Authors' response (AC3) to comments (CC1) by Koji Fujita

Comment:

The model of this study yielded the insensitive response of glacier runoff to precipitation change but this is not discussed in depth. The model can resolve how each component responds (that's why we utilize numerical models, right?). Figure 11a of Fujita and Sakai (2014, HESS) could be helpful for this issue. Runoff responses to precipitation change are different in ice-containing and ice-free surfaces, and the compensation of these opposite responses could yield the insensitive response. I suggest that the authors perform this kind of analysis. It would be interesting if the authors find a different reason.

Reply:

Fujita & Sakai (2014) showed that for a glacier catchment in the central Himalaya, a contrasting response of runoff of the clean-ice ('glacier') and debris-covered ('debris') parts, and that of the off-glacier part ('ground') led to a weak response of the catchment runoff. For a 10% increase in precipitation, the runoff of the glacier+debris parts decreases by ~7% and that of the 'ground' increases by ~7%, leading to a subdued response of the total runoff (less than 1% change).

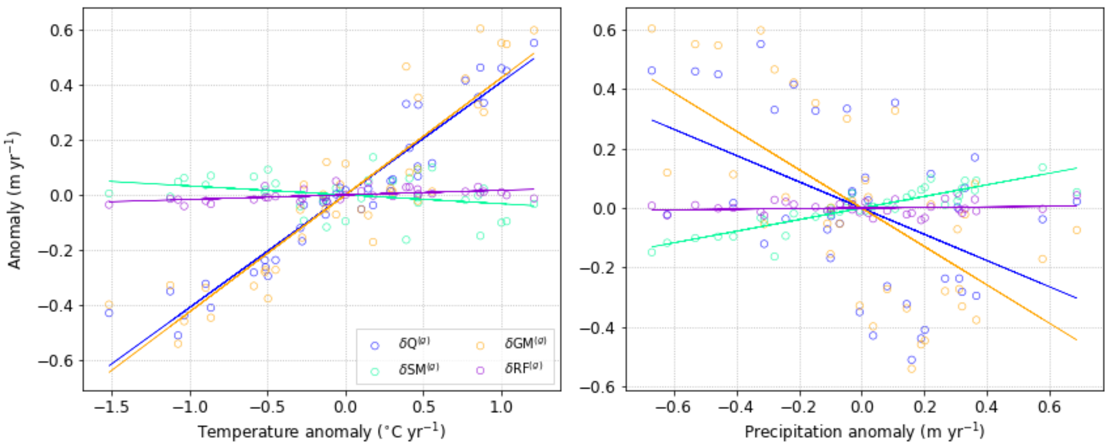
What we are seeing in Chandra and Dudhkoshi, is a subdued response of the glacier runoff itself (0-1% change) for a 10% change in P. Our observations are in line with those reported for a few other glaciers in the world (see reply [23] in AC2).

We thank Koji Fujita for his suggestions about plotting the response of individual runoff components. The plots are provided below. Overall, they indicate that precipitation anomalies on glaciers contribute to that of accumulation, so that glacier runoff remains largely unaffected. In contrast, a higher temperature causes a higher glacier melt, and thus, a glacier runoff.

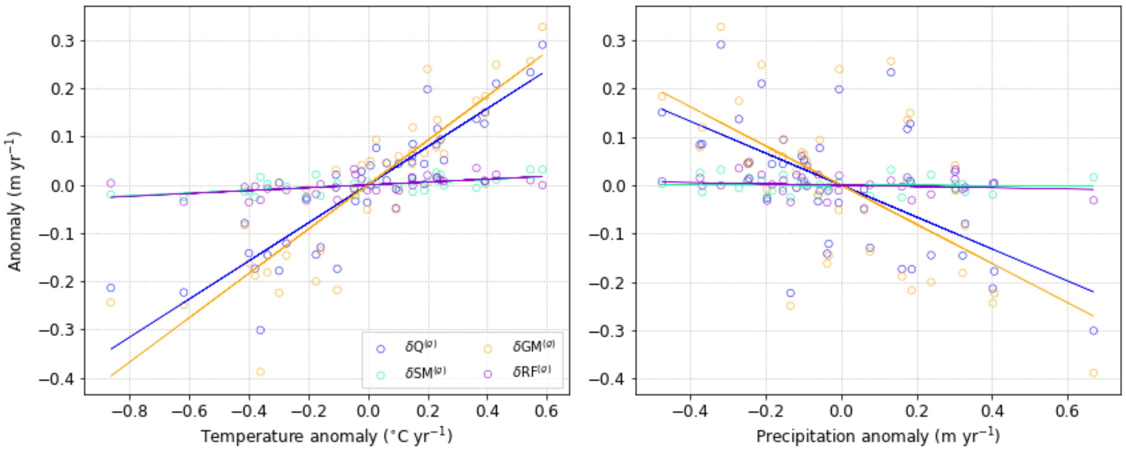
Sensitivities of summer runoff of the glacierised area

The anomalies of glacier runoff ($Q^{(g)}$), and its components snowmelt (SM), glacier ice melt (GM), and rainfall (RF) for the glacierised parts of the catchments are shown below.

