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Predicting sediment yields from undisturbed catchments: the dominant role of tectonics

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Objective

- The purpose of this study is to develop a model that allows to predict the average annual catchment sediment yield SY (t km^{-2} y^{-1}) for catchments under 'pristine' conditions, i.e. the SY that could be expected from a catchment if it was unaffected by human impacts.
- Special attention was given to the role of tectonic activity in explaining SY.

Data collection and analyses

- Based on an extensive literature review, a dataset of measured SY-values for 146 catchments in Europe was established (**Figure 1**)
- All catchments are (almost) undisturbed in terms of land use and have no significant reservoirs, lakes or glaciers in their upstream area.
- Catchment areas (A) range between 0.3 and 4,000 km².
- Measured SY-values range between 0.5 and 3,100 t km^{-2} y^{-1}.

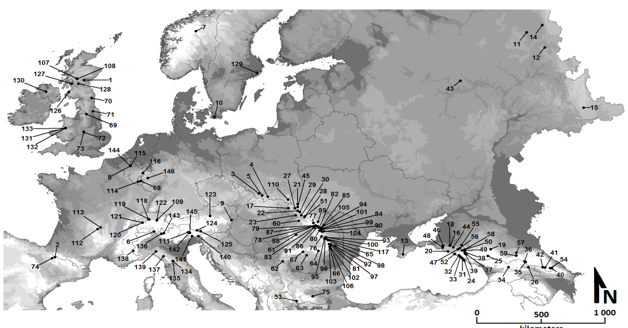

Figure 1: Location of the considered catchments. This maps indicates the outlet locations of the 146 undisturbed catchments for which measured sediment yield data were available.

- For each catchment a large dataset of parameters was collected, describing the catchment's topography, lithology and climatic characteristics
- Tectonic activity was described as the average peak ground acceleration (PGA, m s^{-2}) of an earthquake that has a 10% exceedance probability in 50 years. PGA-values were derived from a global Seismic Hazard map (GSHAP; Giardini et al., 1999).
- Based on this dataset, (partial) correlation analyses were carried out to see which (combination of) parameters explains best the observed variation in SY.

Results

- Climate or runoff explained no significant part of the observed variation in SY.
- The strongest correlations were found with the average slope (S,°), a lithology-factor (L, as defined by Syvitski and Milliman (2007) in the BQART-model), and the average PGA of the catchments (**Figure 2**).
- Partial correlation analyses indicated that, although S, L and PGA are also correlated with each other, they each explained a significant part of the observed variability in SY. Our proposed model therefore predicts SY, based on the product of S, L and PGA (**figure 2**).
- This model explains around 55% of the observed variance in SY. >95% of the predicted SY-values deviated less than one order of magnitude from their measured value. Thorough model validation further indicated that the model is stable.

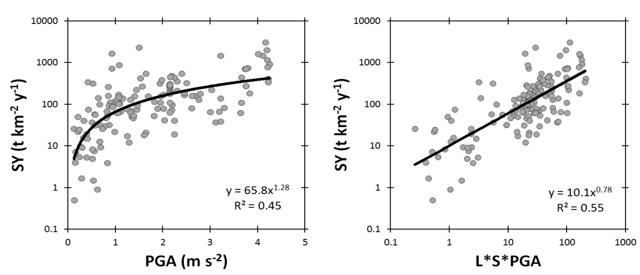

Figure 2: **A regression model to predict pristine sediment yield**. The **Left** figure displays the strong correlation between Peak Ground Acceleration (PGA) and SY. The **right** figure displays the proposed model, were x is the multiplication of slope (S), PGA and a lithology factor (L).

