GSA Data Repository 2018131

Li et al., 2018, Some signals are not the same as they appear: How do erosional landscapes transform tectonic history into sediment flux records?: Geology, https://doi.org/10.1130/G40026.1.

Supplemental Discussion:

Lag time following a decrease in uplift rate - LT_L

In the experiments with constant *T*, the mean lag time (LT_L) decreases with an increase in the duration of high uplift rate (t_H) (Supplementary Fig. 3A). If the previous rock uplift interval is longer, the landscape is closer to steady state when the uplift rate decreases. In addition, LT_L can have a value greater than 50% of t_L (Supplementary Fig 3.B), which means sediment flux is out of phase (sediment flux continuously increasing while rock uplift rate is low) with rock uplift changes for at least half the duration of rock uplift changes.

Normalized minimum sediment flux - $Q_s^{min}/Q_{s\_eq}^{min}$

Comparing among the experiments with the same *T*, the normalized minimum sediment flux ($Q_s^{min}/Q_{s\_eq}^{min}$) decreases as the duration of low rock uplift rate increases (Supplementary Fig. 4A). The normalized sediment flux difference ($(Q_s^{max}-Q_s^{min})/(Q_{s\_eq}^{max}-Q_{s\_eq}^{min})$) increases with increasing *T* (Fig 4B), which suggests that Q_s^{min} and/or Q_s^{max} will be closer to $Q_{s\_eq}^{min}$ and $Q_{s\_eq}^{max}$, respectively. As a result, the implied uplift rates ($\frac{Q_s^{min}}{A}$ and/or $\frac{Q_s^{max}}{A}$) might be closer to the real low and high uplift rate, respectively. For a given *T*, the largest normalized sediment flux difference occurs when the high and low uplift rate intervals have the same duration.

Reasons for a lag time

To further explain why we observe lag times, we illustrate landscape evolution following a decrease in rock uplift from the experiment with periodicity (*T*) of rock uplift rate equal to 75% RT and proportion of high uplift (t_H) is 50%. We highlight erosion rates when rock uplift rate is about to decrease, just decreases, and 20,000 years after the decrease, respectively (Supplementary Fig. 5) to explain why there is a lag time in some cases. In this case we observe that the sediment flux continues increasing after the rock uplift rate decreases (Supplementary Figs. 5C, E). In other words, there is a lag time. Next, we map the erosion rate across the entire landscape at each of the specified times (Supplementary Figs. 5B, D, F). Using the erosion rate maps, we calculate the change in erosion rate across the entire landscape during two periods (Supplementary Fig. 6). The first interval is between the time just before and just after rock uplift rate decreases (Supplementary Fig. 6A). The second interval is between the time just before rock uplift rate decreases and 20,000 years after the decrease (Supplementary Fig. 6B). We observe that the area in which erosion rates are increasing is much larger than the area in which erosion rates are decreasing. Only the few downstream channel cells closest to the outlet have experience a decrease in erosion rate. This is why we observe the time lag. Because of the network structure, the earlier uplift signal is more widely spread through the landscape than the new uplift signal is, at least immediately following the change in uplift rate.

We calculated the sediment flux if only considering the contribution from the main river channel, as illustrated by the white line in the Supplementary Fig. 6. We observe that the sediment flux from the main channel responds immediately to changes in rock uplift rate (Supplementary Fig. 7). In other words, there is no lag time if only the main channel is modeled because the behavior of the tributaries is not captured. 1D models typically use Hack's law, but this is not necessary in this study because we model the entire network structure (see Braun and Willett (2013) for an excellent illustration of how drainage area accumulation is captured in 2D landscape evolution models). As such, 1D models will apply any changes that occur at a single cell in the main channel to all the accumulated area that is represented by the downstream channel length associated with a single cell. In contrast, in a 2D model rock uplift signals can propagate from one cell only to the upstream neighboring cells. For example, when rock uplift rate decreases, a 1D model will apply the decreased erosion rate of the most downstream cell to the entire area accumulated between the downstream cell and the next upstream cell as represented by Hack's law, while only the most downstream cell experiences the decrease in erosion rate in 2D model (Supplementary figure 8). One of the impacts of this difference in drainage area accumulation between a 1D and 2D model is that the 1D model cannot capture this upstream network propagation of signals, which has been observed in many landscapes (e.g. DiBiase et al, 2015) and illustrated in previous modeling studies (E.g. Tucker and Whipple, 2002). This highlights the importance of considering the entire network structure when modeling changes in sediment flux.

