

1 **Reply to Comment by Seybold et al.** Climate vs. tectonics as controls on river profiles

2 Katerina Michaelides^{1,2}, Shiu-an-Chen³, Stuart Grieve⁴, Michael Bliss Singer^{2,5}

3 1 School of Geographical Sciences, University of Bristol, UK

4 2 Earth Research Institute, University of California Santa Barbara, USA

5 3 Institute of Water Resources Development, Feng Chia University, Taiwan

6 4 School of Geography, Queen Mary University of London, UK

7 5 School of Earth and Environmental Sciences, Cardiff University, UK

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9 Corresponding author: Katerina Michaelides (katerina.michaelides@bristol.ac.uk)

10 The accompanying Comment¹ claims that our original study² disregarded correlations between our
11 metric of river longitudinal profile concavity (NCI) and four morphometric variables (relief, channel
12 gradient and length, and drainage area)³. Seybold et al.¹ show these four variables to be more highly
13 correlated with NCI than Aridity Index (AI, a climatic classification metric), and they use these rank
14 sum correlations to imply stronger controls of tectonics over climate. However, the correlations
15 presented by Seybold et al.¹ are flawed for the following reasons: (1) It is well known that relief, river
16 slope, length, and drainage basin area are interdependent with concavity⁴⁻⁶ and, therefore, are not
17 independent drivers of the concavity of long profiles. (2) These four morphometric variables co-evolve
18 with NCI in response to external forcings including both tectonics and climate and, therefore, they
19 cannot be considered independent metrics of tectonic activity. (3) The calculation of NCI uses relief,
20 channel length and channel gradient in the equation (Eq. 1 in Chen et al.²), and therefore, there is a
21 direct numerical dependency between those variables and NCI. For all these reasons, it is not
22 defensible to correlate NCI with these internally dependent morphometric variables to make the point
23 that tectonics exert a stronger control on long profile evolution than climate.

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25 In Chen et al.² we normalised concavity by relief to enable comparison of channels across different
26 scales through removal of scale-induced bias – the normalization does not remove dependency
27 between NCI and its composite variables, nor does it remove the co-evolving relationship between
28 these variables and NCI. The density scatterplots between these morphometrics and NCI were
29 included in Chen et al.² (Extended Data Fig 4) as a bias check for NCI, and this is clearly stated in the
30 figure caption and in the text (Chen et al.² Methods section on River long profile extraction). In the
31 part of our Methods section focused on NCI, we mistakenly used the words “correlated with” instead
32 of “biased by” in the following sentence of the original supplemental material (Chen et al.²): “We
33 confirmed that NCI values for extracted rivers in GLoPro are not correlated with key river metrics, such
34 as river length, gradient, relief or basin area (Chen et al.² Extended Data Fig. 4).” The wording has been

35 corrected in the online Article to: “We confirmed that NCI values for extracted rivers in GLoPro are not
36 biased by key river metrics, such as river length, gradient, relief or basin area (Extended Data Fig. 4).”
37 This wording is now consistent with the caption of Extended Data Figure 4.

38

39 Our original study² concluded that climate (translated into streamflow generation) is a first-order
40 control on river long profile concavity (NCI) based on four independent lines of evidence which
41 included analysis of global NCI distributions by two climate classifications, modelling, and empirical
42 analysis of streamflow. Our sensitivity analysis using a numerical model of long profile evolution
43 revealed that downstream rate-of-change of discharge (α) is a first-order control on NCI compared to
44 other drivers, including tectonic uplift rate (which we varied over two orders of magnitude up to 1
45 mm/y) and base level change (Chen et al.² Figs 3 and 6), and our analysis of empirical streamflow data
46 demonstrated a direct link between α and AI climate classes.

47

48 Leveraging this empirical and modelling evidence, we provided a new theoretical explanation² that
49 links climate to NCI through the cascade from: aridity, to runoff-generation, to the downstream rate-
50 of-change in discharge (α), to long profile concavity. This theoretical framework is supported by our
51 previous work explaining straight long profiles in arid regions⁷⁻¹⁰ as a function of dryland runoff
52 regimes¹¹⁻¹³ and is underpinned by stream power theory after relaxing the assumption of discharge-
53 area (Q-A) dependency. We highlighted the hitherto unacknowledged importance of zero to negative
54 α values which we found to be common in dryland ephemeral rivers (Chen et al.² Extended Data Figs
55 7, 8 and Extended Data Table 2). Therefore, this analysis is not simply an “empirical verification of the
56 stream power model” as suggested by Seybold et al.¹, but rather an extension of stream power theory
57 into the domain where Q is disconnected from A leading to straighter long profiles.