The neglected role of tectonics

- In terms of processes, the observed variation in SY is mainly explained by differences in susceptibility to landslides. This also explains the important role of PGA.
- Although the influence of tectonics on long term erosion rates is generally recognized (e.g. Montgomery and Brandon, 2002), current models focusing on SY generally neglect the role of tectonics and assume that tectonic activity is expressed in the catchment's topgraphy.
- This is only true to some extend: areas of low relief can also have significant tectonic activity and vice versa. Also for catchments with a low Mean Local Relief (M... differences in PGA explained a significant part of the observed variation in SY (fig

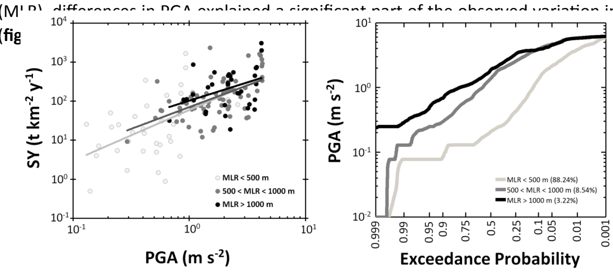

Figure 3: **Decoupling relief from tectonic activity.** The **left** figure shows the relationships between the measured sediment yield (SY) and the Peak Ground Accelerations (PGA) for different ranges of mean local Relief (MLR). Regression Equations: MLR < 500m: SY = $59.2PGA^{1.30}$, n = 40, R^2 = 0.28; 500 < MLR < 1000m: SY = $70.2PGA^{1.11}$, n = 70, R^2 = 0.32; MLR > 1000m: SY = $102.3PGA^{0.94}$, n = 36, R^2 = 0.17. The **right** figure shows the exceedance probability of PGA-values in Europe. The percentage between brackets indicates the areal fraction of each MLR-class.

- Considering topography to be fully representative for tectonic activity can lead to important over- or underestimation of the actual SY, depending on the considered region. This is illustrated in **figure 4**.

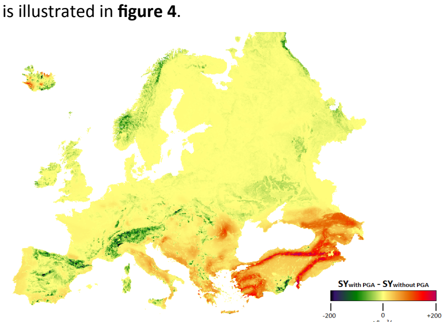

Figure 4 : Estimated tectonic impact on sediment yields in Europe. This map indicates the differences in SY that can be expected due the effect of tectonics. The map is based on the difference of two separately calibrated regression models: one based on the product of MLR and L alone ($SY_{without\ PGA}$) and one based on the product of L, MLR and PGA ($SY_{with\ PGA}$). Values on this map should be interpreted with caution, since this method assumes that each pixel can be considered as a catchment. Nevertheless, the map clearly illustrates that considering topography to be representative for tectonic activity can lead to important regional dependent errors in SY-prediction.

A global perspective …

- Although our original analyses were based on a carefully selected dataset of undisturbed catchments in Europe (**figure 1**), application of our model concept to a global SY dataset also explains a significant part of the observed variation (**figure 5**).
- Although at this scale also other factors (e.g. climate) are important (explaining the larger scatter), these results open promising perspectives. They indicate that also at a global scale SY-models may benefit from including PGA as an explaining factor.

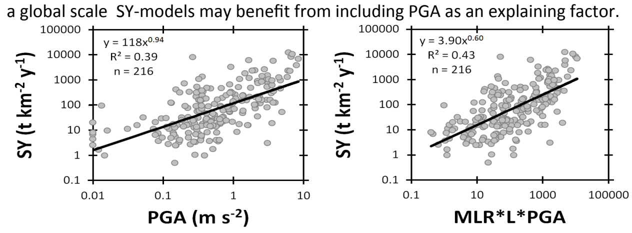

Figure 5: The role of tectonics at a global scale. The **left** figure displays the relationship between average PGA and measured SY for a global dataset of 216 rivers (Syvitski et al., 2005). The **right** figure displays, similar to **figure 2**, the relationship between SY and the product of the Mean Local Relief (MLR, a topographic measure closely correlated with slope), L and PGA.