RC2: 'Comment on egusphere-2023-2651', Julien Babault, 21 Mar 2024

Review of manuscript by Gong, Ling Xiao et al. submitted to Earth Surface Dynamics (ESurf) and titled "Drainage rearrangement in an intra-continental mountain belt: A case study from the central South Tian Shan, Kyrgyzstan"

Authors: Lingxiao Gong, Peter van der Beek, Taylor F. Schildgen, Edward R. Sobel, Simone Racano, Apolline Mariotti

Gong et al observe transient knickpoints in tributaries downstream of a sharp 180º bend in the main stem of the Saryjaz River in the south flank of the Tian Shan mountains. The analysis of the knickpoint distribution show that their elevations decrease downstream, whereas incision depth, χ values of knickpoints (measured from the trunk river tributary junctions) and steepness index (ksn) values and ratios are constant among tributaries. They interpret ~500 m of incision as driven "top-down" by a large-magnitude river-capture event, and that late Cenozoic tectonic rock and surface uplift did not trigger the capture.

Main comment

That is a very interesting study that should help gain insight into the interactions between mountain building and the dynamics of surface processes. Disentangle the relative effect of external factor and intrinsic drainage dynamics on river profile evolution in tectonically active settings is not an easy task. However, in its current form the manuscript lacks some analysis to support the conclusions, and I recommend the authors to add analysis following my comments below, before publication. In general, the text is clear and concise, well written and the figures are of good quality. References to previous work is also good.

We thank the reviewer for his overall positive assessment and constructive comments. In the following we detail how we addressed these. We made the following modifications to the text (***bold, italic text*** is new):

The authors base their interpretation on diagnostic features for river capture extracted mainly from three papers cited in the manuscript (Giachetta and Willett, 2018; Whipple et al., 2017 and Rohrmann et al., 2023). However, my main concern is that the geomorphic evidence highlighted in their analysis of the topography do not exactly fit with such diagnostic features for river captures. The geomorphic evidence presented in the manuscript is:

1) in the tributaries of the Saryjaz River, the increase of elevation of knickpoints (interpreted as transient features) parallel the modern trunk river profile, and

2) their location at similar chi values (5.4+-30%) measured from the trunk river.

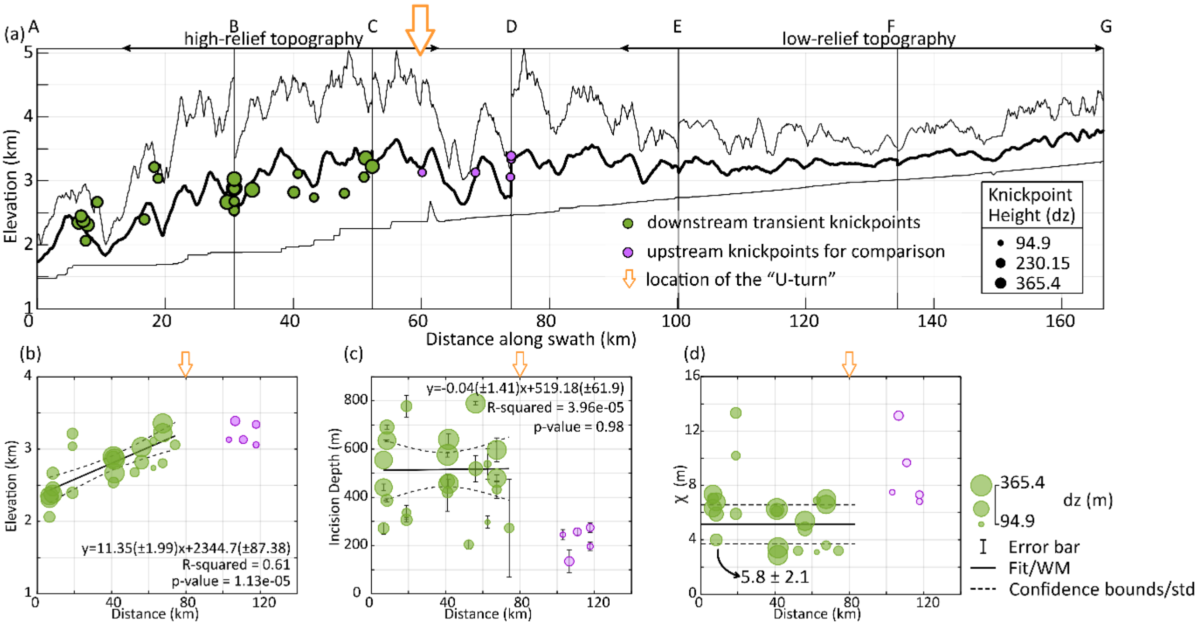
The authors analyze the amount of incision in tributaries of the downstream reach below the capture point inferred to be located at a prominent "U-turn" in map view of the Saryjaz River. The amount of tributaries incision in the downstream reach of the Saryjaz River does not increases upstream. However, I would have expected to see a graph where knickpoint elevation increases upstream, jointly with an increasing amount of incision.

