Modelling the migration of a mid-Pleistocene erosion wave in the Ardennes (western Europe) drainage network: approach and first implications

A. Beckers [1], B. Bovy [1,2] & A. Demoulin [1,2]

[1] Université de Liege, Dept. of Physical Geography and Quaternary, Liege, Belgium
[2] FSR-FNRS Belgium and Université de Liege, Dept. of Physical Geography and Quaternary, Liege, Belgium

Corresponding author : abeckers@student.ulg.ac.be

1. Introduction

In studies of bedrock river incision in response to a base level change, one frequently models the upstream propagation of a wave of erosion by means of the stream power model, expressing the erosion rate E as

$$E = K A^m S^n \quad (1)$$

where K characterizes the erosional efficiency, A is the drainage area, S the channel slope, and m and n are positive constants derived from exponents involved in various relations linking drainage area, discharge and channel width. A general expression for the knickpoint propagation celerity c has often been derived from this model:

$$c = \mathcal{K}^{1/n} A^{m/n} \quad (2)$$

where $\mathcal{K} = KU^{n-1}$ and U is the uplift rate.

The parameters appearing in these two equations can be determined by knickpoint propagation modelling. The aim is usually to minimize the stream-wise distance between observed and modeled knickpoint positions. *But are the distance residuals the most efficient indicator of the best fit?*

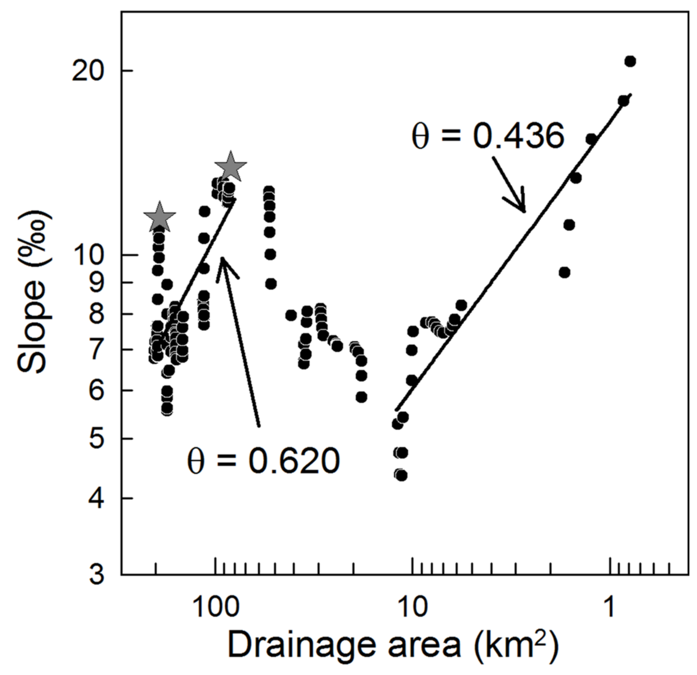

Fig. 2 – Knickpoint detection

2. Data set

68 streams have been selected in the Ourthe basin (3600 km², Ardennes massif, Belgium) (see fig. 1). Mainly composed of Paleozoic slaty rocks, this watershed was affected by an erosion wave which entered it ~700 ka ago and caused the abandonment of the so-called "Younger Main Terrace" (YMT) level (Rixhon et al., 2011).

From 80 knickpoints detected in slope-area space, 18 have been attributed to the post-YMT erosion phase by geometrical correlation with the YMT profile (fig. 1 and 3).

