 1 shows, the area of OAAs in each watershed in the DAC reached a maximum of 21699.18 km^2 (Middle Rivers Basin), with an average of 6543.69 km^2, while the precipitation in the DAC

reached a maximum of 323.09 mm (Qinghai Lake Drainage System), with an average of 134.56 mm, which revealed that runoff in the DAC was extremely important, especially in some basins where runoff originated almost entirely from glaciers."

[Reviewer #2 Specific Comment 3] L15 Is this total annual glacier runoff? Specify time in the sentence or units.

[Response] We are sorry for the unclear sentence. Following your comment, the corrected sentence reads as:

"The total annual glacier runoff in the DAC is (98.52 ± 67.37) × 10^8 m^3 during 1961-2015, in which the meltwater runoff is (63.43 ± 42.17) × 10^8 m^3, accounting for 64.38%."

[Reviewer #2 Specific Comment 4] L29 Add "Glaciers and ice sheets are the…."

[Response] Thanks for your comments. The corrected sentence reads as:

"Glaciers and ice sheets are the largest reservoirs of fresh water on Earth, and they store most of the ice and snow (Beniston & Stoffel, 2014; Kraaijenbrink et al., 2017)."

[Reviewer #2 Specific Comment 5] L35 This is not a feedback, it is a one-way relationship, glaciers melt, producing runoff, increasing sea level. These citations do not fit your point.

[Response] Thanks for your comments. As mentioned in response to Reviewer #1's specific comment 1, what we want to point here is that warming expedites glaciers to melt and then speeds up raising sea levels under current climatic conditions. The increase in meltwater can alleviate drought in the river basins originated from glaciers like the drylands of China, but sea level rise poses risks to coastal areas, meaning that the meltwater of glaciers is not only a result of climate change but also contributing to the consequences of climate change such as rising sea levels. So, we think we could change the sentence and references as follows:

> "Under current climatic conditions, warming expedites glaciers to melt and meltwater speeds raising sea levels, which is why glaciers are both the result of and contributor to climate change."

[Reviewer #2 Specific Comment 6] L51-57 The problem is not clearly stated here. You state that "Continuous yearly mass balance data for long time series could not be calculated effectively due to the time consumption and high energy consumption of field observations (Brun et al., 2017; Shean et al., 2020)." This is poorly worded and incorrect. Long time series cannot be calculated because the data don't exist, which in turn is because field observations are logistically and financially difficult.

[Response] We are sorry for the unclear statement. We intended to express that the financial and logistic difficulties of field observations result in the lack of long-time series in regional scales. Thank you very much for your comment so we will amend this sentence to read as:

> "Continuous yearly mass balance data for long time series in regional scales could not be calculated effectively due to the financial and logistic difficulties of field observations (Brun et al., 2017; Shean et al., 2020)."

[Reviewer #2 Specific Comment 7] L62 Two problems here, one, this is an incomplete sentence, and further, why is the resolution so low? Perhaps because the data are not sufficient to use at finer resolutions? "…while the energy balance model could be applied in 62 large regions but with low resolution (such as 0.25 degrees (Sakai et al., 2015))".

[Response] We are sorry for the incomplete sentence. In this sentence, we wanted to express two messages. First, we wanted to indicate that the relationship between the recorded data of meteorological stations based on the degree-day factor model and glacier runoff cannot be applied in regional scales limited by the distribution of meteorological stations (Duan et al., 2017). Second, although Sakai et al. established the map of ELA in regional scales, the resolution was low with 0.5 degrees, which could not be applied in scales of basins proposed in this paper. Sakai et al. derived Asian glaciers from the Glacier Area Mapping for Discharge in Asian Mountains (GAMDAM) glacier inventory (GGI) (Nuimura et al., 2015) to evaluate the clime regime at high-mountain Asia. While the GGI occupied the grids of glacier regions as 0.25 degrees and datasets used such as ERA-Interim reanalysis data – including temperature (level), surface wind (surface flux 10m), surface humidity (surface), and solar radiation (surface flux) - from 1952 to 2007, and APHRODITE from 1952 to 2007 was at a spatial resolution of 0.75 degrees and 0.50 degrees, respectively, so Sakai's paper was with a resolution of 0.50 degrees. Following your comment, the modified sentence and references read as:

> "However, limitations were obvious. Establishing the relationship between stations and the degree-day factor model was too difficult in large regional scales limited by numbers and the distribution of meteorological stations (Duan et al., 2017). Also, the energy balance model could be applied in large regions but limited by resolution for multiple datasets (Sakai et al., 2015)."

[Reviewer #2 Specific Comment 8] L99 erased the range?

[Response] While using the aridity index to zone arid regions, the Qinghai-Tibet Plateau will be included in arid areas. Due to the specificity of the Qinghai-Tibet Plateau, our team thinks the area should be studied separately. Therefore, the arid zone used in this paper excludes the Qinghai-Tibet Plateau. Following your comment, the corrected sentence reads as:

> "The region of DAC was obtained relying on aridity index supported by the United Environment Programme (UNEP) excluding the range of the Tibetan Plateau which should be discussed separately because of its particularity."