The increase in incision depth with distance upstream could be subtle in a capture scenario, as it is the result of the change in the slope of the trunk stream after it has adjusted to the increased discharge. Differences in incision depths downstream of the capture point will be even less apparent if we are only looking at a limited stretch of the channel. Considering that the Saryjaz River extends several hundreds of km farther downstream from the South Tian Shan range front, the difference in predicted incision depths due to drainage capture along our study reach could be substantially reduced compared to predictions shown by, for example, Giachetta and Willett (2018). **We will add some sentences to the main text to explain this caveat when comparing our study to previous modelling studies.** Given the scatter we see in the data (original Fig. 6c), any subtle trend is difficult to discern. We therefore focus more on the knickpoint elevations, which are predicted to differ more strongly in the two scenarios we outline in Fig. 3. Indeed, knickpoint elevations vs. distance do show a significant trend, which guides our assessment of the potential mechanism of knickpoint generation. We have added regression lines and confidence intervals to the plots in ***Fig. 7*** (old Fig. 6) to support a more robust interpretation of these knickpoint features. Please see the plots below.

Upstream of the capture point, knickpoints in tributaries of the Saryjaz trunk river would be expected to lie at the same elevation, jointly with a decreasing amount of incision headward, which is what is theoretically expected in the case of a gain in drainage area of a trunk river. Because these behaviors are not recorded in the tributaries, I conclude the authors do not show an analysis that support the transient knickpoints to result from an increase in erosion rate downstream of a capture point. Rather, the slight decrease in the amount of incision from km40 to km80 (Figure 6c) seems to disprove their interpretation.

The knickpoints that we unambiguously identify as transient above the capture point lie at similar elevations, in contrast to those downstream of the capture point. This difference is consistent with a capture mechanism. We acknowledge that we do not see a significant decrease in incision depth upstream of the inferred capture point (km 90-120 in the original Fig. 6c), although the incision depths for these knickpoints are significantly smaller than for those downstream of the capture point, and given the scatter typically seen in such analyses, we are not entirely surprised by this lack of a clear trend.

After adding linear regressions to this plot, we show that there is actually no significant trend in the incision depths downstream from the knickpoint (km0 to km80 in the original Fig. 6c, see the figure below), which is consistent with the drainage-capture scenario if we consider that our study area is relatively far upstream from the final outlet of the river. Also, by scaling the marker size with the size of the knickpoint, we show that many of the datapoints contributing to scatter (and the apparent decrease in incision depths noted by the reviewer) are due to very small knickpoints.