In order to understand the impact of resolution our modelling results, we run another experiment where periodicity (T) of rock uplift rate is 75% RT and proportion of high uplift (t_H) is 50% with the exception that we decrease the spatial resolution from 100 m to 50 m. We still observe that there is a lag time between rock uplift change and sediment flux responses when considering the entire 2D structure of the network. However, the sediment flux from the main channel only responds immediately to changes in rock uplift rate (Supplementary Fig. 8). In other words, our results persist even when the resolution is decreased. This is because they are controlled by the network structure. We note that using 50 m resolution without modeling hillslopes would not be common practice for landscape evolution modelling, but we illustrate this example only to show that model resolution is not responsible for our results.

We also acknowledge that the absolute value of response time and lag time changes slightly when we decrease a space resolution. However, the general trend is not changing. In fact, grid resolution has impacts on all modeling studies, whether they are 1D or 2D. We discuss a hypothetical example to illustrate the impact of resolution on a 2D model. First, take a watershed of 1 km^2 and represent it with one grid cell that is 1 km by 1 km. Because there is only one grid cell, the entire landscape will immediately respond to any base-level signal, and there would be no modeled lag time. Now, take a 1 km^2 watershed and represent it with 0.1 km by 0.1 km cells, or 100 grid cells of size 0.01 km^2. Now if that watershed is perturbed with a base-level signal, the first response will impact a single cell of size 0.01 km^2. If other signals are propagating upstream in the network, and they cover an area greater than 0.01 km^2, depending on the magnitude of the different signals, the new signal has the potential to be lost. As this thought experiment is taken to higher and higher resolutions (or smaller and smaller grid cells), the immediate impact of a base-level signal has an even higher potential to be lost because of the presence of earlier signals still in the landscape. In real landscapes, which presumably are better "matched" by smaller grid cells, we would expect the same behavior.

References:

Braun, J., & Willett, S. D. (2013). A very efficient O (n), implicit and parallel method to solve the stream power equation governing fluvial incision and landscape evolution. *Geomorphology*, *180*, 170-179.

DiBiase, R. A., Whipple, K. X., Lamb, M. P., & Heimsath, A. M. (2015). The role of waterfalls and knickzones in controlling the style and pace of landscape adjustment in the western San Gabriel Mountains, California. *Geological Society of America Bulletin*, *127*(3-4), 539-559.

Tucker, G. E., & Whipple, K. X. (2002). Topographic outcomes predicted by stream erosion models: Sensitivity analysis and intermodel comparison. *Journal of Geophysical Research: Solid Earth*, *107*(B9).