Chandra:



Upper Dudhkoshi:



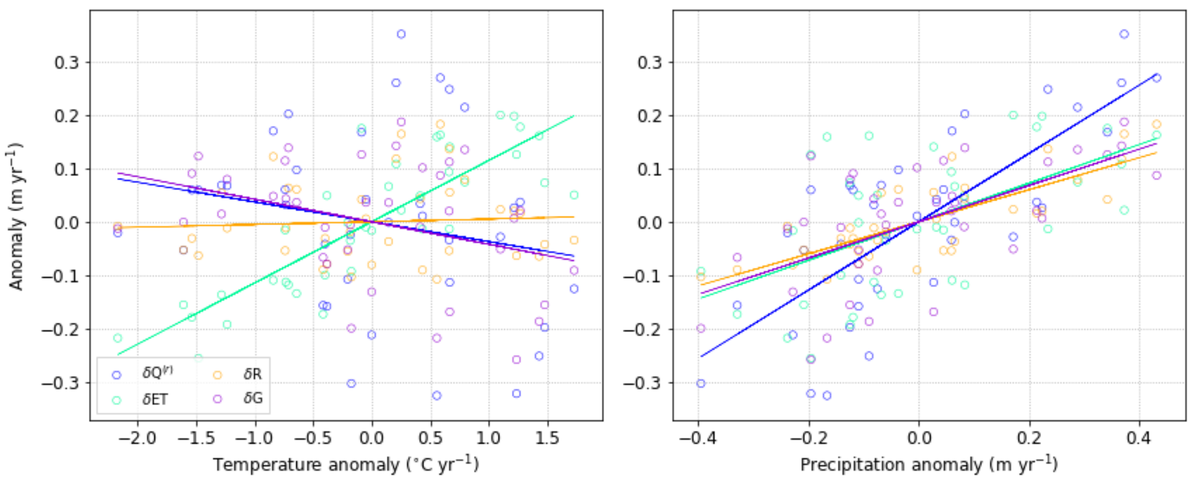
In both the catchments, rising GM with mean summer temperature causes a high temperature sensitivity of $Q^{(g)}$ (410±28 and 435±72 mm yr^{-1} $°C^{-1}$). RF and SM are largely unaffected by the changes with temperature. A weak (insignificant) decline in SM in Chandra with increasing summer temperature is likely due to a weak but insignificant anticorrelation (r = -0.3) between summer temperature and annual precipitation.

With increasing precipitation, RF remains unchanged and SM shows a very weak (Chandra) or no (Dudhkoshi) increase. Thus a higher precipitation contributes mostly to snow accumulation on glaciers. In addition, a higher snowcover and/or an association between higher-than-normal precipitation and less-than-normal temperature, causes a weak decline in GM, and consequently, in $Q^{(g)}$ (−0.12±0.08 and 0.00±0.02 mm yr^{-1} mm^{-1}).

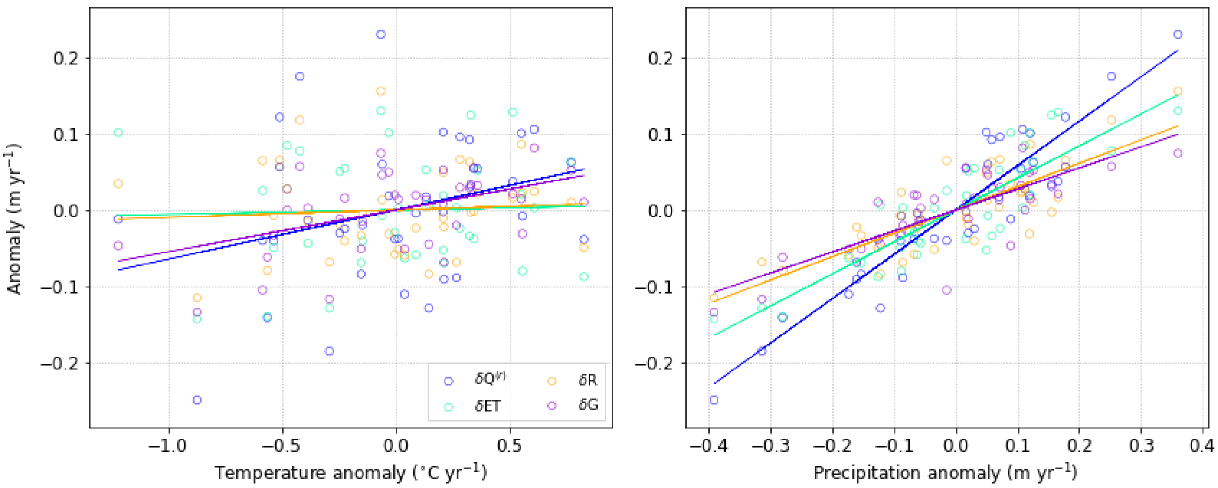
Sensitivities of summer runoff of the non-glacierised area

The anomalies of off-glacier runoff ($Q^{(r)}$), and its components, surface runoff (R) and groundwater/baseflow (G) are plotted below. The corresponding evapotranspiration (ET) anomalies are also shown.

Chandra:



Upper Dudhkoshi:



The above plots suggest a roughly equal distribution of any precipitation change into the corresponding changes in R, G, and ET ,such that ~60% of the additional precipitation contributes to runoff changes. Interestingly, ET anomalies in Chandra (Dudhkoshi) are controlled by the summer temperature (precipitation) suggesting energy- (water-) limited conditions.

Note that the sensitivities as obtained from in the above plots are slightly different than those quoted in the main text, as only the anomalies over the calibration period of 1997-2018 were used in the main text.

References

Fujita, K. and Sakai, A.: Modelling runoff from a Himalayan debris-covered glacier, Hydrol. Earth Syst. Sci., 18, 2679–2694, https://doi.org/10.5194/hess-18-2679-2014, 2014