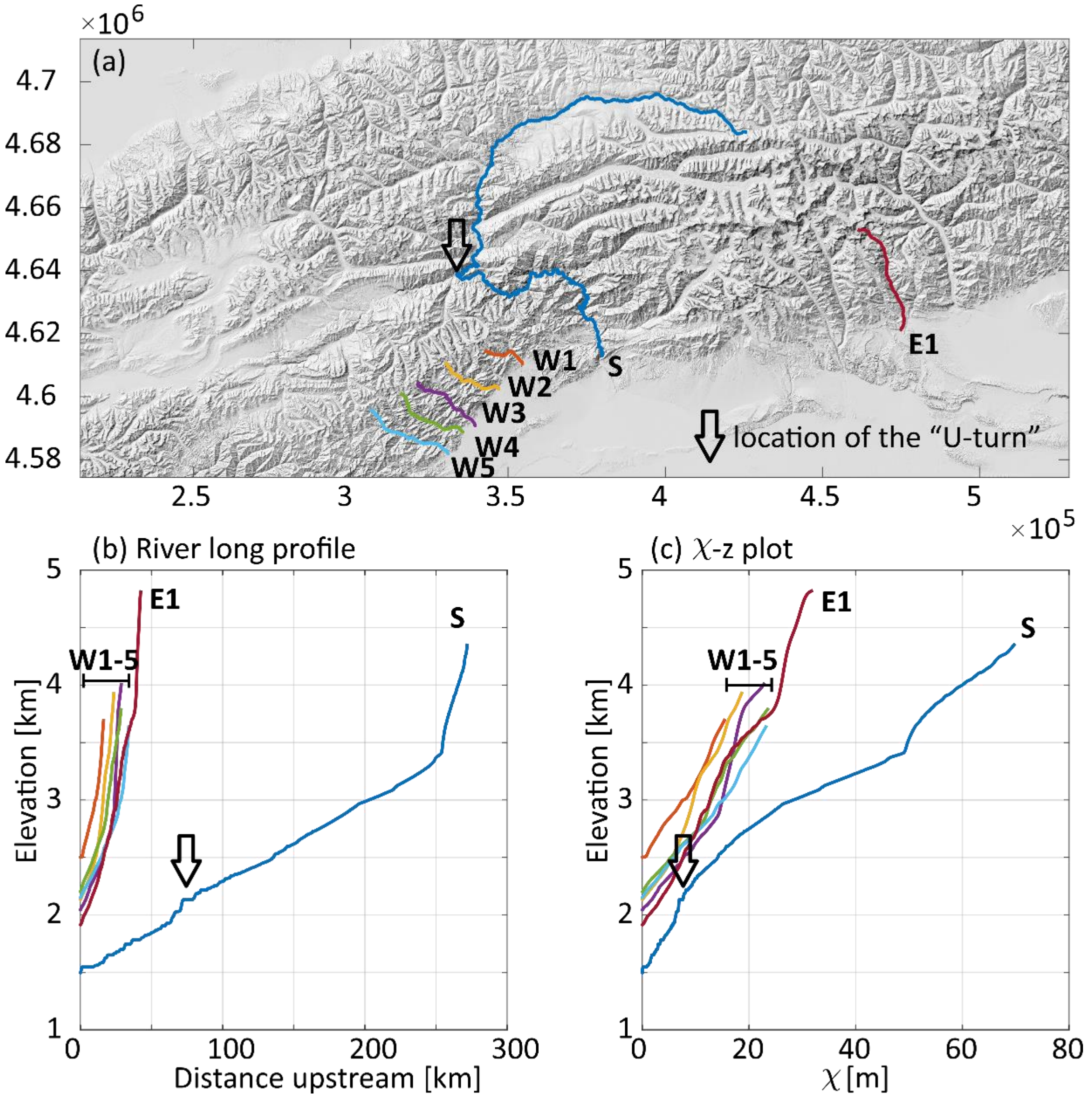
However, they refer in the discussion to geological evidence that support a capture event around the "U-turn" in the Saryjaz River. The contradiction between geomorphic and geological data should be investigated. The problem may lie in the location of the capture point which may not be located at the "U-turn" in the modern river path, as proposed by the authors. I think the effect of drainage integration of the upper Saryjaz catchment on the chi-elev plot should be quantified to predict the amount of incision such a capture would produce at the capture point and downstream, like the test of capture gain effect on river profiles in Giachetta and Willett (2018).

We agree with the reviewer that the capture point may or may not be exactly at the "U-turn", since the trend from incision is not that clear. One possibility is that the capture may have occurred slightly downstream of the "U-turn"– it was actually a tributary of the Saryjaz that was captured, as indicated in ***Fig. 8***.

Reviewer 1 provided a helpful thought experiment that illustrated that our original capture scenario would predict an amount of incision near the capture point (ca. 1800 m) that far exceeds the amount we observe (ca. 300 to 600 m). For this reason, we have reconsidered the possible capture scenario, particularly raising the possibility that the upper Saryjaz river could be a closed basin that simply overtopped a divide to flow into what is now the lower Saryjaz river. This refined scenario would be consistent with our observations (or more specifically, nothing is inconsistent with this scenario). We doubt that river-profile modelling can provide further constraints in the case of Saryjaz, as it would also require assumptions that are difficult to test (notably, how drainage area relates to river discharge, which is particularly complicated in such a strongly glacially impacted area). This is the reason we focus on general differences in geomorphic metrics between different knickpoint-generation scenarios, rather than attempting to model the system explicitly.

