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# A tale of two nuclides in the formerly half-glaciated Vosges Mountains: cosmogenic (un-)steadiness revealed by catchment-wide denudation rates

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## Résumé

Although catchment-wide denudation rates inferred from *in situ* cosmogenic nuclide concentrations measured in stream sediments has represented a ground-breaking progress in geomorphology over the last three decades, most of these studies rely on  $^{10}\text{Be}$  concentrations only. It seems that this current and routine one-nuclide approach to infer catchment-wide denudation rates has somehow overshadowed two key assumptions that are cosmogenic steady-state and short sediment transit time at the catchment scale. Although a paired-nuclide approach allows testing these assumptions, it is rarely performed on stream sediments and this can become highly problematic in slow-eroding, formerly glaciated contexts. In this study, we thus measure both  $^{10}\text{Be}$  and  $^{26}\text{Al}$  in stream sediments pertaining to twenty-one rivers draining an entire low mountain range: the Vosges Massif (NE France). If its northern part remained void of glacial cover during Quaternary cold stages, its southern part was significantly and repeatedly glaciated. We aim to quantitatively explore the impact of both repeated glacial cover and storage of glacially derived sediments on  $^{26}\text{Al}/^{10}\text{Be}$  ratios, hence cosmogenic (un-)steadiness in modern river samples. Our results also show that catchments in strong cosmogenic disequilibrium ( $^{26}\text{Al}/^{10}\text{Be}$  ratios from 1.4 to 5.2) spatially cluster in the SW part of the Vosges Mountains that was the most intensively glaciated during Quaternary cold stages. This study is the first to quantify the impact of past glaciations on cosmogenic (un-)steadiness measured in stream sediments. A statistically significant relationship between the degree of depletion of the  $^{26}\text{Al}/^{10}\text{Be}$  ratios and the spatial pattern of glaciation is found: the larger the former glacial cover in each catchment, the lower the  $^{26}\text{Al}/^{10}\text{Be}$  ratio. Equally important is the significant correlation reported between the degree of depletion of the  $^{26}\text{Al}/^{10}\text{Be}$  ratios and the proportion of glacial and fluvio-glacial deposits within each catchment. These two relationships underline the link between cosmogenic unsteadiness in the stream cosmogenic signal and long-lasting and repetitive ice shielding, and complex sediment routing systems in glacial environments, respectively. We thus argue to systematically measure  $^{26}\text{Al}$  in complement to  $^{10}\text{Be}$  and to test the steady-state assumption when it

**Mots-Clés:** Cosmogenic nuclides ( $^{10}\text{Be}/^{26}\text{Al}$ ), catchment wide denudation rates, unsteadiness, glacial landscapes

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