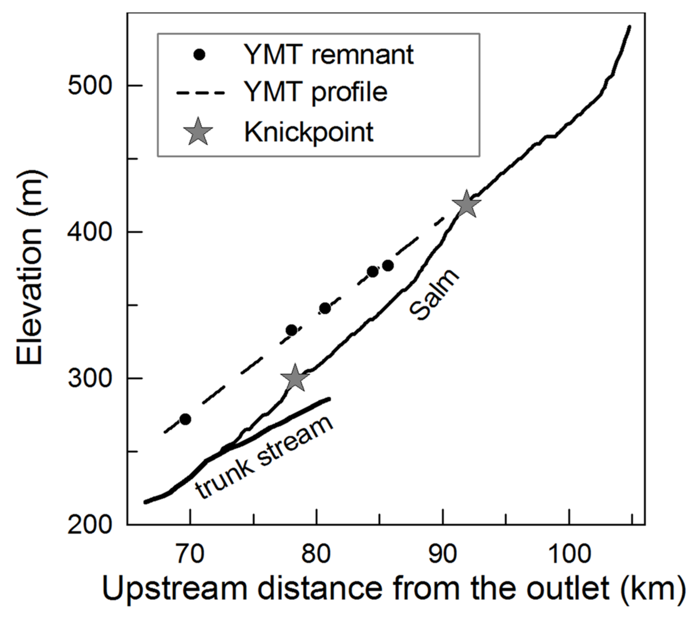

Fig. 3 – Knickpoint validation

3. Methods

We used eq. (2) to model the knickpoint propagation in the Ourthe watershed. The parameterization was carried out by a brute force two-parameter search, with a 300x300 search matrix, m/n varying linearly between 0.2 and 1.3, and $\mathcal{K}^{1/n}$ logarithmically between 10^{-12} and 10^{-3}. We tested 3 adjustment methods:

(1) distance-based adjustment: least squares adjustment based on the stream-wise distances between observed and modelled knickpoint positions at time t = 0.7 Ma;

(2) time-based adjustment: least squares adjustment based on differences between observed (0.7 Ma) and modelled times at the actual knickpoint locations;

(3) least rectangles adjustment: intermediate method based on the minimization of the sum of the products between distance residuals and time residuals.

4. Results

The m/n best fit value significantly varies between the distance-based adjustment (0.86) and the time-based one (0.75), the least rectangle best fit yielding an intermediate result of m/n = 0.78 (fig. 4).

Residuals change between methods (table 1). They show Gaussian-like distribution, which is consistent with a good model performance. For example, time residuals for the time-based adjustment are shown on fig. 5.

