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Weathering and denudation rates determined by the combined analysis of Uranium series nuclides and in situ Beryllium in a weathering profile (Vosges massif, Strengbach catchment, France)

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The determination of soil sustainability is a major issue for societies. It is crucial to estimate the soil formation and denudation rates to evaluate the landscapes stability and their response to natural or anthropological forcings. In this work, we propose to combine the analysis of Uranium-Thorium-Radium isotopes with the cosmogenic in situ Beryllium in a weathering profile located in the Strengbach catchment to estimate both production rate of regolith and denudation rate of soil and to establish a soil mass balance at millennial timescales. The weathering profile is located on the summit of the watershed and extending from the top soil to the granitic fractured bedrock at 2 m depth. Whole rock data shows different trends of variation of major and trace element concentrations and also of U-Th-Ra disequilibria in the upper part of the regolith (0-80 cm) and the deeper part of the fractured saprolith and/or bedrock (100cm-200cm). Modeling of the U-Th-Ra data in this deeper part of the profile, using a particle swarm optimization model dedicated to isotopic ratios leads to a regolith production rate at the summit of the watershed of 35 $\pm$ 9 T/km^2/year. In addition, a numerical optimization for nonlinear inverse problem has been performed to estimate the regolith residence time and the mean denudation rate at the summit from the Beryllium data. The results show that the regolith residence time is about 14 000 years and the mean denudation rate is 32 $\pm$ 8 T/km^2/year. The consistency between the regolith production rate and the soil denudation rate suggests therefore that in such a temperate context, the long-term mass balance of soil developed on granitic bedrock would be close to a steady state. The data also highlights that the determination of a weathering production rate from analysis of Uranium series nuclides in whole rock samples cannot be easily obtained by analyzing only surficial soil samples, and requires the analysis of the deeper fractured saprolith/bedrock (1-2 m depth).