Maybe a comparison of the longitudinal river profiles of the transverse rivers sourced in the South Flank of the Tian Shan and that emerge in the Tarim Basin, with the Saryjaz trunk river and its tributaries would help convince the reader that a capture event produced the main transient knickpoints. See Giachetta and Willett (JGR 2018) for the diagnostic features suggesting capture events (Scenario 2). Please consider also to add a plot of knickpoint distance from the Saryjaz outlet vs chi (calculated from the trunk river outlet) to compare with the theoretical prediction of the scenario 3 in Giachetta and Willett (JGR 2018).

We appreciate this suggestion from the reviewer. We extracted the trunk channels of 6 streams from the south flank of the South Tian Shan to the west and east of the Saryjaz, and plot them in both long profile and χ space (see figure below). Importantly, these catchments lack knickzones between 2000 and 3000 m, which would be expected if the knickpoints along the Saryjaz river were driven by faster uplift along the south flank of the South Tian Shan ***(Fig. S4).*** These comparisons, together with knickpoint metrics from tributaries of the Saryjaz (which we assessed based on predictions in Giachetta and Willett, 2018, together with similar findings reported by Yanites et al. 2013 and Rohrmann et al., 2023), support our inference that the transient knickpoints in the Saryjaz were triggered by capture rather than by base-level drop from (a change in) Cenozoic uplift along the South Tian Shan fault (or Maidan fault). The plot noted by the reviewer (χ versus distance from the Saryjaz outlet) was included in the original Fig. 6d. We also added a χ plot of all transient knickpoints and their tributaries in ***Fig. 5*** (old Fig. 4) to show the locations of knickpoints along the river profile.



Specific comments

L171 [… the amount of incision recorded below the knickpoint will be similar for all Tributaries…], what data or model support this assertion? that's not what Giachetta and Willett, 2018 and Rohrmann et al., 2023 show in their studies. They argue for a downstream decrease in the amount of incision in the downstream portion located below a capture point, after a gain in stream power of a capturing river. Channel gradients typically tend to relax downstream of a capture due to the amplified stream power, whereas upstream of a capture, a knickzone tends to gradually form and expand.

We agree with the reviewer, that our original sketch in Fig. 3 and incision depth trend from tributaries downstream of the capture point should be slightly modified. However, we emphasize that the change in incision depth with distance in a capture scenario (upstream increase) could be far smaller than the change in incision depth predicted for a base-level fall scenario (upstream decrease). Soon after the capture, only a limited amount of incision will occur, which could make it hard to detect the trend. Our revised cartoon (*updated **Fig. 4***) shows a slight flattening of the trunk stream and a slight decrease in incision depth downstream from the capture point in the capture scenario, but one that may not be detectable in some natural cases.

We added transient knickpoints upstream of the capture point to the topographic map (i.e. the *new* ***Fig. 3***), as well as χ plot (i.e. updated ***Fig. 4***) to reflect this "gradually formed and expanded knickzone".

The authors decided to show only a subset of the tributaries and the associated knickpoints they studied. I think the reader needs to see the raw data in a synthetic figure in the main text. Please add a chi-elevation plots of each tributary subcatchment with all their tributaries (not a stack of S4 subplots), together with the localization of the knickpoints used in the inversion. this would help support the interpretations. I think the 'representative' χ – z plot of transient slope-break knickpoints in figure 4b does not give enough information of the general geometry of the tributary profiles of the Saryjaz River. Also, a companion figure of fig 4a with the geological map would help to assess any possible tectonic/lithologic control on the spatial distribution of transient knickpoint.

In the new ***Fig. 5*** (old Fig. 4), we plotted all the transient knickpoints from the same outlet in χ space. For geological information, we think that the ***Fig. 2a*** contains quite enough details to give readers an impression of possible tectonic/lithologic control. The level of detail used in our analysis is not practical to include in a figure, as this extends over several full-scale geologic maps.