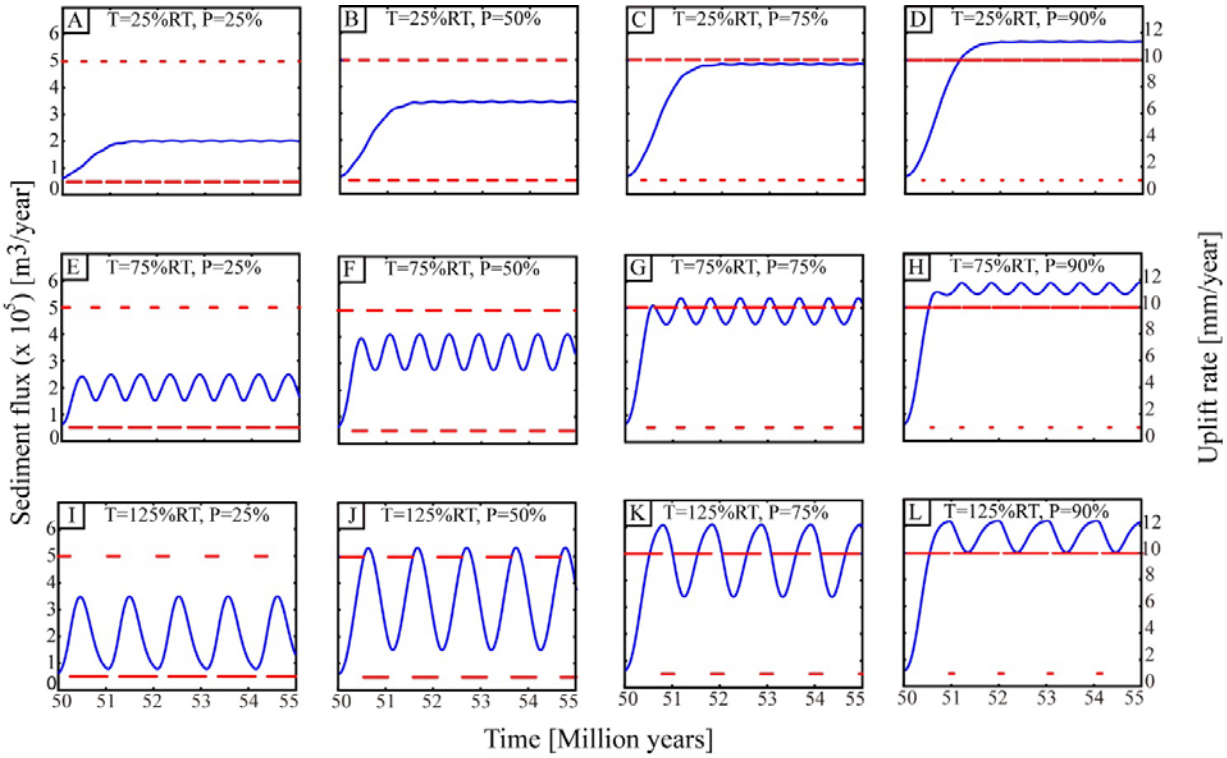

Figure DR1. Time series of sediment flux. (A-L) The red lines represent the time series of uplift and the blue line shows how sediment flux responds to the change in uplift rates.

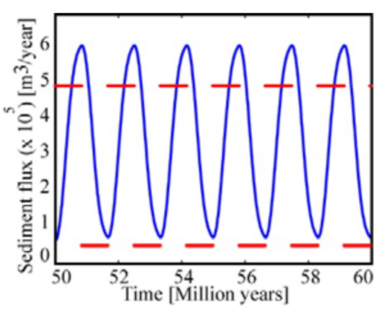

Figure DR2. Time series of sediment flux where T is 200% of RT and P_H is 50%.

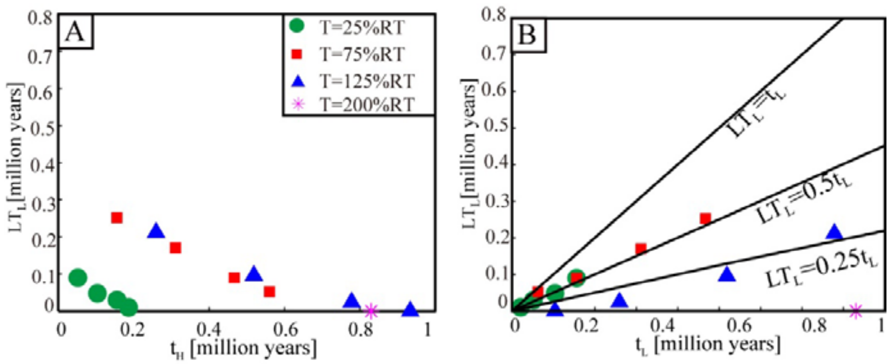

Figure DR3. Variation in lag time. (A) Lag time following a decrease in rock uplift rate, LT_L, as a function of the duration of high rock uplift (t_H); (B) LT_L as a function of the duration of high rock uplift. The black lines illustrate the cases in which LT_L is equal to 25%, 50% and 100% of the duration of low rock uplift rate.