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59 Seybold et al.¹ suggest that tectonic uplift is the key control on long profile concavity globally. We do
60 not dispute the importance of tectonic uplift on drainage basin morphometry in active margins - this
61 effect has been well understood based on decades of literature, e.g.^{4,14-15}, as we acknowledged in Chen
62 et al.². The real question we addressed in Chen et al.² was whether a climatic signal can be detected
63 across the globe, despite strong tectonic and other controls that are geographically restricted. We
64 found that the signal of aridity was expressed within two independent climate classifications: a) in the
65 Köppen-Geiger (K-G) Arid class, long profiles are distinctly straighter compared to the humid climate

66 classes, and b) within the non-humid AI climate classes², distributions of profiles are monotonically
67 straighter with higher aridity from Dry Sub-humid to Hyper-arid.

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69 Our complete analysis revealed 'climate-sensitive flow accumulation'¹⁶ as a dominant global control
70 on channel long profiles. These results can be emphasised more clearly through a comparison of NCI
71 within and outside of zones of active uplift. Here we present an additional analysis of NCI with AI and
72 K-G climate classes for tectonic v. non-tectonic regions by masking GLoPro using an assumed threshold
73 of >0.08g in peak ground acceleration¹⁷ (PGA), which measures seismic activity. This threshold
74 conservatively defines areas of high uplift coinciding with current active margins. It should be noted
75 that there is no global dataset of tectonic uplift, so PGA is often used a proxy, however an imperfect
76 one, since seismicity does not always correspond with uplift. Our analysis revealed that: 1) only 25%
77 of channels in GLoPro (n=83,041) fall in tectonically active regions; 2) the aridity signal leading to
78 straighter profiles in drier basins is systematically stronger in the 75% of channels in GLoPro
79 (n=250,461) that lie outside of tectonically active zones (as expected); and 3) NCI distributions become
80 less negative (straighter) with increasing aridity classes for both tectonic and non-tectonic areas (Fig
81 1).

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83 We conclude that the signal of aridity in NCI is, therefore, expressed in both tectonic and non-tectonic
84 regions across the globe, and most strongly in increasingly arid regions outside zones of high tectonic
85 uplift, where rainfall-runoff regimes tend to disconnect Q from A. These results also suggest a spatially
86 restricted influence of tectonics and the more global influence of climate on landscape morphometrics
87 such as long profiles. Specifically, long profiles in zones of high uplift rates are likely to be affected by
88 both climate and tectonic uplift, creating a mixed signal¹⁸. However, the influence of tectonics on
89 channels outside of potentially high uplift zones (75% of the channels studied) apparently declines in
90 favour of a stronger climate signature across most of the global land area (Fig.1). This conclusion is
91 corroborated by other studies showing that long profile concavity is most sensitive to spatial patterns
92 in runoff, and that rock uplift rates only influence relief in zones where uplift rate is high¹⁹.

