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Earth Surface Dynamics Discussions

Interactive comment on "The destiny of orogen-parallel streams in the Eastern Alps: the Salzach–Enns drainage system" *by* Georg Trost et al.

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EGU Earth Surface Dynamics – Review Summary

'The destiny of orogen-parallel streams in the Eastern Alps: the Salzach-Enns drainage system'

by Trost et al.

General comments

The study by Trost et al. is centred on the characterisation of drainage divides along the Salzach-Enns drainage systems in the Eastern Alps, and how the geomorphology

along these systems reflect the past Alpine tectonic and climatic evolution since Early Miocene. In their approach the authors employ state-of-the art geomorphic metrics, i.e. χ stream profile analysis, swath profiling along the divides and Gilbert metrics in order to determine the potential mobility of drainage divides. Their main conclusion describes a general eastward migrating trend for the drainage divides in the Eastern Alps mainly as a result of Mid-Miocene extrusion tectonics. In this sense χ stream profile analysis indicates a rather long-term trend whereas the Gilbert metrics are partially influenced by the last glacial maximum. The geomorphic analysis is very detailed and thorough appearing overall robust to me. In this review I found rather few minor issues regarding the general approach. The study is in line with recent studies on Alpine geomorphology, e.g. Robl et al. (2017) and Winterberg and Willett (2019). Thus, its conclusions are not surprising from a fundamental note but add an important link between long-term and short-term drainage re-organisation by comparing divide mobility through χ analysis and Gilbert metrics, respectively. I am convinced the manuscript will find wider interest in the Alpine geomorphology community as well as add new constraints on effects of the eastern Alpine tectonic and climatic evolution on major rivers in the region. I am listing below some mostly minor issues and suggestions that may aid in improving the current version of the manuscript. However, this list contains also points on two topics that may require some more attention. These are concerned with general clarifications regarding processes at geologic time scales and more detailed background on the nature of Figure 7.

Specific comments

Lines 8-9

Here 'stages of the alpine orogeny' and 'late orogenic uplift' are mentioned. I would add a brief notion on the time frame that this study is covering. The Alpine orogeny is fairly complex and long lasting on a geologic time scale. I also would be more conservative in directly linking eastward flow direction caused by fault activity (there have been many other faults active that were not strike-slip faults, e.g. the Sub-Tauern Ramp). Perhaps

just refer to E-W directed flow.

Line 14

Perhaps also provide a rough idea on the relative time scales at which catchment geometries, headwater and hillslopes are operating.

Line 25

This reconstruction of the drainage network appears very prominently here in the abstract and I kept wondering throughout the manuscript how the respective Figure 7 has been produced (including the 'palaeo-χ stream profile analysis'). Maybe this should be improved. Further below a more detailed comment on this.

Line 30

I think the phrasing might be somewhat misleading since 'link' also implies that the drainage system would also somehow influence climate and tectonics (I assume this was not meant this way here). In case it is meant as such I would regard this issue as rather controversial. See discussions on this in Willett et al. (2006) or Schlunegger et al. (2007).

Lines 33-36

Perhaps add works by Miller et al. (2007) and Willet et al. (2001) since horizontal advection is being mentioned here? Also, from a structural geologist's point of view I find the description on mountain formation and orogeny a bit too simplified. There is nothing itself wrong with a simplification. However, fault activity does play an important role in this study. Thus, I would perhaps include a more solid tectonic background here considering basic principles of structural geology.

Lines 40-42

A recent study by Eizenhöfer et al. (2019) discusses the impact of horizontal advection on drainage systems in convergent orogens, which might be of some general interest

in this field.

Line 43

Horizontal advection also affects channel slopes (e.g., Miller et al., 2007) which should be acknowledged here as well.

Lines 48-49

It is certainly correct that previous disturbances in a drainage system are erased after a knickpoint has traversed through it, but I would add that this also involves a time component needed for a knickpoint to reach the headwaters, which is not trivial, especially in glacially influenced parts of the Alps.