[Reviewer #2 Specific Comment 9] L102 7 glaciers? Or 7 glacier regions?

[Response] We are sorry for the wrong expression. The modified sentence reads as:

"The seven glacier regions affect 22 tertiary watersheds in the DAC, including six drainage basins which all originated directly from glaciers and across arid and hyper-arid regions (hereafter, AH)."

[Reviewer #2 Specific Comment 10] Figure 1 Font is too small in axes and legend (commonly in many figures)

[Response] Following your comment, we make fonts in each figure larger to make it easier for readers.

[Reviewer #2 Specific Comment 11] L122-123 Doesn't make sense. You are implying that you did the work of Shean et al. (2020).

[Response] Thanks for your comment. This sentence is meant to introduce how Shean et al. (2020) obtained the mass balance dataset. Following your comment, the modified sentence reads as:

"We used regional available glacier mass balance dataset to correct high-altitude precipitation."

[Reviewer #2 Specific Comment 12] L126-148 Way too long of a description of these studies, if you want to show the comparison in lines 136-145, use a table, this is hard to read.

[Response] Thanks for your comment, we are going to illustrate this comparison using a table attached in supplementary materials. The table is attached at the end of this response.

[Reviewer #2 Specific Comment 13] L267 Blocks represent modules (add the s)

[Response] Thanks for your careful reading. The corrected sentence reads as:

"Fig. 2. Conceptual framework of glacier runoff calculating. Blocks represent modules of 267 the

> glacier runoff calculation in each category. Shading indicated results with uncertainties and different lines and blocks indicated the corresponding modules."

[Reviewer #2 Specific Comment 14] L289-290 "and we overcame the difficulty of large-scale geodetic mass balance assessment" What? Brun et al. (2017) and Shean et al. (2020) did this.

[Response] We are sorry for the wrong expression. The corrected sentence reads as:

> "In this paper, Shean Estimation was used to reconcile high-altitude precipitation. The yearly mass balance of glaciers influencing the DAC from 1961 to 2015 was calculated by the difference between accumulation obtained from corrected precipitation and ablation calculated by the DDF model. A long-time series dataset of total glacier runoff dataset including delayed runoff and meltwater runoff based on temperature was created, which was at large regional scales with a spatial resolution of 100 m. It is important to note that glacier runoff in this paper means runoff generated within the geographical area of a glacier"

[Reviewer #2 Specific Comment 15] L300-301 "The creeks of the Kriya Rivers basin were the most unique, with 93.67% of the components coming from delayed runoff; therefore, more attention should be paid to glacier disasters in this basin", wouldn't the opposite be true? Delayed runoff is not directly from glacier wastage (stored seasonal precip), so is more sustainable than ice wastage.

[Response] As mentioned in Response to Reviewer #1's specific comment 17, Kriya Rivers Basin is special where 93.67% of glacier runoff comes from delayed runoff. It could be said that delayed runoff is basically determined by rainfall and temperature, which is distinguished from meltwater runoff. Therefore, when extreme precipitation climate occurs, it is easy to cause geologic hazards such as flash floods which should be paid attention to (Kaltenborn et al., 2010; Shen et al., 2004). The hazards here are more related to extreme rainfall than with the glaciers themselves. But referring to your and Reviewer #1's comment and some references, we think Kashgar River basin, Hotan River basin, and Yarkand River basin should be paid more attention to because delayed runoff and meltwater runoff account for a certain proportion in each basin. The combination of extreme precipitation and rapid snow melting would increase runoff in glacier areas and make them more prone to disasters. The corrected sentence reads as:

> "The creeks of the Kriya Rivers basin were the most unique, with 93.67% of the components coming from delayed runoff. More attention should be paid to Kashgar River basin, Hotan River basin, and Yarkand River basin where delayed runoff and meltwater runoff account for a certain proportion and annual total glacier runoff was large. While extreme precipitation happened with rapid snow melting, glacier runoff would increase in haste to make these basins more prone to disasters (Kaltenborn et al., 2010; Shen et al., 2004)."

[Reviewer #2 Specific Comment 16] Figure 3 Units on runoff?? The legend just says "5.6". How useful are raw runoff numbers versus percent contributions of total river discharge?

[Response] We are sorry for the unclear legend in Figure 3. The "5.6" represents that the longest column in the legend was 5.6×10^8 m^3. We will correct our figures to make them more clearly. The percentage of glacier runoff relative to total river discharge is helpful to distinguish water sources and provide some references for water allocation after glacier shrinkage under climate change in the future.

[Reviewer #2 Specific Comment 17] L323-338 Replace most this paragraph with a table and reference that table with a few lines.

[Response] Thanks for your comment and we simplify the description with tables to make it easier for readers to understand.

[Reviewer #2 Specific Comment 18] L324 Glaciers should be lowercase.