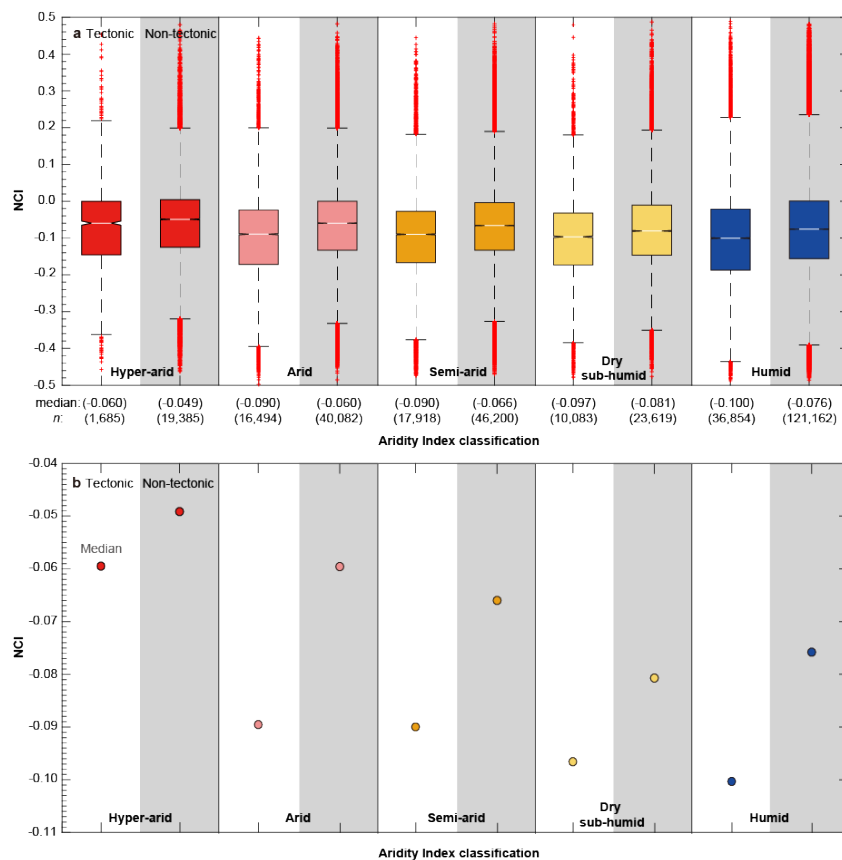
93

94 In summary, Seybold et al.¹ present correlations between the morphometric variables of channel
95 relief, slope, length, drainage basin area and NCI that are flawed on three counts: 1) these
96 morphometric variables cannot be considered as independent metrics of tectonic activity, since they
97 also influenced by climate; 2) these morphometric variables are interdependent with concavity and,

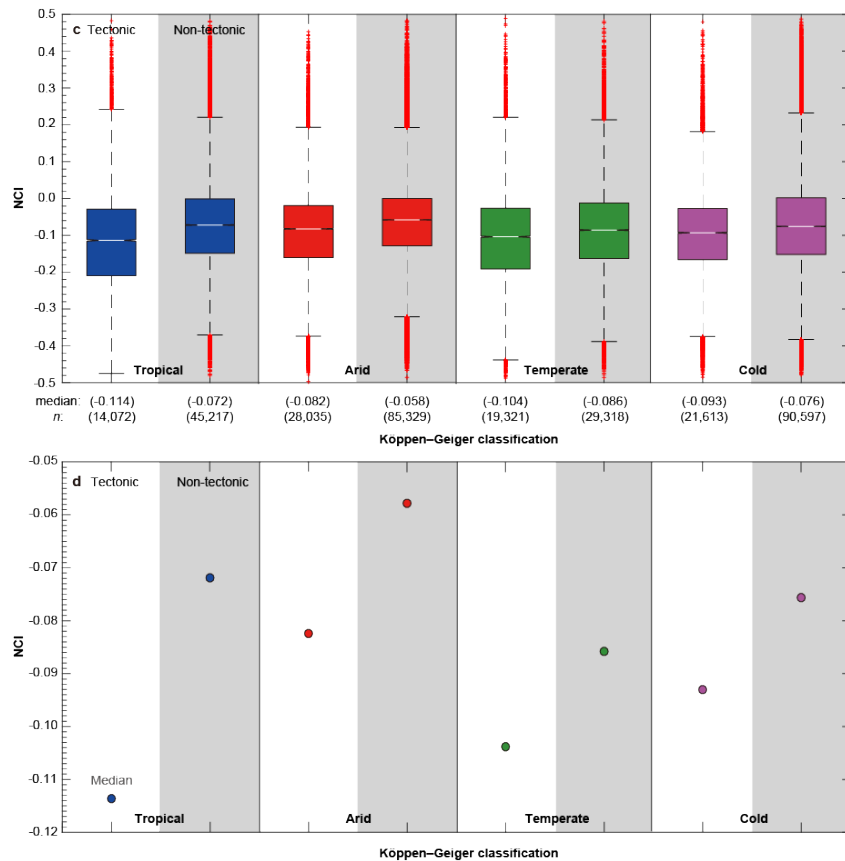
98 therefore, are not independent drivers of concavity change and; 3) these morphometric variables are
 99 used in the calculation of our normalized concavity index (NCI). Beyond presenting rank sum
 100 correlations, Seybold et al. have not provided a mechanistic explanation of how tectonics influences
 101 NCI within or outside of zones of high uplift, nor how/why tectonic drivers of long profile evolution
 102 should be stronger than climatic drivers in parts of the world where tectonic uplift is low. We argue
 103 that since potentially high uplift zones are spatially restricted to 25% of the rivers in our global
 104 database, tectonics cannot be a first-order control on NCI at the global scale. Climate on the other
 105 hand, and its influence on streamflow regimes, is ubiquitous in shaping river basins around the globe
 106 with and without high uplift. Our findings are corroborated by steadily mounting evidence pointing to
 107 the nuanced relationship between climate and streamflow patterns and its dominant control on the
 108 topographic development of drainage basins^{16,18-21}. Further evidence to assess the role of climate in
 109 drainage basin evolution will require overcoming regional biases in geomorphic analyses focused only
 110 in tectonically active zones.

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115 **Figure 1.** NCI classified by aridity in tectonic v. non-tectonic regions: a) distributions of NCI based on AI; b) median values
 116 from the AI distributions in a; c) distributions of NCI based on K-G; and d) median values from the K-G distributions in c.

117

118 **Author contributions**

119 K.M. wrote the reply and all other authors provided edits. S-A.C. produced Fig. 1.

120 **Competing interests**

121 The authors declare no competing interests.

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