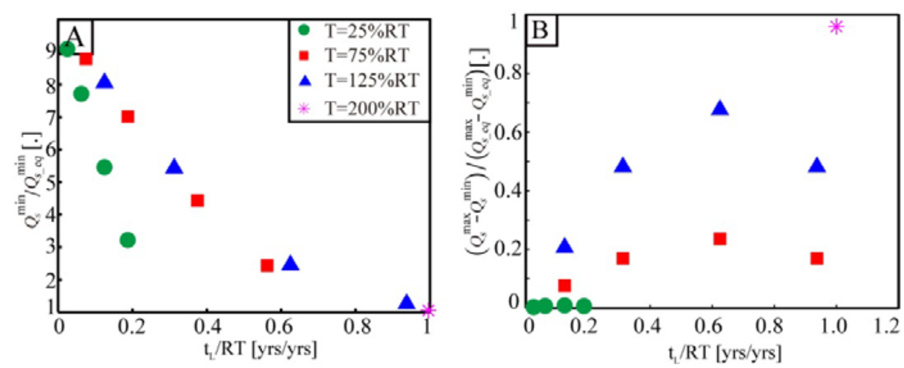

Figure DR4. (A) Normalized minimum sediment flux, $Q_s^{min}/Q_{s\_eq}^{min}$ as a function of the normalized duration of low rock uplift rate, t_L/RT. (B) Normalized sediment flux difference, $(Q_s^{max}-Q_s^{min})/(Q_{s\_eq}^{max}-Q_{s\_eq}^{min})$, as a function of the normalized duration of low rock uplift rate t_L/RT.