[Response] Thanks for your comment. The corrected sentence reads as:

"From 1961 to 2015, glaciers in the arid regions provided (63.43 ± 42.17) × 10^8 m^3 of glacial excess meltwater."

References:

Andreassen, L. M., Elvehoy, H., Kjollmoen, B., Engeset, R. V. and Haakensen, N.: Glacier mass-balance and length variation in Norway, Ann Glaciol, 42, 317-325, doi: 10.3189/172756405781812826, 2005.

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```
}
```

Supplementary materials:

1. Codes about extracting glacier areas by NDSI:

```
var StudyArea = Glacier Regions;
Map.addLayer(StudyArea, {},'StudyArea', 0);

var startDate = ee.Date.fromYMD(Y,M,D);
var endDate = ee.Date.fromYMD(Y,M,D);

var Landsat1 = imageCollection.filterDate(startDate,endDate);
Map.addLayer(Landsat1.filterBounds(StudyArea), {bands:['B4','B3','B2']},'Landsat Raw');

var dataset_m = imageCollection.filterDate(startDate,endDate).filterBounds(StudyArea);
var dataset_raw = dataset_m.mosaic();
var dataset_cloudfree = dataset_m.map(cloudfree_landsat).mean();

var Feature = table.filterBounds(StudyArea);
Map.addLayer(Feature,{},'GLIMS Glacier',0);

Map.addLayer(LandsatNoCloud.clip(StudyArea),{bands:['B4','B3','B2']},'Landsat No cloud');
print(LandsatNoCloud);

//Define a function about bitwise
function bitwiseExtract(value, fromBit, toBit){
   if(toBit === undefined) toBit = fromBit;
   var maskSize = ee.Number(1).add(toBit).subtract(fromBit);
   var mask = ee.Number(1).leftShift(maskSize).subtract(1);
   return value.rightShift(fromBit).bitwiseAnd(mask);
}

//Define a function to free-cloud Landsat
function cloudfree_landsat (image){
```

```
  var qa = image.select('BQA')
  var cloudState = bitwiseExtract(qa, 4)
  var cloudShadowState = bitwiseExtract(qa, 5,6)
  var mask = cloudState.eq(0) // Clear
  .and(cloudShadowState.eq(1)) // No cloud shadow
  return image.updateMask(mask)
}

Map.addLayer(dataset_cloudfree.clip(StudyArea),{bands:['B4','B3','B2']},'Dataset No cloud');

var ndsi = LandsatNoCloud.expression(
  '(green-swir1)/(green+swir1)',{
    'green':LandsatNoCloud.select('B2'),
    'swir1':LandsatNoCloud.select('B5')
  });
Map.addLayer(ndsi.clip(StudyArea),{palette: ['000000', 'FFFFFF']},'ndsi',0);
print(ndsi);

var LandsatNdsi = LandsatNoCloud.addBands(ndsi,['B2']);
//print(LandsatNdsi);
var LandsatNdsiRename = LandsatNdsi.rename(['B1','B2','B3','B4','B5','B6','B7','BQA','ndsi']);
print('LandsatNdsiRename',LandsatNdsiRename);



var NdsiMask = LandsatNdsiRename.updateMask(ndsi.gte(0.4));
Map.addLayer(NdsiMask.clip(StudyArea),{}, 'NdsiStudyArea',0);

Export.image.toDrie();
```

2. *Table and figure about comparing mass balance datasets.*

Comparison about mass balance datasets in different glacier regions

RGI regions	MB from IceSat [2003-2009]	MB from Brun (Aster) [2000-2016]	MB from Shean (ASTER-SPOT) [2000-2018]	geodetic surveying (m w. e.)
13-01 Hissar Alay	-0.12±0.24	-0.04±0.07	-0.03±0.20	
13-02 Pamir		-0.06±0.07	-0.05±0.09	
13-03 W Tien Shan	-0.52±0.24	-0.20±0.08	-0.22±0.33	
13-04 E Tien Shan		-0.40±0.20	-0.42±0.25	
13-05 W Kun Lun	0.16±0.18	0.16±0.08	0.10±0.17	
13-06 E Kun Lun	-0.01±0.15	-0.01±0.07	-0.02±0.15	
13-07 Qilian Shan	-0.29±0.33	-0.29±0.08	-0.29±0.25	0.372±0.108
13-08 Inner Tibet	-0.01±0.15	-0.19±0.08	-0.24±0.21	
13-09 S and E Tibet	-0.27±0.16	-0.55±0.23	-0.48±0.32	
14-01 Hindu Kush	-0.10±0.18	-0.13±0.07	-0.13±0.17	
14-02 Karakoram		-0.03±0.07	-0.05±0.13	
14-03 W Himalaya	-0.48±0.17	-0. 38±0.09	-0. 36±0.11	-0.72±0.22
15-01 C Himalaya	-0.40±0.23	-0.28±0.08	-0.28±0.15	
15-02 E Himalaya	-0.80±0.22	-0.38±0.20	-0.35±0.20	
15-03 Hengduan Shan	-0.36±0.43	-0.56±0.23	-0.50±0.15