Lines 50-52

I might be a bit more cautious here since horizontal advection has been mentioned and is also present in the Eastern Alps. Horizontal advection causes an asymmetry across drainage divides in the direction of advection with the geomorphic characteristics listed here. However, in most cases the divide remains immobile despite the presence of a lateral advection component (see, for example, Miller et al., 2007; Eizenhöfer et al., 2019).

Lines 56-58

I am convinced that major tectonic phases do influence drainage patterns but would add some time notion to ensure that the reader understands that these drainage patterns reflect events at geologic time scales.

Line 64

Please add a rough time information on the onset of topography information in the Alps.

Line 73

I suggest being more precise with the term 'fault tectonics' since this does theoreti-

cally also involve thrusting, normal faulting and/or displacement along a décollement. I assume you refer to extrusion tectonics here.

Lines 84-86

Perhaps briefly elaborate from a more geological point of view (here or better in the next section) why sediment provenance is consistent with the drainage systems here.

Lines 99-100

The exhumation of the Tauern Window and the tectonics behind this process are still debated. Since this is not a major concern in this study, I would rephrase this sentence by moving away from a causal relationship and perhaps just state a coeval occurrence.

Lines 104-106

Echoing my earlier comment on sedimentary provenance, I would be a bit more precise geologically in terms of location of sources (e.g., Austroalpine units covering the Tauern Window) and indicators that were used to identify provenance.

Line 113

'recent geological past' is a fairly vague term. Please be more precise regarding timing.

Section 2.1

I do not think it is required to go into such detail here regarding χ transformation and/or the derivation of channel steepness since the equations shown here do not contain any modifications and/or update on already existing literature. I would simply describe their use and theoretical background and refer to the literature in order to keep this section short and focussed.

Line 131

In the case of n = 1 (as assumed further below to derive the ratio U over K directly, and very often used in the literature), this relation is linear.

Line 162

I think it would be good to show (perhaps only as supplementary material) in a simple slope/area plot that this threshold has been chosen meaningfully in excluding hillslope processes (e.g. the brake-down of a linear slope/area relationship).

Line 167

Generalization of the Gilbert Metrics and applying the stream-power relation.

Lines 178-179

Just a minor quibble, but I would ensure that this is phrased in a way that the reader is aware that exactly across divide channel head elevation, hillslope gradient and local relief are the Gilbert Metrics.

Line 194

I suggest mentioning early on to which base level elevation you are referring to when discussing χ stream profile analyses. This is not right away clear at the beginning of this (and actually throughout) the paragraph.

Line 203

It needs to be clear at which base level you started (0? or something higher?). This is not trivial (otherwise you would not have computed χ at different base levels). I recommend, however, to consider in your selection for the lowest base level the bedrock/alluvial transition as done by Winterberg & Willett (2019) and briefly explain why you chose this lowest base level.

Lines 270-271

Besides climate and lithology, I would also add tectonics.

Line 276

I think the nature of this 'signal', especially its origin (i.e., climate or tectonics) needs

to be more precisely elaborated. A brief description on how such 'signals' traverse through the channel up to the hillslope domain should be included.

Lines 277-279

Are there additional references that dealt with lowering base levels due to glacial erosion (perhaps not necessarily an example from the Alps) to underline the generality of this hypothesis?

Section 4.1

This section might be better located towards the end of the manuscript (I would rather expect early on a discussion on your results followed by a description of the limitations), but this might be a matter of taste.

Lines 281-282

From a geological point of view, I struggled with this argumentation, since mm/yr translates over geologic time scales to km/Ma, which I regard as rather significant and geologists deal with this magnitude of rates on a daily basis. Over such time period a drainage divide might have migrated over kilometre distances (Eizenhöfer et al, 2019, provides a, perhaps more theoretical, example of a drainage divide that migrates significantly over geologic time). So, determining divide migration might be challenging, but probably not 'unfeasible'. Since the scope of the study ranges over geologic time scale (starting at initial collision at ca. 30 Ma) I think this phrasing needs to be modified.