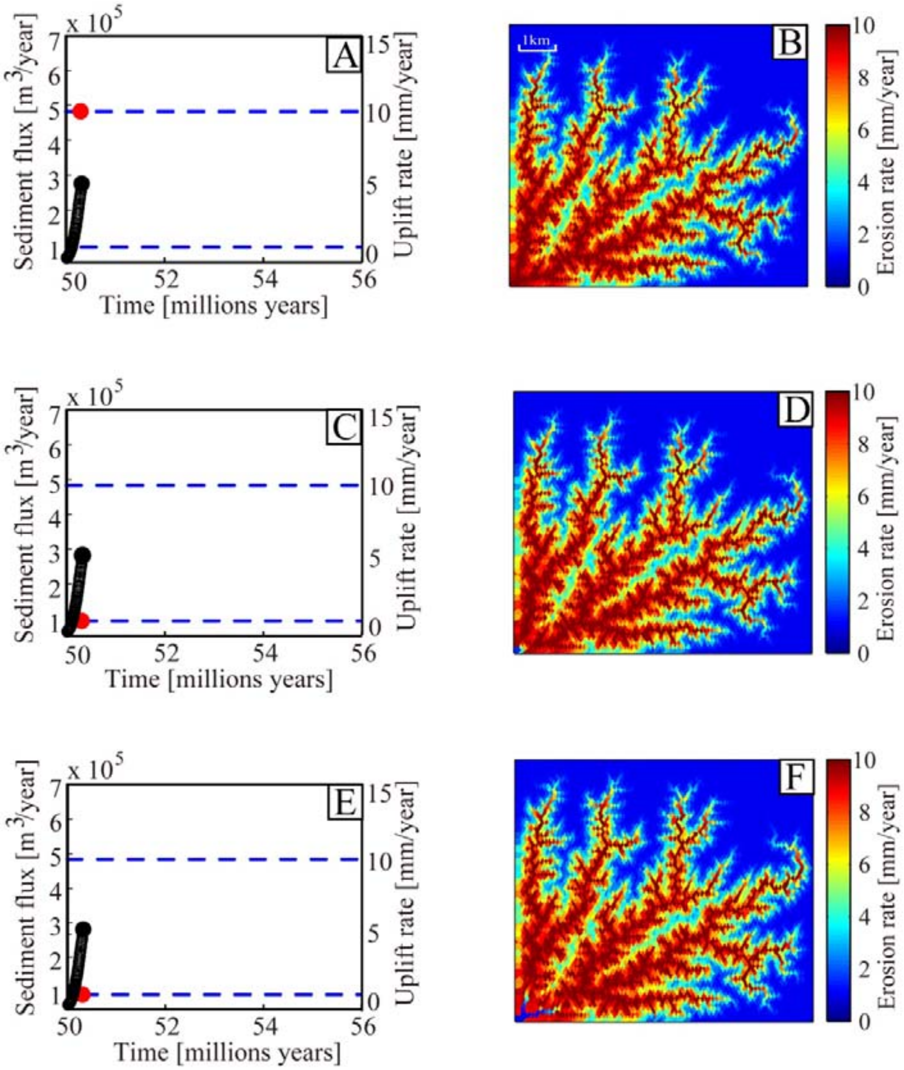

Figure DR5. Uplift rate, sediment flux, and erosion maps at three times in the experiment with T = 75% RT and P = 50%. Illustrated are the time just before rock uplift rate decreases (A, B,), just after it decreases (C, D), and 20,000 years after it has decreased (E, F). Red dot in A, C, E illustrates the current uplift rate.

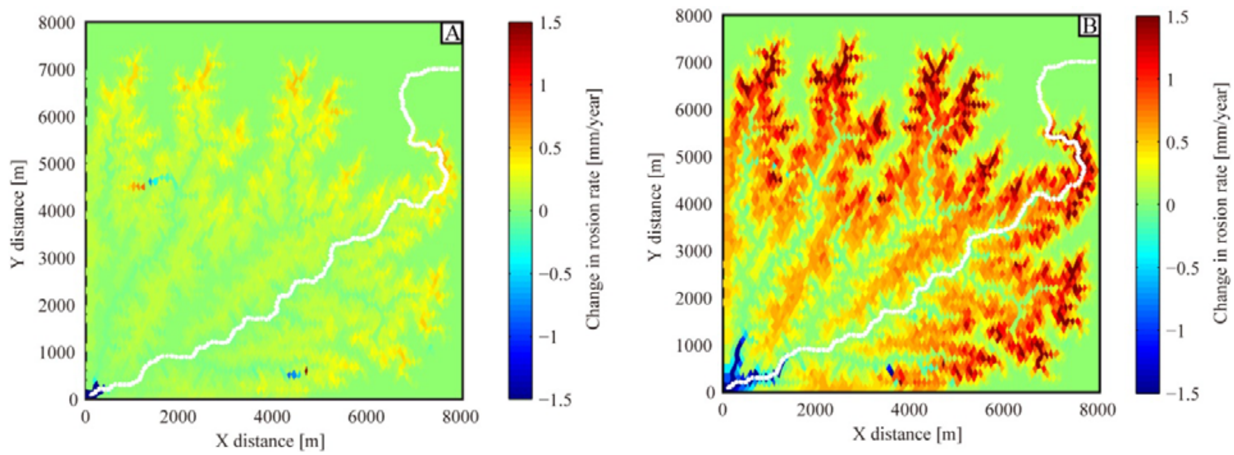

Figure DR6. Erosion rate difference maps. (A) Difference in erosion rates between the time just after and just before rock uplift rate increases. (B) Difference in erosion rates between the time 20,000 years after rock uplift decreased and just before rock uplift decreased. The white line denotes the longest river channel in the system. Red colors indicate locations in which erosion rates have increased (more erosion) and blue colors indicate locations in which erosion rates have decreased (less erosion).

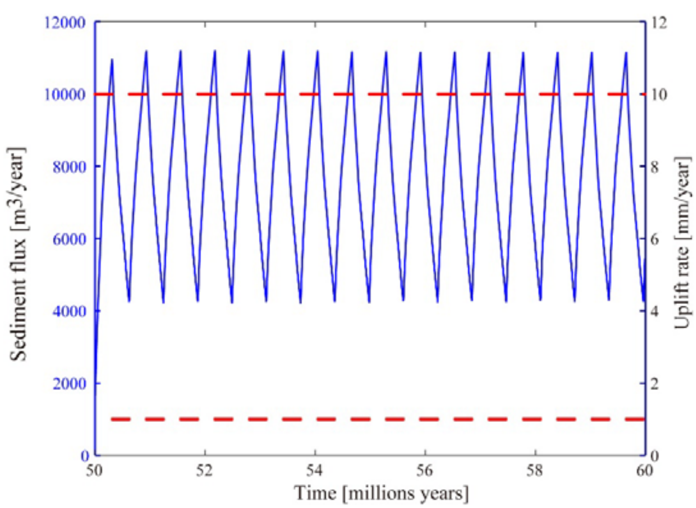

Figure DR7. Sediment flux time series from the experiment shown in Supplementary Figure 2A if only considering the main river channel and not including the tributaries.