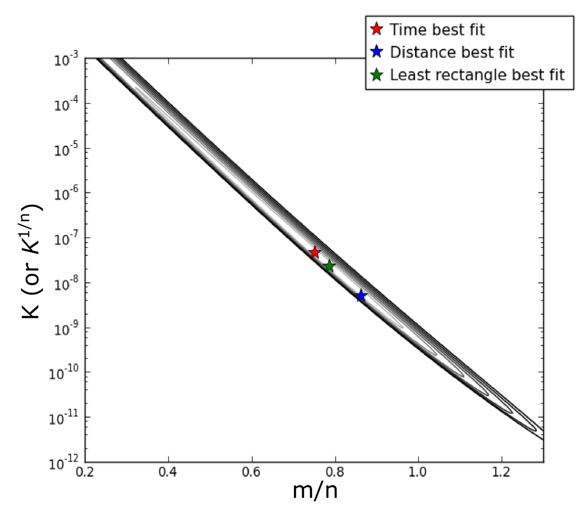

Fig. 4 – Best fits. Contours represent time misfit

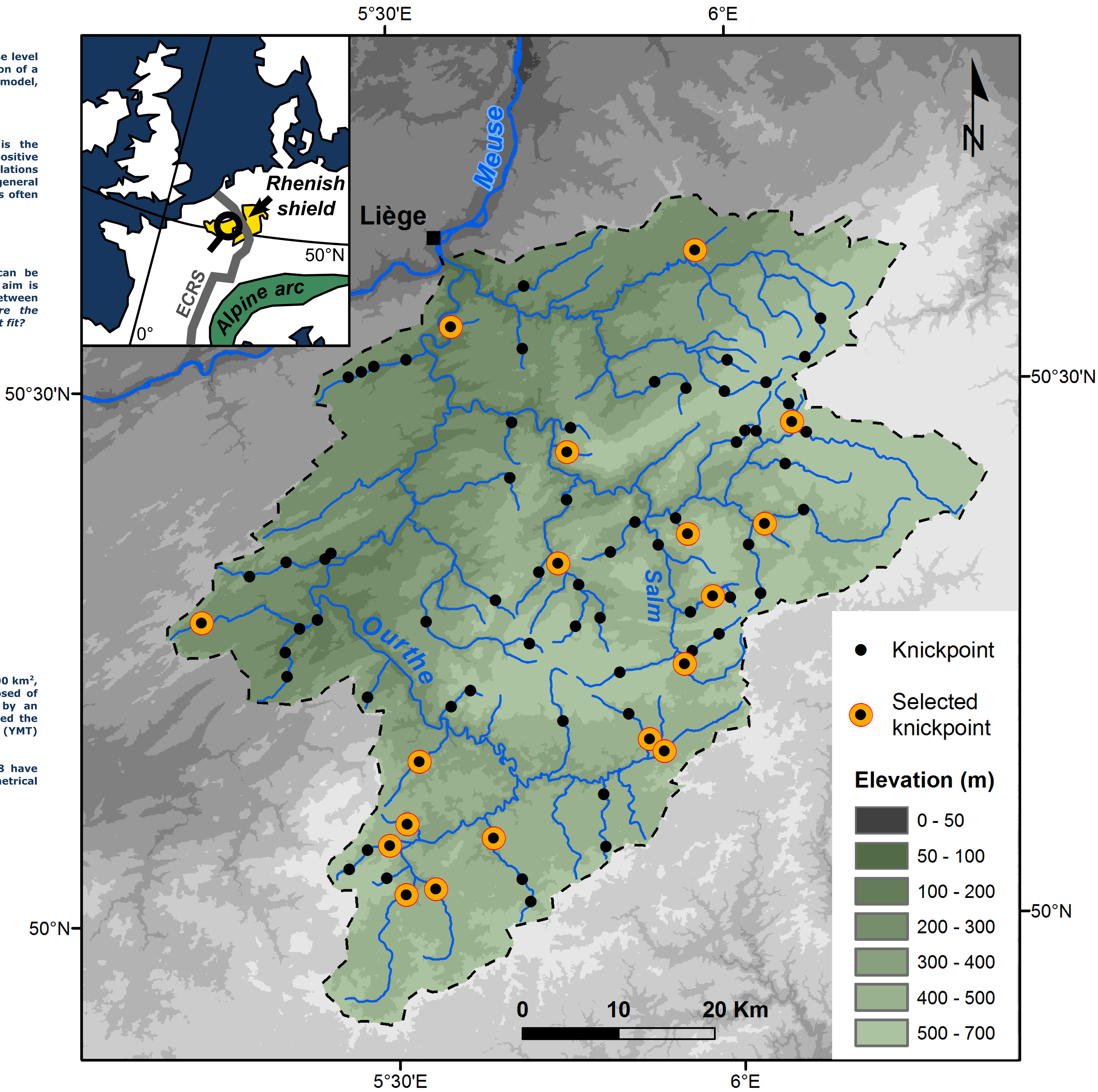

Fig. 1 – Study area and knickpoint spatial distribution

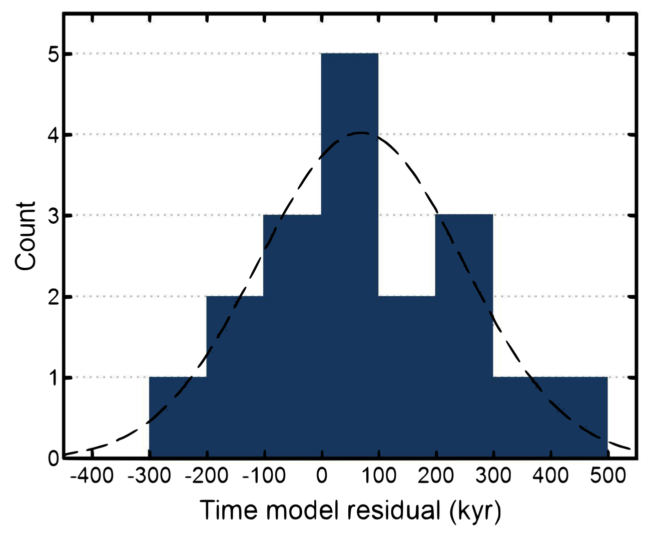

Fig. 5 – Time residuals for the time adjustment

5. Discussion

Which method to choose?

The characteristics of the data set may potentially bias the estimation of m/n and K, as illustrated on Fig. 6. The distribution of the data mainly either on the right side of the graph (in case of an older generation of knickpoints) or on the left side (for a more recent erosion wave) will determine the most sensitive adjustment. Young knickpoints (green point on Fig. 6) are located in the steeper part of the x = f(t) curve where the adjustment on distances is much more sensitive than that on time, and the reverse is true for a set of older knickpoints (red point) appearing in the flattened part of the curve. Consequently, if a data set contains knickpoints distributed over a large range of drainage areas, best fits based on distance or time will adjust preferentially on the knickpoints respectively located in the larger or smaller streams.

As there is no physical reason to privilege distance over time, or conversely, in the adjustment, the intermediate least rectangles approach may appear the most appropriate. In the case of the Ardennes, a time adjustment seems to be more appropriate because most of the knickpoints are located close to the headwaters.

Comparison between modelled and field derived m/n ratio values

If we now recall that m/n = c(1-b) (Whipple & Tucker, 1999), where c and b are the exponents of the power law relations respectively linking discharge to drainage area and channel width to discharge, we can compare the calculated m/n value with that derived from field measurements of channel width, discharge and drainage area in the presently graded sections of the rivers. Such data taken from Petit et al. (2005) allow us to derive m/n = 0.48 at equilibrium. As c may be considered constant, the higher m/n value obtained from the knickpoint retreat modelling must be ascribed to a lower b, which indicates that channel narrowing was associated with the transient phase of knickpoint migration.