We also added one more figure in the supplementary information to show all tributary sub-catchments in chi plots.

l411-412: "infer that the capture position is marked by the "U-turn" in the Saryjaz River" models predict deeper incision at capture point! This is not what fig6c shows.

We appreciated this very good point. In our newly added **linear regression that now shows a high p value (0.977), and low R square value (3.96e-5) demonstrating that there is no significant trend in the incision depths with distance below the capture point.** Furthermore, the apparent decrease in incision depth close to the U-turn is due to very small knickpoints that may not be as reliable as the larger ones, which we now indicate with differing marker sizes. In the main text, we discussed this lack of a statistically significant trend, and acknowledged that ***the capture point may have been somewhat downstream of the "U-turn"***.

L412"Ak Shyyrak River corresponds to a paleo-downstream reach of the upper Saryjaz," in this interpretation, but the authors don't show new data (e.g. paleoflow directions) to support that. Maybe, better say "…would correspond…"

We agree with the reviewer, and changed to "***would correspond***" to the text. However, we have reconsidered this scenario based on comments from Reviewer 1, and we no longer believe that this is likely to have been the case.

L416-418: that's not what models show… maximum amounts of incision are expected at and around a capture point.

See our comments above regarding this point.

L442-444: "The divide lies within Neogene sediments, providing a minimum elevation reached by the fill of the Ak Shyyrak basin prior to the capture and supporting a scenario in which capture was driven by overtopping of the Ak Shyyrak basin." Please add the position of the sediment remnants on the topographic profile in figure 6a. This would help visualize the degree of overfilling in the previously closed longitudinal valleys in the interior of the Tian Shan.

We agree with the reviewer, and added the mid-Pleistocene deposits mapped from Quaternary Geological Map of the Khan Tengri Massif (ISTC project KR-920) on both the swath profile in ***Fig. 6a*** and the ***supplementary figure.***

L449-452: "Our analysis of the Saryjaz catchment demonstrates that over a long period of time after the capture event, the impacts of drainage capture will migrate from the trunk to the tributaries, producing transient ksn anomalies, and eventually reshaping the whole river profile into a new equilibrium state." If true, why do only ~200m of incision is observed around the U-turn (fig 6c)? I would expect a deeper incision after 2.8 ± 1.3 Ma (l459) of upstream propagation of the capture-induced wave of incision. Actually, models predict the maximum of capture-induced incision at the capture point which is not what is observed. Please discuss this point.

This is a very good point, and similar to a point made by Reviewer 1. Indeed, the "Incision Depth" measured downstream of the 'U-turn' shows a lot of scatter between 200 and 600 m. In our updated swath profile (new ***Fig. 7***), we weighted the knickpoints by knickpoint height (dz), and use linear regression to fit the trend of incision depth downstream of the 'U-turn'. It is clear that the knickpoints "**around the U-turn**" with around 200 m of incision are more vertical-step in long profile, while the main slope-break knickpoints indicate higher incision of around 500 m. However, the issue here is that the value of incision is still much smaller than the elevation difference between the relict surface (~3200 m) and valley bottom near the 'U-turn' (~2300 m). We suggest two possibilities: (1) our scenario for the paleodrainage flowing into the upper Naryn River basin is incorrect, or (2) the upper Naryn River basin had substantial sedimentary infill since the capture time to raise its elevation. Absent any direct age constraints on the basin fill, we cannot rule out (2). But the possibility of (1) remains. A simple overtopping of a divide to the north of the U-turn could similarly result in a drainage capture. **That scenario would suggest that the modern upper Saryjaz catchment was a closed basin, not one that flowed into the upper Narin Basin.** This scenario would explain our observations without requiring what appears to be an unrealistic amount of incision. We added this possibility into the main text, and modified the final sketch (new ***Fig. 8***) of the drainage evolution process.

l480-482 "our study here do not see transient knickpoints associated with this reactivation from Saryjaz catchment, which might indicate that the change in uplift rates was rather low, or that it actually occurred earlier and no longer visible as a transient signal in river profiles" please explain why the knickpoints in the Saryjaz River especially the ones close to the South Tian Shan Fault may not be tectonically-induced. I guess the inversion of river profile with chi values calculated from the outlet of the Saryjaz River would give ages similar to l477-478 "[…] sharp change in provenance from a mixed Tian Shan-Pamir source to local source between 6 and 3.5 Ma (Rittner et al., 2016; Richter et al., 2022)." If true, rock uplift may explain some of the observed transient knickpoint, while others could have been driven by a river capture event. If not, this point would reinforce authors' interpretation.