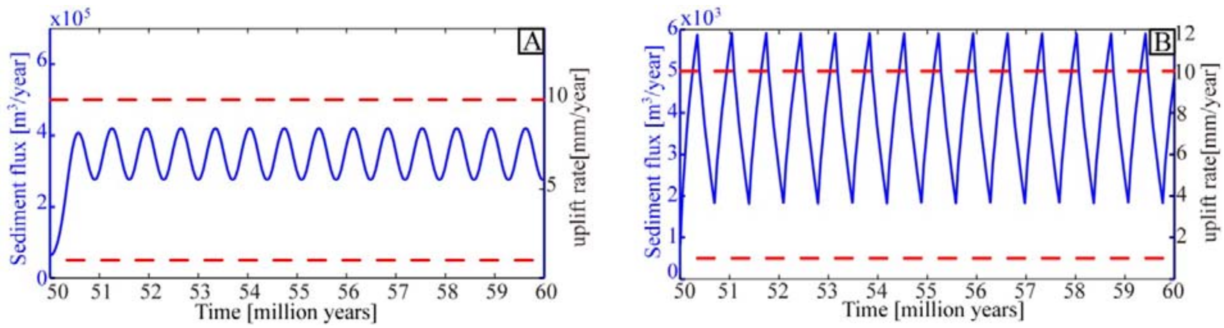

Figure DR8. (A) Time series of sediment flux where T is 75% of RT, P_H is 50%, and space resolution is 50 m. (B) Sediment flux time series if only considering the main river channel of this 2D experiment and not including data from the tributaries.

Table DR1. Experimental parameters used in all CHILD numerical experiments.

Domain size	Resolution (m)	*m*	*n*	K (yr^{-1})
8 km x 8 km	100	0.5	1	0.00001

The stream power model is described by the equation: $E = KA^{m}S^{n}$, where K is a dimensional erosional efficiency factor affected by climate and the type of bedrock (m^{1-2m}yr^{-1}), Q is fluvial discharge (m^3/yr), S is the slope (m/m), m and n are positive dimensionless exponents and depend on hydrology, hydraulic geometry, and erosion process.

Table DR2. The periodicity and proportion of high rock uplift among experiments.

Experiments	T (Ma)	P_H (%)	t_H (Ma)	t_L (Ma)
T=25%RT, P=25%	0.32	25	0.08	0.24
T=25%RT, P=50%	0.32	50	0.16	0.16
T=25%RT, P=75%	0.32	75	0.24	0.08
T=25%RT, P=90%	0.32	90	0.28	0.04
T=75%RT, P=25%	0.95	25	0.24	0.71
T=75%RT, P=50%	0.95	50	0.475	0.475
T=75%RT, P=75%	0.95	75	0.71	0.24
T=75%RT, P=90%	0.95	90	0.85	0.1
T=125%RT, P=25%	1.58	25	0.40	1.18
T=125%RT, P=50%	1.58	50	0.79	0.79
T=125%RT, P=75%	1.58	75	1.18	0.40
T=125%RT, P=90%	1.58	90	1.42	0.16

In a preliminary experiment, we perturb the steady-state landscape with a uniform and constant uplift rate of 1 mm/yr and increase rock uplift rate to 10 mm/yr, in order to estimate the response time (*RT*) of the landscape to be 1.26 Ma. Note that although we do not use the relationship presented in equation 1 for calculating response time, we find that our results scale with this equation.

Table DR3. The units of parameters in equation 1. Dimensionless parameters are indicated by [.].

T_{ND}	T_U	RT	k_a	x_c	m	n	h
yrs/yrs	yrs	yrs	m^{2-h}	m	[.]	[.]	[.]

Movie DR1: Landscape evolution (2018131-MovieDR1.mp4).