Lines 288-289

I would elaborate in some more detail on these tectonic phases and spatial and temporal changes in uplift patterns since these are very distinct, i.e. Early Miocene collision followed by Middle Miocene extrusion tectonics. A good start are works by Frisch et al. (1998) and Kuhlemann (2007).

Lines 289-290

Please clarify whether these hillslopes are at critical slopes following glacial erosion, or potentially something else (e.g., deep mantle processes as discussed by Schlunegger & Castelltort, 2007).

Lines 293-300

I suggest rephrasing this paragraph by focusing on and more systematically discuss the effects the three parameters (climate, tectonics and erodibility/lithology) can have on χ stream profile analysis. Here climate and tectonics are emphasised in the beginning of the paragraph while lithology appears as some 'side effect'. This issue might appear a bit nit-picky, but I would prefer to have the limitations of χ stream profile analyses clearly outlined.

Lines 309-310

Perhaps elaborate this 'future divide mobility' aspect a bit more?

Lines 312-314

This base level strategy adopted here might be strategically better placed in the methodology section.

Lines 334-337

Perhaps go even one step further: what is / could be the nature and potential origin of these signals with respect to these different amplitudes and time scales?

Line 343

These simplifying assumptions (i.e., uniform climate, lithology, tectonics) should be emphasised a bit more in the limitations section.

Line 358

Even though glacial erosion stopping divide migration appears trivial, is there any reference out there that would support this and could be added here?

Line 363

I suggest being more precise regarding this 'peculiar west-east directed migration', and directly implement your results (i.e., a divide migration from W to E).

Lines 372-373

I do not think basic background on χ stream profile analysis needs to be repeated here and should belong to the methodology section.

Lines 374-377

It is not entirely clear from the way it is phrased here whether basic background regarding χ stream profile analysis is being discussed or implications of your analyses in the Eastern Alps as a whole. Perhaps add some broad geographic location indicators?

Lines 381-383

Echoing my earlier comment on time scales, I think it is problematic to use the slow mm/yr rate of divide migration as argument for the longevity of geomorphic features (this needs to be tested) in the context of tectonic forces that operate at these time scales

Figure 7

There are a couple of issues I had with this figure (technically and geologically/geomorphologically). 1. How has this figure been produced? 2. Does it show some kind of 'model'? What are the model assumptions in detail? 3. How has χ been produced after changing the geometry of the drainage basins, especially that of the drainage divides? Have all elevations been the same as present-day? 4. Since Oligocene time uplift patterns and the geometry of tectonic units in the Eastern Alps have considerably changed (e.g., Frisch et al., 1998). Assuming that the drainage geometry and river courses are largely the same since then (perhaps with exception of the major strike-parallel drainage systems) and only locations of divides are changed, I find

rather problematic. 5. It is very likely very challenging to accurately depict the fluvial geometry of the Eastern Alps in Early Miocene simply because numerous tectonic and climatic events (Messinian crisis, Pleistocene glaciations, Middle Miocene Optimum, significant changes of the drainage basin of the Danube far to the east, rapid Miocene exhumation of the Tauern Window, switch from convergence to extrusion-dominated tectonics, just to name a few examples) would have had a deep impact on the drainage system. Thus, Figure 7 is from my point of view an overly optimistic simplification that might be rather misleading than helpful. In applying χ analyses across the present-day Eastern Alps a number of simplifying assumptions have already been made and we somewhat already turn a blind eye to this (for good reasons), but doing the same back in geologic time, I find, is rather problematic.

Lines 389-391

Exactly these assumptions stated here I regard as problematic, and Figure 7 is probably not the best approach to simulate palaeo-drainage geometries.

Lines 442

Since Figure 7 is indeed a very rough restoration, making many in my opinion rather oversimplifying assumptions (see my comment on this above), I would be very cautious in drawing conclusions based on this figure.

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