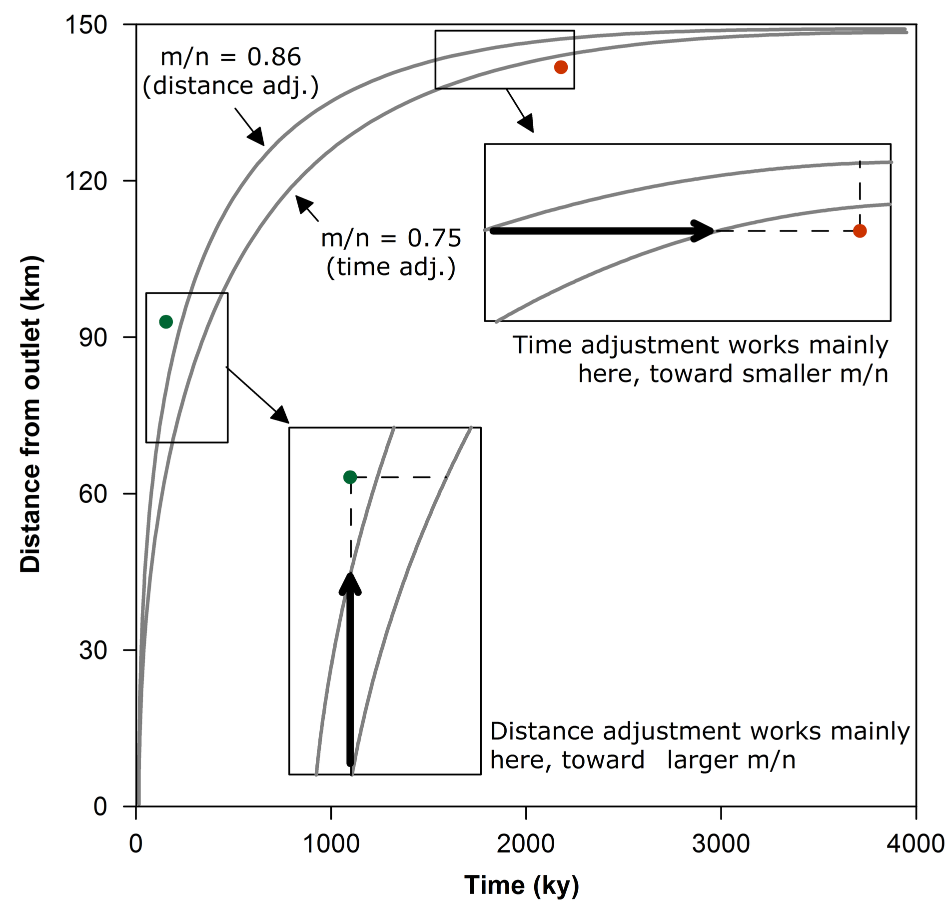

Fig. 6 – Schematic representation of the influence of the knickpoint spatial distribution on the parameterization.

Table 1 – Results of the three types of adjustment performed on the knickpoint data set of the Ourthe catchment

	m/n		K (10^{-9} $m^{1-2m}y^{-1}$)		time residuals (ky)		distance residuals (km)	
Type of adjustment	**best fit**	**1,04 misfit$_{min}$**	**best fit**	**1,04 misfit$_{min}$**	**mean**	**st. deviation**	**mean**	**st. deviation**
distance adjustment	0.86	0.83 - 0.95	5.04	0,96 - 8.77	-41,31	225,25	0,035	2,20
time adjustment	0.75	0.69 - 0.81	46.3	14.3 - 161.2	68,27	178,01	-0,84	2,30
least rectangles	0.78	0.73 - 0.83	23.1	9.40 - 70.2	20,61	192,46	-0,26	2,28

References

***Petit F. et al., 2005**. Evaluation des puissances spécifques de rivières de moyenne et de haute Belgique. BSGLg 46, 37-50*

***Rixhon G. et al., 2011**. Quaternary river incision in NE Ardennes (Belgium) - Insights from 10Be/26Al dating of river terraces. Quat. Geochr. 6, 273-284*

***Whipple K. X. & G. E. Tucker, 1999**. Dynamics of the stream power river incision model: implications for height limits of mountain ranges, landscape response timescales and research needs. J. Geophys. Res. 104, 17,661-17,674*