Reconstructing Neogene surface uplift of the Alps: Integrating stable isotope paleoaltimetry and paleoclimate modelling

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Paleoaltimetry - the reconstruction of the elevation of mountain ranges in the geological past - is key to understanding the geodynamic drivers of surface uplift. Simultaneously, surface uplift of Earth's major mountain ranges redirected atmospheric flow and impacted climate globally. At a smaller scale, mountain building affects regional climate and biodiversity.

Stable isotope paleoaltimetry is a powerful tool to quantify the past elevation of mountain ranges. It is based on the inverse relationship between the stable isotopic composition of meteoric waters and elevation, which is represented by the so-called isotopic lapse rate. However, variations in climatic parameters modify isotopic lapse rates and impact moisture transport over the continents and consequently affect paleoelevation reconstructions.

Here, we show the results of a combined stable isotope paleoaltimetry and paleoclimate modeling approach in the European Alps. This approach allows for an improved and more realistic estimation of isotopic lapse rates, large-scale isotope-in-precipitation patterns over Europe and hence Alpine paleoaltimetry calculations. The European Alps are an ideal target for a combined paleoaltimetry - climate modeling approach, given that they are (a) one of the most-studied mountain ranges for which many geoscientific data are available, and (b) sufficiently small and oriented near-parallel to dominant atmospheric circulation patterns. The latter implies that no major global climatic changes are expected in response to Alpine surface uplift, as opposed to e.g. the Andes or the Tibet-Himalaya mountain ranges.

Results from 4D-MB SPP phase 1 and 2 show that: (1) Changing the surface elevation of even a small orogen can complicate stable isotope paleoaltimetry by mixing the elevation and climate signal in a more complex way than commonly assumed. Climate models can help separate these signals and constrain surface uplift histories. (2) The Central Alps were already high during the Early and Middle Miocene, whereas the Eastern Alps were still at significantly lower elevations, thereby confirming that surface uplift propagated from west to east, as would be expected from oblique continent-continent collision. Together, the results highlight the importance and viability of this combined, interdisciplinary approach.

Based on the results from 4D-MB SPP phase 1 and 2, we propose that future efforts to reconstruct surface uplift of mountain ranges follow this state-of-the-art approach, while keeping local limitations to proxy material availability and access to facilities in mind.

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