The lack of knickpoints in the channels draining the southern flank of the South Tian Shan argue against any change in uplift rate accommodated by the South Tian Shan Fault or Maidan Fault in generating knickpoints, at least up to an elevation of ca. 3000 m, which is as high as any of the knickpoints we map along the lower Saryjaz River. For this reason, together with all of the other arguments and metrics presented, we have no evidence to support a contribution from tectonics in generating any of the knickpoints visible along the lower Saryjaz River today. It may be necessary to reconsider what the change in provenance between 6 and 3.5 Ma really implies. Incidentally, thermochronology data presented by another group in the vicinity of the lower Saryjaz River (Lyu et al., 2024) show a decrease in exhumation rates in the last ca. 5 Ma, which further supports the conclusions we arrived at through our morphometric analyses. We will add one sentence about this in our ***Discussion***, although we do not want to put too much emphasis on results that are so far only presented in an abstract.

Lyu, L., Li, T., Jia, Y., & Chen, J.: Multi-stage Cenozoic exhumation history of southern Central Tian Shan: implications for geodynamic and sedimentary evolution. No. EGU24-7773. Copernicus Meetings, 2024.

L486-496. In the last paragraph the authors suggest a 3 phases evolution, with 1) uplift of a new south topographic barrier, 2) the infill of closed basins in the center of the Tian Shan and 3) the opening of the closed basins by overtopping of sediments at the origin of a capture event. The bottom Paleozoic bedrock of the longitudinal valleys in the central Tian Shan, where late Cenozoic clastic sediments aggraded, is more than 1000 m above the northern margin of the Tarim Basin. If such a difference would have existed at the time of disconnection/closure of the Ak Shyyrak and Saryjasz Basins in the center of the orogen, one may have expected the erosion by the Saryjaz River to have balanced the uplift rate. The authors claim this did not append and that the Saryjaz River have been defeated by rock uplift, which in turn would imply that in Miocene times(?) the Saryjaz River did not have yet its present high potential energy toward the South. A corollary is that the center of the Tian Shan should have been surface uplifted by 1000 m with respect to the Tarim Basin before event 3. This would support the view that a delay exists between orogen building and drainage reorganization, as observed in many geological settings (e.g. Babault et al., J of Asian Earth Sci 2018, Rohrmann et al., Science Advances 2023). Maybe the authors may discuss this reasoning in their model of mountain building and drainage evolution.

This is a very good thought. We added this possible reasoning in the discussion ***Section 5.3***.

Specific comments

Please add a cross-section in the geological settings of the South Tian Shan that passes close to the transverse reach of the Saryjaz River.

Although the pre-Cenozoic geological evolution is not a main part of this manuscript, we added a cross-section extending N-S and passes close to the U-turn to the supplementary information, based on **Geological Map** and **Structural Sections** of the Khan Tengri Massif (ISTC project KR-920).

I did not find a reference to the method that has been used to calculate the steepness index values.

This is explained in ***section 3.1.***, and ***Fig. S1*** in the supplementary information, in which we used the function 'mnoptim' within TopoToolbox 2 to calculate *best-fit m/n* = 0.4 as reference concavity. Then we calculated k_{sn} from gradient (G) and drainage area (A) of the stream, based on detachment-limited stream power law (i.e. equation (2)). Please see the refence in the main text.

It may help the reader to see the Figure S3 in the main text, also add the location of the U-turn in that figure and highlight the location of the transient knickpoints upstream of the U-turn, I can't see them.

Following what the reviewer suggested, we moved Fig. S3 to the main text as a new figure ***Fig. 3***. We slightly changed colormaps of river steepness and knickpoints to highlight key information, and added the location of "U-turn" as well.

L406 "tributaries upstream of the "U-turn", especially within the intermontane basins, show lower slopes (mostly < 30°) and generally lack slope-break knickpoints." Please give a comment/explanation for this feature which seems significant to understand the drainage evolution of the Saryjaz River.

The new ***Fig. 3*** (based on old Fig. S3) shows the location and possible origins of all knickpoints in Saryjaz catchment, the only transient knickpoints recognized upstream of the 'U-turn' mostly sit within 40 km of it, *indicating that the* ***migration of this group of knickpoints has not reached the upstream Saryjaz basin yet. In combination with the low-slope topography (old Fig. 2b), low k_{sn} of stream (old Fig. 2c), we think that upstream part of the Saryjaz has not yet responded to the relative base-level drop induced by the capture.*** We also added this discussion to the main text.

l409-410: 'Considering theoretical predictions of the differences in patterns of knickpoint elevation and incision depth for knickpoints triggered by drainage capture versus base-level fall (Fig. 3),' there is a difference between theoretical predictions and the trends in figure 3. This should be corrected, with increasing incision upstream in the tributaries of the downstream reach of the Saryjaz River, see comments above.

We appreciate that the reviewer's thoughts and modified the text in describing difference between theoretical predictions and our data from Saryjaz. We also updated ***Fig. 3*** to better reflect predictions.

L410-412: "our observations are clearly more consistent with transient knickpoint migration being triggered by drainage capture. We infer that the capture position is marked by the "U-turn" in the Saryjaz River" to help the reader, it may be worth to recall here which are the features you observed that you take as diagnostic for river capture.

Good point! We added the observed features in the main text.

Other comments

L52-53 and L83-84 "…transverse drainage in the east…" true in the south flank only! Should be explained with more details

It is true that the south flank of the South Tian Shan shows a major composition of 'transverse' drainage, while the north flank also includes streams perpendicular to the strike, with peaks between [0,45] and [135, 180] in total. Please see the histogram plots in our new ***Fig. 1c***.

L168: "…up tributary valleys" specify downstream of the capture point

We added "***downstream of the capture point***".

L169 "…constant vertical velocity" specify, true if n=1 in the detachment-limited stream power incision model.

Based on Playfair's law, when uplift rate varies temporally, knickpoints are shown to travel through the basins with constant vertical velocity, and independent of the value of n (although the velocity itself depends on n). See equation (12) in Niemann et al., 2001.

L172-173: "…all tributary knickpoints will have retreated a similar distance from the tributary junctions because they were all initiated around the same time" assuming detachment-limited stream power model and n=1. I would expect this is not true if $n \neq 1$. Horizontal and vertical migrations of knickpoint are function of the erosion rate of the propagating slope patch raised to the power of 1/n, and of the background uplift rate also raised to the power of 1/n (Royden and Perron 2013). If you have a look the figure 3b in Giachetta and Willett (2018), after a capture event, knickpoints in the lower tributaries have lower slopes than tributaries just below a capture point. The difference of migration rates might be small but it would be interesting to quantify it.

See the point above regarding n and vertical knickpoint velocity. The difference in vertical migration rates that would be predicted scale similarly to the difference in total incision for the different knickpoints downstream from the capture point. We see scatter in that relationship (incision depth vs. distance) without any significant trend, so vertical migration rates would show a similar pattern. Still we showed raw k_{sn} downstream of the transient knickpoints in ***Table 1***, and calculated average vertical incision rates from incision depth (ID) and migration time (τ), and will add discussion in updated main text. Please see further details there.

Figure 6d please reverse axis and plot distance from outlet vs chi as in Giachetta and Willett JGR 2018. Although I understand that the plots 6b and 6c show distance from outlet in the x axis. Please check you specify/add everywhere in the ms. i.e., in the text and in the figures (not only in the figure captions of the plots) if chi is measured from the trunk stream or from the outlet (of the trunk river) in the Tarim Basin. Because the studies you refer to values are plotted against both variables.

We agree with the reviewer that the definitions of χ from outlet and tributaries could be confusing to readers. Here we updated the term using subscripts, e.g. χ_o: χ measured from outlet; χ_t: χ measured from tributary junction. As for reversing the axis, since we have shown theoretical trend in ***Figs. 4e and 4f: duration of knickpoints migration*** (old Fig. 3), we think it would be easier, and clearer to plot observed data following the same way. Moreover, standard convention, which is also required for linear regression analysis, is to plot the independent variable on the x-axis, which we have done in our plots.